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Introduction

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Introduction

Often times you have to do a project yourself to obtain the best value and achieve 100% personal satisfaction. We are do it yourself (DIY) minded at heart and we support like-minded people. We believe that being self-reliant and building energy efficient homes that use renewable energy resources in a responsible manner is a good philosophy for our planet. To this end, these calculators were developed to enable everyone who shares this philosophy an opportunity to accomplish this goal. ***Please use these calculators and the results they provide at your own discretion and at your own risk...we are NOT responsible for any damage or harm that you may inflict on yourself or on others...please read and comply with our Terms of Use located at the bottom of our website pages.***

The first page of this Adobe Portable Document File (PDF) contains a bookmarked Table of Contents (TOC) to assist you in navigating to the specific set of instructions for the calculator that you would like to use. There is a Return to TOC link at the end of each set of instructions. The calculator titles in the beginning of each specific set of instructions hyperlink to the actual calculators that are hosted on our high speed file server.

All of our **Hydronic Radiant Floor Heating**, **Passive Solar Heating**, **Water Work Project** and **Sundry** calculators were developed using JavaScript code that runs using your trusted browser application. ***As such, all of our calculators may be used on your PC or on your mobile device.*** Our calculators only run for a brief time after you actually click a `Solve` button. Therefore, unlike some applications, you are not downloading software that may run continuously in the background and may contain malware that mines your personal data too. You may always view ALL of the JavaScript code that is used in our calculators by right clicking the calculator form and selecting "View Page Source." Our calculator design objective was to use a very simple user interface and only the minimal inputs required to properly solve each specific engineering design problem. Multiple calculators are used in some cases (e.g., our passive solar design calculators) to break up each engineering design problem into logical design phases. After you have obtained the calculator solution, you may save your results by right clicking the calculator form and selecting "Print" to create a PDF.

We welcome your feedback and suggestions for improving these DIY calculators and associated instructions. The development and maintenance of these DIY calculators and associated instructions is supported 100% by voluntary user contributions. **If you found this information to be useful, please consider making a $10 donation which can be accomplished quickly and securely using Amazon Pay on the Calculator Tab of our website.**

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This calculator enables you to properly design/size a buffer tank for use in a hydronic radiant floor heating system. A properly designed/sized buffer tank will prevent the hydronic radiant heat source (e.g., boiler or heat pump) from short cycling which, if allowed to occur, will significantly decrease the life expectancy of the heat source.

When low thermal mass heat sources are combined with zoned hydronic radiant distribution systems, it is possible for the heat source to short cycle when only a couple of these zones call for heat. This occurs because the rate of heat produced by the heat source is much greater than the rate of heat used/released by these zones. Low thermal mass heat sources in combination with low volume hydronic circuit and distribution systems cannot absorb this excess heat rate without experiencing a rapid rise in temperature. This causes the heat source to reach its high temperature limit very quickly resulting in very short on times and short cycling. While electric heating elements may tolerate short cycling, gas valves, oil burners, ignition systems, and compressors will have a significantly reduced life expectancy.

Before using this calculator, you should first exercise our **Hydronic Radiant Floor Heating Design Calculator** to properly design the hydronic radiant floor heating system, to determine the actual heat source supply temperature that will be used, to determine the allowed circuit temperature drop, and to determine the heat output of all the zones. As discussed in the hydronic radiant floor heating design calculator instructions, some States do not even require a contractor license, any insurance, or any bonding. There are many online companies in the HVAC industry that operate from these States without any licensing credentials, requisite knowledge, experience, or proficiency. Therefore, you should definitely apply due diligence when selecting your hydronic radiant floor heating system design/installation team. We highly recommend using a licensed/experienced professional engineering company to perform the analysis/design and using a licensed/experienced HVAC company to install the system.

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Hydronic Fluid Mixture (Percent Propylene Glycol/Water)** - This is the percentage of propylene glycol used in the hydronic fluid. ***You should NEVER use ethylene glycol in a hydronic heating system.*** You may enter any valve between 0 and 50% to specify the concentration of propylene glycol you will use. If you elect to use propylene glycol, you should use at least 30% to inhibit the growth of bacteria in the system. Propylene glycol has a higher viscosity than water (which will result in increased hydraulic friction) and a lower specific heat than water (which will result in reduced heat transfer). Therefore, using propylene glycol will result in a less efficient heating system. As such, you should avoid using propylene glycol unless you are actually at risk of freezing the tube. We recommend using 100% water and entering 0 into the calculator. Please use this same value in our **Hydronic Radiant Floor Heating Design Calculator** and **Expansion Tank Design Calculator**.

2) **Heat Source + Misc Hydronic Fluid Volume (Gallons)** - This is the volume of hydronic fluid contained in the heat source and miscellaneous distribution pipe leading to/from the manifold station(s). ***The volume of hydronic fluid contained by the buffer tank should NOT be included because this is the currently unknown volume that is determined by this calculator.*** You may enter 0 to obtain a conservative **Minimum Buffer Tank Volume** output parameter.

3) **Circuit Hydronic Fluid Volume (Gallons)** - This is the volume of hydronic fluid contained in all the circuits of the smallest zone that may call for heat. This volume may be obtained from our **Hydronic Radiant Floor Heating Design Calculator**. You may enter 0 to obtain a conservative **Minimum Buffer Tank Volume** output parameter.

4) **System Load (BTU/Hour)** - This is the minimum system heat load placed on the heat source that results when the smallest BTU/Hour zone that may call for heat does so at the historically expected average monthly outdoor temperature when the system will actually be operated (i.e., when the lowest expected required heat gain occurs in the smallest BTU/Hour zone when the system will be operated). You may exercise our **Heat Loss Analysis Calculator** using this historically expected average monthly outdoor temperature instead of the historical Winter heating 99% dry bulb temperature (i.e., instead of the coldest expected 99% annual outdoor temperature which is normally used for this calculator for determining maximum system heat load) to estimate this minimum system heat load which corresponds to the **Total Heat Loss (BTU/Hour)** output parameter at this historically expected average monthly outdoor temperature.

5) **Heat Source Output (BTU/Hour)** - This is the heat output that the heat source will provide the system load. This is typically the maximum heat source output, however, this may be the minimum heat output if the heat source is capable of reducing its heat output as the system load decreases.

6) **Heat Source High Temp Setting (Degrees Fahrenheit)** - This is the highest temperature that the heat source has been set and is allowed to reach before it turns off.

7) **Heat Source Low Temp Setting (Degrees Fahrenheit)** - This is the lowest temperature that the heat source has been set and is allowed to reach before it turns on.

8) **Heat Source Minimum Cycle Time (Minutes)** - This is the desired minimum length of "on time" that the heat source will be allowed to operate. Heat pump manufacturers typically recommend a minimum of 5 to 10 minutes. Boiler manufacturers typically recommend a minimum of 10 minutes. Longer cycle times will typically result in higher heat pump Coefficient of Performance (COP) and higher boiler Average Fuel Utilization Efficiency (AFUE).

Click [Solve] after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Tank Minimum Required Volume (Gallons)** - This is the minimum volume that the buffer tank must be to achieve the desired **Heat Source Minimum Cycle Time** input parameter. For economic reasons, it is preferable to use a buffer tank size that just meets or slightly exceeds this minimum volume.

Please exercise our **Expansion Tank Design Calculator** to properly design and setup a diaphragm-type expansion tank which is always required in a hydronic radiant floor heating system to protect it from potentially destructive hydronic fluid expansion.

It is important that you do a proper building heat loss analysis, circuit/zone design, and hydronic radiant floor heat gain analysis BEFORE actually constructing the system. If you are working with a company who cannot perform this analysis and provide data that is sealed/signed by a licensed professional engineer for the specific design and location, you should apply due diligence and consider finding a more competent company to do this. If you find that you need this service, we hope that you will consider Borst Engineering and Construction.

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Building Assembly Moisture Analysis Calculator

Besides providing the required insulation properties necessary to maintain a comfortable indoor temperature with minimal use of cooling/heating energy, a well-designed building envelope (e.g., ceilings, floors, and walls) will accomplish two other important design objectives: 1) keep water and water vapor from getting into the building assembly and 2) allow any water or water vapor that does manage to get in, to get out as quickly as possible.

This calculator is based on the 2013 American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Fundamentals Handbook historical steady-state dew-point or Glaser methodology for evaluating moisture accumulation and drying within building envelopes. Please see our **Psychrometrics Calculator** for more information about dew-point and psychrometrics in general. There are several limitations to this moisture analysis method which should be recognized and fully considered. Vapor diffusion is the only moisture transport mechanism considered by this method and this calculator. Building assembly air infiltration/ventilation, building assembly material moisture capillary transport, direct rain intrusion/wetting, and solar heating moisture transport mechanisms are NOT considered and these moisture transport mechanisms may often be very significant when they exist. Much more accurate building assembly moisture analysis is possible using transient software models which are capable of considering all of these moisture transport mechanisms as well as the humidity, pressure, and temperature initial conditions.

In order to use this calculator, you will first need to look up the R-values and permeance values of the materials used to construct the building envelope. The following is a list of R-values (in units of Degrees F-Hour-Square Feet/BTU) for material commonly used in the building construction industry:

AIR FILMS:

Inside surface	0.64
Outside surface (15 MPH wind)	0.17

COATINGS AND FACINGS:

Building felt (15 PSF)	0
Foil facing	0
Latex paint	0
MemBrain™	0
Oil paint	0
Polyethlene vapor barriers	0
Typar™	0
Tyvek™	0

CONCRETE AND MASONRY:

Common brick	0.3 per inch
Concrete	0.10 per inch
8" concrete block	1.11 for 8"

FLOORING:

Carpet (1/4" nylon level loop)	1.36 for 1/4"
Carpet (1/2" polyester plush)	1.92 for 1/2"
Ceramic tile	0.6 per inch

| Polyurethane foam padding (8 PCF) | 4.4 per inch |
| Vinyl tile or sheet flooring (1/8") | 0.21 for 1/8" |

INSULATION:

Blown cellulose fiber	3.4 per inch
Expanded polystyrene (EPS) panels	4.76 (Type II) - 5.0 (Type IX) per inch
Extruded polystyrene (XPS) panels	5.4 per inch
Fiberglass/Rockwool batt (standard density)	3.17 per inch
Foam in place urethane	5.9 per inch
Polyisocyanurate panels	5.6 per inch

WALL CLADINGS AND SHEATHINGS:

Drywall	0.9 per inch
Hardwoods	0.9 per inch
Oriented Strand Board (OSB)	1.59 per inch
Plywood	1.24 per inch
Softwoods	1 per inch
Wood lap siding	1.24 per inch
Vinyl lap siding	0.61 per inch

The following is a list of permeance values for material commonly used in the building construction industry:

AIR FILMS:

| Inside surface | 160 perms |
| Outside surface (15 MPH wind) | 1000 perms |

COATINGS AND FACINGS:

Building felt (15 PSF)	18.2 perms
Foil facing	0.02 perms
Latex paint	5 perms
MemBrain™	1 perm (0-35% RH) to 25 perms (at 90% RH)
Oil paint	1 perm
Polyethlene vapor barriers	0.06 perms
Typar™	14 perms
Tyvek™	58 perms

CONCRETE AND MASONRY:

Common brick	3.2 perms/inch
Concrete	3.2 perms/inch
8" concrete block	2.4 perms
Stucco	4.8 perms/inch

INSULATION:

Blown cellulose fiber	75 perms/inch
Expanded polystyrene (EPS) panels	2.7 perms/inch
Extruded polystyrene (XPS) panels	1.1 perms/inch
Fiberglass/Rockwool batt (unfaced)	144 perms/inch

| Foam in place urethane | 16 perms/inch |
| Polyisocyanurate panels (unfaced) | 3.6 perms/inch |

WALL CLADDINGS AND SHEATHINGS:

Drywall (unpainted)	40 perms/inch
Hardwoods	1.4 perms/inch
Oriented Strand Board (OSB)	0.75-2 perms/inch
Plywood	0.75-3.5 perms/inch
Softwoods	2.9 perms/inch
Wood lap siding	35 perms
Vinyl lap siding	70 perms

A perm rating of 1.0 represents 1 grain of water passing through 1 square foot of material in 1 hour. One pound or 16 fluid ounces of water is equal to 7000 grains. If the building assembly layer has a permeance of 0.1 perms or less, it is considered vapor impermeable and classified as a Class I vapor retarder or a vapor barrier. If the building assembly layer has a permeance of 1 perm or less and greater than 0.1 perms, it is considered vapor semi-impermeable and classified as a Class II vapor retarder. If the building assembly layer has a permeance of 10 perms or less and greater than 1 perm, it is considered vapor semi-permeable and classified as a Class III vapor retarder. If the building assembly layer has a permeance of 10 perms or greater, it is considered vapor permeable (also referred to as breathable) and it is not classified as being a vapor barrier/retarder.

The permeance of a material is approximately inversely proportional to its thickness and doubling the thickness halves the permeance. So increasing or decreasing the thickness of the building assembly layer will affect the permeance of this building assembly layer and both how it should be considered (i.e., vapor impermeable, vapor semi-impermeable, vapor semi-permeable, or vapor permeable) and how it is classified (i.e., a Class I vapor barrier, a Class II vapor retarder, a Class III vapor retarder, or not a vapor barrier/retarder). For example, a XPS building assembly layer having a thickness of 1 inch has a permeance of 1.1 perm and causes this 1 inch XPS building assembly layer to be considered vapor semi-permeable and classified as a Class III vapor retarder. However, increasing the thickness of this XPS building assembly layer from 1 inch to 2 inch results in a permeance of 0.55 perms (i.e., 1.1 perm per inch divided by 2 inches). So increasing the thickness of this XPS building assembly layer by a factor of two reduces the permeance by a factor of two and causes this 2 inch XPS building assembly layer to be considered vapor semi-impermeable and classified as a Class II vapor retarder. Increasing the thickness of this XPS building assembly layer from 1 inch to 12 inch results in a permeance of 0.09 perms (i.e., 1.1 perm per inch divided by 12 inches). So increasing the thickness of this XPS building assembly layer by a factor of twelve reduces the permeance by a factor of twelve and causes this 12 inch XPS building assembly layer to be considered vapor impermeable and classified as a Class I vapor retarder or a vapor barrier.

In order to use this calculator, you will need to determine the typical conditions for the building location. This is typically the historical Summer or Winter average monthly historical dry bulb temperature and coincident wet bulb temperature (or coincident relative humidity). You should NOT use the monthly 1% or 99% outdoor design values as would be appropriate for our **Cooling Load Analysis Calculator**, **Evaporative Cooling Performance Calculator**, **Existing Building Energy Usage Analysis Calculator**, and **Heat Loss Analysis Calculator**. A good source of weather data may be found here:

Weather Spark

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Design Indoor Dry Bulb Temp (Degrees Fahrenheit)** - This is typically 65 to 80 degrees F or as specified by the local building code. Please use this same value in our **Evaporative Cooling Performance Calculator**, **Existing Building Energy Usage Analysis Calculator**, **Heat Loss Analysis Calculator**, **Hydronic Radiant Floor Heating Design Calculator** and Passive Solar Thermal Mass Performance Calculator.

2) **Design Indoor Relative Humidity (Percent)** - This is the ratio of the actual amount of water vapor in the indoor air to the amount of the water vapor in the air at the state of saturation. A state of saturation exists when the air is holding the maximum amount of water possible (i.e., at 100% relative humidity) at a given temperature. Preferred indoor relative humidity values of comfort for people are between 35% and 60%. Please use this same value in our **Cooling Load Analysis Calculator**.

3) **Average Outdoor Dry Bulb Temp (Degrees Fahrenheit)** - This is the historical Summer or Winter average monthly historical dry bulb temperature for the local climate. You should NOT use the monthly 1% or 99% values as would be appropriate for our **Cooling Load Analysis Calculator**, **Evaporative Cooling Performance Calculator**, **Existing Building Energy Usage Analysis Calculator**, and **Heat Loss Analysis Calculator**.

4) **Average Outdoor Wet Bulb Temp (Degrees Fahrenheit)** - This is the historical Summer or Winter average monthly historical wet bulb temperature that is coincident with the **Average Outdoor Dry Bulb Temp** input parameter for the local climate. You should NOT use the monthly 1% value as would be appropriate for our **Cooling Load Analysis Calculator** and **Evaporative Cooling Performance Calculator**. Leave this input parameter blank if you will enter a value for the **Average Relative Outdoor Humidity** input parameter.

5) **Average Relative Outdoor Humidity (Percent)** - This is the ratio of the actual amount of water vapor in the outdoor air to the amount of the water vapor in the air at the state of saturation. A state of saturation exists when the air is holding the maximum amount of water possible (i.e., at 100% relative humidity) at a given temperature. You should use the historical Summer or Winter average monthly relative outdoor humidity that is coincident with the **Average Outdoor Dry Bulb Temp** input parameter for the local climate. Leave this input parameter blank if you will enter a value for the **Average Outdoor Wet Bulb Temp** input parameter.

6) **R-value (Degrees F-Hour-Square Feet/BTU)** - This is the R-value of each of the associated layers of material used to construct the building envelope assembly. . R-value is a measure of thermal resistance (i.e., how much a material resists heat flow), is the inverse of U-factor, and is the more commonly used term in the building construction industry. Please see the above construction material R-value table and directions for using it. R-values values for material commonly used in the building construction industry may often be found on the Internet or by contacting the manufacturer of the specific product. The first layer entered must be the indoor surface air film R-value (typically 0.64) and the last layer entered must be the outdoor surface air film R-value (typically 0.17).

7) **Vapor Permeance (Perms)** - This is the vapor permeance value of each of the associated layers of material used to construct the building envelope assembly. Vapor permeance is the degree to which a material admits a flow of water vapor. Permeance values for material commonly used in the building construction industry may often be found on the Internet or by contacting the manufacturer of the specific product. Please see the above construction material permeance table and directions for using it. The first layer entered must be the indoor surface air film permeance (typically 160) and the last layer entered must be the outdoor surface air film permeance (typically 1000).

Click Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Is there a moisture problem?** - This answers the fundamental question of why you are using this calculator. Namely, will any water vapor condense out of the air that is passing through the building assembly and form liquid water that will accumulate in the building assembly?   There may be a moisture problem whenever a material layer interface **Partial Vapor Pressure** output parameter becomes as large as the associated **Saturation Vapor Pressure** output parameter. If this occurs, the calculator will indicate "Yes" and will indicate the building assembly material layer interface where this will occur.

2) **Moisture Accumulation Rate (Grains/Square Foot-Hour)** - This is the rate at which liquid water will condense out of the air and accumulate in the building assembly if a material layer interface **Partial Vapor Pressure** output parameter becomes as large as the associated **Saturation Vapor Pressure** output parameter. One pound or 16 fluid ounces of water is equal to 7000 grains.

3) **Temperature (Degrees Fahrenheit)** - This is the steady-state resulting temperature at each of the interfaces between the layers of material used to construct the building envelope assembly given the **Design Indoor Dry Bulb Temp**, **Average Outdoor Dry Bulb Temp**, and **R-value** input parameters.

4) **Saturation Vapor Pressure (Inches of Mercury)** - This is the partial vapor pressure that would coincide with a state of saturation at each of the interfaces between the layers of material used to construct the building envelope assembly given the associated **Temperature** output parameter. A state of saturation exists when the air is holding the maximum amount of water possible (i.e., at 100% relative humidity) at a given temperature.

5) **Partial Vapor Pressure (Inches of Mercury)** - This is the steady-state resulting partial pressure of the water vapor in the air that will occur at each of the interfaces between the layers of material used to construct the building envelope assembly given the **Design Indoor Dry Bulb Temp**, **Design Indoor Relative Humidity**, **Average Outdoor Dry Bulb Temp**, **Average Outdoor Wet Bulb Temp** (or **Average Relative Outdoor Humidity**), and **Vapor Permeance** input parameters. There may be a moisture problem whenever a material layer interface partial vapor pressure becomes as large as the associated **Saturation Vapor Pressure** output parameter.

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Cooling Load Analysis Calculator

If you are just looking to replace the existing air conditioning system with a similar system and you only want to ensure that the replacement system will provide the appropriate cooling capacity during the hottest expected climatic design conditions where the existing building is located, please see our **Existing Building Energy Usage Analysis Calculator**.

If you are located in a low humidity climate that has a significant diurnal temperature variation, you may be able to take advantage of passive solar cooling. For more information about passive solar cooling, please see the instructions for our **Passive Solar Altitude Angle Calculator**. If you are located in a non-diurnal climate where the temperature is continuously above comfort level, but the humidity is continuously below comfort level, you may be able to use an evaporative cooling system. For more information about assessing the performance of evaporative cooling systems, please see our **Evaporative Cooling Performance Calculator**.

This calculator will allow you to determine the required air conditioning system cooling capacity for a new building to keep the occupants comfortable at the hottest expected climatic design condition. One ton of AC cooling capacity is equivalent to the cooling capacity that would be obtained by using one ton (i.e., 2000 pounds) of ice per day to accomplish this cooling, which is equivalent to 12,000 BTU/hour of cooling capacity. So, how was this 12,000 BTU/hour cooling capacity derived?

When ice is at its melting point of 32° F and absorbs heat, the temperature of the ice does not change. Instead, the ice melts to form 32° F liquid water. The amount of heat needed to melt ice into 32° F liquid water is called the latent heat of fusion which has a value of 144 BTU/pound (or 1201 BTU/gallon). If you have a pound of ice at 32° F, it takes 144 BTU of heat to completely melt all of it. If you have one ton of ice, it takes 144 BTU/pound times 2000 pounds or 288,000 BTU of heat to completely melt all of it. You could completely melt this one ton of ice in one hour, one day, or one year, depending on how quickly you heat it. At some point, it was decided to use one day for this standard. So, if one ton of ice melts uniformly over one day or 24 hours, it absorbs heat at the rate of 288,000 BTU divided by 24 hours or 12,000 BTU/hour.

A slight educational digression… After the ice has been melted into liquid water, it only takes 1 BTU to raise the temperature of one pound of liquid water by 1° F (or 8.34 BTU/gallon). This happens to be the definition of the BTU (British Thermal Unit). So, it only takes an additional 180 BTU to raise the temperature of this one pound of liquid water from 32° F to 212° F, the boiling point of water at sea level (i.e., at 14.696 PSI). When water is at its boiling point of 212° F and absorbs heat, the temperature of the water does not change. Instead, the water vaporizes to form steam. The amount of heat needed to vaporize water at 212° F into steam is called the latent heat of vaporization which has a value of 970.4 BTU/pound (or 8093.1 BTU/gallon). If you have a pound of liquid water at 212° F, it takes 970.4 BTU of heat to completely vaporize all of it into steam. So, if you are starting out with a pound of ice that you want to melt, heat up to 212° F, and then completely vaporize all of it into steam, it will take a total of 1294.4 BTU (i.e., 144 + 180 + 970.4). If you have one ton of ice, it takes 1294.4 BTU/pound times 2000 pounds or 2,588,800 BTU of heat to completely vaporize all of it into steam.

The air conditioning cooling capacity that is required to keep the building occupants comfortable at the hottest expected climatic design condition is exactly the same as the heat gain that will occur from the building at this hottest expected climatic design condition given the size of the building and the materials used to construct the building. Building heat gain occurs from:

1) Heat transfer through the walls, ceilings, floors and fenestration (i.e., exterior doors and windows) exposed to the climatic conditions and
2) Air infiltration caused by leaky building construction and/or created by controlled air ventilation which causes cool dry inside air to be exchanged with hot humid outside air.
3) Internal heat gain and humidly resulting from people, appliances, and lighting.

The actual heat gain is proportional to the building surface area exposed to the climatic conditions, the rate of heat transfer by the materials used in the building construction (defined as the heat transfer coefficient or U-factor), and the effective difference between inside wall temperature and the outside wall temperature. For heat loss analysis during the heating season, the effective difference between the inside wall temperature and the outside wall temperature is simply the difference between the inside and outside air temperatures. However, for cooling load analysis during the cooling season, the effective difference between the inside wall temperature and the outside wall temperature is typically significantly higher than the difference between the inside and outside air temperatures because of solar exposure. As such, this significantly higher effective difference between the inside wall temperature and the outside wall temperature is addressed by using a Cooling Load Temperature Difference (CLTD). R-value is a measure of thermal resistance (i.e., how much a material resists heat flow), is the inverse of U-factor, and is the more commonly used term in the building construction industry. Even the worst wall assembly will have a much higher R-value (or much lower U-factor) than the best available window. As such, there are significant economic and energy efficiency benefits to minimizing the quantity and size of windows used in buildings. ***To minimize the building heat gain and the associated cooling capacity required by the air conditioning system for any given climate, one should consider BOTH minimizing the building size and maximizing the R-value of the materials used to construct the building envelope.***

In order to use this calculator, you will first need to look up the R-values of the materials used to construct the building envelope from the below table and then determine the total R-value of the wall, ceiling, and floor assemblies. You will need to determine the total R-value for the exterior fenestration (i.e., the windows and doors). The total R-value is provided by fenestration manufacturers (often specified as the total U-factor which may be inverted to obtain the total R-value). All of these total R-values are then entered into the calculator and converted by the calculator into total U-factors for the assemblies which are then used to determine the heat gain in a manner consistent with the 2013 American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Fundamentals Handbook Cooling Load Temperature Difference (CLTD)/Cooling Load Factor (CLF) methodology and recommendations.

The following is a list of R-values (in units of Degrees F-Hour-Square Feet/BTU) for material commonly used in the building construction industry:

AIR FILMS:

Inside surface	0.64
Outside surface (15 MPH wind)	0.17

COATINGS AND FACINGS:

Building felt (15 PSF)	0
Foil facing	0
Latex paint	0
MemBrain™	0
Oil paint	0

Polyethlene vapor barriers	0
Typar™	0
Tyvek™	0

CONCRETE AND MASONRY:

Common brick	0.3 per inch
Concrete	0.10 per inch
8" concrete block	1.11 for 8"

FLOORING:

Carpet (1/4" nylon level loop)	1.36 for 1/4"
Carpet (1/2" polyester plush)	1.92 for 1/2"
Ceramic tile	0.6 per inch
Polyurethane foam padding (8 PCF)	4.4 per inch
Vinyl tile or sheet flooring (1/8")	0.21 for 1/8"

INSULATION:

Blown cellulose fiber	3.4 per inch
Expanded polystyrene (EPS) panels	4.3 - 5.0 per inch
Extruded polystyrene (XPS) panels	5.4 per inch
Fiberglass/Rockwool batt (standard density)	3.17 per inch
Foam in place urethane	5.9 per inch
Polyisocyanurate panels	5.6 per inch

WALL CLADINGS AND SHEATHINGS:

Drywall	0.9 per inch
Hardwoods	0.9 per inch
Oriented Strand Board (OSB)	1.59 per inch
Plywood	1.24 per inch
Softwoods	1.42 per inch
Wood lap siding	1.24 per inch
Vinyl lap siding	0.61 per inch

The R-value for a specific thickness of a material may be obtained by multiplying the R-value per inch by the thickness in inches. The R-values for each layer of material should be added together to determine the total R-value of the wall and ceiling assemblies.

For a typical 2x4 wall we might have 0.64 (inside air film) plus 0.45 (0.9 x 0.5 inch drywall) plus 11.09 (3.17 x 3.5 inches of fiberglass batt) plus 0.62 (1.24 x 0.5 inch plywood sheathing) plus 0.31 (0.61 x 0.5 inch vinyl clapboard siding) plus 0.17 (outside air film) for a total 2x4 wall R-value of 13.28. Please note that this corresponds to a U-factor of 0.0753. You will not find a window at any price that comes close to performing as well as even this poor performing wall assembly.

For a typical 2x6 wall we might have 0.64 (inside air film) plus 0.45 (0.9 x 0.5 inch drywall) plus 17.44 (3.17 x 5.5 inches of fiberglass batt) plus 0.62 (1.24 x 0.5 inch plywood sheathing) plus 0.31 (0.61 x 0.5 inch vinyl clapboard siding) plus 0.17 (outside air film) for a total 2x6 wall R-value of 19.63.

You may want to further refine these 2x4 and 2x6 wall R-values to properly determine and account for the real R-value of non-uniform material assemblies (i.e., account for the thermal bridging that results from the 2x4 and 2x6 studs). To accomplish this:

1) Determine what percentage of the wall assembly consists of different non-uniform materials (e.g., 16 inch on center 2x4 stud construction wall area consists of about 14% stud area and 86% fiberglass batt area),

2) Determine the associated U-factors (i.e., the inverse of the R-value) for each non-uniform material. The 14% of wall area that consists of 2x4 studs has a U-factor of 0.2012 [i.e., 1 / (1.42 x 3.5" of softwood) = 0.2012]. The 86% of wall area that consists of fiberglass batt has a U-factor of 0.0902 [i.e., 1 / 11.09 = 0.0902],

3) Determine the total percent-weighted U-factor of the non-uniform material assembly (e.g., 0.14 x 0.2012 + 0.86 x 0.0902 = 0.1057),

4) Determine the real R-value of the non-uniform material assembly by inverting the total percent-weighted U-factor (e.g., 1 / 0.1057 = 9.46). The real R-value of this non-uniform material assembly is 9.46 in lieu of the previous 11.09 value that assumed 100% fiberglass batt, and

5) Determine the total wall R-value by summing the real R-value of the non-uniform material assembly with the R-values of the uniform material assemblies [e.g., 0.64 (inside air film) plus 0.45 (0.9 x 0.5 inch drywall) plus 9.46 (the real R-value of the non-uniform material assembly) plus 0.62 (1.24 x 0.5 inch plywood sheathing) plus 0.31 (0.61 x 0.5 inch vinyl clapboard siding) plus 0.17 (outside air film)] for a total 2x4 wall R-value of 11.65 in lieu of the previous 13.28 total 2x4 wall R-value.

For a typical 11 inch thick Insulated Concrete Form (ICF) wall we might have 0.64 (inside air film) plus 0.45 (0.9 x 0.5 inch drywall) plus 0.6 (0.1 x 6 inches concrete) plus 22.5 (4.5 x 5 inches of EPS) plus 0.31 (0.61 x 0.5 inch vinyl clapboard siding) plus 0.17 (outside air film) for a total ICF wall R-value of 24.67. Please see our **ICF Performance Calculator** to determine the ICF effective R-value that accounts for the thermal mass effect where the building will actually be constructed. Then consider using this ICF effective R-value in lieu of the previous 0.6 and 22.5 R-values (i.e., the previous 23.10 ICF conventional R-value). For example, for standard ICF in Rogue River, Oregon, the ICF effective R-values are 21.38 in Spring, 66.15 in Summer, 63.42 in Fall, and 21.07 in Winter. This is an average annual ICF effective R-value performance of 43.07 in lieu of the 23.10 conventional ICF R-value. This results in an average annual total ICF wall effective R-value of 44.64 in lieu of the previous 24.67 total ICF wall R-value.

It should be noted that if you have an existing building and you would like to determine the total R-values of the building envelope, this can often be easily accomplished without knowing anything about the building material that were actually used in the original construction. All you need is an IR temperature gun to measure the interior and exterior surface temperature of the building envelope, know the indoor temperature, and apply some math. Any existing building envelope R-value can be calculated using this equation:

$$R = 0.64 \, (T_{is} - T_{es}) / (T_i - T_{is})$$

where R is the building envelope R-value, T_{is} is the interior surface temperature of the building envelope, T_{es} is the exterior surface temperature of the building envelope, and T_i is the indoor temperature. This equation assumes that the indoor air film R-value is 0.64 and that both the indoor and outdoor temperatures are reasonably constant for a couple hours prior to measuring the interior and exterior surface temperatures. This approach is very accurate for 2x and SIP construction, but may be less accurate for ICF construction because

the thermal mass effect time lag associated with ICF is typically much longer than the time that the outdoor temperature stays reasonably constant prior to measuring the interior and exterior surface temperatures. Furthermore, the effective R-value performance of ICF is often vastly different than the conventional R-value and is highly dependent on the daily outdoor temperature variation as explained in the instructions for our **ICF Performance Calculator**.

In order to use this calculator, you will need to determine the outdoor design conditions for the building location. This is typically the historical Summer cooling 1% dry bulb temperature, the coincident wet bulb temperature, and the daily temperature range for the local climate or as specified by the local building code. The 1% means that the historical temperature has only exceeded this temperature 1% of the time (i.e., it has historically only been hotter than this temperature 1% of the time). Design outdoor dry bulb temperatures for many locations are published by the Air Conditioning Contractors of America (ACCA) at this website:

Outdoor Design Conditions

Initially performing a cooling load analysis on just the overall building is a good way to quickly evaluate the air conditioning cooling capacity required for the building size and climate. You may then vary the total R-values of the wall, ceiling and floor assemblies to evaluate different insulation strategies to refine and finalize the building envelope construction material requirements. You may want to perform a room-by-room analysis.

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Design Outdoor Dry Bulb Temp (Degrees Fahrenheit)** - This is the historical Summer cooling 1% dry bulb temperature for the local climate and obtained as previously described or as specified by the local building code. Please use this same value in our **Evaporative Cooling Performance Calculator** and **Existing Building Energy Usage Analysis Calculator**.

2) **Design Outdoor Wet Bulb Temp (Degrees Fahrenheit)** - This is the historical Summer wet bulb temperature that is coincident with the **Design Outdoor Dry Bulb Temp** input parameter for the local climate and obtained as previously described or as specified by the local building code. Please see our **Psychrometrics Calculator** for more information about wet bulb temperature. Please use this same value in our **Evaporative Cooling Performance Calculator**.

3) **Design Outdoor Daily Temp Range (Degrees Fahrenheit)** – This is the historical Summer dry bulb daily temperature range that corresponds to the **Design Outdoor Dry Bulb Temp** input parameter for the local climate and obtained as previously described or as specified by the local building code.

4) **Design Indoor Dry Bulb Temp (Degrees Fahrenheit)** - This is typically 70 to 80 degrees F or as specified by the local building code. Please use this same value in our **Building Assembly Moisture Analysis Calculator**, **Evaporative Cooling Performance Calculator** and **Existing Building Energy Usage Analysis Calculator**.

5) **Design Indoor Relative Humidity (Percent)** - Preferred values of comfort for people are between 35% and 60%. Please see our **Psychrometrics Calculator** for more information about relative humidity. Please use this same value in our **Building Assembly Moisture Analysis Calculator**.

6) **Mid-Morning or Mid-Afternoon (0=Morning, 1=Afternoon)** – This is a logic input parameter that tells the calculator whether to perform the cooling load analysis at 10 AM or 3 PM. Peak cooling load for buildings with their long axis oriented along the east-west direction typically occurs at 3 PM in most climates. Enter 0 for 10 AM or 1 for 3 PM.

7) **Elevation (Feet)** - This is the elevation of the building above sea level.

8) **Latitude (Degrees)** - This is a geographic coordinate that specifies the north-south position of a point on the Earth's surface. Latitude is an angle which ranges from 0 degrees at the Equator to 90 degrees northward and to -90 degrees southward. If the latitude is south, enter a negative value. You may need to convert latitude that is in degrees, minutes and seconds into decimal degrees. For example, if the latitude is North 42° 26' 24", the correct entry is 42.44 (i.e., 24"/60 equals 0.4' and 26.4'/60 equals 0.44 °). Please use this same value in our **Passive Solar Altitude Angle Calculator**, **Passive Solar Fenestration Exposure Calculator** and **Passive Solar Heat Gain Calculator**.

9) **South Wall Deviation from True South (Degrees)** - This is the direction angle that the south wall deviates from facing true south, which ideally should be 0. The south wall deviation from true south should be less than 20 degrees to maximize desired passive solar heating performance during the winter months and to minimize undesired heat gain and cooling capacity requirements during the summer months. It is normally better to deviate toward the east than toward the west to avoid the potential for afternoon overheating during the summer months. Please use this same value in our **Passive Solar Roof Overhang Design Calculator**, **Passive Solar Fenestration Exposure Calculator** and **Passive Solar Heat Gain Calculator**.

10) **Window Zone Type (1 to 4)** – This is the North, East, South and West facing window zone type as defined by ASHRAE based on the number of exposed walls, type of floor covering, inside wall partition type, and presence/absence of an inside shade. Valid entries are 1, 2, 3, or 4, with 1 being the most conservative and 4 being the least conservative.

11) **Window Area (Square Feet)** - This is the North, East, South and West facing window rough opening area of the building or room that is exposed to the outside temperature. Please use this same value in our **Heat Loss Analysis Calculator**.

12) **Window Total R-value (Degrees F-Hour-Square Feet/BTU)** - This is the North, East, South and West facing window total R-value as specified by the window manufacturer. Often times a window manufacturer may specify a total U-factor and you will need to convert this total U-factor to a total R-value. For example, if the window manufacturer specifies a total U-factor of 0.45 for the window, the correct total R-value to enter into the calculator is 2.2 (i.e., 1 divided by 0.45). If you use multiple windows with different R-values, you will first need to perform an area-weighted average calculation to obtain the window total R-value to enter into the calculator as explained for the **Door Total R-value** input parameter. Please see the above construction material R-value table and directions for using it. Please use this same value in our **Heat Loss Analysis Calculator**.

13) **Window SHGC** - This is the North, East, South and West facing window fraction of solar energy that the window transmits into the building/room. The Solar Heat Gain Coefficient "whole window value" as provided by window manufacturers should be used. Windows with a SHGC value of 1.0 will transmit 100% of the solar energy that it receives. Windows with a SHGC value of 0 won't transmit any of the solar energy that it receives. There is another term called Shading Coefficient (SC) that is often used to describe window solar energy transmission. Multiply SC by 0.87 to convert it to SHGC for use in this calculator. If the south wall windows are fully shaded by perhaps a passive solar roof overhang, enter 0.1.

Typically, you will be using a combination of different window styles with different SHGC ratings. So you will need to determine the average SHGC rating to use in this calculator by first determining the percentage of the total window area provided by each different window style and factoring the different window style area percentages with their associated SHGC ratings. For example, if 30% of the total window area consists of casement windows with a SHGC rating of 0.56 and 70% of the total window area consists of picture windows with a SHGC rating of 0.63, the correct SHGC value to enter into the calculator is 0.609 (i.e., 0.3 x 0.56 + 0.7 x 0.63).

14) **Wall Type (1 to 16, except 8)** - This is the North, East, South and West facing wall type as defined by ASHRAE primarily based on whether the wall mass is located inside the insulation, evenly distributed, or outside the insulation and secondarily based on the color and material of exterior siding and the R-value range of the wall. Valid entries are 1 to 16 (except for 8) with 1 being the most conservative and 16 being the least conservative.

15) **Wall Area (Square Feet)** - This is the North, East, South and West facing wall area of the building or room that is exposed to the outside temperature. If a wall is an interior wall and therefore not exposed to the outside temperature, do not include this wall area. Please note that the calculator will subtract the area of any exposed doors or windows associated with this exposed wall area, so you do not need to accomplish this math manually. Please use this same value in our **Heat Loss Analysis Calculator**.

16) **Wall Total R-value (Degrees F-Hour-Square Feet/BTU)** - This is the North, East, South and West facing total R-value of the materials used for the wall assembly. Please see the above construction material R-value table and directions for using it. Please use this same value in our **Heat Loss Analysis Calculator**.

17) **Door Area (Square Feet)** - This is the North, East, South and West facing door rough opening area of the building or room that is exposed to the outside temperature. Please use this same value in our **Heat Loss Analysis Calculator**.

18) **Door Total R-value (Degrees F-Hour-Square Feet/BTU)** - This is the North, East, South and West facing door total R-value as specified by the door manufacturer. Often times a door manufacturer may specify a total U-factor and you will need to convert this total U-factor to a total R-value. For example, if the door manufacturer specifies a total U-factor of 0.45 for the door, the correct total R-value to enter into the calculator is 2.2 (i.e., 1 divided by 0.45). If you use multiple doors with different R-values, you will first need to perform an area-weighted average calculation to obtain the average door total R-value to enter into the calculator. For example, if you use two exterior doors in a room such that the first door is a 96 SF garage door that has a R-value of 4.6

and the second door is a 18 SF walk-in-door that has a R-value of 8.2, you would calculate the area-weighted average door total R-value to enter into the calculator to be 5.17 [i.e., (96 x 4.6 + 18 x 8.2) / (96 + 18)]. Please use this same value in our **Heat Loss Analysis Calculator**.

19) **Ceiling/Roof Type (1 to 14, except 6,7,11 and 12)** - This is the ceiling/roof type as defined by ASHRAE primarily based on whether the roof mass is located inside the insulation, evenly distributed, or outside the insulation and secondarily based on the presence/absence of a suspended ceiling and the R-value range of the ceiling. Valid entries are 1 to 14 (except for 6, 7, 11, and 12) with 1 being the most conservative and 14 being the least conservative.

20) **Ceiling Area (Square Feet)** - This is the total ceiling area of the building or room that is exposed to the outside temperature. If the ceiling is below a heated upstairs living area and therefore not exposed to the outside temperature, do not include this ceiling area. Please use this same value in our **Heat Loss Analysis Calculator**.

21) **Ceiling Total R-value (Degrees F-Hour-Square Feet/BTU)** - This is the total R-value of the materials used for the ceiling assembly. Please see the above construction material R-value table and directions for using it. Please use this same value in our **Heat Loss Analysis Calculator**.

22) **Building/Room Volume (Cubic Feet or 0 for Cubic Feet/Minute)** - This is a logic input parameter that tells the calculator whether the **Infiltration Rate** input parameter is entered as Air Changes/Hour (ACH) based on the actual building/room volume or simply entered as Cubic Feet/Minute (CFM). If the **Infiltration Rate** is entered as ACH, enter the total inside volume of the building or room and include the volume of ALL the rooms even if they are NOT exposed to the outside temperature. If the **Infiltration Rate** is entered as CFM, enter 0. Please use this same value in our **Heat Loss Analysis Calculator**.

23) **Infiltration Rate (Air Changes/Hour or Cubic Feet/Minute)** - This is the air infiltration rate of the building/room caused by uncontrolled air infiltration (e.g., leaky building construction) and/or created by controlled air ventilation. Depending on whether the actual building/room volume or 0 is entered for the **Building/Room Volume** logic input parameter, enter either ACH or CFM. 1.0 ACH or more is typical of older, leaky building construction. 0.5 ACH is typical of new construction. 0.35 ACH is typically the minimum allowed for health reasons and is often accomplished in airtight, energy efficient building construction (e.g., ICF construction) by using a basic air ventilation system, Heat Recovery Ventilation (HRV) system, or Energy Recovery Ventilation (ERV) system. If a HRV or ERV system is used, you should reduce the calculator ACH entry by properly accounting for the efficiency of the heat recovery system. For example, if you use an air-to-air HRV system that is 60% efficient and the controlled ventilation is 0.35 ACH or 200 CFM, the correct calculator entry would be 0.14 ACH (i.e., 0.40 x 0.35 ACH) or 80 CFM (i.e., 0.40 x 200 CFM). Please use this same value in our **Heat Loss Analysis Calculator**.

24) **Number of People** – This is the number of people occupying the building.

25) **Internal Appliance Sensible Heat Gain (BTU/Hour)** – This is the total heat gain from internal appliances that may be determined using the rated sensible BTU/Hour of the appliances.

26) **Internal Appliance Latent Heat Gain (BTU/Hour)** – This is the total heat gain from internal appliances that may be determined using the rated latent BTU/Hour of the appliances.

27) **Internal Lighting Sensible Heat Gain (Watts)** - This is the total heat gain from internal lighting that may be determined by using the rated watts of the lighting.

Click Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Window Solar Sensible Heat Gain (BTU/Hour)** - This is the solar radiation sensible heat transfer gain through the exterior windows.

2) **Window Conduction Sensible Heat Gain (BTU/Hour)** - This is the conduction sensible heat transfer gain through the exterior windows.

3) **Wall Sensible Heat Gain (BTU/Hour)** - This is the conduction sensible heat transfer gain through the exposed wall assembly.

4) **Door Sensible Heat Gain (BTU/Hour)** - This is the conduction sensible heat transfer gain through the exterior doors.

5) **Ceiling Sensible Heat Gain (BTU/Hour)** - This is the conduction sensible heat transfer gain through the exposed ceiling assembly.

6) **Infiltration Rate (Cubic Feet/Minute)** - This is the air infiltration rate of the building/room caused by uncontrolled air infiltration (e.g., leaky building construction) and/or created by controlled air ventilation. If the **Infiltration Rate** input parameter is entered as a CFM value, this output parameter is the same CFM value. If the **Infiltration Rate** input parameter is entered as an ACH value, this output parameter will use the **Building/Room Volume** logic input parameter to convert this output parameter to CFM.

7) **Infiltration Sensible Heat Gain (BTU/Hour)** - This is the sensible heat gain caused by uncontrolled dry air infiltration (e.g., leaky building construction) and/or created by controlled dry air ventilation.

8) **Infiltration Latent Heat Gain (BTU/Hour)** - This is the latent heat gain caused by uncontrolled moist air infiltration (e.g., leaky building construction) and/or created by controlled moist air ventilation.

9) **People Sensible Heat Gain** - This is the sensible heat gain caused by people and this calculator uses a value of 245 BTU/Hour per person.

10) **People Latent Heat Gain** - This is the latent heat gain caused by people and this calculator uses a value of 155 BTU/Hour per person.

11) **Internal Sensible Appliance Heat Gain** - This is the sensible heat gain caused by internal appliances and is equal to the **Internal Sensible Appliance Heat Gain** input parameter.

12) **Internal Latent Appliance Heat Gain** - This is the latent heat gain caused by internal appliances and is equal to the **Internal Latent Appliance Heat Gain** input parameter.

13) **Internal Lighting Heat Gain** - This is the sensible heat gain caused by internal lighting and is based on the **Internal Lighting Heat Gain** input parameter.

14) **Total Sensible Heat Gain (BTU/Hour)** - This is the total sensible heat gain of the building or room per hour.

15) **Total Latent Heat Gain (BTU/Hour)** - This is the total latent heat gain of the building or room per hour.

16) **Total Heat Gain (BTU/Hour)** - This is the total <u>hourly</u> heat gain of the building or room. The cooling system needs to provide this cooling capacity. If you did a room-by-room heat gain analysis, you will need to add the total <u>hourly</u> heat gain of each room to determine the total <u>hourly</u> heat gain of the <u>building</u>. This value (room or building as appropriate) is used to assess how well the cooling capacity achieved by the cooling system meets the <u>hourly</u> cooling needs.

17) **Total Heat Gain (BTU/Day)** - This is the total <u>daily</u> heat gain of the building or room. The cooling system needs to provide this cooling capacity. If you did a room-by-room heat gain analysis, you will need to add the total <u>daily</u> heat gain of each room to determine the total <u>daily</u> heat gain of the <u>building</u>. This value (room or building as appropriate) is used to assess how well the cooling capacity achieved by the cooling system meets the <u>daily</u> cooling needs.

18) **Total Heat Gain (BTU/ Hour-Degrees F)** - This important design parameter is the **Total Heat Gain (BTU/Hour)** output parameter divided by the difference between the **Design Indoor Dry Bulb Temp** and the **Design Outdoor Dry Bulb Temp** input parameters. If you did a room-by-room heat gain analysis, you will need to add the **Total Heat Gain (BTU/Hour)** of each room and divide this quantity by the difference between the **Design Indoor Dry Bulb Temp** and the **Design Outdoor Dry Bulb Temp** to determine the total heat gain of the <u>building</u> in BTU/Degrees F-Hour. This total heat gain of the building in conjunction with published climatic Cooling Degree Day data where the building is located are used as input parameters in our **Integrated Cooling System Performance Calculator** to assess how well the cooling capacity achieved by the cooling system meets the <u>monthly/annual</u> climatic cooling needs.

19) **Recommended Air Conditioning Cooling Capacity (Tons)** - This is recommended cooling capacity to remove 110% of the total forecast building heat gain. One ton of cooling capacity is equivalent to 12,000 BTU/Hour.

   It is important that you know the required cooling capacity of the building BEFORE designing the building air conditioning system. If you are working with a company who cannot perform this analysis and provide data that is sealed/signed by a licensed professional engineer for the specific design and location, you should apply due diligence

and consider finding a more competent company to do this. If you find that you need this service, we hope that you will consider Borst Engineering and Construction.

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Evaporative Cooler Performance Calculator

This calculator allows you to determine the design and performance characteristics (leaving dry bulb temperature, air flow rate, cooling capacity, water evaporation rate, water bleed-off rate, water makeup rate and water recirculation rate) of a direct (open circuit) evaporative cooler. An evaporative cooler (also known as a desert cooler, swamp cooler, and wet cooler) is a device that takes advantage of the latent heat of vaporization that occurs during the phase change of liquid water to water vapor (evaporation). Evaporative cooling differs from typical air conditioning systems which use vapor-compression or absorption refrigeration cycles.

Evaporative cooling is only effective in climates having a relative humidity that is less than 30%. When this is the case, hot dry outside air may be transformed to cool moist inside air and the heat of the outside air may be used to accomplish the required evaporation effect. Therefore, in hot dry climates, evaporative cooling may cool air using much less energy than typical air conditioning systems. The temperature of the hot dry air may be brought down to a temperature approaching that of the coincident wet bulb temperature. The relative humidity of the hot dry air may be increased to the 70 to 90% range. In extremely dry climates, evaporative cooling of air has the added benefit of conditioning the air with more moisture for the comfort of the building occupants. Evaporative cooler performance increases with increasing elevation and decreasing relative humidity. To determine the evaporative cooling system cooling capacity that is required to keep building occupants comfortable at the hottest expected climatic design condition, please see the instructions for our **Cooling Load Analysis Calculator**.

In order to use this calculator, you will need to determine the outdoor design conditions for the building location. This is typically the historical Summer cooling 1% dry bulb temperature, the coincident wet bulb temperature, and the daily temperature range for the local climate or as specified by the local building code. The 1% means that the historical temperature has only exceeded this temperature 1% of the time (i.e., it has historically only been hotter than this temperature 1% of the time). Design outdoor dry bulb temperatures for many locations are published by the Air Conditioning Contractors of America (ACCA) at this website:

Outdoor Design Conditions

If the wet bulb temperature is not directly entered, this calculator uses psychrometrics to determine the wet bulb temperature that is coincident with the entered outdoor dry bulb temperature and either the entered relative humidly or dew point temperature. Psychrometrics is the determination of the heat and water vapor properties of air. Primary psychrometric parameters are barometric pressure (which is a function of elevation), dry bulb temperature, wet bulb temperature, relative humidity, and dew point temperature. For more information about these parameters and about psychrometrics in general, please see the instructions for our **Psychrometrics Calculator**.

To use this calculator, first enter ALL of the following input parameters:

1) **Design Outdoor Dry Bulb Temp (Degrees Fahrenheit)** - This is the historical Summer cooling 1% dry bulb temperature for the local climate and obtained as previously described or as specified by the local building code. Please use this same value in our **Cooling Load Analysis Calculator** and **Existing Building Energy Usage Analysis Calculator**.

2) **Design Indoor Dry Bulb Temp (Degrees Fahrenheit)** - This is typically 70 to 80 degrees F or as specified by the local building code. Please note that this temperature must be greater than **Cooler Leaving Dry Bulb Temp** output parameter or the calculator will be unable to calculate many of the output parameters. Please use this same value in our **Building Assembly Moisture Analysis Calculator**, **Cooling Load Analysis Calculator** and **Existing Building Energy Usage Analysis Calculator**.

Then enter ONE of the following three input parameters:

3) **Design Outdoor Wet Bulb Temp (Degrees Fahrenheit)** - This is the historical Summer wet bulb temperature that is coincident with the **Design Outdoor Dry Bulb Temp** input parameter for the local climate and obtained as previously described or as specified by the local building code. Please see our **Psychrometrics Calculator** for more information about wet bulb temperature. If a value is entered for the design outdoor wet bulb temp, do not enter values for the **Design Outdoor Relative Humidity** or **Design Outdoor Dew Point Temp** input parameters. Please use this same value in our **Cooling Load Analysis Calculator**.

4) **Design Outdoor Relative Humidity (Percent)** - This is the historical Summer cooling outdoor relative humidity that is coincident with the **Design Outdoor Dry Bulb Temp** input parameter. If a value is entered for the design relative humidity, do not enter values for the **Design Outdoor Wet Bulb Temp** or **Design Outdoor Dew Point Temp** input parameters. Please see our **Psychrometrics Calculator** for more information about relative humidity.

5) **Design Outdoor Dew Point Temp (Degrees Fahrenheit)** - This is the historical Summer cooling outdoor dew point temperature that is coincident with the **Design Outdoor Dry Bulb Temp** input parameter. If a value is entered for the design outdoor dew point temp, do not enter values for the **Design Outdoor Wet Bulb Temp** or **Design Outdoor Relative Humidity** input parameters. Please see our **Psychrometrics Calculator** for more information about dew point temperature.

Then enter ONE of the following two input parameters:

6) **Design Air Flow Rate (CFM)** - This is the design air flow rate that the cooler will be operated at in lieu of designing for a specific cooling capacity. This value is often specified when purchasing a commercial cooler. If a value is entered for the design air flow rate, do not enter a value for the **Design Cooling Capacity** input parameter.

7) **Design Cooling Capacity (Tons)** - This is the cooling capacity that is required to cool the space in lieu of designing for a specific air flow rate. One ton of cooling capacity is equivalent to 12,000 BTU/Hour. This value is an output parameter of our **Cooling Load Analysis Calculator**. If a value is entered for the design cooling capacity, do not enter a value for the **Design Air Flow Rate** input parameter.

Then enter ALL of the following input parameters:

8) **Design Efficiency (Percent)** - This is the efficiency of the cooler which is typically between 80-90% and depends on the air flow rate through the evaporative media, the effective flow rate area of the evaporative media, and the material used as the evaporative media.

9) **Elevation (Feet)** - This is the elevation of the building.

Click [Solve] after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Barometric Pressure (Inches of Mercury)** - This is the standard atmospheric barometric pressure at the **Elevation** input parameter.

2) **Design Outdoor Wet Bulb Temp (Degrees Fahrenheit)** - This is either the calculated or entered wet bulb temperature as described for the **Design Outdoor Wet Bulb Temp** input parameter. If "NA" is displayed, this indicates that the input parameters are not entered appropriately.

3) **Design Outdoor Relative Humidity (Percent)** - This is either the calculated or entered relative humidity as described for the **Design Outdoor Relative Humidity** input parameter. If "NA" is displayed, this indicates that the input parameters are not entered appropriately.

4) **Design Outdoor Dew Point Temp (Degrees Fahrenheit)** - This is either the calculated or entered dew point temperature as described for the **Design Outdoor Dew Point Temp** input parameter. If "NA" is displayed, this indicates that the input parameters are not entered appropriately.

5) **Cooler Leaving Dry Bulb Temp (Degrees Fahrenheit)** - This is the temperature of the air that leaves the cooler. Please note that this temperature must be less than the **Design Indoor Dry Bulb Temp** input parameter or the calculator will be unable to calculate many of the output parameters. If "NA" is displayed, this indicates that the input parameters are not entered appropriately.

6) **Cooler Air Flow Rate (Cubic Feet/Minute)** - This is air flow rate of the cooler given the input parameters. This is the rate at which a blower draws outside air through the evaporative media pads and into the conditioned building space. Since coolers are designed for 100% outside air intake, provisions must be made to exhaust this same quantity of air from the conditioned building space. If "NA" is displayed, this indicates that the input parameters are not entered appropriately.

7) **Cooler Cooling Capacity (Tons)** - This is the cooling capacity of the cooler given the input parameters. One ton of cooling capacity is equivalent to 12,000 BTU/Hour. Please see our **Cooling Load Analysis Calculator** for more information about cooling capacity. If "NA" is displayed, this indicates that the input parameters are not entered appropriately.

8) **Cooler Water Evaporation Rate (Gallons/Hour)** - This is the water evaporation rate of the cooler given the input parameters. If "NA" is displayed, this indicates that the input parameters are not entered appropriately.

9) **Cooler Water Bleed-off Rate (Gallons/Hour)** - This is the water bleed off rate of the cooler given the input parameters. Water Bleed-off is water that is not recirculated that is removed from the cooler. Water bleed-off reduces the buildup of lime scale and scale on the evaporative media

pads. This calculator assumes 1 GPH of water bleed-off per 1,000 CFM of air flow rate up to 50% of the evaporation rate. Depending on the mineral content of the water, more or less water bleed-off may be appropriate. If "NA" is displayed, this indicates that the input parameters are not entered appropriately.

10) **Cooler Water Makeup Rate (Gallons/Hour)** - This is the water makeup rate of the cooler given the input parameters. Water makeup rate is the summation of the water evaporation and water bleed-off rates and is the water rate that must be continuously supplied to the cooler. If "NA" is displayed, this indicates that the input parameters are not entered appropriately.

11) **Cooler Water Recirculation Rate (Gallons/Minute)** - This is the recommended water recirculation rate of the cooler given the input parameters. This is the rate that the pump lifts water from the sump and delivers it to the perforated troughs at the top of the cooler that continuously feed and keep the evaporative media pads moist. This calculator assumes the recirculation rate is three times the evaporation rate. If "NA" is displayed, this indicates that the input parameters are not entered appropriately.

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Existing Building Energy Usage Analysis Calculator

If you are just looking to replace the existing cooling/heating system with a similar system and you only want to ensure that the replacement system will provide the appropriate cooling/heating capacity during the hottest/coldest expected climatic design conditions where the building is located, this calculator will provide a very simple and very accurate way to do this. This calculator allows you to use the existing cooling/heating system to remove/add heat in a quantifiable manner to allow accurate determination of the actual heat transfer characteristics of the existing building. However, if you are designing a cooling/heating system for a new building that does NOT yet exist or if you are designing a totally different type of heating system for an existing building (e.g., replacing an existing furnace forced air heating system with a hydronic radiant floor heating system), you will need to exercise our **Cooling Load Analysis Calculator** and **Heat Loss Analysis Calculator**, and you will likely need to accomplish a room-by-room analysis as well.

It is entirely possible that the existing cooling/heating system is significantly under or over-sized for the existing building. If a system is significantly under-sized, the system may not provide adequate cooling/heating capacity for the existing building during the hottest/coldest expected climatic design conditions. If a system is significantly over-sized, the system may short cycle resulting in reduced efficiency and reduced furnace life. Unfortunately, many HVAC contractors are often not capable of performing a proper analysis or simply do not want to expend the effort/time required to perform a proper analysis. Conversely, you may find yourself in a situation where the HVAC contractor recommends doing a more expensive standard cooling load analysis or heat loss analysis when only this relatively simple analysis of the existing building energy usage is really required. Please see our **Hydronic Radiant Floor Heating Design Calculator** instructions for more information about HVAC contractor problems.

Performing this existing building energy usage analysis is often much more accurate than performing a standard cooling load analysis or heat loss analysis. The reason for this is because a standard cooling load analysis or heat loss analysis requires making assumptions about the building material R-values used in the construction and estimating the building outdoor infiltration rate that will result from the construction. There is a lot of opportunity to make errors when doing the standard cooling load analysis or heat loss analysis and making these errors is unfortunately very common in the HVAC industry. The only factor that limits the accuracy of this existing building energy usage analysis is the accuracy of measuring the fuel used during the measurement period and this can normally be accomplished within a couple percent accuracy.

When replacing an old inefficient furnace with a new efficient furnace, you need to be cognizant about not allowing the rated efficiency improvement to cause over-sizing the new furnace. This is easier to get wrong than you might think. For example, if your old furnace is rated for 50,000 BTU per hour and 60% Average Fuel Utilization Efficiency (AFUE), it is currently providing 30,000 BTU per hour of heat to the building. If "catalog engineering" is the extent of your HVAC knowledge and you happen to replace it with a new furnace rated for 55,000 BTU per hour and 95% AFUE because the next smaller size is less than 50,000 BTU per hour, this new furnace will provide 52,250 BTU per hour of heat to the building. This is almost 75% more heat than the original furnace provided and this over-sizing will most likely cause short cycling resulting in reduced efficiency and reduced furnace life. Assuming 30,000 BTU per hour is truly the maximum design heat load required for this building, you would be much better served by installing a new 95 AFUE furnace have a rating of 31,500 BTU per hour or perhaps even less. This smaller furnace will cost less to install, will cost less to operate, will have a longer life, and will provide the required heat.

In order to use this calculator, you will need to know the Coefficient of Performance (COP) of the existing cooling/heating system and record how much fuel is used by the existing cooling/heating system during some specific measurement period. AFUE or Seasonal Energy Efficiency Ratio (SEER) can be converted to COP as explained below. Any measurement period may be used (e.g., day, week, month or year). We recommend at least one month and preferably a year to maximize accuracy. *So the wise homeowner will accomplish this analysis well in advance of actually needing to replace their existing cooling/heating system.* It is important that ONLY the fuel used by the cooling/heating system during this measurement period be entered into the calculator. Any fuel used for lighting or other building appliances must be accounted for and excluded.

In order to use this calculator, you will need to determine the outdoor design conditions for the building location. This is typically the historical Summer cooling 1% or Winter heating 99% dry bulb temperature for the local climate or as specified by the local building code. The 1% means that the historical temperature has only exceeded this temperature 1% of the time (i.e., it has historically only been hotter than this temperature 1% of the time). The 99% means that the historical temperature has exceeded this temperature 99% of the time (i.e., it has historically only been colder than this temperature 1% of the time). Design outdoor dry bulb temperatures for many locations are published by the Air Conditioning Contractors of America (ACCA) at this website:

Outdoor Design Conditions

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Design Outdoor Dry Bulb Temp (Degrees Fahrenheit)** - This is the historical Summer cooling 1% or Winter heating 99% dry bulb temperature for the local climate and obtained as previously described or as specified by the local building code. Please use this same value in our **Cooling Load Analysis Calculator**, **Evaporative Cooling Performance Calculator**, **Heat Loss Analysis Calculator**, **Hydronic Radiant Floor Heating Design Calculator** and **Passive Solar Thermal Mass Performance Calculator**. The default value is 20.

2) **Design Indoor Dry Bulb Temp (Degrees Fahrenheit)** - This is typically 65 to 80 degrees F or as specified by the local building code. You should set the existing cooling/heating system to this set point for the duration of the measurement period and the existing cooling/heating system MUST be capable of maintaining this indoor temperature during the entire measurement period. Please use this same value in our **Building Assembly Moisture Analysis Calculator**, **Existing Building Energy Usage Analysis Calculator**, **Evaporative Cooling Performance Calculator**, **Heat Loss Analysis Calculator**, **Hydronic Radiant Floor Heating Design Calculator** and **Passive Solar Thermal Mass Performance Calculator**. The default value is 70.

3) **Cooling/Heating Degree Days** - This is an important design parameter used to reflect the climatic demand for energy needed to cool/heat a building during January through December. The cooling/heating requirements for a building at a specific location are considered to be directly proportional to the number of cooling/heating degree days at that location. Cooling/heating degree day data are published by Degree Days, National Renewable Energy Laboratory (NREL) and Weather Data Depot at these websites:

**Degree Days**

Only the actual cooling/heating degree days that occurred during the measurement period should be entered into the calculator. The default value is 4,611.

4) **Fuel Type/Units** - This is a logic input parameter to allow selecting the fuel type, the associated fuel units and the associated heating BTU that the fuel provides. Enter 1 for Coal in units of Tons at 25,000,000 BTU/Ton. Enter 2 for Electric in units of KWH at 3,412 BTU/KWH. Enter 3 for Natural Gas in units of Cubic Feet at 1,020 BTU/Cubic Foot. Enter 4 for Oil in units of Gallons at 138,690 BTU/Gallon. Enter 5 for Propane in units of Gallons at 91,500 BTU/Gallon. Enter 6 for Wood in units of Cords at 25,622,500 BTU/Cord (i.e., dry Douglas Fir of 9,250 BTU/Pound times 2,770 Pounds/Cord). The default value is 2.

5) **Quantity of Fuel (Fuel Unit)** - This is the total amount of fuel used by ONLY the cooling/heating system during the measurement period. Any measurement period may be used (e.g., day, week, month or year). We recommend at least one month and preferably a year to maximize accuracy. It is important that ONLY the fuel used by the cooling/heating system during this measurement period be entered into the calculator. Any fuel used for lighting or other building appliances must be accounted for and excluded. Enter the actual quantity of fuel that was used during the measurement period for the associated fuel unit as defined in the above **Fuel Type/Units** logic input parameter instructions. The default value is 11,350.

6) **Cooling/Heating Coefficient of Performance (COP)** - This is the Coefficient of Performance (COP) associated with the air conditioner or the heat source currently being used in the existing building.

   Air conditioner performance is often reported as Seasonal Energy Efficiency Ratio (SEER). To convert SEER to COP, SEER must first be converted to Energy Efficiency Ratio (EER) and then EER must be converted to COP. EER is calculated as 1.12 times the SEER minus 0.02 times the SEER squared. COP is then calculated by dividing the EER by 3.412. For example, a 13.0 SEER equals 11.2 EER which then equals 3.3 COP.

   If the heat source is a device that converts fuel to heat (e.g., a coal, natural gas, oil, propane or wood fired boiler), the performance is often reported as Average Fuel Utilization Efficiency (AFUE) in percent. To convert AFUE to COP, divide the AFUE in percent by 100 to obtain the COP. For example, an AFUE of 96% equals 0.96 COP. An electric boiler has an AFUE of 100% and a corresponding 1 COP which is the maximum value for a device that converts fuel to heat. If the heat source is a device that moves environmental heat in lieu of converting fuel to heat (e.g., an air source or ground source heat pump), the performance is often reported as Heating Seasonal Performance Factor (HSPF). To convert HSPF to COP, divide the HSPF by 3.412 to obtain the COP. For example, 6.8 HSPF equals 2.0 COP. The default value is 1.

Click Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Total Heat Gain/Loss (BTU/100K or Therm)** - This is the total building heat loss during the measurement period in BTU divided by 100,000 which must be removed/replaced by the building cooling/heating system. A Therm is 100,000 BTU or approximately the heat generated by burning 100 cubic feet (1 CCF) of natural gas.

2) **Total Heat Gain/Loss (BTU/Hour)** - This is the total heat gain/loss of the building per hour. The cooling/heating system needs to provide this total heat gain/loss. One ton of cooling capacity is equivalent to 12,000 BTU/Hour. Please see our **Cooling Load Analysis Calculator** for more information about cooling capacity.

3) **Total Heat Gain/Loss (BTU/Day)** - This is the total heat gain/loss of the building per day. The cooling/heating system needs to provide this total heat gain/loss.

4) **Total Heat Gain/Loss (BTU/ Hour-Degrees F)** - This important design parameter is the **Total Heat Gain/Loss (BTU/Hour)** output parameter divided by the difference between the **Design Indoor Dry Bulb Temp** and the **Design Outdoor Dry Bulb Temp** input parameters. This total heat gain/loss of the building in conjunction with published climatic Cooling/heating degree day data where the building is located are used as input parameters in our **Integrated Cooling System Performance Calculator** and **Integrated Heating System Performance Calculator** to assess monthly/annual climatic cooling/heating needs.

It is important that you know the heat gain/loss of the building BEFORE designing the building cooling/heating system. If you are working with a company who cannot perform this analysis and provide data that is sealed/signed by a licensed professional engineer for the specific design and location, you should apply due diligence and consider finding a more competent company to do this. If you find that you need this service, we hope that you will consider Borst Engineering and Construction.

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For all practical purposes, hydronic fluid is incompressible, will significantly expand when heated, and may generate high pressure that may destroy an unprotected hydronic radiant floor heating system. Typically, both an expansion tank and a backup pressure relief valve are used to protect a hydronic radiant floor heating system from this potentially destructive hydronic fluid expansion.

This calculator enables you to properly design/size and setup a diaphragm-type expansion tank for use in a hydronic radiant floor heating system. A properly designed/sized diaphragm-type expansion tank allows the system pressure to reach within about 5 PSI lower than the pressure relief valve opening pressure setting when the system reaches its maximum operating temperature.

The pressure on the air-side of the diaphragm must be adjusted to the required design pre-pressurization value BEFORE the system is filled with hydronic fluid. An under-pressurized tank will perform like an under-sized tank and may cause the relief valve to open each time the system is heated.

A properly designed/sized and pre-pressurized diaphragm-type expansion tank will not contain any hydronic fluid until the system first begins to get heated and the fluid begins expanding. As such, the volume of hydronic fluid that is contained within the expansion tank while the system is operating need not and should NOT be entered into the calculator.

Before using this calculator, you should first exercise our **Hydronic Radiant Floor Heating Design Calculator** to properly design the hydronic radiant floor heating system, to determine the circuit hydronic fluid volume contained in all of the zone circuits, and to determine the actual heat source supply temperature that will be used. As discussed in the hydronic radiant floor heating design calculator instructions, some States do not even require a contractor license, any insurance, or any bonding. There are many online companies in the HVAC industry that operate from these States without any licensing credentials, requisite knowledge, experience, or proficiency. Therefore, you should definitely apply due diligence when selecting the hydronic radiant floor heating system design/installation team. We highly recommend using a licensed/experienced professional engineering company to perform the analysis/design and using a licensed/experienced HVAC company to install the system.

This calculator will determine the minimum expansion tank volume, total system hydronic fluid volume, required volume of propylene glycol (if any will be used), and the required design pre-pressurization value on the air-side of the expansion tank diaphragm BEFORE the system is filled with hydronic fluid.

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Hydronic Fluid Mixture (Percent Propylene Glycol/Water)** - This is the percentage of propylene glycol used in the hydronic fluid. *You should NEVER use ethylene glycol in a hydronic heating system.* You may enter any valve between 0 and 50% to specify the concentration of propylene glycol you will use. If you elect to use propylene glycol, you should use at least 30% to inhibit the growth of bacteria in the system. Propylene glycol has a higher viscosity than water (which will result in increased hydraulic friction) and a lower specific heat than water (which will result in reduced heat transfer). Therefore, using propylene glycol will result in a less efficient heating system. As such, you should avoid using propylene glycol unless you are actually at risk of freezing the tube. We recommend using 100% water and entering 0 into the

calculator. Please use this same value in our **Hydronic Radiant Floor Heating Design Calculator** and **Buffer Tank Design Calculator**.

2) **Hydronic Fluid Fill Temp (Degrees Fahrenheit)** - This is the temperature of hydronic fluid at the time the system is filled. This is typically 50 to 60 degrees F.

3) **Actual Heat Source Supply Temp (Degrees Fahrenheit)** - This is the temperature that the heat source will actually be set to supply ALL the circuits in ALL the zones. Please use this same value in our **Hydronic Radiant Floor Heating Design Calculator**.

4) **Pressure Relief Valve Setting (Pounds/Square Inch)** - This is the actual setting of the system's pressure relief valve.

5) **Height of Top of System above Tank Connection (Feet)** - This is the height that the top most portion of system is above the expansion tank connection.

6) **Heat Source + Misc Hydronic Fluid Volume (Gallons)** - This is the volume of hydronic fluid contained in the heat source (including the volume of the buffer tank if one is used) and contained in the miscellaneous distribution pipe leading to/from the manifold station(s) that is heated to the **Actual Heat Source Supply Temp** input parameter. ***Do NOT include the volume of the expansion tank.*** The volume of the expansion tank is NOT included because the expansion tank will not contain a significant volume of hydronic fluid if the expansion tank is properly pre-pressurized to the **Required Air-Side Pre-Pressurization** output parameter BEFORE the system is filled with hydronic fluid. The expansion tank only begins filling with hydronic fluid when the hydronic fluid begins to get heated to the **Actual Heat Source Supply Temp** as the hydronic fluid expands.

7) **Circuit Hydronic Fluid Volume (Gallons)** - This is the volume of hydronic fluid contained in all the circuits of each specific zone that is either at the **Actual Heat Source Supply Temp** input parameter or at the specific zone **Maximum Operating Temp** input parameter. These volume input parameters are output parameters of our **Hydronic Radiant Floor Heating Design Calculator**. You may initially leave these volume input parameters blank or enter 0 for those zones that you will NOT use.

8) **Maximum Operating Temp (Degrees Fahrenheit)** - This is the maximum temperature the hydronic fluid will reach in each specific zone. You may initially leave these temperature input parameters blank or enter 0 which will force the calculator to use the **Actual Heat Source Supply Temp** input parameter for that zone. You should normally use the **Actual Heat Source Supply Temp**; however, if you are perhaps injecting/mixing lower temperature water to operate some zones at significantly lower temperatures than the **Actual Heat Source Supply Temp**, entering this lower maximum operating temperature may significantly reduce the **Minimum Expansion Tank Volume** output parameter.

Click Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Minimum Expansion Tank Volume (Gallons)** - This is the minimum volume that the expansion tank must be to protect a hydronic radiant floor heating system from potentially destructive hydronic fluid expansion. For economic reasons, it is preferable to use an expansion tank size that just meets or slightly exceeds this minimum volume. However, there is no issue associated with using an over-sized expansion tank provided that the tank is properly pre-pressurized and installed as described in the instructions.

2) **Total System Volume (Gallons)** - This is the total volume of hydronic fluid contained in the system and the amount needed to fill the system.

3) **Required Volume of Propylene Glycol (Gallons)** - This is the required volume of propylene glycol that should be used when filling the system to satisfy the **Hydronic Fluid Mixture** input parameter.

4) **Required Air-Side Pre-Pressurization (Pounds/Square Inch)** - This is the required pressure that the air-side of the tank diaphragm must be adjusted BEFORE the system is filled with hydronic fluid.

Diaphragm-type expansion tanks should always be mounted vertically with their inlet connection at the top and should always be installed in the system very close to the inlet side of the circulator pump(s). Failing to do this may result in air being trapped on the fluid-side of the diaphragm (which may result in premature tank corrosion/failure), may reduce the system's ability to expel air (or even result in air being drawn into the system via the air separators), and may encourage destructive circulator pump(s) cavitation and premature failure.

Please exercise our **Buffer Tank Design Calculator** to determine if a buffer tank is required in the hydronic radiant floor heating system to prevent the heat source short cycling.

It is important that you do a proper building heat loss analysis, circuit/zone design, and hydronic radiant floor heat gain analysis BEFORE actually constructing the system. If you are working with a company who cannot perform this analysis and provide data that is sealed/signed by a licensed professional engineer for the specific design and location, you should apply due diligence and consider finding a more competent company to do this. If you find that you need this service, we hope that you will consider Borst Engineering and Construction.

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Heat Loss Analysis Calculator

If you are just looking to replace the existing heating system with a similar system and you only want to ensure that the replacement system will provide the appropriate heating capacity during the coldest expected climatic design conditions where the existing building is located, please see our **Existing Building Energy Usage Analysis Calculator**.

This calculator will allow you to determine the required heating system capacity for a new building to keep the occupants comfortable at the coldest expected climatic design condition. The heating system capacity that is required is exactly the same as the heat loss that will occur from the building at this coldest expected climatic design condition given the size of the building and the materials used to construct the building. Building heat loss occurs from:

1) Heat transfer through the walls, ceilings, floors and fenestration (i.e., exterior doors and windows) exposed to the climatic conditions and
2) Air infiltration caused by leaky building construction and/or created by controlled air ventilation which causes warm inside air to be exchanged with cold outside air.

The actual heat loss is proportional to the building surface area exposed to the climatic conditions, the rate of heat transfer by the materials used in the building construction (defined as the heat transfer coefficient or U-factor), and the difference between inside wall temperature and the outside wall temperature. The inside wall temperature is typically the same as the inside temperature. In the winter months, the outside wall temperature is typically the same as the outside temperature. R-value is a measure of thermal resistance (i.e., how much a material resists heat flow), is the inverse of U-factor, and is the more commonly used term in the building construction industry. Even the worst wall assembly will have a much higher R-value (or much lower U-factor) than the best available window. As such, there are significant economic and energy efficiency benefits to minimizing the quantity and size of windows used in buildings. *To minimize the building heat loss and the associated heat gain required by the heating system for any given climate, one should consider BOTH minimizing the building size and maximizing the R-value of the materials used to construct the building envelope.*

A sample of a professional Air Conditioning Contractors of America (ACCA) Manual J8 heat loss analysis and hydronic radiant (HR) floor heating system design may be found on the Consultation tab of our website:

Sample ACCA MJ8 Analysis & HR Design

In order to use this calculator, you will first need to look up the R-values of the materials used to construct the building envelope from the below table and then determine the total R-value of the wall, ceiling, and floor assemblies. You will need to determine the total R-value for the exterior fenestration (i.e., the windows and doors). The total R-value is provided by fenestration manufacturers (often specified as the total U-factor which may be inverted to obtain the total R-value). All of these total R-values are then entered into the calculator and converted by the calculator into total U-factors for the assemblies which are then used to determine the heat loss in a manner consistent with the 2013 American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Fundamentals Handbook methodology and recommendations.

The following is a list of R-values (in units of Degrees F-Hour-Square Feet/BTU) for material commonly used in the building construction industry:

AIR FILMS:

Inside surface	0.64
Outside surface (15 MPH wind)	0.17

COATINGS AND FACINGS:

Building felt (15 PSF)	0
Foil facing	0
Latex paint	0
MemBrain™	0
Oil paint	0
Polyethlene vapor barriers	0
Typar™	0
Tyvek™	0

CONCRETE AND MASONRY:

Common brick	0.3 per inch
Concrete	0.10 per inch
8" concrete block	1.11 for 8"

FLOORING:

Carpet (1/4" nylon level loop)	1.36 for 1/4"
Carpet (1/2" polyester plush)	1.92 for 1/2"
Ceramic tile	0.6 per inch
Polyurethane foam padding (8 PCF)	4.4 per inch
Vinyl tile or sheet flooring (1/8")	0.21 for 1/8"

INSULATION:

Blown cellulose fiber	3.4 per inch
Expanded polystyrene (EPS) panels	4.3 - 5.0 per inch
Extruded polystyrene (XPS) panels	5.4 per inch
Fiberglass/Rockwool batt (standard density)	3.17 per inch
Foam in place urethane	5.9 per inch
Polyisocyanurate panels	5.6 per inch

WALL CLADDINGS AND SHEATHINGS:

Drywall	0.9 per inch
Hardwoods	0.9 per inch
Oriented Strand Board (OSB)	1.59 per inch
Plywood	1.24 per inch
Softwoods	1.42 per inch
Wood lap siding	1.24 per inch
Vinyl lap siding	0.61 per inch

The R-value for a specific thickness of a material may be obtained by multiplying the R-value per inch by the thickness in inches. The R-values for each layer of material should be added together to determine the total R-value of the wall, ceiling, and framed floor

assemblies. Please note, if you have a fully insulated slab-on-grade floor, you only need to know the R-value of the perimeter/under-slab insulation and you need to enter the exposed perimeter and NOT the exposed area into the calculator.

For a typical 2x4 wall we might have 0.64 (inside air film) plus 0.45 (0.9 x 0.5 inch drywall) plus 11.09 (3.17 x 3.5 inches of fiberglass batt) plus 0.62 (1.24 x 0.5 inch plywood sheathing) plus 0.31 (0.61 x 0.5 inch vinyl clapboard siding) plus 0.17 (outside air film) for a total 2x4 wall R-value of 13.28. Please note that this corresponds to a U-factor of 0.0753. You will not find a window at any price that comes close to performing as well as even this poor performing wall assembly.

For a typical 2x6 wall we might have 0.64 (inside air film) plus 0.45 (0.9 x 0.5 inch drywall) plus 17.44 (3.17 x 5.5 inches of fiberglass batt) plus 0.62 (1.24 x 0.5 inch plywood sheathing) plus 0.31 (0.61 x 0.5 inch vinyl clapboard siding) plus 0.17 (outside air film) for a total 2x6 wall R-value of 19.63.

You may want to further refine these 2x4 and 2x6 wall R-values to properly determine and account for the real R-value of non-uniform material assemblies (i.e., account for the thermal bridging that results from the 2x4 and 2x6 studs). To accomplish this:

1) Determine what percentage of the wall assembly consists of different non-uniform materials (e.g., 16 inch on center 2x4 stud construction wall area consists of about 14% stud area and 86% fiberglass batt area),
2) Determine the associated U-factors (i.e., the inverse of the R-value) for each non-uniform material. The 14% of wall area that consists of 2x4 studs has a U-factor of 0.2012 [i.e., 1 / (1.42 x 3.5" of softwood) = 0.2012]. The 86% of wall area that consists of fiberglass batt has a U-factor of 0.0902 [i.e., 1 / 11.09 = 0.0902],
3) Determine the total percent-weighted U-factor of the non-uniform material assembly (e.g., 0.14 x 0.2012 + 0.86 x 0.0902 = 0.1057),
4) Determine the real R-value of the non-uniform material assembly by inverting the total percent-weighted U-factor (e.g., 1 / 0.1057 = 9.46). The real R-value of this non-uniform material assembly is 9.46 in lieu of the previous 11.09 value that assumed 100% fiberglass batt, and
5) Determine the total wall R-value by summing the real R-value of the non-uniform material assembly with the R-values of the uniform material assemblies [e.g., 0.64 (inside air film) plus 0.45 (0.9 x 0.5 inch drywall) plus 9.46 (the real R-value of the non-uniform material assembly) plus 0.62 (1.24 x 0.5 inch plywood sheathing) plus 0.31 (0.61 x 0.5 inch vinyl clapboard siding) plus 0.17 (outside air film)] for a total 2x4 wall R-value of 11.65 in lieu of the previous 13.28 total 2x4 wall R-value.

For a typical 11 inch thick Insulated Concrete Form (ICF) wall we might have 0.64 (inside air film) plus 0.45 (0.9 x 0.5 inch drywall) plus 0.6 (0.1 x 6 inches concrete) plus 22.5 (4.5 x 5 inches of EPS) plus 0.31 (0.61 x 0.5 inch vinyl clapboard siding) plus 0.17 (outside air film) for a total ICF wall R-value of 24.67. Please see our **ICF Performance Calculator** to determine the ICF effective R-value that accounts for the thermal mass effect where the building will actually be constructed. Then consider using this ICF effective R-value in lieu of the previous 0.6 and 22.5 R-values (i.e., the previous 23.10 ICF conventional R-value). For example, for standard ICF in Rogue River, Oregon, the ICF effective R-values are 21.38 in Spring, 66.15 in Summer, 63.42 in Fall, and 21.07 in Winter. So this is an average annual ICF performance of R43.07 or 1.86 higher performance than the conventional R23.10 R-value. This results in an average annual total ICF wall effective R-value of 44.64 in lieu of the previous 24.67 total ICF wall R-value.

It should be noted that if you have an existing building and you would like to determine the total R-values of the building envelope, this can often be easily accomplished without knowing anything about the building material that were actually used in the original construction. All you need is an IR temperature gun to measure the interior and exterior surface temperature of the building envelope, know the indoor temperature, and apply some math. Any existing building envelope R-value can be calculated using this equation:

$$R = 0.64 (T_{is} - T_{es}) / (T_i - T_{is})$$

where R is the building envelope R-value, T_{is} is the interior surface temperature of the building envelope, T_{es} is the exterior surface temperature of the building envelope, and T_i is the indoor temperature. This equation assumes that the indoor air film R-value is 0.64 and that both the indoor and outdoor temperatures are reasonably constant for a couple hours prior to measuring the interior and exterior surface temperatures. This approach is very accurate for 2x and SIP construction, but may be less accurate for ICF construction because the thermal mass effect time lag associated with ICF is typically much longer than the time that the outdoor temperature stays reasonably constant prior to measuring the interior and exterior surface temperatures. Furthermore, the effective R-value performance of ICF is often vastly different than the conventional R-value and is highly dependent on the daily outdoor temperature variation as explained in the instructions for our **ICF Performance Calculator**.

In order to use this calculator, you will need to determine the outdoor design conditions for the building location. This is typically the historical Winter heating 99% dry bulb temperature for the local climate or as specified by the local building code. The 99% means that the historical temperature has exceeded this temperature 99% of the time (i.e., it has historically only been colder than this temperature 1% of the time). Design outdoor dry bulb temperatures for many locations are published by the Air Conditioning Contractors of America (ACCA) at this website:

Outdoor Design Conditions

Initially performing a heat loss analysis on just the overall building is a good way to quickly evaluate the heat loss for the building size and climate. You may then vary the total R-values of the wall, ceiling and floor assemblies to evaluate different insulation strategies to refine and finalize the building envelope construction material requirements. *After you have finalized the building envelope construction material requirements, it is highly recommended that you perform a room-by-room heat loss analysis so you will have all the data necessary to exercise our other calculators.*

To use this calculator, enter ALL of the following required input parameters as indicated:
1) **Design Outdoor Dry Bulb Temp (Degrees Fahrenheit)** - This is typically the historical Winter heating 99% dry bulb temperature for the local climate and obtained as previously described or as specified by the local building code. However, if you are designing a passive solar building or hydronic radiant floor heating system, you will need to accomplish this heat loss analysis using the historically expected average monthly outdoor temperatures (i.e., NOT just the coldest expected 99% annual outdoor temperature). Please use this same value in our **Existing Building Energy Usage Analysis Calculator** and **Hydronic Radiant Floor Heating Design Calculator**. The default value is 20.

2) **Design Indoor Dry Bulb Temp (Degrees Fahrenheit)** - This is typically 65 to 75 degrees F or as specified by the local building code. Please use this same value in our **Building Assembly Moisture Analysis Calculator**, **Existing Building Energy Usage Analysis Calculator**, **Hydronic Radiant Floor Heating Design Calculator** and **Passive Solar Thermal Mass Performance Calculator**. The default value is 70.

3) **Window Area (Square Feet)** - This is the total exterior window rough opening area of the building or room that is exposed to the outside temperature. Please use this same value in our **Cooling Load Analysis Calculator**. The default value is 160.

4) **Window Total R-value (Degrees F-Hour-Square Feet/BTU)** - This is the window total R-value as specified by the window manufacturer. Often times a window manufacturer may specify a total U-factor and you will need to convert this total U-factor to a total R-value. For example, if the window manufacturer specifies a total U-factor of 0.45 for the window, the correct total R-value to enter into the calculator is 2.2 (i.e., 1 divided by 0.45). If you use multiple windows with different R-values, you will first need to perform an area-weighted average calculation to obtain the window total R-value to enter into the calculator as explained for the **Door Total R-value** input parameter. Please use this same value in our **Cooling Load Analysis Calculator**. The default value is 2.2.

5) **Wall Area (Square Feet)** - This is the total wall area of the building or room that is exposed to the outside temperature. If a wall is an interior wall and therefore not exposed to the outside temperature, do not include this wall area. Please note that the calculator will subtract the area of any exposed doors or windows associated with this exposed wall area, so you do not need to accomplish this math manually. Please use this same value in our **Cooling Load Analysis Calculator**. The default value is 1,620.

6) **Wall Total R-value (Degrees F-Hour-Square Feet/BTU)** - This is the total R-value of the materials used for the wall assembly. Please see the above construction material R-value table and directions for using it. Please use this same value in our **Cooling Load Analysis Calculator**. The default value is 40.

7) **Door Area (Square Feet)** - This is the total door rough opening area of the building or room that is exposed to the outside temperature. Please use this same value in our **Cooling Load Analysis Calculator**. The default value is 100.

8) **Door Total R-value (Degrees F-Hour-Square Feet/BTU)** - This is the door total R-value as specified by the door manufacturer. Often times a door manufacturer may specify a total U-factor and you will need to convert this total U-factor to a total R-value. For example, if the door manufacturer specifies a total U-factor of 0.45 for the door, the correct total R-value to enter into the calculator is 2.2 (i.e., 1 divided by 0.45). If you use multiple doors with different R-values, you will first need to perform an area-weighted average calculation to obtain the average door total R-value to enter into the calculator. For example, if you use two exterior doors in a room such that the first door is a 96 SF garage door that has a R-value of 4.6 and the second door is a 18 SF walk-in-door that has a R-value of 8.2, you would calculate the area-weighted average door total R-value to enter into the calculator to be 5.17 [i.e., (96 x 4.6 + 18 x 8.2) / (96 + 18)]. Please use this same value in our **Cooling Load Analysis Calculator**. The default value is 5.

9) **Ceiling Area (Square Feet)** - This is the total ceiling area of the building or room that is exposed to the outside temperature. If the ceiling is below a heated upstairs living area and therefore not exposed to the outside temperature, do not include this ceiling area. Please use this same value in our **Cooling Load Analysis Calculator**. The default value is 2,000.

10) **Ceiling Total R-value (Degrees F-Hour-Square Feet/BTU)** - This is the total R-value of the materials used for the ceiling assembly. Please see the above construction material R-value table and directions for using it. Please use this same value in our **Cooling Load Analysis Calculator**. The default value is 50.

11) **Floor Type (0=No Exposed Floor, 1=Framed Floor, 2=Basement Floor, 3=Slab-on-Grade Floor)** - This is a logic input parameter that tells the calculator the type of building or room floor. Entering a 0 tells the calculator that there is NO EXPOSED FLOOR to the outside temperature. Entering a 1 tells the calculator that the building or room floor is an insulated FRAMED FLOOR with a space below at the **Design Outdoor Dry Bulb Temp** input parameter value and the downward heat loss is calculated. Entering a 2 tells the calculator that the building or room floor is an uninsulated BASEMENT FLOOR at least two feet below ground level and the downward heat loss is calculated. Entering a 3 tells the calculator that the building or room floor is a fully insulated SLAB-ON-GRADE FLOOR and the combined edgewise and downward heat loss is calculated. A fully insulated slab-on-grade floor has insulation at the BOTH the exposed PERIMETER EDGES and BELOW the SLAB. The default value is 3.

12) **Floor Area or Exposed Perimeter (Square Feet or Feet)** - If you entered 1 or 2 for logic input parameter 11), this is the AREA of the building or room floor that is exposed to the outside temperature. If you entered 3 for logic input parameter 11), this is the PERIMETER of the building or room slab-on-grade floor that is exposed to the outside temperature. If some portion of the slab-on-grade floor perimeter is not exposed to the outside temperature, do not include this perimeter footage. The default value is 180.

13) **Floor Insulation R-value (Degrees F-Hour-Square Feet/BTU)** - If you entered 1 for logic input parameter 11), this is the total R-value of the materials used for the framed floor assembly. If you entered a 3 for logic input parameter 11), this is the slab-on-grade insulation R-value used for BOTH the exposed PERIMETER EDGES and BELOW the SLAB. The majority of heat loss from a fully insulated slab-on-grade floor occurs from the edgewise exposed perimeter and relatively little heat loss occurs downward from the internal area of the floor. The default value is 10.

14) **Building/Room Volume (Cubic Feet or 0 for Cubic Feet/Minute)** - This is a logic input parameter that tells the calculator whether the **Infiltration Rate** input parameter is entered as Air Changes/Hour (ACH) based on the actual building/room volume or simply entered as Cubic Feet/Minute (CFM). If the **Infiltration Rate** is entered as ACH, enter the total inside volume of the building or room and include the volume of ALL the rooms even if they are NOT exposed to the outside temperature. If the **Infiltration Rate** is entered as CFM, enter 0. Please use this same value in our **Cooling Load Analysis Calculator**. The default value is 14,580.

15) **Infiltration Rate (Air Changes/Hour or Cubic Feet/Minute)** - This is the air infiltration rate of the building/room caused by uncontrolled air infiltration (e.g., leaky building construction) and/or created by controlled air ventilation. Depending on whether the actual building/room volume or 0

is entered for the **Building/Room Volume** logic input parameter, enter either ACH or CFM. 1.0 ACH or more is typical of older, leaky building construction. 0.5 ACH is typical of new construction. 0.35 ACH is typically the minimum allowed for health reasons and is often accomplished in airtight, energy efficient building construction (e.g., ICF construction) by using a basic air ventilation system, Heat Recovery Ventilation (HRV) system, or Energy Recovery Ventilation (ERV) system. If a HRV or ERV system is used, you should reduce the calculator ACH entry by properly accounting for the efficiency of the heat recovery system. For example, if you use an air-to-air HRV system that is 60% efficient and the controlled ventilation is 0.35 ACH or 200 CFM, the correct calculator entry would be 0.14 ACH (i.e., 0.40 x 0.35 ACH) or 80 CFM (i.e., 0.40 x 200 CFM). Please use this same value in our **Cooling Load Analysis Calculator**. The default value is 0.5.

Click Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Window Heat Loss (BTU/Hour)** - This is the heat transfer loss through the exterior windows.

2) **Wall Heat Loss (BTU/Hour)** - This is the heat transfer loss through the exposed wall assembly.

3) **Door Heat Loss (BTU/Hour)** - This is the heat transfer loss through the exterior doors.

4) **Ceiling Heat Loss (BTU/Hour)** - This is the heat transfer loss through the exposed ceiling assembly.

5) **Floor Heat Loss (BTU/Hour)** - This is the heat transfer loss through the unheated exposed floor. This value (room or building as appropriate) is used as an input parameter to our **Hydronic Radiant Floor Heating Design Calculator** and **Passive Solar Thermal Mass Performance Calculator**.

6) **Infiltration Rate (Cubic Feet/Minute)** - This is the air infiltration rate of the building/room caused by uncontrolled air infiltration (e.g., leaky building construction) and/or created by controlled air ventilation. If the **Infiltration Rate** input parameter is entered as a CFM value, this output parameter is the same CFM value. If the **Infiltration Rate** input parameter is entered as an ACH value, this output parameter will use the **Building/Room Volume** logic input parameter to convert this output parameter to CFM.

7) **Infiltration Heat Loss (BTU/Hour)** - This is the heat loss caused by uncontrolled air infiltration (e.g., leaky building construction) and/or created by controlled air ventilation.

8) **Total Heat Loss (BTU/Hour)** - This is the total <u>hourly</u> heat loss of the building or room. The heating system needs to provide this heating capacity. If you performed the recommended <u>room-by-room</u> heat loss analysis, you will need to add the total <u>hourly</u> heat loss for each room to determine the total <u>hourly</u> heat loss of the <u>building</u>. This value (room or building as appropriate) is used with our **Hydronic Radiant Floor Heating Design Calculator**, **Masonry Heater Performance Calculator**, and **Passive Solar Heat Gain Calculator** to assess how well the heat

gain achieved by the hydronic radiant floor, masonry heater and/or passive solar heating system meets the <u>hourly</u> heating needs.

9) **Total Heat Loss (BTU/Day)** - This is the total <u>daily</u> heat loss of the building or room. The heating system needs to provide this heating capacity. If you performed the recommended <u>room-by-room</u> heat loss analysis, you will need to add the total <u>daily</u> heat loss for each room to determine the total <u>daily</u> heat loss of the <u>building</u>. This value (room or building as appropriate) is used with our **Hydronic Radiant Floor Heating Design Calculator** and **Masonry Heater Performance Calculator** to assess how well the heat gain achieved by the hydronic radiant floor heating system and/or masonry heater meets the <u>daily</u> heating needs.

10) **Total Heat Loss (BTU/ Hour-Degrees F)** - This important design parameter is the **Total Heat Loss (BTU/Hour)** output parameter divided by the difference between the **Design Indoor Dry Bulb Temp** and the **Design Outdoor Dry Bulb Temp** input parameters. If you performed the recommended <u>room-by-room</u> heat loss analysis, you will need to add the **Total Heat Loss (BTU/Hour)** for each room and then divide this quantity by the difference between the **Design Indoor Dry Bulb Temp** and the **Design Outdoor Dry Bulb Temp** to determine the total heat loss of the <u>building</u> in BTU/Degrees F-Hour. This total heat loss of the building in conjunction with published climatic Heating Degree Day data where the building is located are used as input parameters in our **Integrated Heating System Performance Calculator** to assess how well the heat gain achieved by the hydronic radiant floor, masonry heater and/or passive solar heating system meets <u>monthly/annual</u> heating needs.

It is important that you know the heat loss of the building BEFORE designing the building heating system. If you are working with a company who cannot perform this analysis and provide data that is sealed/signed by a licensed professional engineer for the specific design and location, you should apply due diligence and consider finding a more competent company to do this. If you find that you need this service, we hope that you will consider Borst Engineering and Construction.

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Radiant heating is the effect you feel when you feel the warmth of the sun. A hydronic radiant floor heating system consists of a controller, boiler, pumps, distribution plumbing, manifold stations (often fitted with solenoid shutoff valves, flow rate balance valves and supply/return water temperature and flow rate gauges), and tube placed within the floor of your building to successfully transform it into an efficient heat emitter. Hot water silently runs through this system to radiant heat your room from the floor up providing immediate and luxurious comfort to the building occupants. A hydronic radiant floor heating system does not actually heat the air like forced air or traditional electric heating systems and consequently the heat does not rise to the ceiling where it does not benefit the building occupants and is more readily lost through the ceiling/roof insulation.

Radiant heat has been proven to be by far the most comfortable and efficient heating system available today. The lack of moving air can be advantageous to people with severe allergies or if you simply do not like a drafty home. Without the need for air vents or baseboard registers, you have no restriction in furniture placement and you have full control over room decor. A hydronic radiant floor heating system uses little energy which is a significant benefit for buildings located off the power grid or in areas with high utility expenses. A hydronic radiant floor heating system can be heated with a wide variety of energy sources including: conventional heat pumps and electric, propane, natural gas, fossil oil fired boilers; or unconventional solar water heaters and hydroelectric, vegetable oil, wood fired boilers; or some combination of these energy sources. It is very cost effective to provision for a future radiant floor heating system when you are initially constructing the building. We recommend placing tube whenever pouring a slab these days, even if you do not intend to immediately use it. It may be very expensive to add a radiant floor heating system to a building after it is constructed.

It is important that you do a proper building heat loss analysis, circuit/zone design and hydronic radiant floor heat gain analysis BEFORE actually constructing the system. Our **Heat Loss Analysis Calculator** enables you to accomplish a proper building heat loss analysis. This hydronic radiant floor heating design calculator enables you to accomplish a proper circuit/zone design and hydronic radiant floor heat gain analysis. A sample of a professional Air Conditioning Contractors of America (ACCA) Manual J8 heat loss analysis and hydronic radiant (HR) floor heating system design may be found on the Consultation tab of our website:

<p style="text-align:center">Sample ACCA MJ8 Analysis & HR Design</p>

The engineering equations used in this calculator are consistent with the methodology and recommendations published in "Modern Hydronic Heating for Residential and Light Commercial Buildings" by John Siegenthaler. John is the recognized expert in this field and is a fellow licensed professional engineer too. In our opinion, this is currently the best book on this subject and is highly recommended reading. Even if you elect not to purchase this wonderful book, you may Google the book title and read much of the contents. There is a wealth of information in this book on proper hydronic radiant floor heating system component selection, installation, and operational setup; important topics that we do NOT address in these instructions.

You could easily spend several hundred dollars on hydronic radiant floor heating design software that is not nearly as accurate or as capable as this calculator. Many manufactures of hydronic radiant floor pumps provide "free" hydronic radiant floor heating design software that you may use. However, this software typically has to be downloaded, often not very accurate/capable, often runs continuously on your PC, and may possibly expose you to malware that may mine your personal data. Another limitation is that this software only contains

pump performance curve data for their pumps which makes it difficult to evaluate pumps from different manufactures to select the best pump that meets your requirements at the lowest cost. This calculator allows you to enter the pump performance curve data for ANY pump that you select, uses JavaScript code that uses your trusted browser application, and only runs for a brief time after you click a Solve button.

Please be forewarned that this calculator and design process may be very intimidating at first sight. To assist you, we have provided very detailed instructions for this calculator, which if carefully followed, will enable you to properly design a hydronic radiant floor heating system with up to 7 heating zones and up to 12 recommended minimum number of circuits per zone (and an UNLIMITED actual number circuits per zone if you manually keep the circuit lengths within acceptable hydraulic friction limits) that uses a common heat source supply temp and a single pump to supply ALL the heating zones. Designing a hydronic radiant floor heating system in this manner minimizes complexity, electrical power requirements, and expenses (both initial installation and operational). The benefits of this design approach are often very important to DIY people, especially those people with buildings located off the power grid or in areas with high utility expenses.

Please pardon a slight digression to allow us to satisfy both our legal and moral obligation to educate and protect the public welfare by first advising you about the construction industry in general and the HVAC industry in particular. If you do not feel like you have the time or are up to the challenge of accomplishing HVAC as a DIY project, you might be considering hiring a company to accomplish this for you. There are likely some very good HVAC companies that legally and successfully accomplish hydronic radiant heating system design/installation in your State. However, there are some companies that would be best avoided, so you really need to do some homework to select a good one.

We would highly recommend that you Google search the company names that you are considering hiring by entering their company name plus "problems" and "complaints" into the search field to initially assess them and perhaps weed some out straight away. In the States that Borst Engineering & Construction operates (Oregon and Washington), we have to be licensed, bonded and insured to legally operate in these States. We have State contractor regulations that protect consumers if there are any problems requiring resolution...as long as the consumer first verifies and hires a company that is legally operating within the State. So we highly recommend carefully checking the company's credentials (experience, reputation, license status, bonding, insurance, and legal operating jurisdiction), requesting them to provide some customer references, and directly checking these references too.

You should become knowledgeable about HVAC licenses. Some States have minimal HVAC license requirements and some States do not have any HVAC license requirements at all. HVAC licensing requirements for contractors in each State are published by the National Contractors Association at this website:

State HVAC License Requirements

We prefer and recommend State professional engineering licenses and State sub/general contractor licenses which have strict and vigorous education, experience, and testing requirements. Please keep in mind that a City license is NOT a State HVAC license. A City license is only valid for the specific City and the specific specialty for which it is was issued. So a City license will likely not apply to your jurisdiction and or provide expertise in the HVAC specialty that you need. So perhaps start getting worried if your State only has minimal HVAC license requirements. Perhaps get very worried if your State does not have any HVAC license

requirements at all. Perhaps run away if you are considering hiring a company from one of the States that does not have any HVAC license requirements at all that is illegally soliciting business from your State which does have HVAC license requirements and perhaps help other consumers by making your State Attorney General aware of this situation as soon as possible.

You should become knowledgeable about the significant differences between Alliances/Associations and Societies. In general, we do not put much credence in Alliances/Associations (e.g., Radiant Professionals Alliance, Radiant Panel Association, etc.) because they typically just sell memberships to any company that simply pays their membership fee. Alliances/ Associations are more about marketing and making the companies that purchase their memberships appear competent. This is not to say that all companies that are members of these Alliances/Associations are incompetent. It is just that these Alliances/Associations do not typically have any membership acceptance criteria that actually evaluates HVAC competence and experience. Some of the "certifications" provided by these Alliances/Associations require little or no demonstration of actual HVAC competence. In fact, there was a study done several years ago that showed that the vast majority of these Alliance/Association certifications went to HVAC companies that were based in the States that did not have any State HVAC licensing requirements at all. We speculate that having a HVAC certification from an Alliance/Association that few potential customers know is practically worthless is far better than not having anything at all when it comes to marketing and soliciting HVAC business. Unfortunately, feigning competence by using creative marketing and solicitation techniques has become a true art form that is well executed by some HVAC companies. Even the Better Business Bureau (BBB) has been accused of some shady business practices in recent years, so you may not want to put much credence in them either:

Better Business Bureau Concerns

In lieu of Alliances/Associations, we prefer and recommend professional Societies like the American Society of Mechanical Engineers (ASME) and the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE), which have strict and vigorous membership acceptance criteria.

Please be aware that a company can only legally use "engineering" or "construction" in their company name if they actually have State licensed professional engineering staff or State licensed construction contractors. There are many companies who just use design rules of thumb or "catalog engineering" and offer free "design" service to sell their over-priced products. We are not a product retailer and we do not feign competence to entice you to purchase over-priced products. So while others may offer similar services, few architects, builders, product retailers, or technicians really understand both the engineering principals and the construction techniques required to achieve an integrated and successful end result. We highly recommend hiring an experienced and knowledgeable company having respectable credentials that is fully licensed, bonded and insured to legally operate within your State to ensure maintaining your consumer protection rights. ***If you are in Oregon or Washington, please consider hiring Borst Engineering & Construction.***

Before using this calculator, there is some terminology and requirements associated with hydronic radiant floor heating systems that first needs to be explained and fully understood. A "circuit" is defined as a specified length of tube that receives hot water supplied by a heat source and pump. Circuits are typically placed within the floor assembly of the building. Hot water, typically from a heat source (e.g., heat pump or boiler), is pumped through the circuits at the appropriate supply temperature and appropriate flow rate to heat the floor to the appropriate surface temperature such that it radiates the appropriate heat gain upward into the rooms to replace the heat loss from the rooms. After the heat energy is extracted from the hot water supplied to the circuits and used to heat the floor, the cooler circuit water is returned back to the heat source. The maximum

allowed difference between this supply and return temperature is called the "allowed circuit temperature drop" which is an important design input parameter.

Typically a building will have multiple heating "zones". A single zone may be used to heat each room of a building or a single zone may be used to heat multiple rooms of a building. Depending on the area of the floor area being heated, a single circuit or multiple circuits may be required for each zone. The reason multiple circuits may be required will be fully explained later. A zone may be turned ON or OFF as required and each zone may provide a different amount of heat gain than the other heating zones. Solenoid control valves are used to accomplish the zone ON/OFF control functionality and balance valves are used to regulate the heat gain that each zone provides by regulating the hot water flow rate provided to each zone. ***If a zone uses multiple circuits, the length of tube used in each circuit must all be very close to being the same length.*** Very close, in this case, means that all the circuit lengths are within about 5% of the average length of the circuits used for this zone. A good tube layout drawing and a good installer will easily allow this to be successfully accomplished. Failing to accomplish this will result in different flow rates for each circuit which will then result in each circuit providing a different heat gain than what is required for the floor area that this circuit serves. Different length circuits in a zone may be accommodated by using and adjusting additional balance valves for each circuit, but this unnecessarily increases system installation and operational setup complexity which may significantly increase the system and maintenance cost. This is typically beyond the scope of a DIY project and beyond the scope of this calculator.

A "manifold station" is used to supply the various zones and circuits with hot water from the heat source and then return the resulting cooler water back to the heat source. Please note that each manifold station actually consists of two separated manifolds:
1) A hot water supply manifold which has a single large inlet that gets connected to the heat source outlet and multiple smaller outlets that get connected to the inlets of the circuits.
2) A cooler water return manifold which has a single large outlet that gets connected to the heat source inlet and multiple smaller inlets that get connected to the outlets of the circuits.

A manifold station typically has temperature gauges to display both the hot water supply and cooler water return temperatures and may have solenoid control valves and balance valves, if these are required. Temperature gauges are very useful in verifying that all the zone circuits are receiving the design supply water temperature and that the actual circuit temperature drop of all the circuits is consistent with the design allowed circuit temperature drop. A single large manifold station may be used to connect all of the zone circuits or multiple smaller manifold stations may be used to connect all of the zone circuits. This decision is largely driven by the need to keep the manifold leader lengths that are required between the zone circuits and the manifold station (s) as short as possible. Manifold leader lengths add undesirable hydraulic friction to the system and typically do not put the heat gain where you actually need it. When multiple manifold stations are used, the heat source outlet will provide the same hot water supply temperature to all the manifold station inlets, but each manifold station outlet may provide a different cooler water return temperature back to the heat source inlet.

The reason you may need more than one circuit per zone is because there is a maximum circuit length that can be achieved before the hydraulic friction in each circuit becomes excessive and a pump will become overly challenged to supply the necessary head to overcome this hydraulic friction at the flow rate necessary to provide the required heat gain. For nominal 0.5 inch diameter tube, hydraulic friction begins to become excessive at about 300 feet, which is the maximum circuit length that should be used for this diameter tube. This calculator will limit each circuit length accordingly and will advise the recommended minimum number of

equal length circuits that should be used for each zone. Once you exceed about seven zones, simply using a common heat source supply temp and single pump for all the zones may become problematic. There are ways to address these challenges (e.g., operating with a higher heat source supply temperature, using multiple pumps, and injecting/mixing lower temperature water to some zones as required), but this is typically beyond the scope of a DIY project and beyond the scope of this calculator.

This calculator will provide the recommended minimum floor insulation R-value for each zone based on the recommendations published in "Modern Hydronic Heating for Residential and Light Commercial Buildings" by John Siegenthaler. Only the design outdoor dry bulb temperature, design outdoor dry bulb temperature and floor assembly type need be entered into the calculator for each zone to only obtain these recommended minimum floor insulation R-values.

Before you get too far with hydronic radiant floor system design, you should consider the upward heat effectiveness of the various floor emitters that you may be considering. The upward heat effectiveness percentage of a floor emitter may be calculated as $(1 - R_{ELR}/2) \times 100$, where R_{ELR} is the emitter efficiency loss ratio and is defined as the R-value above the tube divided by the R-value below the tube.

As a point of mental reference, the emitter efficiency loss ratio is zero if all of the R-value is below the tube and the floor emitter has a 100% upward heat effectiveness. The emitter efficiency loss ratio is 1 if 50% of the R-value is above the tube and 50% is below the tube and the floor emitter has a 50% upward heat effectiveness. This means that only 50% of the heat supplied to the floor emitter actually moves upward into the living space. The other 50% percent of the heat is lost to the ground or space below the floor emitter. Once the emitter efficiency loss ratio becomes or exceeds 2, the floor emitter has a 0% upward heat effectiveness.

Slab-on-Grade, Thin-Slab, Above-Floor Tube & Plate and Below-Floor Tube & Plate floor emitters all having a 12 inch tube spacing provide 98.8%, 89.2%, 62.4% and 40.8% upward heat effectiveness respectively. These values are further degraded if any floor finishing material is used above these floor emitters. For example, using 3/4 inch hardwood flooring above these floor emitters results in 70.3%, 64.6%, 49.9% and 36.3% upward heat effectiveness respectively.

Even the location of where you place the tube in Slab-on-Grade will have an effect on the floor emitter upward heat effectiveness. Concrete is about 0.1 R-value per inch and EPS/XPS is about 5.0 R-value per inch. If you place the tube in the middle of a 5 inch thick Slab-on-Grade, the emitter efficiency loss ratio is $(0.1)(2.5")/[(0.1)(2.5") +(5.0)(2")]$ or 0.024 and $(1 - 0.024/2) \times 100$ results in 98.8% upward heat effectiveness. If you instead place the tube on top of the 2" EPS, the emitter efficiency loss ratio is $(0.1)(5")/(5.0)(2")$ or 0.05 and $(1 - 0.05/2) \times 100$ results in a 97.5% upward heat effectiveness. This is a difference of 1.3% in floor emitter upward heat effectiveness.

In order to use this calculator, you will need to determine the outdoor design conditions for the building location. This is typically the historical Winter heating 99% dry bulb temperature for the local climate or as specified by the local building code. The 99% means that the historical temperature has exceeded this temperature 99% of the time (i.e., it has historically only been colder than this temperature 1% of the time). Design outdoor dry bulb temperatures for many locations are published by the Air Conditioning Contractors of America (ACCA) at this website:

Outdoor Design Conditions

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Hydronic Fluid Mixture (Percent Propylene Glycol/Water)** - This is the percentage of propylene glycol used in the hydronic fluid. ***You should NEVER use ethylene glycol in a hydronic heating system.*** You may enter any valve between 0 and 50% to specify the concentration of propylene glycol you will use. If you elect to use propylene glycol, you should use at least 30% to inhibit the growth of bacteria in the system. Propylene glycol has a higher viscosity than water (which will result in increased hydraulic friction) and a lower specific heat than water (which will result in reduced heat transfer). Therefore, using propylene glycol will result in a less efficient heating system. As such, you should avoid using propylene glycol unless you are actually at risk of freezing the tube. We recommend using 100% water and entering 0 into the calculator. Please use this same value in our **Buffer Tank Design Calculator** and **Expansion Tank Design Calculator**. The default value is 0.

2) **Design Outdoor Dry Bulb Temp (Degrees Fahrenheit)** - This is the historical Winter heating 99% dry bulb temperature for the local climate and obtained as previously described or as specified by the local building code. Please use this same value in our **Heat Loss Analysis Calculator**. The default value is 20.

3) **Design Indoor Dry Bulb Temp (Degrees Fahrenheit)** - This is typically 65 to 75 degrees F or as specified by the local building code. Please use this same value in our **Building Assembly Moisture Analysis Calculator**, **Existing Building Energy Usage Analysis Calculator**, **Heat Loss Analysis Calculator** and **Passive Solar Thermal Mass Performance Calculator**. The default value is 70 for zone 1 and 0 for all the other zones.

4) **Allowed Circuit Temp Drop (Degrees Fahrenheit)** - This is the maximum allowed temperature change of the hydronic fluid after it passes through the circuit(s) for this zone. The fluid temperature leaving the circuit (s) is allowed to drop by this amount from its initial **Required Supply Temp** output parameter value. 15 degrees F or less is recommended for barefoot friendly residential floors. The allowed circuit temp drop significantly affects the **Required Flow Rate** output parameter and may often be varied to achieve the recommended **Reynolds Number** and **Velocity** output parameters. The default value is 15 for all the zones.

5) **Heated Area (Square Feet)** - This is the actual floor area for this zone minus the floor area that will NOT actually be heated (i.e., will not have tube placed in the floor assembly of this area) such as below bath/kitchen counters, etc. The default value is 2000 for zone 1 and 0 for all the other zones.

6) **Unblocked Heated Area (Square Feet)** - This is the **Heated Area** input parameter for this zone minus the floor area in this zone "blocked" by heavy carpets, furniture, etc. The default value is 2000 for zone 1 and 0 for all the other zones.

7) **Total Heat Loss (BTU/Hour)** - This is the total hourly heat loss of the room(s) for this zone. This value is an output parameter of our **Heat Loss Analysis Calculator**. The default value is 8000 for zone 1 and 0 for all the other zones.

8) **Exposed Floor Heat Loss (BTU/Hour)** - This is the downward heat loss from the UNHEATED floor for this zone, one component of the **Total Heat Loss** input parameter. This value is an output parameter of our **Heat Loss Analysis Calculator**. This value and the **Design Outdoor**

Dry Bulb Temp input parameter are used to determine the HEATED floor **Downward Heat Loss** output parameter. The default value is 400 for zone 1 and 0 for all the other zones.

9) **Required Leader Length to Manifold Station (Feet)** - This is the additional length of tube that may be required to reach the actual zone circuit(s) depending on where you locate the manifold station(s) for this zone. The default value is 0 for all the zones.

10) **Tube Nominal Diameter (Inches, 0.25, 0.375, 0.5, 0.625, 0.75, 1.0)** - This is the standard nominal diameter of the tube in inches used for the circuits in this zone. If you enter a standard nominal size such as 0.25, 0.375, 0.5, 0.625, 0.75, or 1.0 inches, the calculator will determine the actual inside diameter and the Siegenthaler pipe size coefficient of the tube and use these values in the calculation. The default value is 0.5 for all the zones.

11) **Tube Type (0=PEX, 1=PEX-AL-PEX)** - This is a logic input parameter that tells the calculator which type of tube will be placed in the floor assembly for this zone. Entering a 0 tells the calculator that PEX tube will be placed in the floor assembly. Entering a 1 tells the calculator that PEX-AL-PEX tube will be placed in the floor. The default value is 0 for all the zones.

12) **Floor Assembly Type (0=Slab-on-Grade, 1=Thin Slab, 2=Above-Floor, 3=Below-Floor)** - This is a logic input parameter that tells the calculator which type of floor assembly will be used for this zone. Entering a 0 tells the calculator a 4-6 inch thick SLAB-ON-GRADE floor assembly will be used. Entering a 1 tells the calculator a 1.5 inch THIN-SLAB floor assembly will be used. Entering a 2 tells the calculator that an ABOVE-FLOOR assembly will be used consisting of tubes placed in 6 inch wide aluminum plates installed above the subfloor. Entering a 3 tells the calculator that a BELOW-FLOOR assembly will be used consisting of tubes placed in 6 inch wide aluminum plates installed below a 0.75 inch plywood subfloor. The default value is 0 for all the zones.

13) **Floor Surface R-value (Degrees F-Hour-Square Feet/BTU)** - This is the R-value of any additional floor surface (e.g., tile, light wood or light carpet) above the basic floor assembly. Siegenthaler allowed R-value ranges for SLAB-ON-GRADE, THIN-SLAB and BELOW-FLOOR are 0 to 2. Siegenthaler allowed R-value ranges for ABOVE-FLOOR are 0.5 to 2. The calculator will limit this input parameter entry to these ranges. If you plan to use any additional floor surface that has an R-value greater than 2, you should consider this surface area as being "blocked" and reduce the **Unblocked Heated Area** input parameter accordingly. The default value is 0 for all the zones.

14) **Actual Tube Spacing (Inches, 0=Recommended)** - Initially enter 0 which will force the calculator to use the **Recommended Maximum Tube Spacing** output parameter. This is the actual tube spacing between the tube runs in the floor for this zone that you will actually use after first considering the **Recommended Maximum Tube Spacing** output parameter and the following guidance. 12 inches or less is recommended for barefoot friendly residential floors. Valid values for a SLAB-ON-GRADE floor assembly are 6, 9, 12, 18, or 24 inches. Valid values for a THIN-SLAB floor assembly are 6, 9, or 12 inches. Valid values for an ABOVE-FLOOR assembly are 8 or 12 inches. Valid values for a BELOW-FLOOR assembly are 8 or 12 inches. The default value is 12 for zone 1 and 0 for all the other zones.

15) **Actual Number of Circuits (0=Recommended)** - Initially enter 0 which will force the calculator to use the **Recommended Minimum Number of Circuits** output parameter. This is the actual number of circuits that you will use for this zone. You should normally use the **Recommended Minimum Number of Circuits**; however, there could be a reason why you might choose to use more circuits. You should NEVER use less circuits than the **Recommended Minimum Number of Circuits**. *Please note that the calculator will NOT recommend more than 12 circuits per zone.* If you require more than 12 circuits per zone, you must manually keep the circuit lengths within acceptable hydraulic friction limits. Circuit lengths that stay within acceptable hydraulic friction limits for 0.25, 0.375, 0.5, 0.625, 0.75 and 1.0 inch nominal diameter PEX and PEX-AL-PEX tube are 125, 250, 300, 450, 600 and 750 feet, respectively. The default value is 0 for all the other zones.

16) **Supplemental Heat Gain (BTU/Day)** - You should normally enter 0. This input parameter is provided to enable you to evaluate the effect of using additional heat sources such as passive solar heating or a masonry heater for zoning, control system, and heat source sizing considerations. The default value is 0 for all the zones.

17) **Balance Valve Flow Coefficient Setting (Cv)** - Initially enter 0. This is the manifold balance valve setting that controls the flow rate for this zone.

    If you only have one zone, enter a large value such as 1000 to effectively remove the balance valve from the system and click Solve . This will allow the **Total Design Flow Rate** and **Total Design Head Loss** output parameters, which are used for proper pump selection, to be correctly calculated. The **Required Flow Rate** and **Design Flow Rate** output parameters should now be identical for this single zone. *A balance valve is typically not required for a single zone if a suitable pump may be selected.*

    If you have multiple zones, adjust the balance valve settings so the **Design Flow Rate** output parameters become equal to the **Required Flow Rate** output parameters for each zone clicking Solve multiple times as necessary until you achieve this. AFTER you have selected a pump and AFTER you have actually ENTERED the selected pump's performance curve into the calculator, you will need to readjust the balance valve settings so the **Actual Pump Flow Rate** output parameters become equal to the **Required Flow Rate** for each zone clicking Solve multiple times as necessary until you achieve this. Adjusting the balance valve settings may be a tedious process, but it is very important that you do this properly. Please see the below detailed directions. The default value is 0 for all the other zones.

18) **Pump Performance Curve Data Points (Gallons/Minute versus Feet)** - You may initially leave these input parameters blank or enter 0 which will enable the calculator to generate the initial output results which will then enable you to refine the input parameters further and select an appropriate pump as described in the below detailed directions. A pump performance curve defines the flow rate and head characteristics of a pump and is published by the manufacturer of the selected pump. The center of the pump performance curve is typically where the pump Best Efficiency Point (BEP) occurs and where you should operate the pump for maximum pump efficiency and minimum operating cost. After you have selected an appropriate pump, enter the actual pump performance curve for the selected pump into the calculator via the 14 data points

(i.e., 28 entries) consisting of pump flow rate (in Gallons/Minute) versus pump head (in Feet). You may enter all 14 data points or you may enter less data points leaving any unused entries blank or 0. It is recommended that you use an adequate number of data points to accurately replicate the pump performance curve recognizing that the calculator will only do a linear interpolation between the data points. Example and illustrative pump performance curve data points are shown for a Grundfos UP15-42F pump. Please see the below detailed directions. The default value is 0 for all data points.

If 777 is entered for the first pump flow rate data point, Grundfos UP15-42F pump data will be used. We highly recommend Grundfos pumps. If 787.1, 787.2 or 787.3 is entered for the first pump flow rate data point, NextGen boiler system Wilo Star S21U15 pump setting 1, setting 2 or setting 3 data will be used respectively. We highly recommend the NextGen boiler system for a nearly DIY "plug and play" hydronic radiant system.

19) **Actual Heat Source Supply Temp (Degrees Fahrenheit)** - You may initially leave this logic input parameter blank or enter 0 which will force the calculator use the **Design Heat Source Supply Temp** output parameter. This is the temperature that the heat source will actually be set to supply ALL the circuits in ALL the zones. You should normally use the **Design Heat Source Supply Temp** output parameter; however, you may enter different values to assess the effect on heat gain. Please use this same value in our **Expansion Tank Design Calculator**. The default value is 0.

Click ⬜Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters for each zone:

1) **Recommended Minimum Floor Insulation R-value (Degrees F-Hour-Square Feet/BTU)** - This is the minimum R-value that should be used for the floor insulation for this zone. Only the **Design Outdoor Dry Bulb Temp**, **Design Outdoor Dry Bulb Temp** and **Floor Assembly Type** input parameters need be entered into the calculator to only obtain this recommended minimum floor insulation R-value.

2) **Downward Heat Loss (Percent of Required Upward Heat Gain)** - This is the downward heat loss going into the ground below the HEATED floor as a percentage of the required upward heat gain for this zone. A downward heat loss of 10% or less is recommended.

3) **Required Floor Temp (Degrees Fahrenheit)** - This is the required temperature that the HEATED floor surface must be in order to radiate the **Required Upward Heat Gain** input parameter for this zone. 85 degrees F or less is recommended for barefoot friendly residential floors. You may need to adjust the design input parameters to achieve this.

4) **Recommended Maximum Tube Spacing (Inches)** - This is the recommended maximum tube spacing to economically meet the required heat gain requirements for this zone. You should normally use this value for the **Actual Tube Spacing** input parameter. However, 12 inches or less is recommended for barefoot friendly residential floors.

5) **Recommended Minimum Number of Circuits** - This is the minimum number of zone circuits required to keep the tube friction in each circuit within acceptable pumping limits for this zone. You should normally use this value for the **Actual Number of Circuits** input parameter, but there could be a reason why you might choose to use more circuits. You should NEVER use less circuits than this recommended minimum number of circuits. *Please note that the calculator will NOT recommend more than 12 circuits per zone.* If you require more than 12 circuits per zone, you must manually keep the circuit lengths within acceptable hydraulic friction limits. Circuit lengths that stay within acceptable hydraulic friction limits for 0.25, 0.375, 0.5, 0.625, 0.75 and 1.0 inch nominal diameter PEX and PEX-AL-PEX tube are 125, 250, 300, 450, 600 and 750 feet, respectively.

6) **Circuit & Leader Tube Length (Feet)** - This is the total length of tube required for each circuit based on the zone area and selected tube spacing, including the additional length required to reach the manifold station. *Please note that the calculator will NOT recommend more than 12 circuits per zone.* If you require more than 12 circuits per zone, you must manually keep the circuit lengths within acceptable hydraulic friction limits. Circuit lengths that stay within acceptable hydraulic friction limits for 0.25, 0.375, 0.5, 0.625, 0.75 and 1.0 inch nominal diameter PEX and PEX-AL-PEX tube are 125, 250, 300, 450, 600 and 750 feet, respectively.

7) **Total Required Tube Length (Feet)** - This is the total length of tube required for each zone, including the additional length required to reach the manifold stations.

8) **Circuit Hydronic Fluid Volume (Gallons)** - This is the volume of hydronic fluid contained in all the circuits of each specific zone. This value is used as an input parameter by our **Expansion Tank Design Calculator**.

9) **Reynolds Number** - This is an important design parameter often used by engineers. Greater than 2300 is recommended to ensure a turbulent circuit flow rate that produces a high heat transfer efficiency. You may need to adjust the design input parameters (e.g., **Tube Nominal Diameter** and **Allowed Circuit Temp Drop**) to achieve this.

10) **Velocity (Feet/Second)** - A design that results with between 2 and 4 FPS is recommended. The lower limitation is important when initially filling the system to ensure air bubble entrainment within the fluid to allow air removal and for long-term operational reliability. The higher limitation is important to ensure that there will not be any objectionable flowing water noise. You may need to adjust the design input parameters (e.g., **Tube Nominal Diameter** and **Allowed Circuit Temp Drop**) to achieve this.

11) **Required Flow Rate (Gallons/Minute)** - This is the flow rate that EACH circuit in this zone MUST be provided in order to meet the heat gain requirements for this zone. *Please note that this is the required flow rate for EACH circuit in this zone.* If there is more than one circuit in the zone, the TOTAL flow rate required by the zone is the **Actual Number of Circuits** input parameter multiplied by this required flow rate.

12) **Design Flow Rate (Gallons/Minute)** - This is the design flow rate EACH circuit in this zone would be provided if the perfect pump for this hydraulic system could be obtained and given the balance valve settings for ALL the zones to meet the unique flow rate and heat gain requirements of

EACH zone at system hydraulic equilibrium. ***Please note that this is the design flow rate for EACH circuit in this zone.*** If there is more than one circuit in the zone, the TOTAL design flow rate for this zone is the **Actual Number of Circuits** input parameter multiplied by this design flow rate. This zone's TOTAL design flow rate is reflected in the **Total Design Flow Rate** output parameter which is used to select an appropriate pump. The calculator accomplishes all the math so you only need to adjust the **Balance Valve Flow Coefficient Setting** input parameter such that this design flow rate become equal to the **Required Flow Rate** output parameter. Please see the below detailed directions.

13) **Actual Pump Flow Rate (Gallons/Minute)** - This is the actual flow rate EACH circuit in this zone will be provided using the selected pump and given the balance valve settings for ALL the zones to meet the unique flow rate and heat gain requirements of EACH zone at system hydraulic equilibrium. ***Please note that this is the actual pump flow rate for EACH circuit in this zone.*** If there is more than one circuit in the zone, the TOTAL actual pump flow rate for this zone is the **Actual Number of Circuits** input parameter multiplied by this pump flow rate. This zone's TOTAL actual pump flow rate is reflected in the **Total Actual Pump Flow Rate** output parameter. The calculator accomplishes all the math so you only need to adjust the **Balance Valve Flow Coefficient Setting** input parameter such that this actual pump flow rate becomes equal to the **Required Flow Rate** output parameter. Please see the below detailed directions.

14) **Required Supply Temp (Degrees Fahrenheit)** - This is the supply temperature that EACH circuit in this zone MUST be provided in order to meet the heat gain requirements for this zone. However, please note that you will be supplying a common heat source supply temperature to ALL the zones as recommended by the **Design Heat Source Supply Temp** output parameter and as specified by you via the **Actual Heat Source Supply Temp** input parameter. It is recommended that you keep the difference between a zone's required supply temperature and the common **Actual Heat Source Supply Temp** used for ALL zones to less than 5 degrees in order to successfully use a common heat source supply temp for ALL the zones. You may need to adjust the design input parameters to successfully achieve this.

15) **Required Upward Heat Gain (BTU/Hour)** - This is the required upward heat gain that the HEATED floor must provide in order to meet the heat gain requirements for this zone. The required upward heat gain is equal to the **Total Heat Loss** input parameter minus the **Exposed Floor Heat Loss** input parameter.

16) **Actual Upward Heat Gain (BTU/Hour)** - This is the actual upward heat gain for this zone that results from using the selected pump, **Balance Valve Flow Coefficient Setting** input parameter, and **Actual Heat Source Supply Temp** input parameter. Any difference between the **Required Upward Heat Gain** output parameter and this actual upward heat gain value is largely the consequence of the common **Actual Heat Source Supply Temp** that will be supplied to ALL the zones NOT being exactly equal to the **Required Supply Temp** output parameter for this SPECIFIC ZONE. Any minor discrepancies at this point may normally be adequately and easily addressed by making minor adjustments to the actual balance valve settings and the actual heat source supply temperature after the system has been constructed.

This calculator will provide the following totalized output parameters:

17) **Total Design Flow Rate (Gallons/Minute)** - This is the TOTAL design flow rate that the selected pump must be capable of supplying in order to provide the required design flow rates for all the circuits in all the zones. The selected pump will need to supply this flow rate while providing the head necessary to overcome the friction in the system which is equal to the **Total Design Head Loss** output parameter. ***This parameter is used to select the pump (please see the below detailed directions).***

18) **Total Actual Pump Flow Rate (Gallons/Minute)** - This is the actual TOTAL flow rate supplied by the selected pump given where the pump is being operated on its performance curve at system hydraulic equilibrium. If you did a good job selecting the pump and adjusting the **Balance Valve Flow Coefficient Setting** input parameters, this total actual pump flow rate should be fairly close to **Total Design Flow Rate** output parameter.

19) **Total Design Head Loss (Feet)** - This is the TOTAL design head loss resulting from all the friction in the tube and balance valve settings while operating at the design flow rates for all the circuits in all the zones. The selected pump will need to supply this total design head loss while supplying the **Total Design Flow Rate** output parameter. ***This parameter is used to select the pump (please see the below detailed directions).***

20) **Total Actual Pump Head Gain (Feet)** - This is the actual TOTAL head supplied by the selected pump, in feet, given where the pump is being operated on its performance curve at system hydraulic equilibrium. If you did a good job selecting the pump and adjusting the **Balance Valve Flow Coefficient Setting** input parameters, this total actual pump head gain should be fairly close to **Total Design Head Loss** output parameter.

21) **Total Actual Pump Head Gain (% of Pump Maximum Head Capacity)** - This is the actual TOTAL head supplied by the selected pump, as a percentage of the maximum head capacity of the pump, given where the pump is being operated on its performance curve at system hydraulic equilibrium. This should ideally be between 40-60% for maximum pump efficiency and minimum operating cost. ***You should avoid operating a pump at more than 90% of its maximum head capacity.***

22) **Total Heat Output (BTU/Hour & BTU/Day)** - This is the TOTAL heat output that the hydronic heating system provides to all the circuits in all the zones and includes both the desired upward heat gain and the undesired downward heat loss. This value is used to select and size the heat source. This value is slightly larger than the sum of the **Total Heat Loss** input parameters for all the zones because the UNHEATED **Exposed Floor Heat Loss** input parameter, one component of the **Total Heat Loss** and as originally determined by the **Heat Loss Analysis Calculator**, did NOT include the increased **Downward Heat Loss** which results from having a HEATED floor at a higher temperature than the **Design Indoor Dry Bulb Temp** input parameter.

23) **Total Required Tube Length (Feet)** - This is the total length of tube required for all the zones, including the additional length required to reach the manifold stations.

24) **Total Circuit Hydronic Fluid Volume (Gallons)** - This is the total volume of hydronic fluid (i.e., water plus any propylene glycol that is used) contained in the total length of tube required for all the circuits in all the zones, including the additional length required to reach the manifold stations.

Please keep in mind that an additional volume of hydronic fluid will be required for the heat source (including the volume of the buffer tank if one is used) and contained in the miscellaneous distribution pipe leading to/from the manifold station(s).

25) **Total Circuit Propylene Glycol Volume (Gallons)** - This is the required volume of propylene glycol that must be added to the hydronic fluid mixture when making up the **Total Circuit Hydronic Fluid Volume** output parameter to satisfy the **Hydronic Fluid Mixture** input parameter. Please keep in mind that an additional volume of hydronic fluid will be required for the heat source (including the volume of the buffer tank if one is used) and contained in the miscellaneous distribution pipe leading to/from the manifold station(s).

26) **Pump Differential Pressure (Pounds/Square Inch)** - This is the pressure difference that would be measured between the pump inlet and pump outlet.

27) **Design Heat Source Supply Temp (Degrees Fahrenheit)** - This is the temperature that the heat source should be set to supply all the circuits in all the zones. You should normally set the **Actual Heat Source Supply Temp** input parameter to this design heat source supply temperature.

First enter design inputs 1) to 17) as described above for all the zones that you plan to use. You may initially leave the input parameters blank (or enter 0) for those zones that you will NOT use. You may initially leave the **Pump Performance Curve Data Points** blank (or enter 0) as well. Then click Solve to get the calculator to generate the initial output parameter results.

If you only have one zone, enter a large value such as 1000 for the **Balance Valve Flow Coefficient Setting** input parameter to effectively remove the balance valve from the system and click Solve . This will allow the **Total Design Flow Rate** and **Total Design Head Loss** output parameters, which are used for proper pump selection, to be correctly calculated. The **Required Flow Rate** and **Design Flow Rate** output parameters should now be identical for this single zone. *A balance valve is typically not required for a single zone if a suitable pump may be selected.*

If you have multiple zones, adjust the **Balance Valve Flow Coefficient Setting** input parameters so the **Design Flow Rate** output parameters become equal to the **Required Flow Rate** output parameters for each zone clicking Solve multiple times as necessary until you achieve this. Reducing the **Balance Valve Flow Coefficient Setting** increases the hydraulic friction in this zone and reduces the associated **Design Flow Rate** for this zone. Please note that the **Required Flow Rate** and **Design Flow Rate** are the flow rates for EACH circuit in this zone. If there is more than one circuit in the zone, the TOTAL design flow rate required by the zone is the **Actual Number of Circuits** multiplied by the **Design Flow Rate** and this zone's TOTAL design flow rate is correctly reflected in the **Total Design Flow Rate** output parameter which is used to select an appropriate pump. The calculator accomplishes this math so you only need to adjust the **Balance Valve Flow Coefficient Setting** values such that the resulting **Design Flow Rate** values become equal to the **Required Flow Rate** values for each zone. Adjusting the balance valve settings may be a tedious process, but it is very important that you do this properly.

Then select an appropriate pump based on the resulting **Total Design Flow Rate** and **Total Design Head Loss** output parameters. The center of the **Pump Performance Curve** is typically where the pump Best Efficiency Point (BEP) occurs and where you should operate the pump for maximum pump efficiency and

minimum operating cost. So, the **Total Design Flow Rate** and **Total Design Head Loss** should be close to the center of the **Pump Performance Curve** (the data that pump manufacturers publish expressly for this very purpose) for the actual pump that you select. Then enter the actual **Pump Performance Curve** for the pump that you have selected into the calculator (example and illustrative data points for a Grundfos UP15-42F pump are shown) and click Solve .

Then adjust the **Balance Valve Flow Coefficient Setting** input parameters so the **Actual Pump Flow Rate** output parameters become equal to the **Required Flow Rate** output parameters for each zone clicking Solve multiple times as necessary until you achieve this. Reducing the **Balance Valve Flow Coefficient Setting** increases the hydraulic friction in this zone and reduces the associated **Actual Pump Flow Rate** for this zone. Please note that the **Required Flow Rate** and **Actual Pump Flow Rate** are the flow rates for EACH circuit in this zone. If there is more than one circuit in the zone, the actual TOTAL flow rate required by the zone is the **Actual Number of Circuits** multiplied by the **Actual Pump Flow Rate** and this zone's actual TOTAL flow rate is correctly reflected in the **Total Actual Pump Flow Rate** output parameter. The calculator accomplishes this math so you only need to adjust the **Balance Valve Flow Coefficient Setting** values such that the resulting **Actual Pump Flow Rate** values become equal to the **Required Flow Rate** values for each zone. Adjusting the balance valve settings may be a tedious process, but it is very important that you do this properly.
If you did a good job selecting the pump and adjusting the **Balance Valve Flow Coefficient Setting** input parameters:

1) The **Actual Pump Flow Rate** should be fairly close to the **Required Flow Rate** for each and every zone.

2) The **Actual Upward Heat Gain** should be fairly close to the **Required Upward Heat Gain** for each and every zone; any difference largely being a consequence of the **Actual Heat Source Supply Temp** supplied to ALL the zones NOT being exactly equal to the **Required Supply Temp** for the SPECIFIC ZONE. For example, if the **Actual Heat Source Supply Temp** supplied to all the zones is a higher temperature than the **Required Supply Temp** for the specific zone, the **Actual Upward Heat Gain** will be higher than the **Required Upward Heat Gain** for this zone. It is recommended that you keep the difference between the **Required Supply Temp** for EACH zone and the common **Actual Heat Source Supply Temp** used for ALL zones to less than 5 degrees in order to successfully use a common heat source supply temp for ALL the zones. You may need to adjust the design input parameters to achieve this.

3) The **Total Actual Pump Flow Rate** should be fairly close to **Total Design Flow Rate**.

4) The **Total Actual Pump Head Gain (Feet)** should be fairly close to the **Total Design Head Loss** and the **Total Actual Pump Head Gain (Percent of Maximum Head Capacity)** should ideally be between 40-60% for maximum pump efficiency and minimum operating cost. ***Confirm that you will NOT be operating the pump at more than 90% of its maximum head capacity.***

5) The **Total Heat Output** should be slightly larger than the summation of **Total Heat Loss** input parameters of all the zones because the UNHEATED **Exposed Floor Heat Loss** input parameter, one component of the **Total Heat Loss** and as originally determined by the **Heat Loss Analysis Calculator**, did NOT include the increased **Downward Heat Loss** which results

from having a HEATED floor at a higher temperature than the **Design Indoor Dry Bulb Temp** input parameter.

Any minor discrepancies at this point may normally be adequately and easily addressed by making minor adjustments to the actual heat source supply temperature and the actual balance valve settings after the system has been constructed. You can use this calculator to make these minor adjustments and assess the effect of these minor adjustments on heat gain. For example, you may vary the **Actual Heat Source Supply Temp** to deviate from the **Design Heat Source Supply Temp** to assess the effect of this temperature deviation on heat gain. You may vary the **Balance Valve Flow Coefficient Setting** to deviate from the **Required Flow Rate** to assess the effect of this flow rate deviation on heat gain.

Please be aware that there may be a significant time lag (i.e., many hours) for a high mass hydronic heated floor to heat up and cool down. Therefore, it is important and may well be worth the additional effort and expense to use a more sophisticated control system that uses actual floor temps, actual indoor air temps, outdoor air temp (actual, derived, and forecast), solar irradiance sensors, and supplemental heat schedule data to provide lead feedback compensation to the control system to ensure the desired comfort level will always be maintained. We use and highly recommend the Allen-Bradley (Rockwell Automation) Micro 800 series of Programmable Logic Controllers (PLCs). Please see this specific post in the **Green Building Talk Forum** for more information about PLCs. The Green Building Talk Forum is a great website to learn about green building construction principals in general and to ask questions related to your specific projects. We frequently participate on the Green Building Talk Forum.

Please exercise our **Expansion Tank Design Calculator** to properly design and setup a diaphragm-type expansion tank which is always required in a hydronic radiant floor heating system to protect it from potentially destructive hydronic fluid expansion. Please exercise our **Buffer Tank Design Calculator** to determine if a buffer tank is required in the hydronic radiant floor heating system to prevent the hydronic radiant heat source (e.g., boiler or heat pump) from short cycling which will significantly decrease the life expectancy of the heat source.

Once your hydronic radiant floor heating system is installed and operating, it may be used to assess the performance of BOTH your building design and your hydronic radiant emitter design. With regard to building design performance for a design indoor temperature of 70 degrees F and design outdoor temperature of 20F, we consider a 74 degree F or less hydronic radiant floor surface temperature as excellent building design performance (i.e., a low-load, energy efficient building), between 75-80 degree F as average performance, and greater than 80 degree F as poor performance (i.e., a high-load, energy inefficient building). A hydronic radiant floor surface temperature of 85 degrees F or less is recommended for barefoot friendly residential floors. With regard to hydronic radiant emitter design performance, we consider a 15 degree F or less temperature difference between the hydronic radiant floor heat source supply temperature and the hydronic radiant floor surface temperature as excellent hydronic radiant emitter design performance, between 16-25 degree F as average performance, and greater than a 25 degree F as poor performance. One should always keep in mind that it can be very difficult and expensive to subsequently improve the performance of your building design and your hydronic radiant emitter design after they have been constructed.

After you have designed the hydronic radiant floor heating system, you will need to purchase hydronic radiant floor heating system components such as air separators, circulator pump, distribution piping, heat source, expansion tank, tube, and manifold station(s). Please see the Affiliates tab on our website for our

recommendations on where you may want to consider purchasing the hydronic radiant floor heating system components.

It is important that you do a proper building heat loss analysis, circuit/zone design, and hydronic radiant floor heat gain analysis BEFORE actually constructing the system. If you are working with a company who cannot perform this analysis and provide data that is sealed/signed by a licensed professional engineer for the specific design and location, you should apply due diligence and consider finding a more competent company to do this. If you find that you need this service, we hope that you will consider Borst Engineering and Construction.

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Integrated Cooling System Performance Calculator

Before using this calculator, you should first exercise our **Existing Building Energy Usage Analysis Calculator** or **Cooling Load Analysis Calculator**. This calculator is used to determine the monthly and annual cooling system needs and to determine the annual cost of electrical power.

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Total Building Heat Gain (BTU/Hour-Degrees F)** - This important design parameter is an output parameter of our **Cooling Load Analysis Calculator** and **Existing Building Energy Usage Analysis Calculator**. Please note that this value is the total heat gain of the <u>building</u>. The default value is 428.

2) **Total Building Living Area (Square Feet)** - This is the total living area of the building and is used to determine the **Annual Cooling Energy Use Intensity** output parameter. The default value is 1,900.

3) **Cooling Degree Days** - This is an important design parameter used to reflect the climatic demand for energy needed to cool a building during January through December. The cooling requirements for a building at a specific location are considered to be directly proportional to the number of cooling degree days at that location. Cooling degree day data are published by Degree Days, National Renewable Energy Laboratory (NREL) and Weather Data Depot at these websites:

   Degree Days

   NREL Solar Radiation Manual for Buildings

   Weather Data Depot

   The default value is 725 applied to July.

4) **Electrical Power Cost ($/KWH)** - This is the cost of the electrical power per KWH. The default value is 0.0845.

5) **Air Conditioner Seasonal Energy Efficiency Ratio (SEER)** - This is the Seasonal Energy Efficiency Ratio (SEER) associated with the air conditioner that will be used. The default value is 13.

Click ⬚ Solve ⬚ after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Annual Heat Gain (BTU/100K or Therm)** - This is the annual heat gain in BTU divided by 100,000 which must be removed by the building cooling system. A Therm is 100,000 BTU or approximately the heat generated by burning 100 cubic feet (1 CCF) of natural gas.

2) **Annual Required Electrical Power (Kilowatt Hours)** - This is the annual electrical power required to remove the **Annual Heat Gain** output parameter given the **Air Conditioner Seasonal Energy Efficiency Ratio** input parameter and assuming 3,412 BTU/KWH.

3) **Annual Cost of Electrical Power (Dollars)** - This is the annual cost of the electrical power required to supply the **Annual Required Electrical Power** output parameter given the **Electrical Power Cost** input parameter.

4) **Annual Cooling Energy Use Intensity (BTU/1K/Square Foot)** - This is the annual building cooling energy use in BTU divided by 1,000 divided by the **Total Building Living Area** input parameter divided by the **Air Conditioner Coefficient of Performance** output parameter. This engineering parameter is used to categorize and compare energy efficient building designs.

5) **Monthly Heat Gain (BTU/100K or Therm)** - This is the monthly heat gain in BTU divided by 100,000 during January through December based on the **Total Heat Gain** and **Cooling Degree Days** input parameters. A Therm is 100,000 BTU or approximately the heat generated by burning 100 cubic feet (1 CCF) of natural gas.

6) **Air Conditioner Energy Efficiency Ratio (EER)** - This is the air conditioner Energy Efficiency Ratio (EER) associated with the **Air Conditioner Seasonal Energy Efficiency Ratio** input parameter. EER is calculated as 1.12 times the SEER minus 0.02 times the SEER squared. For example, 13.0 SEER equals 11.2 EER.

7) **Air Conditioner Coefficient of Performance (COP)** - This is the air conditioner Coefficient of Performance (COP) associated with the **Air Conditioner Energy Efficiency Ratio** output parameter. COP is calculated by dividing the EER by 3.412. For example, 11.2 EER equals 3.3 COP.

It is important that you perform an integrated cooling system performance analysis BEFORE constructing the air conditioning system. If you are working with a company who cannot perform this analysis and provide data that is sealed/signed by a licensed professional engineer for the specific design and location, you should apply due diligence and consider finding a more competent company to do this. If you find that you need this service, we hope that you will consider Borst Engineering and Construction.

Before using this calculator, you should first exercise our **Existing Building Energy Usage Analysis Calculator** or our **Heat Loss Analysis Calculator** and our suite of passive solar calculators: **Passive Solar Altitude Calculator**, **Passive Solar Roof Overhang Design Calculator**, **Passive Solar Fenestration Exposure Calculator**, and **Passive Solar Heat Gain Calculator**. This calculator is used to assess how well the heat gain achieved by the passive solar heating design meets your annual and monthly heating needs and to determine the amount of any supplemental heat gain that may be required. The cost of the associated amount of coal, electric, natural gas, oil, propane, and/or wood that would be required to supply this supplemental heat gain is calculated.

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Total Heat Loss (BTU/Hour-Degrees F)** - This important design parameter is an output parameter of our **Existing Building Energy Usage Analysis Calculator** or **Heat Loss Analysis Calculator**. Please note that this value is the total heat loss of the <u>building</u>. The default value is 428.

2) **Total Building Living Area (Square Feet)** - This is the total living area of the building and is used to determine the **Annual Heating Energy Use Intensity** output parameter. The default value is 1,900.

3) **Heating Degree Days** - This is an important design parameter used to reflect the climatic demand for energy needed to heat a building during January through December. The heat gain requirements for a building at a specific location are considered to be directly proportional to the number of heating degree days at that location. Heating degree day data are published by Degree Days, National Renewable Energy Laboratory (NREL) and Weather Data Depot at these websites:

    Degree Days

   **NREL Solar Radiation Manual for Buildings**

    Weather Data Depot

    The default value is 4,264 applied to January.

4) **Average Daily Climatic Solar Heat Gain (BTU/Day)** - This is an important design parameter used to reflect how much passive solar heat gain will actually be produced for the specified month during January through December. This value is an output parameter of our **Passive Solar Heat Gain Calculator**. If you will NOT use passive solar heating, you may enter 0 for this value and calculate the supplemental heat gain and associated fuel cost. The default value is 0.

5) **Fuel Type/Units** - This is a logic input parameter to allow selecting the fuel type, the associated fuel units and the associated heating BTU that the fuel provides. Enter 1 for Coal in units of Tons at 25,000,000 BTU/Ton. Enter 2 for Electric in units of KWH at 3,412 BTU/KWH. Enter 3 for Natural Gas in units of Cubic Feet at 1,020 BTU/Cubic Foot. Enter 4 for Oil in units of Gallons at

138,690 BTU/Gallon. Enter 5 for Propane in units of Gallons at 91,500 BTU/Gallon. Enter 6 for Wood in units of Cords at 25,622,500 BTU/Cord (i.e., dry Douglas Fir of 9,250 BTU/Pound times 2,770 Pounds/Cord). The default value is 2.

6) **Fuel Cost** - This is the cost of the fuel in dollars for the associated fuel unit as defined in the above **Fuel Type/Units** logic input parameter instructions. The default value is 0.0845.

7) **Heat Source Coefficient of Performance** - This is the Coefficient of Performance (COP) associated with the heat source that will be used. If the heat source is a device that converts fuel to heat (e.g., a coal, natural gas, oil, propane or wood fired boiler), the performance is often reported as Average Fuel Utilization Efficiency (AFUE) in percent. To convert AFUE to COP, divide the AFUE in percent by 100 to obtain the COP. For example, an AFUE of 96% equals 0.96 COP. An electric boiler has an AFUE of 100% and a corresponding 1 COP which is the maximum value for a device that converts fuel to heat. If the heat source is a device that moves environmental heat in lieu of converting fuel to heat (e.g., an air source or ground source heat pump), the performance is often reported as Heating Seasonal Performance Factor (HSPF). To convert HSPF to COP, divide the HSPF by 3.412 to obtain the COP. For example, 6.8 HSPF equals 2.0 COP. The default value is 1.

Click Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following annual output parameters:

1) **Annual Heat Loss (BTU/100K or Therm)** - This is the annual building heat loss in BTU divided by 100,000 which must be replaced by the building heating system. A Therm is 100,000 BTU or approximately the heat generated by burning 100 cubic feet (1 CCF) of natural gas.

2) **Annual Solar Heat Gain (Percent of Annual Heat Loss)** - This is the annual building solar heat gain in percent of the annual heat loss.

3) **Annual Required Supplemental Heat Gain (BTU/100K or Therm)** - This is the annual amount of additional heat gain in BTU divided by 100,000 which must be supplied to supplement the building heat loss that is not provided by the passive solar heating system. A Therm is 100,000 BTU or approximately the heat generated by burning 100 cubic feet (1 CCF) of natural gas.

4) **Annual Cost of Fuel (Dollars)** - This is the annual cost of the fuel required to supply the **Annual Required Supplemental Heat Gain** output parameter given the **Fuel Type/Units**, **Fuel Cost**, and **Heat Source Coefficient of Performance** input parameters.

5) **Annual Heating Energy Use Intensity (BTU/1K/Square Foot)** - This is the annual building heating energy use in BTU divided by 1,000 divided by the **Total Building Living Area** input parameter divided by the **Heat Source Coefficient of Performance** input parameter. This engineering parameter is used to categorize and compare energy efficient building designs.

This calculator will provide the following output parameters for each month:

6) **Monthly Heat Loss (BTU/100K or Therm)** - This is the monthly heat loss in BTU divided by 100,000 during January through December based on the **Total Heat Loss** and **Heating Degree Days** input parameters. A Therm is 100,000 BTU or approximately the heat generated by burning 100 cubic feet (1 CCF) of natural gas.

7) **Monthly Solar Heat Gain (Percent of Monthly Heat Loss)** - This is the best estimate, as a percentage of the monthly heat loss, of how much passive solar heat gain will actually be produced during January through December based on the input parameters.

8) **Monthly Required Supplemental Heat Gain ((BTU/100K)** - This is the difference between the **Monthly Heat Loss** and the **Monthly Solar Heat Gain** output parameters and represents the monthly amount of additional heat gain in BTU divided by 100,000 which must be supplied during January through December to supplement the building heat loss that is not being provided by the passive solar heating system.

9) **Monthly Average Supplemental Heat Gain ((BTU/Hour)** - This is the average heat gain in BTU/Hour which must be supplied during January through December to supplement the building heat loss that is not being provided by the passive solar heating system. This output parameter may be compared to the **Total Heat Loss (BTU/Hour)** output parameter from our **Existing Building Energy Usage Analysis Calculator** or **Heat Loss Analysis Calculator** to gain an understanding of what level of heat source modulation would be appropriate in order to maintain a high operational heat source coefficient of performance. Heat sources are often sized to satisfy the **Total Heat Loss (BTU/Hour)** output parameter while these monthly average supplemental heat gain values can be several times lower. A modulating heat source should be selected that can operate at these lower monthly average supplemental heat gain values while still maintaining a high operational heat source coefficient of performance.

Any supplemental heat gain that may be required may be accomplished by using numerous heating system approaches. We highly recommend that you research and consider using hydronic radiant floor heating and masonry heaters. Please see our **Hydronic Radiant Floor Heating Design Calculator** and our **Masonry Heater Performance Calculator**.

It is important that you perform an integrated heating system performance analysis BEFORE constructing the heating system. If you are working with a company who cannot perform this analysis and provide data that is sealed/signed by a licensed professional engineer for the specific design and location, you should apply due diligence and consider finding a more competent company to do this. If you find that you need this service, we hope that you will consider Borst Engineering and Construction.

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Energy efficient homes may only require 3 to 5 British Thermal Units (BTU) of heat gain per hour per square foot of living space. This would be equivalent to only 8,000 BTU/hour for a home having 2,000 square feet of living space. For most conventional woodstoves, this is well below their critical burn rate for operating cleanly and they will start to smolder. If you operate most conventional woodstoves at or above their critical burn rate, you may easily overheat an energy efficient home. The only solution for this dilemma is to have many small firings, which is not very convenient. Therefore, wood burning and energy efficient homes are not normally compatible unless you have some way to burn the wood at or above the critical burn rate to allow operating cleanly and you have a way to store the excess heat that is created and slowly release it as needed without having to accomplish frequent, inconvenient firings.

We prefer masonry heaters which provide the solution to this problem and have actually been the most efficient way to heat a home with wood for over a hundred years. Unlike fireplaces or woodstoves, there is very little heat loss because the exhaust gases are circulated through the masonry heater several times before going up the chimney. There is very little pollution because masonry heaters burn the wood very quickly and operate at about 1700 degrees so as to fully burn what even certified woodstoves cannot burn. Masonry heaters store and slowly release radiant heat over a 24 hour period accomplished by only one or two firings per day. Masonry heater surfaces never get extremely hot like stoves and will not suddenly overheat your home, which your sinuses will greatly appreciate. A masonry heater may be located to absorb solar radiation and store this form of heat energy too. Therefore, masonry heaters are similar and compatible with hydronic radiant floor heating and passive solar heating. As a side benefit, you may have a nice masonry oven that is available for energy free baking duties perhaps 10 hours per day and you may have heated benches for you, your guests, and your pets to enjoy all day. Constructing a masonry heater is a relatively simple DIY project and there are many good kits available in the marketplace to do this. Please be sure to fully research and comply with all the local building code requirements.

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Amount of Wood Burned per Day (Pounds)** – 10 to 20 pounds per day is typical for an energy efficient home and this amount of wood may be burned in either one or two firings per day.

2) **BTU Value of Wood (BTU/Pound)** – This is the heating value of the wood used as fuel accounting for the water latent heat loss. Douglas Fir with 20% moisture content is about 6,880 BTU/Pound.

3) **Heater Overall Efficiency (Percent)** – Masonry heater overall efficiency is the total measure of how well the masonry heater converts the chemical energy of the wood into heat energy during the combustion process (combustion efficiency) and how well the masonry heater delivers this heat to the house instead of out the chimney (heat transfer efficiency). The heat loss out the chimney consists of the chimney stack temperature which is typically 300-400 degrees Fahrenheit and the water latent heat loss from converting the water in the wood to water vapor. Masonry heater combustion efficiency is typically 96 to 99%. Masonry heater heat transfer efficiency is typically 57 to 80%. Overall efficiency is the combustion efficiency times the heat transfer efficiency. European testing methods ignore the water latent heat loss which is around 9 to 13% depending on the moisture content of the wood. North American testing methods include the

water latent heat loss. The theoretical maximum overall efficiency obtainable from any wood burning device using North American testing methods is 83%. Actual masonry heater overall efficiency is typically 55 to 79%.

4) **Indoor Temp (Degrees F)** – This is the building indoor temperature. This is typically about 68.

5) **Initial Facing Temp (Degrees F)** – This is the initial temperature of the masonry heater facing material. This is typically the same value as the **Indoor Temp** input parameter, but may be significantly higher if the masonry heater has been fired for multiple days.

6) **Firebox Door Area (Square Feet)** – This is the total exposed area of the firebox door. This is typically about 3.5.

7) **Facing Area (Square Feet)** – This is the total exposed area of the masonry heater facing material exposed to the building occupants. This is typically about 100.

8) **Facing Thickness (Inches)** – This is the thickness of the masonry heater facing material. This is typically 5.

9) **Facing Density (Pounds per Cubic Foot)** – This is the density of the masonry heater facing material. This is typically about 150.

10) **Facing Thermal Conductivity (BTU-Inch/H-SF-Degrees F)** – This is the thermal conductivity of the masonry heater material. This is a measure of the ability of a material to conduct or transfer heat. This is typically about 14.

11) **Facing Specific Heat Capacity (BTU/Pounds-Degree F)** – This is the specific heat capacity of the material used to face the masonry heater. This is a measure of the amount of heat per unit mass that is required to raise the temperature of a material by one degree F. This is typically about 0.2.

12) **Facing Emissivity (Percent)** – Emissivity is the relative ability of a material to emit energy by radiation. It is the ratio of energy radiated by the specific material to the energy radiated by a true "black body" at the same temperature. A true "black body" would have an emissivity of 100 percent. A perfectly reflective material would have an emissivity of 0 percent. This is typically 85 to 90.

13) **Facing Convective Heat Transfer Coefficient (BTU/Hour-Square Feet-Degree F)** – This is an engineering coefficient used for calculating heat transfer via convection between a fluid and a solid. In this case, the fluid is the air around the exterior surface of the masonry heater facing material and the solid is the facing material. Still air has a convection heat transfer coefficient of 1.56 BTU/H-SF-Deg F. It is interesting to note that the inverse of this value is 0.64, which is the typical R-value for an inside air film as shown in the instructions for our **Heat Loss Analysis Calculator**. This is typically 1.56.

Click **Solve** after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameter:

1) **Total Heat Gain (BTU/Day)** – This is the total heat gain that the masonry heater will generate during the 24 hours after the firing. It is directly calculated from the **Amount of Wood Burned per Day**, **BTU Value of Wood** and **Heater Overall Efficiency** input parameters.

2) **Average Heat Gain (BTU/Hour)** – This is the average heat gain per hour that the masonry heater will generate. This is the **Total Heat Gain** output parameter divided by 24 hours.

3) **Maximum Heat Gain (BTU/Hour)** – This is the maximum heat gain per hour that the masonry heater will generate which occurs at the time when the exterior surface of the masonry heater facing reaches maximum temperature.

4) **Facing Volumetric Heat Capacity (BTU/Cubic Foot-Degrees F)** – This is the volumetric heat capacity of the material used to face the masonry heater. This is a measure of the amount of heat per unit volume that is required to raise the temperature of a material by one degree F. This is the **Facing Density** input parameter times the **Facing Specific Heat Capacity** input parameter.

5) **Facing Thermal Diffusivity (Square Feet/Hour)** – This is the thermal diffusivity of the material used to face the masonry heater. This is a measure of the rate of heat transfer through a thickness of material from the hot to the cold side. This is the **Facing Thermal Conductivity** input parameter (in BTU-**Feet**/Hours-Square Feet-Degrees F) divided by the **Facing Volumetric Heat Capacity** output parameter.

6) **Facing Maximum Surface Temp (Degrees F)** – This is the maximum temperature that the exterior surface of the masonry heater facing will reach.

7) **Time of Facing Maximum Surface Temp & Maximum Heat Gain (Hours after Firing)** – This is the number of hours after the firing that the masonry heater exterior facing material surface will reach the **Facing Maximum Surface Temp** and **Maximum Heat Gain** output parameters.

8) **Heat Gain (BTU/Hour)** – This the heat gain that the masonry heater will generate at 30 minutes, 1 hour, 2 hours, 4 hours, 6 hours, 8 hours, 10 hours, 12 hours, 14 hours, 16 hours, 18 hours, 20 hours, 22 hours, 24 hours, 36 hours and 48 hours after the firing.

9) **Facing Surface Temp (Degrees F)** – This the masonry heater exterior facing material surface temperature at 30 minutes, 1 hour, 2 hours, 4 hours, 6 hours, 8 hours, 10 hours, 12 hours, 14 hours, 16 hours, 18 hours, 20 hours, 22 hours and 24 hours, 36 hours and 48 hours after the firing.

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The steady state room temperature is the room temperature at which the heat loss out of the room is equal to the heat gain into the room. If the room temperature is initially lower or higher than the steady state room temperature, it may take a significant amount of time for the room temperature to reach this steady state room temperature. There may be an occasion where you may want to determine the steady state room temperature of a closed room that is not directly cooled or heated by a HVAC system, but is indirectly cooled or heated by the room's building assemblies (e.g., ceiling, door, floor, wall, or window building assemblies) that are exposed to a combination of different temperatures (i.e., exposed to outdoor temperatures or exposed to indoor temperatures from other HVAC system cooled or heated rooms located adjacent to this closed room). This calculator allows you to enter the associated heat transfer properties for up to ten room building assemblies, the outdoor air infiltration rate, and the indoor air infiltration rate to determine the steady state room temperature and determine what the heat gain/loss from each of the room's building assemblies and infiltration rates will be at this steady state room temperature.

In order to use this calculator, you will first need to look up the R-values of the materials used to construct the building envelope from the below table and then determine the total R-value of the wall, ceiling, and floor assemblies. You will need to determine the total R-value for the exterior fenestration (i.e., the windows and doors). The total R-value is provided by fenestration manufacturers (often specified as the total U-factor which may be inverted to obtain the total R-value). All of these total R-values are then entered into the calculator and converted by the calculator into total U-factors for the assemblies which are then used to determine the heat gain or loss in a manner consistent with the 2013 American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Fundamentals Handbook methodology and recommendations.

The following is a list of R-values (in units of Degrees F-Hour-Square Feet/BTU) for material commonly used in the building construction industry:

AIR FILMS:

Inside surface	0.64
Outside surface (15 MPH wind)	0.17

COATINGS AND FACINGS:

Building felt (15 PSF)	0
Foil facing	0
Latex paint	0
MemBrain™	0
Oil paint	0
Polyethlene vapor barriers	0
Typar™	0
Tyvek™	0

CONCRETE AND MASONRY:

Common brick	0.3 per inch
Concrete	0.10 per inch
8" concrete block	1.11 for 8"

FLOORING:

Carpet (1/4" nylon level loop)	1.36 for 1/4"
Carpet (1/2" polyester plush)	1.92 for 1/2"
Ceramic tile	0.6 per inch
Polyurethane foam padding (8 PCF)	4.4 per inch
Vinyl tile or sheet flooring (1/8")	0.21 for 1/8"

INSULATION:

Blown cellulose fiber	3.4 per inch
Expanded polystyrene (EPS) panels	4.3 - 5.0 per inch
Extruded polystyrene (XPS) panels	5.4 per inch
Fiberglass/Rockwool batt (standard density)	3.17 per inch
Foam in place urethane	5.9 per inch
Polyisocyanurate panels	5.6 per inch

WALL CLADINGS AND SHEATHINGS:

Drywall	0.9 per inch
Hardwoods	0.9 per inch
Oriented Strand Board (OSB)	1.59 per inch
Plywood	1.24 per inch
Softwoods	1.42 per inch
Wood lap siding	1.24 per inch
Vinyl lap siding	0.61 per inch

The R-value for a specific thickness of a material may be obtained by multiplying the R-value per inch by the thickness in inches. The R-values for each layer of material should be added together to determine the total R-value of the wall, ceiling, and framed floor assemblies.

For a typical 2x4 wall we might have 0.64 (inside air film) plus 0.45 (0.9 x 0.5 inch drywall) plus 11.09 (3.17 x 3.5 inches of fiberglass batt) plus 0.62 (1.24 x 0.5 inch plywood sheathing) plus 0.31 (0.61 x 0.5 inch vinyl clapboard siding) plus 0.17 (outside air film) for a total 2x4 wall R-value of 13.28. Please note that this corresponds to a U-factor of 0.0753. You will not find a window at any price that comes close to performing as well as even this poor performing wall assembly.

For a typical 2x6 wall we might have 0.64 (inside air film) plus 0.45 (0.9 x 0.5 inch drywall) plus 17.44 (3.17 x 5.5 inches of fiberglass batt) plus 0.62 (1.24 x 0.5 inch plywood sheathing) plus 0.31 (0.61 x 0.5 inch vinyl clapboard siding) plus 0.17 (outside air film) for a total 2x6 wall R-value of 19.63.

You may want to further refine these 2x4 and 2x6 wall R-values to properly determine and account for the real R-value of non-uniform material assemblies (i.e., account for the thermal bridging that results from the 2x4 and 2x6 studs). To accomplish this:

1) Determine what percentage of the wall assembly consists of different non-uniform materials (e.g., 16 inch on center 2x4 stud construction wall area consists of about 14% stud area and 86% fiberglass batt area),

2)   Determine the associated U-factors (i.e., the inverse of the R-value) for each non-uniform material. The 14% of wall area that consists of 2x4 studs has a U-factor of 0.2012 [i.e., 1 / (1.42 x 3.5" of softwood) = 0.2012]. The 86% of wall area that consists of fiberglass batt has a U-factor of 0.0902 [i.e., 1 / 11.09 = 0.0902],

3)   Determine the total percent-weighted U-factor of the non-uniform material assembly (e.g., 0.14 x 0.2012 + 0.86 x 0.0902 = 0.1057),

4)   Determine the real R-value of the non-uniform material assembly by inverting the total percent-weighted U-factor (e.g., 1 / 0.1057 = 9.46). The real R-value of this non-uniform material assembly is 9.46 in lieu of the previous 11.09 value that assumed 100% fiberglass batt, and

5)   Determine the total wall R-value by summing the real R-value of the non-uniform material assembly with the R-values of the uniform material assemblies [e.g., 0.64 (inside air film) plus 0.45 (0.9 x 0.5 inch drywall) plus 9.46 (the real R-value of the non-uniform material assembly) plus 0.62 (1.24 x 0.5 inch plywood sheathing) plus 0.31 (0.61 x 0.5 inch vinyl clapboard siding) plus 0.17 (outside air film)] for a total 2x4 wall R-value of 11.65 in lieu of the previous 13.28 total 2x4 wall R-value.

For a typical 11 inch thick Insulated Concrete Form (ICF) wall we might have 0.64 (inside air film) plus 0.45 (0.9 x 0.5 inch drywall) plus 0.6 (0.1 x 6 inches concrete) plus 22.5 (4.5 x 5 inches of EPS) plus 0.31 (0.61 x 0.5 inch vinyl clapboard siding) plus 0.17 (outside air film) for a total ICF wall R-value of 24.67. Please see our **ICF Performance Calculator** to determine the ICF effective R-value that accounts for the thermal mass effect where the building will actually be constructed. Then consider using this ICF effective R-value in lieu of the previous 0.6 and 22.5 R-values (i.e., the previous 23.10 ICF conventional R-value). For example, for standard ICF in Rogue River, Oregon, the ICF effective R-values are 21.38 in Spring, 66.15 in Summer, 63.42 in Fall, and 21.07 in Winter. This is an average annual ICF effective R-value performance of 43.07 in lieu of the 23.10 conventional ICF R-value. This results in an average annual total ICF wall effective R-value of 44.64 in lieu of the previous 24.67 total ICF wall R-value.

It should be noted that if you have an existing building and you would like to determine the total R-values of the building envelope, this can often be easily accomplished without knowing anything about the building material that were actually used in the original construction. All you need is an IR temperature gun to measure the interior and exterior surface temperature of the building envelope, know the indoor temperature, and apply some math. Any existing building envelope R-value can be calculated using this equation:

$$R = 0.64 \, (T_{is} - T_{es}) / (T_i - T_{is})$$

where R is the building envelope R-value, T_{is} is the interior surface temperature of the building envelope, T_{es} is the exterior surface temperature of the building envelope, and T_i is the indoor temperature. This equation assumes that the indoor air film R-value is 0.64 and that both the indoor and outdoor temperatures are reasonably constant for a couple hours prior to measuring the interior and exterior surface temperatures. This approach is very accurate for 2x and SIP construction, but may be less accurate for ICF construction because the thermal mass effect time lag associated with ICF is typically much longer than the time that the outdoor temperature stays reasonably constant prior to measuring the interior and exterior surface temperatures. Furthermore, the effective R-value performance of ICF is often vastly different than the conventional R-value and is highly dependent on the daily outdoor temperature variation as explained in the instructions for our **ICF Performance Calculator**.

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Exposed Temp of Room Building Assembly (Degrees Fahrenheit)** – This is the specific temperature that the specific room building assembly is exposed. This could be the outdoor temperature outside the room's ceiling, door, floor, wall, or window building assembly. This could be indoor temperatures from other cooled or heated rooms located adjacent to the closed room's ceiling, door, floor, or wall building assembly. You may enter all 10 entries or you may leave any unneeded entries blank.

2) **Outdoor Air Infiltration Temp (Degrees Fahrenheit)** – This is the temperature of outdoor air that is entering the room via uncontrolled air infiltration (e.g., leaky building construction) and/or created by controlled air ventilation. You may leave this blank if you will not model this infiltration.

3) **Indoor Air Infiltration Temp (Degrees Fahrenheit)** – This is the temperature of indoor air that is entering the room via uncontrolled air infiltration (e.g., leaky building construction) and/or created by controlled air ventilation. You may leave this blank if you will not model this infiltration.

4) **Area of Room Building Assembly (Square Feet)** – This is the specific area of the specific room building assembly. You may enter all 10 entries or you may enter less leaving any unused entries blank. You may enter all 10 entries or you may leave any unneeded entries blank.

5) **R-Value of Room Building Assembly (Degrees F-Hour-Square Feet/BTU)** - This is the total R-value of the materials used for the room's ceiling, floor, or wall building assembly. Please see the above construction material R-value table and directions for using it. Often time's door and window manufacturers may specify a total U-factor and you will need to convert this total U-factor to a total R-value. For example, if the door manufacturer specifies a total U-factor of 0.45 for the door, the correct total R-value to enter into the calculator is 2.2 (i.e., 1 divided by 0.45). You may enter all 10 entries or you may leave any unneeded entries blank.

6) **Volume of Room (Cubic Feet or 0 for Cubic Feet/Minute)** - This is a logic input parameter that tells the calculator whether the **Outdoor Air Infiltration Rate of Room** and **Indoor Air Infiltration Rate of Room** input parameters are entered as Air Changes/Hour (ACH) based on the actual room volume or simply entered as Cubic Feet/Minute (CFM). If the **Outdoor Air Infiltration Rate of Room** and **Indoor Air Infiltration Rate of Room** are entered as ACH, enter the total inside volume of the building or room and include the volume of ALL the rooms even if they are NOT exposed to the outside temperature. If **Outdoor Air Infiltration Rate of Room** and **Indoor Air Infiltration Rate of Room** are entered as CFM, enter 0. You may leave this blank if you will not model any infiltration.

7) **Outdoor Air Infiltration Rate of Room (Air Changes/Hour or Cubic Feet/Minute)** - This is the outdoor air infiltration rate of the room caused by uncontrolled air infiltration (e.g., leaky building construction) and/or created by controlled air ventilation. Depending on whether the actual room volume or 0 is entered for the **Volume of Room** logic input parameter, enter either ACH or CFM. 1.0 ACH or more is typical of older, leaky building construction. 0.5 ACH is typical of new construction. 0.35 ACH is typically the minimum allowed for health reasons and is often accomplished in airtight, energy efficient building construction (e.g., ICF construction) by using a basic air ventilation system, Heat Recovery Ventilation (HRV) system, or Energy Recovery Ventilation (ERV) system. If a HRV or ERV system is used, you should reduce the calculator

ACH entry by properly accounting for the efficiency of the heat recovery system. For example, if you use an air-to-air HRV system that is 60% efficient and the controlled ventilation is 0.35 ACH or 200 CFM, the correct calculator entry would be 0.14 ACH (i.e., 0.40 x 0.35 ACH) or 80 CFM (i.e., 0.40 x 200 CFM). You may leave this blank if you will not model this infiltration.

8) **Indoor Air Infiltration Rate of Room (Air Changes/Hour or Cubic Feet/Minute)** - This is the indoor air infiltration rate of the room caused by uncontrolled air infiltration (e.g., leaky building construction) and/or created by controlled air ventilation. Depending on whether the actual room volume or 0 is entered for the **Volume of Room** logic input parameter, enter either ACH or CFM. You may leave this blank if you will not model this infiltration.

Click $\boxed{\text{Solve}}$ after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameter:

1) **Steady State Room Temp (Degrees Fahrenheit)** - This is the steady state temperature that the inside of the room will reach given the input parameters.

2) **Heat Gain/Loss from Room Building Assembly (BTU/Hour)** - This is the specific heat gain or heat loss from the specific building assembly that will occur at the **Steady State Room Temp** output parameter given the input parameters.

3) **Outdoor Air Infiltration Rate of Room (Cubic Feet/Minute)** - This is the air infiltration rate of the building/room caused by uncontrolled air infiltration (e.g., leaky building construction) and/or created by controlled air ventilation. If the **Outdoor Air Infiltration Rate of Room** input parameter is entered as a CFM value, this output parameter is the same CFM value. If the **Outdoor Air Infiltration Rate of Room** input parameter is entered as an ACH value, this output parameter uses the **Volume of Room** logic input parameter to convert this output parameter to CFM.

4) **Heat Loss/Loss from Outdoor Air Infiltration (BTU/Hour)** - This is the specific heat gain or heat loss from the **Outdoor Air Infiltration Rate of Room** input parameter that occurs at the **Steady State Room Temp** output parameter.

5) **Indoor Air Infiltration Rate of Room (Cubic Feet/Minute)** - This is the air infiltration rate of the building/room caused by uncontrolled air infiltration (e.g., leaky building construction) and/or created by controlled air ventilation. If the **Indoor Air Infiltration Rate of Room** input parameter is entered as a CFM value, this output parameter is the same CFM value. If the **Indoor Air Infiltration Rate of Room** input parameter is entered as an ACH value, this output parameter uses the **Volume of Room** logic input parameter to convert this output parameter to CFM.

6) **Heat Gain/Loss from Indoor Air Infiltration (BTU/Hour)** - This is the specific heat gain or heat loss from the **Indoor Air Infiltration Rate of Room** input parameter that will occur at the **Steady State Room Temp** output parameter.

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Psychrometrics Calculator

Psychrometrics is the determination of the heat and water vapor properties of air. Primary psychrometric parameters are barometric pressure (which is a function of elevation), dry bulb temperature, wet bulb temperature, relative humidity, and dew point temperature. Secondary psychrometric parameters are partial vapor pressure, saturation vapor pressure, humidity ratio, specific volume, density, and enthalpy.

A psychrometric chart or psychrometric calculator describes the relationships between all these psychrometric parameters. All of these psychrometric parameters may be determined by knowing only the elevation and the dry bulb temperature, and then either the wet bulb temperature, the relative humidity, or the dew point temperature. Use of a dry bulb thermometer in conjunction with a wet bulb thermometer is a common method for determining all these psychrometric variables. For example, if the elevation, the dry bulb temperature and the wet bulb temperature are known, then the relative humidity, the dew point temperature, and all of the secondary psychrometric parameters may be determined by exercising this calculator.

To use this calculator, first enter ALL of the following input parameters:

1) **Elevation (Feet)** - This is the elevation of the building.

2) **Dry Bulb Temp (Degrees Fahrenheit)** - We typically measure the temperature of air with a thermometer. Traditional thermometers have a bulb that contains a liquid that expands, and a tube indicating the temperature on a scale. As the liquid expands, it rises up the scale. You may use a thermocouple and electronic meter or an infrared thermometer because these are faster and more rugged. Whichever method is used, this measurement is called the dry bulb temperature because the effective end of the thermometer making the measurement has NOT been wetted.

Then enter ONE of the following three input parameters:

3) **Wet Bulb Temp (Degrees Fahrenheit)** - The wet bulb temperature is measured by having the bulb of the thermometer moist. The moisture evaporates, lowering the temperature recorded by the thermometer. Less moisture in the air will result in a faster rate of evaporation and therefore a colder reading. In practice, we use an electronic thermometer with a wetted cotton wick secured around the thermocouple. A state of saturation exists when the air is holding the maximum amount of water possible (i.e., at 100% relative humidity) at a given temperature. At a state of saturation, no water can evaporate from the wetted cotton wick so the wet bulb temperature is the same as the dry bulb temperature. This temperature is therefore referred to as the saturation temperature. When the wet bulb temperature and **Dry Bulb Temp** input parameters have the same value, the **Dew Point Temp** output parameter will have this same temperature value, the **Relative Humidity** output parameter is 100%, and the **Partial Vapor Pressure** and **Saturation Vapor Pressure** output parameters will have the same pressure value. If a value is entered for the wet bulb temp, do not enter values for the **Relative Humidity** or **Dew Point Temp** input parameters.

4) **Relative Humidity (Percent)** - This is the ratio of the actual amount of water vapor in the air to the fraction of the water vapor in the air at the state of saturation. A state of saturation exists when the air is holding the maximum amount of water possible (i.e., at 100% relative humidity) at a given temperature. Relative humidity is dimensionless, and is usually expressed as a percentage. When the relative humidity is 0%, the **Partial Vapor Pressure** and **Humidity Ratio** output parameters are 0. When the relative humidity is 100%, the **Dry Bulb Temp**, **Wet Bulb Temp**, and **Dew Point Temp** output parameters will have the same temperature value and the **Partial Vapor Pressure** and **Saturation Vapor Pressure** output parameters will have the same pressure value. Preferred relative humidity values of comfort for people are between 35% and 60%. If a value is entered for the relative humidity, do not enter values for the **Wet Bulb Temp** or **Dew Point Temp** input parameters.

5) **Dew Point Temp (Degrees Fahrenheit)** - This is the temperature of the air at which a moist air sample reaches water vapor saturation and is equivalent to a wet bulb temperature at 100% relative humidity. At this combination of temperature and humidity, further removal of heat results in water vapor condensing into liquid. When the dew point temperature and **Dry Bulb Temp** input parameters have the same value, the **Wet Bulb Temp** output parameter will have this same temperature value, the **Relative Humidity** output parameter is 100%, and the **Partial Vapor Pressure** and **Saturation Vapor Pressure** output parameters will have the same pressure value. If a value is entered for the dew point temp, do not enter values for the **Wet Bulb Temp** or **Relative Humidity** input parameters.

Click Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Barometric Pressure (Inches of Mercury)** - This is the standard atmospheric barometric pressure at the **Elevation** input parameter.

2) **Wet Bulb Temp (Degrees Fahrenheit)** - This is either the calculated or entered wet bulb temperature as described for the **Wet Bulb Temp** input parameter. If "NA" is displayed, this indicates that the input parameters are not entered appropriately.

3) **Relative Humidity (Percent)** - This is either the calculated or entered relative humidity as described for the **Relative Humidity** input parameter. If "NA" is displayed, this indicates that the input parameters are not entered appropriately.

4) **Dew Point Temp (Degrees Fahrenheit)** - This is either the calculated or entered dew point temperature as described for the **Dew Point Temp** input parameter. If "NA" is displayed, this indicates that the input parameters are not entered appropriately.

5) **Partial Vapor Pressure (Inches of Mercury)** - This is the partial pressure of the water vapor in the air given the actual relative humidity. When the relative humidity is 0%, the partial vapor pressure is 0. When the relative humidity is 100%, the partial vapor pressure and **Saturation Vapor Pressure** output parameters will have the same pressure value. If "NA" is displayed, this indicates that the input parameters are not entered appropriately.

6) **Saturation Vapor Pressure (Inches of Mercury)** - This is the partial pressure of the water vapor in the air at the state of saturation. A state of saturation exists when the air is holding the maximum amount of water possible (i.e., at 100% relative humidity) at a given temperature. When the relative humidity is 100%, the saturation vapor pressure and **Partial Vapor Pressure** output parameters will have the same pressure value. If "NA" is displayed, this indicates that the input parameters are not entered appropriately.

7) **Humidity Ratio** - This is the ratio of the mass of the water vapor to the unit mass of dry air. When the relative humidity is 0%, the humidity ratio is 0. If "NA" is displayed, this indicates that the input parameters are not entered appropriately.

8) **Specific Volume (Cubic Feet/Pound)** - This is the ratio of the volume of the air sample to the unit mass of dry air. When the relative humidity is 0%, the specific volume is the inverse of the **Density** output parameter. If "NA" is displayed, this indicates that the input parameters are not entered appropriately.

9) **Density (Pounds/Cubic Foot)** - This is the mass of the air sample per cubic foot. When the relative humidity is 0%, the density is the inverse of the **Specific Volume** output parameter. If "NA" is displayed, this indicates that the input parameters are not entered appropriately.

10) **Enthalpy (BTU/Pound)** - This is the total amount of heat energy of the moist air and therefore includes the amount of heat of the dry air and the water vapor in the air. Enthalpy increases with increasing relative humidity and with increasing elevation. If "NA" is displayed, this indicates that the input parameters are not entered appropriately.

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A building's roof, windows, walls, and floors may be designed to collect, store, and distribute solar energy in the form of heat in the winter and reject solar heat in the summer without requiring the use of any electrical/mechanical devices to distribute this heat throughout the building. This is called passive solar heating and this is really the first step toward environmentally friendly construction and reducing utility expenses. Passive solar heating may typically provide between 30 to 98% of a building's heating needs depending on the building's available south window area, construction materials/methods, location (i.e., latitude, building orientation, and climate), and the overall integrated heating system design approach.

A hydronic radiant floor heating design that is fully integrated with the passive solar heating system design is typically required to provide passive solar heating which exceeds about 50% of a building's annual heating needs in order to provide the necessary heat storage/rejection capability to address periods without sun and ensure never overheating the building.

In short, passive solar heating design involves:

1) Orienting the long axis of the building along the east-west direction so that there is a lot of wall area facing as due south as possible. *If you live in the southern hemisphere, replace "south" with "north" in this previous sentence and throughout all of our calculator instructions.*

2) Designing a roof overhang for the building's location such that the windows on the south wall receive full sun during the cold winter months, are fully shaded during the hot summer months, and receive the appropriate amount of sun during the variable spring and fall months so as to minimize the need for supplemental heating while NEVER overheating the building. *An often cited but misused "design rule of thumb" is to design a passive solar roof overhang using design solar altitude angles for full shade and full sun that are the latitude plus 18.5 degrees and the latitude minus 18.5 degrees, respectively.*

3) Determining the passive solar fenestration area (i.e., area of south facing, vertically oriented, windows and doors containing glass) that is necessary to provide the required amount of heat gain. *An often cited but misused "design rule of thumb" is that passive solar buildings should have a total south wall passive solar fenestration area between 7% and 12% of the total building floor area.*

4) Minimizing the window area in the other walls to reduce heat loss during the cold winter months and to reduce heat gain during the hot summer months. Even the worst wall assembly will have a much higher R-value (or much lower U-factor) than the best available window. As such, there are significant economic and energy efficiency benefits to minimizing the quantity and size of windows used in buildings.

5) Determining the correct amount of thermal mass needed to absorb, store, and slowly release the correct amount of heat gain during the daily passive solar heating cycle. *An often cited but misused "design rule of thumb" is that for every square foot of south wall passive solar fenestration area in excess of the 7% "design rule of thumb", a passive solar building should have 5.5 square feet of 4 inch thick thermal mass material.*

Amazingly and regrettably, there are many passive solar companies that market their services based on using these overly simplistic and often grossly inaccurate "design rules of thumb" for above items 2), 3) and 5) and they often charge exorbitant fees for their less-than-competent expertise and their defective passive solar house plans. Frankly, using "design rules of thumb" that may be grossly inaccurate is a very risky design approach that we believe should not be accepted or tolerated. Relative to the above item 2) "design rule of thumb", in addition to properly addressing the building's local latitude, it is important to properly address the building's local climate when designing the passive solar roof overhang as explained below. This may be easily accomplished using this calculator and our **Passive Solar Roof Overhang Design Calculator**. The problems associated with just using above item 3) and 5) "design rules of thumb" are fully explained in the specific instructions for our **Passive Solar Heat Gain Calculator** and **Passive Solar Thermal Mass Performance Calculator**. We advise applying due diligence and avoiding companies who follow this practice if you want to ensure having a passive solar design that will keep the building occupants comfortable and happy without depleting your bank account. A sample of a professional passive solar analysis may be found on the Consultation tab of our website:

Sample Passive Solar Analysis

From a simplistic perspective, the passive solar roof overhang design objective is to capture all the possible solar heat gain during the cold winter months when maximum solar heat gain is needed, and to reject solar heat gain during the hot summer months when solar heat gain is not wanted. However, without first properly determining the building heat loss and comparing it to this captured solar heat gain, you could end up creating a situation that will lead to overheating the building during the variable spring and fall months. If you truly get the design wrong, you could end up creating a situation that will cause overheating the building during the winter and summer months too. Our **Passive Solar Heat Gain Calculator** will allow you to properly determine the passive solar heat gain and avoid these building overheating problems. Our **Passive Solar Thermal Mass Performance Calculator** will allow you to design and use thermal mass to further mitigate the risk of building overheating problems. Now let's first explain how passive solar roof overhangs work, discuss some of the issues associated with designing them, and do some simple illustrative passive solar roof overhang design examples.

The solar altitude angle is the angle between the direction of the geometric center of the sun's apparent disk and the horizon. There is a difference of 46.9 degrees between the Summer Solstice (June 21st) and Winter Solstice (December 21st) solar altitude angles. The Summer Solstice solar altitude angle (which is 90 degrees minus the latitude PLUS 23.45 degrees) is higher than the Winter Solstice solar altitude angle (which is 90 degrees minus the latitude MINUS 23.45 degrees). We use this information to design a passive solar roof overhang that will provide full sun to the passive solar fenestration during the winter months when the solar altitude angle is LOW and provide full shade to the passive solar fenestration during the summer months when the solar altitude angle is HIGH. During the Spring Equinox (March 21th) and Fall Equinox (September 21st), the solar altitude angle (which is 90 degrees minus the latitude) is exactly the same. In the northern hemisphere for most climates, September 21st is markedly warmer than March 21st. This creates an issue that must be considered and addressed.

If you will be using standard height passive solar fenestration (e.g., passive solar fenestration that is between 4 to 6 feet in height) and locating passive solar fenestration in the wall as is typically done (e.g., having the bottom of the passive solar fenestration 2 feet above the floor), there are three options to address the aforementioned Spring/Fall Equinox climate unequal warmness issue. First, in climates that require very little winter heating, the best solution is to design the passive roof overhang to provide mostly full shade to the

passive solar fenestration during the Spring Equinox and Fall Equinox dates and restrict significant solar heat gain to only occur during the two months centered on the Winter Solstice (December 21st). Second, in climates that require considerable winter heating, the best solution is to design the passive solar roof overhang to provide mostly full sun to the passive solar fenestration during the Spring Equinox and Fall Equinox dates and plan to use moveable shades during late Summer and early Fall to prevent overheating. Third, in climates that are between the first and second condition, the best solution is to design the passive solar roof overhang to provide about 50% solar exposure to the passive solar fenestration during the Spring Equinox and Fall Equinox dates. This third compromise solution may sacrifice some solar heat in March when it may be desired and may require the use of moveable shades during September to prevent overheating.

Please keep in mind that moveable shades may be vegetation that grows leaves and loses leaves at the right time. You will suffer a slight performance loss when using vegetation as your moveable shade approach because even without leaves, the vegetation branches will cause you to lose some irradiance when all of it is desired. However, this may be a worthwhile tradeoff in some circumstances to avoid the additional time, effort, and expense associated with using manual moveable shades.

If you are willing deviate from only using standard height passive solar fenestration (e.g., passive solar fenestration that is between 4 to 6 feet in height) and only locating passive solar fenestration in the wall as is typically done (e.g., having the bottom of the passive solar fenestration 2 feet above the floor), there is another option called Winter Passive Solar Fenestration that will provide the required heat gain and only during the desired winter months. Winter Passive Solar Fenestration is accomplished by using reduced height fenestration (e.g., perhaps 2 feet in height) and locating this fenestration in the wall up near the ceiling. While Winter Passive Solar Fenestration does not allow low direct line of sight for building occupants, Winter Passive Solar Fenestration does allow high direct line of sight of terrain views and provides valuable daylighting. More importantly, Winter Passive Solar Fenestration may be designed so as to only provide the required heat gain during the desired winter months without providing any heat gain during the spring, summer, and fall months.

This calculator may be used to determine the solar altitude angle during various times of the year. Exercising this calculator at solar noon near the middle of each month of the year and tabulating the solar altitude data will enable you to begin designing a passive solar heated building for the local latitude and local climate. You will see that the solar altitude angle data varies significantly over the course of the year. ***To further assist you in accomplishing a passive solar design, an example for a building located in Rogue River, Oregon is used to illustrate the use of this calculator.***

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Latitude (Degrees)** - This is a geographic coordinate that specifies the north-south position of a point on the Earth's surface. Latitude is an angle which ranges from 0 degrees at the Equator to 90 degrees northward and to -90 degrees southward. If the latitude is south, enter a negative value. You may need to convert latitude that is in degrees, minutes and seconds into decimal degrees. The default value is 42.60. Please use this same value in our **Cooling Load Analysis Calculator**, **Passive Solar Fenestration Exposure Calculator** and **Passive Solar Heat Gain Calculator**.

   For our Rogue River, Oregon design example, the latitude is North 42° 36' 0". For this location the correct entry is 42.60 (i.e., 0"/60 equals 0' and 36.0'/60 equals 0.60 °).

2) **Longitude (Degrees)** - This is a geographic coordinate that specifies the east-west position of a point on the Earth's surface. Longitude is an angle which ranges from 0 degrees at the Prime Meridian to 180 degrees eastward and to -180 degrees westward. If the longitude is west, enter a negative value. You may need to convert longitude that is in degrees, minutes and seconds into decimal degrees. The default value is -122.99. Please use this same value in our **Passive Solar Fenestration Exposure Calculator**.

   For our Rogue River, Oregon design example, the longitude is West 122° 59' 24". For this location the correct entry is -122.99 (i.e., 24"/60 equals 0.4' and 59.4'/60 equals 0.99°).

3) **Time Zone (Hours)** - This is the difference in hours from Greenwich Mean Time (GMT) or Coordinated Universal Time (UTC) for a particular time zone. If west of GMT/UTC, enter a negative value. Time zones typically change 1 hour for every 15 degrees of longitude change (i.e., 360 degrees of longitude divided by 24 hours). So if you divide the longitude by 15 and round to the nearest integer, this should be the approximate time zone. While actual time zones usually follow 1 hour increments, they are often set by local law and therefore may not have boundaries that follow straight lines of longitude. Consequently, this rule may not always yield the correct time zone for every location. Leaving this input parameter blank results in this rule being used. Please use this same value in our **Passive Solar Fenestration Exposure Calculator**.

   For our Rogue River, Oregon design example, -122.99 longitude divided by 15 is equal to -8.2 and when rounded to the nearest integer is equal to -8. The time zone of Rogue River, Oregon is indeed -8, so the aforementioned rule does work for this location and the correct entry is -8.

4) **Daylight Saving Time (0=No, 1=Yes, Blank=USA)** - This is a logic input parameter to tell the calculator whether Daylight Saving Time (DST) is used and is in effect. For Rogue River, Oregon, DST is in effect from 2 AM on the second Sunday of March until 2 AM on the first Sunday of November. Leaving this input parameter blank results in this USA DST rule being used. Please use this same value in our **Passive Solar Fenestration Exposure Calculator**.

   For our Rogue River, Oregon design example, this is left blank.

5) **Twilight Definition (0=Sunrise/Sunset, 1=Civil, 2=Nautical, 3=Astronomical Twilight)** - This is a logic input parameter to tell the calculator whether Sunrise/Sunset Time or Civil, Nautical or Astronomical Dawn/Dusk Time should be used when determining the **Sunrise Time (or Selected Twilight Dawn Time)** and **Sunset Time (or Selected Twilight Dusk Time)** output parameters. Civil Twilight marks the beginning and end of the time period when artificial light is required for outdoor activities and is often used to define civil regulations related to aviation, hunting and the usage of headlights and street lamps. Nautical Twilight marks the beginning and end of the time period when both bright navigation stars and the horizon can be viewed by sailors using a sextant for celestial navigation. Astronomical Twilight marks the beginning and end of the time period when the sky is sufficiently dark to allow any astronomical objects that can be viewed by the naked eye to be viewed. Sunrise/Sunset Time is defined to occur when the center of the sun is 50 minutes (0.833 degrees) below the horizon. Civil Twilight is defined to occur when the center of the sun is between 50 minutes (0.833 degrees) below the horizon (i.e., at Sunrise/Sunset) and 6 degrees below the horizon. Nautical Twilight is defined to occur when the center of the sun is between 6 degrees below the horizon and 12 degrees below the horizon. Astronomical Twilight is

defined to occur when the center of the sun is between 12 degrees below the horizon and 18 degrees below the horizon. Civil Dawn/Dusk Time is defined as the moment the center of the sun is 6 degrees below the horizon. Nautical Dawn/Dusk Time is defined as the moment the center of the sun is 12 degrees below the horizon. Astronomical Dawn/Dusk Time is defined as the moment the center of the sun is 18 degrees below the horizon. Enter 0 to determine the Local Time of Sunrise/Sunset Time. Enter 1 to determine the Local Time of Civil Dawn/Dusk Time. Enter 2 to determine the Local Time of Nautical Dawn/Dusk Time. Enter 3 to determine the Local Time of Astronomical Dawn/Dusk Time. The default value is 0.

For our Rogue River, Oregon design example, this is 0.

6) **Solar or Local Time (0=Solar, 1=Local)** - This is a logic input parameter to tell the calculator whether the **Hour** input parameter is in Solar Time or Local Time. Enter 0 for Solar Time or enter 1 for Local Time. The default value is 0. ***Solar time should always be used when designing a passive solar building.***

For our Rogue River, Oregon design example, this is 0.

7) **Hour** - This is the actual hour of the day in either Solar Time or the Local Time depending on the value of the **Solar or Local Time** logic input parameter and ranges from 1 to 24. If the **Solar or Local Time** logic input parameter is 0, a value of 12 corresponds to solar noon which is the time when the **Solar Altitude Angle** output parameter is the maximum value for the day and when the **Solar Azimuth Angle** output parameter is exactly 180 degrees (true south). If the **Solar or Local Time** logic input parameter is 1, a value of 12 is noon Local Time. If the **Solar or Local Time** logic input parameter is 1, a value of 15 is 3 PM Local Time. You may enter decimal values such as 15.5 for 3:30 PM or 15.75 for 3:45 PM. Please be sure to account for Daylight Saving Time (DST) if this is used and in effect. Leaving this input parameter blank results in the current local hour being used.

For our Rogue River, Oregon design example, this is 12.

8) **Day** - This is the actual day of the month and ranges from 1 to 31, where 1 is the first day of the month and 31 is the last day of a 31 day month. You should only enter an integer value within this range. Leaving this input parameter blank results in the current local day being used.

For our Rogue River, Oregon design example, this is 15.

9) **Month** - This is the actual month of the year and ranges from 1 to 12, where 1 is January and 12 is December. You should only enter an integer value within this range. Leaving this input parameter blank results in the current local month being used.

For our Rogue River, Oregon design example, these are:
January (1), February (2), March (3), April (4), May (5), June (6), July (7), August (8), September (9), October (10), November (11) and December (12).

Click Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Solar Declination Angle (Degrees)** - This is the solar declination angle at this actual hour, day, and month that you selected. The solar declination angle varies seasonally due to the tilt of the Earth on its axis of rotation and the rotation of the Earth around the sun. If the Earth were not tilted on its axis of rotation, the solar declination angle would always be 0 degrees. However, the Earth is tilted by 23.45 degrees and the solar declination angle varies plus or minus this amount. Only during the Spring Equinox and Fall Equinox is the solar declination angle exactly equal to 0 degrees. Therefore, in the northern hemisphere, the solar declination angle ranges from 0 degrees at the Spring Equinox (March 21th) and the Fall Equinox (September 21st), 23.45 degrees at Summer Solstice (June 21st), and -23.45 degrees at Winter Solstice (December 21st). It is this seasonal solar declination angle variation effect on the solar altitude angle that makes passive solar heating possible.

   For our Rogue River, Oregon design example, these are:
   January (-21.27 degrees), February (-13.29 degrees), March (-2.82 degrees), April (9.41 degrees), May (18.79 degrees), June (23.31 degrees), July (21.52 degrees), August (13.78 degrees), September (2.22 degrees), October (-9.60 degrees), November (-19.15 degrees) and December (-23.34 degrees).

2) **Solar Azimuth Angle (Degrees)** - This is the solar azimuth angle at this actual hour, day, and month that you selected. The solar azimuth angle is most often defined as the clockwise angle from true north to the direction of the sun similar to a standard compass dial. As such, a solar azimuth angle of 90 degrees is true east, 180 degrees is true south and 270 degrees is true west. If you are using a compass, be sure to consider the local magnetic declination (also known as magnetic variation) which changes over time. Westerly magnetic declination should be added to compass heading to determine true heading. Easterly magnetic declination should be subtracted from compass heading to determine true heading. For Rogue River, Oregon, the local magnetic declination was 14.9 degrees east of true in 2016. Therefore, true south in Rogue River, Oregon was equivalent to a magnetic compass reading of 165.1 degrees at this time.

   For our Rogue River, Oregon design example, this is exactly 180 degrees for every month since we used solar time.

3) **Solar Altitude Angle (Degrees)** - This is the solar altitude angle at this actual hour, day, and month that you selected. The solar altitude angle is the angle between the direction of the geometric center of the sun's apparent disk and the horizon. Depending on the latitude and the solar declination angle, the solar altitude angle may range from 0 to 90 degrees during the daylight hours.

   For our Rogue River, Oregon design example, these are:
   January (26.13 degrees), February (34.11 degrees), March (44.58 degrees), April (56.81 degrees), May (66.19 degrees), June (70.71 degrees), July (68.92 degrees), August (61.18 degrees), September (49.62 degrees), October (37.80 degrees), November (28.25 degrees) and December (24.06 degrees).

4) **Sunrise Time (or Selected Twilight Dawn Time)** - This is either the Local Time of Sunrise or the Civil, Nautical or Astronomical Dawn Time based on the entered **Twilight Definition** logic input parameter value and accounting for the **Daylight Saving Time** logic input parameter value, but NOT accounting for any terrain obstacles. Sunrise Time is defined as the moment the center of the sun is 50 minutes (0.833 degrees) below the horizon. Civil Dawn Time is defined as the moment the center of the sun is 6 degrees below the horizon. Nautical Dawn Time is defined as the moment the center of the sun is 12 degrees below the horizon. Astronomical Dawn Time is defined as the moment the center of the sun is 18 degrees below the horizon.

For our Rogue River, Oregon design example, these are:
January (7:39 AM), February (7:12 AM), March (7:26 AM), April (6:31 AM), May (5:49 AM), June (5:33 AM), July (5:48 AM), August (6:21 AM), September (6:56 AM), October (7:30 AM), November (7:08 AM) and December (7:36 AM).

5) **Sunset Time (or Selected Twilight Dusk Time)** - This is either the Local Time of Sunset or the Civil, Nautical or Astronomical Dusk Time based on the entered **Twilight Definition** logic input parameter value and accounting for the **Daylight Saving Time** logic input parameter value, but NOT accounting for any terrain obstacles. Sunset Time is defined as the moment the center of the sun is 50 minutes (0.833 degrees) below the horizon. Civil Dusk Time is defined as the moment the center of the sun is 6 degrees below the horizon. Nautical Dusk Time is defined as the moment the center of the sun is 12 degrees below the horizon. Astronomical Dusk Time is defined as the moment the center of the sun is 18 degrees below the horizon.

For our Rogue River, Oregon design example, these are:
January (5:02 PM), February (5:41 PM), March (7:17 PM), April (7:53 PM), May (8:27 PM), June (8:51 PM), July (8:47 PM), August (8:12 PM), September (7:18 PM), October (6:25 PM), November (4:47 PM) and December (4:39 PM).

Let's use the previously calculated Rogue River, Oregon data to do an illustrative example to show how to design a passive solar roof overhang that will provide full sun to the passive solar fenestration for some defined period of time (let's say between November 15th and February 15th) and provide full shade to the passive solar fenestration for some defined period of time (let's say between May 15th and August 15th). For November 15th and February 15th, we previously obtained the solar altitudes angles 28.25 degrees and 34.11 degrees, respectively. So our objective is to design a passive solar roof overhang that will provide full sun to the passive solar fenestration whenever the solar altitude angle is equal to or less than 34.11 degrees. This solar altitude angle is called the **Design Solar Altitude Angle for Full Sun** and the passive solar roof overhang may be designed to provide full sun to the passive solar fenestration (i.e., provide maximum solar heat gain) whenever the solar altitude angle is equal to or less than this value (i.e., 34.11 degrees between November 15th and February 15th for this example). For May 15th and August 15th, we previously obtained the solar altitudes angles 66.19 degrees and 61.18 degrees, respectively. So our other objective is to design a passive solar roof overhang that will provide full shade to the passive solar fenestration whenever the solar altitude angle is equal to or greater than 61.18 degrees. This solar altitude angle is called the **Design Solar Altitude Angle for Full Shade** and the passive solar roof overhang may be designed to provide full shade to the passive solar fenestration (i.e., provide 0 heat gain) whenever the solar altitude angle is equal to or greater than this value (i.e., 61.18 degrees between May 15th and August 15th for this example).

While it is always possible to design a passive solar roof overhang that will provide either full sun or full shade for some defined period, it may not be always be possible to accomplish both these design objectives depending on the latitude, fenestration height, fenestration location relative to the passive solar roof overhang, and the defined periods that are selected. This issue may occur because the amount of passive solar roof overhang that is required to achieve the full shade design objective is so large that it conflicts with the small amount of overhang that is required to achieve the full sun design objective. Conversely, this issue may occur because the amount of passive solar roof overhang that is required to achieve the full sun design objective is so small that it conflicts with the large amount of overhang that is required to achieve the full shade design objective. After entering the **Design Solar Altitude Angle for Full Sun** and **Design Solar Altitude Angle for Full Shade** values into our **Passive Solar Roof Overhang Design Calculator**, the calculator will tell you if both these design objectives have been successfully accomplished or if the design is a compromise between these two design objectives because of the aforementioned issue. If the design is a compromise, our **Passive Solar Roof Overhang Design Calculator** will provide you a means to fully understand why this issue occurred so you may make design changes as necessary.

Now that we explained how passive solar roof overhangs work and discussed some of the issues associated with designing them, let's discuss how to accomplish a passive solar roof overhang design that properly addresses the local climate.

Research what the average daily high temperatures are for the local climate to select a date during the spring or summer months when the average daily high temperature reaches the desired indoor temperature. A good source of weather data for conducting this research may be found here:

       Weather Spark

Use this calculator to determine the corresponding solar altitude angle at solar noon for this selected date. Using this solar altitude angle on this date as the **Design Solar Altitude Angle for Full Shade** to design the passive solar roof overhang will result in the overhang begin to provide full shade to the passive solar fenestration (i.e., provide 0 heat gain) on this date. If you typically have warm spring months, perhaps select an earlier date which will result in a lower **Design Solar Altitude Angle for Full Shade** which will then result in the passive solar roof overhang begin to provide full shade earlier and for a longer duration during the spring and summer months. Conversely, if you typically have cool spring months, perhaps select a later date which will result in a higher **Design Solar Altitude Angle for Full Shade** which will then result in the passive solar roof overhang begin to provide full shade later and for a shorter duration during the spring and summer months. In Rogue River, Oregon, the average daily high temperature reaches 68 degrees F on April 27 and the solar altitude angle is 61.02 degrees at solar noon on this date. Therefore, 61.02 degrees is an appropriate **Design Solar Altitude Angle for Full Shade** selection for our Rogue River, Oregon design example.

Research what the average daily high temperatures are for the local climate to select a date during the fall or winter months when the average daily high temperature reaches the lowest temperature of the year. Use this calculator to determine the corresponding solar altitude angle at solar noon for this selected date. Using the solar altitude angle on this date as the **Design Solar Altitude Angle for Full Sun** to design the passive solar roof overhang will result in the overhang begin to provide full sun to the passive solar fenestration (i.e., provide maximum solar heat gain) on this date. If you typically have cool fall months, perhaps select an earlier date which will result in a higher **Design Solar Altitude Angle for Full Sun** which will result in the passive solar roof overhang begin to provide full sun earlier and for a longer duration during the fall and winter months. Conversely, if you typically have warm fall months, perhaps select a later date which will result in a lower

Design Solar Altitude Angle for Full Sun which will result in the passive solar roof overhang begin to provide full sun later and for a shorter duration during the fall and winter months. In Rogue River, Oregon, the average daily high temperature reaches an annual low of 44 degrees F on December 25 and the solar altitude angle is 24.01 degrees at solar noon on this date. Therefore, 24.01 degrees is an appropriate **Design Solar Altitude Angle for Full Sun** selection for our Rogue River, Oregon design example.

While passive solar heating may be successfully accomplished in most climates, not all climates are amenable to successfully accomplishing passive solar cooling. Passive solar cooling is more applicable and appropriate for a low humidity climate that has a significant diurnal temperature variation. In southern Oregon where we are located, the temperature may reach a dry 100 degrees F during the summer days. However, the temperature will drop to a dry 50 degrees F during the summer nights enabling the use of either passive solar stack effect or active ventilation to successfully accomplish cooling at this time. Passive solar cooling makes use of a chimney or stack effect to ventilate and cool the building without requiring the use of any electrical/mechanical devices to remove heat from the building. Passive solar cooling depends on having a well-insulated building that often uses significant interior thermal mass that resists heating up during the summer days. If you are located in a non-diurnal climate where the temperature is continuously above comfort level, but the humidity is continuously below comfort level, you may be able to use an evaporative cooling system. For more information about assessing the performance of evaporative cooling systems, please see our **Evaporative Cooling Performance Calculator**. If you are located in a non-diurnal climate where the temperature or the humidly is continuously above comfort level, you will most certainly need an air conditioning system. To determine the required air conditioning system cooling capacity for a building to keep the occupants comfortable at the hottest expected climatic design condition, please see our **Cooling Load Analysis Calculator**. *A heating/cooling analysis for the specific building location and climate should always be first performed to determine the best heating/cooling system strategy that should be used.* Please see our **Cooling Load Analysis Calculator** and **Heat Loss Analysis Calculator** for information on how to accomplish this analysis.

Relative to using passive solar cooling stack effect versus using active ventilation cooling, we will always use the building's architecture design to take advantage of any passive solar stack effect to the maximum extent possible. However, some energy efficiency conscience clients rightly avoid multi-story buildings, high ceiling styles, and large vertical corridors which are great for maximizing the passive solar stack effect, but unfortunately tend to increase the overall heating/cooling requirements. We prefer and we always recommend active ventilation cooling accomplished by using an Energy Recovery Ventilation (ERV) or a Heat Recovery Ventilation (HRV) system even when we can take full advantage of passive solar cooling stack effect. While we have even successfully designed automated window opening/closing systems and automated drape opening/closing systems at the specific request of clients, it is really hard to beat the operational simplicity of an autonomous ERV/HRV system and a properly designed passive solar roof overhang. The energy usage and associated cost of operating an ERV/HRV system the small amount of time that is necessary to actually cool a building in a diurnal temperature, low humidity climate is negligible. Furthermore, most well-constructed/insulated buildings will require active ventilation anyhow and these buildings will preferably use an energy efficient ERV/HRV system to accomplish this.

The next step is using the **Design Solar Altitude Angle for Full Shade** and **Design Solar Altitude Angle for Full Sun** selections in our **Passive Solar Roof Overhang Design Calculator** to design the passive solar roof overhang.

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This calculator is used to design a passive solar roof overhang that will allow full sunshine to enter the passive solar fenestration (i.e., south facing, vertically oriented, windows and doors containing glass) during the cold winter months when the solar altitude angle is LOW (i.e., below the **Design Solar Altitude Angle for Full Sun** that you selected after exercising our **Passive Solar Altitude Angle Calculator**), but will NOT allow sunshine to enter the passive solar fenestration during the hot summer months when the solar altitude angle is HIGH (i.e., above the **Design Solar Altitude Angle for Full Shade** that you selected after exercising our **Passive Solar Altitude Angle Calculator**). A sample of a professional passive solar roof overhang design may be found on the Consultation tab of our website:

Sample Passive Solar Roof Overhang Design

This calculator will determine the height that the passive solar roof overhang must be from the top of the passive solar fenestration and the depth that the passive solar roof overhang must be from the passive solar fenestration in order to achieve the passive solar design objectives that you previously selected after exercising our **Passive Solar Altitude Angle Calculator**. ***To further assist you in accomplishing the passive solar design, an example for a building located in Rogue River, Oregon is used to illustrate the use of this calculator.***

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **South Wall Deviation from True South (Degrees)** - This is the direction angle that the south wall deviates from facing true south, which ideally should be 0. The south wall deviation from true south should be less than 20 degrees to maximize desired passive solar heating performance during the winter months and to minimize undesired heat gain and cooling capacity requirements during the summer months. It is normally better to deviate toward the east than toward the west to avoid the potential for afternoon overheating during the summer months. The default value is 0. Please use this same value in our **Cooling Load Analysis Calculator**, **Passive Solar Fenestration Exposure Calculator** and **Passive Solar Heat Gain Calculator**.

   For our Rogue River, Oregon design example, this is 0 degrees.

2) **Height of Glass (Feet)** - This is the vertical dimension between the top and bottom of the glass surface in the passive solar fenestration. The default value is 6. Please use this same value in our **Passive Solar Fenestration Exposure Calculator** and **Passive Solar Heat Gain Calculator**.

   For our Rogue River, Oregon design example, this is 6 feet.

3) **Design Solar Altitude Angle for Full Shade (Degrees)** - This is the solar altitude angle that you selected after exercising our **Passive Solar Altitude Angle Calculator** above which the passive solar roof overhang will provide full shading of the passive solar fenestration during the summer months. The default value is 61.02.

   For our Rogue River, Oregon design example, this is 61.02 degrees.

4) **Design Solar Altitude Angle for Full Sun (Degrees)** - This is the solar altitude angle that you selected after exercising our **Passive Solar Altitude Angle Calculator** below which the passive solar roof overhang will allow full sun to enter the passive solar fenestration during the winter months. The default value is 24.01.

   For our Rogue River, Oregon design example, this is 24.01 degrees.

5) **Build Height of Roof Overhang from Top of Glass (Feet)** - This is the actual build vertical dimension between the top of the glass surface in the passive solar fenestration and the lowest surface of the passive solar roof overhang. You may initially leave this build height and the **Build Depth of Roof Overhang from Glass** input parameter blank to have the calculator attempt to determine the optimum solution that provides BOTH full shade at the **Design Solar Altitude Angle for Full Shade** input parameter AND full sun at the **Design Solar Altitude Angle for Full Sun** input parameter, and determine the optimum **Height of Roof Overhang from Top of Glass** and **Depth of Roof Overhang from Glass** output parameters. You may subsequently enter an actual build height value that will be used for building the actual roof and have the calculator determine the corresponding **Depth of Roof Overhang from Glass**. You may ultimately enter BOTH the actual roof overhang build height and the actual roof overhang build depth values that will be used for building the roof and have the calculator assess whether these actual build values will provide "Full Shade & Full Sun", "Less than Full Shade/Sun", "Less than Full Shade" or "Less than Full Sun" by reviewing the **Actual Solution** output parameter. The **Requested Solution** input parameter should be 0 when entering both values and performing this assessment.

   For our Rogue River, Oregon design example, this is left blank.

6) **Build Depth of Roof Overhang from Glass (Feet)** - This is the actual build horizontal dimension between the glass surface in the passive solar fenestration and outer most edge of the passive solar roof overhang, including the width dimension of any roof gutter being used. You may initially leave this build depth and the **Build Height of Roof Overhang from Glass** input parameter blank to have the calculator attempt to determine the optimum solution that provides BOTH full shade at the **Design Solar Altitude Angle for Full Shade** input parameter AND full sun at the **Design Solar Altitude Angle for Full Sun** input parameter, and determine the optimum **Height of Roof Overhang from Top of Glass** and **Depth of Roof Overhang from Glass** output parameters. You may subsequently enter an actual build depth value that will be used for building the actual roof and have the calculator determine the corresponding **Height of Roof Overhang from Glass**. You may ultimately enter BOTH the actual roof overhang build height and the actual roof overhang build depth values that will be used for building the roof and have the calculator assess whether these actual build values will provide "Full Shade & Full Sun", "Less than Full Shade/Sun", "Less than Full Shade" or "Less than Full Sun" by reviewing the **Actual Solution** output parameter. The **Requested Solution** input parameter should be 0 when entering both values and performing this assessment.

   For our Rogue River, Oregon design example, this is left blank.

7) **Requested Solution (0=Full Shade & Full Sun, 1=Full Shade, 2=Full Sun)** - This is a logic input parameter that tells the calculator where to place the emphasis when solving the passive solar roof overhang geometry design problem. You should normally leave this input parameter

blank or enter 0 to have the calculator attempt to determine the optimum solution that provides BOTH full shade at the **Design Solar Altitude Angle for Full Shade** input parameter AND full sun at the **Design Solar Altitude Angle for Full Sun** input parameter. The **Actual Solution** output parameter will confirm that the calculator is able to determine this optimum solution by indicating "Full Shade & Full Sun".

You may enter 1 to have the calculator ONLY find the minimum **Height of Roof Overhang from Top of Glass** and **Depth of Roof Overhang from Glass** output parameters that provide full shade at the **Design Solar Altitude Angle for Full Shade** given the entered **Build Height of Roof Overhang from Top of Glass** input parameter or the entered **Build Depth of Roof Overhang from Glass** input parameter. This requested solution may often be useful in understanding the output parameters and in refining the passive solar roof overhang design.

You may enter 2 to have the calculator ONLY find the maximum **Height of Roof Overhang from Top of Glass** and **Depth of Roof Overhang from Glass** output parameters that provide full sun at the **Design Solar Altitude Angle for Full Sun** given the entered **Build Height of Roof Overhang from Top of Glass** input parameter or the entered **Build Depth of Roof Overhang from Glass** input parameter. This requested solution may often be useful in understanding the output parameters and in refining the passive solar roof overhang design.

Finally, you may enter 0 and enter BOTH **Build Height of Roof Overhang from Top of Glass** and **Build Depth of Roof Overhang from Glass** input parameters that will ultimately be used for building the roof and have the calculator assess whether these actual build values will provide "Full Shade & Full Sun", "Less than Full Shade/Sun", "Less than Full Shade" or "Less than Full Sun".

For our Rogue River, Oregon design example, this is left blank.

Click [Solve] after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Height of Roof Overhang from Top of Glass (Feet)** - This is the required vertical dimension between the top of the glass surface in the passive solar fenestration and the lowest surface of the passive solar roof overhang. This value is used as an input parameter by our **Passive Solar Fenestration Exposure Calculator** and **Passive Solar Heat Gain Calculator**.

   For our Rogue River, Oregon design example, this is 1.96 feet. However, given our construction design constraints, we decide to make this exactly 1.5 feet.

2) **Depth of Roof Overhang from Glass (Feet)** - This is the required horizontal dimension between the glass surface in the passive solar fenestration and outer most edge of the passive solar roof overhang, including the width dimension of any roof gutter being used. This value is used as an input parameter by our **Passive Solar Fenestration Exposure Calculator** and **Passive Solar Heat Gain Calculator**.

   For our Rogue River, Oregon design example, this is 4.41 feet. However, given our construction design constraints, we decide to make this exactly 4 feet.

3) **Actual Solution** - This output parameter provides the status of passive solar roof overhang design solution largely based on the **Requested Solution** input parameter and the realities of the passive solar roof overhang design geometry problem given the other entered input parameters. Normally, you will want to see "Full Shade & Full Sun" which indicates that the calculator is able to successfully determine the requested optimum solution that provides BOTH full shade at the **Design Solar Altitude Angle for Full Shade** input parameter AND full sun at the **Design Solar Altitude Angle for Full Sun** input parameter.

If requested, you may see "Full Shade" which indicates that the calculator is able to determine the minimum **Height of Roof Overhang from Top of Glass** and **Depth of Roof Overhang from Glass** output parameters that will ONLY provide full shade at the **Design Solar Altitude Angle for Full Shade** given the entered **Build Height of Roof Overhang from Top of Glass** input parameter or the entered **Build Depth of Roof Overhang from Glass** input parameter.

If requested, you may see "Full Sun" which indicates that the calculator is able to determine the maximum **Height of Roof Overhang from Top of Glass** and **Depth of Roof Overhang from Glass** output parameters that will ONLY provide full sun at the **Design Solar Altitude Angle for Full Sun** given the entered **Build Height of Roof Overhang from Top of Glass** input parameter or the entered **Build Depth of Roof Overhang from Glass** input parameter.

You may see "Less than Full Shade", "Less than Full Sun" or "Less than Full Shade/Sun" which indicates that the calculator is NOT able to determine the requested optimum solution that provides BOTH full shade at the **Design Solar Altitude Angle for Full Shade** input parameter AND full sun at the **Design Solar Altitude Angle for Full Sun** input parameter. As such, the solution that is found may provide less than full shade, may provide less than full sun, or may not provide either full shade and full sun.

You may see "Invalid" which indicates that the calculator is NOT able to determine any solution given the entered input parameters.

For our Rogue River, Oregon design example, this is "Full Shade & Full Sun".

The next step is to use the **Height of Roof Overhang from Top of Glass** and **Depth of Roof Overhang from Glass** output parameters in our **Passive Solar Fenestration Exposure Calculator** to validate the design and determine the exact amount of solar radiation (i.e., irradiance) that reaches the passive solar fenestration (i.e., south facing, vertically oriented, windows and doors containing glass) during the various times of the year.

It is important that you perform a passive solar roof overhang analysis before constructing the passive solar building. If you are working with a company who cannot perform this analysis and provide data that is sealed/signed by a licensed professional engineer for the specific design and location, you should apply due diligence and consider finding a more competent company to do this. If you find that you need this service, we hope that you will consider Borst Engineering and Construction.

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Passive Solar Fenestration Exposure Calculator

This calculator enables you to further validate the passive solar design that you developed by exercising our **Passive Solar Altitude Angle Calculator** and our **Passive Solar Roof Overhang Design Calculator**. Given the latitude, roof overhang design, and actual building orientation relative to due South, this calculator determines the amount of solar radiation (i.e., irradiance) that reaches the passive solar fenestration (i.e., south facing, vertically oriented, windows and doors containing glass) during the various times of the year. This calculator determines how far into the building this irradiance strikes the floor so you may plan the furniture placement and room decor. By exercising this calculator, you will gain good insight on how passive solar heating is accomplished by using a passive solar roof overhang design that controls the amount irradiance that reaches the passive solar fenestration during the various times of the year. ***To further assist you in accomplishing the passive solar design, an example for a building located in Rogue River, Oregon is used to illustrate the use of this calculator.***

A sample of a professional passive solar fenestration exposure analysis may be found on the Consultation tab of our website:

<div align="center">

Sample Passive Solar Fenestration Exposure Analysis

</div>

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Latitude (Degrees)** - This is a geographic coordinate that specifies the north-south position of a point on the Earth's surface. Latitude is an angle which ranges from 0 degrees at the Equator to 90 degrees northward and to -90 degrees southward. If the latitude is south, enter a negative value. You may need to convert latitude that is in degrees, minutes and seconds into decimal degrees. The default value is 42.60. Please use this same value in our **Cooling Load Analysis Calculator**, **Passive Solar Altitude Angle Calculator** and **Passive Solar Heat Gain Calculator**.

    For our Rogue River, Oregon design example, the latitude is North 42° 36' 0". For this location the correct entry is 42.60 (i.e., 0"/60 equals 0' and 36.0'/60 equals 0.60°).

2) **Longitude (Degrees)** - This is a geographic coordinate that specifies the east-west position of a point on the Earth's surface. Longitude is an angle which ranges from 0 degrees at the Prime Meridian to 180 degrees eastward and to -180 degrees westward. If the longitude is west, enter a negative value. You may need to convert longitude that is in degrees, minutes and seconds into decimal degrees. The default value is -122.99. Please use this same value in our **Passive Solar Altitude Angle Calculator**.

    For our Rogue River, Oregon design example, the longitude is West 122° 59' 24". For this location the correct entry is -122.99 (i.e., 24"/60 equals 0.4' and 59.4'/60 equals 0.99°).

3) **Time Zone (Hours)** - This is the difference in hours from Greenwich Mean Time (GMT) or Coordinated Universal Time (UTC) for a particular time zone. If west of GMT/UTC, enter a negative value. Time zones typically change 1 hour for every 15 degrees of longitude change (i.e., 360 degrees of longitude divided by 24 hours). So if you divide the longitude by 15 and round to the nearest integer, this should be the approximate time zone. While actual time zones

usually follow 1 hour increments, they are often set by local law and therefore may not have boundaries that follow straight lines of longitude. Consequently, this rule may not always yield the correct time zone for every location. Leaving this input parameter blank results in this rule being used.   Please use this same value in our **Passive Solar Altitude Angle Calculator**.

For our Rogue River, Oregon design example, -122.99 longitude divided by 15 is equal to -8.2 and when rounded to the nearest integer is equal to -8. The time zone of Rogue River, Oregon is indeed -8, so the aforementioned rule does work for this location and the correct entry is -8.

4) **Daylight Saving Time (0=No, 1=Yes, Blank=USA)** - This is a logic input parameter to tell the calculator whether Daylight Saving Time (DST) is used and is in effect. For Rogue River, Oregon, DST is in effect from 2 AM on the second Sunday of March until 2 AM on the first Sunday of November. Leaving this input parameter blank results in this USA DST rule being used.

For our Rogue River, Oregon design example, this is left blank.

5) **Twilight Definition (0=Sunrise/Sunset, 1=Civil, 2=Nautical, 3=Astronomical Twilight)** - This is a logic input parameter to tell the calculator whether Sunrise/Sunset Time or Civil, Nautical or Astronomical Dawn/Dusk Time should be used when determining the **Sunrise Time (or Selected Twilight Dawn Time)** and **Sunset Time (or Selected Twilight Dusk Time)** output parameters. Civil Twilight marks the beginning and end of the time period when artificial light is required for outdoor activities and is often used to define civil regulations related to aviation, hunting and the usage of headlights and street lamps. Nautical Twilight marks the beginning and end of the time period when both bright navigation stars and the horizon can be viewed by sailors using a sextant for celestial navigation. Astronomical Twilight marks the beginning and end of the time period when the sky is sufficiently dark to allow any astronomical objects that can be viewed by the naked eye to be viewed. Sunrise/Sunset Time is defined to occur when the center of the sun is 50 minutes (0.833 degrees) below the horizon. Civil Twilight is defined to occur when the center of the sun is between 50 minutes (0.833 degrees) below the horizon (i.e., at Sunrise/Sunset) and 6 degrees below the horizon. Nautical Twilight is defined to occur when the center of the sun is between 6 degrees below the horizon and 12 degrees below the horizon. Astronomical Twilight is defined to occur when the center of the sun is between 12 degrees below the horizon and 18 degrees below the horizon. Civil Dawn/Dusk Time is defined as the moment the center of the sun is 6 degrees below the horizon. Nautical Dawn/Dusk Time is defined as the moment the center of the sun is 12 degrees below the horizon. Astronomical Dawn/Dusk Time is defined as the moment the center of the sun is 18 degrees below the horizon. Enter 0 to determine the Local Time of Sunrise/Sunset Time. Enter 1 to determine the Local Time of Civil Dawn/Dusk Time. Enter 2 to determine the Local Time of Nautical Dawn/Dusk Time. Enter 3 to determine the Local Time of Astronomical Dawn/Dusk Time. The default value is 0.

For our Rogue River, Oregon design example, this is 0.

6) **Solar or Local Time (0=Solar, 1=Local)** - This is a logic input parameter to tell the calculator whether the **Hour** input parameter is in Solar Time or Local Time. Enter 0 for Solar Time or enter 1 for Local Time. The default value is 0. ***Solar time should always be used when designing a passive solar building.***

For our Rogue River, Oregon design example, this is 0.

7) **Hour** - This is the actual hour of the day in either Solar Time or the Local Time depending on the value of the **Solar or Local Time** logic input parameter and ranges from 1 to 24. If the **Solar or Local Time** logic input parameter is 0, a value of 12 corresponds to solar noon which is the time when the **Solar Altitude Angle** output parameter is the maximum value for the day and when the **Solar Azimuth Angle** output parameter is exactly 180 degrees (true south). If the **Solar or Local Time** logic input parameter is 1, a value of 12 is noon Local Time. If the **Solar or Local Time** logic input parameter is 1, a value of 15 is 3 PM Local Time. You may enter decimal values such as 15.5 for 3:30 PM or 15.75 for 3:45 PM. Please be sure to account for Daylight Saving Time (DST) if this is used in the area. Leaving this input parameter blank results in the current hour being used.

For our Rogue River, Oregon design example, this is 12.

8) **Day** - This is the actual day of the month and ranges from 1 to 31, where 1 is the first day of the month and 31 is the last day of a 31 day month. You should only enter an integer value within this range. . Leaving this input parameter blank results in the current local day being used.

For our Rogue River, Oregon design example, this is 15.

9) **Month** - This is the actual month of the year and ranges from 1 to 12, where 1 is January and 12 is December. You should only enter an integer value within this range. Leaving this input parameter blank results in the month day being used.

For our Rogue River, Oregon design example, these are:
January (1), February (2), March (3), April (4), May (5), June (6), July (7), August (8), September (9), October (10), November (11) and December (12).

10) **South Wall Deviation from True South (Degrees)** - This is the direction angle that the south wall deviates from facing true south, which ideally should be 0. The south wall deviation from true south should be less than 20 degrees to maximize desired passive solar heating performance during the winter months and to minimize undesired heat gain and cooling capacity requirements during the summer months. It is normally better to deviate toward the east than toward the west to avoid the potential for afternoon overheating during the summer months. The default value is 0. Please use this same value in our **Cooling Load Analysis Calculator**, **Passive Solar Roof Overhang Design Calculator** and **Passive Solar Heat Gain Calculator**.

For our Rogue River, Oregon design example, this is 0 degrees.

11) **Height of Glass (Feet)** - This is the vertical dimension between the top and bottom of the glass surface in the passive solar fenestration. The default value is 6. Please use this same value in our **Passive Solar Roof Overhang Design Calculator**.

For our Rogue River, Oregon design example, this is 6 feet.

12) **Height of Bottom of Glass above Floor (Feet)** - This is the vertical dimension between the bottom of the glass surface in the passive solar fenestration and the top surface of the floor inside the building. The default value is 2.

For our Rogue River, Oregon design example, this is 2 feet.

13) **Height of Roof Overhang from Top of Glass (Feet)** - This is the vertical dimension between the top of the glass surface in the passive solar fenestration and the lowest surface of the roof overhang. This value is an output parameter of our **Passive Solar Roof Overhang Design Calculator**. The default value is 1.5.

For our Rogue River, Oregon design example, this is 1.5 feet.

14) **Depth of Roof Overhang from Glass (Feet)** - This is the horizontal dimension between the glass surface in the passive solar fenestration and outer most edge of the roof overhang, including the width dimension of any roof gutter being used. This parameter is an output parameter of our **Passive Solar Roof Overhang Design Calculator**. The default value is 4.

For our Rogue River, Oregon design example, this is 4 feet.

15) **Terrain Obstacle Altitude Angles** - Terrain obstacles are objects such as hills, mountains, or trees that may block sunshine from reaching the passive solar fenestration. The angular measurement in degrees that a terrain obstacle is above the horizon at the indicated azimuth angle is the value that should be entered into the calculator. Entering the terrain obstacle altitude angles for each associated and indicated terrain obstacle azimuth angle allows the calculator to account for the adverse effect that these terrain obstacles may have on limiting the amount of irradiance that reaches the passive solar fenestration. If you do not have any terrain obstacles (i.e., if you can see an unobstructed southern horizon between true east and true west), just leave these terrain obstacle altitude angle input parameters blank or enter 0. If you do have terrain obstacles, you should consider using a Solar Pathfinder (please see the Affiliates tab on our website) or an Abney level and a compass to acquire this data or hire someone to do this for you. If 97537 is entered as the first input parameter value, terrain obstacle altitude angles for the Rogue River, Oregon example will be used. Enter the terrain obstacle altitude angle for each associated and indicated terrain obstacle azimuth angle. The default is no terrain obstacles.

For our Rogue River, Oregon design example, these are either left blank or if 97537 is entered as described above, these are the Azimuth Angles (Altitude Angles):
60 degrees (10 degrees), 70 degrees (12 degrees), 80 degrees (17 degrees), True East (24 degrees), 100 degrees (26 degrees), 110 degrees (29 degrees), 120 degrees (33 degrees), 130 degrees (31 degrees), 140 degrees (29 degrees), 150 degrees (29 degrees), 160 degrees (27 degrees), 170 degrees (25 degrees), True South (23 degrees), 190 degrees (20 degrees), 200 degrees (17 degrees), 210 degrees (13 degrees), 220 degrees (12 degrees), 230 degrees (11 degrees), 240 degrees (7 degrees), 250 degrees (10 degrees), 260 degrees (16 degrees), True West (13 degrees), 280 degrees (12 degrees), 290 degrees (13 degrees) and 300 degrees (14 degrees).

Click [Solve] after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Solar Declination Angle (Degrees)** - This is the solar declination angle at this actual hour, day, and month that you selected. The solar declination angle varies seasonally due to the tilt of the Earth on its axis of rotation and the rotation of the Earth around the sun. If the Earth were not tilted on its axis of rotation, the solar declination angle would always be 0 degrees. However, the Earth is tilted by 23.45 degrees and the solar declination angle varies plus or minus this amount. Only during the Spring Equinox and Fall Equinox is the solar declination angle exactly equal to 0 degrees. Therefore, in the northern hemisphere, the solar declination angle ranges from 0 degrees at Spring Equinox (March 21th) and Fall Equinox (September 21st), 23.45 degrees at Summer Solstice (June 21st), and -23.45 degrees at Winter Solstice (December 21st). It is this seasonal solar declination angle variation effect on the solar altitude angle that makes passive solar heating possible.

   For our Rogue River, Oregon design example, these:
   January (-21.27 degrees), February (-13.29 degrees), March (-2.82 degrees), April (9.41 degrees), May (18.79 degrees), June (23.31 degrees), July (21.52 degrees), August (13.78 degrees), September (2.22 degrees), October (-9.60 degrees), November (-19.15 degrees) and December (-23.34 degrees).

2) **Solar Azimuth Angle (Degrees)** - This is the solar azimuth angle at this actual hour, day, and month that you selected. The solar azimuth angle is most often defined as the clockwise angle from true north to the direction of the sun similar to a standard compass dial. As such, a solar azimuth angle of 90 degrees is true east, 180 degrees is true south and 270 degrees is true west. If you are using a compass, be sure to consider the local magnetic declination (also known as magnetic variation) which changes over time. Westerly magnetic declination should be added to compass heading to determine true heading. Easterly magnetic declination should be subtracted from compass heading to determine true heading. For Rogue River, Oregon, the local magnetic declination was 14.9 degrees east of true in 2016. Therefore, true south in Rogue River, Oregon was equivalent to a magnetic compass reading of 165.1 degrees at this time.

   For our Rogue River, Oregon design example, this is exactly 180 degrees for every month since we used solar time.

3) **Solar Altitude Angle (Degrees)** - This is the solar altitude angle at this actual hour, day, and month that you selected. The solar altitude angle is the angle between the direction of the geometric center of the sun's apparent disk and the horizon. Depending on the latitude and the solar declination angle, the solar altitude angle may range from 0 to 90 degrees during the daylight hours.

   For our Rogue River, Oregon design example, these are:
   January (26.13 degrees), February (34.11 degrees), March (44.58 degrees), April (56.81 degrees), May (66.19 degrees), June (70.71 degrees), July (68.92 degrees), August (61.18 degrees), September (49.62 degrees), October (37.80 degrees), November (28.25 degrees) and December (24.06 degrees).

4) **Is irradiance available to fenestration at this time?** - This answers the fundamental question whether the passive solar fenestration is being exposed to any sun at this actual hour, day, and month that you selected. *It is recommended that you exercise the calculator from dawn to dusk for several different months.* "Yes" means the passive solar fenestration is receiving some irradiance. "No, TFNE" means the sun is too far north of east to strike the south wall and the passive solar fenestration is NOT receiving any irradiance. "No, TFNW" means the sun is too far north of west to strike the south wall and the passive solar fenestration is NOT receiving any irradiance. "No, TO" means the sun is blocked by a terrain obstacle and the passive solar fenestration is NOT receiving any irradiance. "No, BH" means the sun is below the horizon and the passive solar fenestration is NOT receiving any irradiance. "No, RO" means the sun is being fully shaded by the roof overhang and the passive solar fenestration is NOT receiving any irradiance. The answer to this question may provide confirmation that you have entered all the calculator inputs correctly, or the answer to this question may help you sort out the issue if you have NOT entered all the calculator inputs correctly. It is important that you validate that you have correctly defined the input parameters prior to using them in our **Passive Solar Heat Gain Calculator**.

For our Rogue River, Oregon design example, these are:
January ("Yes"), February ("Yes"), March ("Yes"), April ("Yes"), May ("No, RO"), June ("No, RO"), July ("No, RO"), August ("Yes"), September ("Yes"), October ("Yes"), November ("Yes") and December ("Yes").

5) **Irradiance Allowed by Roof Overhang (Percent of Glass Area)** - This is the percentage of the passive solar fenestration glass surface area being exposed to the sun and passing irradiance to the inside of the building at this actual hour, day, and month that you selected.

For our Rogue River, Oregon design example, these are:
January (92%), February (80%), March (59%), April (23%), May (0%), June (0%), July (0%), August (4%), September (47%), October (73%), November (89%) and December (95%).

6) **Distance from Glass Irradiance Strikes Floor (Feet)** - This is the horizontal dimension between the inside glass surface in the passive solar fenestration and the top surface of the floor inside the building that the sunlight will reach at this actual hour, day, and month that you selected. You may use this information to plan the furniture placement and room decor. This value (i.e., the value at solar noon on day 15 of the month being analyzed) may be used to determine the thermal mass irradiance area when using our **Passive Solar Thermal Mass Performance Calculator**.

For our Rogue River, Oregon design example, these are:
January (15.37 feet), February (10.03 feet), March (5.64 feet), April (2.21 feet), May (0 feet), June (0 feet), July (0 feet), August (1.23 feet), September (4.08 feet), October (8.25 feet), November (13.68 feet) and December (17.27 feet).

7) **Sunrise Time (or Selected Twilight Dawn Time)** - This is either the Local Time of Sunrise or the Civil, Nautical or Astronomical Dawn Time based on the entered **Twilight Definition** logic input parameter value and accounting for the **Daylight Saving Time** logic input parameter value,

but NOT accounting for any terrain obstacles. Sunrise Time is defined as the moment the center of the sun is 50 minutes (0.833 degrees) below the horizon. Civil Dawn Time is defined as the moment the center of the sun is 6 degrees below the horizon. Nautical Dawn Time is defined as the moment the center of the sun is 12 degrees below the horizon. Astronomical Dawn Time is defined as the moment the center of the sun is 18 degrees below the horizon.

For our Rogue River, Oregon design example, these are:
January (7:39 AM), February (7:12 AM), March (7:28 AM), April (6:33 AM), May (5:50 AM), June (5:33 AM), July (5:48 AM), August (6:20 AM), September (6:56 AM), October (7:29 AM), November (7:06 AM) and December (7:35 AM).

8) **First Irradiance Time** - This is the Local Time that direct sunshine will first become available in the geographical area accounting for the **Daylight Saving Time** logic input parameter value and accounting for the entered terrain obstacles. First irradiance time is defined as the moment the center of the sun reaches the horizon or reaches the altitude angle of the entered terrain obstacles, whichever occurs later.

For our Rogue River, Oregon design example when terrain obstacles are NOT entered, these are:
January (7:45 AM), February (7:17 AM), March (7:32 AM), April (6:37 AM), May (5:55 AM), June (5:39 AM), July (5:53 AM), August (6:25 AM), September (6:59 AM), October (7:33 AM), November (7:11 AM) and December (7:41 AM).

For our Rogue River, Oregon design example when terrain obstacles are entered, these are:
January (11:36 AM), February (10:40 AM), March (10:36 AM), April (9:03 AM), May (7:32 AM), June (6:51 AM), July (7:13 AM), August (8:42 AM), September (10:04 AM), October (10:39 AM), November (10:52 AM) and December (11:49 AM).

9) **Last Irradiance Time** - This is the Local Time that direct sunshine will last be available in the geographical area accounting for the **Daylight Saving Time** logic input parameter value and accounting for the entered terrain obstacles. Last irradiance time is defined as the moment the center of the sun reaches the horizon or reaches the altitude angle of the entered terrain obstacles, whichever occurs sooner.

For our Rogue River, Oregon design example when terrain obstacles are NOT entered, these are:
January (4:57 PM), February (5:36 PM), March (7:11 PM), April (7:47 PM), May (8:21 PM), June (8:45 PM), July (8:43 PM), August (8:09 PM), September (7:16 PM), October (6:22 PM), November (4:42 PM) and December (4:34 PM).

For our Rogue River, Oregon design example when terrain obstacles are entered, these are:
January (3:40 PM), February (4:49 PM), March (6:02 PM), April (7:38 PM), May (7:27 PM), June (7:27 PM), July (7:35 PM), August (7:40 PM), September (5:52 PM), October (5:29 PM), November (3:36 PM) and December (3:10 PM).

10) **Sunset Time (or Selected Twilight Dusk Time)** - This is either the Local Time of Sunset or the Civil, Nautical or Astronomical Dusk Time based on the entered **Twilight Definition** logic input parameter value and accounting for the **Daylight Saving Time** logic input parameter value, but NOT accounting for any terrain obstacles. Sunset Time is defined as the moment the center of

the sun is 50 minutes (0.833 degrees) below the horizon. Civil Dusk Time is defined as the moment the center of the sun is 6 degrees below the horizon. Nautical Dusk Time is defined as the moment the center of the sun is 12 degrees below the horizon. Astronomical Dusk Time is defined as the moment the center of the sun is 18 degrees below the horizon.

For our Rogue River, Oregon design example, these are:
January (5:02 PM), February (5:41 PM), March (7:16 PM), April (7:52 PM), May (8:26 PM), June (8:51 PM), July (8:48 PM), August (8:14 PM), September (7:20 PM), October (6:27 PM), November (4:47 PM) and December (4:39 PM)

11) **Length of Day (Hours:Minutes)** - This is the length of time between sunrise and sunset.

For our Rogue River, Oregon design example, these are:
January (9:23), February (10:29), March (11:48), April (13:19), May (14:36), June (15:18), July (15:01), August (13:54), September (12:25), October (10:58), November (9:41) and December (9:04).

12) **Length of Irradiance (Hours:Minutes)** - This is the length of time that irradiance is available in the geographical area accounting for the entered terrain obstacles.

For our Rogue River, Oregon design example when terrain obstacles are NOT entered, these are:
January (9:12), February (10:20), March (11:39), April (13:10), May (14:26), June (15:07), July (14:50), August (13:54), September (12:16), October (10:48), November (9:31) and December (8:53).

For our Rogue River, Oregon design example when terrain obstacles are entered, these are:
January (4:04), February (6:09), March (7:27), April (10:35), May (11:55), June (12:37), July (12:21), August (10:58), September (7:48), October (6:49), November (4:44) and December (3:21).

If you are happy with the passive solar fenestration exposure design, the next step is to use this data in our **Passive Solar Heat Gain Calculator** to determine how much passive solar heat gain you will produce.

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This calculator determines the passive solar heat gain that is produced for the specified month of the year for the passive solar design that you previously developed by exercising our **Passive Solar Altitude Angle Calculator**, **Passive Solar Roof Overhang Design Calculator**, and **Passive Solar Fenestration Exposure Calculator**. By knowing the passive solar heat gain by exercising this calculator and by knowing the building heat loss by exercising our **Heat Loss Analysis Calculator**, you may assess the performance and acceptability of the passive solar heating system design. By knowing the passive solar heat gain by exercising this calculator and by exercising our **Passive Solar Thermal Mass Performance Calculator**, you may assess the benefit and performance of incorporating thermal mass into the passive solar heating system design to absorb, store, and slowly release any excess solar heat gain. By knowing the passive solar heat gain by exercising this calculator and then exercising our **Integrated Heating System Performance Calculator**, you may assess the need for any additional supplemental heating (e.g., hydronic radiant floor heating and/or masonry heater).

An often cited but misused "design rule of thumb" is that passive solar buildings should have a total south wall passive solar fenestration area between 7% and 12% of the total building floor area. We have found this "design rule of thumb" to be overly simplistic and often grossly inaccurate for forecasting passive solar heat gain. There are many factors besides the actual fenestration area that have a significant effect on the passive solar heat gain. For example and perhaps most obviously, the amount of irradiance that actually enters the fenestration has a significant effect on the actual solar heat gain. The amount of irradiance that actually enters the fenestration depends on the building's local latitude, local atmospheric optical transparency quality, local climatic sunshine availability, local terrain obstacles, actual Solar Heat Gain Coefficient (SHGC) of the fenestration, and the actual hourly utilized fenestration area as governed by the actual passive solar roof overhang. And perhaps more importantly, the maximum amount of daily/monthly building solar heat gain should always be equal to or less than the daily/monthly building heat loss as determined by performing an actual building heat loss analysis. This "design rule of thumb" was likely originally developed by the passive solar design pioneers back in the 1960/70s before the widespread use of computers. This "design rule of thumb" may have worked reasonably well for the specific building locations and the construction materials/methods used at the time. However, there are many reports of passive solar designs with seriously over-heated or under-heated buildings as a consequence of following this "design rule of thumb".

Amazingly and regrettably, there are still many passive solar companies marketing services based on this "design rule of thumb" and they often charge exorbitant fees for their less-than-competent expertise and their defective passive solar house plans. We advise applying due diligence and avoiding companies who follow this practice if you want to ensure having a passive solar design that will keep the building occupants comfortable and happy without depleting your bank account. It should be noted that this "design rule of thumb" has little significance if you have a well-designed and integrated passive solar heating and hydronic radiant floor heating system. ***Borst Engineering & Construction has successfully designed integrated passive solar heating and hydronic radiant floor heating systems to enable conveying heat from passive solar heated areas to other areas of the building where it is immediately needed, to store this excess heat until it is actually needed, or to reject this heat if it is NOT needed.***

A sample of a professional passive solar fenestration heat gain analysis may be found on the Consultation tab of our website:

This calculator uses the 2013 American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Fundamentals Handbook methodology to determine the actual amount of incident solar radiation (i.e., irradiance) that reaches the passive solar fenestration (i.e., south facing, vertically oriented, windows and doors containing glass) and the energy heat flow through the fenestration based on the "whole" Solar Heat Gain Coefficient (SHGC) provided by fenestration manufacturers. Two new scientific parameters (clear sky optical depths for beam and diffuse irradiances) are used to model and determine the "clear sky" direct beam, diffuse, and ground-reflected irradiance for the various times and days of the month for a specific location. Climatic sunshine data are used to forecast the actual amount of total incident irradiance that reaches the passive solar fenestration for a specific location. The desired effect of the passive solar roof overhang design to control the amount of irradiance that reaches the passive solar fenestration is included. The adverse effect that any local terrain obstacles may have on limiting the amount of desired irradiance that reaches the passive solar fenestration may be significant (and regrettably is often ignored by many passive solar companies) is included as a calculator user option. The calculator determines the passive solar heat gain that is produced at 6 minute intervals for every day of the month and then numerically integrates this data to provide both clear sky and climatic monthly heat gain information. ***To further assist you in accomplishing the passive solar design, an example for a building located in Rogue River, Oregon is used to illustrate the use of this calculator.***

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Latitude (Degrees)** - This is a geographic coordinate that specifies the north-south position of a point on the Earth's surface. Latitude is an angle which ranges from 0 degrees at the Equator to 90 degrees northward and to -90 degrees southward. If the latitude is south, enter a negative value. You may need to convert latitude that is in degrees, minutes and seconds into decimal degrees. The default value is 42.60. Please use this same value in our **Cooling Load Analysis Calculator**, **Passive Solar Altitude Angle Calculator** and **Passive Solar Fenestration Exposure Calculator**.

    For our Rogue River, Oregon design example, the latitude is North 42° 36' 0". For this location the correct entry is 42.60 (i.e., 0"/60 equals 0' and 36.0'/60 equals 0.60 °).

2) **Month** - This is the actual month of the year and ranges from 1 to 12, where 1 is January and 12 is December. You should only enter an integer value within this range. Leaving this input parameter blank results in the current local month being used.

    For our Rogue River, Oregon design example, these are:
    January (1), February (2), March (3), April (4), May (5), June (6), July (7), August (8), September (9), October (10), November (11) and December (12).

3) **South Wall Deviation from True South (Degrees)** - This is the direction angle that the south wall deviates from facing true south, which ideally should be 0. The south wall deviation from true south should be less than 20 degrees to maximize desired passive solar heating performance during the winter months and to minimize undesired heat gain and cooling capacity requirements during the summer months. It is normally better to deviate toward the east than toward the west to avoid the potential for afternoon overheating during the summer months. The default value is

0. Please use this same value in our **Cooling Load Analysis Calculator**, **Passive Solar Roof Overhang Design Calculator** and **Passive Solar Fenestration Exposure Calculator**.

For our Rogue River, Oregon design example, this is 0 degrees.

4) **Height of Glass (Feet)** - This is the vertical dimension between the top and bottom of the glass surface in the passive solar fenestration. The default value is 6. Please use this same value in our **Passive Solar Roof Overhang Design Calculator** and **Passive Solar Fenestration Exposure Calculator**.

For our Rogue River, Oregon design example, this is 6 feet.

5) **Height of Roof Overhang from Top of Glass (Feet)** - This is the required vertical dimension between the top of the glass surface in the passive solar fenestration and the lowest surface of the roof overhang. This value is an output parameter of our **Passive Solar Roof Overhang Design Calculator**. The default value is 1.5.

For our Rogue River, Oregon design example, this is 1.5 feet.

6) **Depth of Roof Overhang from Glass (Feet)** - This is the required horizontal dimension between the glass surface in the passive solar fenestration and outer most edge of the roof overhang, including the width dimension of any roof gutter being used. This value is an output parameter of our **Passive Solar Roof Overhang Design Calculator**. The default value is 4.

For our Rogue River, Oregon design example, this is 4 feet.

7) **Passive Solar Fenestration SHGC** - This is the fraction of solar energy that the passive solar fenestration transmits into the building/room. The Solar Heat Gain Coefficient "whole window value" as provided by window manufacturers should be used. Windows with a SHGC value of 1.0 will transmit 100% of the solar energy that it receives. Windows with a SHGC value of 0 won't transmit any of the solar energy that it receives. There is another term called Shading Coefficient (SC) that is often used to describe window solar energy transmission. Multiply SC by 0.87 to convert it to SHGC for use in this calculator.

Milgard Windows® manufactures fiberglass framed double pane glazing windows without low emissivity (low-E) coatings. While low-E coating fenestration is popular for increased energy efficiency in mass produced tract housing designs, low-E coating fenestration significantly reduces passive solar heat gain and is NOT recommended for the fenestration in the south wall of a properly designed passive solar heated building. Milgard Windows® picture window styles using clear glass glazing without low-E coatings have an SHGC rating of 0.63 and a total U-factor of 0.45 (total R-value of 2.2). Milgard Windows® casement window styles have an SHGC rating of 0.56.

Typically, you will be using a combination of different window styles with different SHGC ratings. So you will need to determine the average SHGC rating to use in this calculator by first determining the percentage of the total window area provided by each different window style and factoring the different window style area percentages with their associated SHGC ratings. For

example, if 30% of the total window area consists of casement windows with a SHGC rating of 0.56 and 70% of the total window area consists of picture windows with a SHGC rating of 0.63, the correct SHGC value to enter into the calculator is 0.609 (i.e., 0.3 x 0.56 + 0.7 x 0.63). The default value is 0.609.

For our Rogue River, Oregon design example, this is 0.609.

8) **Total Passive Solar Fenestration Area (Square Feet)** - This is the total rough opening area of the passive solar fenestration. This input parameter may be varied to assess the actual heat gain that is produced. By knowing the **Height of Glass** from previously accomplishing the roof overhang design by exercising our **Passive Solar Roof Overhang Design Calculator**, the total required fenestration width may be determined (i.e., the total width is the total area divided by the **Height of Glass**). Then, by knowing the style and width of the fenestration elements that will actually be used, the number and placement of each style of fenestration element may be determined. The default value is 198.

For our Rogue River, Oregon design example, this is 198 square feet.

9) **Clear Sky Optical Depth for Beam Irradiance** - This is a measure of the atmosphere optical transparency quality (i.e., the amount of irradiance that is not scattered or absorbed by the atmosphere) for a beam of sunshine directly striking the ground. Values for each month of the year for specific locations are published and may be purchased directly from ASHRAE:

ASHRAE Climate Design Data

A sample of this ASHRAE climate design data may be found here:

Sample ASHRAE Climate Design Data

The clear sky optical depth for beam irradiance data is located near the bottom of the data sheet in the "Clear Sky Solar Irradiance" section and is labelled "taub". If 97537 is entered for this input parameter, the appropriate values for the Rogue River, Oregon example for each entered month will be used. The default value is 0.297.

For our Rogue River, Oregon design example, 97537 is entered as described above and these are:
January (0.297), February (0.305), March (0.327), April (0.363), May (0.347), June (0.347), July (0.356), August (0.360), September (0.341), October (0.332), November (0.314) and December (0.305).

10) **Clear Sky Optical Depth for Diffuse Irradiance** - This is a measure of the atmosphere optical transparency quality (i.e., the amount of irradiance that is not scattered or absorbed by the atmosphere) for diffuse sunshine (i.e., sunshine that has been scattered by the effect of the atmosphere) indirectly reaching the ground. Values for each month of the year for specific locations are published and may be purchased directly from ASHRAE:

ASHRAE Climate Design Data

A sample of this ASHRAE climate design data may be found here:

Sample ASHRAE Climate Design Data

The clear sky optical depth for diffuse irradiance data is located near the bottom of the data sheet in the "Clear Sky Solar Irradiance" section and is labelled "taud". If 97537 is entered for the **Clear Sky Optical Depth for Beam Irradiance** input parameter, the appropriate values for the Rogue River, Oregon example for each entered month will be used. The default value is 2.693.

For our Rogue River, Oregon design example, 97537 is entered as described above and these are:
January (2.693), February (2.662), March (2.516), April (2.324), May (2.390), June (2.590), July (2.582), August (2.534), September (2.601), October (2.577), November (2.646) and December (2.586).

11) **Ground Reflectance Coefficient** - This is the fraction of solar energy that the passive solar fenestration receives from the reflectivity of the ground outside the building. A ground reflectance coefficient of 1.0 is representative of a completely reflective ground surface. A ground reflectance coefficient of 0 is representative of a completely non-reflective surface. Solar ground reflectance may be significant and must be included in the heat gain calculation. A coniferous forest has a value of 0.07. Dry bare ground has a value of 0.2. Dry grassland has a value between 0.2 and 0.3. Desert sand has a value of 0.4. A snow covered rural site has a value between 0.6 and 0.9. 0.2 is often a typical and reasonable value to use for most locations unless you have one of the aforementioned ground surfaces. The default value is 0.2.

For our Rogue River, Oregon design example, this is 0.2.

12) **Climatic Sunshine (Percent)** - This is the forecast average percentage of possible sunshine that reaches the ground during the month in a specific location accounting for the effect of cloud cover and other climatic conditions that block irradiance. The climatic sunshine value determines the **Average Daily Climatic Solar Heat Gain** output parameter. The **Maximum Daily Clear Sky Solar Heat Gain** output parameter is the heat gain that would occur if perfect "clear sky" conditions occurred during the entire day. Setting the climatic sunshine value to 100% will result in the **Average Daily Climatic Solar Heat Gain** output parameter being identically the same as the **Maximum Daily Clear Sky Solar Heat Gain** output parameter. Historical average climatic data are published for many places for each month of the year at this NOAA website:

Sunshine - Average Percent of Possible

If 97537 is entered for the **Clear Sky Optical Depth for Beam Irradiance** input parameter, the appropriate values for the Rogue River, Oregon example for each entered month will be used. The default value is 32.26.

For our Rogue River, Oregon design example, 97537 is entered as described above and these are:

January (32.26%), February (28.57%), March (32.26%), April (43.33%), May (53.33%), June (66.67%), July (90.32%), August (87.10%), September (76.67%), October (54.84%), November (35.48%) and December (29.03%).

13) **Terrain Obstacle Altitude Angles** - Terrain obstacles are objects such as hills, mountains, or trees that may block sunshine from reaching the passive solar fenestration. The angular measurement in degrees that a terrain obstacle is above the horizon at the indicated azimuth angle is the value that should be entered into the calculator. Entering the terrain obstacle altitude angles for each associated and indicated terrain obstacle azimuth angle allows the calculator to account for the adverse effect that these terrain obstacles may have on limiting the amount of irradiance that reaches the passive solar fenestration. If you do not have any terrain obstacles (i.e., if you can see an unobstructed southern horizon between true east and true west), just leave these terrain obstacle altitude angle input parameters blank or enter 0. If you do have terrain obstacles, you should consider using a Solar Pathfinder (please see the Affiliates tab on our website) or an Abney level and a compass to acquire this data or hire someone to do this for you. If 97537 is entered as the first input parameter value, terrain obstacle altitude angles for the Rogue River, Oregon example will be used. Enter the terrain obstacle altitude angle for each associated and indicated terrain obstacle azimuth angle. The default is no terrain obstacles.

For our Rogue River, Oregon design example, these are either left blank or if 97537 is entered as described above, these are the Azimuth Angles (Altitude Angles):
60 degrees (10 degrees), 70 degrees (12 degrees), 80 degrees (17 degrees), True East (24 degrees), 100 degrees (26 degrees), 110 degrees (29 degrees), 120 degrees (33 degrees), 130 degrees (31 degrees), 140 degrees (29 degrees), 150 degrees (29 degrees), 160 degrees (27 degrees), 170 degrees (25 degrees), True South (23 degrees), 190 degrees (20 degrees), 200 degrees (17 degrees), 210 degrees (13 degrees), 220 degrees (12 degrees), 230 degrees (11 degrees), 240 degrees (7 degrees), 250 degrees (10 degrees), 260 degrees (16 degrees), True West (13 degrees), 280 degrees (12 degrees), 290 degrees (13 degrees) and 300 degrees (14 degrees).

Click Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Average Daily Irradiance Time Period (Hours/Day)** - This is the average daily irradiance time that irradiance actually enters the building through the passive solar fenestration for the month being analyzed. This value is used as an input parameter by our **Passive Solar Thermal Mass Performance Calculator**.

For our Rogue River, Oregon design example, these are:
January (4.1 hours), February (6.1 hours), March (7.4 hours), April (6.1 hours), May (0 hours), June (0 hours), July (0 hours), August (2.8 hours), September (7.7 hours), October (6.7 hours), November (4.8 hours) and December (3.4 hours).

It should be noted that if the terrain obstacles are NOT properly accounted for, these are:

January (9.2 hours), February (10.2 hours), March (11.3 hours), April (6.5 hours), May (0 hours), June (0 hours), July (0 hours), August (2.8 hours), September (10.3 hours), October (10.8 hours), November (9.5 hours) and December (8.9 hours).

This example illustrates the importance of properly accounting for terrain obstacles.

2) **Maximum Instantaneous Clear Sky Solar Heat Gain (BTU/Hour)** - This is the maximum hourly heat gain found to occur during the month for perfect "clear sky" conditions. While you will never likely experience this heat gain value for the entire month, you will experience this heat gain value for several days of the month and you do not want the building to overheat when this occurs. To assess the likelihood of overheating the room or building, you should compare these hourly heat gain values against the associated building or room **Total Heat Loss (BTU/Hour)** values that you previously obtained by exercising our **Heat Loss Analysis Calculator** at the historically expected average monthly outdoor temperatures (i.e., NOT at the coldest expected 99% annual outdoor temperature). You may need to reduce the area of the passive solar fenestration if any of these hourly heat gain values exceed the **Total Heat Loss (BTU/Hour)** values. Alternatively, you may want to incorporate thermal mass into the passive solar heating system design to absorb, store and release this excess solar heat gain slowly after the irradiance period.

For our Rogue River, Oregon design example, these are:
January (32,051 BTU/Hour), February (29,759 BTU/Hour), March (23,525 BTU/Hour), April (12,291 BTU/Hour), May (0 BTU/Hour), June (0 BTU/Hour), July (0 BTU/Hour), August (6,844 BTU/Hour), September (18,509 BTU/Hour), October (27,010 BTU/Hour), November (30,857 BTU/Hour) and December (31,762 BTU/Hour).

It should be noted that if the terrain obstacles are NOT properly determined and included, this has no effect on this output parameter.

3) **Maximum Daily Clear Sky Solar Heat Gain (BTU/Day)** - This is the maximum daily heat gain found to occur during the month for perfect "clear sky" conditions. This heat gain value is used as the **Daily Irradiance (BTU/Day)** input parameter by our **Passive Solar Thermal Mass Performance Calculator**.

For our Rogue River, Oregon design example, these are:
January (114,598 BTU/Day), February (139,785 BTU/Day), March (109,205 BTU/Day), April (30,610 BTU/Day), May (0 BTU/Day), June (0 BTU/Day), July (0 BTU/Day), August (7,602 BTU/Day), September (75,913 BTU/Day), October (130,363 BTU/Day), November (123,351 BTU/Day) and December (96,142 BTU/Day).

It should be noted that if the terrain obstacles are NOT properly accounted for, these are:
January (208,750 BTU/Day), February (197,386 BTU/Day), March (133,691 BTU/Day), April (31,389 BTU/Day), May (0 BTU/Day), June (0 BTU/Day), July (0 BTU/Day), August (7,602 BTU/Day), September (86,595 BTU/Day), October (171,997 BTU/Day), November (201,734 BTU/Day) and December (200,632 BTU/Day).

This example illustrates the importance of properly accounting for terrain obstacles.

4) **Average Daily Climatic Solar Heat Gain (BTU/Day)** - This is the forecast daily heat gain that will occur based on the **Climatic Sunshine** input parameter value used. This is the best estimate of how much passive solar heat gain will actually be produced during the month. This heat gain value is used as an input parameter by our **Integrated Heating System Performance Calculator** to assess the need for any additional supplemental heating requirements (e.g., hydronic radiant floor heating and/or masonry heater).

For our Rogue River, Oregon design example, these are:
January (36,969 BTU/Day), February (39,937 BTU/Day), March (35,230 BTU/Day), April (13,263 BTU/Day), May (0 BTU/Day), June (0 BTU/Day), July (0 BTU/Day), August (6,622 BTU/Day), September (58,202 BTU/Day), October (71,491 BTU/Day), November (43,765 BTU/Day) and December (27,910 BTU/Day).

It should be noted that if the terrain obstacles are NOT properly accounted for, these are:
January (67,343 BTU/Day), February (56,393 BTU/Day), March (43,129 BTU/Day), April (13,601 BTU/Day), May (0 BTU/Day), June (0 BTU/Day), July (0 BTU/Day), August (6,622 BTU/Day), September (66,392 BTU/Day), October (94,323 BTU/Day), November (71,575 BTU/Day) and December (58,243 BTU/Day).

This example illustrates the importance of properly accounting for terrain obstacles.

This calculator should be exercised to determine and tabulate the **Average Daily Irradiance Time Period**, **Maximum Instantaneous Clear Sky Solar Heat Gain (BTU/Hour)**, **Maximum Daily Clear Sky Solar Heat Gain**, and **Average Daily Climatic Solar Heat Gain** output parameter data for January through December.

To assess the likelihood of overheating the room or building, you should compare the tabulated **Maximum Instantaneous Clear Sky Solar Heat Gain (BTU/Hour)** values against the associated building or room **Total Heat Loss (BTU/Hour)** values that you previously obtained by exercising our **Heat Loss Analysis Calculator** at the historically expected average monthly outdoor temperatures (i.e., NOT at the coldest expected 99% annual outdoor temperature). You may need to reduce the area of the passive solar fenestration if any of the monthly **Maximum Instantaneous Clear Sky Solar Heat Gain (BTU/Hour)** values exceed the monthly **Total Heat Loss (BTU/Hour)** values.

Alternatively, you may want to use the **Average Daily Irradiance Time Period** and **Maximum Daily Clear Sky Solar Heat Gain** data to evaluate the performance of any thermal mass that you plan to use to absorb, store, and slowly release any excess solar heat gain that occurs during the daily irradiance period by exercising our **Passive Solar Thermal Mass Performance Calculator**.

The final step to complete the passive solar heating system design is to use the **Average Monthly Climatic Solar Heat Gain** data in our **Integrated Heating System Performance Calculator** to assess how well the heat gain achieved by the passive solar design meets your monthly and annual heating needs given the actual Heating Degree Days for your local climate.

The objective of a good passive solar heating system design is to minimize the need for supplemental heating while NEVER overheating the building. If you are working with a company who cannot perform this analysis and provide data that is sealed/signed by a licensed professional engineer for the specific design and location, you should apply due diligence and consider finding a more

competent company to do this. If you find that you need this service, we hope that you will consider Borst Engineering and Construction.

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This calculator determines how much passive solar heat is absorbed and released by a passively heated thermal mass (i.e., a thermal mass that is only heated by irradiance). You will first need to determine the daily irradiance magnitude and the daily irradiance time period that the thermal mass is directly exposed to irradiance by exercising our **Passive Solar Altitude Angle Calculator**, **Passive Solar Roof Overhang Design Calculator**, **Passive Solar Fenestration Exposure Calculator**, and **Passive Solar Heat Gain Calculator**.

An often cited but misused "design rule of thumb" is that for every square foot of south wall passive solar fenestration area in excess of the 7% "design rule of thumb", a passive solar building should have 5.5 square feet of 4 inch thick thermal mass material. We have found this "design rule of thumb" to be overly simplistic and often grossly inaccurate for forecasting thermal mass performance. There are many factors that may significantly affect thermal mass performance. For example, the maximum temperature that a thermal mass will reach during the daily irradiance time period depends on the initial temperature of the thermal mass, the daily irradiance magnitude (BTU/Day), the daily irradiance time period (Hours/Day), the absorptivity of the thermal mass material, the specific heat capacity of the thermal mass material, the actual mass of the thermal mass, and the exposed floor heat loss. The heat gain provided by a thermal mass during the night time hours depends on this maximum temperature, the surface area of the thermal mass, the emissivity of the thermal mass material, the convective heat transfer coefficient of the surrounding air, the specific heat capacity of the thermal mass material, the actual mass of the thermal mass, and the exposed floor heat loss. A thermal mass will release heat during and after the daily irradiance time period when the thermal mass temperature exceeds the room temperature. Consequently, the passive solar heat gain that occurs during and after the daily irradiance time period may result from both the irradiance that enters the building that is NOT absorbed by the thermal mass PLUS any heat gain that is released by the thermal mass. This "design rule of thumb" was likely originally developed by the passive solar design pioneers back in the 1960/70s before the widespread use of computers. This "design rule of thumb" may have worked reasonably well for the specific building locations and the construction materials/methods used at the time. However, there are many reports of passive solar designs with seriously over-heated or under-heated buildings as a consequence of following this "design rule of thumb".

Amazingly and regrettably, there are still many passive solar companies marketing services based on this "design rule of thumb" and they often charge exorbitant fees for their less-than-competent expertise and their defective passive solar house plans. We advise applying due diligence and avoiding companies who follow this practice if you want to ensure having a passive solar design that will keep the building occupants comfortable and happy without depleting your bank account. It should be noted that this "design rule of thumb" has little significance if you have a well-designed and integrated passive solar heating and hydronic radiant floor heating system. *Borst Engineering & Construction has successfully designed integrated passive solar heating and hydronic radiant floor heating systems to enable conveying heat from passive solar heated areas to other areas of the building where it is immediately needed, to store this excess heat until it is actually needed, or to reject this heat if it is NOT needed.*

A sample of a professional passive solar thermal mass analysis may be found on the Consultation tab of our website:

Sample Passive Solar Thermal Mass Analysis

This calculator uses the 2013 American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Fundamentals Handbook methodology to determine the actual amount of incident solar radiation (i.e., irradiance) that is absorbed by a thermal mass, the resulting temperature increase of the thermal mass (based on heat capacity equation), and the resulting release of heat from the thermal mass (via both convective and radiation heat transfer) whenever the thermal mass temperature exceeds the design indoor dry bulb temperature. This calculator provides the duration (Hours) and total heat gain values (BTU/Day) that occur during the irradiance heating period (i.e., the time period when irradiance actually occurs), during the non-irradiance heating period (i.e. the time period after the irradiance is not actually occurring, but the thermal mass temperature is still higher than the building indoor temperature) and after the non-irradiance heating period (i.e. the time period the thermal mass temperature is lower than the building indoor temperature until the end of the day). The calculator provides the total heat gain values (BTU/Day) that result from the downward heat loss of the floor and the total heat contained in the thermal mass at the end of the day. The calculator provides the average heat gain values (BTU/Hour) that occur during the irradiance heating period and during the non-irradiance heating period. A thermal mass design that results in both these two average heat gain values being equal to or less than the total building heat loss (BTU/Hour) will enable controlling the indoor temperature to the desired comfort level and keep the building occupants happy. ***To further assist you in accomplishing the passive solar design, an example for a building located in Rogue River, Oregon is used to illustrate the use of this calculator.***

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Design Indoor Dry Bulb Temp (Degrees Fahrenheit)** - This is typically 65 to 75 degrees F or as specified by the local building code. The default value is 70. Please use this same value in our **Building Assembly Moisture Analysis Calculator**, **Existing Building Energy Usage Analysis Calculator**, **Heat Loss Analysis Calculator** and **Hydronic Radiant Floor Heating Design Calculator**.

   For our Rogue River, Oregon design example, this is 70 degrees F for every month.

2) **Daily Irradiance Heat Gain (BTU/Day)** - This is normally the **Maximum Daily Clear Sky Solar Heat Gain** which is the maximum daily heat gain that will occur if perfect "clear sky" conditions occur during the entire day. While you will never likely experience this heat gain value for the entire month, you will experience this heat gain value for several days of the month and you do not want the building to overheat when this occurs. This value is an output parameter of our **Passive Solar Heat Gain Calculator**. If 1, 2, etc. is entered for this input parameter where this value represents the month, the appropriate values for the Rogue River, Oregon example for this month will be used respectively. The default value is 114,598.

   For our Rogue River, Oregon design example, these are:
   January (114,598 BTU/Day), February (139,785 BTU/Day), March (109,205 BTU/Day), April (30,610 BTU/Day), May (0 BTU/Day), June (0 BTU/Day), July (0 BTU/Day), August (7,602 BTU/Day), September (75,913 BTU/Day), October (130,363 BTU/Day), November (123,351 BTU/Day) and December (96,142 BTU/Day).

3) **Average Daily Irradiance Time Period (Hours/Day)** - This is the average daily irradiance time that irradiance actually enters the building through the passive solar fenestration for the month being analyzed. This value is an output parameter of our **Passive Solar Heat Gain Calculator**.

If 1, 2, etc. is entered for this **Daily Irradiance Heat Gain** input parameter where this value represents the month, the appropriate values for the Rogue River, Oregon example for this month will be used respectively. The default value is 4.1.

For our Rogue River, Oregon design example, these are:
January (4.1 hours), February (6.1 hours), March (7.4 hours), April (6.1 hours), May (0 hours), June (0 hours), July (0 hours), August (2.8 hours), September (7.7 hours), October (6.7 hours), November (4.8 hours) and December (3.4 hours).

4)   **Convection Heat Transfer Coefficient (BTU/Degrees F-Hour-Square Feet)** - This is an engineering coefficient used for calculating heat transfer via convection between a fluid and a solid. In this case, the fluid is the air above the thermal mass and the solid is the thermal mass. Still air has a convection heat transfer coefficient of 1.56 BTU/Deg F-H-SF. It is interesting to note that the inverse of this value is 0.64, which is the typical R-value for an inside air film as shown in the instructions for our **Heat Loss Analysis Calculator**. The default value is 1.5.

For our Rogue River, Oregon design example, this is 1.5 BTU/Deg F-H-SF.

5)   **Thermal Mass Temp prior to Irradiance (Degrees F)** - This is the initial temperature of the thermal mass just prior to the irradiance time period. For a passively heated thermal mass (i.e., a thermal mass that is only heated by irradiance), this is the steady state temperature of the thermal mass when it has NOT received any irradiance for a long period of time. This temperature may be measured by using an IR temperature gun in the morning before the irradiance begins. The default value is 70.

For our Rogue River, Oregon design example, this is 70 degrees F for every month.

6)   **Thermal Mass Area (Square Feet)** - This is the thermal mass area that is directly exposed to the irradiance. By knowing the **Height of Glass** from previously exercising our **Passive Solar Roof Overhang Design Calculator** and by knowing the **Total Passive Solar Fenestration Area** by previously exercising the **Passive Solar Heat Gain Calculator**, the total width of the passive solar fenestration may be determined. As a starting point you might multiply the total width of the passive solar fenestration by the **Distance from Glass Irradiance Strikes Floor** output parameter value that may be obtained by exercising our **Passive Solar Fenestration Exposure Calculator** at solar noon on day 15 of the month being analyzed. If 1, 2, etc. is entered for this **Daily Irradiance Heat Gain** input parameter where this value represents the month, the appropriate values for the Rogue River, Oregon example for this month will be used respectively.

Please note that this thermal mass area is somewhat arbitrary and not critical to obtaining good heat transfer rates. However, getting this area close to the actual irradiated area allows the calculator to accurately determine the maximum temperature that the thermal mass will reach at the end of the irradiance period. In reality, thermal mass heat will move beyond this initial area during the course of the day and the actual thermal mass temperature that you will measure will be a cooler temperature. However, a proportionally larger thermal mass area at a proportionally cooler thermal mass temperature provides exactly the same heat transfer rate. Thermal mass temperature in excess of 90 degrees F can become uncomfortable if there is prolonged personal contact. The default value is 548.

For our Rogue River, Oregon design example, the total width of the passive solar fenestration is 36 feet and these are:
January (548 SF), February (358 SF), March (201 SF), April (78 SF), May (0 SF), June (0 SF), July (0 SF), August (43 SF), September (145 SF), October (295 SF), November (488 SF) and December (616 SF).

7) **Thermal Mass Thickness (Inches)** - This is the thickness of the thermal mass. Slab-on-grade concrete floors are typically 4 to 6 inches thick. This value and the **Thermal Mass Area** input parameter are used to determine the volume of the thermal mass, which is then used in conjunction with the **Thermal Mass Density** input parameter to determine the actual mass of the thermal mass. Increasing the thickness of thermal mass to more than 6 inches is not recommended. The default value is 4.

   For our Rogue River, Oregon design example, this is 4 inches.

8) **Thermal Mass Density (Pounds/Cubic Foot)** - This is the density of the thermal mass material. Slab-on-grade concrete floors are typically 150 PCF. The default value is 150.

   For our Rogue River, Oregon design example, this is 150 PCF.

9) **Thermal Mass Specific Heat Capacity (BTU/Degrees F-Pound)** - This is a measure of the amount of heat per unit mass that is required to raise the temperature of a material by one degree F. Slab-on-grade concrete floors are typically 0.18 BTU/Deg F-Lb. The default value is 0.18.

   For our Rogue River, Oregon design example, this is 0.18 BTU/Deg F-Lb.

10) **Thermal Mass Insulation R-Value (Degrees F-Hour-Square Feet/BTU)** - This is total R-value of the floor assembly associated with the upward heat flux. Under-slab 2 inch thick EPS/XPS insulation typically has a total R-value of 10 Deg F-H-SF/BTU. Please see the instructions for our **Heat Loss Analysis Calculator** for more information about R-values. The default value is 20.

   For our Rogue River, Oregon design example, this is 20 Deg F-H-SF/BTU.

11) **Thermal Mass Absorptivity (Percent)** - This is a measure of how much irradiance is absorbed by a material. Slab-on-grade concrete floors typically absorb between 60 to 80 percent of the irradiance that they receive. The default value is 70.

   For our Rogue River, Oregon design example, this is 70%.

12) **Thermal Mass Emissivity (Percent)** - Emissivity is the relative ability of a material to emit energy by radiation. It is the ratio of energy radiated by the specific material to the energy radiated by a true "black body" at the same temperature. A true "black body" would have an emissivity of 100 percent. A perfectly reflective material would have an emissivity of 0 percent. Slab-on-grade concrete floors typically have an emissivity of 85 to 95 percent. The default value is 90.

   For our Rogue River, Oregon design example, this is 90%.

Click ⬚Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Total Heat Gain during Irradiance Heating Period (BTU/Day)** - This is the total daytime heat gain or loss of the space during the time period when irradiance actually occurs resulting from the irradiance heat gain that is NOT absorbed by the thermal mass, and the convection and radiation heat transfer between the indoor space and the thermal mass given the temperature profile of the thermal mass. A positive value indicates that the irradiance and the thermal mass provides space heat gain during this period. A negative value indicates that the thermal mass causes space heat loss during this period.

   For our Rogue River, Oregon design example, these are:
   January (66,470 BTU/Day), February (92,291 BTU/Day), March (76,487 BTU/Day), April (20,210 BTU/Day), May (0 BTU/Day), June (0 BTU/Day), July (0 BTU/Day), August (3,893 BTU/Day), September (53,765 BTU/Day), October (88,603 BTU/Day), November (75,371 BTU/Day) and December (52,406 BTU/Day).

   Please recall that WITHOUT the thermal mass, the total heat gain during the irradiance period would have been:
   January (114,598 BTU/Day), February (139,785 BTU/Day), March (109,205 BTU/Day), April (30,610 BTU/Day), May (0 BTU/Day), June (0 BTU/Day), July (0 BTU/Day), August (7,602 BTU/Day), September (75,913 BTU/Day), October (130,363 BTU/Day), November (123,351 BTU/Day) and December (96,142 BTU/Day).

   This example illustrates how a thermal mass significantly reduces the building heat gain during the irradiance period from what it otherwise would be.

2) **Total Heat Gain during Non-Irradiance Heating Period (BTU/Day)** - This is the total night time heat gain or loss of the space during the time period after the irradiance is not occurring, but the thermal mass temperature is still higher than the building indoor temperature resulting from the convection and radiation heat transfer between the space and the thermal mass given the temperature decay profile of the thermal mass. A positive value indicates that the thermal mass provides space heat gain during this period. A negative value indicates that the thermal mass causes space heat loss during this period.

   For our Rogue River, Oregon design example, these are:
   January (46,376 BTU/Day), February (45,265 BTU/Day), March (30,923 BTU/Day), April (9,912 BTU/Day), May (0 BTU/Day), June (0 BTU/Day), July (0 BTU/Day), August (3,595 BTU/Day), September (20,888 BTU/Day), October (39,652 BTU/Day), November (46,073 BTU/Day) and December (42,280 BTU/Day).

   Please recall that WITHOUT the thermal mass, these would have been:
   January (0 BTU/Day), February (0 BTU/Day), March (0 BTU/Day), April (0 BTU/Day), May (0 BTU/Day), June (0 BTU/Day), July (0 BTU/Day), August (0 BTU/Day), September (0 BTU/Day), October (0 BTU/Day), November (0 BTU/Day) and December (0 BTU/Day).

This example illustrates how a thermal mass significantly increases the building heat gain after the irradiance period from what it otherwise would be.

3) **Total Heat Gain after Non-Irradiance Heating Period (BTU/Day)** - This is the total night time heat gain or loss of the space during the time period the thermal mass temperature is lower than the building indoor temperature until the end of the day resulting from the convection and radiation heat transfer between the space and the thermal mass given the temperature decay profile of the thermal mass. A positive value indicates that the thermal mass provides space heat gain during this period. A negative value indicates that the thermal mass causes space heat loss during this period.

   For our Rogue River, Oregon design example, these are: January (0 BTU/Day), February (0 BTU/Day), March (0 BTU/Day), April (0 BTU/Day), May (0 BTU/Day), June (0 BTU/Day), July (0 BTU/Day), August (0 BTU/Day), September (0 BTU/Day), October (0 BTU/Day), November (0 BTU/Day) and December (0 BTU/Day).

4) **Total Heat Loss of Floor (BTU/Day)** - This is the total heat loss of the floor which largely depends on the temperature profile of the thermal mass and the **Thermal Mass Insulation R-Value** input parameter.

   For our Rogue River, Oregon design example, these are:
   January (1,575 BTU/Day), February (1,912 BTU/Day), March (1,489 BTU/Day), April (419 BTU/Day), May (0 BTU/Day), June (0 BTU/Day), July (0 BTU/Day), August (105 BTU/Day), September (1,177 BTU/Day), October (1,781 BTU/Day), November (1,693 BTU/Day) and December (1,323 BTU/Day).

5) **Total Heat Contained in Thermal Mass at End of Day (BTU/Day)** - This is the total heat that is contained in the thermal mass at the end of the day relative to the heat that was in the thermal mass at the start of the day. The total heat contained in the thermal mass at the end of the day should be very small indicating that the value entered for the **Thermal Mass Temp prior to Irradiance** input parameter was appropriate. A positive value indicates that the thermal mass temperature at the end of the day is warmer than the **Thermal Mass Temp prior to Irradiance**. A negative value indicates that the thermal mass temperature at the end of the day is cooler than the **Thermal Mass Temp prior to Irradiance**.

   Please note that the summation of this output parameter with the **Total Heat Gain during Irradiance Heating Period**, **Total Heat Gain during Non-Irradiance Heating Period**, **Total Heat Gain after Non-Irradiance Heating Period** and **Total Heat Loss of Floor** output parameters will always equal the **Daily Irradiance Heat Gain** input parameter. If the **Thermal Mass Temp prior to Irradiance** is significantly cooler than the **Design Indoor Dry Bulb Temp** input parameter, the thermal mass may absorb significant additional heat by convection and radiation heat transfer from the space resulting in the thermal mass at the end of the day being significantly warmer than the **Thermal Mass Temp prior to Irradiance**. Nevertheless, conservation of energy must always prevail and the aforementioned output parameter summation will always equate to the **Daily Irradiance Heat Gain**. However, these other output parameters

will indicate significantly reduced heat gain or even indicate significant heat loss as a consequence of how the thermal mass is "charged" or "depleted" of heat at the start of the day.

For our Rogue River, Oregon design example, these are:
January (176 BTU/Day), February (317 BTU/Day), March (306 BTU/Day), April (69 BTU/Day), May (0 BTU/Day), June (0 BTU/Day), July (0 BTU/Day), August (9 BTU/Day), September (255 BTU/Day), October (326 BTU/Day), November (213 BTU/Day) and December (132 BTU/Day).

6) **Duration of Irradiance Heating Period (Hours)** - This is the time period when irradiance actually occurs and is equal to the **Average Daily Irradiance Time Period** input parameter which is an output parameter of our **Passive Solar Heat Gain Calculator**.

For our Rogue River, Oregon design example, these are:
January (4.1 hours), February (6.1 hours), March (7.4 hours), April (6.1 hours), May (0 hours), June (0 hours), July (0 hours), August (2.8 hours), September (7.7 hours), October (6.7 hours), November (4.8 hours) and December (3.4 hours).

7) **Average Heat Gain during Irradiance Heating Period (BTU/Hour)** - This is the average daytime heat gain or loss of the space during the irradiance heating period resulting from the irradiance heat gain that is NOT absorbed by the thermal mass, and the convection and radiation heat transfer between the space and the thermal mass. A positive value indicates that the irradiance and the thermal mass provides space heat gain during this period. A negative value indicates that the thermal mass causes space heat loss during this period.

For our Rogue River, Oregon design example, these are:
January (16,196 BTU/Hour), February (15,130 BTU/Hour), March (10,336 BTU/Hour), April (3,313 BTU/Hour), May (0 BTU/Hour), June (0 BTU/Hour), July (0 BTU/Hour), August (1,390 BTU/Hour), September (6,982 BTU/Hour), October (13,224 BTU/Hour), November (15,702 BTU/Hour) and December (15,414 BTU/Hour).

8) **Thermal Mass Temp at End of Irradiance Heating Period (Degrees F)** - This is the maximum temperature of the thermal mass at the end of the irradiance heating period.

For our Rogue River, Oregon design example, these are:
January (79.6 degrees F), February (84.4 degrees F), March (87.6 degrees F), April (84.5 degrees F), May (70 degrees F), June (70 degrees F), July (70 degrees F), August (79.5 degrees F), September (86.5 degrees F), October (85.4 degrees F), November (80.7 degrees F) and December (77.8 degrees F).

9) **Instantaneous Heat Gain at End of Irradiance Heating Period (BTU/Hour)** - This is the instantaneous heat gain or loss that the thermal mass provides the space at the end of the irradiance heating period. A positive value indicates that the thermal mass provides space heat gain at this time. A negative value indicates that the thermal mass causes space heat loss at this time.

For our Rogue River, Oregon design example, these are:

January (13,196 BTU/Hour), February (12,981 BTU/Hour), March (8,923 BTU/Hour), April (2,843 BTU/Hour), May (0 BTU/Hour), June (0 BTU/Hour), July (0 BTU/Hour), August (1,022 BTU/Hour), September (6,026 BTU/Hour), October (11,396 BTU/Hour), November (13,136 BTU/Hour) and December (12,000 BTU/Hour).

10) **Duration of Non-Irradiance Heating Period (Hours)** - This is the time period after the irradiance is not actually occurring, but the thermal mass temperature is still higher than the building indoor temperature. If the thermal mass receives sufficient irradiance and the **Total Heat Loss of Floor** output parameter is relatively small, the thermal mass may provide space heating the entire day.

For our Rogue River, Oregon design example, these are:
January (19.9 hours), February (17.9 hours), March (16.6 hours), April (17.9 hours), May (0 hours), June (0 hours), July (0 hours), August (21.2 hours), September (16.3 hours), October (17.3 hours), November (19.2 hours) and December (20.6 hours).

11) **Average Heat Gain during Non-Irradiance Heating Period (BTU/Hour)** - This is the average night time heat gain or loss of the space during the non-irradiance heating period resulting from the convection and radiation heat transfer between the space and the thermal mass. A positive value indicates that the thermal mass provides space heat gain during this period. A negative value indicates that the thermal mass causes space heat loss during this period.

For our Rogue River, Oregon design example, these are:
January (2,330 BTU/Hour), February (2,529 BTU/Hour), March (1,863 BTU/Hour), April (554 BTU/Hour), May (0 BTU/Hour), June (0 BTU/Hour), July (0 BTU/Hour), August (170 BTU/Hour), September (1,281 BTU/Hour), October (2,292 BTU/Hour), November (2,400 BTU/Hour) and December (2,052 BTU/Hour).

12) **Thermal Mass Temp at End of Non-Irradiance Heating Period (Degrees F)** - This is the temperature of the thermal mass at the end of the non-irradiance heating period. This temperature will be close to the **Design Indoor Dry Bulb Temp** input parameter.

For our Rogue River, Oregon design example, these are:
January (70.0 degrees F), February (70.1 degrees F), March (70.2 degrees F), April (70.1 degrees F), May (70.0 degrees F), June (70.0 degrees F), July (70.0 degrees F), August (70.0 degrees F), September (70.2 degrees F), October (70.1 degrees F), November (70.0 degrees F) and December (70.0 degrees F).

13) **Duration after Non-Irradiance Heating Period (Hours)** - This is the time period the thermal mass temperature is lower than the building indoor temperature and until the end of the day. If the thermal mass receives sufficient irradiance and the Total Heat Loss of Floor output parameter is relatively small, this period may not occur at all and this value will be 0.

For our Rogue River, Oregon design example, these are: January (0 hours), February (0 hours), March (0 hours), April (0 hours), May (24 hours), June (24 hours), July (24 hours), August (0 hours), September (0 hours), October (0 hours), November (0hours) and December (0 hours).

14) **Average Heat Gain after Non-Irradiance Heating Period (BTU/Hour)** - This is the average night time heat gain or loss of the space after the non-irradiance period has ended resulting from the convection and radiation heat transfer between the space and the thermal mass. A positive value indicates that the thermal mass provides space heat gain during this period. A negative value indicates that the thermal mass causes space heat loss during this period.

For our Rogue River, Oregon design example, these are: January (0 BTU/Hour), February (0 BTU/Hour), March (0 BTU/Hour), April (0 BTU/Hour), May (0 BTU/Hour), June (0 BTU/Hour), July (0 BTU/Hour), August (0 BTU/Hour), September (0 BTU/Hour), October (0 BTU/Hour), November (0 BTU/Hour) and December (0 BTU/Hour).

15) **Thermal Mass Temp at End of Day (Degrees F)** - This is the temperature of the thermal mass at the end of the day. Ideally this temperature should be close to the Thermal Mass Temp prior to Irradiance input parameter.

For our Rogue River, Oregon design example, these are: January (70.0 degrees F), February (70.1 degrees F), March (70.2 degrees F), April (70.1 degrees F), May (70.0 degrees F), June (70.0 degrees F), July (70.0 degrees F), August (70.0 degrees F), September (70.2 degrees F), October (70.1 degrees F), November (70.0 degrees F) and December (70.0 degrees F).

A good thermal mass design will result in both the **Average Heat Gain during Irradiance Heating Period (BTU/ Hour)** and **Average Heat Gain during Non-Irradiance Heating Period (BTU/Hour)** output parameters being equal to or less than the **Total Heat Loss** (**BTU/Hour)** output parameter that you previously obtained by exercising our **Heat Loss Analysis Calculator**. A thermal mass design that achieves this condition will enable controlling the indoor temperature to the desired comfort level and keep the building occupants happy. You may need to vary the area of the passive solar fenestration and/or the thermal mass to achieve this condition. You may even need to re-design the passive solar roof overhang.

Please be aware that there may be a significant time lag (i.e., many hours) for a thermal mass floor to heat up and cool down. If you integrate hydronic radiant floor heating with passive solar heating, it is important and may well be worth the additional effort and expense to use a more sophisticated control system that uses actual floor temps, actual indoor air temps, outdoor air temp (actual, derived, and forecast), solar irradiance sensors, and supplemental heat schedule data to provide lead feedback compensation to the control system to ensure the desired comfort level will always be maintained. We use and highly recommend the Allen-Bradley (Rockwell Automation) Micro 800 series of Programmable Logic Controllers (PLCs). Please see this specific post in the **Green Building Talk Forum** for more information about PLCs. The Green Building Talk Forum is a great website to learn about green building construction principals in general and to ask questions related to your specific projects. We frequently participate on the Green Building Talk Forum.

Again, the objective of a good passive solar heating system design is to minimize the need for supplemental heating while NEVER overheating the building. If you are working with a company who cannot perform this analysis and provide data that is sealed/signed by a licensed professional engineer for the specific design and location, you should apply due diligence and consider finding a more competent company to do this. If you find that you need this service, we hope that you will consider Borst Engineering and Construction.

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A cross flow turbine is a machine for converting the energy of moving water into power. A cross flow turbine consists of a nozzle and runner. Most commonly, the cross flow turbine runner is mounted on a horizontal shaft. The cross flow turbine runner consists of a series of curved blades (often fabricated from commercial pipe sections) which are attached to two parallel circular disks. The horizontal shaft passes through the center of these two parallel circular disks. The cross flow turbine nozzle is designed to have a rectangular cross-sectional area and discharges a rectangular shaped water jet the full length of the cross flow turbine runner. This rectangular shaped water jet typically enters the cross flow turbine runner at a 16 degree angle tangent to the runner exterior diameter. This rectangular shaped water jet then typically enters a blade channel at a 30 degree angle tangent to the blades at the runner exterior diameter on the nozzle near side of runner, flows over the blades, passes through the empty space in the center of the runner (without striking the horizontal shaft or prematurely striking the runner interior diameter) until it actually enters a blade channel at the runner interior diameter, flows over these blades, and finally exits the blade channel at the runner exterior diameter on the nozzle far side of runner. A cross flow turbine is normally fed by water directly from a stream or indirectly from a pond, which is formed when a stream is dammed. A penstock (i.e., a pipe) is used to bring the water from the stream or pond to the cross flow turbine nozzle inlet. The cross flow turbines that we fabricate are about 88% efficient.

While a cross flow turbine is a relatively low speed turbine, it may operate at a higher RPM than a water wheel. As such, a cross flow turbine may be more reliable and suitable for hydroelectric projects. While not as efficient as a Kaplan, a Francis or a Pelton turbine, the cross flow turbine has the following benefits worth considering:

1. Works well for low head streams,
2. Has a flat efficiency curve under variable flow rates,
3. Is self-cleaning and highly reliable,
4. Is relatively easy to self-construct,
5. Is relatively easy to self-maintain.

To fully understand and use this calculator, you must first gain a good understanding about cross flow turbine design/build parameters. One good reference to get started with is "**The Banki Water Turbine**", Bulletin Series no. 25, C.A. Mockmore & Fred Merryfield, Oregon State College, published February 1949. Another good reference is "The Cross-Flow Turbine", Vol. 12, No.1, L.A. Haimerl, Munich-Pasing, published January 1960. If your written technical German is good, the ultimate reference is, "Neue Wasserturbine Zeitschrift fuer das Gesamte Turbinenwesen", Vol. 15, No. 21, D. Banki, R. Oldenbourg Verlag, Berlin, published July 1918.

This calculator is based on the Hazen-Williams formula, which is used to determine the penstock minimum hydraulic diameter which depends of the penstock design friction head loss given the penstock design flow rate and the other secondary penstock design parameters (i.e., length and Hazen-Williams friction coefficient). The hydraulic diameter is defined as FOUR times the "hydraulic radius" (i.e., NOT two times as might be expected). The hydraulic radius is defined as the ditch or pipe cross-sectional area divided by the "wetted perimeter". The wetted perimeter is defined as the perimeter of the ditch or pipe cross sectional area that is "wet". *For a full flowing circular pipe, the hydraulic diameter is equal to the pipe interior diameter.*

We prefer to fabricate our cross flow turbine runners using stainless steel to ensure a long life. You probably should avoid using ordinary steel (e.g., A36 or B36). If ordinary steel is used and the runner if fabricated by

welding, the runner will eventually fail because of corrosion induced fatigue failure at the weld joints. We always fabricate our cross flow turbine shafts using stainless steel and we always fabricate our shaft bearings using acetal plastic. Acetal plastic bearings have a much longer life than stainless steel ball/sleeve bearings or nylon bearings. In addition to being an extremely strong and durable material, acetal plastic has self-lubricating properties and is dimensionally stable in a water environment.

The hydroelectric capacity that can be generated at a given site is primarily dependent on two design parameters, the penstock design flow rate and the head available at the penstock outlet. The penstock design flow rate is the amount of water that is available from the water source that will actually be fed to the cross flow turbine via the penstock measured in gallons/minute. The head available at the penstock outlet (and hence the head available to the cross flow turbine nozzle to generate water velocity) is the sum of the penstock design inlet pressure and the penstock design elevation change minus the penstock actual friction head loss measured in feet. Cross flow turbines will typically operate at significantly higher rotational speeds as water wheels. However, depending on the penstock design flow rate and the head available at the penstock outlet, a cross flow turbine may operate below the required rotational speed of conventional generators. As a consequence, a drive system may have to be used which reduces overall system efficiency and increases maintenance and associated operating cost. Permanent Magnet Generators (PMG) are now available that provide high efficiency power generation even at relatively slow rotational speeds. This calculator allows you to design and build a cross flow turbine optimized to your specific hydroelectric site. Just clicking Solve without entering any input parameters will reproduce the laboratory cross flow turbine design detailed in "**The Banki Water Turbine**", Bulletin Series no. 25, C.A. Mockmore & Fred Merryfield, Oregon State College, published February 1949..

You should always first communicate and coordinate with the local Department of Fish and Wildlife, and local Water Resources Department BEFORE constructing any water work project.

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Penstock Design Flow Rate (Gallons/Minute)** - This is the design flow rate of water that is available from the water source that will actually be fed to the cross flow turbine via the penstock after accounting for penstock actual friction head loss.

2) **Penstock Design Inlet Pressure (Pounds/Square Inch)** - This is the static pressure at the penstock inlet. This allows addressing the situation of feeding the cross flow turbine from below the base of a dam. If you can determine the water depth above the drive line inlet, the design inlet pressure in PSI is this water depth in feet multiplied by 0.433.

3) **Penstock Design Elevation Change (Feet)** - This is the elevation difference between the penstock inlet elevation at the water source location and the penstock outlet elevation at the cross flow turbine location. This allows addressing the situation of feeding the cross flow turbine from just below the surface of a stream using a gravity flow pipe. This parameter may be measured by running a hose from the water source location to the cross flow turbine location and using a pressure gauge to measure the static water pressure in PSI at the cross flow turbine location. The penstock design elevation change in feet is this static water pressure in PSI divided by 0.433. The site and installation may have a combination of penstock design inlet pressure and penstock design elevation and you may need to enter values for both.

4) **Penstock Design Hydraulic Diameter (Inches)** - This is the actual hydraulic diameter that will be used for the penstock. For a full flowing circular pipe, the hydraulic diameter is equal to the pipe interior diameter. Initially enter 0 or leave this blank and enter an appropriate value for the **Penstock Design Friction Head Loss** input parameter to have the calculator determine the **Penstock Minimum Hydraulic Diameter** output parameter. The **Penstock Minimum Hydraulic Diameter** output parameter should be considered and a standard interior diameter of commercially available pipe should be selected and entered as this penstock design hydraulic diameter. Please note that the output parameters are ALWAYS based on the entered penstock design hydraulic diameter and are NEVER based on the **Penstock Minimum Hydraulic Diameter** unless it is actually entered.

5) **Penstock Design Length (Feet)** - This is the effective length of the penstock. If the penstock is other than straight (e.g., if the penstock has elbows, valves, etc.), the effective length should be increased from the actual length in accordance with best engineering fluid dynamic practices.

6) **Penstock Design Hazen-Williams Friction Coefficient** - This is used to determine the penstock actual friction head loss resulting from the penstock material being used. This is typically 150 for PVC, 130 for plain steel, and 120 for concrete.

7) **Penstock Design Friction Head Loss (Feet)** - This design parameter allows trading the **Penstock Actual Friction Head Loss** output parameter (and the associated penstock construction economics) against the **Head Available at Penstock Outlet** and **Estimated Power** output parameters to determine a suitable **Penstock Minimum Hydraulic Diameter** output parameter. Decreasing the penstock design friction head loss will increase the **Head Available at Penstock Outlet** and **Estimated Power**, but will increase the **Penstock Minimum Hydraulic Diameter** (and increase the associated penstock construction economics). Increasing the penstock design friction head loss will have the opposite effect. The penstock design friction head loss is typically 5 to 15% of either the **Penstock Design Length** input parameter or the **Head Available at Site** output parameter.

8) **Turbine Design Speed (Rotations/Minute)** - This is the runner rotation speed you will operate the cross flow turbine. We recommend that you initially enter a very low RPM and then slowly increase the RPM to see the effect this has on the output parameters. Adjust this turbine design speed to stay within the optimal range of the **Banki Experimental Coefficient** output parameter. You should consider and determine the torque and RPM requirements of the generator before selecting this turbine design speed. Decreasing this turbine design speed will increase the **Maximum Steady Shaft Torque** output parameter. You may need to consider using a pulley drive system to have this turbine design speed and the **Maximum Steady Shaft Torque** meet the requirements of the generator. Please see our **Pulley Drive System Design Calculator**.

9) **Turbine Nozzle Velocity Coefficient** - This is used to determine the friction head loss caused by the nozzle and is typically between 0.95 and 1.0 for a well fabricated nozzle.

10) **Water Jet Angle of Attack (Degrees)** - This is the angle tangent to the runner exterior diameter that the nozzle directs the rectangular shaped water jet into the runner. Ideally, for maximum

mechanical efficiency, we would like this angle to be as close to 0 degrees as possible. However, 16 degrees may be achieved without too much difficulty and is the typical value used.

11) **Number of Blades** - This is the total number of blades you would like to have on the cross flow turbine. 18 blades are typical. Please use this same value in our **Blade Stress Analysis Calculator (Verhaart)**.

12) **Blade Thickness (Inches)** - This is the thickness of the cross flow turbine blade material. If you can fabricate the blades to an exact, specified thickness, you may use our **Blade Stress Analysis Calculator (Euler-Bernoulli)** to determine the minimum recommended blade thickness to ensure long blade life. If you are using standard commercially available pipe to fabricate the blades, the standard nominal pipe wall thickness of the selected commercially available pipe is the blade thickness. In this case, you may use either our **Blade Stress Analysis Calculator (Euler-Bernoulli)** or **Blade Stress Analysis Calculator (Verhaart)** to determine the maximum recommended blade length between supports to ensure long blade life.

13) **Shaft Diameter (Inches)** - This is the diameter of the shaft material. You may use our **Shaft Stress Analysis Calculator (Soderberg)** to determine the minimum recommended shaft diameter to ensure a long shaft life.

14) **Expected Turbine Efficiency (Percent)** - This is a measure of how well the cross flow turbine converts the energy of the stream (head and flow rate) into mechanical energy (torque and RPM). This is typically 60 to 90%.

15) **Expected Generator Efficiency (Percent)** - This is a measure of how well the generator converts mechanical energy (torque and RPM) into electrical energy (volts and amps). 90% is typical for a Permanent Magnet Generator (PMG).

Click Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Maximum Theoretical Power (Kilowatts)** - This is the maximum theoretical power that could be generated given the **Penstock Design Flow Rate**, **Penstock Design Inlet Pressure**, and **Penstock Design Elevation Change** input parameters assuming that the cross flow turbine and the generator are 100% efficient. You will never actually be able to generate this much power in actual operation, however, this value must often be reported to water resource authorities when seeking a water right permit.

2) **Estimated Power (Kilowatts)** - This is the estimated power output that should be generated at the **Penstock Design Flow Rate**, **Expected Turbine Efficiency**, and **Expected Generator Efficiency** input parameters and the **Head Available at Penstock Outlet** output parameter.

3) **Estimated Energy (Kilowatt Hours/Month)** - This is the estimated energy that should be generated based on the **Estimated Power** output parameter.

4) **Maximum Steady Shaft Torque (Foot-Pounds)** - This is the maximum steady shaft torque that the cross flow turbine will produce given the design inputs. If you require more torque, decrease the **Turbine Design Speed** input parameter. This value is used as an input parameter by our **Shaft Stress Analysis Calculator (Soderberg)**.

5) **Turbine Specific Speed** - This is a dimensionless speed parameter used by engineers to categorize different types of turbines. Cross flow turbines typically fall within the range of 20 to 200. You should consider using a different type of turbine (i.e., Pelton, Francis, Kaplan or Turgo) or using a water wheel (overshot or undershot) if the **Penstock Design Flow Rate** and **Turbine Design Speed** input parameters and the **Head Available at Penstock Outlet** output parameter cause you to not be within this range.

6) **Penstock Minimum Hydraulic Diameter (Inches)** - This is the minimum hydraulic diameter that the penstock must be to satisfy the **Penstock Design Friction Head Loss** input parameter and given the other penstock design input parameters. For a full flowing circular pipe, the hydraulic diameter is equal to the pipe interior diameter. The penstock should be constructed to have a hydraulic diameter that equals or slightly exceeds this minimum hydraulic diameter in order to actually provide the **Penstock Design Flow Rate** input parameter required to achieve the **Head Available at Penstock Outlet** and **Estimated Power** output parameters. This penstock minimum hydraulic diameter should be considered and a standard interior diameter of commercially available pipe should be selected and entered as the **Penstock Design Hydraulic Diameter** input parameter. Please note that the output parameters are ALWAYS based on the entered **Penstock Design Hydraulic Diameter** input parameter and are NEVER based on the penstock minimum hydraulic diameter unless it is actually entered.

7) **Penstock Actual Flow Rate (Gallons/Minute)** - This is the flow rate of water through the penstock which is always equal to the **Penstock Design Flow Rate** input parameter.

8) **Penstock Actual Velocity (Feet/Second)** - This is the **Penstock Actual Flow Rate** output parameter divided by the cross-sectional area of the pipe.

9) **Penstock Actual Reynolds Number** - This is an important design parameter often used by engineers. Greater than 4600, which is indicative of turbulent flow rate, is required to ensure the empirical Hazen-Williams formula used by this calculator remains valid for the calculation.

10) **Head Available at Site (Feet and Pounds/Square Inch)** - This is total head that is available from the water source and is the **Penstock Design Inlet Pressure** input parameter plus the **Penstock Design Elevation Change** input parameter (converted to feet and PSI).

11) **Penstock Actual Friction Head Loss (Feet and Pounds/Square Inch)** - This is the actual friction head loss of the penstock given the **Penstock Design Hydraulic Diameter**, **Penstock Design Length** and **Penstock Design Hazen-Williams Friction Coefficient** input parameters. This penstock actual friction head loss is typically 5 to 15% of either the **Penstock Design Length** or the **Head Available at Site** output parameter.

12) **Penstock Specific Friction Head Loss (Feet and Pounds/Square Inch)** - This is the specific friction head loss of the penstock measured in feet and PSI per 100 feet of pipe given the

Penstock Design Length input parameter and **Penstock Actual Friction Head Loss** output parameter.

13) **Head Available at Penstock Outlet (Feet and Pounds/Square Inch)** - This is the head that is available at the penstock outlet and cross flow turbine inlet which is the **Head Available at Site** output parameter minus the **Penstock Actual Friction Head Loss** output parameter. Please use this same value in our **Blade Stress Analysis Calculator (Verhaart)**.

14) **Turbine Nozzle Water Velocity (Feet/Second)** - This is the velocity of the water that enters the cross flow turbine runner from the cross flow turbine nozzle. This turbine nozzle water velocity is a function of the **Turbine Nozzle Velocity Coefficient** input parameter and the **Head Available at Penstock Outlet** output parameter.

15) **Turbine Nozzle Water Jet Thickness (Inches)** - This is the thickness of the cross flow turbine nozzle rectangular shaped water jet that will exit the turbine nozzle and enter the runner channel created by the runner blade orientation and the turbine nozzle orientation relative to the runner. This turbine nozzle water jet thickness is a function of the **Penstock Actual Flow Rate**, **Turbine Nozzle Water Velocity**, and **Runner Length** output parameters. The turbine nozzle should be fabricated to have a width equal to this turbine nozzle water jet thickness. The

16) **Runner Entrance Channel Width** - This is effective width of the runner channel created by the runner blade orientation and the turbine nozzle orientation relative to the runner. This runner entrance channel thickness is a function of the **Blade Inlet Angle** and **Blade Spacing on Runner Exterior Diameter** output parameters. Please note that this runner entrance channel width is equal to the **Turbine Nozzle Water Jet Thickness** output parameter to allow the water jet to fully enter the runner along the blade contour without any interference that would reduce the cross flow turbine efficiency.

17) **Turbine Runaway Speed (Rotations/Minute)** - This is the speed that the cross flow turbine will reach without any shaft load given the **Penstock Actual Flow Rate** and **Runner Exterior Diameter** output parameters. The cross flow turbine must be designed and fabricated to survive the mechanical forces created at this speed.

18) **Banki Experimental Coefficient** - This is the ratio of the **Runner Entrance Channel Width** and **Runner Exterior Diameter** output parameters. This ratio is an important performance design parameter for a cross flow turbine and has a significant effect on the cross flow turbine efficiency. The acceptable ratio range as determined by extensive experimentation by Dr. Banki is 0.075 to 0.1, with 0.087 being the optimum ratio that is required to achieve maximum cross flow turbine efficiency. Adjust the **Turbine Design Speed** and **Number of Blades** input parameters as necessary to stay within this optimal Banki experimental coefficient range and ideally have this ratio be 0.087.

19) **Runner Length (Inches)** - This is the length of the runner. The runner length is a function of the **Turbine Nozzle Velocity Coefficient** input parameter and the **Penstock Actual Flow Rate**, **Banki Experimental Coefficient**, and **Head Available at Penstock Outlet** output parameters. The turbine nozzle should be fabricated to have a length equal to this runner length.

20) **Runner Exterior Diameter (Inches)** - This is the exterior diameter of the runner. The runner exterior diameter is a function of the **Turbine Design Speed** and **Water Jet Angle of Attack** input parameters and the **Turbine Nozzle Water Velocity** output parameter.

21) **Runner Interior Diameter (Inches)** - This is the interior diameter of the runner. The runner interior diameter is a function of the **Runner Exterior Diameter** and the **Blade Inlet Angle** output parameters.

22) **Runner Hub Width (Inches)** - This is the width of the runner hub which is the difference between the **Runner Exterior Diameter** and **Runner Interior Diameter** output parameters divided by two. Please note that the runner hub width is nearly equal to the **Blade Spacing on Runner Exterior Diameter** output parameter.

23) **Water Jet Thickness Inside Runner (Inches)** - This is the thickness of the rectangular shaped water jet as it passes through the empty space in the center of the runner. This water jet thickness inside the runner is a function of the **Water Jet Angle of Attack** input parameter and the **Blade Inlet Angle** and **Turbine Nozzle Water Jet Thickness** output parameters.

24) **Water Jet Clearance from Shaft (Inches)** - This is the clearance between the inner surface of the rectangular shaped water jet as it passes through the empty space in the center of the runner and the runner shaft surface. This water jet clearance from shaft is a function of the **Shaft Diameter** input parameter and the **Blade Inlet Angle**, **Water Jet Thickness Inside Runner**, and **Runner Interior Diameter** output parameters. A positive value indicates an adequate amount of clearance. A negative value indicates an inadequate amount of clearance and an unacceptable design.

25) **Water Jet Clearance from Runner Interior Diameter (Inches)** - This is the clearance between the outer surface of the rectangular shaped water jet as it passes through the empty space in the center of the runner and the runner interior diameter surface. This water jet clearance from runner interior diameter is a function of the **Shaft Diameter** input parameter and the **Water Jet Thickness Inside Runner**, **Water Jet Clearance from Shaft**, and **Runner Interior Diameter** output parameters. A positive value indicates an adequate amount of clearance. A negative value indicates an inadequate amount of clearance and an unacceptable design.

26) **Blade Inlet Angle (Degrees)** - This is the optimal angle tangent to the runner exterior diameter to orient the blades given the **Water Jet Angle of Attack** input parameter. This is 29.8 degrees when the **Water Jet Angle of Attack** is 16 degrees.

27) **Blade Curvature Radius (Inches)** - This is the optimum interior radius of the blades given the cross flow turbine input design parameters. This blade curvature radius is a function of the **Blade Inlet Angle**, **Runner Exterior Diameter**, and **Runner Interior Diameter** output parameters. If standard commercially available pipe will be used to fabricate the blades, this is the interior radius of the standard commercially available pipe that is required and you should consider varying the **Turbine Design Speed** input parameter to achieve a standard commercially available **Blade Pipe Exterior Diameter** output parameter. This value is used as an input parameter by our **Blade Stress Analysis Calculator (Euler-Bernoulli)** and **Blade Stress Analysis Calculator (Verhaart)**.

28) **Blade Width (Inches)** - This is the width of the blades. This blade width is a function of the **Blade Inlet Angle** and **Blade Curvature Radius** output parameters.

29) **Blade Pitch Circle Diameter (Inches)** - This is a fabrication parameter used to scribe the slots on the side plates for the blades.

30) **Blade Pitch on Pitch Circle (Inches)** - This is another fabrication parameter used to scribe the slots on the side plates for the blades.

31) **Blade Spacing on Runner Exterior Diameter (Inches)** - This is the spacing between the center of the blades as measured at the runner exterior diameter. The blade spacing on runner exterior diameter is a function of the **Number of Blades** input parameter and the **Runner Exterior Diameter** output parameter. Please note that the blade spacing on runner exterior diameter is nearly equal to the **Runner Hub Width** output parameter.

32) **Blade Spacing on Runner Interior Diameter (Inches)** - This is the spacing between the blades as measured at the runner interior diameter. The blade spacing on runner interior diameter is a function of the **Number of Blades** input parameter and the **Runner Interior Diameter** output parameter.

33) **Blade Pipe Exterior Diameter (Inches)** - This is the exterior diameter of standard commercially available pipe that will be used to fabricate the blades. This blade pipe exterior diameter is two times the **Blade Curvature Radius** output parameter accounting for the **Blade Thickness** input parameter.

34) **Blade Pipe Section Angle (Degrees)** - This is the pipe section angle to fabricate the blades from standard commercially available pipe. This parameter is used to determine the **Number of Blades per Pipe Section** output parameter required to fabricate the blades.

35) **Number of Blades per Pipe Section** - This is the number of blades that will be fabricated from each section of standard commercially available pipe considering that the material lost for each cut is the same dimension as the pipe thickness. This fabrication parameter is used to determine the **Blade Pipe Total Length** output parameter required to fabricate the blades.

36) **Blade Pipe Section Length (Inches)** - This is the section length of standard commercially available pipe that would be cut to fabricate the blades. This fabrication parameter is used to determine the **Blade Pipe Total Length** output parameter required to fabricate the blades. It is assumed the blades will just be welded to the inside surface of the side plates (i.e., the side plates will NOT have slots). If side plate slots will be used, consider and add two times the side plate thickness to these parameters.

37) **Number of Blade Pipe Sections** - This is the number of pipe sections required to fabricate the **Number of Blades** input parameter. This fabrication parameter is used to determine the **Blade Pipe Total Length** output parameter required to fabricate the blades.

38) **Blade Pipe Total Length (Inches)** - This is the total length of standard commercially available pipe required to fabricate the blades.

39) **Weight of Runner** - This is the fully fabricated weight of the runner including the blades, shaft, and side plates. It is assumed that the entire runner is constructed using the same thickness steel as the blades.

40) **Maximum Blade Force (Pounds)** - This is the maximum total force experienced by the blades based on the **Penstock Actual Flow Rate** and the **Turbine Nozzle Water Velocity** output parameters. This value is used as an input parameter by our **Blade Stress Analysis Calculator (Euler-Bernoulli)**.

41) **Maximum Shaft Force (Pounds)** - This is the maximum total force experienced by the shaft. The engineering equations consider both the **Weight of Runner** and **Maximum Blade Force** output parameters.

42) **Maximum Blade Bending Moment (Inch-Pounds)** - This is the maximum bending moment experienced by the blade resulting from the **Maximum Blade Force** output parameter acting as a distributed load across the length of a fixed blade. This value is used as an input parameter by our **Blade Stress Analysis Calculator (Euler-Bernoulli)**.

43) **Maximum Shaft Bending Moment (Inch-Pounds)** - This is the maximum bending moment experienced by the shaft resulting from the **Maximum Shaft Force** output parameter acting as a concentrated load at the mid-span of a fixed shaft. This value is used as an input parameter by our **Shaft Stress Analysis Calculator (Soderberg)**.

Under Oregon and Washington law, all water is publicly owned. Landowners must obtain a permit from the Water Resources Department to use water flowing past, through, or under their property. Only after a permit is granted, may the applicant construct a water project and begin using water. After the water project is completed, the permit holder must hire a Certified Water Rights Examiner to complete a survey of water use and submit a map and report detailing how and where the water is being used for beneficial use. If the water has been shown to be used according to the provision of the permit, a water right certificate will be issued by the Water Resources Department. If you find that you need this service, we hope that you will consider Borst Engineering and Construction.

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
[Ditch Capacity Calculator](#)

This calculator is based on the Manning Formula and is specifically used by Oregon Certified Water Right Examiners (CWREs) to determine the water flow rate capacity of a gravity flow ditch. An example of this situation would be a ditch installed near the surface of a stream used to divert water to a lower location or used as a penstock for an overshot water wheel. This calculator provides identical results to the Excel spreadsheet version available at the Oregon Water Resources Department at this website:

[OWRD](#)

You should always first communicate and coordinate with the local Department of Fish and Wildlife, and local Water Resources Department BEFORE constructing any water work project.

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Top Width (Feet)** - This is the width of the top of the ditch.

2) **Bottom Width (Feet)** - This is the width of the bottom of the ditch.

3) **Depth (Feet)** - This is the depth of the water flowing in the ditch.

4) **Fall (Feet)** - This is the elevation difference between the beginning and the end of the ditch.

5) **Length (Feet)** - This is the length of the ditch between the beginning and the end of the ditch.

6) **Manning Roughness Coefficient** - This is used to determine the friction in the ditch and the associated head loss resulting from the ditch lining material being used. This is typically 0.015 for concrete or steel lined ditch/pipe.

Click ⬚Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Gradient (Percent)** - This is the ratio of the Fall divided by the length of the ditch.

2) **Area of Cross-Section (Square Feet)** - This is the effective cross sectional area of the ditch through which the water is flowing.

3) **Wetted Perimeter (Feet)** - This is the interior perimeter of the ditch walls that the flowing water is actually in contact and this may vary depending on the actual depth of the water flowing in the ditch.

4) **Hydraulic Radius (Feet)** - This is the effective radius of the pipe and is obtained by dividing the **Area of Cross-Section** output parameter by the **Wetted Perimeter** output parameter.

5) **Maximum Velocity (Feet/Second)** - This is the maximum velocity that can be obtained.

6) **Ditch Capacity (Cubic Feet/Second)** - This is the maximum flow rate that can be obtained.

Under Oregon and Washington law, all water is publicly owned. Landowners must obtain a permit from the Water Resources Department to use water flowing past, through, or under their property. Only after a permit is granted, may the applicant construct a water project and begin using water. After the water project is completed, the permit holder must hire a Certified Water Rights Examiner to complete a survey of water use and submit a map and report detailing how and where the water is being used for beneficial use. If the water has been shown to be used according to the provision of the permit, a water right certificate will be issued by the Water Resources Department. If you find that you need this service, we hope that you will consider Borst Engineering and Construction.

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This calculator is based on an Oregon Water Resources Department developed formula and is specifically used by Oregon Certified Water Right Examiners (CWREs) to determine the water flow rate capacity provided by centrifugal or turbine electric pumps. This calculator provides identical results to the Excel spreadsheet version available at the Oregon Water Resources Department at this website:

OWRD

You should always first communicate and coordinate with the local Department of Fish and Wildlife, and local Water Resources Department BEFORE constructing any water work project.

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Horse Power** - This is the HP of pump as shown on the pump faceplate.

2) **Efficiency** - This is a measure of how well the pump converts electrical energy (amps and volts) into mechanical energy (head and flow rate). Oregon CWREs use 6.61 for centrifugal pumps and use 7.04 for turbine pumps.

3) **Lift (Feet)** - This is the total lift accomplished by the pump. For a well, this is the well drawdown level, plus the well static water level, plus the elevation difference from the well head to the place of use.

4) **Operating Pressure (Pounds/Square Inch)** - This is the measured pressure in the pump line while the pump is operating.

Click Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **HP times Efficiency** - This is an intermediate parameter used by Oregon CWREs for reporting purposes.

2) **Operating Pressure Head (Feet)** - This is the operating pressure converted to head and assuming a 10% head loss from friction in the pipe.

3) **Total Dynamic Head (Feet)** - This is the sum of the Lift and the Operating Pressure Head.

4) **Pump Capacity (Cubic Feet/Second)** - This is the maximum flow rate that the pump will deliver.

Under Oregon and Washington law, all water is publicly owned. Landowners must obtain a permit from the Water Resources Department to use water flowing past, through, or under their property. Only after a permit is granted, may the applicant construct a water project and begin using water. After the water project is completed, the permit holder must hire a Certified Water Rights Examiner to complete a survey of water use and submit a map and report detailing how and where the water is being used for beneficial use. If the water has been shown to be used according to the provision of the permit, a

water right certificate will be issued by the Water Resources Department. If you find that you need this service, we hope that you will consider Borst Engineering and Construction.

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Protecting the fish and aquatic life in our lakes, ponds, rivers and streams should always be our first priority when designing water machines. One way this may be successfully accomplished is by using our fish screen by-pass tank to supply the water machine. Our fish screen by-pass tank design uses gravity and fluid dynamic engineering principals to create the required hydraulic conditions necessary to safely by-pass fish while eliminating fish screen clogging and associated maintenance without the need for any mechanical cleaning mechanism.

Our fish screen by-pass tank design consists of three pipes (i.e., input pipe, by-pass pipe, and output pipe) and a cylindrical reinforced concrete tank. The tank is divided into separate upper and lower chambers using fish screen material. Primary flow through the tank is from the water source into the tank lower chamber via the input pipe, then into the tank upper chamber via the fish screen, and then to the water machine via the output pipe. By-pass flow is from the tank lower chamber back to the water source via the by-pass pipe. The pipe flow rates may be designed and the pipe may be arranged to meet all fish protection regulations. ***Given the vigorous fish screen sweeping action that can be achieved by this design and given that the water containing debris/sediment always flows BELOW the fish screen, quick and safe fish by-pass is ensured while fish screen clogging and associated maintenance is eliminated.*** The other advantages of this design are that the input and by-pass pipe arrangement in the tank lower chamber prevents debris/sediment from accumulating in the tank and the tank may be conveniently located where maintenance may always be easily accomplished should this ever be required.

The required fish screen approach velocity is defined as the maximum water velocity component perpendicular and adjacent to the fish screen face that the local species of fish being protected need to be able to out swim and this value is specified by local fish and wildlife regulations. The required fish screen sweep velocity is defined as the minimum water velocity component parallel and adjacent to the fish screen face as specified by local fish and wildlife regulations. The required fish screen approach velocity typically must be between 0.08 to 0.40 FPS depending on the flow rate category of the diversion (e.g., less than or greater than 40 CFS) and whether the fish screen is considered self-cleaning or not. We recommend using the largest fish screen approach velocity value that is allowed to minimize the size of required fish screen area and associated tank diameter. The fish screen sweep velocity typically must be at least one to two times greater than the required fish screen approach velocity. We recommend designing a design fish screen sweep velocity that is at least five times greater than the required fish screen approach velocity and preferably at least 2 FPS. Both the input pipe and the by-pass pipe velocities contribute to the fish screen sweep velocity. As such, these two pipes should be designed to have a velocity that is about five to ten times the design fish screen sweep velocity and preferably at least 10 FPS.

A trash rack should be used at the water source entrance to the input pipe which supplies the tank lower chamber. The openings in the trash rack should be designed to NOT allow large debris and large fish from entering the input pipe and the tank, but should be designed to ALLOW small debris and small fish to quickly and safely enter the input pipe and the tank. The diameter of the by-pass pipe must be sufficiently larger than the largest opening in the trash rack to ensure that any debris or fish that enter the tank is quickly and safely returned to the water source. The by-pass pipe keeps sediment from collecting in the tank and assists in creating the vigorous fish screen sweeping action.

We prefer to construct our fish screen by-pass tanks using high strength concrete with basalt rebar reinforcement to eliminate any possibility reinforcement corrosion and concrete spalling to ensure a long tank

life. The tank should be located sufficiently away from the water source to ensure maintenance may always be easily accomplished should this ever be required. The three pipes should enter the tank such that the vertical dimension between the bottom of the tank floor and the top of the output pipe is minimized to maximize the fish screen sweeping action and to minimize the overall required tank height. The input pipe outlet and the by-pass pipe inlet in the tank lower chamber should be located directly opposite from each other with both pipes entering the tank parallel to the fish screen to maximize the fish screen sweeping action and to facilitate quick and safe fish by-pass. The output pipe inlet in the tank upper chamber should be located directly above the by-pass pipe inlet in the tank upper chamber to maximize the fish screen sweeping action. The top of the tank should be higher than the highest expected water level of the water source and should be adequately covered and secured to ensure wildlife or people cannot enter the tank. To ensure that the water level in the tank will always be above the output pipe inlet when the water machine is operating with the required supply flow rate, select an appropriate tank operational water level above the output pipe and use this operational water level as the elevation datum for the tank end of ALL the pipes when designing the pipe elevation changes and pipe diameters to achieve the required pipe gravity flow rates as determined/specified by this calculator. The majority of the tank may often be buried allowing the pipes to be trenched in and properly anchored, thereby protecting the tank and the pipes during any flood conditions as well as preserving the natural beauty of the riparian zone.

We prefer to fabricate our fish screen using perforated stainless steel plate to minimize fish screen corrosion. The material used for the fish screen should not have any opening dimension that exceeds 3/32 inch. We prefer to incorporate active galvanic corrosion control into the design to totally eliminate fish screen corrosion and any associated fish screen clogging. The material used for the fish screen material should be the maximum porosity (i.e., the ratio of the fish screen opening area divided by the total fish screen area) that can be obtained. Maximizing fish screen porosity reduces the minimum fish screen area and the associated minimum tank diameter that is required to satisfy the regulations. Minimizing the minimum tank diameter has the added benefit of maximizing the design fish screen sweep velocity. The tank should be designed and constructed to facilitate removing, cleaning, and replacing the fish screen should this ever be required. As such, the fish screen should have lifting points fitted with lifting arms that lead to the top of the tank where they are normally locked in place.

For a given required output pipe flow rate (as required by the water machine), required fish screen approach velocity, design fish screen porosity, and design by-pass percentage, this calculator allows you to determine the minimum input pipe flow rate, the design by-pass flow rate, the minimum fish screen area, and the associated minimum tank diameter. Design input pipe and by-pass pipe diameters may be entered into the calculator and varied to assess the effect that these pipe diameters have on the design fish screen sweep velocity and allow you to target the design velocities for these pipes. The design pipe lengths may be determined by knowing where the tank is located relative to the water source and the water machine. Given the required pipe flow rates, design pipe lengths, and selected design pipe material, the remaining design pipe parameters (i.e., design pipe elevation changes and design pipe diameters) may be determined by exercising our **Pipe & Pump System Design Calculator (Hazen-Williams)**. For a given design pipe length; the design pipe elevation change and the design pipe diameter may be varied and traded so as to achieve the required pipe flow rate and associated design pipe velocity. Once you have determined the final pipe design parameters that will provide the required pipe flow rates (i.e., design pipe material, design pipe lengths, design pipe diameters, and design pipe elevation changes), you should re-enter the final design input pipe and by-pass pipe diameters into the calculator to determine the design fish screen sweep velocity and confirm the design velocities of these pipes.

You should always first communicate and coordinate with the local Department of Fish and Wildlife, and local Water Resources Department BEFORE constructing any water work project.

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Required Output Pipe Flow Rate (Gallons/Minute)** - This is the required flow rate needed to supply the water machine.

2) **Required Fish Screen Approach Velocity (Feet/Second)** - This is the maximum water velocity component perpendicular and adjacent to the fish screen face that the local species of fish being protected need to be able to out swim and this value is specified by local regulations. This requirement typically varies from 0.08 to 0.40 FPS depending on the flow rate category of the diversion (e.g., less than or greater than 40 CFS) and whether the fish screen is considered self-cleaning or not. The largest allowed value should be used to minimize the **Minimum Fish Screen Area** and **Minimum Tank Diameter** output parameters.

3) **Design Fish Screen Porosity (Percent)** - This is the ratio in percent of the fish screen opening area divided by the total fish screen area. This is typically a minimum of 27%, but should be maximized to minimize the **Minimum Fish Screen Area** and **Minimum Tank Diameter** output parameters and to maximize the **Design Fish Screen Sweep Velocity** output parameter.

4) **Design By-Pass Percentage (Percent)** - This is the percentage that the **Design By-Pass Flow Rate** output parameter is greater than the **Required Output Pipe Flow Rate** input parameter. The **Design By-Pass Flow Rate** MUST always be larger than the **Required Output Pipe Flow Rate**. This value is typically 10 - 25%.

5) **Design Input Pipe Hydraulic Diameter (Inches)** - This is the hydraulic diameter of the input pipe as designed and determined as described in the instructions. For a full flowing circular pipe, the hydraulic diameter is equal to the pipe interior diameter. Entering this value and the **Design By-Pass Pipe Hydraulic Diameter** input parameter allows the **Design Fish Screen Sweep Velocity**, **Design Input Pipe Velocity** and **Design By-Pass Pipe Velocity** output parameters to be calculated. You may initially leave this input parameter blank or enter 0 which will enable the calculator to generate the initial output results to allow you to design the pipe and determine this value.

6) **Design By-Pass Pipe Hydraulic Diameter (Inches)** - This is the hydraulic diameter of the by-pass pipe as designed and determined as described in the instructions. For a full flowing circular pipe, the hydraulic diameter is equal to the pipe interior diameter. Entering this value and the **Design Input Pipe Hydraulic Diameter** input parameter allows the **Design Fish Screen Sweep Velocity**, **Design Input Pipe Velocity** and **Design By-Pass Pipe Velocity** output parameters to be calculated. You may initially leave this input parameter blank or enter 0 which will enable the calculator to generate the initial output results to allow you to design the pipe and determine this value.

Click Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Minimum Input Pipe Flow Rate (Gallons/Minute)** - This is the minimum flow rate that must enter the tank which is equal to the sum of the **Required Output Pipe Flow Rate** input parameter and the **Design By-Pass Pipe Flow Rate** output parameter. Providing additional flow rate capacity in excess of this minimum value is acceptable and perhaps even preferable if economics and site location allow for this. The input pipe velocity contributes to the fish screen sweep velocity and should be designed as described in the instructions.

2) **Design By-Pass Pipe Flow Rate (Gallons/Minute)** - This is the design flow rate that is by-passed directly back to water source and NOT supplied to the water machine. This flow rate MUST always be larger than the **Required Output Pipe Flow Rate** input parameter. The by-pass pipe should be designed to provide this exact flow rate. The by-pass pipe velocity contributes to the fish screen sweep velocity and should be designed as described in the instructions.

3) **Minimum Fish Screen Area (Square Feet)** - This is the minimum tank fish screen area that satisfies the **Required Fish Screen Approach Velocity** input parameter given the **Required Output Pipe Flow Rate** input parameter.

4) **Minimum Tank Diameter (Feet)** - This is the minimum inside diameter of the tank given the **Minimum Fish Screen Area** output parameter.

5) **Design Fish Screen Sweep Velocity (Feet/Second)** - This is the estimated minimum water velocity component parallel and adjacent to the fish screen face based on the **Design Input Pipe Hydraulic Diameter** and **Design By-Pass Pipe Hydraulic Diameter** input parameters and the **Minimum Input Pipe Flow Rate**, **Design By-Pass Pipe Flow Rate**, and **Minimum Tank Diameter** output parameters. Both the **Design Input Pipe Hydraulic Diameter** and the **Design By-Pass Pipe Hydraulic Diameter** must first be designed and determined as described in the instructions and then entered into the calculator BEFORE this design velocity may be calculated.

6) **Design Input Pipe Velocity (Feet/Second)** - This is the design velocity of the input pipe to achieve the **Design Fish Screen Sweep Velocity** output parameter given the **Design Input Pipe Hydraulic Diameter** input parameter and **Minimum Input Pipe Flow Rate** output parameter. Both the **Design Input Pipe Hydraulic Diameter** and the **Design By-Pass Pipe Hydraulic Diameter** must first be designed and determined as described in the instructions and then entered into the calculator BEFORE this design velocity may be calculated.

7) **Design By-Pass Pipe Velocity (Feet/Second)** - This is the design velocity of the by-pass pipe to achieve the **Design Fish Screen Sweep Velocity** output parameter given the **Design By-Pass Pipe Hydraulic Diameter** input parameter and **Design By-Pass Pipe Flow Rate** output parameter. Both the **Design Input Pipe Hydraulic Diameter** and the **Design By-Pass Pipe Hydraulic Diameter** must first be designed and determined as described in the instructions and then entered into the calculator BEFORE this design velocity may be calculated.

Under Oregon and Washington law, all water is publicly owned. Landowners must obtain a permit from the Water Resources Department to use water flowing past, through, or under their property. Only after a permit is granted, may the applicant construct a water project and begin using water. After the water project is completed, the permit holder must hire a Certified Water Rights Examiner to complete

a survey of water use and submit a map and report detailing how and where the water is being used for beneficial use. If the water has been shown to be used according to the provision of the permit, a water right certificate will be issued by the Water Resources Department. If you find that you need this service, we hope that you will consider Borst Engineering and Construction.

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Hydraulic Ram Pump Performance Calculator

This calculator is dedicated to our good friend and affiliate, Harry Landis, who died in an ultra-light airplane accident on 1 November 2015 while in Guatemala at his *Finca Ixobel* ***hydram testing site. As requested by his family and in honor of Harry, we are now manufacturing and selling the Landis hydraulic ram pump to keep it available to those who need this pump. This calculator is for the improved 2-inch diameter drive line version of the hydraulic ram pump that we helped Harry Landis design and which he sold on eBay for several years. Thank you Harry for all your contributions in improving the state-of-the-art hydraulic ram pumps. You will be sorely missed.***

A hydraulic ram pump (often called a "hydram") is a cyclic water pump powered by hydropower. It functions as a hydraulic transformer that uses water at a low head pressure and high flow rate to deliver water at a higher head pressure and lower flow rate. A hydram uses water hammer physics to pump a portion of the input water that powers the hydram to be lifted to a point higher than where the water is originally obtained. A hydram does not require any additional source of power and only uses energy obtained from the water source. As such, a hydram may be used in remote areas where there is both a source of hydropower and a need to deliver water to a destination higher in elevation than the water source. When designing a conventional electro-mechanical pump installation it is entirely acceptable to treat the hydraulic line and pump characteristics separately and then combine these characteristics. However, this would not be an acceptable approach for designing a hydram installation because the operation and performance of a hydram is very strongly influenced by the water hammer physics occurring within the drive line.

There is some terminology associated with a hydram that first needs to be explained and fully understood. The pipe feeding water to the hydram is called the "drive line". The pipe delivering water to the storage tank is called the "delivery line". "Fall" is the total elevation that the water feeding the hydram falls before reaching the hydram. "Lift" is the total elevation that the hydram lifts the water to the storage tank. The water that is used to generate the hydram pumping power, but that does not get delivered to the storage tank, is called "waste" and flows out of the clack/waste valve of the hydram. The hydram operating frequency can be readily heard, timed with a stopwatch, and set to the appropriate frequency (typically between 40 and 100 cycles/minute) to govern how much water is used to generate the hydram pumping power and the associated delivery line flow rate.

Hydrams are mechanically simple and only have two moving parts, a clack/waste valve and a delivery line check valve. The clack/waste valve essentially senses the velocity of the water flowing through the drive line and at the required peak drive flow rate (which is normally set by tuning the hydram to the frequency setting required to achieve the optimum and maximum delivery flow rate performance), quickly closes causing the water to suddenly stop which creates the water hammer effect that produces the hydram pumping power. The purpose of the delivery line check valve is to only allow water to flow one-way through the delivery line when this water hammer effect occurs, and to not allow any delivered water to back-flow into the hydram and out the clack/waste valve when the water hammer effect is not present. While the function of this delivery line check valve may sound simple enough, this check valve must be very efficient (i.e., not create significant friction head loss) in order to maximize delivery flow rate performance, operate at high delivery line pressures, operate at high instantaneous flow rates that may be several hundred times larger than the average delivery line flow rate, and accomplish about 100,000 cycles per day for many decades without failing.

A hydram has three distinct operational phases: acceleration, delivery and recoil. During the acceleration phase, which begins at the exact moment when the clack/waste valve first opens, the water accelerates down

the drive line, through the hydram, and discharges out the open clack/waste valve. As the flow rate increases, it reaches a velocity where the drag force is sufficient to start closing the clack/waste valve very quickly. During the <u>delivery phase</u>, which begins at the exact moment when the clack/waste valve first closes, the water that is flowing down the drive line with considerable momentum suddenly slows down. It is this large change in kinetic water energy that is used to create the hydram pumping power. For a fraction of a second, the water in the hydram, which is normally considered to be incompressible, is actually compressed causing a very large and very rapid rise in the water pressure within the hydram which is known as water hammer. When this water hammer pressure wave exceeds the delivery line pressure, the delivery line check valve opens and water is forced through the check valve and through the delivery line into the storage tank. The delivery line check valve stays open until the water flow in the drive line is nearly stopped and the pressure in the hydram drops below the delivery line pressure, causing the check valve to close. During the <u>recoil phase</u>, which begins at the exact moment when the delivery line check valve first closes, the water that is flowing down the drive line finally comes to a complete stop and recoils against BOTH the closed check valve and the closed clack/waste valve (e.g., like a rubber ball thrown against a hard wall) sending both a water hammer pressure wave and water hammer flow wave back up the drive line and out the drive line inlet. The water hammer pressure wave travels at the effective speed of sound in drive line and the water hammer flow wave travels much slower. The water hammer flow wave recoil effect causes the pressure in the hydram to then drop below atmospheric pressure causing the clack/waste valve to open, causing air to be drawn through the high friction snifter valve (if one is installed) and causing air to be drawn through the low friction clack/waste valve. These three operational phases then repeat continuously, which steadily forces water through the delivery line into the storage tank. Hydrams often incorporate a hydraulic accumulator (i.e., either an air bladder tank or a non-bladder air tank that uses a hydram snifter valve to keep the non-bladder tank full of air) to smooth the pulsating water that flows through delivery line check valve into a smoother delivery line flow rate.

The hydram design that we experimented with and refined has been successfully designed and fabricated to achieve maximum delivery flow rate performance with zero maintenance. This hydram may be purchased here:

Landis Hydraulic Ram Pumps - For Sale Here!

We have seen hydrams made with plastic or aluminum components, but they never work very well and don't last very long because the plastic flexes which reduces efficiency and the aluminum/plastic eventually fails from the large number of water hammer pressure stress cycles, often in excess of 150,000 cycles per day. Plastic is also subject to sunlight UV degradation. You will notice that manufacturers who sell production aluminum/plastic hydrams often sell repair kits for them too. And these mass produced aluminum/plastic hydrams that always seem to come and go on the marketplace often cost way more than the 40+ year time tested Landis hydram. Furthermore, drinking water that comes in contact with aluminum or plastics containing BPA has been shown to be detrimental to one's health. The Landis hydram is constructed mostly of carbon steel (stronger and more rust resistant than cast iron) and the remaining other components are constructed from NSF certified materials. Unlike many hydrams, every component of the Landis hydram is DIY friendly and can be easily DIY modified/repaired as desired/needed.

Traditionally, hydrams have used a waste (clack) valve much like the valves in a car engine to close the drive pipe and generate the pressure pulse which pumps the water to the storage reservoir. The main cause of failure or reduced efficiency in these pumps has been the wearing of the waste valve guide due to metal against metal movement, sometimes aggravated by silt or grit in the water, as well as uneven wear on the valve seat, leading to incomplete sealing and loss of pressure.

The Landis hydram design is a considerable improvement over traditional hydrams, as it basically eliminates this cause of failure and poor operation. In the Landis design, the waste valve and guide is replaced by a polished glass ball which closes against a thick rubber seat. The ball rests in a sort of cage, and when the flow of water past it is sufficient, it is carried upward against the rubber seat, thus stopping the flow, and causing a water hammer pressure pulse in the drive pipe. This pressure pulse opens the check valve beneath the ballast tank which causes water to flow into the ballast tank until the pressure pulse is dissipated. The check valve then closes, the waste valve ball drops, and the cycle repeats. Since the waste valve ball is round, it will wear evenly (if it ever wears at all), so it will always seal well against the rubber seat. The frequency setting of the Landis hydram is adjusted by loosening a nut on the bottom of the clack/waste valve cylinder, turning the shaft to raise or lower the cage holding the glass ball, and then tightening the nut after the required operating frequency is achieved. Raising the cage increases the operational frequency and lowering the cage decreases the operational frequency.

It should be noted that the flexibility and capability of the Landis hydram to use different delivery line check valve options is a very worthwhile benefit that other commercial hydrams do not currently offer. Several years ago, Borst Engineering & Construction designed and fabricated a highly efficient delivery line check valve for the original Landis hydram that significantly increased delivery flow rate performance. With this new Borst delivery line check valve, the maximum delivery flow rate performance at our Rogue River, Oregon company headquarters hydram test site went from 514 to 1531 GPD with our 5.5 feet of Fall; 28.3 feet of Lift; 1.5 inch diameter times 63 feet long galvanized steel drive line; and 2 inch diameter times 320 feet long PVC delivery line; operating at 36 CPM. We normally operate this hydram at 70 CPM to deliver 1004 GPD into underground water storage tanks which more than satisfies all of our domestic water, fire suppression, and irrigation water needs. A standpipe was used in this installation. Videos of this standpipe and this hydram may be found here:

[Borst Standpipe Installation](#)

[Borst Hydram Installation](#)

While appearing mechanically simple, hydrams do exhibit complex behavior that can result in erratic and unreliable operation. This calculator determines the kinetic water energy that can be generated by accelerating water through the drive line given the initial potential water energy after accounting for the friction characteristics of the drive line and the hydram. This calculator then determines the percentage of this kinetic energy that may be used for hydram pumping power after accounting for the friction characteristics of the delivery line check valve, the friction characteristics of the delivery line, and the quantized energy effect caused by the even or odd number of water hammer flow waves that occur in the drive line based on the innovative research and excellent work done by O'Brien 1933, Rennie 1980 and Thomas 1994. As such, this calculator models the complex behavior that can result in erratic and unreliable operation so this behavior can be accurately forecast during the hydram installation design phase and thus avoided during actual hydram operation. This may well be the most sophisticated and accurate hydram performance calculator available today.

You should always first communicate and coordinate with the local Department of Fish and Wildlife, and local Water Resources Department BEFORE constructing any water work project.

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Maximum Available Water Source Flow Rate (Gallons/Minute)** - This is the maximum flow rate of the water source that is available to feed the hydram. You may measure this maximum flow rate with a bucket and a stopwatch. You should initially enter a very large value (e.g., 1000) into the calculator and click Solve, to determine the **Drive Flow Rate** output parameter. The **Drive Flow Rate** is the minimum amount of water source flow rate required by the hydram to operate at the optimum **Actual Frequency Setting** output value for the installation input parameters you entered into the calculator. If the water source can easily supply this minimum flow rate, the water source is NOT limiting and you should just continue to use this very large value for the maximum available water source flow rate.

   If the water source can NOT supply this amount, you will need to use the **Desired Frequency Setting** logic input parameter to operate the hydram at a higher frequency than the previously determined optimum **Actual Frequency Setting** so as to reduce the **Drive Flow Rate** to a flow rate that can be easily supplied by the water source. Doing this will likely increase the **Installation Efficiency** output parameter and decrease the **Delivery Flow Rate** output parameter. You may need to change the installation input parameters in order to reduce the **Drive Flow Rate** to a flow rate that can be easily supplied by the water source. This maximum available water source flow rate input parameter is primarily intended to make sure that you are fully aware that each hydram installation has a minimum **Drive Flow Rate** requirement that can NOT be violated. If the water source flow rate ever becomes less than this required **Drive Flow Rate** (perhaps because of a drive line blockage or a decrease in the Fall), the hydram may stop operating, which will usually result in the clack/waste valve getting stuck in the <u>open</u> position.

2) **Fall 1 - Water Elevation above Drive Line Inlet (Feet)** - This is the height of the water surface above the drive line inlet. This allows addressing the situation of feeding the hydram from below the base of a dam. If you can measure the static pressure at the drive line inlet, Fall 1 is this pressure in PSI divided by 0.433.

3) **Fall 2 - Drive Line Inlet Elevation above Pump (Feet)** - This is the elevation difference between the drive line inlet and the hydram inlet. This allows addressing the situation of feeding the hydram from just below the surface of a stream using a gravity flow pipe. The site and installation may have a combination of Fall 1 and Fall 2 and you may need to enter values for both.

4) **Lift - Desired Pumping Elevation above Pump (Feet)** - This is the elevation of the delivery line outlet at the storage tank located above the hydram. The Lift must be at least greater than two times the total **Fall** input parameters in order for the hydram to operate. It is recommended that the Lift be greater than five times the total **Fall** input parameters to ensure good operational reliability.

5) **Drive Line Inlet Loss Coefficient** - This is used to determine the drive line inlet friction and the associated head loss given how the drive line inlet is constructed. This is typically 0.3.

6) **Drive Line Nominal Diameter (Inches)** - This is the standard nominal diameter of the drive line pipe. If you enter a standard pipe size (e.g., 0.5, 0.75, 1.0, 1.25, 1.5, 2, 2.5 or 3.0 inches), the calculator will use the actual inside diameter of standard steel pipe. For example, the actual

inside diameter of 1.5 inch standard steel pipe is 1.61 inches. If you have nonstandard pipe, enter the actual inside diameter.

7) **Drive Line Length (Feet)** - This is the length of the drive line, which should be completely straight, between the drive line inlet and the hydram (i.e., drive line outlet). Standard steel pipe generally comes in lengths of 21 ft. ***Please note that there is both a minimum and maximum acceptable drive line length.*** Please consider the **Minimum Drive Line Length** and **Maximum Drive Line Length** output parameter limits. The **Actual Frequency Setting** output parameter that is required to operate a hydram with a drive line that violates these drive line limits may be higher or lower than the hydram is actually capable of achieving. The drive line length has a significant effect on delivery flow rate performance and the optimum drive length is typically midway between the **Minimum Drive Line Length** and **Maximum Drive Line Length**. So, in some cases, it may be appropriate to put a standpipe somewhere between the water source and the drive line inlet to shorten the drive line length to allow staying within these limits.   If this is done, the pipe upstream of the standpipe may be made of polyethylene or PVC for economic advantage. The standpipe should be at least 4 times the diameter of the drive line. The top of the standpipe should be a couple feet higher in elevation than the water surface elevation of the water source feeding it.

8) **Drive Line Darcy-Weisbach Absolute Roughness (Inches)** - This is the absolute roughness of the drive line pipe material and this parameter is used to determine the friction head loss. Enter 0 for steel pipe having a Darcy-Weisbach absolute roughness of 0.006 inches. Enter 1 for polyethylene tube or PVC pipe having a Darcy-Weisbach absolute roughness of 0.00006 inches. If you are using some other material for the drive line, enter the actual Darcy-Weisbach absolute roughness for the material.

9) **Drive Line Material Elastic Modulus (Pounds/Square Inch)** - This is the elastic modulus of the drive line pipe material. The elastic modulus is a measure of how much a material deforms elastically (i.e., non-permanently) when a force is applied to it. Enter 0 for galvanized steel pipe having an elastic modulus of 29,000,000 PSI. Enter 1 for PVC pipe having an elastic modulus of 490,000 PSI. If you are using some other material for the drive line, enter the actual elastic modulus for the material. The drive line material elastic modulus is used to determine the drive line effective speed of sound which has a significant effect on hydram performance.

10) **Delivery Line Nominal Diameter (Inches)** - This is the standard nominal diameter of the delivery line. If you enter a standard pipe size (e.g., 0.5, 0.75, 1.0, 1.25, 1.5, 2, 2.5 or 3.0 inches), the calculator will use the actual inside diameter of polyethylene or PVC pipe. For example, the actual inside diameter of 0.75 inch standard polyethylene tube is 0.82 inches. If you have nonstandard pipe, enter the actual inside diameter.

11) **Delivery Line Length (Feet)** - This is the length of the delivery line between the hydram and the storage tank.

12) **Delivery Line Darcy-Weisbach Absolute Roughness (Inches)** - This is the absolute roughness of the delivery line pipe material and this parameter is used to determine the friction head loss. Enter 0 for steel pipe having a Darcy-Weisbach absolute roughness of 0.006 inches. Enter 1 for polyethylene tube or PVC pipe having a Darcy-Weisbach absolute roughness of 0.00006 inches.

If you are using some other material for the delivery line, enter the actual Darcy-Weisbach absolute roughness for the material.

13) **Desired Frequency Setting (Cycles/Minute)** - This is a logic input parameter that allows you to either request the calculator to attempt to determine the optimum frequency setting that will provide the maximum **Delivery Flow Rate** output parameter with at least 75% operational reliability, or to request the calculator to attempt to determine the **Delivery Flow Rate** at some other desired frequency setting without any operational reliability restriction. You should normally just leave this logic input parameter blank and have the calculator attempt to determine the optimum frequency setting. ***Please be aware that the calculator may NOT be able to determine an optimum frequency setting for all possible installation input parameters that are entered.*** If the calculator is able to determine an optimum frequency setting, this optimum frequency setting is displayed by the **Actual Frequency Setting** output parameter and ALL the output parameters are based on this optimum frequency setting.

Using some other desired frequency setting in lieu of the optimum frequency setting may be beneficial when the **Maximum Available Water Source Flow Rate** input parameter is limiting. You may enter a desired frequency setting to have the calculator attempt to determine the **Delivery Flow Rate** at this different frequency setting. ***Please be aware that the calculator may NOT be able to determine a solution for every Desired Frequency Setting that is entered.*** If the calculator is NOT able to determine a solution for the entered desired frequency setting, the **Actual Frequency Setting** output parameter will display the optimum frequency setting and ALL the output parameters are based on this optimum frequency setting and NOT on the entered desired frequency setting. If the calculator is able to determine a solution within plus or minus 0.49 CPM of the entered desired frequency setting, this desired frequency setting is displayed by the **Actual Frequency Setting** output parameter and ALL the output parameters are based on this desired frequency setting. You should carefully consider the ramifications of the **Operational Reliability** output parameter BEFORE planning on operating the hydram at this desired frequency setting.

Click Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Delivery Flow Rate (Gallons/Day & Gallons/Minute)** - This is the average flow rate through the delivery line into the storage tank. This delivery flow rate is used to determine the friction head loss of the delivery line its effect on the associated **Installation Efficiency** output parameter. Please note that the delivery flow rate will change for different frequency settings. You may measure this average flow rate with a bucket and a stopwatch.

If the delivery flow rate is 0, the calculator could not determine an optimum frequency solution for the installation input parameters. You should check the **Drive Line Length** input parameter to verify that it is within the acceptable range of the **Minimum Drive Line Length** and **Maximum Drive Line Length** output parameters. You should check the **Lift** input parameter to verify that it is significantly less than the **Maximum Pumping Elevation** output parameter. Check if any of the other installation input parameters are perhaps not reasonable. Consider using the **Desired Frequency Setting** logic input parameter to enter different frequency settings to see if the

calculator can determine any solutions. If a solution can be determined, but the **Operational Reliability** output parameter is less than 75%, this may well be the problem. The calculator will only provide an optimum frequency setting and the associated delivery flow rate if it can find a solution that results in the operational reliability being equal or greater than 75%. The installation input parameters you have entered may NOT provide adequate operational reliability.

2) **Waste Flow Rate (Gallons/Minute)** - This is the average flow rate through the clack/waste valve. Please note that the waste flow rate will change for different frequency settings. You may measure this average flow rate with a bucket and a stopwatch.

3) **Drive Flow Rate (Gallons/Minute)** - This is the average flow rate through the drive line between the time when the flow rate is 0 (i.e., when the clack/waste valve just opens) and the time when the **Actual peak Drive Flow Rate** output parameter occurs (i.e., when the clack/waste valve just closes), while accounting for the time duration that the clack/waste valve remains closed.   As such, the drive flow rate is less than the **Mean Drive Flow Rate** output parameter, which does NOT account for the time duration that the clack/waste valve remains closed. Please note that the drive flow rate will change for different frequency settings and is limited to the **Maximum Available Water Source Flow Rate** input parameter. Since this average flow rate is internal to the installation, you can NOT measure this flow rate with a bucket and a stopwatch. However, this average flow rate is equal to the sum of the **Delivery Flow Rate** and **Waste Flow Rate** output parameters, which you may measure with a bucket and a stopwatch.

4) **Actual Frequency Setting (Cycles/Minute)** – This is the actual frequency setting that the calculator is able to determine a solution and ALL the output parameters are ALWAYS based on this displayed actual frequency setting solution. When the **Desired Frequency Setting** logic input parameter is left blank and the calculator is able to determine a solution, this is the optimum frequency setting such that the hydram delivers the maximum **Delivery Flow Rate** output parameter with at least 75% operational reliability. For this case, this optimum frequency setting is displayed and ALL the output parameters are based on this optimum frequency setting solution. When a desired frequency setting is entered for the **Desired Frequency Setting** and the calculator is able to determine a solution within plus or minus 0.49 CPM of this desired frequency setting, this desired frequency setting is displayed and ALL the output parameters are based on this desired frequency setting. The hydram operational frequency can be readily heard, timed with a stopwatch and set to this displayed actual frequency setting, which is typically between 40 and 100 CPM.

5) **Installation Efficiency (Percent)** - This is a measure of how well the overall hydram installation converts the available input power of the water source into output pumping power. As such, the installation efficiency represents the **Pumping Power** output parameter divided by the **Drive Power** output parameter. The installation efficiency may theoretically range from 0 to 100%. Please note that maximum installation efficiency does NOT result in maximum delivery flow rate performance. A hydram typically provides maximum delivery flow rate performance when the installation efficiency is between 50% and 70%. However, operating at a higher installation efficiency may be beneficial when the **Maximum Available Water Source Flow Rate** is limited.

6) **Minimum Drive Line Length (Feet)** - This is an estimate of the shortest length of drive line that can be successfully used as established by Calvert (1960). The calculator does NOT limit the

Delivery Flow Rate output parameter based on this minimum drive line length estimate. However, the optimum **Actual Frequency Setting** output parameter that is required to operate a hydram with a drive line less than this minimum drive line length estimate may be <u>higher</u> than the hydram is actually capable of achieving (e.g., more than 140 CPM).

7) **Maximum Drive Line Length (Feet)** - This is an estimate of the longest length of drive line that can be successfully used as established by Calvert (1960). The calculator does NOT limit the **Delivery Flow Rate** output parameter based on this maximum drive line length estimate. However, the optimum **Actual Frequency Setting** output parameter that is required to operate a hydram with a drive line more than this maximum drive line length estimate may be <u>lower</u> than the hydram is actually capable of achieving (e.g., less than 20 CPM).

8) **Nominal Delivery Line Pressure (Pounds/Square Inch)** - This is the pressure that would be measured in the delivery line at the hydram outlet while the hydram is operating. This pressure is the sum of the static water pressure between the hydram and the storage tank plus the increased pressure caused by friction in the delivery line from operating at the **Delivery Flow Rate** output parameter.

9) **Nominal Drive Line Pressure (Pounds/Square Inch)** - This is the pressure that would be measured in the drive line at the hydram inlet while the hydram is operating when the clack/waste valve is open. This pressure is the static water pressure between the hydram and the drive line inlet minus the reduced pressure caused by friction in the drive line from operating at the **Drive Flow Rate** output parameter.

10) **Maximum Water Hammer Drive Line Pressure (Pounds/Square Inch)** - This is the pressure that would be measured in the drive line that results from the water hammer pressure wave developed at the instant the clack/waste valve closes. This maximum water hammer drive line pressure is a function of the **Fall** input parameters, the effective speed of sound in the drive line (which is a function of the **Drive Line Material Elastic Modulus** input parameter) and the **Actual Peak Drive Flow Rate** output parameter (which is a function of the **Actual Frequency Setting** output parameter).

11) **Maximum Pumping Elevation (Feet)** - This is an estimate of the maximum pumping elevation that the hydram is capable of delivering water to a storage tank based on the **Maximum Water Hammer Drive Line Pressure** output parameter. The calculator does NOT actually limit the **Delivery Flow Rate** output parameter based on this maximum pumping elevation estimate. However, the **Delivery Flow Rate** will tend to approach 0 as the **Lift** input parameter approaches this maximum pumping elevation.

12) **Maximum Drive Line Flow Rate (Gallons/Minute)** - This is the maximum possible flow rate through the drive line that will be measured if the hydram is NOT installed at the drive line outlet. Please note that for a given installation, the maximum drive line flow rate will NOT change for different frequency settings and is NOT limited to the **Maximum Available Water Source Flow Rate** input parameter. The maximum drive line flow rate should be at least 3.5 times the **Drive Flow Rate** output parameter. You may measure this maximum flow rate with a bucket and a stopwatch.

13) **Mean Drive Line Flow Rate (Gallons/Minute)** - This flow rate is the mathematical mean value between the time when the clack/waste valve just opens and the time the clack/waste valve just closes (i.e., the time when the **Actual Peak Drive Flow Rate** output parameter occurs). As such, the mean drive flow rate is greater than the **Drive Flow Rate** output parameter, which accounts for the time duration that the clack/waste valve remains closed. Please note that the mean drive flow rate will change for different frequency settings and is NOT limited to the **Maximum Available Water Source Flow Rate** input parameter. You can NOT measure this mathematical flow rate with a bucket and a stopwatch.

14) **Drive Line Friction Head Loss at Mean Drive Line Flow Rate (Percent of Total Fall)** - This is the head loss caused by friction in the drive line from operating at the **Mean Drive Line Flow Rate** output parameter. This friction head loss reduces the effective Fall which reduces the delivery flow rate performance. 5% or less is recommended.

15) **Installation Friction Head Loss at Mean Drive Line Flow Rate (Percent of Total Fall)** - This is the head loss caused by friction in the BOTH the drive line and the hydram from operating at the **Mean Drive Line Flow Rate** output parameter. The clack/waste valve diameter should not be much less than the drive line diameter in order to minimize hydram friction. This installation friction head loss reduces the effective Fall which reduces the delivery flow rate performance. 10% or less is recommended.

16) **Delivery Line Friction Head Loss at Delivery Flow Rate (Percent of Lift)** - This is the head loss caused by friction in the delivery line from operating at the **Delivery Flow Rate** output parameter. This friction head loss increases the effective Lift which reduces the delivery flow rate performance. 10% or less is recommended.

17) **Maximum Peak Drive Flow Rate (Gallons/Minute)** - This is the maximum possible flow rate through the clack/waste valve that will be measured if the clack/waste valve is locked open. Please note that for a given installation, the maximum peak drive flow rate will NOT change for different frequency settings and is NOT limited to the **Maximum Available Water Source Flow Rate** input parameter. You may measure this maximum flow rate with a bucket and a stopwatch.

18) **Actual Peak Drive Flow Rate (Gallons/Minute)** - This is the instantaneous flow rate through the clack/waste valve just prior to the clack/waste valve closing. At the optimum frequency setting, the clack/waste valve closes at the optimum actual peak drive flow rate such that the hydram delivers the maximum **Delivery Flow Rate** output parameter. Please note that the actual peak drive flow rate will change for different frequency settings and is NOT limited to the **Maximum Available Water Source Flow Rate** input parameter. You can NOT measure this instantaneous flow rate with a bucket and a stopwatch.

19) **Drive Power (Watts)** - This is the available input power to the hydram that is generated from the acceleration of water through the drive line. The drive power is a function of the **Nominal Drive Line Pressure** and **Drive Flow Rate** output parameters.

20) **Pumping Power (Watts)** - This is the actual output power of the hydram used to deliver the water to the storage tank. The pumping power is a function of the **Nominal Delivery Line Pressure**

and **Delivery Flow Rate** output parameters. The pumping power represents the **Drive Power** output parameter times the **Installation Efficiency** output parameter.

21) **Head Ratio** - This is the ratio of the **Lift** to **Fall** input parameters after accounting for the friction head losses in the drive line and in the delivery line. The head ratio is useful for forecasting the hydram operational reliability. A minimum head ratio of 2 is required for a hydram to operate. A head ratio of 5 is needed to achieve the recommended minimum 75% operational reliability, which is the minimum operational reliability value the calculator will determine an optimum **Actual Frequency Setting** output parameter.

22) **Joukowski Ratio** - The Joukowski ratio is useful for forecasting the installation operational reliability. The Joukowski ratio must be greater than 1 for a hydram to operate. The fraction of available kinetic energy applied to pumping power goes from 0 to 89% when the Joukowski ratio goes from 1 to 1.5. Therefore, it is recommended that the Joukowski ratio be greater than 1.5. When the Joukowski ratio is within plus or minus the **Joukowski Ratio Unreliability Zone** output parameter from an even integer value, the **Operational Reliability** output parameter begins to quickly approach 0 and the hydram may stop operating, which will usually result in the clack/waste valve getting stuck in the <u>closed</u> position.

23) **Joukowski Ratio Unreliability Zone** - The Joukowski ratio unreliability zone is the quantity 1/(**Head Ratio** output parameter - 1). When the **Joukowski Ratio** output parameter is within plus or minus this quantity from an even integer value, the **Operational Reliability** output parameter begins to quickly approach 0 and the hydram may stop operating, which will usually result in the clack/waste valve getting stuck in the <u>closed</u> position.

24) **Operational Reliability (Percent)** - This is the hydram clack/waste valve operational reliability forecast at the **Actual Frequency Setting** output parameter based on the **Head Ratio** and the **Joukowski Ratio** output parameters. The lower the operational reliability, the higher is the likelihood that clack/waste valve operation will be unreliable. When the clack/waste valve operation is unreliable, the hydram may not initially start or the hydram may eventually stop operating after some period of time if any of the installation conditions change (e.g., the Fall or the frequency setting change), which will usually result in the clack/waste valve getting stuck in the <u>closed</u> position. Operational reliability will vary between 1% and 100% when the **Head Ratio** is greater than 2 and the **Joukowski Ratio** is greater than 1, with higher operational reliability occurring at higher **Head Ratio** values. Operational reliability is 0% when the **Head Ratio** is less than 2, when the **Joukowski Ratio** is less than 1, or when the **Joukowski Ratio** is an exact even integer value. At least 75% operational reliability is recommended, which is the minimum value the calculator will determine an optimum **Actual Frequency Setting** output parameter when the **Desired Frequency Setting** input parameter is left blank and NOT used to enter a frequency setting.

Under Oregon and Washington law, all water is publicly owned. Landowners must obtain a permit from the Water Resources Department to use water flowing past, through, or under their property. Only after a permit is granted, may the applicant construct a water project and begin using water. After the water project is completed, the permit holder must hire a Certified Water Rights Examiner to complete a survey of water use and submit a map and report detailing how and where the water is being used for beneficial use. If the water has been shown to be used according to the provision of the permit, a

water right certificate will be issued by the Water Resources Department. If you find that you need this service, we hope that you will consider Borst Engineering and Construction.

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Hydroelectric Capacity Calculator

Before investing in hydroelectric equipment, it is always worthwhile to determine if the site can provide the hydroelectric capacity (i.e., power in kilowatts and energy in kilowatt hours per month) that you believe you require. And before you form a firm belief about your electrical requirements, you should first consider doing everything possible beforehand to reduce the overall electrical footprint.

A penstock is the pipe or ditch used to feed water to the turbine. The hydroelectric capacity that can be generated at a given site is primarily dependent on two design parameters, the penstock design flow rate and the head available at the penstock outlet. The penstock design flow rate is the amount of water that is available from the water source that will actually be fed to the turbine via the penstock measured in gallons/minute. The head available at the penstock outlet (and hence available to the turbine inlet) is the sum of the penstock design inlet pressure and the penstock design elevation change minus the penstock actual friction head loss measured in feet.

This calculator is based on the Hazen-Williams formula, which is used to determine the minimum hydraulic diameter that is governed by the resulting actual friction head loss given the design flow rate and the other secondary penstock design parameters (i.e., hydraulic radius, length, and Hazen-Williams friction coefficient). The hydraulic diameter is defined as FOUR times the "hydraulic radius" (i.e., NOT two times as might be expected). The hydraulic radius is defined as the ditch or pipe cross-sectional area divided by the "wetted perimeter". The wetted perimeter is defined as the perimeter of the ditch or pipe cross sectional area that is "wet". ***For a full flowing circular pipe, the hydraulic diameter is equal to the pipe interior diameter.***

You should always first communicate and coordinate with the local Department of Fish and Wildlife, and local Water Resources Department BEFORE constructing any water work project.

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Penstock Design Flow Rate (Gallons/Minute)** - This is the design flow rate of water that is available from the water source that will actually be fed to the turbine via the penstock after accounting for actual friction head loss.

2) **Penstock Design Inlet Pressure (Pounds/Square Inch)** - This is the static pressure at the penstock inlet. This allows addressing the situation of feeding the turbine from below the base of a dam. If you can determine the water depth above the drive line inlet, the design inlet pressure in PSI is this water depth in feet multiplied by 0.433.

3) **Penstock Design Elevation Change (Feet)** - This is the elevation difference between the penstock inlet elevation at the water source location and the penstock outlet elevation at the turbine location. This allows addressing the situation of feeding the turbine from just below the surface of a stream using a gravity flow pipe. This parameter may be measured by running a hose from the water source location to the turbine location and using a pressure gauge to measure the static water pressure in PSI at the turbine location. The design head in feet is this static water pressure in PSI divided by 0.433. The site and installation may have a combination of design inlet pressure and design elevation and you may need to enter values for both.

4) **Penstock Design Hydraulic Diameter (Inches)** - This is the hydraulic diameter that will be used for the penstock. For a full flowing circular pipe, the hydraulic diameter is equal to the pipe interior diameter. However, the hydraulic diameter may be entered for a noncircular ditch or for a less than full flowing pipe. Initially enter 0 or leave this blank and enter an appropriate value for the **Penstock Design Friction Head Loss** input parameter to have the calculator determine the **Penstock Minimum Hydraulic Diameter** output parameter. The **Penstock Minimum Hydraulic Diameter** output parameter should be considered and a standard interior diameter of commercially available pipe should be selected and entered as this penstock design hydraulic diameter. The output parameters are ALWAYS based on the entered penstock design hydraulic diameter and are NEVER based on the **Penstock Minimum Hydraulic Diameter** unless it is actually entered.

5) **Penstock Design Length (Feet)** - This is the effective length of the penstock. If the penstock is other than straight (e.g., if the penstock has elbows, valves, etc.), the effective length should be increased from the actual length in accordance with best engineering fluid dynamic practices.

6) **Penstock Design Hazen-Williams Friction Coefficient** - This is used to determine the actual friction head loss resulting from the penstock material being used. This is typically150 for PVC, 130 for plain steel, and 120 for concrete.

7) **Penstock Design Friction Head Loss (Feet)** - This design parameter allows trading the **Penstock Actual Friction Head Loss** output parameter (and the associated penstock construction economics) against the **Head Available at Penstock Outlet** and **Estimated Power** output parameters to determine a suitable **Penstock Minimum Hydraulic Diameter** output parameter. Decreasing the penstock design friction head loss will increase the **Head Available at Penstock Outlet** and **Estimated Power**, but will increase the **Penstock Minimum Hydraulic Diameter** (and increase the associated penstock construction economics). Increasing the penstock design friction head loss will have the opposite effect. The penstock design friction head loss is typically 5 to 15% of either the **Penstock Design Length** input parameter or the **Head Available at Site** output parameter.

8) **Turbine Design Speed (Rotations/Minute)** - This is the rotation speed you will operate the turbine. This input parameter is used to determine the **Maximum Steady Shaft Torque**, **Turbine Specific Speed** and **Turbine Type Recommendation** output parameters and may be left blank if this information is not desired. We recommend that you initially enter a very low RPM and then slowly increase the RPM to see the effect this has on the output parameters. You should consider and determine the torque and RPM requirements of the generator before selecting this turbine design speed. Decreasing this turbine design speed will increase the **Maximum Steady Shaft Torque** output parameter. You may need to consider using a pulley drive system to have this turbine design speed and the **Maximum Steady Shaft Torque** meet the requirements of the generator. Please see our **Pulley Drive System Design Calculator**.

9) **Expected Turbine Efficiency (Percent)** - This is a measure of how well the turbine converts the energy of the stream (head and flow rate) into mechanical energy (torque and RPM). This is typically 60 to 80% for a cross flow turbine.

10) **Expected Generator Efficiency (Percent)** - This is a measure of how well the generator converts mechanical energy (torque and RPM) into electrical energy (volts and amps). 90% is typical for a Permanent Magnet Generator (PMG).

Click [Solve] after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Maximum Theoretical Power (Kilowatts)** - This is the maximum theoretical power that could be generated given the design flow rate and design head assuming that the turbine and the generator are 100% efficient. You will never actually be able to generate this much power in actual operation, however, this value must often be reported to water resource authorities when seeking a water right permit.

2) **Estimated Power (Kilowatts)** - This is the estimated power output that should be generated at the **Penstock Design Flow Rate**, **Expected Turbine Efficiency**, and **Expected Generator Efficiency** input parameters and the **Head Available at Penstock Outlet** output parameter.

3) **Estimated Energy (Kilowatt Hours/Month)** - This is the estimated energy that should be generated based on the **Estimated Power** output parameter.

4) **Maximum Steady Shaft Torque (Foot-Pounds)** - This is the maximum steady shaft torque that the turbine will produce given the design inputs. If you require more torque, decrease the **Turbine Design Speed** input parameter. If the **Turbine Design Speed** input parameter is not entered, the maximum steady shaft torque will indicate "NR" for Not Requested.

5) **Turbine Specific Speed** - This is a dimensionless speed parameter used by engineers to categorize different types of turbines. Pelton turbines have a turbine specific speed range of 10-30. Pelton turbines have a turbine specific speed range of 10-30. Turgo turbines have a turbine specific speed range of 20-70. Cross Flow turbines have a turbine specific speed range of 20-200. Francis turbines have a turbine specific speed range of 30-400. Kaplan turbines have a turbine specific speed range of 200-1000. If the **Turbine Design Speed** input parameter is not entered, the turbine specific speed will indicate "NR" for Not Requested.

6) **Turbine Type Recommendation** - This is the acceptable and recommended turbine type(s) for the site based on the **Turbine Specific Speed** output parameter. "C" indicates a Cross Flow turbine is recommended. "F" indicates a Francis turbine is recommended. "K" indicates a Kaplan turbine is recommended. "P" indicates a Pelton turbine is recommended. "T" indicates a Turgo turbine is recommended. There are turbine specific speed ranges where multiple turbine types are acceptable and recommended. If the **Turbine Design Speed** input parameter is not entered, the turbine type recommendation will indicate "NR" for Not Requested.

7) **Penstock Minimum Hydraulic Diameter (Inches)** - This is the minimum hydraulic diameter that the penstock must be to satisfy the **Penstock Design Friction Head Loss** input parameter and given the other penstock design input parameters. For a full flowing circular pipe, the hydraulic diameter is equal to the pipe interior diameter. The penstock should be constructed to have a hydraulic diameter that equals or slightly exceeds this minimum hydraulic diameter in order to

actually provide the **Penstock Design Flow Rate** input parameter required to achieve the **Head Available at Penstock Outlet** and **Estimated Power** output parameters. This penstock minimum hydraulic diameter should be considered and a standard interior diameter of commercially available pipe should be selected and entered as the **Penstock Design Hydraulic Diameter** input parameter. The output parameters are ALWAYS based on the entered **Penstock Design Hydraulic Diameter** input parameter and are NEVER based on the penstock minimum hydraulic diameter unless it is actually entered.

8) **Head Available at Site (Feet and Pounds/Square Inch)** - This is total head that is available from the water source and is the **Design Inlet Pressure** input parameter plus the **Design Elevation Change** input parameter (converted to feet and PSI).

9) **Penstock Actual Friction Head Loss (Feet and Pounds/Square Inch)** - This is the actual friction head loss of the penstock measured given the **Penstock Minimum Hydraulic Diameter** output parameter and given the other design input parameters. The penstock actual friction head loss is typically 5 to 15% of either the **Penstock Design Length** input parameter or the **Head Available at Site** output parameter.

10) **Penstock Specific Friction Head Loss (Feet and Pounds/Square Inch)** - This is the specific friction head loss of the penstock measured in feet and PSI per 100 feet of pipe given the **Penstock Design Length** input parameter and **Penstock Actual Friction Head Loss** output parameter.

11) **Head Available at Penstock Outlet (Feet and Pounds/Square Inch)** - This is the head that is available at the penstock outlet and turbine inlet which is the **Head Available at Site** output parameter minus the **Penstock Actual Friction Head Loss** output parameter.

Under Oregon and Washington law, all water is publicly owned. Landowners must obtain a permit from the Water Resources Department to use water flowing past, through, or under their property. Only after a permit is granted, may the applicant construct a water project and begin using water. After the water project is completed, the permit holder must hire a Certified Water Rights Examiner to complete a survey of water use and submit a map and report detailing how and where the water is being used for beneficial use. If the water has been shown to be used according to the provision of the permit, a water right certificate will be issued by the Water Resources Department. If you find that you need this service, we hope that you will consider Borst Engineering and Construction.

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Orifice Plate Capacity Calculator

Like our **Sprinkler Capacity Calculator**, this calculator is based on the Orifice Formula and is specifically used to design an orifice plate by determining the orifice flow rate coefficient, orifice diameter, orifice plate flow rate capacity, and orifice plate friction head loss. An orifice plate is a relatively thin plate with a relatively small diameter hole (i.e., an orifice) in the middle of the plate which is typically placed in a pipe system in which fluid flows. When the fluid reaches the orifice plate, the fluid is restricted and forced to converge to go through the orifice. The actual point of maximum convergence occurs immediately downstream of the orifice plate and is known as the vena contracta point. The fluid velocity increases and the fluid pressure decreases at the vena contracta point. Downstream of the vena contracta point, the fluid "recovers" such that the fluid velocity subsequently decreases and the fluid pressure subsequently increases. However, the fluid does not recover to the same velocity and pressure prior to encountering the orifice plate because of the friction head loss introduced by the orifice plate.

Some reasons for installing a restrictive orifice plate in a pipe system might include: measuring the differential pressure across the orifice plate as a means to determine the flow rate, increasing the pipe system friction head loss to allow running a pump close to the Best Efficiency Point (BEP), increasing the pipe velocity immediately downstream of the orifice plate for some specific purpose, decreasing the pipe pressure immediately downstream of the orifice plate for some specific purpose, or simply to just restrict and reduce the flow rate capacity of the pipe system for some specific purpose. You may have a situation where you need to add a device to the pipe system that will behave like an orifice plate (e.g., a check valve) and you want to size this device properly so that it does NOT overly restrict the flow rate. A good example of this situation is the check valve required for a hydram which must be designed to be highly efficient (i.e., result in minimal friction head loss at the required operational flow rate). Please see our **Hydraulic Ram Pump Performance Calculator** instructions for more information about this orifice plate check valve application as well as this fascinating water machine.

If the orifice flow rate coefficient is known, it should just be entered into the calculator. If the orifice flow rate coefficient is NOT known, this calculator can determine the orifice flow rate coefficient several different ways. The orifice flow rate coefficient may be determined by entering the measured orifice plate thickness, the measured pipe diameter upstream of the orifice plate, and the measured orifice diameter. The orifice flow rate coefficient may be determined by entering the measured orifice diameter, the measured flow rate, and the measured differential pressure across the orifice plate. The orifice flow rate coefficient may be determined by entering the measured orifice plate thickness, the measured pipe diameter upstream of the orifice plate, the measured flow rate, and the measured differential pressure across the orifice plate. Once the orifice flow rate coefficient or the aforementioned parameters required to determine the orifice flow rate coefficient are entered, this calculator will then determine the orifice diameter, orifice plate flow rate capacity, and the orifice plate friction head loss (i.e., the differential pressure across the orifice plate) if any two of these three parameters are then entered. Please note that the orifice plate flow rate capacity and orifice plate friction head loss are highly dependent on the orifice flow rate coefficient, orifice diameter, orifice plate thickness/orifice diameter ratio, and orifice diameter/pipe diameter ratio. These parameters and ratios must be carefully considered and selected when designing an orifice plate for each specific application.

You should always first communicate and coordinate with the local Department of Fish and Wildlife, and local Water Resources Department BEFORE constructing any water work project.

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Orifice Flow Rate Coefficient** - This is the known orifice flow rate coefficient which will typically range between 0.62 and 0.82 for a properly designed restrictive orifice plate. Leave this input parameter blank if you do NOT know this orifice flow rate coefficient and instead enter the measured **Orifice Plate Thickness**, **Pipe Diameter** and **Orifice Diameter** input parameters to have the calculator determine the **Orifice Flow Rate Coefficient** output parameter. You may enter the measured **Orifice Diameter**, **Flow Rate**, and **Differential Pressure** input parameters to have the calculator determine the **Orifice Flow Rate Coefficient** output parameter. You may enter the measured **Orifice Plate Thickness**, **Pipe Diameter**, **Flow Rate**, and **Differential Pressure** input parameters to have the calculator determine the **Orifice Flow Rate Coefficient** output parameter. The **Orifice Flow Rate Coefficient** output parameter is equal to this orifice flow rate coefficient input parameter, the **Flow Rate** output parameter is proportional to this orifice flow rate coefficient, and the **Friction Head Loss** output parameter is inversely proportional to the square of this orifice flow rate coefficient.

2) **Orifice Plate Thickness (Inches)** - This is the measured thickness of the orifice plate. Leave this input parameter blank if you know the **Orifice Flow Rate Coefficient** input parameter. If you do NOT know the **Orifice Flow Rate Coefficient** input parameter, but you do know and enter this measured orifice plate thickness and the measured **Pipe Diameter** and **Orifice Diameter** input parameters, the calculator will determine the **Orifice Flow Rate Coefficient** output parameter. When the orifice plate thickness/orifice diameter ratio is less than 0.25, the **Orifice Flow Rate Coefficient** output parameter is 0.62, the maximum restriction will occur, and the minimum **Flow Rate** output parameter will occur. When the orifice plate thickness/orifice diameter ratio is between 0.25 and 2, the **Orifice Flow Rate Coefficient** will range between 0.62 and 0.82. When the orifice plate thickness/orifice diameter ratio is between 2 and 3, the **Orifice Flow Rate Coefficient** is 0.82, the minimum restriction will occur, and the maximum **Flow Rate** output parameter will occur. When the orifice plate thickness/orifice diameter ratio is greater than 3, the engineering equations used in this calculator become invalid. When this occurs, the associated output parameters will indicate "NA".

3) **Pipe Diameter (Inches)** - This is the measured interior diameter of the pipe supplying the orifice plate. Leave this input parameter blank if you know the **Orifice Flow Rate Coefficient** input parameter. If you do NOT know the **Orifice Flow Rate Coefficient**, but you do know and enter this measured pipe interior diameter and the measured **Orifice Plate Thickness** and **Orifice Diameter** input parameters, the calculator will determine the **Orifice Flow Rate Coefficient** output parameter. When the orifice diameter/pipe diameter ratio becomes greater than 0.3, the orifice plate becomes less restrictive and the **Orifice Flow Rate Coefficient** output parameter will increase beyond the aforementioned **Orifice Flow Rate Coefficient** 0.62 to 0.82 range, with an increase the **Flow Rate** output parameter and a decrease in the **Friction Head Loss** output parameter. When the orifice plate orifice diameter/pipe Diameter ratio is greater than 0.95, the engineering equations used in this calculator become invalid. When this occurs, the associated output parameters will indicate "NA".

4) **Orifice Diameter (Inches)** - This is the measured diameter of the orifice in the orifice plate. Leave this input parameter blank if you do NOT know this orifice diameter and enter the desired/measured **Flow Rate** and **Differential Pressure** input parameters to have the calculator determine the **Orifice Flow Rate Coefficient**, **Orifice Diameter**, **Flow Rate**, and **Friction Head**

Loss output parameters. The **Orifice Flow Rate Coefficient** output parameter is inversely proportional to the square of this orifice diameter, the **Flow Rate** output parameter is proportional to the square of this orifice diameter, and the **Friction Head Loss** output parameter is inversely proportional to the fourth power of this orifice diameter.

5) **Flow Rate (Gallons/Minute)** - This is the desired or measured flow rate through the orifice plate. The calculator will use this flow rate to determine the **Orifice Flow Rate Coefficient** and **Friction Head Loss** output parameters at this flow rate. Leave this input parameter blank if you do NOT know this flow rate and enter the desired/measured **Orifice Diameter** and **Differential Pressure** input parameters to have the calculator determine this **Flow Rate** (i.e., the flow rate capacity of the orifice plate) and **Friction Head Loss** output parameters. The **Orifice Flow Rate Coefficient** output parameter is proportional to this flow rate, the **Flow Rate** output parameter is equal to this flow rate, and the **Friction Head Loss** output parameter is proportional to the square of this flow rate.

6) **Differential Pressure (Pounds/Square Inch)** - This is the desired or measured differential pressure across the orifice plate which is the orifice plate friction head loss. The calculator will use this differential pressure to determine the **Orifice Flow Rate Coefficient**, **Flow Rate** (i.e., the flow rate capacity of the orifice plate), and **Friction Head Loss** (i.e., the differential pressure across the orifice plate) output parameters at this differential pressure. Leave this input parameter blank if you do NOT know this differential pressure and enter the desired/measured **Orifice Diameter** and **Flow Rate** input parameters to have the calculator determine this **Friction Head Loss** (i.e., the differential pressure across the orifice plate) output parameter. The **Orifice Flow Rate Coefficient** output parameter is inversely proportional to the square root of this differential pressure, the **Flow Rate** output parameter is proportional to the square root of this differential pressure, and the **Friction Head Loss** output parameter is equal to this differential pressure.

If the orifice plate is being supplied from a pressurized source, and the orifice plate is at the end of an open pipe (e.g., a sprinkler), the differential pressure across the orifice plate is the source supply pressure. This Orifice Plate Capacity calculator will provide identical results as our **Sprinkler Capacity Calculator** plus provide the additional output parameters that would allow designing a sprinkler system if you enter 0.970 for the orifice flow rate coefficient and the same nozzle size and pressure. The Sprinkler Capacity calculator uses an orifice diameter/pipe diameter ratio equal to 0.876 and an orifice plate thickness/orifice diameter ratio less than 0.25, which results in this 0.970 orifice flow rate coefficient.

7) **Fluid Density (Pounds/Cubic Foot)** - This is the density of the fluid. 62.3 is typical for water at 60 degrees Fahrenheit.

Click Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Orifice Flow Rate Coefficient** - This is either the **Orifice Flow Rate Coefficient** input parameter or the calculated orifice flow rate coefficient based on the other entered input parameters if the **Orifice Flow Rate Coefficient** input parameter is NOT entered. This will typically range between

0.62 and 0.82 for a properly designed restrictive orifice plate. When the orifice diameter/pipe diameter ratio is greater than 0.3, the orifice plate will become less restrictive and the orifice flow rate coefficient will increase beyond the aforementioned range. If the **Orifice Flow Rate Coefficient** input parameter is NOT entered and "NA" is displayed, this indicates that the engineering equations used in this calculator are no longer valid because the orifice plate thickness/orifice diameter ratio is greater than 3, because the orifice diameter/pipe diameter ratio is greater than 0.95, or because the combination of entered input parameters are not possible and creates a conflict that the calculator can NOT resolve.

2) **Orifice Diameter (Inches)** - This is either the **Orifice Diameter** input parameter or the calculated orifice diameter based on the other entered input parameters if the **Orifice Diameter** input parameter is NOT entered. If the **Orifice Diameter** and **Orifice Flow Rate Coefficient** input parameters are NOT entered and "NA" is displayed, this indicates that the engineering equations used in this calculator are no longer valid because the orifice plate thickness/orifice diameter ratio is greater than 3, because the orifice diameter/pipe diameter ratio is greater than 0.95, or because the combination of entered input parameters are not possible and creates a conflict that the calculator can NOT resolve.

3) **Flow Rate (Gallons/Minute)** - This is either the **Flow Rate** input parameter or the calculated flow rate based on the other entered input parameters if the **Flow Rate** input parameter is NOT entered. If the **Flow Rate** and **Orifice Flow Rate Coefficient** input parameters are NOT entered and "NA" is displayed, this indicates that the engineering equations used in this calculator are no longer valid because the orifice plate thickness/orifice diameter ratio is greater than 3, because the orifice diameter/pipe diameter ratio is greater than 0.95, or because the combination of entered input parameters are not possible and creates a conflict that the calculator can NOT resolve.

4) **Friction Head Loss (Feet and Pounds/Square Inch)** - This is either the **Differential Pressure** input parameter or the calculated friction head loss based on the other entered input parameters if the **Differential Pressure** input parameter is NOT entered. If the **Differential Pressure** and **Orifice Flow Rate Coefficient** input parameters are NOT entered and "NA" is displayed, this indicates that the engineering equations used in this calculator are no longer valid because the orifice plate thickness/orifice diameter ratio is greater than 3, because the orifice diameter/pipe diameter ratio is greater than 0.95, or because the combination of entered input parameters are not possible and creates a conflict that the calculator can NOT resolve.

Under Oregon and Washington law, all water is publicly owned. Landowners must obtain a permit from the Water Resources Department to use water flowing past, through, or under their property. Only after a permit is granted, may the applicant construct a water project and begin using water. After the water project is completed, the permit holder must hire a Certified Water Rights Examiner to complete a survey of water use and submit a map and report detailing how and where the water is being used for beneficial use. If the water has been shown to be used according to the provision of the permit, a water right certificate will be issued by the Water Resources Department. If you find that you need this service, we hope that you will consider Borst Engineering and Construction.

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An overshot water wheel is a machine for converting the energy of falling water into power. An overshot water wheel consists of a large metal wheel, with a number buckets arranged on the outer rim forming the driving surface. Most commonly, the wheel is mounted vertically on a horizontal shaft. Overshot water wheels are normally fed indirectly by water from a pond, which is formed when a stream is dammed. A flume (i.e., a ditch or pipe) is typically used to bring the water from the pond to a few feet above the wheel. Overshot water wheels may be fed from below the base of a dam using an appropriate pipe sized so as to result in 0 head and minimal horizontal velocity at the overshot water wheel location. The overshot water wheels that we fabricate are about 88% efficient.

We prefer to fabricate our overshot water wheels using either stainless steel or weathering steel (e.g., COR-TEN steel) to eliminate any need for painting and to ensure a long life. You definitely should NOT use wood and you probably should avoid using ordinary steel (e.g., A36 or B36) too. Wood tends to absorb water unevenly which results in wheel unbalance and wood eventually rots. Ordinary steel requires excessive painting maintenance just to keep the wheel attractive. If ordinary steel is used and the wheel if fabricated by welding, the wheel will eventually fail because of corrosion induced fatigue failure at the weld joints. We always fabricate our overshot water wheel shafts using stainless steel and we always fabricate our shaft bearings using acetal plastic. Acetal plastic bearings have a much longer life than stainless steel ball/sleeve bearings, nylon bearings, or oil impregnated wood bearings. In addition to being an extremely strong and durable material, acetal plastic has self-lubricating properties and is dimensionally stable in a water environment.

As the water fills the overshot wheel buckets, there must be adequate ventilation to allow the air to escape the buckets quickly. This calculator sizes the flume width and the overshot wheel width to ensure this adequate ventilation is provided. Overshot water wheel buckets should be curved so as to match the horizontal/vertical velocity profile of the water from the flume so the water enters the buckets smoothly and without any splashing. The buckets should have several small holes on the bottom of each bucket to prevent air from getting drawn into and trapped in the buckets while they are submerged which may significantly reduce the efficiency of the overshot water wheel.

Overshot water wheels typically operate well below the required rotational speed of conventional generators. As a consequence, a high ratio drive system (e.g., often 100:1) must often be used which reduces overall system efficiency and increases maintenance and associated operating cost. Cross flow turbines will typically operate at significantly higher rotational speeds as overshot water wheels. If the water work project application is hydroelectric power generation, you may want consider our **Cross Flow Turbine Design Calculator**. Permanent Magnet Generators (PMG) are now available that provide high efficiency power generation even at relatively slow rotational speeds. This calculator allows you to design and build an overshot water wheel optimized to the specific design objectives and site conditions.

You should always first communicate and coordinate with the local Department of Fish and Wildlife, and local Water Resources Department BEFORE constructing any water work project.

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Flume Design Flow Rate (Gallons/Minute)** - This is the design flow rate of water that is available from the water source that will flow from the flume outlet with 0 head as a rectangular stream of water, travel horizontally through the air the **Horizontal Water Distance Flume Outlet**

Water travels to Wheel output parameter dimension, and fall vertically through the air the **Flume Outlet Height above Wheel** input parameter dimension and fill the top wheel buckets.

2) **Flume Design Inlet Pressure (Pounds/Square Inch)** - This is the static pressure at the flume inlet. This allows addressing the situation of feeding the overshot water wheel from below the base of a dam. If you can determine the water depth above the drive line inlet, the design inlet pressure in PSI is this water depth in feet multiplied by 0.433.

3) **Flume Design Elevation Change (Feet)** - This is the elevation difference between the flume inlet elevation at the water source location and the flume outlet elevation above the overshot water wheel location. This allows addressing the situation of feeding the overshot water wheel from just below the surface of a stream using a gravity flow pipe. This parameter may be measured by running a hose from the water source location to the overshot water wheel location and using a pressure gauge to measure the static water pressure in PSI at the overshot water wheel location. The flume design elevation change in feet is this static water pressure in PSI divided by 0.433. The site and installation may have a combination of flume design inlet pressure and flume design elevation and you may need to enter values for both.

4) **Flume Design Hydraulic Diameter (Inches)** - This is the hydraulic diameter that will be used for the flume. For a full flowing circular pipe, the hydraulic diameter is equal to the pipe interior diameter. The **Flume Minimum Hydraulic Diameter** output parameter should be considered and a standard interior diameter of commercially available pipe should be selected and entered as this flume design hydraulic diameter such that the **Flume Design Flow Rate** input parameter and the **Flume Actual Flow Rate** output parameter are nearly equal. The output parameters are ALWAYS based on the entered flume design hydraulic diameter and are NEVER based on the **Flume Minimum Hydraulic Diameter** unless it is actually entered.

5) **Flume Design Length (Feet)** - This is the effective length of the flume. If the flume is other than straight (e.g., if the flume has elbows, valves, etc.), the effective length should be increased from the actual length in accordance with best engineering fluid dynamic practices.

6) **Flume Design Hazen-Williams Friction Coefficient** - This is used to determine the flume actual friction head loss resulting from the flume material being used. This is typically150 for PVC, 130 for plain steel, and 120 for concrete.

7) **Flume Outlet Height above Wheel (Feet)** - This is the vertical dimension that the flume outlet is located above the top wheel buckets. The flume outlet should be designed to produce a rectangular stream of water that travels horizontally and vertically through the air, and flows into the top wheel buckets.

8) **Wheel Design Diameter (Feet)** - This is the diameter of the wheel. Larger wheel design diameters will increase the **Maximum Steady Shaft Torque** output parameter, but will reduce the **Wheel Optimal Rotation Speed** output parameter. Smaller wheel design diameters will increase the **Wheel Optimal Rotation Speed**, but will reduce the **Maximum Steady Shaft Torque**. You may need to consider and determine the torque and RPM requirements of the generator before selecting the wheel design diameter. You may need to consider using a pulley drive system to

change the **Maximum Steady Shaft Torque** and **Wheel Optimal Rotation Speed** to meet the requirements of the generator. Please see our **Pulley Drive System Design Calculator**.

9) **Bucket Thickness (Inches)** - This is the thickness of the bucket material. You may use our **Blade Stress Analysis Calculator (Euler-Bernoulli)** to determine the minimum recommended thickness of the bucket material to ensure long blade life.

10) **Shaft Diameter (Inches)** - This is the diameter of the shaft material. You may use our **Shaft Stress Analysis Calculator (Soderberg)** to determine the minimum recommended shaft diameter to ensure a long shaft life.

11) **Expected Wheel Efficiency (Percent)** - This is a measure of how well the wheel converts the kinetic energy of the flume water (head and flow rate) into mechanical energy (torque and RPM). This is typically 80 to 90%.

12) **Expected Generator Efficiency (Percent)** - This is a measure of how well the generator converts mechanical energy (torque and RPM) into electrical energy (volts and amps). 90% is typical for a Permanent Magnet Generator (PMG).

Click Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Maximum Theoretical Power (Kilowatts)** - This is the maximum theoretical power that could be generated given the design flow rate and head assuming that the overshot water wheel and the generator are 100% efficient. You will never actually be able to generate this much power in actual operation, however, this value must often be reported to water resource authorities when seeking a water right permit.

2) **Estimated Power (Kilowatts)** - This is the estimated power output that should be generated given the **Flume Outlet Height above Wheel**, **Wheel Design Diameter**, **Expected Wheel Efficiency** and **Expected Generator Efficiency** input parameters and the **Flume Actual Flow Rate** output parameter.

3) **Estimated Energy (Kilowatt Hours/Month)** - This is the estimated energy that should be generated based on the **Estimated Power** output parameter.

4) **Maximum Steady Shaft Torque (Foot-Pounds)** - This is the maximum steady shaft torque that the overshot water wheel will produce given the design inputs. If you require more torque, increase the **Wheel Design Diameter** input parameter.

5) **Flume Minimum Hydraulic Diameter (Inches)** - This is the minimum hydraulic diameter that the flume must be in order to provide the **Flume Design Flow Rate** input parameter given the other flume design input parameters. For a full flowing circular pipe, the hydraulic diameter is equal to the pipe interior diameter. The flume should be constructed to have a hydraulic diameter that equals or slightly exceeds this minimum hydraulic diameter in order to actually provide the **Flume Design Flow Rate** required to achieve the **Head Available at Flume Outlet** and **Estimated**

Power output parameters. This flume minimum hydraulic diameter should be considered and a standard interior diameter of commercially available pipe should be selected and entered as the **Flume Design Hydraulic Diameter** input parameter. The output parameters are ALWAYS based on the entered **Flume Design Hydraulic Diameter** input parameter and are NEVER based on the flume minimum hydraulic diameter unless it is actually entered.

6) **Flume Actual Flow Rate (Gallons/Minute)** - This is the actual flow rate of water through the flume given the given the flume design input parameters. The **Flume Minimum Hydraulic Diameter** output parameter should be considered and a standard diameter of commercially available pipe should be selected and entered as the **Flume Design Hydraulic Diameter** input parameter such that this flume actual flow rate is nearly equal to the **Flume Design Flow Rate** input parameter.

7) **Flume Actual Velocity (Feet/Second)** - This is the **Flume Actual Flow Rate** output parameter divided by the cross-sectional area of the flume.

8) **Flume Actual Reynolds Number** - This is an important design parameter often used by engineers. Greater than 4600, which is indicative of turbulent flow rate, is required to ensure the empirical Hazen-Williams formula used by this calculator remains valid for the calculation.

9) **Head Available at Site (Feet and Pounds/Square Inch)** - This is total head that is available from the water source and is the **Flume Design Inlet Pressure** input parameter plus the **Flume Design Elevation Change** input parameter (converted to feet and PSI).

10) **Flume Actual Friction Head Loss (Feet and Pounds/Square Inch)** - This is the actual friction head loss of the flume given the flume design input parameters. The flume actual friction loss should always be equal to the **Head Available at Site** output parameter.

11) **Flume Specific Friction Head Loss (Feet and Pounds/Square Inch)** - This is the specific friction head loss of the flume measured in feet and PSI per 100 feet of pipe given the **Flume Design Length** input parameter and **Flume Actual Friction Head Loss** output parameter.

12) **Head Available at Flume Outlet (Feet and Pounds/Square Inch)** - This is the head that is available at the flume outlet which is the **Head Available at Site** output parameter minus the **Flume Actual Friction Head Loss** output parameter. The head available at the flume outlet should always be equal to 0.

13) **Required Flume Outlet Width at Wheel (Inches)** - This is the required flume outlet width at the location where the rectangular water stream flows into the top wheel buckets so as to allow the air in the buckets to quickly escape and properly fill with water. The flume outlet should be designed to produce a rectangular water stream having this width dimension.

14) **Minimum Flume Outlet Depth at Wheel (Inches)** - This is the minimum flume outlet depth at the location where the stream of water flows into the top wheel buckets given the **Required Flume Outlet Width at Wheel** output parameter and the **Flume Actual Flow Rate** output parameter. The actual flume depth should be 10% to 20% larger than this depth to provide adequate design margin.

15) **Horizontal Water Distance Flume Outlet Water travels to Wheel (Inches)** - This is the horizontal distance that the rectangular stream of water travels through the air before flowing into the top wheel buckets given the **Flume Outlet Height above Wheel** input parameter.

16) **Wheel Water Velocity from Flume Outlet Height above Wheel (Feet/Second)** - This is the vertical velocity that the rectangular stream of water reaches while traveling through the air before flowing into the top wheel buckets given the **Flume Outlet Height above Wheel** input parameter.

17) **Wheel Optimal Tangential Velocity (Feet/Second)** - This is the optimal linear velocity at the **Wheel Working Diameter** found by experimentation to be 93% of the **Wheel Water Velocity from Flume Outlet Height above Wheel** output parameter.

18) **Wheel Optimal Rotation Speed (Rotations/Minute)** - This is the optimal rotational speed of the wheel given the **Wheel Optimal Tangential Velocity** and the **Wheel Working Circumference** output parameters. If you require more rotation speed, reduce the **Wheel Design Diameter** input parameter and/or increase the **Flume Outlet Height above Wheel** input parameter.

19) **Wheel Operating Head (Feet)** - This is the head resulting from the sum of the **Wheel Design Diameter** and the **Flume Outlet Height above Wheel** input parameters. The site must have this amount of head PLUS the additional head required to achieve the **Flume Actual Flow Rate** output parameter. To maximize the **Estimated Power** output parameter, it is preferable to apply as much of the available site head as possible to the **Wheel Design Diameter** and **Flume Outlet Height above Wheel** as opposed to applying it to the flume. To minimize flume construction cost, it may be preferable to apply more of the available site head to the flume thereby allowing a smaller **Flume Minimum Hydraulic Diameter** output parameter for a given **Flume Design Flow Rate** input parameter.

20) **Wheel Working Circumference (Feet)** - This is the effective wheel "working" circumference based on the **Wheel Design Diameter** input parameter.

21) **Wheel Working Cross-Sectional Area (Square Feet)** - This is the effective wheel "working" cross-sectional area given the **Flume Actual Flow Rate** and **Wheel Optimal Tangential Velocity** output parameters.

22) **Number of Wheel Buckets** - This is the recommended number of total buckets. It is recommended that the **Wheel Design Diameter** input parameter be varied so as to result in an even number of buckets to simplify construction. If radial arms will be used for the design in lieu of solid side plates, the number of wheel buckets should be a multiple of the **Number of Wheel Radial Arms** output parameter.

23) **Wheel Width & Bucket Length (Inches) -** This is the width of the wheel and the length of the buckets.

24) **Bucket Spacing & Width (Inches)** - This is the spacing between the center of the buckets as measured at the wheel design diameter. The buckets are connected such that there is NOT any

actual space between the buckets. This is the width of the buckets. This bucket width is used as an input parameter by our **Blade Stress Analysis Calculator (Euler-Bernoulli)**.

25) **Bucket Depth (Inches)** - This is the depth of the buckets which is 10% of the **Wheel Design Diameter** input parameter.

26) **Bucket Volume (Gallons)** - This is the volume of a single bucket.

27) **Number of Wheel Radial Arms** - The calculator determines the optimum even number of wheel radial arms (based on the Redtenbacher formula) that may be used to connect the wheel rim to the shaft hub if solid side plates are not used for the design. The number of wheel radial arms should be a multiple of the **Number of Wheel Buckets** output parameter.

28) **Weight of Wheel (Pounds)** - This is the fully fabricated weight of the wheel including the buckets, shaft, and solid side plates. It is assumed that the entire wheel is constructed using the same thickness steel as the buckets. The weight of the wheel may be significantly reduced by using radial arms in lieu of solid side plates.

29) **Maximum Bucket Force (Pounds)** - This is the maximum total force experienced by the buckets. The engineering equations consider both the water entry force into the buckets as well as the weight of the bucket being completely full of water. This maximum bucket force value must first be factored (i.e., multiplied by 0.0568) to account for the increased strength provided by overshot water wheel bucket structure as compared to blade structure BEFORE this value is used as an input parameter by our **Blade Stress Analysis Calculator (Euler-Bernoulli)**.

30) **Maximum Shaft Force (Pounds)** - This is the maximum total force experienced by the shaft. The engineering equations consider the **Weight of Wheel** output parameter and the weight of 50% of the buckets being completely full of water. There are potential failure modes that could result in 100% of the buckets being completely full of water and this is something that should be considered and addressed.

31) **Maximum Bucket Bending Moment (Inch-Pounds)** - This is the maximum bending moment experienced by a bucket resulting from the **Maximum Bucket Force** output parameter acting as a distributed load across the length of a fixed bucket. This maximum bucket bending moment value must first be factored (i.e., multiplied by 0.0568) to account for the increased strength provided by overshot water wheel bucket structure as compared to blade structure BEFORE this value is used as an input parameter by our **Blade Stress Analysis Calculator (Euler-Bernoulli)**.

32) **Maximum Shaft Bending Moment (Inch-Pounds)** - This is the maximum bending moment experienced by the shaft resulting from the **Maximum Shaft Force** output parameter acting as a concentrated load at the mid-span of a fixed shaft. This value is used as an input parameter by our **Shaft Stress Analysis Calculator (Soderberg)**.

Under Oregon and Washington law, all water is publicly owned. Landowners must obtain a permit from the Water Resources Department to use water flowing past, through, or under their property. Only after a permit is granted, may the applicant construct a water project and begin using water. After the water project is completed, the permit holder must hire a Certified Water Rights Examiner to complete

a survey of water use and submit a map and report detailing how and where the water is being used for beneficial use. If the water has been shown to be used according to the provision of the permit, a water right certificate will be issued by the Water Resources Department. If you find that you need this service, we hope that you will consider Borst Engineering and Construction.

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Unlike our **Pipe Capacity Calculator (Hazen-Williams)** and **Pipe & Pump System Design Calculator (Hazen-Williams)**, this Darcy-Weisbach formula based calculator is NOT limited to only water at 60 degrees Fahrenheit at turbulent flow rates, and is considered by many to be more accurate than Hazen-Williams formula based calculators. This calculator uses a Haaland simplified Colebrook-White equation to obtain the Darcy-Weisbach pipe friction factor using absolute pipe roughness and is valid for either laminar or turbulent flow based on the Reynolds number.

This calculator may be used to determine the maximum flow rate capacity of a gravity-fed pipe (perhaps from having the pipe inlet installed just below surface of stream), a pipe with a pressurized inlet (perhaps from having the pipe inlet installed at below the base of a dam or perhaps from being fed by a pump), or some combination. An example of this situation is the need to determine the maximum flow rate capacity that a ditch or pipe will divert water from one location to another location. Please see our **Ditch Capacity Calculator** and **Pipe Capacity Calculator (Hazen-Williams)**. *This type of calculation requires you to enter a known pipe hydraulic diameter into the calculator and determines the maximum flow rate capacity of a gravity-fed pipe which results in 0 head at the pipe outlet.* To perform this type of calculation, <u>enter 0</u> for logic input parameter 1) and enter the **Design Inlet Pressure** (if any), **Design Elevation Change** (if any), **Design Hydraulic Diameter**, **Design Length**, **Design Darcy-Weisbach Absolute Roughness**, **Fluid Density**, and **Fluid Dynamic Viscosity** input parameters. The **Design Flow Rate**, **Design Friction Head Loss** and **Pump Performance Curve Data Points** do NOT need to be entered.

This calculator may be used to determine the minimum hydraulic diameter of a gravity-fed pipe that will provide the required design flow rate and required head at the pipe outlet. The head at the pipe outlet is the head available at the pipe inlet minus the actual pipe friction head loss which results at the design flow rate. An example of this situation is the need to select an economical interior pipe diameter size to provide the required flow rate and the required head to feed a cross flow turbine or hydraulic ram pump. Please see our **Pipe Capacity Calculator (Hazen-Williams)**. *This type of calculation requires you to enter a design flow rate and design friction head loss into the calculator and determines the pipe minimum hydraulic diameter of a gravity-fed pipe which results in the required design flow rate and the required head at the pipe outlet.* A standard commercially available exterior pipe diameter size MUST first be selected, based on this minimum hydraulic diameter, and the standard interior diameter of this selected pipe MUST then be entered as the design hydraulic diameter input parameter in order to have the calculator correctly determine the associated output parameters. To perform this type of calculation, <u>enter 1</u> for logic input parameter 1) and enter the **Design Flow Rate**, **Design Inlet Pressure** (if any), **Design Elevation Change** (if any), **Design Length**, **Design Darcy-Weisbach Absolute Roughness**, **Fluid Density**, **Fluid Dynamic Viscosity**, and **Design Friction Head Loss** input parameters. After considering the minimum hydraulic diameter output parameter and selecting the design hydraulic diameter that will be used, then enter the **Design Hydraulic Diameter** input parameter. The **Pump Performance Curve Data Points** do NOT need to be entered.

This calculator may be used to determine the actual flow rate and pipe friction head loss (and associated pump head gain) which occurs when pumping water through an <u>open pipe/pump system</u> (i.e., water is pumped one-way from the pump to some destination) using a selected pump and selected pipe. An example of this situation would be the need to select an appropriate pump and pipe to pump a required water flow rate from one location to a different location. Please see our **Electric Pump Capacity Calculator**. *This type of calculation requires you to enter a pump performance curve for a selected pump into the calculator and determines the flow rate and head gain which results from using this selected pump in an open pipe/pump system.* A pump performance curve defines the flow rate and head characteristics of a pump and is published by the manufacturer

of the selected pump. The center of the pump performance curve is typically where the pump Best Efficiency Point (BEP) occurs and where you should operate the pump for maximum pump efficiency and minimum operating cost. To perform this type of calculation, <u>enter 2</u> for logic input parameter 1) and enter the **Design Inlet Pressure** (if any), **Design Elevation Change** (if any), **Design Hydraulic Diameter**, **Design Length** (the length of pipe between pump outlet and pipe outlet), **Design Darcy-Weisbach Absolute Roughness**, **Fluid Density**, **Fluid Dynamic Viscosity**, and **Pump Performance Curve Data Points** input parameters. The **Design Flow Rate** and **Design Friction Head Loss** input parameters do NOT need to be entered.

This calculator may be used to determine the actual flow rate and pipe friction head loss (and associated pump head gain) which occurs at hydraulic equilibrium when pumping water through a <u>closed pipe/pump system</u> (i.e., the pump outlet feeds a pressurized, closed pipe system that returns the water back to the pump inlet) using a selected pump and selected pipe. An example of this situation would be a closed circuit for a hydronic radiant floor heating system. Please see our <u>**Hydronic Radiant Floor Heating Design Calculator**</u>. ***This type of calculation requires you to enter a pump performance curve for a selected pump into the calculator and determines the flow rate and head gain which results from using this selected pump in a closed pipe/pump system.*** A pump performance curve defines the flow rate and head characteristics of a pump and is published by the manufacturer of the selected pump. The center of the pump performance curve is typically where the pump Best Efficiency Point (BEP) occurs and where you should operate the pump for maximum pump efficiency and minimum operating cost. To perform this type of calculation, <u>enter 3</u> for logic input parameter 1) and enter the **Design Hydraulic Diameter**, **Design Length** (the total length of pipe between pump outlet and pump inlet), **Design Darcy-Weisbach Absolute Roughness**, **Fluid Density**, **Fluid Dynamic Viscosity**, and **Pump Performance Curve Data Points** input parameters. The **Design Flow Rate**, **Design Inlet Pressure**, **Design Elevation Change**, and **Design Friction Head Loss** input parameters do NOT need to be entered.

This calculator is valid for noncircular ditch or pipe if the "hydraulic diameter" is entered for the **Design Hydraulic Diameter** input parameter. The hydraulic diameter is defined as FOUR times the "hydraulic radius" (i.e., NOT two times as might be expected). The hydraulic radius is defined as the ditch or pipe cross-sectional area divided by the "wetted perimeter". The wetted perimeter is defined as the perimeter of the ditch or pipe cross sectional area that is "wet". ***For a full flowing circular pipe, the hydraulic diameter is equal to the pipe interior diameter.***

You should always first communicate and coordinate with the local Department of Fish and Wildlife, and local Water Resources Department BEFORE constructing any water work project.

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Calculation Type (0=Pipe Capacity, 1=Pipe Design Flow Rate, 2=Open Pipe/Pump System Design, 3=Closed Pipe/Pump System Design)** - This is a logic input parameter that is used to tell the calculator which type of calculation should be performed. When 0 is entered, the calculator will determine the pipe maximum flow rate capacity **Actual Flow Rate** and other output parameters. When 1 is entered, the calculator will determine the **Minimum Hydraulic Diameter** and other output parameters for the entered **Design Flow Rate**. When 2 is entered, the calculator will determine the **Actual Flow Rate**, **Pump Head Gain** and other output parameters for an open pipe/pump system (i.e., water is pumped one-way from the pump to some destination) at system hydraulic equilibrium. When 3 is entered, the calculator will determine the **Actual Flow Rate**, **Pump Head Gain** and other output parameters for a closed pipe/pump system (i.e., the

pump outlet feeds a pressurized, closed pipe system that returns the water back to the pump inlet) at system hydraulic equilibrium.

2) **Design Flow Rate (Gallons/Minute)** - This is the design flow rate of water that is available from the water source that will flow through the pipe after accounting for actual friction head loss. The design flow rate is only used by the calculator when 1 is entered for logic input parameter 1).

3) **Design Inlet Pressure (Pounds/Square Inch)** - This is the static pressure at the pipe inlet. This allows addressing the situation of feeding the pipe inlet from below the base of a dam. If you can determine the water depth above the drive line inlet, the design inlet pressure in PSI is this water depth in feet multiplied by the quantity of 144 divided by the fluid density in pounds per cubic foot (i.e., 0.433 for water at 60 degrees Fahrenheit).

4) **Design Elevation Change (Feet)** - This is the elevation difference between the pipe inlet and the pipe outlet. This allows addressing the situation of feeding the pipe inlet from just below the surface of a stream using a gravity flow pipe. This parameter may be measured by running a hose from the pipe inlet location to the pipe outlet location and using a pressure gauge to measure the static water pressure in PSI at the pipe outlet location. The design head in feet is this static water pressure in PSI by the quantity of 144 divided by the fluid density in pounds per cubic foot (i.e., 0.433 for water at 60 degrees Fahrenheit). The site and installation may have a combination of design inlet pressure and design elevation change and you may need to enter values for both.

5) **Design Hydraulic Diameter (Inches)** - This is the hydraulic diameter that will be used for the pipe. However, the hydraulic diameter may be entered for a noncircular ditch or for a less than full flowing pipe. Initially enter 0 or leave this blank and enter an appropriate value for the **Design Friction Head Loss** input parameter to have the calculator determine the **Minimum Hydraulic Diameter** output parameter. **Minimum Hydraulic Diameter** should be considered and a standard interior diameter of commercially available pipe should be selected. Then enter this selected standard diameter as the design hydraulic diameter to have the calculator determine the output parameters. The output parameters are ALWAYS based on the entered design hydraulic diameter and are NEVER based on the **Minimum Hydraulic Diameter** unless it is actually entered.

6) **Design Length (Feet)** - This is the length of the pipe. If the pipe is other than straight (e.g., if the pipe has elbows, valves, etc.), the effective length should be increased from the actual length in accordance with best engineering fluid dynamic practices. For an open pipe/pump system, this is the length of pipe between pump outlet and pipe outlet. For a closed pipe/pump system, this is the total length of pipe between pump outlet and pump inlet.

7) **Darcy-Weisbach Absolute Roughness (Inches)** - This is the absolute roughness of the pipe material and this parameter is used to determine the friction head loss. This is typically 0.00006 inches for PVC, 0.0018 inches for plain steel, and 0.015 inches for concrete.

8) **Design Friction Head Loss (Feet)** - This design parameter allows trading the **Actual Friction Head Loss** output parameter (and the associated pipe construction economics) against the **Head Available at Outlet** output parameter to determine a suitable **Minimum Hydraulic Diameter**

output parameter. Decreasing the design friction head loss will increase the **Head Available at Outlet**, but will increase the **Minimum Hydraulic Diameter** (and increase the associated pipe construction economics). Increasing the design friction head loss will have the opposite effect. The design friction head loss is typically 5 to 15% of either the **Design Length** input parameter or the **Head Available at Site** output parameter. The design friction head loss is only used by the calculator when 1 is entered for logic input parameter 1).

9) **Fluid Density (Pounds/Cubic Foot)** - This is the density of the fluid. 62.3 is typical for water at 60 degrees Fahrenheit.

10) **Fluid Dynamic Viscosity (Pound-Second/Square Feet)** - This is the dynamic viscosity of the fluid. 0.00076 is typical for water at 60 degrees Fahrenheit.

11) **Pump Performance Curve Data Points (Gallons/Minute versus Feet)** - You may initially leave these input parameters blank or enter 0. A pump performance curve defines the flow rate and head characteristics of a pump and is published by the manufacturer of the selected pump. The center of the pump performance curve is typically where the pump Best Efficiency Point (BEP) occurs and where you should operate the pump for maximum pump efficiency and minimum operating cost. After you have selected an appropriate pump, enter the actual pump performance curve for the selected pump into the calculator via the 14 data points (i.e., 28 entries) consisting of pump flow rate (in Gallons/Minute) versus pump head (in Feet).   You may enter all 14 data points or you may enter less data points leaving any unused entries blank or 0. It is recommended that you use an adequate number of data points to accurately replicate the pump performance curve recognizing that the calculator will only do a linear interpolation between the data points. Example and illustrative pump performance curve data points are shown for a Grundfos UP15-42F pump.

Click Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Minimum Hydraulic Diameter (Inches)** - This is the minimum hydraulic diameter that the pipe must be to satisfy the **Design Friction Head Loss** input parameter and given the other design input parameters. For a full flowing circular pipe, the hydraulic diameter is equal to the pipe interior diameter. The pipe should be constructed to have a hydraulic diameter that equals or slightly exceeds this minimum hydraulic diameter in order to actually provide the **Design Flow Rate** input parameter. This minimum hydraulic diameter should be considered and a standard interior diameter of commercially available pipe should be selected and entered as the **Design Hydraulic Diameter** input parameter. The output parameters are ALWAYS based on the entered **Design Hydraulic Diameter** input parameter and are NEVER based on the minimum hydraulic diameter unless it is actually entered. "NA" is displayed when this output parameter is Not Applicable given the entered input parameters.

2) **Actual Flow Rate (Gallons/Minute)** - If 0 is entered for logic input parameter 1), this is the pipe maximum flow rate capacity given the other input parameters. If 1 is entered for logic input parameter 1), this is the **Design Flow Rate** input parameter. If 2 or 3 is entered for logic input parameter 1), this is the flow rate provided by the pump at system hydraulic equilibrium given the **Pump Performance Curve Data Points** input parameters.

3) **Actual Velocity (Feet/Second)** - If 0 is entered for logic input parameter 1), this is the pipe maximum velocity capacity given the other input parameters. If 1 is entered for logic input parameter 1), this is the **Design Flow Rate** input parameter divided by the cross-sectional area of the pipe. If 2 or 3 is entered for logic input parameter 1), this is the velocity provided by the pump at system hydraulic equilibrium given the **Pump Performance Curve Data Points** input parameters.

4) **Reynolds Number** - This is an important design parameter often used by engineers. The flow rate is considered laminar when the flow rate is less than 4000. The flow rate is considered turbulent when the Reynolds number if greater than 4000. Unlike Hazen-Williams based calculators, this calculator is valid for BOTH laminar and turbulent flow rates.

5) **Head Available at Site (Feet and Pounds/Square Inch)** - This is any head provided to the pipe inlet or pump inlet by the water source. The head available at site is the sum of the **Design Inlet Pressure** and the **Design Elevation Change** input parameters converted to feet and PSI. "NA" is displayed when this output parameter is Not Applicable given the entered input parameters.

6) **Actual Head Loss (Feet and Pounds/Square Inch)** - This is the pipe actual head loss (in feet) and pipe pressure drop (in PSI).

7) **Specific Head Loss (Feet and Pounds/Square Inch)** - This is the pipe specific head loss (in feet) and pipe pressure drop (in PSI) normalized per 100 feet of pipe. An economical pipe diameter to use for a project will typically result in 5 to 15 feet of head loss per 100 feet of pipe.

8) **Head Available at Outlet (Feet and Pounds/Square Inch)** - This is the head that is available at the pipe outlet which is the **Head Available at Site** output parameter plus the **Pump Head Gain** output parameter minus the **Actual Friction Head Loss** output parameter converted to feet and PSI. "NA" is displayed when this output parameter is Not Applicable given the entered input parameters.

9) **Pump Head Gain (% of Maximum Head Capacity)** - This is the head supplied by the selected pump, as a percentage of the maximum head capacity of the pump, given where the pump is being operated on its performance curve at system hydraulic equilibrium. The actual head gain (in feet) is equal to the actual head loss at system hydraulic equilibrium. This should ideally be between 40-60% for maximum pump efficiency and minimum operating cost. ***You should avoid operating a pump at more than 90% of its maximum head capacity.*** "NA" is displayed when this output parameter is Not Applicable given the entered input parameters.

Under Oregon and Washington law, all water is publicly owned. Landowners must obtain a permit from the Water Resources Department to use water flowing past, through, or under their property. Only after a permit is granted, may the applicant construct a water project and begin using water. After the water project is completed, the permit holder must hire a Certified Water Rights Examiner to complete a survey of water use and submit a map and report detailing how and where the water is being used for beneficial use. If the water has been shown to be used according to the provision of the permit, a water right certificate will be issued by the Water Resources Department. If you find that you need this service, we hope that you will consider Borst Engineering and Construction.

This calculator is based on the Hazen-Williams formula, which is likely the most common method employed for performing water flow rate analysis. This Hazen-Williams formula based calculator is limited to water at 60 degrees Fahrenheit at turbulent flow rates, which is typical of most water work projects. To avoid this restriction, please consider using our **Pipe & Pump System Design Calculator (Darcy-Weisbach)**.

This calculator may be used to determine the maximum flow rate capacity of a gravity-fed pipe (perhaps from having the pipe inlet installed just below surface of stream), a pipe with a pressurized inlet (perhaps from having the pipe inlet installed at below the base of a dam or perhaps from being fed by a pump), or some combination. An example of this situation is the need to determine the maximum flow rate capacity that a ditch or pipe will divert water from one location to another location. Please see our **Ditch Capacity Calculator** and **Pipe Capacity Calculator (Hazen-Williams)**. *This type of calculation requires you to enter a known pipe hydraulic diameter into the calculator and determines the maximum flow rate capacity of a gravity-fed pipe which results in 0 head at the pipe outlet.* To perform this type of calculation, enter 0 for logic input parameter 1) and enter the **Design Inlet Pressure** (if any), **Design Elevation Change** (if any), **Design Hydraulic Diameter**, **Design Length**, and **Design Hazen-Williams Friction Coefficient** input parameters. The **Design Flow Rate**, **Design Friction Head Loss** and **Pump Performance Curve Data Points** do NOT need to be entered.

This calculator may be used to determine the minimum hydraulic diameter of a gravity-fed pipe that will provide the required design flow rate and required head at the pipe outlet. The head at the pipe outlet is the head available at the pipe inlet minus the actual pipe friction head loss which results at the design flow rate. An example of this situation is the need to select an economical interior pipe diameter size to provide the required flow rate and the required head to feed a cross flow turbine or hydraulic ram pump. Please see our **Pipe Capacity Calculator (Hazen-Williams)**. *This type of calculation requires you to enter a design flow rate and design friction head loss into the calculator and determines the pipe minimum hydraulic diameter of a gravity-fed pipe which results in the required design flow rate and the required head at the pipe outlet.* A standard commercially available exterior pipe diameter size MUST first be selected, based on this minimum hydraulic diameter, and the standard interior diameter of this selected pipe MUST then be entered as the design hydraulic diameter input parameter in order to have the calculator correctly determine the associated output parameters. To perform this type of calculation, enter 1 for logic input parameter 1) and enter the **Design Flow Rate**, **Design Inlet Pressure** (if any), **Design Elevation Change** (if any), **Design Length**, **Design Hazen-Williams Friction Coefficient**, and **Design Friction Head Loss** input parameters. After considering the minimum hydraulic diameter output parameter and selecting the design hydraulic diameter that will be used, then enter the **Design Hydraulic Diameter** input parameter. The **Pump Performance Curve Data Points** do NOT need to be entered.

This calculator may be used to determine the actual flow rate and pipe friction head loss (and associated pump head gain) which occurs when pumping water through an open pipe/pump system (i.e., water is pumped one-way from the pump to some destination) using a selected pump and selected pipe. An example of this situation would be the need to select an appropriate pump and pipe to pump a required water flow rate from one location to a different location. Please see our **Electric Pump Capacity Calculator**. *This type of calculation requires you to enter a pump performance curve for a selected pump into the calculator and determines the flow rate and head gain which results from using this selected pump in an open pipe/pump system.* A pump performance curve defines the flow rate and head characteristics of a pump and is published by the manufacturer of the selected pump. The center of the pump performance curve is typically

where the pump Best Efficiency Point (BEP) occurs and where you should operate the pump for maximum pump efficiency and minimum operating cost. To perform this type of calculation, <u>enter 2</u> for logic input parameter 1) and enter the **Design Inlet Pressure** (if any), **Design Elevation Change** (if any), **Design Hydraulic Diameter**, **Design Length** (the length of pipe between pump outlet and pipe outlet), **Design Hazen-Williams Friction Coefficient** and **Pump Performance Curve Data Points** input parameters. The **Design Flow Rate** and **Design Friction Head Loss** input parameters do NOT need to be entered.

This calculator may be used to determine the actual flow rate and pipe friction head loss (and associated pump head gain) which occurs at hydraulic equilibrium when pumping water through a <u>closed pipe/pump system</u> (i.e., the pump outlet feeds a pressurized, closed pipe system that returns the water back to the pump inlet) using a selected pump and selected pipe. An example of this situation would be a closed circuit for a hydronic radiant floor heating system. Please see our **Hydronic Radiant Floor Heating Design Calculator**. ***This type of calculation requires you to enter a pump performance curve for a selected pump into the calculator and determines the flow rate and head gain which results from using this selected pump in a closed pipe/pump system.*** A pump performance curve defines the flow rate and head characteristics of a pump and is published by the manufacturer of the selected pump. The center of the pump performance curve is typically where the pump Best Efficiency Point (BEP) occurs and where you should operate the pump for maximum pump efficiency and minimum operating cost. To perform this type of calculation, <u>enter 3</u> for logic input parameter 1) and enter the **Design Hydraulic Diameter**, **Design Length** (the total length of pipe between pump outlet and pump inlet), **Design Hazen-Williams Friction Coefficient** and **Pump Performance Curve Data Points** input parameters. The **Design Flow Rate**, **Design Inlet Pressure**, **Design Elevation Change**, and **Design Friction Head Loss** input parameters do NOT need to be entered.

This calculator is valid for noncircular ditch or pipe if the "hydraulic diameter" is entered for the **Design Hydraulic Diameter** input parameter. The hydraulic diameter is defined as FOUR times the "hydraulic radius" (i.e., NOT two times as might be expected). The hydraulic radius is defined as the ditch or pipe cross-sectional area divided by the "wetted perimeter". The wetted perimeter is defined as the perimeter of the ditch or pipe cross sectional area that is "wet". ***For a full flowing circular pipe, the hydraulic diameter is equal to the pipe interior diameter.***

You should always first communicate and coordinate with the local Department of Fish and Wildlife, and local Water Resources Department BEFORE constructing any water work project.

To use this calculator, enter ALL of the following required input parameters as indicated:

1)   **Calculation Type (0=Pipe Capacity, 1=Pipe Design Flow Rate, 2=Open Pipe/Pump System Design, 3=Closed Pipe/Pump System Design)** - This is a logic input parameter that is used to tell the calculator which type of calculation should be performed. When 0 is entered, the calculator will determine the pipe maximum flow rate capacity **Actual Flow Rate** and other output parameters. When 1 is entered, the calculator will determine the **Minimum Hydraulic Diameter** and other output parameters for the entered **Design Flow Rate**. When 2 is entered, the calculator will determine the **Actual Flow Rate**, **Pump Head Gain** and other output parameters for an open pipe/pump system (i.e., water is pumped one-way from the pump to some destination) at system hydraulic equilibrium. When 3 is entered, the calculator will determine the **Actual Flow Rate**, **Pump Head Gain** and other output parameters for a closed pipe/pump system (i.e., the pump outlet feeds a pressurized, closed pipe system that returns the water back to the pump inlet) at system hydraulic equilibrium.

2) **Design Flow Rate (Gallons/Minute)** - This is the design flow rate of water that is available from the water source that will flow through the pipe after accounting for actual friction head loss. The design flow rate is only used by the calculator when 1 is entered for logic input parameter 1).

3) **Design Inlet Pressure (Pounds/Square Inch)** - This is the static pressure at the pipe inlet. This allows addressing the situation of feeding the pipe inlet from below the base of a dam. If you can determine the water depth above the drive line inlet, the design inlet pressure in PSI is this water depth in feet multiplied by 0.433.

4) **Design Elevation Change (Feet)** - This is the elevation difference between the pipe inlet and the pipe outlet. This allows addressing the situation of feeding the pipe inlet from just below the surface of a stream using a gravity flow pipe. This parameter may be measured by running a hose from the pipe inlet location to the pipe outlet location and using a pressure gauge to measure the static water pressure in PSI at the pipe outlet location. The design head in feet is this static water pressure in PSI divided by 0.433. The design elevation is only used by the calculator when 0 is entered for logic input parameter 1). The site and installation may have a combination of design inlet pressure and design elevation change and you may need to enter values for both.

5) **Design Hydraulic Diameter (Inches)** - This is the hydraulic diameter that will be used for the pipe. However, the hydraulic diameter may be entered for a noncircular ditch or for a less than full flowing pipe. Initially enter 0 or leave this blank and enter an appropriate value for the **Design Friction Head Loss** input parameter to have the calculator determine the **Minimum Hydraulic Diameter** output parameter. **Minimum Hydraulic Diameter** should be considered and a standard interior diameter of commercially available pipe should be selected. Then enter this selected standard diameter as the design hydraulic diameter to have the calculator determine the output parameters. The output parameters are ALWAYS based on the entered design hydraulic diameter and are NEVER based on the **Minimum Hydraulic Diameter** unless it is actually entered.

6) **Design Length (Feet)** - This is the length of the pipe. If the pipe is other than straight (e.g., if the pipe has elbows, valves, etc.), the effective length should be increased from the actual length in accordance with best engineering fluid dynamic practices. For an open pipe/pump system, this is the length of pipe between pump outlet and pipe outlet. For a closed pipe/pump system, this is the total length of pipe between pump outlet and pump inlet.

7) **Design Hazen-Williams Friction Coefficient** - This is used to determine the friction in the pipe and the associated head loss resulting from the pipe material being used. This is typically 150 for PVC, 130 for plain steel, and 120 for concrete.

8) **Design Friction Head Loss (Feet)** - This design parameter allows trading the **Actual Friction Head Loss** output parameter (and the associated pipe construction economics) against the **Head Available at Outlet** output parameter to determine a suitable **Minimum Hydraulic Diameter** output parameter. Decreasing the design friction head loss will increase the **Head Available at Outlet**, but will increase the **Minimum Hydraulic Diameter** (and increase the associated pipe construction economics). Increasing the design friction head loss will have the opposite effect.

The design friction head loss is typically 5 to 15% of either the **Design Length** input parameter or the **Head Available at Site** output parameter. The design friction head loss is only used by the calculator when 1 is entered for logic input parameter 1).

9) **Pump Performance Curve Data Points (Gallons/Minute versus Feet)** - You may initially leave these input parameters blank or enter 0. A pump performance curve defines the flow rate and head characteristics of a pump and is published by the manufacturer of the selected pump. The center of the pump performance curve is typically where the pump Best Efficiency Point (BEP) occurs and where you should operate the pump for maximum pump efficiency and minimum operating cost. After you have selected an appropriate pump, enter the actual pump performance curve for the selected pump into the calculator via the 14 data points (i.e., 28 entries) consisting of pump flow rate (in Gallons/Minute) versus pump head (in Feet). You may enter all 14 data points or you may enter less data points leaving any unused entries blank or 0. It is recommended that you use an adequate number of data points to accurately replicate the pump performance curve recognizing that the calculator will only do a linear interpolation between the data points. Example and illustrative pump performance curve data points are shown for a Grundfos UP15-42F pump.

Click Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Minimum Hydraulic Diameter (Inches)** - This is the minimum hydraulic diameter that the pipe must be to satisfy the **Design Friction Head Loss** input parameter and given the other design input parameters. For a full flowing circular pipe, the hydraulic diameter is equal to the pipe interior diameter. The pipe should be constructed to have a hydraulic diameter that equals or slightly exceeds this minimum hydraulic diameter in order to actually provide the **Design Flow Rate** input parameter. This minimum hydraulic diameter should be considered and a standard interior diameter of commercially available pipe should be selected and entered as the **Design Hydraulic Diameter** input parameter. The output parameters are ALWAYS based on the entered **Design Hydraulic Diameter** input parameter and are NEVER based on the minimum hydraulic diameter unless it is actually entered. "NA" is displayed when this output parameter is Not Applicable given the entered input parameters.

2) **Actual Flow Rate (Gallons/Minute)** - If 0 is entered for logic input parameter 1), this is the pipe maximum flow rate capacity given the other input parameters. If 1 is entered for logic input parameter 1), this is the **Design Flow Rate** input parameter. If 2 or 3 is entered for logic input parameter 1), this is the flow rate provided by the pump at system hydraulic equilibrium given the **Pump Performance Curve Data Points** input parameters.

3) **Actual Velocity (Feet/Second)** - If 0 is entered for logic input parameter 1), this is the pipe maximum velocity capacity given the other input parameters. If 1 is entered for logic input parameter 1), this is the **Design Flow Rate** input parameter divided by the cross-sectional area of the pipe. If 2 or 3 is entered for logic input parameter 1), this is the velocity provided by the pump at system hydraulic equilibrium given the **Pump Performance Curve Data Points** input parameters.

4) **Actual Reynolds Number** - This is an important design parameter often used by engineers. Greater than 4600, which is indicative of turbulent flow rate, is required to ensure the empirical Hazen-Williams formula used by this calculator remains valid for the calculation.

5) **Head Available at Site (Feet and Pounds/Square Inch)** - This is any head provided to the pipe inlet or pump inlet by the water source. The head available at site is the sum of the **Design Inlet Pressure** and **Design Elevation Change** input parameters converted to feet and PSI. "NA" is displayed when this output parameter is Not Applicable given the entered input parameters.

6) **Actual Head Loss (Feet and Pounds/Square Inch)** - This is the pipe actual head loss (in feet) and pipe pressure drop (in PSI).

7) **Specific Head Loss (Feet and Pounds/Square Inch)** - This is the pipe specific head loss (in feet) and pipe pressure drop (in PSI) normalized per 100 feet of pipe. An economical pipe diameter to use for a project will typically result in 5 to 15 feet of head loss per 100 feet of pipe.

8) **Head Available at Outlet (Feet and Pounds/Square Inch)** - This is the head that is available at the pipe outlet which is the **Head Available at Site** output parameter plus the **Pump Head Gain** output parameter minus the **Actual Friction Head Loss** output parameter converted to feet and PSI. "NA" is displayed when this output parameter is Not Applicable given the entered input parameters.

9) **Pump Head Gain (% of Maximum Head Capacity)** - This is the head supplied by the selected pump, as a percentage of the maximum head capacity of the pump, given where the pump is being operated on its performance curve at system hydraulic equilibrium. The actual head gain (in feet) is equal to the actual head loss at system hydraulic equilibrium. This should ideally be between 40-60% for maximum pump efficiency and minimum operating cost. ***You should avoid operating a pump at more than 90% of its maximum head capacity.*** "NA" is displayed when this output parameter is Not Applicable given the entered input parameters.

Please note that the Hazen-Williams equation used in this calculator is only valid for cold water (i.e., 60 degrees Fahrenheit) at turbulent flow rates (i.e., Reynolds numbers greater than 4600). Our **Pipe & Pump System Design Calculator (Darcy-Weisbach)** is NOT limited by this restriction.

Under Oregon and Washington law, all water is publicly owned. Landowners must obtain a permit from the Water Resources Department to use water flowing past, through, or under their property. Only after a permit is granted, may the applicant construct a water project and begin using water. After the water project is completed, the permit holder must hire a Certified Water Rights Examiner to complete a survey of water use and submit a map and report detailing how and where the water is being used for beneficial use. If the water has been shown to be used according to the provision of the permit, a water right certificate will be issued by the Water Resources Department. If you find that you need this service, we hope that you will consider Borst Engineering and Construction.

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This calculator is based on the Hazen-Williams formula and is specifically used by Oregon Certified Water Right Examiners (CWREs) to determine the water maximum flow rate capacity of a gravity flow pipe. An example of this situation would be a pipe installed near the surface of a stream used to divert water to a lower location or as a penstock for a cross flow turbine, hydraulic ram pump or overshot water wheel. This calculator provides identical results to the Excel spreadsheet version available at the Oregon Water Resources Department at this website:

<div align="center">

OWRD

</div>

You should always first communicate and coordinate with the local Department of Fish and Wildlife, and local Water Resources Department BEFORE constructing any water work project.

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Interior Diameter (Inches)** - This is the interior diameter of the pipe.

2) **Length (Feet)** - This is the length of the pipe.

3) **Hazen-Williams Friction Coefficient** - This is used to determine the friction in the pipe and the associated head loss resulting from the pipe material being used. This is typically150 for PVC, 130 for plain steel, and 120 for concrete.

4) **Fall (feet)** - This is the elevation difference between the pipe inlet and the pipe outlet. This may only be a positive value (indicating that the pipe outlet is below the pipe inlet) since this is a gravity flow calculator.

Click Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Gradient (Percent)** - This is the ratio of the Fall divided by the length of the pipe.

2) **Area of Cross-Section (Square Feet)** - This is the effective cross sectional area of the pipe through which the water is flowing.

3) **Wetted Perimeter (Feet)** - This is the interior perimeter of the pipe that the flowing water is in contact.

4) **Hydraulic Radius (Feet)** - This is the effective radius of the pipe and is obtained by dividing the **Area of Cross-Section** output parameter by the **Wetted Perimeter** output parameter.

5) **Maximum Velocity (Feet/Second)** - This is the maximum velocity that can be obtained.

6) **Pipe Capacity (Cubic Feet/Second)** - This is the maximum flow rate that can be obtained.

Please note that the Hazen-Williams equation used in this calculator is only valid for cold water (i.e., 60 degrees Fahrenheit) at turbulent flow rates (i.e., Reynolds numbers greater than 4600). Our **Pipe & Pump System Design Calculator (Darcy-Weisbach)** is NOT limited by this restriction.

Under Oregon and Washington law, all water is publicly owned. Landowners must obtain a permit from the Water Resources Department to use water flowing past, through, or under their property. Only after a permit is granted, may the applicant construct a water project and begin using water. After the water project is completed, the permit holder must hire a Certified Water Rights Examiner to complete a survey of water use and submit a map and report detailing how and where the water is being used for beneficial use. If the water has been shown to be used according to the provision of the permit, a water right certificate will be issued by the Water Resources Department. If you find that you need this service, we hope that you will consider Borst Engineering and Construction.

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This calculator is based on the Orifice Formula and is specifically used by Oregon Certified Water Right Examiners (CWREs) to determine the water flow rate capacity of a sprinkler system. This calculator provides identical results to the Excel spreadsheet version available at the Oregon Water Resources Department at this website:

OWRD

You may want to consider and use our **Orifice Plate Capacity Calculator** to design a sprinkler system. If you enter 0.970 for the orifice flow rate coefficient and the same nozzle size and pressure, our Orifice Plate Capacity calculator will provide identical results as this Sprinkler Capacity calculator. This Sprinkler Capacity calculator uses an orifice diameter/pipe diameter ratio equal to 0.876 and an orifice plate thickness/orifice diameter ratio less than 0.25, which results in this 0.970 orifice flow rate coefficient.

You should always first communicate and coordinate with the local Department of Fish and Wildlife, and local Water Resources Department BEFORE constructing any water work project.

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Nozzle Size (Inches)** - This is the diameter of the sprinkler orifice.

2) **Pressure (Pounds/Square Inch)** - This is the irrigation system operating pressure.

3) **Number of Heads** - This is the total number of sprinkler heads being used in the irrigation system.

Click ⬚Solve⬚ after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameter:

1) **Sprinkler Capacity (Cubic Feet/Second)** - This is the maximum flow rate of the irrigation system.

Under Oregon and Washington law, all water is publicly owned. Landowners must obtain a permit from the Water Resources Department to use water flowing past, through, or under their property. Only after a permit is granted, may the applicant construct a water project and begin using water. After the water project is completed, the permit holder must hire a Certified Water Rights Examiner to complete a survey of water use and submit a map and report detailing how and where the water is being used for beneficial use. If the water has been shown to be used according to the provision of the permit, a water right certificate will be issued by the Water Resources Department. If you find that you need this service, we hope that you will consider Borst Engineering and Construction.

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Undershot Water Wheel Design Calculator

An undershot water wheel is a machine for converting the energy of moving water into power. An undershot water wheel consists of a large metal wheel, with a number blades arranged on the outer rim which allows the wheel to be rotated by the water striking the blades. Most commonly, the wheel is mounted vertically on a horizontal shaft. A flume/penstock (i.e., a ditch or pipe) is NOT required to feed an undershot wheel. The undershot water wheels that we fabricate are about 73% efficient.

While undershot water wheels are not as efficient at producing power as compared to cross flow turbines or overshot water wheels, they are relatively easy to fabricate. While undershot water wheels do not require a flume/penstock, you do need to have a relatively fast moving stream to generate any significant amount of power. If an undershot water wheel is located such that the wheel is submerged into the stream the recommended full blade width amount and the blade width is correctly designed, the amount of power that can be generated is proportional to the wheel design width and proportional to the stream velocity raised to the fifth power. So it is largely the stream velocity that is responsible for the amount of power that can be generated by an undershot water wheel. It is interesting to note that the British industrial revolution was initially started with this simple machine before steam engines came along.

We prefer to fabricate our undershot water wheels using either stainless steel or weathering steel (e.g., COR-TEN steel) to eliminate any need for painting and to ensure a long life. You definitely should NOT use wood and you probably should avoid using ordinary steel (e.g., A36 or B36) too. Wood tends absorb water unevenly which results in wheel unbalance and wood eventually rots. Ordinary steel requires excessive painting maintenance just to keep the wheel attractive. If ordinary steel is used and the wheel if fabricated by welding, the wheel will eventually fail because of corrosion induced fatigue failure at the weld joints. We always fabricate our undershot water wheel shafts using stainless steel and we always fabricate our shaft bearings using acetal plastic. Acetal plastic bearings have a much longer life than stainless steel ball/sleeve bearings, nylon bearings, or oil impregnated wood bearings. In addition to being an extremely strong and durable material, acetal plastic has self-lubricating properties and is dimensionally stable in a water environment.

Undershot water wheels typically operate well below the required rotational speed of conventional generators. As a consequence, a high ratio drive system (e.g., often 100:1) must often be used which reduces overall system efficiency and increases maintenance and associated operating cost. Cross flow turbines will typically operate at significantly higher rotational speeds as undershot water wheels. If the water work project application is hydroelectric power generation, you may want consider our **Cross Flow Turbine Design Calculator**. Permanent Magnet Generators (PMG) are now available that provide high efficiency power generation even at relatively slow rotational speeds. This calculator allows you to design and build an undershot water wheel optimized to the specific design objectives and site conditions.

You should always first communicate and coordinate with the local Department of Fish and Wildlife, and local Water Resources Department BEFORE constructing any water work project.

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Stream Velocity (Feet/Second)** - This is the velocity of the water moving in the stream. This may be measured by dropping an object that floats into the stream and using a stop watch to time how long it takes this object to travel a known distance. Dividing this known distance (in feet) by the number of seconds it takes to travel this distance is the stream velocity.

2) **Wheel Design Diameter (Feet)** - This is the diameter of the wheel. Larger wheel design diameters will increase the **Maximum Steady Shaft Torque** output parameter, but will reduce the **Optimal Rotation Speed** output parameter. Smaller wheel design diameters will increase the **Optimal Rotation Speed**, but will reduce the **Maximum Steady Shaft Torque**. You may need to consider and determine the torque and RPM requirements of the generator before selecting the wheel design diameter. You may need to consider using a pulley drive system to change the **Maximum Steady Shaft Torque** and **Optimal Rotation Speed** to meet the requirements of the generator. Please see our **Pulley Drive System Design Calculator**.

3) **Wheel Design Width (Inches)** - This is the width of the wheel. Larger wheel widths will increase the **Effective Flow Rate** output parameter and increase the wheel **Maximum Theoretical Power** and **Estimated Power** output parameters.

4) **Blade Thickness (Inches)** - This is the thickness of the blade material.   You may use our **Blade Stress Analysis Calculator (Euler-Bernoulli)** to determine the minimum recommended blade thickness to ensure long blade life.

5) **Shaft Diameter (Inches)** - This is the diameter of the shaft material. You may use our **Shaft Stress Analysis Calculator (Soderberg)** to determine the minimum recommended shaft diameter to ensure a long shaft life.

6) **Expected Wheel Efficiency (Percent)** - This is a measure of how well the wheel converts the kinetic energy of the stream (head and flow rate) into mechanical energy (torque and RPM). This is typically 15 to 25% with "flat" blades and 65 to 75% with "curved" Jean V. Poncelet style blades.

7) **Expected Generator Efficiency (Percent)** - This is a measure of how well the generator converts mechanical energy (torque and RPM) into electrical energy (volts and amps). 90% is typical for a Permanent Magnet Generator (PMG).

Click <u>Solve</u> after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Maximum Theoretical Power (Kilowatts)** - This is the maximum theoretical power that could be generated given the design flow rate and head assuming that the undershot water wheel and the generator are 100% efficient. You will never actually be able to generate this much power in actual operation, however, this value must often be reported to water resource authorities when seeking a water right permit.

2) **Estimated Power (Kilowatts)** - This is the estimated power output that should be generated accounting for **Expected Wheel Efficiency** and **Expected Generator Efficiency** input parameters.

3) **Estimated Energy (Kilowatt Hours/Month)** - This is the estimated energy that should be generated based on the **Estimated Power** output parameter.

4) **Maximum Steady Shaft Torque (Foot-Pounds)** - This is the maximum steady shaft torque that the undershot water wheel will produce given the design inputs. If you require more torque, increase the **Wheel Design Diameter** input parameter.

5) **Effective Head (Feet)** - This is the effective head which is proportional to the square of the **Stream Velocity** input parameter. Normally, head is the result of an elevation change between the penstock inlet and the water machine inlet. This "normal" head is then converted to a water velocity that strikes the water machine blades. With an undershot water wheel, the stream velocity is already directly striking the blades so there is no need to have a penstock to create this water velocity. This effective head dimension determines the **Blade Width** output parameter and in conjunction with the **Wheel Design Width** input parameter determines the wheel **Working Cross-Sectional Area** output parameter. The depth that the wheel is submerged below the stream surface is typically and has been assumed to be this effective head dimension.

6) **Effective Flow Rate (Gallons/Minute)** - This is the effective flow rate which is proportional to both the **Stream Velocity** input parameter and the wheel **Working Cross-Sectional Area** output parameter.

7) **Minimum Optimal Diameter (Feet)** - This is the minimum recommended wheel diameter. This has been found by experimentation to be approximately 3 times the **Effective Head** dimension.

8) **Maximum Optimal Diameter (Feet)** - This is the maximum recommended wheel diameter. This has been found by experimentation to be approximately 6 times the **Effective Head** dimension.

9) **Working Diameter (Feet)** - This is the effective wheel "working" diameter given that a portion of the wheel is submerged below the stream surface which is typically and has been assumed to be the **Effective Head** dimension.

10) **Working Circumference (Feet)** - This is the effective wheel "working" circumference based on the **Working Diameter** output parameter.

11) **Working Cross-Sectional Area (Square Feet)** - This is the effective wheel "working" cross-sectional area which is proportional to both the **Wheel Design Width** input parameter and the depth that the wheel is submerged below the stream surface which is typically and has been assumed to be the **Effective Head** dimension.

12) **Optimal Rim Tangential Speed (Feet/Second)** - This is the optimal linear velocity of the wheel rim which has been found by experimentation to be 67% of the **Stream Velocity** input parameter.

13) **Optimal Rotation Speed (Rotations/Minute)** - This is the optimal rotational velocity of the wheel given the **Optimal Rim Tangential Speed** and the **Working Circumference** output parameters. If you require more rotation speed, reduce the **Wheel Design Diameter** input parameter.

14) **Number of Blades** - This is the recommended number of total blades. The calculator determines the optimum even number of blades. If radial arms will be used for the design in lieu of solid side

plates, the number of blades should be a multiple of the **Number of Radial Arms** output parameter.

15) **Blade Spacing (Inches)** - This is the recommended spacing between the center of the blades as measured at the wheel design diameter which has been found by experimentation to be 95% of the **Effective Head** dimension.

16) **Blade Width (Inches)** - This is the width of the blades which is typically and has been assumed to be the **Effective Head** dimension. An undershot water wheel should be located such that the wheel is submerged into the stream just this full blade width value. This value is used as an input parameter by our **Blade Stress Analysis Calculator (Euler-Bernoulli)**.

17) **Number of Radial Arms** - The calculator determines the optimum even number of radial arms (based on the Redtenbacher formula) that may be used to connect the wheel rim to the shaft hub if solid side plates are not used for the design. If radial arms will be used for the design in lieu of solid side plates, the number of radial arms should be a multiple of the **Number of Blades** output parameter.

18) **Weight of Wheel** - This is the fully fabricated weight of the wheel including the blades, shaft, and solid side plates. It is assumed that the entire wheel is constructed using the same thickness steel as the blades. The weight of the wheel may be significantly reduced by using radial arms in lieu of solid side plates.

19) **Maximum Blade Force (Pounds)** - This is the maximum total force experienced by the blades based on the **Stream Velocity** input parameter and the **Effective Flow Rate** output parameter. This value is used as an input parameter by our **Blade Stress Analysis Calculator (Euler-Bernoulli)**.

20) **Maximum Shaft Force (Pounds)** - This is the maximum total force experienced by the shaft. The engineering equations consider the **Weight of Wheel** and the **Maximum Blade Force** output parameters.

21) **Maximum Blade Bending Moment (Inch-Pounds)** - This is the maximum bending moment experienced by the blade resulting from the **Maximum Blade Force** output parameter acting as a distributed load across the length of a fixed blade. This value is used as an input parameter by our **Blade Stress Analysis Calculator (Euler-Bernoulli)**.

22) **Maximum Shaft Bending Moment (Inch-Pounds)** - This is the maximum bending moment experienced by a fixed shaft resulting from the **Maximum Shaft Force** output parameter acting as a concentrated load at the mid-span of a fixed shaft. This value is used as an input parameter by our **Shaft Stress Analysis Calculator (Soderberg)**.

Under Oregon and Washington law, all water is publicly owned. Landowners must obtain a permit from the Water Resources Department to use water flowing past, through, or under their property. Only after a permit is granted, may the applicant construct a water project and begin using water. After the water project is completed, the permit holder must hire a Certified Water Rights Examiner to complete a survey of water use and submit a map and report detailing how and where the water is being used for

beneficial use. If the water has been shown to be used according to the provision of the permit, a water right certificate will be issued by the Water Resources Department. If you find that you need this service, we hope that you will consider Borst Engineering and Construction.

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Andersen Weight Distribution Hitch Calculator

In 2021 we decided to purchase a **2023 Casita Travel Trailer** as backpack, canoe and kayak camping trips requiring us to sleep in a tent on the ground was getting less fun. A Casita travel trailer must be picked up in Rice Texas (i.e., Casita does direct sales only and has no dealerships that would take more of your money) and they have a long lead order time before pickup as demand for them is very high as they last forever and can be easily resold for more than their purchase price. Upon returning home, Gayle named our Casita travel trailer "Los Gatos Casita" as a tribute to our cats who traveled with us. Here are some photos from this 12,630 mile, 3 month and 24 State camping trip:

Our "Los Gatos Casita" Spring 2023 Trip

An Andersen Weight Distribution Hitch (WDH) helps ensure towing stability and enables shifting the weight from the tow vehicle rear axle to the tow vehicle front axle and to the trailer axle while also reducing the trailer tongue weight. Restoring a tow vehicle's front axle load becomes increasingly important when road/weather conditions degrade because of rain, snow or ice in order to retain good tow vehicle handling and retain a solid tow vehicle foundation to deal with a sway situation. The Andersen WDH also retains the comfortable/smooth ride provided by the tow vehicle while towing which significantly reduces wear and tear on both the travel trailer and tow vehicle. And unlike other WDHs, the Andersen WHD does NOT need to be removed in order to back up the trailer.

Andersen Weight Distribution Hitch

Experts agree that WDHs work very well and work even better on modern unibody-based design tow vehicles designed to use WDHs because a unibody structure can be made extremely strong and rigid. There is no significant flexibility on unibody-based design tow vehicles designed to use WDHs as is unfortunately the case with older frame-based design tow vehicles. Frame flex may use up a significant portion of the WDH effort before the WDH can even begin to restore the load on the tow vehicle front axle.

In addition to different tow vehicle and trailer structural characteristics, there are also different Andersen WDH configurations resulting from different installed chain lengths and different elastomer bushing changes over the years. *To address differences in tow vehicle and trailer structure characteristics and in different Andersen WDH configurations, this calculator has a feature to enable precisely calibrating this calculator for these differences (please see detailed instructions for input parameter 10).*

It is often argued that a WDH isn't needed to tow a Casita trailer if it is hooked to a 3/4 or 1 ton tow vehicle. And this is indeed true because the front axle load of these behemoth tow vehicles is so great that the relatively light tongue weight of the Casita trailer has no significant effect on their front axle load. But if you only need to tow a Casita trailer, you don't need anything larger than a 1/2 ton tow vehicle and you likely also don't want the larger acquisition and operational costs associated with having a behemoth 3/4 or 1 ton tow vehicle either.

Interestingly, a fully loaded 1/2 ton tow vehicle and trailer with a WDH hitch can be made more stable than any size fully loaded tow vehicle by itself. This is because any size fully loaded tow vehicle will experience some understeer from the lighter front axle load that can't be corrected. This understeer can be easily corrected on the tow vehicle/trailer combo with a WDH.

This WDH calculator was designed specifically for the Andersen WDH and is used in conjunction with our **Travel Trailer Weight & Balance Calculator**. If the input parameters don't provide sufficient data or contain

data that is not valid to allow the calculator to correctly calculate some of the output parameters, the affected output parameters will display "NVD!"

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Trailer Tongue Weight (Pounds or leave blank)** - This is the trailer tongue weight. This can be determined by using a tongue weight scale to measure it. This can also be determined by using our **Travel Trailer Weight & Balance Calculator** to estimate it. If the **Trailer Weight** and **Trailer Axle Load Hitched without Tensioned WDH** input parameters are entered, this may be left blank and will be calculated. If the **Tow Vehicle Front Axle Load Hitched without Tensioned WDH**, **Tow Vehicle Rear Axle Load Hitched without Tensioned WDH** and the **Tow Vehicle Weight** input parameters are entered, this may also be left blank and will be calculated.

2) **Trailer Weight (Pounds or leave blank)** - This is the trailer weight. This can be determined by using a certified truck scale to measure the hitched trailer axle load and adding the trailer tongue weight as measured by a tongue weight scale. This can also be determined by using our **Travel Trailer Weight & Balance Calculator** to estimate it. If the **Trailer Axle Load Hitched without Tensioned WDH** input parameter is entered and the **Trailer Tongue Weight** input parameter is entered or can be calculated, this may be left blank and will be calculated. If the **Tow Vehicle Front Axle Load Hitched without Tensioned WDH**, **Tow Vehicle Rear Axle Load Hitched without Tensioned WDH**, **Trailer Axle Load Hitched without Tensioned WDH** and the **Tow Vehicle Weight** input parameters are entered, this may also be left blank and will be calculated.

3) **Trailer Axle Load Hitched without Tensioned WDH (Pounds or leave blank)** - This is the trailer axle load while hitched to the tow vehicle, but without the WDH tensioned. This can be determined by using a certified truck scale to measure the hitched trailer axle load. This can also be determined by using our **Travel Trailer Weight & Balance Calculator** to estimate it. If the **Trailer Weight** and the **Trailer Tongue Weight** input parameters are entered or can be calculated, this may be left blank and will be calculated. If the **Tow Vehicle Front Axle Load Hitched without Tensioned WDH**, **Tow Vehicle Rear Axle Load Hitched without Tensioned WDH** and the **Tow Vehicle Weight** input parameters are entered and the **Trailer Weight** input parameter is entered or can be calculated, this may also be left blank and will be calculated.

4) **Tow Vehicle Weight (Pounds or leave blank)** - This is the tow vehicle weight. This can be determined by using a certified truck scale to measure the unhitched front/rear axle loads at the same time. This can be also be determined by using a certified truck scale to measure the hitched front/rear axle loads at the same time and subtracting the trailer tongue weight as measured by a tongue weight scale. If the **Tow Vehicle Front Axle Load Hitched without Tensioned WDH** and the **Tow Vehicle Rear Axle Load Hitched without Tensioned WDH** input parameters are entered and the **Trailer Tongue Weight** input parameter is entered or can be calculated, this may be left blank and will be calculated. If the **Tow Vehicle Front Axle Load Hitched without Tensioned WDH** and the **Tow Vehicle Rear Axle Load Hitched without Tensioned WDH** input parameters are entered and the **Trailer Weight** and the **Trailer Axle Load Hitched without Tensioned WDH** input parameters are entered or can be calculated, this may also be left blank and will be calculated.

5) **Tow Vehicle Front Axle Load Hitched without Tensioned WDH (Pounds or leave blank)** - This is the tow vehicle front axle load while hitched to trailer, but without the WDH tensioned. This can be determined by using a certified truck scale to measure only the hitched front axle load. If the **Tow Vehicle Rear Axle Load Hitched without Tensioned WDH** is entered and the **Tow Vehicle Weight** and the **Trailer Tongue Weight** input parameters are entered or can be calculated, this may be left blank and will be calculated. If the **Trailer Weight**, **Tow Vehicle Weight** and the **Trailer Axle Load Hitched without Tensioned WDH** input parameters are entered or can be calculated, this may be left blank and will also be calculated. If only the **Tow Vehicle Weight** input parameter is entered or can be calculated, the **Tow Vehicle Front Axle Load Unhitched** output parameter will be based on the Ridgeline truck payload weight distribution curve (57.1% when at the 4,510 pound Curb Weight and varying/decreasing to 47.7% when reaching 5,400 pounds) and this may be left blank and will also be calculated. If the **Tow Vehicle Weight** input parameter is entered or can be calculated, and if a value in percent greater than 0 and less than 100 is also entered for this input parameter, the **Tow Vehicle Front Axle Load Unhitched** output parameter will be made equal to this entered percent of the **Tow Vehicle Weight** input parameter and the **Tow Vehicle Rear Axle Load Unhitched** output parameter will be made equal to 100 percent minus this entered percent of the **Tow Vehicle Weight** input parameter.

6) **Tow Vehicle Rear Axle Load Hitched without Tensioned WDH (Pounds or leave blank)** - This is the tow vehicle rear axle load while hitched to trailer, but without the WDH tensioned. This can be determined by using a certified truck scale to measure only the hitched rear axle load. If the **Tow Vehicle Front Axle Load Hitched without Tensioned WDH** is entered and the **Tow Vehicle Weight** and the **Trailer Tongue Weight** input parameters are entered or can be calculated, this may be left blank and will be calculated. If the **Trailer Weight**, **Tow Vehicle Weight** and the **Trailer Axle Load Hitched without Tensioned WDH** input parameters are entered or can be calculated, this may be left blank and will also be calculated. If only the **Tow Vehicle Weight** input parameter is entered or can be calculated, the **Tow Vehicle Rear Axle Load Unhitched** output parameter will be based on the Ridgeline truck payload weight distribution curve (42.9% when at the 4,510 pound Curb Weight and varying/increasing to 52.3% when reaching 5,400 pounds) and this may be left blank and will also be calculated. If the **Tow Vehicle Weight** input parameter is entered or can be calculated, and if a value in percent greater than 0 and less than 100 is also entered for this input parameter, the **Tow Vehicle Rear Axle Load Unhitched** output parameter will be made equal to this entered percent of the **Tow Vehicle Weight** input parameter and the **Tow Vehicle Front Axle Load Unhitched** output parameter will be made equal to 100 percent minus this entered percent of the **Tow Vehicle Weight** input parameter.

7) **Distance Between Tow Vehicle Axles (Inches, Default is Ridgeline 125)** - This is the distance measured in inches between the tow vehicle axles.

8) **Distance Between Tow Vehicle Front Axle & Trailer Hitch (Inches, Default is Ridgeline 182)** - This is the distance measured in inches between the tow vehicle front axle and trailer hitch ball.

9) **Distance Between Trailer Hitch & Trailer Axle (Inches, Default is Ridgeline 137.5)** - This is the distance measured in inches between the trailer hitch ball and the trailer axle.

10) **Trailer Axle Load Hitched with Tensioned WDH (Leave blank or see Instructions to Calibrate Calculator)** - This is the certified truck scale measured trailer axle load in pounds while hitched to the tow vehicle with the WDH tensioned to precisely the same number of threads entered into the **Number of Threads used to Tension WDH** input parameter. This measured/entered input parameter in conjunction with the **Number of Threads used to Tension WDH** input parameter and the entered or calculated **Trailer Axle Load Hitched without Tensioned WDH** input parameter may be used to precisely calibrate the calculator for a specific tow vehicle, specific trailer and for a specific Andersen WDH configuration by determining the effective Andersen WDH spring stiffness value that makes the calculator produce this measured/entered input parameter. Once this effective Andersen WDH spring stiffness value is known by being displayed by the **Andersen WDH Spring Stiffness** output parameter and as long as it is greater than 0 and is less than 1500, this now known effective Andersen WDH spring stiffness value may then be directly entered into this input parameter and it will then be subsequently used by the calculator and displayed by the **Andersen WDH Spring Stiffness** output parameter. If this input parameter is left blank, a generic 687.5 pounds/inch Andersen WDH spring stiffness value will be used and displayed by the **Andersen WDH Spring Stiffness** output parameter.

11) **Number of Threads used to Tension WDH (Number of Threads or leave blank)** – The WDH is typically installed so the two bolt ends are flush with the two tensioning nuts when tension only just starts getting applied to the two WDH chains. Then the two tensioning nuts are equally turned and tensioned thereby exposing some same number of bolt threads on each bolt. This input parameter is the equal number of exposed bolt threads (or the equal number of applied tensioning nut turns) used to tension the WHD beyond the zero tension installation point. For example, if there are 4 exposed threads on each of the bolts (i.e., or 4 complete tensioning turns were applied to both tensioning nuts), enter 4. Enter 0 or leave blank for zero tension being applied to the WDH chains.

Click Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Trailer Tongue Weight (Pounds)** - This is either the **Trailer Tongue Weight** input parameter or the calculated trailer tongue weight based on the other entered input parameters. This **Trailer Tongue Weight** output parameter will decrease as the WDH is tensioned. However, as far as staying within your tow vehicle tongue weight limit and other limits, you MUST use your higher entered **Trailer Tongue Weight** input parameter or the higher calculated **Trailer Tongue Weight** output parameter when the WDH is NOT tensioned, i.e., when the **Number of Threads used to Tension WDH** input parameter is entered as 0 or is left blank

2) **Trailer Weight (Pounds)** - This is either the **Trailer Weight** input parameter or the calculated trailer weight based on the entered input parameters.

3) **Trailer Weight CG Location (Inches Aft of Hitch Ball** - This is the calculated location of the center of gravity of the trailer weight based on the other entered input parameters.

4) **Trailer Tongue Weight to Trailer Weight Ratio (Percent, 9-15% Recommended)** - This is the ratio of the entered **Trailer Tongue Weight** to the **Trailer Weight** input parameters or the ratio of these calculated values. This should be between 9-15% to ensure tow vehicle and trailer stability. Too much tongue weight reduces tow vehicle front-tire traction and steering control. Too little tongue weight can make the trailer unstable and cause it to sway.

5) **Tow Vehicle Weight (Pounds)** - This is either the **Tow Vehicle Weight** input parameter or the calculated tow vehicle weight based on the other entered input parameters.

6) **Tow Vehicle CG Location (Inches Aft of Front Axle)** - This is the calculated location of the center of gravity of the tow vehicle weight based on the entered input parameters. If only the **Tow Vehicle Weight** input parameter is entered or can be calculated, but both the **Tow Vehicle Front Axle Load Hitched without Tensioned WDH** and the **Tow Vehicle Rear Axle Load Hitched without Tensioned WDH** input parameters are not entered or can't be calculated to allow accurate determination of the tow vehicle CG location, it will be based on the Ridgeline truck weight distribution curve. If the **Tow Vehicle Weight** input parameter is entered or can be calculated, and either the **Tow Vehicle Front Axle Load Hitched without Tensioned WDH** or the **Tow Vehicle Rear Axle Load Hitched without Tensioned WDH** input parameters are entered with a value in percent greater than 0 and less than 100, this percent of unhitched tow vehicle front/rear axle loading will be used to calculate the tow vehicle CG location.

7) **Tow Vehicle Front Axle Load Unhitched (Pounds)** - This is the calculated tow vehicle front axle load when unhitched based on the entered input parameters. If only the **Tow Vehicle Weight** input parameter is entered or can be calculated, this output parameter will be based on the Ridgeline truck payload weight distribution curve (57.1% when at the 4,510 pound Curb Weight and varying/decreasing to 47.7% when reaching 5,400 pounds). If the **Tow Vehicle Weight** input parameter is entered or can be calculated, and if a value in percent greater than 0 and less than 100 is also entered for the **Tow Vehicle Front Axle Load Hitched without Tensioned WDH** input parameter, then this output parameter will be made equal to this entered percent of the **Tow Vehicle Weight** input parameter and the **Tow Vehicle Rear Axle Load Unhitched** output parameter will be made equal to 100 percent minus this entered percent of the **Tow Vehicle Weight** input parameter. This output parameter is used to calculate the **Front Axle Load Restoration** output parameter.

8) **Tow Vehicle Rear Axle Load Unhitched (Pounds)** - This is the calculated tow vehicle rear axle load when unhitched based on the entered input parameters. If only the **Tow Vehicle Weight** input parameter is entered or can be calculated, this output parameter will be based on the Ridgeline truck payload weight distribution curve (42.9% when at the Curb Weight and varying/increasing to 52.3% when reaching 5,400 pounds). If the **Tow Vehicle Weight** input parameter is entered or can be calculated, and if a value in percent greater than 0 and less than 100 is also entered for the **Tow Vehicle Rear Axle Load Hitched without Tensioned WDH** input parameter, then this output parameter will be made equal to this entered percent of the **Tow Vehicle Weight** input parameter and the **Tow Vehicle Front Axle Load Unhitched** output parameter will be made equal to 100 percent minus this entered percent of the **Tow Vehicle Weight** input parameter.

9) **Trailer Axle Load Unhitched (Pounds)** - This is the calculated trailer axle load when unhitched based on the entered input parameters.

10) **Tow Vehicle Front Axle Load Hitched (Pounds)** - This is the calculated tow vehicle front axle load when hitched either with or without the WDH tensioned based on the entered input parameters. This **Tow Vehicle Front Axle Load Hitched** output parameter will increase as the WDH is tensioned. This output parameter is used to calculate the **Front Axle Load Restoration** output parameter.

11) **Tow Vehicle Rear Axle Load Hitched (Pounds)** - This is the calculated tow vehicle rear axle load when hitched either with or without the WDH tensioned based on the entered input parameters. This **Tow Vehicle Rear Axle Load Hitched** output parameter will decrease as the WDH is tensioned.

12) **Trailer Axle Load Hitched (Pounds)** - This is the calculated trailer axle load when hitched either with or without the WDH tensioned based on the entered input parameters. This **Trailer Axle Load Hitched** output parameter will increase as the WDH is tensioned.

13) **Andersen WDH Spring Stiffness** – This is the Andersen WDH spring stiffness value used by the calculator to determine the **Andersen WDH Chain Tension**, **Andersen WDH Moment** and **Front Axle Load Restoration** output parameters and is only used for calibrating the calculator and for engineering design and understanding. The measured/entered **Trailer Axle Load Hitched with Tensioned WDH** input parameter in conjunction with the **Number of Threads used to Tension WDH** input parameter and the entered or calculated **Trailer Axle Load Hitched without Tensioned WDH** input parameter may be used to precisely calibrate the calculator for a specific tow vehicle, specific trailer and for a specific Andersen WDH configuration by determining the effective Andersen WDH spring stiffness value that makes the calculator produce this measured/entered **Trailer Axle Load Hitched with Tensioned WDH** input parameter. Once this effective Andersen WDH spring stiffness value is known by being displayed by this output parameter and as long as it is greater than 0 and is less than 1500, this now known effective Andersen WDH spring stiffness value may then be directly entered for the **Trailer Axle Load Hitched with Tensioned WDH** input parameter and it will then be subsequently used by the calculator and displayed by this output parameter. If the **Trailer Axle Load Hitched with Tensioned WDH** input parameter was left blank, a generic 687.5 pounds/inch Andersen WDH spring stiffness value will be used and displayed by the **Andersen WDH Spring Stiffness** output parameter.

14) **Andersen WDH Chain Tension (Pounds per Chain)** - This is the tension in each of the WDH chains and is only used for engineering design and understanding. The total tension applied is twice this value as two chains are used. This **Andersen WDH Chain Tension** output parameter will increase as the WDH is tensioned.

15) **Andersen WDH Moment (Inch-Pounds)** - This is the moment created by the **Andersen WDH Chain Tension** output parameter and is only used for engineering design and understanding. This **Andersen WDH Moment** output parameter will increase as the WDH is tensioned.

16) **Front Axle Load Restoration (Percent, 50-100% Recommended)** - This ratio in percent indicates how much of the tow vehicle's front axle load that is lost when it is just hitched to trailer without the WDH being tensioned is then subsequently restored given how much the WDH is subsequently tensioned. This output parameter is calculated as the quantity of 1 minus the quantity of the **Tow Vehicle Front Axle Load Unhitched** output parameter minus the **Tow Vehicle Front Axle Load Hitched** output parameter with the WDH tensioned divided by the quantity of the **Tow Vehicle Front Axle Load Unhitched** output parameter minus the **Tow Vehicle Front Axle Load Hitched** output parameter without the WDH tensioned times 100. Restoring a tow vehicle's front axle load becomes increasingly important when road/weather conditions degrade because of rain, snow or ice in order to retain good tow vehicle handling and retain a solid tow vehicle foundation to deal with a sway situation.

If you just click "Solve" without entering any input parameters, you will get our 2023 Casita OEM Liberty Deluxe travel trailer _empty-weight_ and our 2023 Honda OEM Ridgeline _empty-weight_ default values WITHOUT the Andersen WDH being used:

Our Casita trailer has a maximum axle load rating of 3,500 pounds, an empty weight of 2,480 pounds with the CG location 117.3 inches aft of hitch ball, an axle load of 2,115 pounds and a measured tongue weight of **365 pounds**. As a check, the trailer axle load PLUS the tongue weight MUST be equal to the trailer weight. This is indeed the case.

Our 2023 Honda OEM Ridgeline has a Curb Weight of 4,510 pounds, a Gross Vehicle Weight Rating (GVWR) of 6,019 pounds, a Gross Combination Weight Rating (GCWR) of 10,031 pounds, a Gross Axle Weight Rating-Front (GAWR-F) of 3,131 pounds, a Gross Axle Weight Rating-Rear (GAWR-R) of 3,263 pounds, a Maximum Payload Capacity of 1,509 pounds (i.e., 6,019 pounds GVWR minus 4,510 pounds Curb Weight), a Maximum Tongue Weight Limit of 600 pounds and a Maximum Towing Capacity of 5,521 pounds (i.e., 10,031 pounds GCWR minus 4,510 pounds Curb Weight). **Please be aware that it is nearly ALWAYS either the Maximum Payload Capacity or the GAWR-R which will ultimately limit your maximum towing capability!**

Our empty-weight Honda Ridgeline weighs 4,510 pounds with the CG location 53.7 inches aft of front axle and has an unhitched front axle load of 2,576 pounds and an unhitched rear axle load of 1,934 pounds **(which is 59% of our Honda Ridgeline GAWR-R)**. As a check, the sum of the axle loads MUST be equal to the tow vehicle weight. This is indeed the case.

Our empty-weight Honda Ridgeline still weighs 4,510 pounds with the CG location 53.7 inches aft of front axle when hitched to our empty-weight Casita trailer, has a hitched front axle load of 2,416 pounds and a hitched rear axle load of 2,459 pounds **(which is 75% of our Honda Ridgeline GAWR-R)**. Since the sum of the axle loads MINUS the tongue weight MUST be equal to the tow vehicle weight, we can calculate the tongue weight to be **365 pounds**. Note that this is the same tongue weight value as the trailer calculation and this value was also confirmed with strain gauge measurement.

If you then just enter "7" for the "Number of Threads used to Tension WDH" input parameter and click "Solve", you will get our 2023 Casita OEM Liberty Deluxe travel trailer _empty-weight_ and our 2023 Honda OEM Ridgeline _empty-weight_ default values WITH the Andersen WDH being used:

Using the Andersen WDH with 7 threads to tension it, we can determine our empty-weight Casita trailer when hitched to our empty-weight Honda Ridgeline still weighs 2,480 pounds with the CG location 117.3 inches aft of

hitch ball and our trailer axle load increases to 2,206 pounds. Since the trailer axle load PLUS the tongue weight MUST be equal to the trailer weight, we can calculate the tongue weight to now be a reduced **274 pounds**. As a secondary check, this tongue weight value was also confirmed with strain gauge measurement.

Using the Andersen WDH with 7 threads to tension it, our empty-weight Honda Ridgeline still weighs 4,510 pounds with the CG location 53.7 inches aft of front axle when hitched to our empty-weight Casita trailer, **our hitched front axle load increases or restores 87.5% to 2,556 pounds** and our hitched rear axle load decreases to 2,228 pounds **(which is 68% of our Honda Ridgeline GAWR-R)**. Since the sum of the axle loads MINUS the tongue weight MUST be equal to the tow vehicle weight, we can calculate the tongue weight to now be a reduced **274 pounds**. Note that this is the same tongue weight value as the trailer calculation and this value was also confirmed with strain gauge measurement.

Of course, you can't go camping with an empty trailer and empty tow vehicle, so here are our modified/refined and fully-loaded 2023 Casita Liberty Deluxe travel trailer and our fully-loaded 2023 Honda Ridgeline numbers:

We modified/refined our Casita trailer as detailed in **Our Los Gatos Casita Spring 2023 Trip**. We typically do dry camping and travel in our Casita trailer with two filled 20 pound propane tanks (74 pounds total), 20 gallons of water in our potable water tank since this reduces our tongue weight by 44 pounds, empty black and gray tanks, 100 pounds of items in our entry closet, 215 pounds of items in our kitchen cabinets, 430 pounds of items in our sleeping area cabinets and we use a 26 pound Group 27 100AH LiFePO4 battery (which is 26 pounds lighter weight than the Casita OEM lead acid battery).

Using these numbers and our **Travel Trailer Weight & Balance Calculator**, we can determine our fully-loaded Casita trailer weighs 3,437 pounds with the CG location 120.5 inches aft of hitch ball and has a trailer axle load of 3,011 pounds and a tongue weight of **426 pounds**. As a check, the trailer axle load PLUS the tongue weight MUST be equal to the trailer weight. This is indeed the case.

Subtracting from our 1,509 pounds of Honda Ridgeline Maximum Payload Capacity our 426 pounds of tongue weight, our 300 pounds of passengers and our 212 pound truck canopy, our Honda Ridgeline remaining Maximum Payload Capacity is 571 pounds. However, we adhere to a very conservative truck bed loading policy and limit our additional cargo payload to only 220 pounds which only uses 77% of our Maximum Payload Capacity because a worse case aft loading of our truck bed can move the truck CG significantly aft which can then result in our rear axle load exceeding our GAWR-R limit even though we well within our Maximum Payload Capacity. We place our heavy cargo items in our Casita trailer sleeping area cabinets given that our Casita trailer has a 3,500 pound axle load limit which can potentially create as much as 1,620 pounds of trailer payload capacity (i.e., our 3,500 pound trailer axle load limit minus our 2,480 pound trailer empty weight plus our 600 pound truck maximum tongue weight limit) and doing this also significantly reduces our tongue weight and hence our rear axle load too.

So our fully-loaded Honda Ridgeline weighs 5,242 pounds (i.e., our 4,510 pound empty weight plus our 300 pounds of passengers plus our 212 pound truck canopy plus our 220 pounds of additional cargo payload) with the CG location 59.9 inches aft of front axle, has an unhitched front axle load of 2,732 pounds and an unhitched rear axle load of 2,510 pounds **(which is 77% of our Honda Ridgeline GAWR-R)**. As a check, the sum of the axle loads MUST be equal to the tow vehicle weight. This is indeed the case.

Our fully-loaded Honda Ridgeline still weighs 5,242 pounds with the CG location 59.9 inches aft of front axle when hitched to our fully-loaded Casita trailer, has a hitched front axle load of 2,546 pounds and a hitched rear axle load of 3,122 pounds **(which is 96% of our Honda Ridgeline GAWR-R)**. Since the sum of the axle loads MINUS the tongue weight MUST be equal to the tow vehicle weight, we can calculate the tongue weight to be **426 pounds**. Note that this is the same tongue weight value as the trailer calculation and this value was also confirmed with strain gauge measurement.

Using our Andersen WDH with 7 threads to tension it, our fully-loaded Casita trailer when hitched to our fully-loaded Honda Ridgeline still weighs 3,437 pounds with the CG location 120.5 inches aft of hitch ball and our trailer axle load increases to 3,102 pounds. Since the trailer axle load PLUS the tongue weight MUST be equal to the trailer weight, we can calculate the tongue weight to now be a reduced **335 pounds**. As a secondary check, this tongue weight value was also confirmed with strain gauge measurement.

Using the Andersen WDH with 7 threads to tension it, our fully-loaded Honda Ridgeline still weighs 5,242 pounds with the CG location 59.9 inches aft of front axle when hitched to our fully-loaded Casita trailer, **our hitched front axle load increases or restores 75.0% to 2,686 pounds** and our hitched rear axle load decreases to 2,891 pounds **(which is 89% of our Honda Ridgeline GAWR-R)**. Since the sum of the axle loads MINUS the tongue weight MUST be equal to the tow vehicle weight, we can calculate the tongue weight to now be a reduced **335 pounds**. Note that this is the same tongue weight value as the trailer calculation and this value was also confirmed with strain gauge measurement.

Hopefully, this clearly illustrates the benefit of taking the time to accurately determine your actual loading and the benefit of using a WDH. And it also becomes clear why people who use simpler methods or approximations can often over-load their tow vehicles and trailers without even knowing it until they experience premature axle and/or transmission failure. If nothing else, at least check your axle loads occasionally using a certified scale.

And just for 100% clarity and emphasis, you can NOT take credit for this tongue weight reduction when using an Andersen WDH! Attempting to take credit for this lower tongue weight value by using a tensioned WDH could still result in overloading the tow vehicle hitch and create an unsafe situation. There is no sure way to absolutely ensure that the higher tongue weight value would NOT overload the tow vehicle PRIOR to tensioning the WDH and/or AFTER untensioning the WDH. It doesn't matter when or how you exceed your tow vehicle tongue weight limit, the microsecond that you do so may permanently damage the structure and make you unsafe hence forth. The unhitched and measured higher tongue weight value MUST ALWAYS be LESS than the tow vehicle Maximum Tongue Weight Limit AND this higher tongue weight value MUST ALWAYS be used for determining your actual payload weight which MUST ALWAYS be LESS than the tow vehicle Maximum Payload Capacity and result in axle loads which MUST ALWAYS be LESS than the axle load limits. However, you can perhaps take some comfort in knowing that your actual tongue weight while rolling down the road while using your Andersen WDH is significantly less than if you were not using it.

ALL of these axle load numbers were validated by certified scale measurement. ALL of these unhitched tongue weight numbers were validated by tongue scale measurement. ALL of these hitched tongue weight numbers were validated by strain gauge measurement. And perhaps most importantly, ALL of these numbers are well within the limits of BOTH our 2023 Honda Ridgeline tow vehicle and our 2023 Casita Liberty Deluxe travel trailer.

This calculator is based on the Euler-Bernoulli simple beam formula for determining EITHER the minimum recommended blade thickness for a given blade length OR the maximum recommended blade length between supports for a given blade thickness. The engineering equations are applicable for a blade or bucket subjected to an alternating maximum bending moment (e.g., induced by water forces acting on a rotating blade or bucket). This is a common loading for water work project machines and this calculator may be used for performing a load/stress analysis on cross flow turbine blades, undershot water wheel blades, and overshot water wheel buckets. Please note that this calculator provides nearly identical stress analysis results as our **Blade Stress Analysis Calculator (Verhaart)** when a 28,000 PSI material endurance limit and a 1.9 design factor of safety are used.

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Blade Thickness (Inches or Enter 0 for Blade Thickness Calculation)** - This is a logic input parameter that tells the calculator what type of stress analysis to perform. If you are using standard commercially available pipe to fabricate the blades, the standard nominal thickness of the standard commercially available pipe is the blade thickness and you should enter this thickness value to have the calculator determine the **Maximum Recommended Blade Length between Supports** output parameter. If you can specify and obtain an exact blade or bucket thickness, enter 0 to have the calculator determine the **Minimum Recommended Blade Thickness** output parameter.

2) **Maximum Blade Force or Maximum Blade Bending Moment (Pounds or Inch-Pounds)** - If you entered the blade thickness for logic input parameter 1), enter the maximum blade force in pounds. If you entered 0 for logic input parameter 1), enter the maximum blade bending moment in inch-pounds. These values are output parameters of our **Cross Flow Turbine Design Calculator, Overshot Water Wheel Design Calculator**, and **Undershot Water Wheel Design Calculator**. If this analysis is for an overshot water wheel bucket structure, you must first factor (i.e., multiply by 0.0568) both the **Overshot Water Wheel Design Calculator Maximum Blade Force** and **Maximum Blade Bending Moment** output parameters to account for the increased strength provided by overshot water wheel bucket structure as compared to blade structure BEFORE entering these values into this calculator.

3) **Blade Curvature Radius or Blade Width (Inches)** - This is either the curvature of the cross flow turbine blade or the width of the overshot water wheel bucket or undershot water wheel blade. This value is an output parameter of our **Cross Flow Turbine Design Calculator, Overshot Water Wheel Design Calculator**, and **Undershot Water Wheel Design Calculator**.

4) **Material Endurance Limit (Pounds/Square Inch)** - This is the cyclic stress (e.g., induced by water forces acting on a rotating blade) that may be applied to the chosen material without causing fatigue failure. This is typically 28000 PSI for A36 low carbon steel.

5) **Design Factor of Safety** - This is the ratio of the **Material Yield Strength** to the design load. In this case, the design load results from the **Maximum Blade Bending Moment**. The design factor of safety may range from 1.1 (where weight is an important design consideration such as in

airplanes where the loading is well known and where the material properties are well known and held to a high quality standard) to 5 or much more to ensure safety when weight is not a significant factor and there is perhaps less certainty about the loading and material properties. 1.5 may be a reasonable value to use for cross flow turbine and undershot water wheel blade stress analysis. If you factored (i.e., multiplied by 0.0568) both the **Overshot Water Wheel Design Calculator** **Maximum Blade Force** and **Maximum Blade Bending Moment** output parameters to account for the increased strength provided by overshot water wheel bucket structure as compared to blade structure BEFORE entering these values into this calculator, 1.5 may be a reasonable value to use for overshot water wheel bucket stress analysis.

Click Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Minimum Recommended Blade Thickness (Inches)** - This is the minimum recommended blade or bucket thickness given the input parameters.

2) **Maximum Recommended Blade Length between Supports (Inches)** - This is the maximum recommended blade or bucket length between the end plates of the cross flow turbine or water wheel given the input parameters. If the design blade or bucket length exceeds this recommendation, you may need additional support plates to stay within this recommendation to ensure long blade or bucket life.

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This calculator is based on "Blade Calculations for Water Turbines of the Banki Type", Report WPS3-83.03R351, P. Verhaart, Eindhoven University of Technology, published March 1983. It uses a "strength product" concept to address the common practice of fabricating cross flow turbine blades from standard commercially available pipe such that the resulting runner blade thickness is the standard nominal pipe wall thickness. The strength product was defined by Verhaart to be the cross flow turbine design head multiplied by the runner blade length squared which was determined by Verhaart to be proportional to the blade material endurance limit (determined by Verhaart to be 22 Newton's/Millimeter^2 for "mild steel" standard commercially available pipe), proportional to the blade area moment of inertia, and inversely proportional to the blade maximum fiber distance. By knowing the cross flow turbine design head, blade curvature radius (i.e., the standard nominal pipe interior radius), and blade thickness (i.e., the standard nominal pipe wall thickness); a safe blade length between the supports may be determined. The 22 Newton's/Millimeter^2 value was chosen by Verhaart according to "fatigue strength criteria" and because the "alternating load takes place in the presence of water and a low fatigue strength results." Please note that this 22 Newton's/Millimeter^2 value (i.e., 3,191 PSI) is about a factor of 10 less than one would normally use as a material endurance limit for A36 low carbon steel (i.e., 28,000 PSI).

Prior to Verhaart's innovative efforts in this field, cross flow turbine blades often experienced cracks at the point they were attached to the side plates. The Verhaart method has been successfully used by cross flow turbine manufacturers for many years and has reportedly resulted in significantly longer blade life. ***This calculator should only be used for performing a load/stress analysis on cross flow turbine blades.*** Please note that this calculator provides nearly identical stress analysis results as our generic **Blade Stress Analysis Calculator (Euler-Bernoulli)** when a 28,000 PSI material endurance limit and a 1.9 design factor of safety are used.

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Head Available at Penstock Outlet (Feet)** - This is the head that is available to the cross flow turbine at the penstock outlet. Please use this same value in our **Cross Flow Turbine Design Calculator**.

2) **Blade Curvature Radius (Inches)** - This is the optimum radius of the cross flow turbine blades given the cross flow turbine input design parameters. This value is an output parameter of our **Cross Flow Turbine Design Calculator**.

3) **Blade Thickness (Inches)** - This is the thickness of the cross flow turbine blade material. Please use this same value in our **Cross Flow Turbine Design Calculator**.

4) **Number of Blades** - This is the total number of blades used for the cross flow turbine. 18 blades are typical. Please use this same value in our **Cross Flow Turbine Design Calculator**.

Click Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Area Moment of Inertia (Inches^4)** - This is an engineering parameter used to predict the deflection and stress in beams.

2) **Maximum Fiber Distance (Inches)** - This is an engineering parameter defined as the distance between the blade neutral axis (i.e., the location of zero stress) and the blade surface experiencing the maximum stress.

3) **Verhaart Strength Product (Feet^3)** - This is an engineering parameter defined by Verhaart to be the **Design Head** input parameter multiplied by the cross flow turbine blade length squared which was found to be proportional to the blade material endurance limit, proportional to the blade area moment of inertia, and inversely proportional to the blade maximum fiber distance. By knowing the **Design Head** and this Verhaart strength product, the **Maximum Recommended Blade Length between Supports** output parameter may be determined.

4) **Maximum Recommended Blade Length between Supports (Inches)** - This is the maximum recommended blade length between the end plates of the cross flow turbine given the input parameters. If the design blade length exceeds this recommendation, you may need additional support plates to stay within this recommendation to ensure long blade life.

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This calculator and our companion **External Ballistics Calculator** ***and*** **Firearm Iron Sight Adjustment Calculator** ***were created for our colleagues and friends, who like us, enjoy the shooting sports and highly value our Constitutional Second Amendment rights. These calculators are dedicated to the men and women in our military and in our local law enforcement agencies who protect our country and our homeland…thank you!***

Internal ballistics is what occurs inside a gun barrel when a projectile is fired. External ballistics is what occurs to a projectile after it leaves a gun barrel. Terminal ballistics is what occurs to a projectile when it encounters the target. A bullet ballistic coefficient is the measure of a bullet's relative ability to overcome aerodynamic drag (i.e., overcome the loss of velocity caused by air resistance encountered during flight). Each specific bullet can be assigned a numerical aerodynamic coefficient of drag to quantify the bullet's aerodynamic drag performance. The bullet ballistic coefficient is a ratio of the aerodynamic coefficient of drag performance of the specific bullet against the known aerodynamic coefficient of drag performance of some standard projectile. This bullet ballistic coefficient calculator is based on Robert L. McCoy's "Modern Exterior Ballistics, The Launch and Flight Dynamics of Symmetric Projectiles", Revised 2nd Edition, Copyright 2012. This bullet ballistic coefficient calculator uses a fourth-order Runge-Kutta algorithm and a 0.0001 second step time increment to solve the non-linear differential equations that govern the point-mass dynamics of symmetric projectiles. ***As such, there isn't a more accurate ballistics calculator available at any price.***

This bullet ballistic coefficient calculator allows you to very accurately determine the bullet coefficient of drag, bullet form factor and bullet ballistic coefficient of any specific bullet by entering the accurately measured bullet speed immediately after the gun muzzle (i.e., the gun muzzle velocity) and by entering the accurately measured bullet speed at some other distance from the gun using a gun chronograph. Either the Army Metro or ICAO Atmosphere Standard may be associated with the calculated bullet ballistic coefficient. Several bullet coefficient of drag standards may be associated with the calculated bullet ballistic coefficient. ***Please keep in mind that this calculator, like all our calculators, may be used on your PC or on your mobile device since it runs using your trusted browser application.*** The calculated bullet ballistic coefficient for the specific bullet may then be used by external ballistics calculators such as our **External Ballistics Calculator** to precisely determine ballistic parameters such as bullet speed, bullet energy, bullet elevation, bullet windage, and bullet time of flight at any range.

The default values used for the input parameters for this calculator and our **External Ballistics Calculator** are based on a Marlin 336 lever action rifle and Hornady 30-30 Winchester 160 grain FTX Lever Revolution rifle ammo example having a claimed gun muzzle velocity of 2400 FPS and claimed bullet ballistic coefficient of 0.330 PSI.

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Atmosphere Standard (1=Army Metro, 2=ICAO)** - This determines what standard atmosphere is associated with the entered **Bullet Ballistic Coefficient** output parameter. The two atmosphere standards are the Army Metro Standard and the ICAO Standard. The Army Metro Standard assumes 59 degrees Fahrenheit temperature, 78% relative humidity, 29.53 inches of mercury barometric pressure and 1120.3 FPS speed of sound at 0 feet geometric altitude. The ICAO Standard assumes 59 degrees Fahrenheit temperature, 0% relative humidity, 29.92 inches of mercury barometric pressure and 1116.4 FPS speed of sound at 0 feet geometric altitude. The

last time we checked, Barnes, Hornady, Sierra and Winchester used the Army Metro Standard. Berger, Nosler and Remington used the ICAO Standard. The default value is the Army Metro Standard. Enter 1 or 2 or leave blank.

2) **Bullet Coefficient of Drag Standard (1=G1, 2=G2, 5=G5, 6=G6, 7=G7, 8=G8, 9=GS, 10=RA4, 11=GL, 12=GI)** - This determines what bullet coefficient of drag standard is associated with the calculated **Bullet Ballistic Coefficient** output parameter. Several bullet coefficient of drag standards may be associated with the calculated **Bullet Ballistic Coefficient** input parameter:

    G1 - For flat based pointed bullet: 3.28 calibers long, 1.32 caliber long nose, and 2 caliber long (blunt) nose ogive. This has been the bullet coefficient of drag standard since ballistics began. This is the default value. Enter 1 for G1.

    G2 - For long, conical point banded artillery projectiles with a 6 degree boat tail. This standard is not generally applicable to small arms.   Enter 2 for G2.

    G5 - For moderate (low base) boat tails: 4.29 calibers long, 0.49 caliber long, 7 degree 30 minute tail taper, 2.1 caliber nose, and 6.19 caliber tangent nose ogive. Enter 5 for G5.

    G6 - For flat based "spire point" type bullets: 4.81 calibers long, 2.53 caliber long nose, and 6.09 caliber secant nose ogive. Enter 6 for G6.

    G7 - For "VLD" type boat tails: 4.23 calibers long, 0.6 caliber long, 7 degree 30 minute tail taper, 2.18 caliber long nose, and 10 caliber tangent nose ogive. Most modern rifle boat tailed bullets match this standard. Enter 7 for G7.

    G8 - For flat base with a similar nose design as G7: 3.64 calibers long, 2.18 caliber long nose, and 10 caliber secant nose ogive. Enter 8 for G8.

    GS – For round balls. Enter 9 for GS.

    RA4 - For 22 Long Rifle. Enter 10 for RA4.

    GL - For traditional blunt nosed exposed lead bullets. Enter 11 for GL.

    GI – The historical and original Ingalls bullet ballistic coefficient of drag table. Enter 12 for GI.

    A bullet coefficient of drag standard should be selected that best matches the specific bullet being used which results in the **Bullet Form Factor** output parameter being very close to 1. The G7 bullet coefficient of drag standard has been shown to be the most representative bullet coefficient projectile standard for most modern rifle bullets; however, most bullet manufacturers still only report bullet ballistic coefficients based on the G1 bullet coefficient of drag standard. Using a bullet coefficient of drag standard that best matches the specific bullet being used minimizes the error associated with calculating the actual real-time bullet coefficient of drag and other ballistic output parameters associated with the bullet speed not being constant.

    Please note that this calculator in combination with our **External Ballistics Calculator** can be used to convert from a known bullet ballistic coefficient that is associated with a known coefficient of drag standard to a different bullet ballistic coefficient that is associated with a new and desired coefficient of drag standard. First use our **External Ballistics Calculator** with the originally

known bullet ballistic coefficient to determine the bullet speed at some range. We have found that the range at which the bullet speed is about 80% of the **Gun Muzzle Velocity** input parameter will typically provide the best results. Then enter this bullet speed and this range into this calculator and select the new and desired bullet coefficient of drag standard. This calculator will determine the new bullet ballistic coefficient that is associated with this new and desired bullet coefficient of drag standard. This new bullet ballistic coefficient may then be used in our **External Ballistics Calculator** to determine the ballistic parameters.

3) **Bullet Diameter (Inches)** - This is the diameter of the bullet. For example, a 30 caliber bullet has a diameter of 0.308 inches and this is the default value. Any positive value may be entered.

4) **Bullet Weight (Grains)** - This is the weight of the bullet in grains. One pound is equal to 7000 grains. The default value is 160. Any positive value may be entered.

5) **Gun Chronograph Measured Bullet Speed (Feet/Second)** - This is the bullet speed as measured at the **Gun Chronograph Range** input parameter using a gun chronograph. We use and highly recommend Oehler gun chronographs because of their high measurement accuracy which results from their chronograph design providing a longer sensor measurement distance and their chronograph design taking two instantaneous bullet speed measurements for each shot. If our **External Ballistics Calculator** is used to determine the ballistic parameters, the value entered for this input parameter should also be entered for the **Bullet Ballistic Coefficient Speed** input parameter. The default value is 1916.2 (i.e., the actual measured bullet speed at the **Gun Chronograph Range** which is about 80% of the **Gun Muzzle Velocity** input parameter). Any positive value may be entered.

6) **Gun Chronograph Range (Yards)** - This is the distance between the gun muzzle and where the **Gun Chronograph Measured Bullet Speed** input parameter is measured. We have found that the range at which the bullet speed is about 80% of the **Gun Muzzle Velocity** input parameter will typically provide the best results. The default value is 200. Any positive value may be entered.

7) **Gun Muzzle Velocity (Feet/Second)** - This is the speed of the bullet immediately after the gun muzzle. While the gun muzzle velocity is typically published by ammo manufacturers, it may be measured directly using a gun muzzle chronograph that uses electromagnetic sensors or measured using a gun chronograph that uses optical sensors placed about 3-4 yards beyond the gun muzzle. A bullet typically loses between 5-15 FPS of speed travelling between the gun muzzle and a gun chronograph placed about 3-4 yards beyond the gun muzzle. This speed loss value may be determined using our **External Ballistics Calculator** **Requested Specific Range** input parameter and this speed loss value should be added to the gun chronograph measured speed to obtain an accurate gun muzzle velocity. We use and highly recommend MagnetoSpeed chronographs for directly measuring the gun muzzle velocity because of their ease of setup and their high measurement accuracy which results from using electromagnetic sensors in lieu of traditional optical sensors which can be sensitive to lighting conditions. However, the MagnetoSpeed chronograph can NOT measure the bullet speed at some other distant range (i.e., the **Gun Chronograph Range** input parameter) which is required to determine the bullet ballistic coefficient. The default value is 2400. Any positive value may be entered.

8) **Altitude (Feet or Inches of Mercury)** - This is the average geometric (feet) or barometric pressure (inches of mercury) altitude between the gun and the target. The default value is 0 feet geometric altitude which results in a **Barometric Pressure** output parameter of 29.53 inches of mercury when the Army Metro Atmosphere Standard is selected, and which results in a **Barometric Pressure** output parameter of 29.92 inches of mercury when the ICAO Atmosphere Standard is selected given the entered **Atmosphere Standard** input parameter. Entered values between 29.92 and 7.06 are treated as barometric pressure altitude (inches of mercury) entries. If a geometric altitude (feet) is entered, either the Army Metro Atmosphere Standard Barometric Pressure Altitude or the ICAO Atmosphere Standard Barometric Pressure Altitude for the entered altitude is determined and used by the calculator given the entered **Atmosphere Standard** input parameter. The actual barometric pressure used by the calculator is indicated by the **Barometric Pressure** output parameter. The default value is 0. Any positive value may be entered or this may be left blank.

9) **Temperature (Degrees Fahrenheit)** - This is the average air temperature between the gun and the target. The default value at 0 feet of altitude is 59 degrees Fahrenheit for both the Army Metro and ICAO atmosphere standards. If a value is entered for the **Altitude** input parameter and this temperature input parameter is left blank, either the Army Metro Atmosphere Standard Temperature or the ICAO Atmosphere Standard Temperature for the entered **Altitude** input parameter is determined and used by the calculator given the entered **Atmosphere Standard** input parameter. Otherwise, the actual value entered for this temperature input value is used by the calculator. The actual temperature used by the calculator is indicated by the **Temperature** output parameter. Any value between -40 and 130 may be entered or this may be left blank.

10) **Relative Humidity (Percent)** - This is the average relative humidity between the gun and the target. The relative humidity is the ratio of the actual amount of water vapor in the outdoor air to the amount of the water vapor in the air at the state of saturation. A state of saturation exists when the air is holding the maximum amount of water possible (i.e., at 100% relative humidity) at a given temperature. Please see our **Psychrometrics Calculator** for more information about relative humidity. The default value is 78% when the Army Metro Atmosphere Standard is selected and the default value is 0% when the ICAO Atmosphere Standard is selected given the entered **Atmosphere Standard** input parameter. The actual relative humidity used by the calculator is indicated by the **Relative Humidity** output parameter. Any positive value may be entered or this may be left blank.

Click Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Barometric Pressure (Inches of Mercury)** - This is the average atmospheric barometric pressure between the gun and the target used by the calculator to determine the ballistic parameters given the entered **Atmosphere Standard**, **Altitude**, **Temperature** and **Relative Humidity** input parameters.

2) **Temperature (Degrees Fahrenheit)** - This is the average air temperature between the gun and the target used by the calculator to determine the ballistic parameters. The default value at 0 feet of altitude is 59 degrees Fahrenheit for both the Army Metro and ICAO atmosphere standards.

3) **Relative Humidity (Percent)** - This is the average relative humidity between the gun and the target used by the calculator to determine the ballistic parameters. The default value is 78% when the Army Metro Atmosphere Standard is selected and the default value is 0% when the ICAO Atmosphere Standard is selected by the **Atmosphere Standard** input parameter.

4) **Air Density Ratio** - This is the average air density ratio of the air between the gun and the target used by the calculator to determine the ballistic parameters. The air density ratio is the calculated air density divided by either the Army Metro Atmosphere Standard Density (i.e., 0.0751 PCF) or divided by the ICAO Atmosphere Standard Density (i.e., 0.0765 PCF) given the entered **Atmosphere Standard**, **Altitude**, **Temperature** and **Relative Humidity** input parameters.

5) **Air Density (Pounds/Cubic Foot)** - This is the average density of the air between the gun and the target used by the calculator to determine the ballistic parameters given the entered **Atmosphere Standard**, **Altitude**, **Temperature** and **Relative Humidity** input parameters.

6) **Speed of Sound (Feet/Second)** - This is the average speed of sound between the gun and the target used by the calculator to determine the ballistic parameters given the entered **Atmosphere Standard**, **Altitude**, **Temperature** and **Relative Humidity** input parameters. At 0 feet altitude and standard temperature and relative humidity, the speed of sound is 1120.3 FPS when the Army Metro Atmosphere Standard is selected and the speed of sound is 1116.4 FPS when the ICAO Atmosphere Standard is selected by the **Atmosphere Standard** input parameter.

7) **Bullet Sectional Density (Pounds/Square Inch)** - This is the weight of the bullet in pounds (i.e., the **Bullet Weight** input parameter divided by 7000) divided by the diameter of the bullet in inches (i.e., the **Bullet Diameter** input parameter) squared. Bullet sectional density is important because it has a significant effect on bullet penetration. For a given bullet design and bullet impact velocity, higher bullet sectional density will result in greater bullet penetration. Probably the best way to compare different caliber bullets is by bullet sectional density and not by bullet weight. For example, a 150 grain 0.277 inch diameter bullet will penetrate further than a 150 grain 0.308 inch diameter bullet if both bullets are of a similar design and both bullets impact at the same velocity. Typically available small game, varmint and small predator (CXP1) bullet sectional density values tend to range between 0.097 (e.g., 20 grain, 0.172 inch diameter) and 0.194 (e.g., 80 grain, 0.243 inch diameter). Typically available medium size big game (CXP2) bullet sectional density values tend to range between 0.216 (e.g., 100 grain, 0.257 inch diameter) and 0.249 (e.g., 115 grain, 0.257 inch diameter). Typically available large size big game (CXP3) bullet sectional density values tend to range between 0.261 (e.g., 140 grain, 0.277 inch diameter) and 0.288 (e.g., 270 grain, 0.366 inch diameter). Typically available thick-skinned dangerous game (CXP4) bullet sectional density values tend to range between 0.305 (e.g., 286 grain, 0.366 inch diameter) and 0.341 (e.g., 500 grain, 0.458 inch diameter). If our **External Ballistics Calculator** is used to determine the ballistic parameters, this output parameter should be in close agreement for both calculators.

8) **Bullet Form Factor** - This is the bullet form factor which indicates how close the **Bullet Coefficient of Drag** output parameter agrees with the bullet coefficient of drag standard that is entered for the **Bullet Coefficient of Drag Standard** input parameter. The bullet form factor is determined by numerical iteration to achieve the **Gun Chronograph Measured Bullet Speed**

input parameter at the **Gun Chronograph Range** input parameter given the other entered input parameters. The closer the bullet form factor is to 1, the closer the bullet coefficient of drag agrees with the bullet coefficient of drag standard. The closer the bullet coefficient of drag agrees with the bullet coefficient of drag standard, the more valid is the assumption that the bullet ballistic coefficient is not significantly affected by bullet speed. The G7 bullet form factor is typically very close to 1 for modern rifle bullets which indicates that the G7 projectile standard exhibits a coefficient of drag that is very close to modern rifle bullets and therefore there is less error associated with using a single G7 bullet ballistic coefficient value across a wide speed range. The G1 projectile standard bullet form factor is typically significantly less than 1 for modern rifle bullets which indicates that the G1 projectile standard exhibits a coefficient of drag that is NOT close to modern rifle bullets and therefore there is more error associated with using a single G1 bullet ballistic coefficient value across a wide speed range. If our **External Ballistics Calculator** is used to determine the ballistic parameters, this output parameter should be in close agreement for both calculators.

9) **Bullet Coefficient of Drag** - This is the bullet coefficient of drag which defines the aerodynamic characteristics of the bullet and how quickly it loses speed when travelling through the air. The bullet coefficient of drag is determined by multiplying the calculated **Bullet Form Factor** output parameter by the coefficient of drag associated with the entered **Bullet Coefficient of Drag Standard** input parameter at the entered **Gun Chronograph Measured Bullet Speed** input parameter. If our **External Ballistics Calculator** is used to determine the ballistic parameters, this output parameter should be in close agreement for both calculators.

Please note that this is only the bullet coefficient of drag associated with the calculated **Bullet Ballistic Coefficient** output parameter at the entered **Gun Chronograph Measured Bullet Speed** input parameter. The actual real-time bullet coefficient of drag used by the calculator is NOT constant and varies with actual bullet speed in accordance with the coefficient of drag profile associated with the entered **Bullet Coefficient of Drag Standard** input parameter.

10) **Bullet Ballistic Coefficient (Pounds/Square Inch)** - This is a parameter that is used to determine the actual real-time bullet coefficient of drag for the specific bullet that is used based on the measured coefficient of drag for some standard projectile. The bullet ballistic coefficient enables external ballistics calculators like our **External Ballistics Calculator** to determine ballistic parameters such as bullet speed, bullet energy, bullet elevation, bullet windage, and bullet time of flight at any range. This calculated bullet ballistic coefficient is the calculated **Bullet Sectional Density** output parameter divided by the calculated **Bullet Form Factor** output parameter.

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This calculator and our companion Bullet Ballistic Coefficient Calculator and Firearm Iron Sight Adjustment Calculator were created for our colleagues and friends, who like us, enjoy the shooting sports and highly value our Constitutional Second Amendment rights. These calculators are dedicated to the men and women in our military and our local law enforcement agencies who protect our country and our homeland…thank you!

Internal ballistics is what occurs inside a gun barrel when a projectile is fired. External ballistics is what occurs to a projectile after it leaves a gun barrel. Terminal ballistics is what occurs to a projectile when it encounters the target. This external ballistics calculator is based on Robert L. McCoy's "Modern Exterior Ballistics, The Launch and Flight Dynamics of Symmetric Projectiles", Revised 2nd Edition, Copyright 2012. This external ballistics calculator uses a fourth-order Runge-Kutta algorithm and a 0.0001 second time step increment to solve the non-linear differential equations that govern the point-mass dynamics of symmetric projectiles. ***As such, there isn't a more accurate ballistics calculator available at any price.***

This external ballistics calculator allows you to determine ballistic parameters such as bullet speed, bullet energy, bullet elevation, bullet windage, and bullet time of flight at any range. Either the Army Metro or ICAO Atmosphere Standard may be associated with the entered bullet ballistic coefficient. Several bullet coefficient of drag standards may be associated with the entered bullet ballistic coefficient. The effects of altitude, temperature, relative humidity, wind, terrain slope, rotating earth and bullet gyroscopic spin drift on the ballistic parameters may be accounted for as desired. Maximum gun range based on minimum bullet speed, minimum bullet energy, maximum bullet time of flight, or maximum point blank range may be determined. Bullet stability factor may be determined for any bullet shape, muzzle velocity and gun barrel rifling twist rate. Laser bore sight parameters may be determined to quickly and conveniently zero a gun at any desired range using a laser bore sight. Bullet initial intercept range may be determined to allow setting up a short range target to confirm sight/optics adjustment and gun zero range. ***Please keep in mind that this calculator, like all our calculators, may be used on your PC or on your mobile device since it runs using your trusted browser application.***

To accurately forecast ballistic data for a specific bullet that will be used, the bullet ballistic coefficient must be accurately determined and associated with a bullet coefficient of drag standard which results in a bullet form factor that is very close to 1. Our **Bullet Ballistic Coefficient Calculator** may be used to accurately determine the bullet ballistic coefficient. This accurately determined bullet ballistic coefficient may than be used in this external ballistics calculator to accurately forecast ballistic data for this specific bullet.

The default values used for the input parameters for this calculator and our **Bullet Ballistic Coefficient Calculator** are based on a Marlin 336 lever action rifle and Hornady 30-30 Winchester 160 grain FTX Lever Revolution rifle ammo example having a claimed gun muzzle velocity of 2400 FPS and claimed bullet ballistic coefficient of 0.330 PSI.

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Atmosphere Standard (1=Army Metro, 2=ICAO)** - This determines what standard atmosphere is associated with the entered **Bullet Ballistic Coefficient** output parameter. The two atmosphere standards are the Army Metro Standard and the ICAO Standard. The Army Metro Standard assumes 59 degrees Fahrenheit temperature, 78% relative humidity, 29.53 inches of

mercury barometric pressure and 1120.3 FPS speed of sound at 0 feet geometric altitude. The ICAO Standard assumes 59 degrees Fahrenheit temperature, 0% relative humidity, 29.92 inches of mercury barometric pressure and 1116.4 FPS speed of sound at 0 feet geometric altitude. The last time we checked, Barnes, Hornady, Sierra and Winchester used the Army Metro Standard. Berger, Nosler and Remington used the ICAO Standard. The default value is the Army Metro Standard. It is important to use the correct atmosphere standard that is associated with the entered **Bullet Ballistic Coefficient** input parameter. Enter 1 or 2 or leave blank.

2) **Bullet Coefficient of Drag Standard (1=G1, 2=G2, 5=G5, 6=G6, 7=G7, 8=G8, 9=GS, 10=RA4, 11=GL, 12=GI)** - This determines what bullet coefficient of drag standard is associated with the entered **Bullet Ballistic Coefficient** output parameter. Several bullet coefficient of drag standards may be associated with the entered **Bullet Ballistic Coefficient** input parameter:

G1 - For flat based pointed bullet: 3.28 calibers long, 1.32 caliber long nose, and 2 caliber long (blunt) nose ogive. This has been the bullet coefficient of drag standard since ballistics began. This is the default value. Enter 1 for G1.

G2 - For long, conical point banded artillery projectiles with a 6 degree boat tail. This standard is not generally applicable to small arms. Enter 2 for G2.

G5 - For moderate (low base) boat tails: 4.29 calibers long, 0.49 caliber long, 7 degree 30 minute tail taper, 2.1 caliber nose, and 6.19 caliber tangent nose ogive. Enter 5 for G5.

G6 - For flat based "spire point" type bullets: 4.81 calibers long, 2.53 caliber long nose, and 6.09 caliber secant nose ogive. Enter 6 for G6.

G7 - For "VLD" type boat tails: 4.23 calibers long, 0.6 caliber long, 7 degree 30 minute tail taper, 2.18 caliber long nose, and 10 caliber tangent nose ogive. Most modern rifle boat tailed bullets match this standard. Enter 7 for G7.

G8 - For flat base with a similar nose design as G7: 3.64 calibers long, 2.18 caliber long nose, and 10 caliber secant nose ogive. Enter 8 for G8.

GS – For round balls. Enter 9 for GS.

RA4 - For 22 Long Rifle. Enter 10 for RA4.

GL - For traditional blunt nosed exposed lead bullets. Enter 11 for GL.

GI – The historical and original Ingalls coefficient of drag table. Enter 12 for GI.

The G7 bullet coefficient of drag standard has been shown to be the most representative bullet coefficient projectile standard for most modern rifle bullets; however, most bullet manufacturers still only report bullet ballistic coefficients based on the G1 bullet coefficient of drag standard. Using a bullet coefficient of drag standard that best matches the specific bullet being used minimizes the error associated with calculating the actual real-time bullet coefficient of drag and other ballistic output parameters associated with the bullet speed not being constant. It is important to use the correct bullet coefficient of drag standard that is associated with the entered **Bullet Ballistic Coefficient** input parameter.

Please note that this calculator in combination with our **Bullet Ballistic Coefficient Calculator** can be used to convert from a known bullet ballistic coefficient that is associated with a known coefficient of drag standard to a different bullet ballistic coefficient that is associated with a new and desired coefficient of drag standard. First use this calculator with the originally known bullet ballistic coefficient to determine the bullet speed at some range. We have found that the range at which the bullet speed is about 80% of the **Gun Muzzle Velocity** input parameter will typically provide the best results. Then enter this bullet speed and this range into our **Bullet Ballistic Coefficient Calculator** and select the new and desired bullet coefficient of drag standard. The **Bullet Ballistic Coefficient Calculator** will determine the new bullet ballistic coefficient that is associated with this new and desired bullet coefficient of drag standard. This new bullet ballistic coefficient may then be used in this calculator to determine the ballistic parameters.

3) **Bullet Ballistic Coefficient (Pounds/Square Inch)** - This is a parameter that is used to determine the actual real-time bullet coefficient of drag for the specific bullet that is used based on the measured coefficient of drag for some standard projectile. The bullet ballistic coefficient enables this external ballistics calculator to determine ballistic parameters such as bullet speed, bullet energy, bullet elevation, bullet windage, and bullet time of flight at any range. Bullet coefficient of drag varies with speed. So the bullet ballistic coefficient that is entered should be the most representative bullet ballistic coefficient over the range of bullet speeds that you are interested in accurately determining ballistic parameters. If your bullet manufacturer only publishes one bullet ballistic coefficient value, that is what should be entered. If your bullet manufacturer publishes multiple bullet ballistic coefficient values for several bullet speeds, then perhaps enter the best average value for the desired range of bullet speeds that you are interested in accurately determining the ballistic parameters. For example, Sierra currently publishes and states that their 30 caliber, 155 grain Tipped Match King (TMK) bullet has a bullet ballistic coefficient of 0.519 when the bullet speed is greater than 1900 FPS, has a bullet ballistic coefficient 0.490 when the bullet speed is between 1900 and 1600 FPS, and has a bullet ballistic coefficient 0.420 when the bullet speed is less than 1600 FPS. It is important to use the correct **Atmosphere Standard** and **Bullet Coefficient of Drag Standard** input parameters that are associated with this entered bullet ballistic coefficient. The default value is 0.330. Any positive value may be entered.

Please note that the bullet ballistic coefficient of any bullet may be determined by accurately measuring the bullet speed immediately after the gun muzzle (i.e., the gun muzzle velocity) and by accurately measuring the bullet speed at some other distance from the gun by using a gun chronograph and then entering this information into a bullet ballistic coefficient calculator such as our **Bullet Ballistic Coefficient Calculator** to determine the bullet ballistic coefficient.

4) **Bullet Ballistic Coefficient Speed (Feet/Second)** - This is the bullet speed associated with the entered **Bullet Ballistic Coefficient** input parameter if this is known. If our **Bullet Ballistic Coefficient Calculator** was used to determine the value entered for the **Bullet Ballistic Coefficient** input parameter, the value entered for the **Gun Chronograph Measured Bullet Speed** input parameter should also be entered for this bullet ballistic coefficient speed input parameter. If this input parameter is left blank, the calculator will assume this bullet speed is equal to 80% of the **Gun Muzzle Velocity** input parameter and this is the default value. Any positive value may be entered or this may be left blank.

5) **Bullet Diameter (Inches)** - This is the diameter of the bullet. For example, a 30 caliber bullet has a diameter of 0.308 inches and this is the default value. Any positive value may be entered.

6) **Bullet Length (Inches)** - This is the total length of the bullet from tip to tail. This input parameter is used to determine the **Bullet Stability Factor** output parameter and determine the effect that bullet gyroscopic spin drift has on the **Bullet Windage** output parameters. The default value is blank. Any positive value may be entered or this may be left blank if bullet stability and gyroscopic spin drift information is not desired.

7) **Bullet Weight (Grains)** - This is the weight of the bullet in grains. One pound is equal to 7000 grains. The default value is 160. Any positive value may be entered.

8) **Gun Barrel Rifling Twist Rate (Inches/Turn)** - This is the twist rate of the barrel bore rifling and is typically published by the gun manufacturer and often stamped on the barrel. If the twist is 1:10 inches, 10 should be entered for this input parameter. This input parameter is used to determine the **Bullet Stability Factor** output parameter and determine the effect that bullet gyroscopic spin drift has on the **Bullet Windage** output parameters. A barrel having a right-handed twist rate (i.e., causing the bullet to rotate clockwise) should be entered as a positive value. A barrel having a left-handed twist rate (i.e., causing the bullet to rotate counterclockwise) should be entered as a negative value. The default value is blank. Any value may be entered or this may be left blank if bullet stability and gyroscopic spin drift information is not desired.

9) **Gun Sight Height (Inches)** - This is the height of the most forward element of the gun sight above the barrel bore centerline. For iron sights, this is the height of the top of front sight blade above the barrel bore centerline. If you need adjust the iron sights on your firearm, please see our **Firearm Iron Sight Adjustment Calculator**. For optics, this is the height of the optic tube centerline above the barrel bore centerline. The gun sight height is typically 0.9 inches for iron sights, 1.5 inches for most rifle optics, and 2.7-3.0 inches for AR-15 platform iron sights/optics. The default value is 0.9. Any positive value may be entered.

10) **Gun Muzzle Velocity (Feet/Second)** - This is the speed of the bullet immediately after the gun muzzle. While the gun muzzle velocity is typically published by ammo manufacturers, it may be measured directly using a gun muzzle chronograph that uses electromagnetic sensors or measured using a gun chronograph that uses optical sensors placed about 3-4 yards beyond the gun muzzle. A bullet typically loses between 5-15 FPS of speed travelling between the gun muzzle and a gun chronograph placed about 3-4 yards beyond the gun muzzle. This speed loss value may be determined using the **Requested Specific Range** input parameter and this speed loss value should be added to the gun chronograph measured speed to obtain an accurate gun muzzle velocity. We use and highly recommend Oehler gun chronographs because of their high measurement accuracy which results from their chronograph design providing a longer sensor measurement distance and their chronograph design taking two instantaneous bullet speed measurements for each shot. We use and highly recommend MagnetoSpeed chronographs for directly measuring the gun muzzle velocity because of their ease of setup and their high measurement accuracy which results from using electromagnetic sensors in lieu of traditional optical sensors which can be sensitive to lighting conditions. However, the MagnetoSpeed chronograph can NOT measure the bullet speed at some other distant range which is required to

determine the bullet ballistic coefficient. The default value is 2400. Any positive value may be entered.

11) **Gun Zero Range (Yards)** – This is the second and farthest desired distance where the gun Point of Aim (POA) or Line of Sight (LOS) intercept the bullet Point of Impact (POI). The **Bullet Elevation** output parameter will be 0 at this gun zero range distance. This gun zero range should NOT be confused with the gun short range zero or **Bullet Initial Intercept Range** output parameter where the POA or LOS first intercept the bullet POI, which typically occurs within about the first 50 yards. The gun zero range is typically optimized such that the **Bullet Elevation** output parameter variation over the likely range that the gun will be used will be acceptable. Acceptable in this case means keeping the **Bullet Elevation** output parameter variation within some +/- value that satisfies the required target accuracy over the likely range that the gun will be used without the need for adjusting sight/optics or adjusting gun POA above/below the target. The required target accuracy is one-half of the target Critical Zone. The target Critical Zone is typically 2 to 4 inches for small game (CXP1) and typically 6 to 8 inches for medium/large size big game (CXP2/CXP3) and for anti-personnel. So the required target accuracy and associated acceptable **Bullet Elevation** output parameter variation is typically +/- 1 to 2 inches for small game and typically +/- 3 to 4 inches for medium/large size big game and anti-personnel.

Therefore, optimizing the gun zero range involves determining the Maximum Point Blank Range (MPBR) for the specific gun and the specific ammunition. The MPBR is the maximum range where the gun POA can be directly at the target and the bullet POI will remain within the target Critical Zone. The optimum MPBR may be determined by entering a value of 4 for the **Maximum Range Criteria** input parameter, entering a value between 1 to 2 inches or between 3 to 4 inches for the **Maximum Range Criteria Value** input parameter, and then varying the gun zero range until the longest **Maximum Range** output parameter is found. The default value is 163 yards which results in a 192 yard +/-2 inch MPBR for this example. A 191 yard gun zero range would result in a 225 yard +/-3 inch MPBR for this example. Any positive value may be entered for the gun zero range.

Please note that once the gun zero range has been determined, the most convenient and quickest way to successfully adjust sight/optics to establish this gun zero range is to use a laser bore sight. Please review the instructions for the **Laser Target Range** input parameter for more information on using a laser bore sight to establish the gun zero range.

Please note that sight/optics adjustment and gun zero range may be confirmed by setting up a short range target at the **Bullet Initial Intercept Range** output parameter range or by setting up a long range target at the actual gun zero range. Sight/optics adjustment and gun zero range may be confirmed by setting up a target at any specific range, entering this specific target range for the **Requested Specific Range** input parameter and then comparing the bullet POI with the **Bullet Elevation at Requested Specific Range** output parameter.

Please note that this calculator will determine the gun zero range and associated **Departure Angle** output parameter for ANY value entered including very long ranges (i.e., well in excess of 1000 yards). As such, the **Departure Angle** output parameter alone can be used for aiming long range firearms as described in the instructions for this output parameter. Computational time can take significantly longer for determining the gun zero range at very long ranges. The only

calculator limit is a maximum time of flight of 120 seconds. To ensure numerical stability, the calculator always limits the bullet down-range speed to 25% of the bullet downward vertical speed (i.e., the situation where the bullet is falling toward the ground four times faster than it is moving down-range).

12) **Requested Specific Range (Yards)** - This input parameter allows the user to enter any specific range and have the calculator determine the requested specific **Bullet Speed**, **Bullet Energy**, **Bullet Elevation**, **Bullet Windage** and **Bullet Time of Flight** output parameters at this requested specific range. While the gun muzzle velocity is typically published by ammo manufacturers, it may be measured directly using a gun muzzle chronograph that uses electromagnetic sensors or a gun chronograph that uses optical sensors placed about 3-4 yards beyond the gun muzzle. A bullet typically loses between 5-15 FPS of speed travelling between the gun muzzle and a gun chronograph placed about 3-4 yards beyond the gun muzzle. This input parameter is useful for determining this speed loss value or for determining the ballistic parameters at some specific range other than the standard range output parameter values. If a value is entered that exceeds the maximum range, the **Maximum Range** output parameter will indicate this maximum range and the requested specific **Bullet Speed**, **Bullet Energy**, **Bullet Elevation**, **Bullet Windage** and **Bullet Time of Flight** output parameters will indicate "MRE" for Maximum Range Exceeded. Any positive value may be entered or this may be left blank.

13) **Requested Elevation/Windage Units (1=Inches, 2=IPHY, 3=MILS, 4=MOA)** - This is the unit that is used for the **Bullet Elevation** and **Bullet Windage** output parameters. Enter 1 for Inches which is the default value. Enter 2 for Inches per Hundred Yards (IPHY). Enter 3 for Milli-Radians (MILs). Enter 4 for Minute of Angle (MOA). Typically, Inches (the default value) are used for basic understanding and the other units are used so as to be consistent and convenient with the units associated with adjusting your choice of sights/optics. An IPHY is 1 inch per hundred yards and trigonometrically equates to 0.0160 degrees (e.g., 1 IPHY at 300 yards is exactly 3 inches). A MOA is 1/60 of a degree or 0.0167 degrees and trigonometrically equates to 1.047 inches per hundred yards (e.g., 1 MOA at 300 yards is 3.141 inches or approximately 3 inches). A MIL is 1/1000 of a radian or 0.0573 degrees and trigonometrically equates to 3.6 inches per hundred yards (e.g., 1 MIL at 300 yards is 10.8 inches). 1 MIL equates to 3.6 IPHYs (i.e., 10.8 inches divided by 3 inches) and equates to 3.438 MOAs (i.e., 10.8 inches divided by 3.141 inches).

14) **Altitude (Feet or Inches of Mercury)** - This is the average geometric (feet) or barometric pressure (inches of mercury) altitude between the gun and the target. The default value is 0 feet geometric altitude which results in a **Barometric Pressure** output parameter of 29.53 inches of mercury when the Army Metro Atmosphere Standard is selected, and which results in a **Barometric Pressure** output parameter of 29.92 inches of mercury when the ICAO Atmosphere Standard is selected given the entered **Atmosphere Standard** input parameter. Entered values between 29.92 and 7.06 are treated as barometric pressure altitude (inches of mercury) entries. If a geometric altitude (feet) is entered, either the Army Metro Atmosphere Standard Barometric Pressure Altitude or the ICAO Atmosphere Standard Barometric Pressure Altitude for the entered altitude is determined and used by the calculator given the entered **Atmosphere Standard** input parameter. The actual barometric pressure used by the calculator is indicated by the **Barometric Pressure** output parameter. Any positive value may be entered or this may be left blank.

15) **Temperature (Degrees Fahrenheit)** - This is the average air temperature between the gun and the target. The default value at 0 feet of altitude is 59 degrees Fahrenheit for both the Army Metro and ICAO atmosphere standards. If a value is entered for the **Altitude** input parameter and this temperature input parameter is left blank, either the Army Metro Atmosphere Standard Temperature or the ICAO Atmosphere Standard Temperature for the entered **Altitude** input parameter is determined and used by the calculator given the entered **Atmosphere Standard** input parameter. Otherwise, the actual value entered for this temperature input value is used by the calculator. The actual temperature used by the calculator is indicated by the **Temperature** output parameter. Any value between -40 and 130 may be entered or this may be left blank.

16) **Relative Humidity (Percent)** - This is the average relative humidity between the gun and the target. The relative humidity is the ratio of the actual amount of water vapor in the outdoor air to the amount of the water vapor in the air at the state of saturation. A state of saturation exists when the air is holding the maximum amount of water possible (i.e., at 100% relative humidity) at a given temperature. Please see our **Psychrometrics Calculator** for more information about relative humidity. The default value is 78% when the Army Metro Atmosphere Standard is selected and the default value is 0% when the ICAO Atmosphere Standard is selected given the entered **Atmosphere Standard** input parameter. The actual relative humidity used by the calculator is indicated by the **Relative Humidity** output parameter. Any positive value may be entered or this may be left blank.

17) **Wind Speed (Miles/Hour)** - This is the absolute magnitude of the average wind speed between the gun and the target. This input parameter is used to determine the wind effect on the **Bullet Speed**, **Bullet Energy**, **Bullet Elevation**, **Bullet Windage** and **Bullet Time of Flight** output parameters. The default value is 0. Any positive value may be entered or this may be left blank.

18) **Wind Direction (O'clock)** - This is the O'clock direction that the wind is coming from relative to the gun and target. For example, if the wind is a 100% headwind coming directly from the target toward the gun, enter 12. A 100% headwind will decrease the **Bullet Speed** and **Bullet Energy** output parameters and will increase the **Elevation** and **Bullet Time of Flight** output parameters. If the wind is a 100% tailwind coming directly from behind the gun toward the target, enter 6. A 100% tailwind will increase the **Bullet Speed** and **Bullet Energy** output parameters and will decrease the **Elevation** and **Bullet Time of Flight** output parameters. A crosswind coming from the left of the gun and target (e.g., between 7 and 11 O'clock) will result in a positive **Bullet Windage** output parameter. A crosswind coming from the right of the gun and target (e.g., between 1 and 5 O'clock) will result in a negative **Bullet Windage** output parameter. The default value is 12. Enter 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 or 12 or this may be left blank.

19) **Terrain Inclination Angle (Degrees)** - This is the inclination or slope of the terrain between the gun and the target. This input parameter is used to determine the effect that sloped terrain has on the **Bullet Speed**, **Bullet Energy**, **Bullet Elevation** and **Bullet Time of Flight** output parameters. This effect is small for slopes less than 5 degrees. The default value is 0. Any value between -90 and 90 may be entered or this may be left blank.

20) **Latitude (Degrees)** - This input parameter is used to determine the Coriolis acceleration effect of the rotating earth on the **Bullet Speed**, **Bullet Energy**, **Bullet Elevation**, **Bullet Windage** and **Bullet Time of Flight** output parameters. Latitude is a geographic coordinate that specifies the

north-south position of a point on the Earth's surface. Latitude is an angle which ranges from 0 degrees at the Equator to 90 degrees northward and to -90 degrees southward. If the latitude is south, enter a negative value. You may need to convert latitude that is in degrees, minutes and seconds into decimal degrees. For example, if the latitude is North 42° 36' 0", the correct entry is 42.60 (i.e., 0"/60 equals 0' and 36.0'/60 equals 0.60 °). The Coriolis acceleration effect is small for ranges less than 500 yards. The default value is blank. Any value between -90 and 90 may be entered or this may be left blank if this information is not desired.

21) **Target Azimuth Angle (Inches)** - This input parameter is used to determine the Coriolis acceleration effect of the rotating earth on the **Bullet Speed**, **Bullet Energy**, **Bullet Elevation**, **Bullet Windage** and **Bullet Time of Flight** output parameters. The target azimuth angle is defined as the clockwise angle from true north to the direction of the target similar to a standard compass dial. As such, a target azimuth angle of 0 degrees is true north, 90 degrees is true east, 180 degrees is true south and 270 degrees is true west. If you are using a compass, be sure to consider the local magnetic declination (also known as magnetic variation) which changes over time. Westerly magnetic declination should be added to compass heading to determine true heading. Easterly magnetic declination should be subtracted from compass heading to determine true heading. For Rogue River, Oregon, the local magnetic declination was 14.9 degrees east of true in 2016. Therefore, true south in Rogue River, Oregon was equivalent to a magnetic compass reading of 165.1 degrees at this time. The Coriolis acceleration effect is small for ranges less than 500 yards. The default value is blank. Any value between 0 and 360 may be entered or this may be left blank if this information is not desired.

22) **Gyroscopic Spin Drift** - This is a logic input parameter for calculating the effect that bullet gyroscopic spin drift has on the **Bullet Windage** output parameters. The **Bullet Length** and **Gun Barrel Rifling Twist Rate** input parameters must first be entered to determine the **Bullet Stability Factor** output parameter BEFORE the effect of gyroscopic spin drift can be calculated and applied to the **Bullet Windage** output parameters. A barrel having a right-handed twist rate (i.e., causing the bullet to rotate clockwise) will result in positive windage toward the right. A barrel having a left-handed twist rate (i.e., causing the bullet to rotate counterclockwise) will result in negative windage toward the left. The sign of the value entered for the **Gun Barrel Rifling Twist Rate** input parameter is used to determine the bullet rotation. The gyroscopic spin drift effect is small for ranges less than 500 yards. The default value is blank. Enter 1 to determine the effect that gyroscopic spin drift has on the **Bullet Windage** output parameters or this may be left blank if this information is not desired.

23) **Maximum Range Criteria (0=No Maximum Range, 1=Minimum Speed, 2=Minimum Energy, 3=Maximum Time of Flight, 4=Maximum Point Blank Range)** - This is the criteria that is used by the calculator to determine the **Maximum Range** output parameter. Enter 0 to not have any maximum range limit. Enter 1 to use minimum bullet down-range speed for the maximum range criteria. Enter 2 to use bullet energy for the maximum range criteria. Enter 3 to use bullet time of flight for the maximum range criteria. Enter 4 to use Maximum Point Blank Range (MPBR) for the maximum range criteria. The MPBR may be determined by using this maximum range criteria and the **Maximum Range Criteria Value** input parameter and may be optimized by varying the **Gun Zero Range** input parameter until the longest **Maximum Range** output parameter is found.. Please review the instructions for the **Gun Zero Range** input parameter for more information

about MPBR. The default value is 0. Enter 0, 1, 2, 3 or 4 or this may be left blank if this information is not desired.

Please note that if the calculated maximum range is greater than 1000 yards and greater than the entered **Requested Specific Range** input parameter, the **Maximum Range** output parameter will indicate "NR" for Not Requested. So a large value (i.e., a value that is larger than the calculated maximum range) may need to be entered for the **Requested Specific Range** input parameter in order to have the **Maximum Range** output parameter display this maximum range.

24) **Maximum Range Criteria Value** - This is the actual value associated with the **Maximum Range Criteria** input parameter that is used by the calculator to determine the **Maximum Range** output parameter. If 1 is entered for the **Maximum Range Criteria** input parameter, the default minimum bullet down-range speed value is 100 FPS. Please note that the **Bullet Speed** output parameter may be significantly higher than the entered minimum bullet down-range speed value because the **Bullet Speed** output parameter represents the total bullet speed magnitude (i.e., includes the combined bullet down-range speed, the bullet downward vertical speed and the bullet windage speed). The bullet downward vertical speed increases toward constant terminal speed (i.e., the speed where the aerodynamic drag force and gravitational force are the same during free fall resulting in zero acceleration and zero deceleration) which may be a couple hundred FPS. If 2 is entered for the **Maximum Range Criteria** input parameter, the default minimum energy value is 1000 foot-pounds. If 3 is entered for the **Maximum Range Criteria** input parameter, the default maximum time of flight value is 6 seconds. The maximum calculator allowed bullet time of flight is 120 seconds. If 4 is entered for the **Maximum Range Criteria** input parameter, the default Maximum Point Blank Range (MPBR) allowed bullet elevation variation value is 2 inches. Please review the instructions for the **Gun Zero Range** input parameter for more information about MPBR. To ensure numerical stability, the calculator always limits the minimum bullet down-range speed to 25% of the bullet downward vertical speed (i.e., the situation where the bullet is falling toward the ground four times faster than it is moving down-range). Any positive value may be entered or this may be left blank if this information is not desired.

25) **Laser Target Range (Yards)** - The most convenient and quickest way to successfully adjust sight/optics to establish the **Gun Zero Range** input parameter is to use a laser bore sight. We use and highly recommend Site Lite laser bore sights because of their superior bore sighting accuracy and powerful lasers that exhibit superior visibility. This laser target range input parameter is the range that a target may be placed to allow using a laser bore sight to establish the **Gun Zero Range** input parameter. If this laser target range input parameter is left blank, the calculator will determine the range where the Line of Sight (LOS) and the laser dot elevation will be the same value (i.e., the laser dot will strike the center of a target placed at this range) after successfully accomplishing the required sight/optics adjustment necessary to establish the **Gun Zero Range** input parameter. If a value is entered for this laser target range input parameter (e.g., to perhaps place the laser bore sight target at a more convenient closer range), the **Laser Height** output parameter will advise the height deviation that the laser dot will strike above or below the center of a target placed at the value entered for this laser target range input parameter after successfully accomplishing the required sight/optics adjustment necessary to establish the **Gun Zero Range** input parameter. This entered range will be indicated by the **Laser Target Range** output parameter. The default value is blank. Any positive value may be entered or this may be left blank.

Please note that using a laser bore sight to successfully accomplish the required sight/optics adjustment does NOT expressly involve external bullet ballistics or the actual path of the bullet. Using a laser bore sight only involves adjusting the sight/optics to get the two straight lines that are formed by the LOS and the barrel bore centerline (i.e., the straight path of the laser beam) to cross at the some predetermined range. The LOS is a level horizontal straight line defined by adjusting the sight/optics. The barrel bore centerline is a straight line that is angled upward at the required **Departure Angle** output parameter. The predetermined range where these straight lines cross is the **Laser Target Range** output parameter when this laser target range input parameter is left blank. So the accuracy of using a laser bore sight to successfully accomplish the required sight/optics adjustment necessary to establish the required **Departure Angle** output parameter depends solely on the specific accuracy of the laser bore sight. The accuracy of the **Departure Angle** output parameter to actually establish the **Gun Zero Range** input parameter largely depends on the accuracy of the **Bullet Ballistic Coefficient** input parameter, the accuracy of the **Gun Muzzle Velocity** input parameter and the accuracy of the external ballistics software. What this implies and what has been our experience is that 1 Minute of Angle (MOA) first shot accuracy can be obtained by using an accurate laser bore site, accurate bullet ballistic coefficient, accurate gun muzzle velocity and accurate external ballistics software. Please review the instructions for the **Requested Elevation/Windage Units** input parameter for more information on MOA.

26) **Departure Angle (Minutes)** - Since sights/optics are mounted above the barrel bore centerline and since a bullet begins to drop after it leaves the gun muzzle, guns must be angled upwards in relation to the Line of Sight (LOS) so that the bullet will strike the point of aim. So the departure angle is normally the angle that the gun must be elevated to zero the gun at the **Gun Zero Range** input parameter. This input parameter should normally always be left blank, which is the default value, so the calculator can determine the departure angle that is required to zero the gun at the **Gun Zero Range** input parameter and report this required departure angle as the **Departure Angle** output parameter. However, any specific departure angle may be entered for this input parameter in lieu of having the calculator determine this value.

Click Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Bullet Speed at Requested Specific Range (Feet/Second)** - This is the bullet speed at the requested range. If the **Requested Specific Range** input parameter is not entered, the bullet speed will indicate "NR" for Not Requested. If the **Requested Specific Range** input parameter exceeds the **Maximum Range** output parameter, the bullet speed will indicate "MRE" for Maximum Range Exceeded.

2) **Bullet Energy at Requested Specific Range (Foot-Pounds)** - This is the bullet energy at the requested range. If the **Requested Specific Range** input parameter is not entered, the bullet energy will indicate "NR" for Not Requested. If the **Requested Specific Range** input parameter exceeds the **Maximum Range** output parameter, the bullet energy will indicate "MRE" for Maximum Range Exceeded.

3) **Bullet Elevation at Requested Specific Range** - This is the vertical distance that the bullet path is from the Line of Sight (LOS) at the **Requested Specific Range** input parameter. The units are as requested and entered for the **Requested Elevation/Windage Units** input parameter. A positive bullet elevation value indicates that the path bullet is above the LOS. A negative bullet elevation value indicates that the bullet path is below the LOS. If the **Requested Specific Range** input parameter is not entered, the bullet elevation will indicate "NR" for Not Requested. If the **Requested Specific Range** input parameter exceeds the **Maximum Range** output parameter, the bullet elevation will indicate "MRE" for Maximum Range Exceeded.

4) **Bullet Windage at Requested Specific Range** - This is the horizontal distance that the bullet path is from the Line of Sight (LOS) at the **Requested Specific Range** input parameter. The units are as requested and entered for the **Requested Elevation/Windage Units** input parameter. A positive bullet windage value indicates that the path bullet is to the right of the LOS. A negative bullet windage value indicates that the bullet path is to the left of the LOS. If the **Requested Specific Range** input parameter is not entered, the bullet windage will indicate "NR" for Not Requested. If the **Requested Specific Range** input parameter exceeds the **Maximum Range** output parameter, the bullet windage will indicate "MRE" for Maximum Range Exceeded.

5) **Bullet Time of Flight at Requested Specific Range (Seconds)** - This is the time the bullet reaches the requested range. The maximum calculator allowed bullet time of flight is 120 seconds. If the **Requested Specific Range** input parameter is not entered, the bullet time of flight will indicate "NR" for Not Requested. If the **Requested Specific Range** input parameter exceeds the **Maximum Range** output parameter, the bullet time of flight will indicate "MRE" for Maximum Range Exceeded.

6) **Maximum Range (Yards)** - This is the range that the bullet can reach and is determined by the calculator given the entered **Maximum Range Criteria** and **Maximum Range Criteria Value** input parameters. The maximum calculator allowed maximum range is 10,000 yards. The maximum range will indicate "NR" for Not Reached if the **Requested Specific Range** input parameter and all the specific ranges (i.e., Muzzle, 25, 50, 75, 100, 200, 300, 400, 500, 600, 700, 800, 900 and 1000 yard ranges) do NOT exceed this maximum range. The maximum range will indicate "MRE" for Maximum Range Exceeded if the maximum range exceeds the 10,000 yards calculator maximum range limit. To ensure numerical stability, the calculator always limits the bullet down-range speed to 25% of the bullet downward vertical speed (i.e., the situation where the bullet is falling toward the ground four times faster than it is moving down-range).

Please note that if the calculated maximum range is greater than 1000 yards and greater than the entered **Requested Specific Range** input parameter, this maximum range output parameter will indicate "NR" for Not Requested. So a very large value (i.e., a value that is larger than the calculated maximum range) may need to be entered for the **Requested Specific Range** input parameter in order to have this maximum range output parameter display this maximum range.

7) **Bullet Speed (Feet/Second)** - This is the bullet speed at the Muzzle, 25, 50, 75, 100, 200, 300, 400, 500, 600, 700, 800, 900 and 1000 yard ranges. The bullet speed at the Muzzle is uninteresting as it is always equal to the **Gun Muzzle Velocity** input parameter. The **Maximum Range Criteria** and **Maximum Range Criteria Value** input parameters may be used to determine the **Maximum Range** output parameter based on a minimum allowed bullet down-range speed

requirement. If any of the specific ranges (i.e., Muzzle, 25, 50, 75, 100, 200, 300, 400, 500, 600, 700, 800, 900 and 1000 yard ranges) exceed the **Maximum Range** output parameter, the bullet speed will indicate "MRE" for Maximum Range Exceeded for those ranges where the exceedance occurs.

8) **Bullet Energy (Foot-Pounds)** - This is the bullet energy at the Muzzle, 25, 50, 75, 100, 200, 300, 400, 500, 600, 700, 800, 900 and 1000 yard ranges. 1000 foot-pounds of energy is generally considered the minimum energy at range to humanly kill a deer (CPX2). 1200 foot-pounds of energy is generally considered the minimum energy at range to humanly kill an elk (CPX3). A significant number of deer and elk have been killed using far less energy than these minimum recommended values. However, a significant number of deer/elk have been wounded and have died a slow death using even more energy than these minimum recommended values. So good shot placement at or above these minimum recommended energy values should always be the objective of a good hunter. The **Maximum Range Criteria** and **Maximum Range Criteria Value** input parameters may be used to determine the **Maximum Range** output parameter based on a minimum allowed bullet energy requirement. If any of the specific ranges (i.e., Muzzle, 25, 50, 75, 100, 200, 300, 400, 500, 600, 700, 800, 900 and 1000 yard ranges) exceed the **Maximum Range** output parameter, the bullet energy will indicate "MRE" for Maximum Range Exceeded for those ranges where the exceedance occurs.

9) **Bullet Elevation** - This is the vertical distance that the bullet path is from the Line of Sight (LOS) at the Muzzle, 25, 50, 75, 100, 200, 300, 400, 500, 600, 700, 800, 900 and 1000 yard ranges. The units are as requested and entered for the **Requested Elevation/Windage Units** input parameter. A positive bullet elevation value indicates that the bullet path is above the LOS. A negative bullet elevation value indicates that the bullet path is below the LOS. The bullet elevation at the Muzzle is uninteresting as it is always equal to the **Gun Sight Height** input parameter. The **Maximum Range Criteria** and **Maximum Range Criteria Value** input parameters may be used to determine the **Maximum Range** output parameter based on a Maximum Point Blank Range (MPBR) requirement. Please review the instructions for the **Gun Zero Range** input parameter for more information about MPBR. If any of the specific ranges (i.e., Muzzle, 25, 50, 75, 100, 200, 300, 400, 500, 600, 700, 800, 900 and 1000 yard ranges) exceed the **Maximum Range** output parameter, the bullet elevation will indicate "MRE" for Maximum Range Exceeded for those ranges where the exceedance occurs.

10) **Bullet Windage** - This is the horizontal distance that the bullet path is from the Line of Sight (LOS) at the Muzzle, 25, 50, 75, 100, 200, 300, 400, 500, 600, 700, 800, 900 and 1000 yard ranges. The units are as requested and entered for the **Requested Elevation/Windage Units** input parameter. A positive bullet windage value indicates that the bullet path is to the right of the LOS. A negative bullet windage value indicates that the bullet path is to the left of the LOS. The bullet windage at the Muzzle is uninteresting as it is always equal to 0. If any of the specific ranges (i.e., Muzzle, 25, 50, 75, 100, 200, 300, 400, 500, 600, 700, 800, 900 and 1000 yard ranges) exceed the **Maximum Range** output parameter, the bullet windage will indicate "MRE" for Maximum Range Exceeded for those ranges where the exceedance occurs.

11) **Bullet Time of Flight (Seconds)** - This is the time the bullet reaches the Muzzle, 25, 50, 75, 100, 200, 300, 400, 500, 600, 700, 800, 900 and 1000 yard ranges. The maximum calculator allowed bullet time of flight is 120 seconds. The bullet windage at the Muzzle is uninteresting as it is

always equal to 0. The **Maximum Range Criteria** and **Maximum Range Criteria Value** input parameters may be used to determine the **Maximum Range** output parameter based on a maximum allowed bullet time of flight requirement. If any of the specific ranges (i.e., Muzzle, 25, 50, 75, 100, 200, 300, 400, 500, 600, 700, 800, 900 and 1000 yard ranges) exceed the **Maximum Range** output parameter, the bullet time of flight will indicate "MRE" for Maximum Range Exceeded for those ranges where the exceedance occurs.

12) **Barometric Pressure (Inches of Mercury)** - This is the average atmospheric barometric pressure between the gun and the target used by the calculator to determine the ballistic parameters given the entered **Atmosphere Standard**, **Altitude**, **Temperature** and **Relative Humidity** input parameters.

13) **Temperature (Degrees Fahrenheit)** - This is the average air temperature between the gun and the target used by the calculator to determine the ballistic parameters. The default value at 0 feet of altitude is 59 degrees Fahrenheit for both the Army Metro and ICAO atmosphere standards.

14) **Relative Humidity (Percent)** - This is the average relative humidity between the gun and the target used by the calculator to determine the ballistic parameters. The default value is 78% when the Army Metro Atmosphere Standard is selected and the default value is 0% when the ICAO Atmosphere Standard is selected by the **Atmosphere Standard** input parameter.

15) **Air Density Ratio** - This is the average air density ratio of the air between the gun and the target used by the calculator to determine the ballistic parameters. The air density ratio is the calculated air density divided by either the Army Metro Atmosphere Standard Density (i.e., 0.0751 PCF) or divided by the ICAO Atmosphere Standard Density (i.e., 0.0765 PCF) given the entered **Atmosphere Standard**, **Altitude**, **Temperature** and **Relative Humidity** input parameters.

16) **Air Density (Pounds/Cubic Foot)** - This is the average density of the air between the gun and the target used by the calculator to determine the ballistic parameters given the entered **Atmosphere Standard**, **Altitude**, **Temperature** and **Relative Humidity** input parameters.

17) **Speed of Sound (Feet/Second)** - This is the average speed of sound between the gun and the target used by the calculator to determine the ballistic parameters given the entered **Atmosphere Standard**, **Altitude**, **Temperature** and **Relative Humidity** input parameters. At 0 feet altitude and standard temperature and relative humidity, the speed of sound is 1120.3 FPS when the Army Metro Atmosphere Standard is selected and the speed of sound is 1116.4 FPS when the ICAO Atmosphere Standard is selected by the **Atmosphere Standard** input parameter.

18) **Bullet Sectional Density (Pounds/Square Inch)** - This is the weight of the bullet in pounds (i.e., the **Bullet Weight** input parameter divided by 7000) divided by the diameter of the bullet in inches (i.e., the **Bullet Diameter** input parameter) squared. Bullet sectional density is important because it has a significant effect on bullet penetration. For a given bullet design and bullet impact velocity, higher bullet sectional density will result in greater bullet penetration.   Probably the best way to compare different caliber bullets is by bullet sectional density and not by bullet weight. For example, a 150 grain 0.277 inch diameter bullet will penetrate further than a 150 grain 0.308 inch diameter bullet if both bullets are of a similar design and both bullets impact at the same velocity. Typically available small game, varmint and small predator (CXP1) bullet sectional density values

tend to range between 0.097 (e.g., 20 grain, 0.172 inch diameter) and 0.194 (e.g., 80 grain, 0.243 inch diameter). Typically available medium size big game (CXP2) bullet sectional density values tend to range between 0.216 (e.g., 100 grain, 0.257 inch diameter) and 0.249 (e.g., 115 grain, 0.257 inch diameter). Typically available large size big game (CXP3) bullet sectional density values tend to range between 0.261 (e.g., 140 grain, 0.277 inch diameter) and 0.288 (e.g., 270 grain, 0.366 inch diameter). Typically available thick-skinned dangerous game (CXP4) bullet sectional density values tend to range between 0.305 (e.g., 286 grain, 0.366 inch diameter) and 0.341 (e.g., 500 grain, 0.458 inch diameter). If our **Bullet Ballistic Coefficient Calculator** was used to determine the value entered for the **Bullet Ballistic Coefficient** input parameter, this output parameter should be in close agreement for both calculators.

19) **Bullet Form Factor** - This is the bullet form factor which indicates how close the **Bullet Coefficient of Drag** output parameter agrees with the bullet coefficient of drag standard that is entered for the **Bullet Coefficient of Drag Standard** input parameter. The bullet form factor is determined by dividing the calculated **Bullet Sectional Density** output parameter by the entered **Bullet Ballistic Coefficient** input parameter. The closer the bullet form factor is to 1, the closer the bullet coefficient of drag agrees with the bullet coefficient of drag standard. The closer the bullet coefficient of drag agrees with the bullet coefficient of drag standard, the more valid is the assumption that the bullet ballistic coefficient is not significantly affected by bullet speed. The G7 bullet form factor is typically very close to 1 for modern rifle bullets which indicates that the G7 projectile standard exhibits a coefficient of drag that is very close to modern rifle bullets and therefore there is less error associated with using a single G7 bullet ballistic coefficient value across a wide speed range. The G1 projectile standard bullet form factor is typically significantly less than 1 for modern rifle bullets which indicates that the G1 projectile standard exhibits a coefficient of drag that is NOT close to modern rifle bullets and therefore there is more error associated with using a single G1 bullet ballistic coefficient value across a wide speed range. If our **Bullet Ballistic Coefficient Calculator** was used to determine the value entered for the **Bullet Ballistic Coefficient** input parameter, this output parameter should be in close agreement for both calculators.

20) **Bullet Coefficient of Drag** - This is the bullet coefficient of drag which defines the aerodynamic characteristics of the bullet and how quickly it loses speed when travelling through the air. The bullet coefficient of drag is determined by multiplying the calculated **Bullet Form Factor** output parameter by the coefficient of drag associated with the entered **Bullet Coefficient of Drag Standard** input parameter at the entered or default **Bullet Ballistic Coefficient Speed** input parameter. If our **Bullet Ballistic Coefficient Calculator** was used to determine the value entered for the **Bullet Ballistic Coefficient** input parameter, this output parameter should be in close agreement for both calculators.

Please note that this is only the bullet coefficient of drag associated with the entered **Bullet Ballistic Coefficient** input parameter at the entered or default **Bullet Ballistic Coefficient Speed** input parameter. The actual real-time bullet coefficient of drag used by the calculator is NOT constant and varies with actual bullet speed in accordance with the coefficient of drag profile associated with the entered **Bullet Coefficient of Drag Standard** input parameter.

21) **Bullet Stability Factor** - This is the bullet stability factor as based on the Miller stability formula for the entered **Gun Muzzle Velocity**, **Altitude**, **Temperature**, **Bullet Diameter**, **Bullet Length**,

Bullet Weight and **Gun Barrel Rifling Twist Rate** input parameters. A value that is greater than 1.4 indicates good stability. A value between 1.4 and 1 indicates marginal stability. A value that is less than 1 indicates inadequate stability. Inadequate stability may result in the bullet yawing or even tumbling which may result in the bullet exhibiting a significantly different coefficient of drag than used by the calculator which will result in increased calculator inaccuracy. If the **Bullet Length** and **Gun Barrel Rifling Twist Rate** input parameters are not entered, the bullet stability factor will indicate "NR" for Not Requested.

22) **Bullet Initial Intercept Range** - This is the first and closest distance where the gun Point of Aim (POA) or Line of Sight (LOS) intercept the bullet Point of Impact (POI). The **Bullet Elevation** output parameter will be 0 at this bullet initial intercept range distance. This bullet initial intercept range should NOT be confused with the **Gun Zero Range** where the POA or LOS subsequently intercept the POI at the desired gun long range distance. The bullet initial intercept range can be used to allow setting up a short range target to confirm gun sight/optics adjustment and gun zero range.

23) **Laser Target Range (Yards)** - This is the range that a target may be placed to allow using a laser bore sight to successfully accomplish the required sight/optics adjustment necessary to establish the **Gun Zero Range** input parameter. This is normally the range that the calculator determined that the Line of Sight (LOS) and the laser dot elevation will be the same value (i.e., the laser dot will strike the center of a target placed at this range) after successfully accomplishing the required sight/optics adjustment necessary to establish the **Gun Zero Range** input parameter. However, if a value is entered for the **Laser Target Range** input parameter, both the **Laser Target Range** input parameter and this output parameter are this same value. If 0 is entered for the **Gun Sight Height** input parameter, this laser target range output parameter will indicate "NR" for Not Requested.

24) **Laser Height (Inches)** – This is the height deviation, if any, that the laser dot will strike above or below the center of a target placed at the **Laser Target Range** output parameter. This will normally be 0 if the **Laser Target Range** input parameter is left blank and this indicates that the laser dot will strike the center of a target placed at this **Laser Target Range** input/output parameter after successfully accomplishing the required sight/optics adjustment necessary to establish the **Gun Zero Range** input parameter. However, if a value is entered for the **Laser Bore Target Range** input parameter, this is the height deviation that the laser dot will strike above or below the center of a target placed at this **Laser Target Range** input/output parameter after successfully accomplishing the required sight/optics adjustment necessary to establish the **Gun Zero Range** input parameter. A positive height deviation indicates that the laser dot is this distance above the center of the target. A negative height deviation indicates that the laser dot is this distance below the center of the target. If 0 is entered for the **Gun Sight Height** input parameter, this laser height output parameter will indicate "NR" for Not Requested.

25) **Departure Angle (Minutes)** - This is normally the angle that the calculator elevated the gun to satisfy the **Gun Zero Range** input parameter. However, this may be the value that was manually entered for the **Departure Angle** input parameter. As such, a precision shooting gun vise (i.e., one having a table that can first be perfectly leveled and having the capability to precisely angle the gun within 0.5 seconds) may be set to this departure angle and a target may be placed at the **Gun Zero Range** input parameter and same elevation as the shooting gun vise (typically by using

a laser directed from the leveled table to the target). The gun sight/optics may than be simply adjusted so as to coincide with this target to accomplish zeroing the gun at the **Gun Zero Range** input parameter. Please keep in mind that this calculator can determine the associated departure angle for ANY entered **Gun Zero Range** input parameter including very long ranges (i.e., well in excess of 1000 yards).

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This calculator and our companion* Bullet Ballistic Coefficient Calculator *and* External Ballistics Calculator *were created for our colleagues and friends, who like us, enjoy the shooting sports and highly value our Constitutional Second Amendment rights. These calculators are dedicated to the men and women in our military and our local law enforcement agencies who protect our country and our homeland…thank you.

Firearm iron sights are a system of alignment markers used as a sighting mechanism to facilitate the aiming of a firearm. Iron sights are often more dependable and reliable than optic sights although not as accurate at longer ranges. Front sights are usually mounted in a dovetail on the firearm muzzle. Rear sights are usually mounted in a dovetail on the firearm receiver, closer to the eye of the shooter. Front and rear iron sights must be adjusted such that Line of Sight (LOS) of the shooter to the target, known as the Point of Aim (POA), results in the actual bullet Point of Impact (POI) hitting the target at the required bullet POI. For any given target range, the required elevation POI may be the same as the POA or it may be higher or lower depending on the actual firearm "zero range" and ballistics. Please see our **External Ballistics Calculator** instructions for more information about ballistics and zero range.

There are many different types of iron sights available. For maximum iron sight shooting accuracy, we prefer aperture or peep sights over the open style of sights. When a rear peep sight aperture is smaller than the shooter's eye pupil diameter, the aperture itself becomes the effective pupil diameter and this reduced diameter causes parallax error to be significantly suppressed. An additional benefit of aperture or peep sights is that the small aperture provides a greater depth of field making the target less blurry when focusing on the front sight and target. As long as the aperture's diameter is completely contained within the eye's pupil diameter, the exact position of the front sight within the rear aperture ring does not affect the accuracy. We use Skinner peep sights on many of our lever action rifles and we highly recommend these sights for the precision and quality of workmanship.

This calculator allows you to determine the required height adjustment that must be accomplished to either the front sight or rear sight to achieve the required bullet Point of Impact (POI) for any desired target range. To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Point of Impact Error (Inches)** - This is the elevation error between the actual bullet Point of Impact (POI) and the required bullet POI. Enter a positive value if the actual bullet POI is higher than the required bullet POI. Enter a negative value if the actual bullet POI is lower than the required bullet POI.

2) **Sight Radius (Inches)** - This is the distance between the front sight and the rear sight. This is typically about 22 inches for most rifles.

3) **Target Range (Yards)** - This is the distance between the gun muzzle and the target.

Click Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Required Front Sight Adjustment (Inches)** - This is the required adjustment to the front sight height that must be accomplished in order to have the **Point of Impact Error** output parameter become 0. A positive value indicates that the front sight height needs to increase in height by this amount. A negative value indicates that the front sight height needs to decrease in height by this amount. *This adjustment ONLY needs to be made to either the front sight or rear sight. Do NOT make this adjustment to BOTH sights.*

2) **Required Rear Sight Adjustment (Inches)** - This is the required adjustment to the rear sight height that must be accomplished in order to have the **Point of Impact Error** output parameter become 0. A positive value indicates that the rear sight height needs to increase in height by this amount. A negative value indicates that rear sight height needs to decrease in height by this amount. *This adjustment ONLY needs to be made to either the front sight or rear sight. Do NOT make this adjustment to BOTH sights.*

3) **Required Skinner Rear Peep Sight Adjustment (Turns)** - This is the required adjustment to a Skinner rear peep sight height that must be accomplished in order to have the **Point of Impact Error** output parameter become 0. A positive value indicates that the Skinner rear peep sight height needs to increase in height by rotating the Skinner rear peep sight counterclockwise this number of turns. A negative value indicates that the Skinner rear peep sight height needs to decrease in height by rotating the Skinner rear peep sight clockwise this number of turns. *This adjustment ONLY needs to be made to either the front sight or rear sight. Do NOT make this adjustment to BOTH sights.*

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This calculator may be used to forecast what the effective R-value performance of Insulated Concrete Form (ICF) will be given the actual climate (i.e., the actual seasonal outdoor temperature profiles) where the ICF building will be constructed for various ICF design parameters.

ICF typically consists of 2.5 inch thick EPS forms that are filled with 6 inch thick reinforced concrete which results in a thermal mass effect that is sandwiched between the exterior and interior insulated forms that are left in place after the concrete pour. ICF companies often claim exaggerated ICF "effective" R-value performance values that are always higher than what a conventional R-value calculation of the ICF material would otherwise indicate based on what is characterized as an almost magical thermal mass effect. In point of fact, ICF effective R-value performance can range from the conventional R-value to infinity depending on many variables (e.g., indoor temperature profile, the outdoor temperature profile, the concrete thickness/R-values, the insulation thickness/R-values, and the thickness ratio of the interior/exterior insulation).

So one really needs to determine what the effective R-value performance of ICF is for the actual climate (i.e., the actual seasonal outdoor temperature profiles) where the ICF building is constructed. Given that not many places have climate seasons with outdoor temperature profiles that always result in higher ICF performance than that of low thermal mass walls; it can be very challenging to design ICF such that it always provides higher ICF performance than that of low thermal mass walls for all climate seasons. However, we have found for many climates that average annual ICF performance is typically significantly higher than that of low thermal mass walls. Furthermore, ICF provides other benefits that often make it the right wall assembly choice for energy efficient buildings (e.g., increased fire resistance, increased structural life, increased structural strength, reduced outdoor air infiltration, reduced outdoor noise infiltration, and thermal mass characteristics that may be successfully designed and better integrated with passive solar heated buildings).

This calculator exercises the fundamental heat transfer equations that govern this ICF heat transfer system at a 0.01 hour (i.e., a 0.6 minute or 36 second) sampling rate over a twenty four hour period using finite element time/temperature numerical differentiation/integration analysis. The calculator assumes that the initial concrete thermal mass temperature at midnight (i.e., 00:00) is what the steady state concrete thermal mass temperature would be if the indoor/outdoor temperature that is entered for midnight were to remain constant for a sufficiently long enough time to reach this steady state temperature. Doing this initializes the simulation with a concrete thermal mass temperature that is neither "over-charged" nor "under-charged" with thermal energy so as to fairly evaluate only the heat flow generated by the entered indoor/outdoor temperature profiles. However, this calculator has a concrete initial temperature input parameter to allow experimentation with "over-charging" or "under-charging" the concrete thermal mass.

It should be noted that this calculator solely considers and only accounts for the effective R-value of the ICF portion of the wall assembly and this calculator does NOT consider or account for the R-value of any additional wall assembly layers (interior/exterior finishes, interior/exterior air film convection, etc), outdoor air infiltration, ground temperature wicking effect, solar heat gain, etc. These other heat transfer mechanisms should be accounted for and are normally accounted for when accomplishing the overall building heat gain/loss analysis.

In order to use this calculator, you will need to research what the typical outdoor hourly temperature profiles are for the local climatic seasons where the building is constructed. A good source of weather data for conducting this research may be found here:

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Indoor Temp Profile (Degrees Fahrenheit)** - This is the typical indoor hourly temperature profile used for analyzing the ICF performance. This is typically 70 degrees F and you may leave these input parameters blank unless you want to change this value. You may use typical indoor hourly temperature profiles that actual building occupants might use for each season of the year (i.e., Spring, Summer, Fall and Winter) for the local climate where the ICF building is constructed. For example, should the occupants change the indoor temp HVAC set point to a different value than 70 degree F or perhaps turn off the HVAC system completely and perhaps open windows or use ventilation for some period of time. If 97537.1, 97537.2, 97537.3 or 97537.4 is entered as the first input parameter value, representative indoor hourly temperature profiles for Rogue River, Oregon in Spring, Summer, Fall or Winter will be used, respectively.

2) **Outdoor Temp Profile (Degrees Fahrenheit)** - This is the typical outdoor hourly temperature profile used for analyzing the ICF performance. It is best to use typical outdoor hourly temperature profiles for each season of the year (i.e., Spring, Summer, Fall and Winter) for the local climate where the ICF building is constructed.

    If 97537.1, 97537.2, 97537.3 or 97537.4 is entered as the first input parameter value, representative outdoor hourly temperature profiles for Rogue River, Oregon in Spring, Summer, Fall or Winter will be used, respectively.

    If 777.1 or 777.2 is entered as the first input parameter value, a sine wave function will be used to generate the outdoor hourly temperature profile. Entering 777.1 results in a Summer sine wave profile having default mean value, amplitude, frequency, and phase angle of 71, 20, 2 Pi / 24 and Pi respectively which results in a minimum temperature of 51 degree F occurring at 0600 (6 AM) and a maximum temperature of 91 degrees F occurring at 1800 (6 PM). Entering 777.2 results in a Winter sine wave profile having default mean value, amplitude, frequency, and phase angle of 35, 10, 2 Pi / 24 and Pi respectively which results in a minimum temperature of 25 degree F occurring at 0600 (6 AM) and a maximum temperature of 45 degrees F occurring at 1800 (6 PM). The second, third, fourth and fifth input values can be used to enter and change the mean value (degrees F), amplitude (degrees F), frequency (radians/hour), and phase angle (radians) respectively as desired.

3) **Interior Insulation Thickness (Inches)** - This is the thickness of the insulated concrete form on the interior building side. This is typically 2.5 inches thick EPS and you may leave this parameter blank unless you want to change this value.

4) **Interior Insulation R-value per Inch (Degrees F-Hour-Square Feet/BTU-Inch)** - This is the R-value of the insulated concrete form on the interior building side per inch of thickness. This is typically R4.5 EPS and you may leave this parameter blank unless you want to change this value.

5) **Exterior Insulation Thickness (Inches)** - This is the thickness of the insulated concrete form on the exterior building side. This is typically 2.5 inch thick EPS and you may leave this parameter blank unless you want to change this value.

6) **Exterior Insulation R-value per Inch (Degrees F-Hour-Square Feet/BTU-Inch)** - This is the R-value of the insulated concrete form on the exterior building side per inch of thickness. This is typically R4.5 EPS and you may leave this parameter blank unless you want to change this value.

7) **Concrete Thickness (Inches)** - This is the thickness of the thermal mass material in the center of the ICF. This is typically 6 inches thick concrete and you may leave this parameter blank unless you want to change this value.

8) **Concrete R-value per Inch (Degrees F-Hour-Square Feet/BTU-Inch)** - This is the R-value per inch of the thermal mass material in the center of the ICF. This is typically R0.1 concrete and you may leave this parameter blank unless you want to change this value.

9) **Concrete Density (Pounds/Cubic Foot)** - This is the density of the thermal mass material in the center of the ICF. This input parameter is used to determine the **Thermal Mass Temp** output parameter. This is typically 150 PCF concrete and you may leave this parameter blank unless you want to change this value.

10) **Concrete Specific Heat Capacity (BTU/Degrees F-Pound)** - This is the specific heat capacity of the thermal mass material in the center of the ICF. Specific heat capacity is a measure of the amount of heat per unit mass that is required to raise the temperature of a material by one degree F. This input parameter is used to determine the **Thermal Mass Temp** output parameter. This is typically 0.18 BTU/Deg F-Lb of concrete and you may leave this parameter blank unless you want to change this value.

11) **Concrete Initial Temp at 00:00 (Degrees Fahrenheit)** – This is the initial temperature of the concrete thermal mass at midnight (i.e., 00:00). The calculator assumes that this initial concrete thermal mass temperature is the steady state temperature value it would be if the indoor/outdoor temperature entered for midnight remained constant for a sufficiently long enough time to allow the concrete thermal mass to reach this steady state temperature. Doing this initializes the simulation with a concrete thermal mass temperature that is neither "over-charged" nor is "under-charged" with thermal energy so as to only evaluate and consider the thermal energy that is provided by the entered indoor/outdoor temperature profiles. You may see what this steady state temperature is by viewing the **Thermal Mass Temp** output parameter at time 00:00.   ***This input parameter should normally ALWAYS be left blank.*** However, you may enter a different temperature to allow experimentation with "over-charging" or "under-charging" the concrete thermal mass.

Click Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Conventional R-value (Degrees F-Hour-Square Feet/BTU)** - This is the ICF total R-value when the individual R-values for all the materials used in the ICF are simply summed as is conventionally done. Please see our **Heat Loss Analysis Calculator** for more information about how this conventional R-value is determined. Changing the concrete thickness/R-values and the insulation thickness/R-values may significantly change this output parameter. This is typically about R23.10 for standard ICF having 2.5 inch interior EPS insulation, 6 inch concrete core, and 2.5 inch exterior EPS insulation.

2) **Thermal Mass Effective R-value (Degrees F-Hour-Square Feet/BTU)** - This is the ICF effective R-value when the temperature profile of the concrete thermal mass material in the center of the ICF is considered. This effective R-value is determined by multiplying the **Conventional R-value** output parameter by the ratio of the **Total Conventional Heat Flow** and **Total Thermal Mass Heat Flow** output parameters. Changing the indoor temperature profile, the outdoor temperature profile, the concrete thickness/R-values, the insulation thickness/R-values, and the thickness ratio of the interior/exterior insulation may significantly change this output parameter. This input parameter will display "Unknown" when the **Total Conventional Heat Flow** and **Total Thermal Mass Heat Flow** output parameters are of the opposite sign which indicates that ICF is providing a total heat flow that is contrary to the expected conventional heat flow (e.g., the ICF may be providing a total thermal mass heat flow loss during a 24 hour summer day when there would have been a total conventional heat flow gain). While this is certainly goodness, there is no good way calculate the thermal mass effective R-value when this occurs. For standard ICF construction using our Rogue River, Oregon outdoor temperature profiles, this is R21.38 in Spring, R66.15 in Summer, R63.42 in Fall, and R21.07 in Winter. So this is an average annual ICF performance of R43.07 or 1.86 higher performance than the conventional R23.10 R-value.

3) **Total Conventional Heat Flow (BTU/Day-Square Feet)** - This is the total heat flow between the building interior and the outdoor temperature that occurs during the 24 hour analysis period. This output parameter is determined by multiplying the inverse of the **Conventional R-value** output parameter by the difference between the **Indoor Temp** and **Outdoor Temp** output parameters and by using finite element time/temperature numerical differentiation/integration analysis as is conventionally done. The total daily building heat gain/loss may be determined by multiplying this output parameter by the exposed ICF wall total square foot area. The average hourly building heat gain/loss rate may then be determined dividing this value by 24 hours. Changing the indoor temperature profile, the outdoor temperature profile, the concrete thickness/R-values and the insulation thickness/R-values may significantly change this output parameter.

4) **Total Thermal Mass Heat Flow (BTU/Day-Square Feet)** - This is the total heat flow between the building interior and the thermal mass that occurs during the 24 hour analysis period. This output parameter is determined by multiplying the inverse of the sum of the **Interior Insulation R-value per Inch** and **Concrete R-value per Inch** input parameters by the difference between the **Indoor Temp** and **Thermal Mass Temp** output parameter and by using finite element time/temperature numerical differentiation/integration analysis. The total daily building heat gain/loss may be determined by multiplying this output parameter by the exposed ICF wall total square foot area. The average hourly building heat gain/loss rate may then be determined dividing this value by 24 hours. Changing the indoor temperature profile, the outdoor temperature profile, the concrete thickness/R-values, the insulation thickness/R-values, and the thickness ratio of the interior/exterior insulation may significantly change this output parameter.

5) **Minimum Conventional Heat Flow Rate (BTU/Hour-Square Feet)** - This is the minimum **Conventional Heat Flow Rate** output parameter that occurs during the 24 hour analysis period.

6) **Maximum Conventional Heat Flow Rate (BTU/Hour-Square Feet)** - This is the maximum **Conventional Heat Flow Rate** output parameter that occurs during the 24 hour analysis period.

7) **Minimum Thermal Mass Heat Flow Rate (BTU/Hour-Square Feet)** - This is the minimum **Thermal Mass Heat Flow Rate** output parameter that occurs during the 24 hour analysis period.

8) **Maximum Thermal Mass Heat Flow Rate (BTU/Hour-Square Feet)** - This is the maximum **Thermal Mass Heat Flow Rate** output parameter that occurs during the 24 hour analysis period.

9) **Time Minimum Conventional Heat Flow Rate Occurs** - This is the time when the **Minimum Conventional Heat Flow Rate** output parameter occurs during the 24 hour analysis period.

10) **Time Maximum Conventional Heat Flow Rate Occurs** - This is the time when the **Maximum Conventional Heat Flow Rate** output parameter occurs during the 24 hour analysis period.

11) **Time Minimum Thermal Mass Heat Flow Rate Occurs** - This is the time when the **Minimum Thermal Mass Heat Flow Rate** output parameter occurs during the 24 hour analysis period.

12) **Time Maximum Thermal Mass Heat Flow Rate Occurs** - This is the time when the **Maximum Thermal Mass Heat Flow Rate** output parameter occurs during the 24 hour analysis period.

13) **Minimum Indoor Temp (Degrees Fahrenheit)** - This is the minimum **Indoor Temp** output parameter that occurs during the 24 hour analysis period.

14) **Maximum Indoor Temp (Degrees Fahrenheit)** - This is the maximum **Indoor Temp** output parameter that occurs during the 24 hour analysis period.

15) **Maximum Thermal Mass Temp (Degrees Fahrenheit)** - This is the maximum **Thermal Mass Temp** output parameter that occurs during the 24 hour analysis period.

16) **Minimum Thermal Mass Temp (Degrees Fahrenheit)** - This is the minimum **Thermal Mass Temp** output parameter that occurs during the 24 hour analysis period.

17) **Minimum Outdoor Temp (Degrees Fahrenheit)** - This is the minimum **Outdoor Temp** output parameter that occurs during the 24 hour analysis period.

18) **Maximum Outdoor Temp (Degrees Fahrenheit)** - This is the maximum **Outdoor Temp** output parameter that occurs during the 24 hour analysis period.

19) **Time Minimum Indoor Temp Occurs** - This is the time when the **Minimum Indoor Temp** output parameter occurs during the 24 hour analysis period.

20) **Time Maximum Indoor Temp Occurs** - This is the time when the **Maximum Indoor Temp** output parameter occurs during the 24 hour analysis period.

21) **Time Minimum Thermal Mass Temp Occurs** - This is the time when the **Minimum Thermal Mass Temp** output parameter occurs during the 24 hour analysis period.

22) **Time Maximum Thermal Mass Temp Occurs** - This is the time when the **Maximum Thermal Mass Temp** output parameter occurs during the 24 hour analysis period.

23) **Time Minimum Outdoor Temp Occurs** - This is the time when the **Minimum Outdoor Temp** output parameter occurs during the 24 hour analysis period.

24) **Time Maximum Outdoor Temp Occurs** - This is the time when the **Maximum Outdoor Temp** output parameter occurs during the 24 hour analysis period.

25) **Indoor Temp (Degrees Fahrenheit)** - This is outdoor temperature based on linear interpolation of the **Indoor Temp Profile** input parameters at this indicated time.

26) **Thermal Mass Temp (Degrees Fahrenheit)** - This is the thermal mass temperature determined by using the associated thermal mass input parameters and by using numerical differentiation/integration analysis at this indicated time. This output parameter is used to determine the **Thermal Mass Heat Flow Rate** and **Total Thermal Mass Heat Flow** output parameters. Changing the indoor temperature profile, the outdoor temperature profile, the concrete thickness/R-values, the insulation thickness/R-values, and the thickness ratio of the interior/exterior insulation may significantly change this output parameter.

27) **Outdoor Temp (Degrees Fahrenheit)** - This is outdoor temperature based on linear interpolation of the **Outdoor Temp Profile** input parameters at this indicated time.

28) **Conventional Heat Flow Rate (BTU/Hour-Square Feet)** - This is the heat flow rate between the building interior and the outdoor temperature that is determined by multiplying the inverse of the **Conventional R-value** output parameter by the difference between the **Indoor Temp** and **Outdoor Temp** output parameters at this indicated time. Changing the indoor temperature profile, the outdoor temperature profile, the concrete thickness/R-values, and the insulation thickness/R-values may significantly change this output parameter.

29) **Thermal Mass Heat Flow Rate (BTU/Hour-Square Feet)** - This is the heat flow rate between the building interior and the thermal mass that is determined by multiplying the inverse of the sum of the **Interior Insulation R-value per Inch** and **Concrete R-value per Inch** input parameters by the difference between the **Indoor Temp** and **Thermal Mass Temp** output parameters at this indicated time. Changing the indoor temperature profile, the outdoor temperature profile, the concrete thickness/R-values, the insulation thickness/R-values, and the thickness ratio of the interior/exterior insulation may significantly change this output parameter.

30) **Thermal Mass Effective R-value (Degrees F-Hour-Square Feet/BTU)** - This effective R-value at this indicated time as determined by multiplying the **Conventional R-value** output parameter by the ratio of the **Conventional Heat Flow Rate** and **Thermal Mass Heat Flow Rate** output

parameters. Changing the indoor temperature profile, the outdoor temperature profile, the concrete thickness/R-values, the insulation thickness/R-values, and the thickness ratio of the interior/exterior insulation may significantly change this output parameter. This input parameter will display "Unknown" when the **Conventional Heat Flow Rate** and **Thermal Mass Heat Flow Rate** output parameters are of the opposite sign which indicates that ICF is providing a heat flow rate that is contrary to the expected conventional heat flow rate (e.g., the ICF may be providing a thermal mass heat flow rate loss when there would have been a conventional heat flow rate gain). While this is certainly goodness, there is no good way calculate the thermal mass effective R-value when this occurs.

Here are some ICF performance observations based on varying the various ICF design parameters from the calculator default values and using our Rogue River, Oregon indoor/outdoor temperature profiles:

When the interior EPS thickness is reduced to 0.1" and the exterior EPS thickness is increased to 4.9" (i.e., essentially putting all the insulation on the exterior side, but keeping the total conventional R-value the same), the summer effective R-value went from R66.15 to R44.05. In this case the concrete temperature stays very close to the indoor temp. The effective R-value remains the same (i.e., R44.05) when all the insulation is put on interior side. However, in this case the concrete temperature stays very close to the outdoor temp. This would imply that both these non-symmetrical ICF designs result in an equal, but lower performance than the standard, symmetrical ICF design for this summer outdoor temperature profile. When this is repeated for the winter outdoor temperature profile, the winter effective R-value went from R21.34 to R21.96, i.e., a slight performance improvement.

When both the interior/exterior insulation thickness is reduced to 0.01" (i.e., essentially removing the interior/exterior insulation), the effective R-value went to R0.77 (i.e., 1.12 times higher than the new R0.69 conventional R-value). This would imply that even an uninsulated, 6" thick concrete wall will exhibit some degree of increased effective R-value. When the insulation is retained, but the concrete thickness is reduced to 0, the effective R-value went to R22.50 (i.e., exactly the same value as the new conventional R-value). This would imply that as the concrete thickness is reduced, the effective R-value tends toward becoming equal to the conventional R-value. When the concrete thickness is then increased to 4", the effective R-value went to R63.40 (i.e., 2.77 times higher than the new conventional R-value). When the concrete thickness is further increased to 8", the effective R-value went to R67.79 (i.e., 2.91 times higher than the new conventional R-value). When the concrete thickness is further increased to12", the effective R-value went to R69.99 (i.e., 2.95 times higher than the new conventional R-value). When the concrete thickness is further increased to 36", the effective R-value went to R78.48 (i.e., 3.01 times higher than the new conventional R-value). When the concrete thickness is further increased to 360", the effective R-value went to R177.12 (i.e., 3.03 times higher than the new conventional R-value). When the interior/exterior insulation is then removed from this 360" concrete thickness, the effective R-value went to R109.25 (i.e., still 3.03 times higher than the new conventional R-value). This would imply that as the concrete thickness is increased, the insulation thickness becomes increasingly less important in achieving the higher effective R-values. Furthermore, for this summer outdoor temperature profile, this would imply that the absolute maximum possible effective R-value is 3.03 times the conventional R-value and we are achieving 2.86 times the conventional R-value with a standard ICF design.

One might expect that higher effective R-values might be achieved by having some portion of the indoor temperature profile be the same as the outdoor temperature profile. For example, having that portion of the indoor temperature profile be the same as the outdoor temperature profile during the summer cooling season when the outdoor temperature is below 70 degrees Fahrenheit to simulate having open windows or using increased ventilation during these times. However, this is NOT the case. While doing this will reduce some of the **Thermal Mass Temp** output parameters, doing this will result in some of the **Conventional Heat Flow Rate** output parameters becoming 0 (where they were previously providing a building heat loss cooling effect), will reduce some of the **Thermal Mass Heat Flow Rate** output parameters (where they were previously providing more of a building heat loss cooling effect), will increase both the **Total Conventional Heat Flow** and **Total Thermal Mass Heat Flow** output parameters (i.e., provide increased building heat gain), but will increase the **Total Thermal Mass Heat Flow** output parameter more than the **Total Conventional Heat Flow** output parameter, and this will REDUCE the **Thermal Mass Effective R-value** output parameter. Doing this for the summer profile resulted in the effective R-value going from R66.15 to R39.06. One needs to keep in mind that this calculator only determines the effective R-value performance for just the ICF for the entered input/output temperature profiles and this calculator does NOT determine the HVAC system performance of the building. Or perhaps another way of thinking about this is that when you run the building AC system, the building cools down to a lower temperature than it would otherwise be, however, the heat transfer through the walls increases because of the increased inside/outside delta temperature. More thermal mass heat transfer is equivalent to having a lower thermal mass heat transfer resistance or a lower thermal mass effective R-value. Obviously, opening windows or increasing ventilation during the summer cooling season when the outdoor temp is below 70 degrees Fahrenheit is a good thing to do as this provides increased building cooling with minimum HVAC energy usage.

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Machines such as engines, electrical motors, pumps, and turbines may create both air-borne (sound) and structure-borne vibrations. These machines and other equipment located near these machines may be sensitive to this vibration excitation. Vibration isolation (using rubber resilient mounts) may be used to achieve significant reductions of transmitted vibrations. This calculator may be used to design an isolation stand where either one or two machines may be fastened to the isolation stand and resilient mounts are fastened to the right and left side of the isolation stand between the isolation stand and the floor (or between one isolation level and another isolation level). To use this calculator, you need to know the weight of the machines/equipment that will be mounted to the isolation stand as well as the weight of the actual isolation stand. You need to know the distance between each machine's center-of-gravity (CG) and the "isolation stand datum" (defined herein to be the location on the isolation stand where the right isolation mounts will be attached to the isolation stand).

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Design Isolation Stand Efficiency (Percent)** - This is the desired design percentage of vibration energy to be absorbed by the resilient mounts (and converted into heat energy) and NOT transmitted to the floor. A design isolation efficiency of 80 to 90% is generally considered satisfactory and within the range of resilient mounts that may be readily obtained from manufacturers.

2) **Weight of Machine 1 (Pounds)** - This is the weight of machine 1 (plus other associated equipment) which is attached directly to the isolation stand and which is typically an engine, electrical motor, pump, or turbine.

3) **Weight of Machine 2 (Pounds)** - This is the weight of machine 2 (plus other associated equipment) which is attached directly to the isolation stand and which is typically a generator. If only one machine will be attached to the isolation stand, enter 0 for this input parameter.

4) **Weight of Isolation Stand (Pounds)** - This is the weight of only the isolation stand structure that the machines are rigidly fastened and does NOT include the weight of the actual machines or the weight of the resilient mounts.

5) **Distance Between Right/Left Mounts (Inches)** - This is the horizontal dimension between the right and left resilient mount attachment locations on the isolation stand.

6) **Distance Between Machine 1 CG and Right Mounts (Inches)** - This is the horizontal dimension between the center-of-gravity of machine 1 and where the right resilient mounts will be attached on the isolation stand (i.e., the aforementioned isolation stand datum).

7) **Distance Between Machine 2 CG and Right Mounts (Inches)** - This is the horizontal dimension between the center-of-gravity of machine 2 and where the right resilient mounts will be attached on the isolation stand (i.e., the aforementioned isolation stand datum).

8) **Number of Right Mounts per Isolation Level** - This is the total number of right resilient mounts for each isolation level that will be used for the design. You may want to use a different number of mounts for each side and use multiple isolation levels to achieve design objectives.

9) **Number of Left Mounts per Isolation Level** - This is the total number of left resilient mounts for each isolation level that will be used for the design. You may want to use a different number of mounts for each side and use multiple isolation levels to achieve design objectives.

10) **Number of Isolation Levels** - This is the total number of isolation levels that will be used for the design. You may want to use a different number of mounts for each side and use multiple isolation levels to achieve design objectives.

11) **Disturbing Frequency of Machine 1 (Rotations/Minute)** - This is the frequency of vibration caused by a source such as an engine expressed as the number of oscillations that occur per unit time. For a single cylinder engine, this is typically the operational RPM of the engine.

12) **Selected Spring Rate of Each Right Mount (Pounds/Inch or Leave Blank)** - This input parameter is the effective spring rate of each right resilient mount as specified by the manufacturer of the selected resilient mounts that will be used in the design and as affected by the isolation levels used in the design. The spring rate is a ratio of the imposed static load to the resulting deflection of a specific resilient mount expressed in pounds/inch. Initially leave this input parameter blank. Please see the below detailed directions and design example.

13) **Selected Spring Rate of Each Left Mount (Pounds/Inch or Leave Blank)** - This input parameter is the effective spring rate of each left resilient mount as specified by the manufacturer of the selected resilient mounts that will be used in the design and as affected by the isolation levels used in the design. The spring rate is a ratio of the imposed static load to the resulting deflection of a specific resilient mount expressed in pounds/inch. Initially leave this input parameter blank. Please see the below detailed directions and design example.

Click Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Load on Each Right Mount (Pounds)** - This is the static load resulting from the weight of the machines and the weight of the isolation stand that each right resilient mount will experience and must be capable of handling. This parameter is used to select acceptable right resilient mounts from a manufacturer. Please see the below detailed directions and design example.

2) **Load on Each Left Mount (Pounds)** - This is the static load resulting from the weight of the machines and the weight of the isolation stand that each left resilient mount will experience and must be capable of handling. This parameter is used to select acceptable left resilient mounts from a manufacturer. Please see the below detailed directions and design example.

3) **Recommended Spring Rate of Each Right Mount (Pounds/Inch)** - This is the recommended spring rate of each right resilient mount required to achieve the **Design Isolation Stand**

Efficiency. This parameter is used to select acceptable right resilient mounts from a manufacturer. Please see the below detailed directions and design example.

4) **Recommended Spring Rate of Each Left Mount (Pounds/Inch)** - This is the recommended spring rate of each left resilient mount required to achieve the **Design Isolation Stand Efficiency**. This parameter is used to select acceptable left resilient mounts from a manufacturer. Please see the below detailed directions.

5) **Actual Deflection of Each Right Mount (Inches)** - This is the deflection each right resilient mount will actually experience resulting from the weight of the machines and the weight of the isolation stand based on the **Selected Spring Rate of Each Right Mount** input parameter. Please see the below detailed directions and design example.

6) **Actual Deflection of Each Left Mount (Inches)** - This is the deflection each left resilient mount will actually experience resulting from the weight of the machines and the weight of the isolation stand based on the **Selected Spring Rate of Each Left Mount** input parameter. Please see the below detailed directions and design example.

7) **Actual Natural Frequency of Right Side (Hertz)** - This is the natural frequency the resilient mounts on right side of isolation stand mount will actually experience based on the **Actual Deflection of Each Right Mount** output parameter. Please see the below detailed directions and design example.

8) **Actual Natural Frequency of Left Side (Hertz)** - This is the natural frequency the resilient mounts on left side of isolation stand mount will actually experience based on the **Actual Deflection of Each Left Mount** output parameter. Please see the below detailed directions and design example.

9) **Actual Isolation of Right Side (Percent)** - This is the actual isolation the resilient mounts on right side will actually provide based on the **Selected Spring Rate of Each Right Mount** input parameter. Please see the below detailed directions and design example.

10) **Actual Isolation of Left Side (Percent)** - This is the actual isolation the resilient mounts on left side will actually provide based on the **Selected Spring Rate of Each Left Mount** input parameter. Please see the below detailed directions and design example.

11) **Actual Isolation Stand Overall Efficiency (Percent)** - This is the actual vibration isolation efficiency that the isolation stand will provide based on the **Selected Spring Rate of Right/Left Mount** input parameters. This is the percentage of vibration energy that is absorbed by the resilient mounts (and converted into heat energy) and NOT transmitted to the floor. Please see the below detailed directions and design example.

Select resilient mounts from a manufacturer that have a maximum compressive load rating equal or greater than the **Load on Each Right/Left Mount** output parameters. Select a spring rate equal or less than the **Recommended Spring Rate of Each Right/Left Mount** output parameters. Please note that overloading resilient mounts is not recommended since this may lead to premature resilient mount failure. However, excessive under loading may not deflect the resilient mounts enough to provide satisfactory vibration isolation.

You may need to change the **Number of Right/Left Mounts** and **Number of Isolation Levels** that will be used in the design to achieve the **Load of Right/Left Mounts** and the **Recommended Spring Rate of Each Right/Left Mounts** that are actually available from a manufacturer. You may also want to change the ratio of the **Number of Right/Left Mounts** if the **Recommended Spring Rate of Each Right/Left Mounts** are significantly different so you may use the same resilient mount manufacturer part number for all the resilient mounts. Once you have selected the resilient mounts, enter the manufacturer specified spring rate for the **Selected Spring Rate of Each Right/Left Mounts** and click ⬚Solve to obtain the **Actual Deflection of Each Right/Left Mounts**, **Actual Natural Frequency of Right/Left Sides**, **Actual Isolation of Right/Left Sides** and the **Actual Isolation Stand Overall Efficiency**. Verify that the **Actual Deflection of Each Right/Left Mount** is less than the manufacturer maximum recommended deflection and that the **Actual Isolation Stand Overall Efficiency** achieves the minimum isolation stand design objective.

For an example of how this approach was used to successfully design and build an isolation stand for a heavy, single cylinder, stationary Lister style diesel engine and generator back in 2005 when several "experts" at the time claimed this was not possible, you may want to see these descriptive photos and design example:

Listeroid 6/1 Engine & ST5 Generator System Build Photos

Isolation Stand Design Example

The actual isolation stand was constructed in two isolation levels to achieve the required effective 500 lbs/inch spring rate as described above resulting in four Karman K730-41 mounts on the Engine Side (two mounts on each isolation level on this side) and four Karman K730-41 mounts on the Generator Side (two mounts on each isolation level on this side) or eight Karman K730-41 mounts total for this isolation stand design. Calculated/Predicted Overall Isolation Stand Efficiency was 80.4%. Actual/Measured Overall Isolation Stand Efficiency was measured using a piezoelectric accelerometer vibration meter and found to be 96% with a frequency of 2.1 Hz. This additional 15.6% of actual/measured overall isolation stand efficiency beyond the calculated/predicted overall isolation stand efficiency is the result of constructing the isolation stand using two isolation levels which was required to achieve the design mount spring rates given the limited availability of mounts as described in the above design example and which resulted in the actual isolation stand natural frequency being significantly lower than the 80% design 4.42 Hz natural frequency and 10.83 Hz original disturbing frequency.

It should also be noted that this engine normally and primarily uses vegetable oil for fuel (i.e., a renewable energy resource in keeping with our environmental philosophy). However, this engine may also be operated by augmenting the diesel or vegetable oil with propane or natural gas to boost the nominal diesel only 3.2 kW to the full 5 kW capability of the ST5 generator continuous power output rating when needed via air fuel ratio lambda curve migration from maximum efficiency to maximum power and turbocharger effect.

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Latitude Longitude Distance

This calculator is used to assist a Certified Water Right Examiner (CWRE) create and validate water right maps where a water right Point of Diversion (POD) must be mapped relative to a known survey monument reference point. This calculator will determine either:

1) The unknown North/South and East/West distances if the known latitude and longitude coordinates of both the survey reference point and the second reference point are entered into the calculator.
2) The unknown second reference point latitude and longitude coordinates if the known survey monument reference point latitude and longitude coordinates are entered into the calculator and the known North/South and East/West distances between these two points are entered into the calculator.
3) The unknown second reference point latitude and longitude coordinates if the known survey monument reference point latitude and longitude coordinates are entered into the calculator and the known bearing and great circle distance to the unknown second reference point are entered into the calculator.

The calculator may use a spherical earth model or an oblate spheroid earth model. The spherical earth model uses the "Haversine" formula method to determine the great circle distances between these latitude and longitude coordinate points resulting in mathematical distance errors less than about 0.3%. The oblate spheroid earth model uses the Vincenty iteration algorithm to determine the great circle distances between these latitude and longitude coordinate points resulting in mathematical distance errors less than 1/64 inch. However, the Vincenty iteration algorithm has the disadvantage that it may not always converge for nearly antipodal points (i.e., points on earth that are diametrically opposite to each other). If and when this occurs, the calculator will output zero values for all the output parameters. Please keep in mind that actual accuracy is still only as good as the entered latitude and longitude coordinate point accuracy. Latitude and longitude coordinate points accurate in degrees to four, five, six, seven, eight and nine significant decimal digits are accurate to about 32 feet, 3.2 feet, 4 inches, 1/2 inch, 1/32 inch and 4/1000 inch respectively. A Global Positioning Satellite (GPS) hand-held device or an application enabled smart cell phone may be used to obtain these latitude and longitude coordinate points to a limited degree of accuracy. Known and documented survey monument latitude and longitude coordinate points (e.g., township, range and section corners) accurate in degrees to seven significant decimal digits or about 1/2 inch accuracy may be found here:

Earth Point

This calculator, in conjunction with our **Planimeter Calculator**, can be used to determine the GPS coordinates from a legal property description so as to accurately determine property boundaries, property perimeter and property area and Google map the property as illustrated here:

Sample Property Boundary Determination

If all the input parameters are left blank, just clicking Solve will generate the Point 2) output parameters shown in this Sample Property Boundary Determination and display the associated Google Map.

Disclaimer: These calculators and resulting analysis are for assisting in the understanding of legal property descriptions only and are not intended to be used for providing legal dimensions of property ownership.

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Point 1 Latitude (Degrees, South is Negative)** - This is a geographic coordinate that specifies the north-south position of a point on the Earth's surface. Latitude is an angle which ranges from 0 degrees at the Equator to 90 degrees northward and to -90 degrees southward. If the latitude is south, enter a negative value. You may need to convert latitude that is in degrees, minutes and seconds into decimal degrees. For example, if the latitude is North 42° 36' 0", the correct entry is 42.60 (i.e., 0"/60 equals 0' and 36.0'/60 equals 0.60°). Point 1 is typically a known survey monument which is shown as the reference point on a water right map created by a CWRE.

2) **Point 1 Longitude (Degrees, West is Negative)** - This is a geographic coordinate that specifies the east-west position of a point on the Earth's surface. Longitude is an angle which ranges from 0 degrees at the Prime Meridian to 180 degrees eastward and to -180 degrees westward. If the longitude is west, enter a negative value. You may need to convert longitude that is in degrees, minutes and seconds into decimal degrees. For example, if the longitude is West 122° 59' 24", the correct entry is -122.99 (i.e., 24"/60 equals 0.4' and 59.4'/60 equals 0.99°). Point 1 is typically a known survey monument which is shown as the reference point on a water right map created by a CWRE.

3) **Point 2 Latitude (Degrees, South is Negative)** - This is a geographic coordinate that specifies the north-south position of a point on the Earth's surface. Latitude is an angle which ranges from 0 degrees at the Equator to 90 degrees northward and to -90 degrees southward. If the latitude is south, enter a negative value. You may need to convert latitude that is in degrees, minutes and seconds into decimal degrees. For example, if the latitude is North 42° 36' 0", the correct entry is 42.60 (i.e., 0"/60 equals 0' and 36.0'/60 equals 0.60°). Point 2 is typically the Point of Diversion (POD) which is shown on a water right map created by a CWRE.

4) **Point 2 Longitude (Degrees, West is Negative)** - This is a geographic coordinate that specifies the east-west position of a point on the Earth's surface. Longitude is an angle which ranges from 0 degrees at the Prime Meridian to 180 degrees eastward and to -180 degrees westward. If the longitude is west, enter a negative value. You may need to convert longitude that is in degrees, minutes and seconds into decimal degrees. For example, if the longitude is West 122° 59' 24", the correct entry is -122.99 (i.e., 24"/60 equals 0.4' and 59.4'/60 equals 0.99°). Point 2 is typically the Point of Diversion (POD) which is shown on a water right map created by a CWRE.

5) **Bearing FROM Point 1 to Point 2 (Degrees)** - This is the true compass bearing from Point 1 to Point 2.

6) **Great Circle Distance between Point 1 & 2 (Feet)** - This is the great circle distance between Point 1 and Point 2.

7) **North/South Distance FROM Point 1 to Point 2 (Feet, South is Negative)** - This is the distance true North or true South that Point 2 is <u>from</u> Point 1. If Point 2 is South of Point 1, enter a negative value. Point 1 is typically a known survey monument which is shown as the reference

point on a water right map created by a CWRE. Point 2 is typically the Point of Diversion (POD) which is shown on a water right map created by a CWRE.

8) **East/West Distance FROM Point 1 to Point 2 (Feet, West is Negative)** - This is the distance true East or true West that Point 2 is <u>from</u> Point 1. If Point 2 is West of Point 1, enter a negative value.   Point 1 is typically a known survey monument which is shown as the reference point on a water right map created by a CWRE. Point 2 is typically the Point of Diversion (POD) which is shown on a water right map created by a CWRE.

9) **Spherical or Oblate Spheroid Earth** - This is a logic input parameter that tells the calculator whether to use a perfectly spherical or more accurate oblate spheroid representation of the earth.

The circumference around the equator and around the north and south poles along the meridian line for a perfectly spherical representation of the earth is 21,600 nautical miles or 24,856.84 statute miles. This results in the radius of the earth for a perfectly spherical representation of the earth being 3,437.75 nautical miles or 3,956.09 statute miles. This results in the length of a degree of latitude being precisely 60 nautical miles or 69.0468 statute miles and results in the length of a degree of longitude at the equator being precisely 60 nautical miles or 69.0468 statute miles.

The circumference around the equator for the more accurate oblate spheroid representation of the earth is 24,901.46 statute miles (i.e., a radius of 3,963.19 statute miles). The circumference around the north and south poles along the meridian line for the more accurate oblate spheroid representation of the earth is 24,859.73 statute miles (i.e., a radius of 3,956.55 statute miles). This is a 41.73 statute mile circumference difference (or a 6.64 statute mile radius difference). This results in the length of a degree latitude varying from 68.7075 statute miles at the equator to 69.4032 statute miles at the north and south poles. This results in the length of a degree of longitude at the equator being 69.1706 statute miles.

Enter 0 for a perfectly spherical representation of the earth. Enter 1 for a more accurate oblate spheroid representation of the earth. The spherical representation of the earth is the default value.

10) **Display Google Map of Points? (0 = No, 1 = Yes)** – Leave blank or enter 0 until after you have worked out a proper solution. Then you may enter 1 to see a Google Map showing Point 1 and Point 2. You may zoom in or out, pan, select road map or satellite view, and toggle the map scale between metric and imperial as desired.

Click Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Point 1 Latitude (Degrees, South is Negative)** - This is a geographic coordinate that specifies the north-south position of a point on the Earth's surface. Latitude is an angle which ranges from 0 degrees at the Equator to 90 degrees northward and to -90 degrees southward. A negative means a South Latitude. Point 1 is typically a known survey monument which is shown as the

reference point on a water right map created by a CWRE. This output parameter will be identical to the corresponding input parameter.

2) **Point 1 Longitude (Degrees, West is Negative)** - This is a geographic coordinate that specifies the east-west position of a point on the Earth's surface. Longitude is an angle which ranges from 0 degrees at the Prime Meridian to 180 degrees eastward and to -180 degrees westward. A negative value means a West Longitude. Point 1 is typically a known survey monument which is shown as the reference point on a water right map created by a CWRE. This output parameter will be identical to the corresponding input parameter.

3) **Point 2 Latitude (Degrees, South is Negative)** - This is a geographic coordinate that specifies the north-south position of a point on the Earth's surface. Latitude is an angle which ranges from 0 degrees at the Equator to 90 degrees northward and to -90 degrees southward. A negative means a South Latitude. Point 2 is typically the Point of Diversion (POD) which is shown on a water right map created by a CWRE. This output parameter may be identical to the corresponding input parameter or may be calculated if **North/South Distance from Point 1 to Point 2** and **East/West Distance from Point 1 to Point 2** input parameters were entered instead of the corresponding input parameter.

4) **Point 2 Longitude (Degrees, West is Negative)** - This is a geographic coordinate that specifies the east-west position of a point on the Earth's surface. Longitude is an angle which ranges from 0 degrees at the Prime Meridian to 180 degrees eastward and to -180 degrees westward. If the longitude is west, enter a negative value. A negative value means a West Longitude. Point 2 is typically the Point of Diversion (POD) which is shown on a water right map created by a CWRE. This output parameter may be identical to the corresponding input parameter or may be calculated if **North/South Distance from Point 1 to Point 2** and **East/West Distance from Point 1 to Point 2** input parameters were entered instead of the corresponding input parameter.

5) **Bearing FROM Point 1 to Point 2 (Degrees)** - This is the true compass bearing from Point 1 to Point 2.

6) **Great Circle Distance between Point 1 & 2 (Feet)** - This is the great circle distance between Point 1 and Point 2.

7) **North/South Distance FROM Point 1 to Point 2 (Feet, South is Negative)** - This is the distance true North or true South that Point 2 is <u>from</u> Point 1. A negative value means Point 2 is South of Point 1. Point 1 is typically a known survey monument which is shown as the reference point on a water right map created by a CWRE. Point 2 is typically the Point of Diversion (POD) which is shown on a water right map created by a CWRE. This output parameter may be identical to the corresponding input parameter or may be calculated if **Latitude Point 2** and **Longitude Point 2** input parameters were entered instead of the corresponding input parameter.

8) **East/West Distance FROM Point 1 to Point 2 (Feet, West is Negative)** - This is the distance true East or true West that Point 2 is <u>from</u> Point 1. A negative value means Point 2 is West of Point 1. Point 1 is typically a known survey monument which is shown as the reference point on a water right map created by a CWRE. Point 2 is typically the Point of Diversion (POD) which is shown on a water right map created by a CWRE. This output parameter may be identical to the

corresponding input parameter or may be calculated if **Latitude Point 2** and **Longitude Point 2** input parameters were entered instead of the corresponding input parameter.

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A planimeter is a measuring device that is used to determine the perimeter and area of an arbitrary two dimensional shape. This calculator is used to assist a Certified Water Right Examiner (CWRE) determine the location and area of a water right place of use and validate this location and area for a water right permit or water right certificate application. Land owners may also find this calculator very useful as it enables one to accurately determine the perimeter and area of an arbitrary shaped section of land or water reservoir if you know the latitude and longitude of several points that define the enclosed land or water reservoir area. Knowing the area of an arbitrary shaped section of land or water reservoir is often necessary in order to determine how much seed is needed to plant a crop on this section of land or estimate how much volume of water is contained by the reservoir. Latitude and longitude coordinate points accurate in degrees to four, five, six, seven, eight and nine significant decimal digits are accurate to about 32 feet, 3.2 feet, 4 inches, 1/2 inch, 1/32 inch and 4/1000 inch respectively. A Global Positioning Satellite (GPS) hand-held device or an application enabled smart cell phone may be used to obtain these latitude and longitude coordinate points to a limited degree of accuracy.

This calculator, in conjunction with our **Latitude Longitude Distance Calculator**, can be used to determine the GPS coordinates from a legal property description so as to accurately determine property boundaries, property perimeter and property area and Google map the property as illustrated here:

Sample Property Boundary Determination

If all the input parameters are left blank, just clicking [Solve] will generate the legal property boundary coordinate output parameters shown in this Sample Property Boundary Determination and display the associated Google Map.

Disclaimer: These calculators and resulting analysis are for assisting in the understanding of legal property descriptions only and are not intended to be used for providing legal dimensions of property ownership.

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Latitude (Degrees, South is Negative)** - This is a geographic coordinate that specifies the north-south position of a point on the Earth's surface. Latitude is an angle which ranges from 0 degrees at the Equator to 90 degrees northward and to -90 degrees southward. If the latitude is south, enter a negative value. You may need to convert latitude that is in degrees, minutes and seconds into decimal degrees. For example, if the latitude is North 42° 36' 0", the correct entry is 42.60 (i.e., 0"/60 equals 0' and 36.0'/60 equals 0.60°). Enter the latitude value for each data point as needed to accurately define the desired enclosed area being measured. A minimum of at least three data points must be entered to calculate the **Perimeter** and **Area** output parameters.

2) **Longitude (Degrees, West is Negative)** - This is a geographic coordinate that specifies the east-west position of a point on the Earth's surface. Longitude is an angle which ranges from 0 degrees at the Prime Meridian to 180 degrees eastward and to -180 degrees westward. If the longitude is west, enter a negative value. You may need to convert longitude that is in degrees, minutes and seconds into decimal degrees. For example, if the longitude is West 122° 59' 24", the correct entry is -122.99 (i.e., 24"/60 equals 0.4' and 59.4'/60 equals 0.99°). Enter the

longitude value for each data point as needed to accurately define the desired enclosed area being measured. A minimum of at least three data points must be entered to calculate the **Perimeter** and **Area** output parameters.

3) **Spherical or Oblate Spheroid Earth** - This is a logic input parameter that tells the calculator whether to use a perfectly spherical or more accurate oblate spheroid representation of the earth.

   The circumference around the equator and around the north and south poles along the meridian line for a perfectly spherical representation of the earth is 21,600 nautical miles or 24,856.84 statute miles. This results in the radius of the earth for a perfectly spherical representation of the earth being 3,437.75 nautical miles or 3,956.09 statute miles. This results in the length of a degree of latitude being precisely 60 nautical miles or 69.0468 statute miles and results in the length of a degree of longitude at the equator being precisely 60 nautical miles or 69.0468 statute miles.

   The circumference around the equator for the more accurate oblate spheroid representation of the earth is 24,901.46 statute miles (i.e., a radius of 3,963.19 statute miles). The circumference around the north and south poles along the meridian line for the more accurate oblate spheroid representation of the earth is 24,859.73 statute miles (i.e., a radius of 3,956.55 statute miles). This is a 41.73 statute mile circumference difference (or a 6.64 statute mile radius difference). This results in the length of a degree latitude varying from 68.7075 statute miles at the equator to 69.4032 statute miles at the north and south poles. This results in the length of a degree of longitude at the equator being 69.1706 statute miles.

   Enter 0 for a perfectly spherical representation of the earth. Enter 1 for a more accurate oblate spheroid representation of the earth. The spherical representation of the earth is the default value.

4) **Average Grade of Terrain (Percent)** – Leave blank or enter the average grade of terrain. Grade in percent is the terrain elevation rise (or fall) divided by the terrain horizontal run distance. 0% is flat terrain. A 45 degree slope (i.e., equal rise elevation and run distance) is a grade of 100%.

5) **Display Google Map of Points? (0 = No, 1 = Yes)** – Leave blank or enter 0 until after you have worked out a proper solution. Then you may enter 1 to see a Google Map showing the entered points. You may zoom in or out, pan, select road map or satellite view, and toggle the map scale between metric and imperial as desired.

Click ⬚ Solve ⬚ after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Perimeter (Feet and Statute Miles)** - This is the perimeter of the enclosed area as defined by the entered **Latitude and Longitude** input parameters.

2) **Area (Square Feet, Acres and Square Statute Miles)** - This is the area enclosed by the **Perimeter** output parameter as defined by the entered **Latitude and Longitude** input parameters.

3) **Length of Degree of Latitude (Statute Miles)** - This is the length of a degree of latitude given the average value of the entered **Latitude** input parameters. The length of a degree latitude is 69.0468 statute miles (i.e., precisely 60 nautical miles) for a perfectly spherical representation of the earth. The length of a degree latitude varies from 68.7075 statute miles at the equator to 69.4032 statute miles at the north and south poles for an oblate spheroid representation of the earth.

4) **Length of Degree of Longitude (Statute Miles)** - This is the length of a degree of longitude given the average value of the entered **Latitude** input parameters. The length of a degree longitude varies from either 69.0468 statute miles (i.e., precisely 60 nautical miles) for a perfectly spherical representation of the earth or from 69.1706 statute miles for an oblate spheroid representation of the earth at the equator to 0 statute miles at the north and south poles.

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Flexible machine elements like pulley/belt drive systems may be used for the transmission of power over comparatively long distances, where relative motion/vibration between the driver and driven element is a concern, and just for economics and convenience. If power transmission is the sole objective, the pulley diameters are often the same. However, you may want to change the driven element RPM or torque from that of the driver element and this may be readily accomplished with a pulley drive system. When doing this, please note that the power transmitted still remains the same.

This calculator is based on the Coulomb Friction Formula and allows you to design and build a pulley drive system. In order for the system to not experience belt slippage for a given power transmission level, the belt lap angle and associated friction developed must be adequate for the pulley diameters used in the design. This typically involves setting the static belt tension to a sufficiently high level. However, if you set the static belt tension too high, you may significantly shorten the bearing life. This calculator solves this problem and provides an accurate solution for both Flat and Vee pulley/belts. This calculator will provide a conservative solution for grooved and ribbed belts.

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Horse Power** - This is the horse power applied to the input pulley shaft by the driving machine (e.g., an engine, cross flow turbine or water wheel).

2) **Input Pulley Speed (Rotations/Minute)** - This is the speed applied to the input pulley shaft by the driving machine (e.g., an engine, cross flow turbine or water wheel).

3) **Desired Output Pulley Speed (Rotations/Minute)** - This is the speed you want on the output pulley shaft for the driven machine (e.g., a generator).

4) **Input Pulley Pitch Diameter (Inches)** - This is the input pulley pitch diameter as indicated by the pulley manufacturer. Please note that the pitch diameter is typically slightly less than the actual measured outer diameter.

5) **Pulley Shaft Center-to-Center Distance (Inches)** - This is the dimension between the center of the input pulley and the center of the output pulley.

6) **Angle of Pulley Groove (Degrees)** - This is the belt capture angle of the pulleys. This is 90 degrees for a flat belt and 20 degrees for a Vee belt.

7) **Coefficient of Friction** - This is the effective coefficient of friction between the belt material and the pulley material. 0.32 is typical for a rubber belt and a steel pulley.

Click Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Input Pulley Torque (Foot-Pounds)** - This is the torque of the input pulley given the horse power and speed being applied by the machine attached to the input pulley shaft.

2)   **Drive Ratio** - This is the ratio of the **Desired Output Pulley Speed** and the **Input Pulley Speed**.

3)   **Output Pulley Pitch Diameter (Inches)** - This is the required output pulley pitch diameter as indicated by the pulley manufacturer. The pitch diameter is typically slightly less than the actual measured outer diameter of the pulley.

4)   **Input Pulley Belt Lap Angle (Degrees)** - This is the effective angle that the belt covers the input pulley given the pulley system geometry established by knowing the **Input/Output Pulley Pitch Diameters** and the **Pulley Shaft Center-to-Center Distance**. Larger belt lap angles are more effective at transmitting a given power without slipping.

5)   **Output Pulley Belt Lap Angle (Degrees)** - This is the angle that the belt covers the output pulley given the pulley system geometry established by knowing the **Input/Output Pulley Pitch Diameters** and the **Pulley Shaft Center-to-Center Distance**.

6)   **Belt Length (Inches)** - This is the required belt length given the pulley system geometry established by knowing the **Input/Output Pulley Pitch Diameters** and the **Pulley Shaft Center-to-Center Distance**.

7)   **Belt Velocity (Feet/Second)** - This is the linear speed of the belt. Belts are rated for a maximum belt velocity and this limit should not be exceeded in the pulley system design.

8)   **Belt Tension Ratio** - This is the ratio of the **Maximum Dynamic Belt Tension** divided by the **Minimum Dynamic Belt Tension**. It is calculated based on the Coulomb Friction Formula.

9)   **Maximum Dynamic Belt Tension (Pounds)** - This is the tension on the taut side of pulley system during operation.

10) **Minimum Dynamic Belt Tension (Pounds)** - This is the tension on the slack side of pulley system during operation.

11) **Cyclic Tension Variation (Pounds)** - This is the difference between the **Maximum Dynamic Belt Tension** and the **Minimum Dynamic Belt Tension**.

12) **Required Static Belt Tension (Pounds)** - This is the tension that the belt must be set in order to not have any slippage during operation.

13) **Static Bearing Load (Pounds)** - This is the load that pulley system applies to pulley bearings when the pulley system is not operating. This load is two times the **Required Static Belt Tension**.

14) **Dynamic Bearing Load (Pounds)** - This is the load that pulley system applies to pulley bearings when the pulley system is operating. This load is the sum of the **Maximum Dynamic Belt Tension** and the **Minimum Dynamic Belt Tension**.

15) **Output Pulley Torque (Foot-Pounds)** - This is the torque of the output pulley given the horse power applied by the machine attached to the input pulley shaft and given the output pulley speed. The **Output Pulley Torque** may be calculated by dividing the **Cyclic Tension Variation** by the output pulley pitch radius, and this is how this parameter is calculated by this calculator. It should be noted that the horse power transmitted by output pulley is the same as the horse power being applied by the machine attached to the input pulley shaft (minus the relatively small amount of energy lost by friction heating the belt).

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Shaft Stress Analysis Calculator (Soderberg)

This calculator is based on the Soderberg approach for determining the minimum recommended diameter of a shaft subjected to a combination of steady torque (e.g., induced by driving a generator) and alternating maximum bending moment (e.g., induced by the weight of a turbine runner and water forces acting on a rotating runner/shaft) is a common loading for water work project machines and this calculator may be used for performing a load/stress analysis on cross flow turbine, undershot water wheel, and overshot water wheel shafts.

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Maximum Steady Shaft Torque (Foot-Pounds)** - This is the maximum steady shaft torque resulting from either the driving machine or the driven machine. This value is an output parameter of our **Cross Flow Turbine Design Calculator**, **Overshot Water Wheel Design Calculator**, and **Undershot Water Wheel Design Calculator**.

2) **Maximum Shaft Bending Moment (Inch-Pounds)** - This is the combination of acting force and moment arm that results in the maximum bending moment applied to the shaft. This value is an output parameter of our **Cross Flow Turbine Design Calculator**, **Overshot Water Wheel Design Calculator**, and **Undershot Water Wheel Design Calculator**.

3) **Material Yield Strength (Pounds/Square Inch)** - This is the stress (i.e., force per area) at which the chosen shaft material begins to deform plastically (i.e., does not return to its original shape). This is typically 36000 PSI for A36 low carbon steel.

4) **Material Endurance Limit (Pounds/Square Inch)** - This is the cyclic stress (e.g., induced by the weight of a turbine runner and water forces acting on a rotating runner/shaft) that may be applied to the chosen material without causing fatigue failure. This is typically 28000 PSI for A36 low carbon steel.

5) **Design Factor of Safety** - This is the ratio of the **Material Yield Strength** to the design load. In this case, the design load results from the combination **Maximum Steady Shaft Torque** and **Maximum Shaft Bending Moment**. The design factor of safety may range from 1.1 (where weight is an important design consideration such as in airplanes and where the material properties are well known and held to a high quality standard) to 5 or much more to ensure safety when material properties and quality are less known. 1.5 might be a reasonable value to use for cross flow turbines and water wheels.

Click ⌊ Solve ⌋ after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameter:

1) **Minimum Recommended Shaft Diameter (Inches)** - This is the minimum recommended shaft diameter given the input parameters.

Return to TOC

In 2021 we decided to purchase a <u>2023 Casita Travel Trailer</u> as backpack, canoe and kayak camping trips requiring us to sleep in a tent on the ground was getting less fun. A Casita travel trailer must be picked up in Rice Texas (i.e., Casita does direct sales only and has no dealerships) and they have a long lead order time before pickup as demand for them is very high as they last forever and can be easily resold for more than their purchase price. Upon returning home, Gayle named our Casita travel trailer "Los Gatos Casita" as a tribute to our cats who traveled with us. Here are some photos from this 12,630 mile, 3 month and 24 State camping trip:

<p align="center"><u>Our "Los Gatos Casita" Spring 2023 Trip</u></p>

It is important to properly load a trailer so as to not exceed the trailer axle load limit, the tow vehicle maximum tongue weight limit, the tow vehicle gross weight rating, the tow vehicle combined gross weight rating (combined weight of tow vehicle and trailer), the tow vehicle maximum payload capacity, the tow vehicle front axle load rating, the tow vehicle rear axle load rating, the tow vehicle maximum towing capacity and stay within the recommended trailer tongue weight to trailer weight ratio range to ensure tow vehicle front-tire traction and steering control and trailer sway stability when towing. This calculator was designed to evaluate the effects of moving items on the trailer with regard to staying well within these limits.

This trailer weight and balance calculator was designed specifically for Casita travel trailers and is used in conjunction with our **Andersen Weight Distribution Hitch Calculator**. If the input parameters don't provide sufficient data or contain data that is not valid to allow the calculator to correctly calculate some of the output parameters, the affected output parameters will display "NVD!"

To use this calculator, enter ALL of the following required input parameters as indicated:

1) **Casita Model Code (Enter '13D', '16D', '16S', '17D' or '17S'; '17D' is default)** – This is a model code used to identify what specific Casita model data to use for the trailer empty weight, the trailer empty tongue weight and the moment arm distances for the **Change in Propane Tanks**, **Change in Potable Water Tank**, **Change in Gray Water Tank**, **Change in Black Water Tank**, **Change in Entry Clothes Closet**, **Change in Kitchen Cabinets**, **Change in Bed/Dinette Area**, **Change in Battery Compartment**, and **Change at Rear Bumper** input parameters. Enter the code with single quotation marks around it, e.g., '13D' for the Casita Patriot, '16D' for Casita Spirit Deluxe, '17S' for Casita Liberty Standard, etc. The "D" is for "Deluxe" models with bathrooms and the "S" is for "Standard" models without bathrooms. Then, just clicking $\boxed{\text{Solve}}$ will display the Casita Travel Trailer manufacturer specified trailer empty weight output parameters associated for this entered Casita trailer model.

2) **Known Trailer Tongue Weight (Pounds or leave blank)** - This is the trailer tongue weight. This can be determined by using a tongue weight scale to measure it. If the **Known Trailer Weight** and **Known Trailer Axle Load Hitched** input parameters are entered, this may be left blank and will be calculated.

3) **Known Trailer Weight (Pounds or leave blank)** - This is the trailer weight. This can be determined by using a certified truck scale to measure the hitched trailer axle load and adding the trailer tongue weight as measured by a tongue weight scale. If the **Known Trailer Tongue Weight** and **Known Trailer Axle Load Hitched** input parameters are entered, this may be left blank and will be calculated.

4) **Known Trailer Axle Load Hitched (Pounds or leave blank)** - This is the trailer axle load while hitched to the tow vehicle. This can be determined by using a certified truck scale to measure the hitched trailer axle load. If the **Known Trailer Tongue Weight** and **Known Trailer Weight** input parameters are entered, this may be left blank and will be calculated.

5) **Change in Propane Tanks (Pounds)** - This is the change in the weight of the propane tanks from the known basis, i.e., **Casita Model Code**, **Known Trailer Tongue Weight**, **Known Trailer Weight** and **Known Trailer Axle Load Hitched** input parameters. A 20 pound propane capacity tank weighs 17 pounds when empty and holds about 20 pounds of propane or about 4.7 gallons when full. Current Casita travel trailers have two 20 pound propane capacity tanks which both weigh a total of 74 pounds when both are full of propane. Adding weight here will increase the trailer tongue weight and increase the trailer weight.

6) **Change in Potable Water Tank (Gallons)** - This is the change in the weight of the potable water tank from the known basis, i.e., **Casita Model Code**, **Known Trailer Tongue Weight**, **Known Trailer Weight** and **Known Trailer Axle Load Hitched** input parameters. Current Casita travel trailers have either a 16 or a 23 gallon potable water tank. Water weighs about 8.3 pounds per gallon. Adding weight here will decrease the trailer tongue weight and increase the trailer weight.

7) **Change in Gray Water Tank (Gallons)** - This is the change in the weight of the gray water tank from the known basis, i.e., **Casita Model Code**, **Known Trailer Tongue Weight**, **Known Trailer Weight** and **Known Trailer Axle Load Hitched** input parameters. Current Casita travel trailers have a 32 gallon gray water tank. Water weighs about 8.3 pounds per gallon. Adding weight here will increase the trailer tongue weight and increase the trailer weight.

8) **Change in Black Water Tank (Gallons)** - This is the change in the weight of the black water tank from the known basis, i.e., **Casita Model Code**, **Known Trailer Tongue Weight**, **Known Trailer Weight** and **Known Trailer Axle Load Hitched** input parameters. Current Casita travel trailers have a 15 gallon black water tank. Water weighs about 8.3 pounds per gallon. Adding weight here will increase the trailer tongue weight and increase the trailer weight.

9) **Change in Entry Clothes Closet (Pounds)** - This is the change in the weight in the entry clothes closet from the known basis, i.e., **Casita Model Code**, **Known Trailer Tongue Weight**, **Known Trailer Weight** and **Known Trailer Axle Load Hitched** input parameters. Adding weight here will increase the trailer tongue weight and increase the trailer weight.

10) **Change in Kitchen Cabinets (Pounds)** - This is the change in the weight in the kitchen cabinets from the known basis, i.e., **Casita Model Code**, **Known Trailer Tongue Weight**, **Known Trailer Weight** and **Known Trailer Axle Load Hitched** input parameters. Adding weight here will increase the trailer tongue weight and increase the trailer weight.

11) **Change in Bed/Dinette Area (Pounds)** - This is the change in the weight in the bed/dinette area from the known basis, i.e., **Casita Model Code**, **Known Trailer Tongue Weight**, **Known Trailer Weight** and **Known Trailer Axle Load Hitched** input parameters. Adding weight here will decrease the trailer tongue weight and increase the trailer weight.

12) **Change in Battery Compartment (Pounds)** - This is the change in the weight in the battery compartment from the known basis, i.e., **Casita Model Code**, **Known Trailer Tongue Weight**, **Known Trailer Weight** and **Known Trailer Axle Load Hitched** input parameters. Adding weight here will <u>decrease</u> the trailer tongue weight and <u>increase</u> the trailer weight.

13) **Change at Rear Bumper (Pounds)** - This is the change in the weight at the rear bumper from the known basis, i.e., **Casita Model Code**, **Known Trailer Tongue Weight**, **Known Trailer Weight** and **Known Trailer Axle Load Hitched** input parameters. Adding weight here will <u>decrease</u> the trailer tongue weight and <u>increase</u> the trailer weight.

14) **Specific Weight Change #1 (Pounds)** - This input parameter may be used to see the effect of some specific weight change in some other location not addressed by the **Change in Propane Tanks**, **Change in Potable Water Tank**, **Change in Gray Water Tank**, **Change in Black Water Tank**, **Change in Entry Clothes Closet**, **Change in Kitchen Cabinets**, **Change in Bed/Dinette Area**, **Change in Battery Compartment**, and **Change at Rear Bumper** input parameters.

15) **Specific Weight Moment Arm #1 (Inches)** - This is the specific moment arm used by the **Specific Weight Change #1** input parameter.

16) **Specific Weight Change #2 (Pounds)** - This input parameter may be used to see the effect of some specific weight change in some other location not addressed by the **Change in Propane Tanks**, **Change in Potable Water Tank**, **Change in Gray Water Tank**, **Change in Black Water Tank**, **Change in Entry Clothes Closet**, **Change in Kitchen Cabinets**, **Change in Bed/Dinette Area**, **Change in Battery Compartment**, and **Change at Rear Bumper** input parameters.

17) **Specific Weight Moment Arm #2 (Inches)** - This is the specific moment arm used by the **Specific Weight Change #2** input parameter.

Click <kbd>Solve</kbd> after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameter:

1) **Trailer Tongue Weight (Pounds)** - This is either the **Known Trailer Tongue Weight** input parameter or the calculated trailer tongue weight based on the other entered input parameters. This output parameter may then be used as the input parameter in our **Andersen Weight Distribution Hitch Calculator**.

2) **Trailer Weight (Pounds)** - This is either the **Known Trailer Weight** input parameter or the calculated trailer weight based on the other entered input parameters. This output parameter may then be used as the input parameter in our **Andersen Weight Distribution Hitch Calculator**.

3) **Trailer Weight CG Location (Inches Aft of Hitch Ball)** - This is the calculated location of the center of gravity of the trailer weight based on the entered input parameters.

4) **Trailer Axle Load Hitched (Pounds)** - This is either the **Known Trailer Axle Load Hitched** input parameter or the calculated trailer axle load based on the other entered input parameters. This

output parameter may then be used as the input parameter in our **Andersen Weight Distribution Hitch Calculator**.

5) **Trailer Tongue Weight to Trailer Weight Ratio (Percent, 9-15% Recommended)** - This is the ratio of **Trailer Tongue Weight** to the **Trailer Weight** output parameters. This should be between 9-15% to ensure tow vehicle and trailer stability. Too much tongue weight reduces tow vehicle front-tire traction and steering control. Too little tongue weight can make the trailer unstable and cause it to sway.

If you just click "Solve" without entering any input parameters, you will get our 2023 Casita OEM Liberty Deluxe travel trailer empty-weight default values:

Our Casita trailer has a maximum axle load rating of 3,500 pounds, an empty weight of 2,480 pounds with the CG location 117.3 inches aft of hitch ball, an axle load of 2,115 pounds and a measured tongue weight of **365 pounds**. As a check, the trailer axle load PLUS the tongue weight MUST be equal to the trailer weight. This is indeed the case.

Using these numbers and our **Andersen Weight Distribution Hitch Calculator** and using 7 threads to tension it, we can determine our empty Casita trailer when hitched to our Honda Ridgeline still weighs 2,480 pounds with the CG location 117.3 inches aft of hitch ball and our trailer axle load increases to 2,206 pounds. Since the trailer axle load PLUS the tongue weight MUST be equal to the trailer weight, we can calculate the tongue weight to now be a reduced **274 pounds**. As a secondary check, this tongue weight value was also confirmed with strain gauge measurement.

Of course, you can't go camping with an empty trailer, so here are our modified/refined and fully-loaded 2023 Casita Liberty Deluxe travel trailer numbers:

We modified/refined our Casita trailer as detailed in **Our Los Gatos Casita Spring 2023 Trip**. We typically do dry camping and travel in our Casita trailer with two filled 20 pound propane tanks (74 pounds total), 20 gallons of water in our potable water tank since this reduces our tongue weight by 44 pounds, empty black and gray tanks, 100 pounds of items in our entry closet, 215 pounds of items in our kitchen cabinets, 430 pounds of items in our sleeping area cabinets and we use a 26 pound Group 27 100AH LiFePO4 battery (which is 26 pounds lighter weight than the Casita OEM lead acid battery).

Using this calculator and these numbers, we can determine our fully-loaded Casita trailer weighs 3,437 pounds with the CG location 120.5 inches aft of hitch ball and has a trailer axle load of 3,011 pounds and a tongue weight of **426 pounds**. As a check, the trailer axle load PLUS the tongue weight MUST be equal to the trailer weight. This is indeed the case.

Using these numbers and our **Andersen Weight Distribution Hitch Calculator** and using 7 threads to tension it, our fully-loaded Casita trailer when hitched to our Honda Ridgeline still weighs 3,437 pounds with the CG location 120.5 inches aft of hitch ball and our trailer axle load increases to 3,102 pounds. Since the trailer axle load PLUS the tongue weight MUST be equal to the trailer weight, we can calculate the tongue weight to now be a reduced **335 pounds**. As a secondary check, this tongue weight value was also confirmed with strain gauge measurement.

And just for 100% clarity and emphasis, you can NOT take credit for this tongue weight reduction when using an Andersen WDH! Attempting to take credit for this lower tongue weight value by using a tensioned WDH could still result in overloading the tow vehicle hitch and create an unsafe situation. There is no sure way to absolutely ensure that the higher tongue weight value would NOT overload the tow vehicle PRIOR to tensioning the WDH and/or AFTER untensioning the WDH. It doesn't matter when or how you exceed your tow vehicle tongue weight limit, the microsecond that you do so may permanently damage the structure and make you unsafe hence forth. The unhitched and measured higher tongue weight value MUST ALWAYS be LESS than the tow vehicle Maximum Tongue Weight Limit AND this higher tongue weight value MUST ALWAYS be used for determining your actual payload weight which MUST ALWAYS be LESS than the tow vehicle Maximum Payload Capacity and result in axle loads which MUST ALWAYS be LESS than the axle load limits. However, you can perhaps take some comfort in knowing that your actual tongue weight while rolling down the road while using your Andersen WDH is significantly less than if you were not using it.

ALL of these axle load numbers were validated by certified scale measurement. ALL of these unhitched tongue weight numbers were validated by tongue scale measurement. ALL of these hitched tongue weight numbers were validated by strain gauge measurement. And perhaps most importantly, ALL of these numbers are well within the limits of our 2023 Casita Liberty Deluxe travel trailer.