RETScreen® International
Clean Energy Decision Support Centre

www.retscreen.net

RETScreen® Software
Online User Manual

Ground-Source Heat Pump
Project Model

Natural Resources Canada | Ressources naturelles Canada

Canada

Background

This document allows for a printed version of the RETScreen® Software Online User Manual, which is an integral part of the RETScreen Software. The online user manual is a Help file within the software. The user automatically downloads the online user manual Help file while downloading the RETScreen Software.

Reproduction

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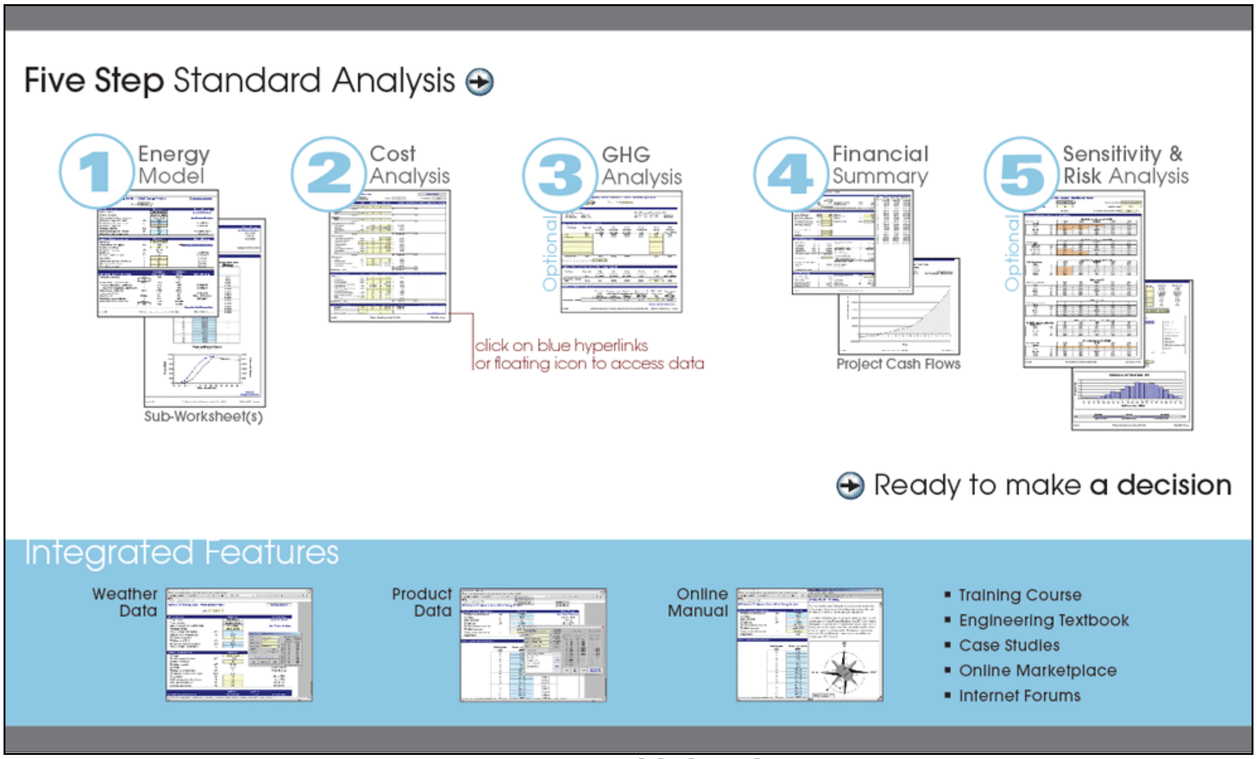
Brief Description and Model Flow Chart

RETScreen® International is a clean energy awareness, decision-support and capacity building tool. The core of the tool consists of a standardised and integrated clean energy project analysis software that can be used world-wide to evaluate the energy production, life-cycle costs and greenhouse gas emission reductions for various types of energy efficient and renewable energy technologies (RETs). Each RETScreen technology model (e.g. Ground-Source Heat Pump Project, etc.) is developed within an individual Microsoft® Excel spreadsheet "Workbook" file. The Workbook file is in-turn composed of a series of worksheets. These worksheets have a common look and follow a standard approach for all RETScreen models. In addition to the software, the tool includes: product, weather and cost databases; an online manual; a Website; an engineering textbook, project case studies; and a training course.

Model Flow Chart

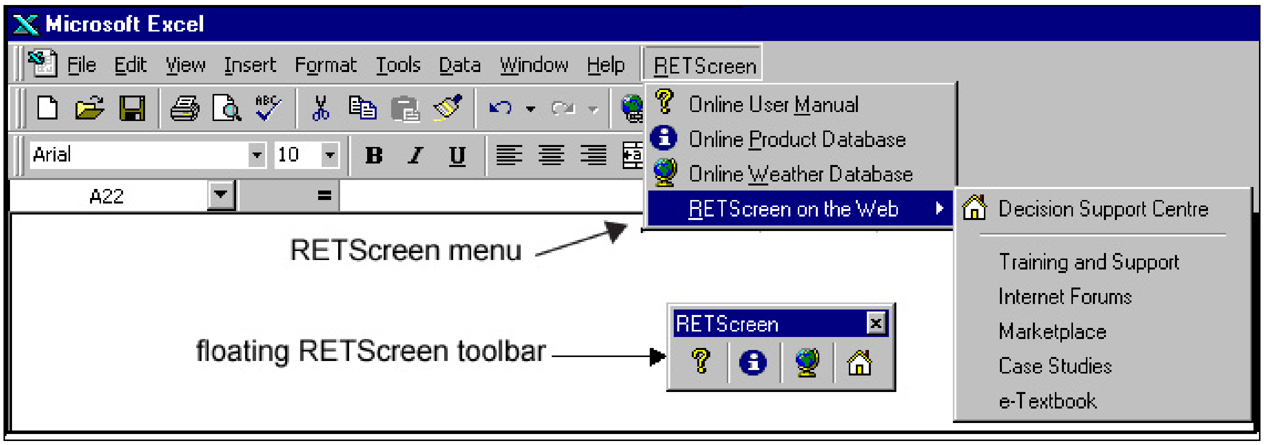
Complete each worksheet row by row from top to bottom by entering values in shaded cells. To move between worksheets simply "click" on the tabs at the bottom of each screen or on the "blue-underlined" hyperlinks built into the worksheets. The RETScreen Model Flow Chart is presented below.



RETScreen Model Flow Chart

Data & Help Access

The RETScreen Online User Manual, Product Database and Weather Database can be accessed through the Excel menu bar under the "RETScreen" option, as shown in the next figure. The icons displayed under the RETScreen menu bar are displayed in the floating RETScreen toolbar. Hence the user may also access the online user manual, product database and weather database by clicking on the respective icon in the floating RETScreen toolbar. For example, to access the online user manual the user clicks on the "?" icon.

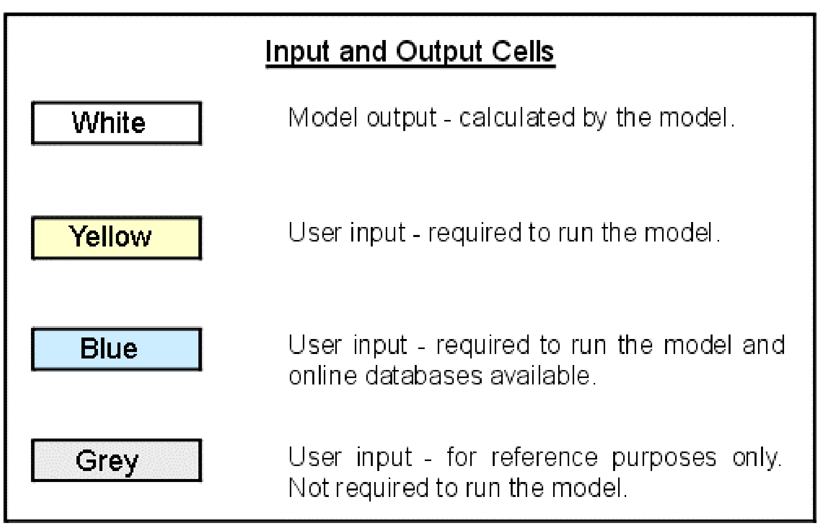


RETScreen Menu and Toolbar

The RETScreen Online User Manual, or help feature, is "cursor location sensitive" and therefore gives the help information related to the cell where the cursor is located.

Cell Colour Coding

The user enters data into "shaded" worksheet cells. All other cells that do not require input data are protected to prevent the user from mistakenly deleting a formula or reference cell. The RETScreen Cell Colour Coding chart for input and output cells is presented below.



RETScreen Cell Colour Coding

Currency Options

To perform a RETScreen project analysis, the user may select a currency of their choice from the "Currency" cell in the *Cost Analysis* worksheet.

The user selects the currency in which the monetary data of the project will be reported. For example, if the user selects "$," all monetary related items are expressed in $.

Selecting "User-defined" allows the user to specify the currency manually by entering a name or symbol in the additional input cell that appears adjacent to the currency switch cell. The currency may be expressed using a maximum of three characters ($US, £, ¥, etc.). To facilitate the presentation of monetary data, this selection may also be used to reduce the monetary data by a factor (e.g. $ reduced by a factor of a thousand, hence k$ 1,000 instead of $ 1,000,000).

If "None" is selected, all monetary data are expressed without units. Hence, where monetary data is used together with other units (e.g. $/kWh) the currency code is replaced with a hyphen (-/kWh).

The user may also select a country to obtain the International Standard Organisation (ISO) three-letter country currency code. For example, if Afghanistan is selected from the currency switch drop-down list, all project monetary data are expressed in AFA. The first two letters of the country currency code refer to the name of the country (AF for Afghanistan), and the third letter to the name of the currency (A for Afghani).

For information purposes, the user may want to assign a portion of a project cost item in a second currency, to account for those costs that must be paid for in a currency other than the currency in which the project costs are reported. To assign a cost item in a second currency, the user must select the option "Second currency" from the "Cost references" drop-down list cell.

Some currency symbols may be unclear on the screen (e.g. €); this is caused by the zoom settings of the sheet. The user can increase the zoom to see those symbols correctly. Usually, symbols will be fully visible on printing even if not fully appearing on the screen display.

Name of unit	Symbol for unit
ampere	A
calorie	cal
cubic feet per minute	cfm
day	d
degree Celsius	°C
degree Fahrenheit	°F
dollar	$
feet	ft
gallon[1]	gal
hectare	ha
hertz	Hz
horse-power	hp
hour	h
joule	J
kilogram	kg
kilometre	km
kilowatt	kW
litre	L
megawatt	MW
metre	m
mile	mi
mile per hour	mph
million Btu	mmBtu
pascal	Pa
percentage	%
person day	p-d
person hour	p-h
person trip	p-trip
person year	p-yr
pound	lb
pound-force/square inch	psi
second	s
tonne[2]	t
volt	V
watt	W
week	w
yard	yd
year	yr

Name of Prefix	Symbol for Prefix
kilo	k
mega	M
giga	G

List of Units, Symbols and Prefixes

Units, Symbols & Prefixes

The previous table presents a list of units, symbols and prefixes that are used in the RETScreen model.

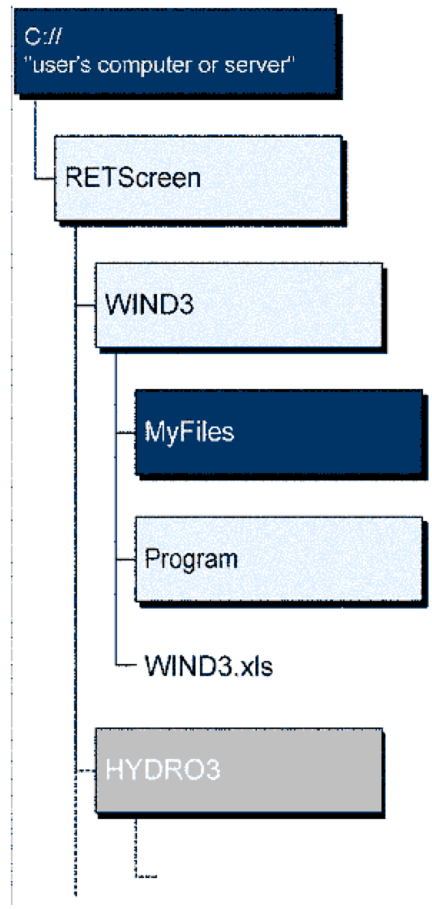
Note: 1. The gallon (gal) unit used in RETScreen refers to US gallon and not to imperial gallon.

2. The tonne (t) unit used in RETScreen refers to metric tonnes.

Saving a File

To save a RETScreen Workbook file, standard Excel saving procedures should be used. The original Excel Workbook file for each RETScreen model can not be saved under its original distribution name. This is done so that the user does not save-over the "master" file. Instead, the user should use the "File, Save As" option. The user can then save the file on a hard drive, diskette, CD, etc. However, it is recommended to save the files in the "MyFiles" directory automatically set by the RETScreen installer program on the hard drive.

The download procedure is presented in the following figure. The user may also visit the RETScreen Website at www.retscreen.net for more information on the download procedure. It is important to note that the user should not change directory names or the file organisation automatically set by RETScreen installer program. Also, the main RETScreen program file and the other files in the "Program" directory should not be moved. Otherwise, the user may not be able to access the RETScreen Online User Manual or the RETScreen Weather and Product Databases.



RETScreen Download Procedure

Printing a File

To print a RETScreen Workbook file, standard Excel printing procedures should be used. The workbooks have been formatted for printing the worksheets on standard "letter size" paper with a print quality of 600 dpi. If the printer being used has a different dpi rating then the user must change the print quality dpi rating by selecting "File, Page Setup, Page and Print Quality" and then selecting the proper dpi rating for the printer. Otherwise the user may experience quality problems with the printed worksheets.

Ground-Source Heat Pump Project Model

The RETScreen® International Ground-Source Heat Pump Project Model can be used world-wide to easily evaluate the energy production (or savings), life-cycle costs and greenhouse gas emissions reduction for the heating and/or cooling of residential, commercial, institutional and industrial buildings. The model can be used to evaluate both retrofit and new construction projects using either ground-coupled (horizontal and vertical closed-loop) or groundwater heat pumps.

Six worksheets (*Energy Model, Equipment Data, Cost Analysis, Greenhouse Gas Emission Reduction Analysis (GHG Analysis), Financial Summary* and *Sensitivity and Risk Analysis (Sensitivity)*) are provided in the Ground-Source Heat Pump Project Workbook file.

The *Energy Model* and *Equipment Data* worksheets are completed first. The *Cost Analysis* worksheet should then be completed, followed by the *Financial Summary* worksheet. The *GHG Analysis* and *Sensitivity* worksheets are optional analyses. The *GHG Analysis* worksheet is provided to help the user estimate the greenhouse gas (GHG) mitigation potential of the proposed project. The *Sensitivity* worksheet is provided to help the user estimate the sensitivity of important financial indicators in relation to key technical and financial parameters. In general, the user works from top-down for each of the worksheets. This process can be repeated several times in order to help optimise the design of the wind energy project from an energy use and cost standpoint.

In addition to the worksheets that are required to run the model, the *Introduction* worksheet and *Blank Worksheets (3)* are included in the Ground-Source Heat Pump Project Workbook file. The *Introduction* worksheet provides the user with a quick overview of the model. *Blank Worksheets (3)* are provided to allow the user to prepare a customised RETScreen project analysis. For example, the worksheets can be used to enter more details about the project, to prepare graphs and to perform a more detailed sensitivity analysis.

As part of the RETScreen Clean Energy Project Analysis Software, the *Energy Model* and *Heating and Cooling Load Calculation* worksheets are used to help the user calculate the annual energy production for a GSHP project based upon local site conditions and system characteristics. Results are calculated in common megawatt-hour (MWh) units for easy comparison of different technologies.

The site conditions associated with estimating the heating and cooling loads and the energy demand of the building where the ground-source heat pump system is to be installed are detailed below.

Energy Model

As part of the RETScreen Clean Energy Project Analysis Software, the Energy Model and Heating and Cooling Load Calculation worksheets are used to help the user calculate the annual energy production for a GSHP project based upon local site conditions and system characteristics. Results are calculated in common megawatt-hour (MWh) units for easy comparison of different technologies.

Site Conditions

The site conditions associated with estimating the annual energy production of a ground-source heat pump project are detailed below.

Project name

The user-defined project name is given for reference purposes only.

For more information on how to use the RETScreen Online User Manual, Product Database and Weather Database, see Data & Help Access.

Project location

The user-defined project location is given for reference purposes only.

Available land area

The user enters the available land area (m^2) at the proposed site. This land area is compared to the "Typical land area required" calculated in the model. A warning message will be displayed in the model if the selected system is not likely to fit in the available land area. The user should then adjust the system design (i.e. vertical vs. horizontal ground heat exchangers, layout, etc.). See "Typical land area required" description which follows.

Soil type

The user selects the type of soil that is found at the proposed site. The soil type has a large influence on the size of the ground heat exchanger (GHX). For example, a light dry soil will require a much longer horizontal GHX than a heavy damp soil would. This is due to the poorer heat transfer characteristics and the lower density of the lighter and dryer soil. The following table presents the properties of the eight soil types considered in the GSHP model [ASHRAE, 1995]. An easy finger assessment procedure for determining soil types is available in the literature [McRae, 1988].

Soil Type	Conductivity W/(m·°C)	Diffusivity m^2/s	Density kg/m^3	Heat Capacity kJ/(kg·°C)
Light Soil – Damp (Loose sand, silt)	0.9	5.16e-7	1,600	1.05
Light Soil – Dry (Loose sand, silt)	0.3	2.84e-7	1,400	0.84
Heavy Soil – Damp (Clay, compacted sand, loam)	1.3	6.45e-7	2,100	0.96
Heavy Soil – Dry (Clay, compacted sand, loam)	0.9	5.16e-7	2,000	0.84
Light Rock (Limestone)	2.4	1.03e-6	2,800	0.84
Heavy Rock (Granite)	3.5	1.29e-6	3,200	0.84
Permafrost – Light	1.4	1.10e-6	1,580	0.76
Permafrost – Dense	2.0	1.37e-6	2,070	0.69

Soil Types Defined in the GSHP Model

Design heating load

The building design heating load (kW) is calculated in the *Heating and Cooling Load* worksheet and copied automatically to the *Energy Model* worksheet.

Note: At this point, the user should complete the *Heating and Cooling Load* worksheet.

Design cooling load

The building design cooling load (kW) is calculated in the *Heating and Cooling Load* worksheet and copied automatically to the *Energy Model* worksheet.

System Characteristics

The system characteristics associated with estimating the annual energy production of a ground-source heat pump system and establishing a comparison with a base case system are detailed below. The system characteristics are divided into four sub-sections: Base Case HVAC System, Ground Heat Exchanger System, Heat Pump System and Supplemental Heating and Heat Rejection System.

Base Case HVAC System

This sub-section allows the user to define the seasonal performances of the conventional heating, ventilation and air conditioning (HVAC) system that would be displaced by the GSHP system.

Building has air-conditioning?

The user indicates by selecting from the drop-down list whether or not an air-conditioning system is used in the building. The selection made in this box alters the calculation algorithm to include or exclude the energy savings or losses that occur due to changes in cooling load. If the building is not equipped with air-conditioning, no reduction in cooling load is calculated and hence, no savings are realised. If an air-conditioning system is included, the effects of the ground-source heat pump system on summer cooling energy demands are taken into consideration.

Changing the selection in this field affects the worksheet display in several locations. Indicating that an air-conditioning system is used causes certain input fields to be added because some additional information is required. Selecting no air-conditioning removes the extraneous entry fields.

Heating fuel type

The user selects the type of fuel that is used to heat the building. A list of common fuels is provided in the drop-down list. This selection allows the model to estimate the peak electrical load that would be required by the conventional heating system. If the user selects "Other," the model assumes that the fuel type has no impact on the base case electric demand. The table below provides the heats of combustion for the heating energy avoided.

Heating Energy Avoided	Fuel Heating Value
Natural gas	37.2 MJ/m³ (10.33 kWh/m³)
Propane	26.6 MJ/L (7.39 kWh/L)
Diesel (# 2 oil)	38.7 MJ/L (10.74 kWh/L)
# 6 oil	40.5 MJ/L (11.25 kWh/L)
Electricity	1.0 kWh/kWh
Other	1.0

Fuel Heating Value

Note: Propane is expressed in terms of liquefied propane.

Heating system seasonal efficiency

The user enters the annual heating system efficiency (%) (not the instantaneous or peak efficiency). This value should include the effects of cycling and part load performance as well as any loss of heat because of ducting that runs outside of the building envelope. This value is used to estimate the gross energy/fuel requirement to meet the building's heating demand in the base case scenario.

Typical values of heating system seasonal efficiency are tabulated in the table below. These values should be reduced by 10% if ducting runs outside of the insulated envelope (e.g. in attics).

Heating System Type	Typical Annual Heating System seasonal efficiency (%)
Standard boilers/furnaces (with pilot light)	**55 to 65**
Mid-efficiency boilers/furnaces (spark ignition)	**65 to 75**
High-efficiency or condensing boilers/furnaces	**75 to 85**
Electric resistance	**100**
Air-source heat pump	**130 to 200**
Ground-source heat pump	**250 to 350**

Typical Heating Systems Seasonal Efficiencies

Air-conditioner seasonal COP

The seasonal Coefficient Of Performance (COP) is a property of the air-conditioning device and represents the average expected performance over the cooling season expressed in terms of the cooling energy output of the device divided by the energy input to the device. This value is used to estimate the net electrical energy requirement and peak load to meet the building's cooling energy demand for the base case HVAC system.

Typical values of COP are tabulated in the table below. These values should be reduced by 10% if ducting runs outside of the insulated envelope (e.g. in attics).

Cooling System Type	Typical Annual COP
Window air-conditioner	2.4
Standard DX (direct expansion) air-conditioner and air-source heat pumps	3.0
High-efficiency air-conditioner	3.5
High-efficiency commercial chiller	5.0
Ground-source heat pump	4.4

Typical Annual COP for Air-Conditioning Systems

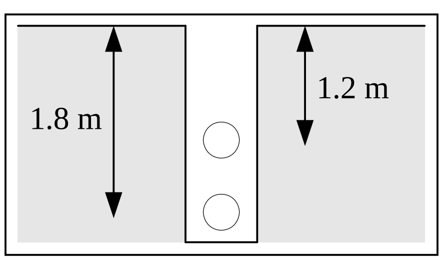
Ground Heat Exchanger System

This sub-section allows the user to define the type of GSHP system that will be evaluated.

System type

The user selects the system type. The options from the drop-down list are: "Vertical closed-loop," "Horizontal closed-loop" and "Groundwater." The vertical closed-loop system is based on one U-tube per borehole type ground heat exchanger, while the horizontal system is based on a stack two-pipe arrangement as shown in the next figure.

The primary type of groundwater system considered is the supply and injection well system, although standing column systems can also be evaluated by the model if the cost of well drilling is corrected to compensate the absence of a separate injection well.



Horizontal Heat Exchanger Configuration

Selecting "Horizontal closed-loop" will lead to the largest required land area but will result in lower initial costs than vertical closed-loop systems. Groundwater systems usually require the smallest land area and can offer the highest performances. However, availability of groundwater and environmental regulations can sometimes prohibit the use of this type of system.

Design criteria

The user selects the design criteria from the two options in the drop-down list: "Heating" and "Cooling." This selection is used in the model to evaluate the size of the ground heat exchanger, the required groundwater flow, and to size the heat pumps.

This selection will have a large influence on the size of the ground heat exchanger, as well as the heat pump and supplemental heating and cooling equipment. For example, many buildings in moderate to warm climates, and to a lesser extent in colder climates, have cooling loads that typically dominate heating loads. Selecting a ground heat exchanger to entirely meet the cooling load could lead to an excessively large ground heat exchanger that could make a GSHP system financially unviable. In such a situation it is often advisable to size the ground heat exchanger to meet only the heating load and have a supplemental heat rejector (e.g. a cooling tower) to compensate for the excess cooling demand. In cold climates this situation can be reversed and sizing the ground heat exchanger for cooling loads can result in a smaller ground heat exchanger but will require the use of supplemental heat in the winter.

The choice of designing the system based on cooling or heating load will be closely linked to the cost and financial viability of each project and can be evaluated by the user during the pre-feasibility stage through sensitivity analysis.

Typical land area required

The model calculates the typical land area (m^2) required for the selected GSHP system type. This land area is compared to the available land area entered by the user; if the available land area is less than the typical land area required, a "Insufficient land area" warning message in red characters will appear next to this value. If this warning message appears, the user can change the GHX system type or layout to fit the available land area.

The typical land area required for a groundwater system is based on a 6 m radius per well and includes the presence of injection wells. The typical land area for a vertical closed-loop system is based on an average borehole depth of 91 m.

Typical values for land area range from 50 to 95 m^2/kW for horizontal systems and 1.5 to 12 m^2/kW for vertical systems.

Ground heat exchanger layout

The user selects one of three layout options: "Standard," "Compact" and "Very compact." This selection determines the minimum separation between boreholes in a vertical system and between trenches in a horizontal system. The table presents the typical distances used in the model corresponding to each layout.

Type of GHX Layout	Borehole Separation m	Trench Separation m
Standard	6.1	3.7
Compact	3.7	2.4
Very compact	2.4	1.5

Distances between Boreholes and Trenches

While a smaller separation distance will reduce the typical land area required it would increase the total length of ground heat exchanger required. Moreover, long term heat imbalance on the ground heat exchanger (cooling loads much greater than heating loads or vice-versa) will reduce to a greater extent the efficiency of closely packed GHXs. When a large difference exists between the heating and cooling loads, long term effects on non-standard layouts should be thoroughly investigated.

Total borehole length

The model calculates the cumulative borehole length (m) needed to meet the building heating or cooling load depending on the selected design option. The borehole length depends on many factors such as the earth temperature, soil type, building load and energy demand. This value is used to obtain the typical land area based on an average depth of 91 m per individual borehole.

Typical values for cumulative borehole length are between 10 to 25 m/kW.

Total loop length

The model calculates the total loop length (m) needed to meet the building heating or cooling load depending on the selected design option. The loop length depends on many factors such as the earth temperature, soil type, building load and energy demand, trench separation(ground heat exchanger layout). This value represents the approximate length of pipe that would be installed underground.

Typical values for total loop length for a stack two-pipe system are between 40 to 65 m/kW.

Total trench length

This value is simply half the total loop length since the horizontal system considered is a two-pipe system. This value is used along with the separation distance to obtain the typical land area required.

Typical values for total loop length for a stack two-pipe system are between 20 to 33 m/kW.

Pumping depth

The user enters the depth (m) from which the water will be pumped. This value is used to evaluate the pumping power required. The pumping depth corresponds to the distance to the static water level in the well to which is added the drawdown. This drawdown corresponds to a lowering of the static water level in the well required to insure the pumping rate. In addition to the pumping depth, a supplementary 15 m of head is added to the pumping head to account for injection well pressure and pressure losses in the piping.

Typical values for pumping depth can vary significantly according to location, with values in the 30 to 60 m range being common. Excessive pumping depth will significantly increase the pumping power and reduce the GSHP system's COP, and consequently impact the cost of the project.

Wellbore depth

The user enters the wellbore depth (m) for a typical well at the site. This value is used to evaluate the cost of drilling the wells.

Typical values for wellbore depth range from 50 to 250 m for open loop systems but can be as deep as 500 m for standing column wells.

Maximum well flow rate

The user enters the maximum flow rate (L/s) that can be delivered on a continuous basis by a typical well. This information usually comes from test wells but initial estimates can sometimes be obtained from experienced well drillers or hydro-geologists at the site. This value is used to determine the number of wells required to meet the building energy demand for both cooling and heating.

Typical values for maximum flow rate vary from 0.5 L/s to over 60 L/s.

Required groundwater flow rate

The model calculates the total groundwater flow rate (L/s) needed to meet the building design heating and cooling load. The flow rate depends on the groundwater temperature and the building's loop heat exchanger efficiency. To determine the required flow rate, the model assumes a 2.8°C approach temperature at the heat exchanger, between the groundwater loop and the building loop.

Typical values for "Required groundwater flow rate" are usually 0.05 L/s/kW or less.

Number of supply wells required

Based on the required groundwater flow rate and the maximum well flow rate, the model calculates the total number of supply wells required. The same number of injection wells is assumed.

Heat Pump System

This sub-section allows the user to define the average efficiency of the heat pumps used in the GSHP system.

Average heat pump efficiency

The user selects the average heat pump efficiency from the options in the drop-down list: "Standard," "Medium," "High" and "User-defined." Values for heating and cooling COP's are displayed in the spreadsheet in the cells below.

Standard, medium and high efficiencies are steady state COPs and not seasonal values. These efficiencies are determined under standard test conditions as defined by the Canadian Standards

Association (CSA) Standard 446 or the Air-conditioning and Refrigeration Institute (ARI) standards 325 and 330. Both organisations have directories which list heat pumps certified under their specific standards. The table below shows the COPs corresponding to the three levels of performance along with the standard test conditions.

Efficiency Level	Heating COP EWT[1]=10°C (GWHP[2]) EWT=0°C (GCHP[3]) Tinterior=21°C	Cooling COP EWT=21°C (GWHP[2]) EWT=25°C (GCHP[3]) Tinterior=26.7°C
Standard	2.8	3.5
Medium	3.2	4.5
High	4.0	5.5

(1: EWT = Entering Water Temperature - water going into the heat pump;
2: GWHP = Groundwater heat pump; 3 = GCHP = Ground-coupled heat pump)

Heat Pump COP and Standard Test Conditions

When the user selects "User-defined" a product selection can be made from the online product database to obtain the heating and cooling COP values. These data can be pasted from the dialogue box to the spreadsheet by clicking on the "Paste Data" button.

Since GSHP systems are generally made up of a number of small to medium size heat pumps, the COP value represents the weighted average of all machines in the system. Selecting a higher efficiency level will reduce electrical consumption but increase the initial cost of the heat pumps. In some cases the GHX might also be somewhat larger for more efficient heat pumps, since the motor energy saved by the efficient heat pump has to be made up through the GHX in heating mode. Cooling GHX length using higher efficiency heat pumps will however be shorter.

Heat pump manufacturer

The user enters the name of the heat pump manufacturer. This information is given for reference purposes only. The user can consult the RETScreen Online Product Database for more information.

Heat pump model

The user enters the name of the heat pump model. This information is given for reference purposes only. The user can consult the RETScreen Online Product Database for more information.

Standard cooling COP

See Average heat pump efficiency explanation.

Standard heating COP

See Average heat pump efficiency explanation.

Total standard heating capacity

The model calculates the suggested total standard heating capacity (kW) of the heat pumps. This value is obtained through the building design heating load or the building design cooling load, and is corrected for the difference between standard rating conditions and actual building's design conditions. The heating capacity is calculated for the building's block load. In a typical distributed heat pump system, the actual size of each zone's heat pump will be selected on that zone's peak load. Therefore, the summation of all installed heat pump heating or cooling capacities will usually exceed the standard cooling capacity calculated by the model.

Units switch: The user can choose to express the total standard heating capacity in different units by selecting among the proposed set of units: "MW," "million Btu/h," "boiler hp," "ton (cooling)," "hp," "W." This value is for reference purposes only and is not required to run the model.

The value for total standard heating capacity depends on the "Design criteria" option chosen by the user.

Heating load design criteria: When the user selects "Heating" as the design criteria, the GHX is sized to meet the heating load while the heat pump system is sized to meet the maximum value between cooling or heating load under standard rating conditions. This selection assumes that when a GSHP system is installed, the cooling load must, at a minimum, be met by the installed heat pumps so that no other mechanical cooling equipment, other than supplemental heat rejection to compensate for undersize GHX, is required. If the building's heating requirements are higher than the cooling requirements, the heat pumps will be sized according to the building's heating energy demand. This may lead to standard cooling capacity far in excess of the actual building's requirements. If the heat pump system cooling capacity exceeds 150% of the building energy demand, the "Oversized" warning message in red characters appears beside the value for "Total standard cooling capacity." It is generally recommended not to design a GSHP system with cooling capacities that are far in excess of the actual building's energy demand. Oversizing the cooling equipment usually leads to control problems and unacceptable performances, especially with regard to dehumidification. Systems with advanced control options, such as variable speed compressors, can eliminate this constraint.

Cooling load design criteria: When the user selects "Cooling" as the design criteria, the GHX is sized to meet the cooling load AND the heat pumps are also sized to meet the entire cooling demand. If the building's cooling load is higher than the heating load, this will lead to a heat pump system with standard capacity higher than the building's required heating capacity. However, if the cooling load is lower than the heating load, the standard heat pump system heating capacity might not be sufficient to meet the building's heating demand. In such cases, supplemental heating would be required. Designing the heat pumps and the GHX for cooling loads can also lead to standard heat pump system capacities, in heating mode, that are in excess of what the GHX can deliver. In such cases the "Insufficient GHX size" warning message appears in red characters beside the value for "Total standard heating capacity." In this situation, the model assumes that the heat pumps will be able to deliver only a fraction of their standard capacity and will require supplemental heat even though the heat pump system might have sufficient capacity to meet the building's demand.

Total standard cooling capacity

The model calculates the suggested total standard cooling capacity (kW) of the heat pumps. This value is obtained through the building's design cooling load and is corrected for the difference between standard rating conditions and actual building's design conditions. The cooling capacity is calculated for the building's block load. In a typical distributed heat pump system, the actual size of each zone's heat pump will be selected on that zone's peak load. Therefore, the summation of all installed heat pump cooling capacities will usually exceed the standard cooling capacity calculated by the model.

Units switch: The user can choose to express the total standard cooling capacity in different units by selecting among the proposed set of units: "MW," "million Btu/h," "boiler hp," "ton (cooling)," "hp," "W." This value is for reference purposes only and is not required to run the model.

The value for total standard cooling capacity depends on the "Design criteria" option chosen by the user.

<u>Heating load design criteria:</u> When the user selects "Heating" as the design criteria the heat pump system is sized to meet the maximum value between cooling or heating load under standard rating conditions. This selection assumes that when a GSHP system is installed, the cooling load must, at a minimum, be met by the installed heat pumps so that no other mechanical cooling equipment, other than supplemental heat rejection to compensate for undersized GHX, is required. If the building's heating requirement is higher than the cooling requirement, the heat pumps will be sized according to the building's heating demand. This may lead to standard cooling capacity far in excess of the actual building's requirements. If the heat pump system cooling capacity exceeds 150% of the building demand, the "Oversized" warning message in red characters appears beside the value for "Total standard cooling capacity." It is generally recommended not to design a GSHP system with cooling capacities that are far in excess of the actual building's demand. Oversizing the cooling equipment usually leads to control problems and unacceptable performances, especially with regard to dehumidification. Systems with advanced control options, such as variable speed compressors, can eliminate this constraint.

<u>Cooling load design criteria:</u> When the user selects "Cooling" as his design criteria the heat pumps are always sized to meet the entire cooling load.

Supplemental Heating and Heat Rejection System

This sub-section presents the characteristics of the supplemental heating and heat rejection system if it is required.

Suggested supplemental heating capacity

The model calculates the supplemental heating capacity (kW) that would be required for the selected GSHP system. Supplemental heating may be necessary for any of the following reasons:

- Heat pump system heating capacity is smaller than the building's heating requirements; and

- GHX is too small for the heat pump system heating capacity.

Units switch: The user can choose to express the supplemental heating capacity in different units by selecting among the proposed set of units: "MW," "million Btu/h," "boiler hp," "ton (cooling)," "hp," "W." This value is for reference purposes only and is not required to run the model.

Suggested supplemental heat rejection

The model calculates the supplemental heat rejection (kW) that would be required for the selected GSHP system to meet the building's cooling load. Supplemental heat rejection is necessary when the GHX is sized to meet the heating load and the building's cooling load is in excess of the heating load.

Units switch: The user can choose to express the supplemental heat rejection in different units by selecting among the proposed set of units: "MW," "million Btu/h," "boiler hp," "ton (cooling)," "hp," "W." This value is for reference purposes only and is not required to run the model.

Annual Energy Production

Items associated with calculating the annual energy production of a ground-source heat pump project are detailed below.

Heating

Electricity used

The model calculates the electricity used (MWh) by the heat pumps to meet the cooling requirements of the building. The "Electricity used" value includes the energy used by the heat pumps and the parasitic energy used by the circulating pumps for the ground loop in horizontal and vertical systems. For groundwater systems, the electricity used also includes the building loop circulating pumps power consumption and the electric energy required for the water well pumps. In all cases, the circulating pump power is assumed to be 17 W for each 1,000 W of capacity used by the heat pump system. The water well pumping power is calculated according to the pumping depth specified by the user.

This value is dependent on the building energy demand but also on the selected "Average heat pump efficiency." This value is transferred to the *Cost Analysis* worksheet where it is used to calculate the GSHP system energy cost.

Supplemental energy delivered

The model calculates the heating energy delivered (MWh) by the supplemental heating system. The model assumes that this energy is delivered by a system equivalent to the base case heating system.

GSHP heating energy delivered

The model calculates the heating energy delivered (MWh) by the GSHP system. The summation of the GSHP heating energy delivered and the supplemental energy used equals the building's heating energy demand calculated in the *Heating and Cooling Load* worksheet.

Units switch: The user can choose to express the energy delivered in different units by selecting among the proposed set of units: "GWh," "Gcal," "million Btu," "GJ," "therm," "kWh," "hp-h," "MJ." This value is for reference purposes only and is not required to run the model.

Seasonal heating COP

The model calculates GSHP system seasonal heating COP. This value takes into account parasitic energy used by circulating pumps and energy used by well pumps.

Cooling

Electricity used

The model calculates the electricity used (MWh) by the heat pumps to meet the heating requirements of the building. The "Electricity used" value includes the energy used by the heat pumps and the parasitic energy used by the circulating pumps for the ground loop in horizontal and vertical systems. For groundwater systems, the electricity used also includes the building loop circulating pumps power consumption and the electric energy required for the water well pumps. In all cases, the circulating pump power is assumed to be 17 W for each 1,000 W of capacity used by the heat pump system. The water well pumping power is calculated according to the pumping depth specified by the user.

This value is dependent on the building energy demand but also on the selected "Average heat pump efficiency." This value is transferred to the *Cost Analysis* worksheet where it is used to calculate the GSHP system annual energy cost.

GSHP cooling energy delivered

The model calculates the cooling energy delivered (MWh) by the GSHP system, including the supplemental heat rejection equipment. This value should be equal to the building's cooling energy demand calculated in the *Heating and Cooling Load* worksheet. The model does not consider any type of free cooling that could be used when estimating the cooling energy delivered. Free cooling can sometimes be accomplished by using cool outside air or cool ground loop fluid to offset the building's cooling demand without using the heat pumps directly.

Units switch: The user can choose to express the energy delivered in different units by selecting among the proposed set of units: "GWh," "Gcal," "million Btu," "GJ," "therm," "kWh," "hp-h," "MJ." This value is for reference purposes only and is not required to run the model.

Seasonal cooling COP

The model calculates GSHP system seasonal cooling COP. This value takes into account parasitic energy used by circulating pumps and well pumps.

Seasonal cooling EER

For the user's convenience, the seasonal COP value is also presented as the Energy Efficiency Ratio (EER). This value represents the ratio of total cooling energy delivered, in thousands of BTUs, to the total electrical energy used by the GSHP system, in kWh. The only difference between COP and EER is the units used for representing the total cooling energy used. A multiplication factor of 3.41 can be used to convert COP to EER. EER is the more common term used to present cooling system performance in North America.

Note: At this point, the user should complete the *Cost Analysis* worksheet.

Heating and Cooling Load Calculation

As part of the RETScreen Clean Energy Project Analysis Software, the *Heating and Cooling Load Calculation* worksheet is used to estimate the heating and cooling load as well as the energy demand for the building where the ground-source heat pump system is to be installed. The user will first enter the standard climatic and geographic information for the location of the GSHP project. The user will then have the choice of estimating the heating and cooling load by giving known load and consumption data or by entering the building physical characteristics. The user can consult the RETScreen Online Weather Database for more information. The user should return to the *Energy Model* worksheet after completing the *Heating and Cooling Load Calculation* worksheet.

Site Conditions

The site conditions associated with estimating the annual energy production of a ground-source heat pump project are detailed below.

Nearest location for weather data

The user enters the weather station location with the most representative weather conditions for the project. This information is given for reference purposes only. The user can consult the RETScreen Online Weather Database for more information.

Heating design temperature

The user enters the heating design temperature (°C), which represents the minimum temperature that has been measured for a frequency level of at least 1% over the year, for a specific area [ASHRAE, 1997]. The heating design temperature is used to determine the heating energy demand. The user can consult the RETScreen Online Weather Database for more information.

Typical values for heating design temperature range from approximately -40 to 15°C.

Note: The heating design temperature values found in the RETScreen Online Weather Database were calculated based on hourly data for 12 months of the year. The user might want to overwrite this value depending on local conditions. For example, where temperatures are measured at airports, the heating design temperature could be 1 to 2ºC milder in core areas of large cities.

Cooling design temperature

The user enters the cooling design temperature (ºC), which represents the minimum temperature that has been measured for a frequency level of at least 99% over the year, for a specific area [ASHRAE, 1997]. The cooling design temperature is used to calculate the annual peak block cooling load and is used, in conjunction with the heating design temperature and average summer daily temperature range, to estimate temperature bins. These values are in turn used to calculate the building's cooling energy requirements. The user can consult the RETScreen Online Weather Database for more information.

Typical values for cooling design temperature range from approximately 10 to 40°C.

Note: The cooling design temperature values found in the RETScreen Online Weather Database were calculated based on hourly data for 12 months of the year. The user might want to overwrite this value depending on local conditions. For example, where temperatures are measured at airports, the cooling design temperature could be 1 to 2ºC warmer in core areas of large cities.

Average summer daily temperature range

The user enters the average summer daily temperature range (ºC), which is the difference between the average daily maximum and average daily minimum temperatures in the warmest month, for a given location [ASHRAE, 1997]. The average summer daily temperature range is used in conjunction with heating and cooling design temperatures to estimate temperature bins used in calculating the building's heating and cooling energy requirements. The user can consult the RETScreen Online Weather Database for more information.

The range of typical values for the mean daily range is approximately 5 to 15°C.

Cooling humidity level

The user selects, from the drop-down list, one of three humidity levels: "Low," "Medium" and "High." Air-conditioning cooling loads are made up of two components called sensible and latent loads. Sensible loads refer to the capacity required to maintain the temperature of the indoor air while latent loads refer to the capacity required to maintain the humidity, or water content, of the indoor air. A typical air-conditioner can be designed with 60 to 80% of its capacity intended for sensible heat loads and 20 to 40% for latent, dehumidifying loads. Most of the latent load comes from fresh air makeup and from building occupants. The selected humidity level is used in the model to calculate the design latent heat load from fresh air makeup ventilation. The table below gives the ratio of latent to sensible load, for ambient air at design conditions, used in the model according to the humidity level selected.

Humidity Level	Latent to Sensible Heat Ratio	Relative Humidity for 30 °C Ambient
Low	0.5	40 %
Medium	1.5	50 %
High	2.5	60 %

Ambient Air Latent to Sensible Heat Ratio at Design Conditions

Users can obtain precise values for this ratio from sources such as national weather and/or environmental organisations. The user can also consult the NASA satellite database (accessed via the RETScreen Online Weather Database) for more information.

Latitude of project location

The user enters the geographical latitude (ºN) of the project site location in degrees measured from the equator. Latitudes north of the equator are entered as positive values and latitudes south of the equator are entered as negative values. The user can consult the RETScreen Online Weather Database for more information.

The latitude of the closest weather location can be pasted to the spreadsheet from the online weather database. If the user knows the latitude for the project location, this value should be entered in the spreadsheet by overwriting the pasted value.

This value is used in estimating the solar gains for the building. Solar gains are calculated following ASHRAE's recommended method [ASHRAE, 1997].

Note: If the "Energy use data" option in the "Available information" input cell is chosen, the latitude of the project location is not used in the model.

Mean earth temperature

The user enters the mean earth temperature (ºC). This value is used to calculate the ground temperature at the depth corresponding to the type of ground heat exchanger selected or to obtain the groundwater temperature. For depths greater than 15 m, the temperature (ground or water) is assumed to be equal to the mean earth temperature.

Depending upon location, the mean earth temperature typically ranges from below 0°C (for permafrost conditions) to 20°C. For example, a cooler location like Quebec City has a mean earth temperature of 7.4°C while a warmer location like Atlanta has a mean earth temperature of 16.8°C. If the mean earth temperature is very low, horizontal GCHP systems might be unable to function efficiently.

The RETScreen Online Weather Database does not provide this value for ground stations. However the NASA satellite database (accessed via the RETScreen Online Weather Database) does provide this value around the globe. Data for 28 Canadian and 111 US ground station locations are available from ASHRAE [ASHRAE, 1995]. The user can also obtain this temperature from local environment or weather monitoring stations.

Annual earth temperature amplitude

The user enters the annual earth temperature amplitude (ºC), which is defined as half the difference between the maximum and minimum of the earth temperature at the depth of measurement. It is used to calculate the earth maximum and minimum temperatures during the year.

Depending upon location, the annual earth temperature amplitude typically ranges from 5 to 20°C. A good first approximation for the annual earth temperature amplitude would be to take 30% of the amplitude between the "Heating design temperature" and the "Cooling design temperature" that are defined in the *Heating and Cooling Load Calculation* worksheet.

Canadian locations typically have an annual earth temperature amplitude of about 15°C while U.S. locations have a typical value of about 12°C. The temperature amplitude tends to be higher in cooler locations and lower in warmer ones. For example, a cooler location like Quebec City (which has a heating design temperature of -24°C and a cooling design temperature of 26.9°C) has an annual earth temperature amplitude of 15.6°C and a warmer location like Atlanta (which has a heating design temperature of -4.9°C and a cooling design temperature of 33°C) has an annual earth temperature amplitude of 10.6°C.

The RETScreen Online Weather Database does not provide this value for ground stations. However the NASA satellite database (accessed via the RETScreen Online Weather Database) does provide this value around the globe. Data for 28 Canadian and 111 US ground station locations are available from ASHRAE [ASHRAE, 1995]. The user can also obtain this data from local environmental or weather monitoring stations.

Depth of measurement of earth temperature

The user enters the depth at which the mean earth temperature and annual earth temperature amplitude were recorded. For the 28 Canadian and 111 US ground station data listed in ASHRAE [1995], this value should be set to 3 m (10 ft). For data provided by the NASA satellite database, this value should be set to 0 m.

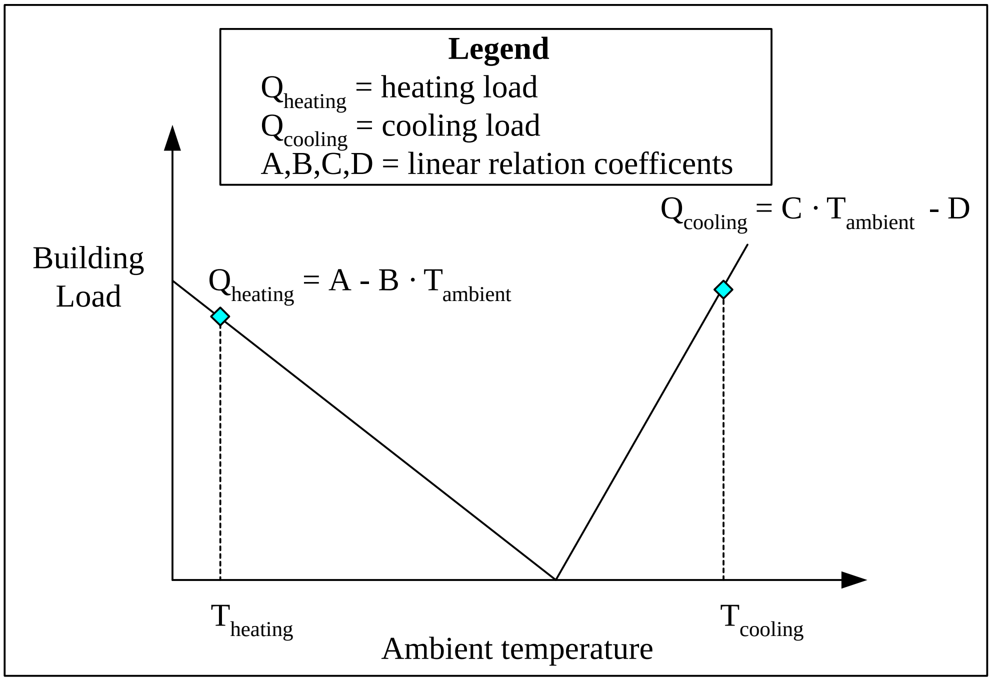
Building Heating and Cooling Load

The building characteristics associated with estimating the heating and cooling loads for the ground-source heat pump project are detailed below.

Type of building

The user selects the type of building intended for the GSHP system. There are three options available from the drop-down list: "Residential," "Commercial" and "Industrial." The selection will affect the way in which the model evaluates the building loads and energy demand. Selecting "Residential" building type will reduce the number of inputs required by the user.

Commercial and industrial buildings have specific features requiring other considerations than those used for residential buildings. Commercial and industrial buildings typically have much higher internal heat gains, higher gains from occupants, potentially higher solar gains and often more complex occupancy schedules. Given all the potential influences upon commercial/industrial building energy use, prediction of loads and energy demand is a very site-specific endeavour. The methodology selected for evaluating a buildings load and energy use is based on the modified bin method [ASHRAE, 1985] where all heat loads and gains are modelled using a linear relationship with ambient temperature as shown in the next figure.



Heating and Cooling Load Relationships

Some simplifying assumptions are made in the case of "Residential" buildings. They are all modelled as having 4 occupants, internal heat gains of 13 W/m² and window area corresponding to 15% of total floor area (excluding basement area).

Available information

The user selects the type of information available to characterise the thermal behaviour of the building where the GSHP system is to be installed. There are two options available: "Descriptive data" and "Energy use data." When "Energy use data" is selected, the same input is required regardless of the building type selected by the user.

Descriptive data: When the user selects this option, physical characteristics of the building are required for the model to calculate heating and cooling loads and energy demand.

Energy use data: When this option is selected, the building design heating and cooling load as well as the annual heating and cooling energy demand are entered by the user. From these values, the model estimates the relationships illustrated in the Heating and Cooling Load Relationships figure. The "Energy use data" option does not offer the same level of flexibility as the "Descriptive data" option; for example it cannot distinguish between occupied and unoccupied periods in a building.

Building floor area

The user enters the total floor area (m²) of all floors combined of the building that is heated and/or cooled, excluding the basement area. This value is the primary variable used in the model to calculate the load and energy demand of the building.

Typical values for total commercial building floor area will range from 500 to 9,000 m². A typical floor area value for an individual house is 140 m².

Numbers of floors

The user enters the number of floors for the building, excluding the basement. This value is used in the model to calculate the heat load/gain from the ceiling of the building.

The range of values for commercial buildings where GSHP are usually installed is between 1 and 6 floors. Individual houses usually have 1 to 2 floors.

Window area

The user selects the type of window area. The options from the drop-down list are: "Standard," "Above average" and "High." From this selection the model determines the total window area as a fraction of the total floor area, as presented in the table below. The type of windows considered in the model, for all cases, are clear insulated double glazed windows with a shading coefficient of 0.81 and a heat transfer coefficient of 3 W/(m²·°C) [ASHRAE, 1985].

Fenestration Level	Ratio of Window Area over Floor Area
Standard	0.15
Above average	0.25
High	0.35

Fenestration Levels

A typical selection for commercial buildings is "Standard" fenestration level.

Insulation level

The user selects the type of insulation level. The options from the drop-down list are: "Low," "Medium" and "High." From this selection the model determines the heat transfer coefficient for the walls and roof of the building, for all building types. Additionally, this selection determines the air infiltration rate and basement insulation level for residential buildings. The different values corresponding to each insulation level are presented in the table below.

Insulation Level	Wall U-Value $W/(m^2 \cdot °C)$	Roof U-Value $W/(m^2 \cdot °C)$	Basement U-value[1] $W/(m^2 \cdot °C)$	Infiltration Rate[1] ACH[2]
Low	0.50	0.33	0.50	0.50
Medium	0.29	0.20	0.33	0.25
High	0.20	0.11	0.25	0.10

(1: Residential buildings only; 2: ACH = air change per hour)

Insulation Levels

Residential buildings in the northern regions of North America built before 1970 will generally have "Low" insulation levels unless improvements have been made to the building envelope. Houses built between 1970 and 1990 usually have "Medium" insulation levels whereas those built after 1990 will have "High" insulation levels.

Commercial buildings will tend to have somewhat lower insulation levels than residential buildings of the same age. Insulation levels for industrial buildings can vary widely but are often lower than either residential or commercial.

Occupancy type

The user selects the occupancy type. The options from the drop-down list are: "Daytime," "Night time" and "Continuous." This selection determines the amount of time during which the building is occupied. "Daytime" occupancy corresponds to a schedule of 07:00-19:00 while "Nighttime" occupancy is from 19:00-07:00. The model uses these schedules to calculate the sensible and latent heat gains from occupants in the building as well as fresh air ventilation rates. Each occupant is considered as having 75 W of sensible and 75 W of latent heat losses and requires 20 L/s of fresh air. For all commercial buildings, the occupant density is 1 person per 10 m² while industrial buildings have a density of 1 person per 50 m².

Typical commercial buildings have "Daytime" occupancy. Industrial occupancy type can vary from "Daytime" to "Continuous." "Nighttime" occupancy is less frequent but can sometimes apply to commercial buildings.

Equipment and lighting usage

The user selects the type of equipment and lighting use. The options from the drop-down list are: "Light," "Moderate" and "Heavy." This selection determines the amount of internal heat gains for the building. Commercial and industrial buildings are characterised by much higher internal heat gains than residential ones. The sources of these internal gains can be very numerous but lighting and office equipment, also called plug loads, usually amount for the majority of internal heat gains in commercial buildings. Industrial buildings necessitate a case by case analysis since their sources of internal gains can be quite variable (compressors, motors, process equipment, etc.). The model uses the selected heat gains in combination with the type of occupancy to evaluate the total daily internal heat gains. The table below presents the heat loads associated with each of the three available options.

Equipment & Lighting Usage	Equipment Heat Load W/m²	Lighting Heat Load W/m²
Light	5	5
Moderate	10	15
Heavy	20	25

Internal Heat Gain Levels

The typical values of equipment and lighting usage will vary depending on the use of the building under consideration. For example, typical office buildings have "Moderate" equipment and lighting usage, schools will have "Light" usage while hospitals will have "Heavy" usage. Industrial buildings will generally have "Moderate" to "Heavy" equivalent internal gains. The term "equivalent" is used in the case of industrial buildings since their actual sources can be different than office equipment or lighting. However, the user should evaluate, whenever possible, the internal gains per m² and select the option that best matches these gains.

Foundation type

The user selects the foundation type. The two options in the drop-down list are: "Full basement" and "Slab on grade." This selection is used in the model to evaluate the foundation heat losses for residential buildings. Selecting "Full basement" leads to higher heating loads but has a smaller impact on cooling loads.

Heat loss through the foundation is the prime heat source for simple slab on grade with ground frost heat pump (GFHP) chilled in permafrost. Heat gain to the ground from building foundations must be considered when calculating ground collector of chilled foundations for buildings on permafrost. Heat must be extracted at the same rate as foundation heat loss to maintain a constant ground temperature and long term balance.

Annual cooling energy demand

If the user selected the "Energy use data" option, then the value for "Annual cooling energy demand" is entered directly by the user.

The annual cooling energy demand is the amount of energy required to cool the building. This value is used to generate the equations shown in the Heating and Cooling Load Relationships which are then used to recalculate the building's actual cooling energy use. The annual cooling energy demand is used in combination with the base case air-conditioner seasonal Coefficient Of Performance (COP) to calculate the baseline cost for cooling.

Units switch: The user can choose to express the energy in different units by selecting among the proposed set of units: "GWh," "Gcal," "million Btu," "GJ," "therm," "kWh," "hp-h," "MJ." This value is for reference purposes only and is not required to run the model.

Note: At this point, the user should return to the *Energy Model* worksheet.

Building design heating load

If the user selected the "Descriptive data" option, the model calculates the building's design heating load, based on the "Heating design temperature" (entered in the site conditions section) and the various building parameters selected by the user.

The model uses the design heating load to determine the suggested heat pump capacity, in combination with the design cooling load. The calculated load corresponds to the block heating load for all types of buildings. The block load refers to the peak load occurring in a building at a specific time under design temperature conditions. For example, in a building with many zones (independent thermostats), the summation of each zone's heating load can exceed the block heating load since these loads might not happen concurrently (for occupancy, exposure, solar gain or other reasons). For a residential building, block heating load is usually the summation of all room loads under the same design conditions.

Typical values for building heating load range from 20 to 120 W/m^2.

Units switch: The user can choose to express the load in different units by selecting among the proposed set of units: "MW," "million Btu/h," "boiler hp," "ton (cooling)," "hp," "W." This value is for reference purposes only and is not required to run the model.

Building heating energy demand

If the user selected the "Descriptive data" option, the model calculates the building's heating energy demand, based on parameters selected by the user.

The building's annual heating energy demand is the amount of energy required to heat the building. This value is used to generate the equations shown in the Heating and Cooling Load Relationships figure which are then used to recalculate the building's actual heating energy use.

The "Building heating energy demand" is used in combination with the base case heating system seasonal efficiency to calculate the baseline cost for heating. Typical commercial buildings in northern regions of North America will use between 50 to 250 kWh/m²/yr. Residential buildings will use approximately 120 kWh/m²/yr for heating or approximately 60% of their total annual energy use.

Units switch: The user can choose to express the energy in different units by selecting among the proposed set of units: "GWh," "Gcal," "million Btu," "GJ," "therm," "kWh," "hp-h," "MJ." This value is for reference purposes only and is not required to run the model.

Building design cooling load

If the user selected the "Descriptive data" option the model calculates the building's design cooling load, based on the "Cooling design temperature" (entered in the site conditions section) and the various building parameters selected by the user.

The model uses the design cooling load to determine the suggested heat pump capacity, in combination with the design heating load. The calculated load corresponds to the block cooling load for each type of building selected. The block load refers to the peak load occurring in a building at a specific time under design temperature conditions. For example, in a building with many zones (independent thermostats), the summation of each zone's cooling load can exceed the block cooling load since these loads might not happen concurrently (for occupancy, exposure, solar gain or other reasons). For a residential building, block cooling load is usually the summation of all room loads under the same design conditions.

Cooling loads are project specific and depend on all building parameters selected in addition to the site conditions and the building's use. The values will generally vary from 50 W/m² for residential buildings in cool climates to 200 W/m² or more for commercial buildings in hot climate with high internal gains.

Units switch: The user can choose to express the load in different units by selecting among the proposed set of units: "MW," "million Btu/h," "boiler hp," "ton (cooling)," "hp," "W." This value is for reference purposes only and is not required to run the model.

Building cooling energy demand

If the user selected the "Descriptive data" option, the model calculates the building's cooling energy demand, based on parameters selected by the user.

The building's annual cooling energy demand is the amount of energy required to cool the building. This value is used to generate the equations shown in the Heating and Cooling Load Relationships figure which are then used to recalculate the building's actual cooling energy use. The "Building cooling energy demand" value is used in combination with the base case air-conditioner seasonal Coefficient Of Performance (COP) to calculate the baseline cost for cooling.

Units switch: The user can choose to express the energy in different units by selecting among the proposed set of units: "GWh," "Gcal," "million Btu," "GJ," "therm," "kWh," "hp-h," "MJ." This value is for reference purposes only and is not required to run the model.

Note: At this point, the user should return to the *Energy Model* worksheet.

Design heating load

If the user selected the "Energy use data" option, then the value for "Design heating load" is entered directly by the user. This value will depend on the design temperature for the specific location and on the building insulation efficiency.

The model uses the design heating load to determine the suggested heat pump capacity, in combination with the design cooling load. The entered load corresponds to the block heating load for all types of buildings. The block load refers to the peak load occurring in a building at a specific time under design temperature conditions. For example, in a building with many zones (independent thermostats), the summation of each zone's heating load can exceed the block heating load since these loads might not happen concurrently (for occupancy, exposure, solar gain or other reasons). For a residential building, block heating load is usually the summation of all room loads under the same design conditions.

Typical values for building heating load range from 20 to 120 W/m^2.

Units switch: The user can choose to express the load in different units by selecting among the proposed set of units: "MW," "million Btu/h," "boiler hp," "ton (cooling)," "hp," "W." This value is for reference purposes only and is not required to run the model.

Annual heating energy demand

If the user selected the "Energy use data" option, then the value for "Annual heating energy demand" is entered directly by the user.

The annual heating energy demand is the amount of energy required to heat the building. This value is used to generate the equations shown in the Heating and Cooling Load Relationships figure which are then used to recalculate the building's actual heating energy use.

The annual heating energy demand is used in combination with the base case heating system seasonal efficiency to calculate the baseline cost for heating. Typical commercial buildings in northern regions of North America will use between 50 to 250 kWh/m²/yr. Residential buildings will use approximately 120 kWh/m²/yr for heating or approximately 60% of their total annual energy use.

Units switch: The user can choose to express the energy in different units by selecting among the proposed set of units: "GWh," "Gcal," "million Btu," "GJ," "therm," "kWh," "hp-h," "MJ." This value is for reference purposes only and is not required to run the model.

Design cooling load

If the user selected the "Energy use data" option, then the value for "Design cooling load" is entered directly by the user. This value will depend on the design temperature for the specific location and on building insulation efficiency.

The model uses the design cooling load to determine the suggested heat pump capacity, in combination with the design heating load. The entered load corresponds to the block cooling load for each type of building selected. The block load refers to the peak load occurring in a building at a specific time under design temperature conditions. For example, in a building with many zones (independent thermostats), the summation of each zone's cooling load can exceed the block cooling load since these loads might not happen concurrently (for occupancy, exposure, solar gain or other reasons). For a residential building, block cooling load is usually the summation of all room loads under the same design conditions.

Cooling loads are project specific and depend on all building parameters selected in addition to the site conditions and the building's use. The values will generally vary from 50 W/m² for residential buildings in cool climates to 200 W/m² or more for commercial buildings in hot climate with high internal gains.

Units switch: The user can choose to express the load in different units by selecting among the proposed set of units: "MW," "million Btu/h," "boiler hp," "ton (cooling)," "hp," "W." This value is for reference purposes only and is not required to run the model.

Cost Analysis[1]

As part of the RETScreen Clean Energy Project Analysis Software, the *Cost Analysis* worksheet is used to help the user estimate costs associated with a ground-source heat pump project. These costs are addressed from the initial, or invesment, cost standpoint and from the annual, or recurring, cost standpoint. The user may refer to the RETScreen Online Product Database for supplier contact information in order to obtain prices or other information required.

The selection of a cost-effective GSHP system will depend of many factors, although some guidelines can be used to orient this selection process.

- GWHPS: When groundwater is available in sufficient quantities with adequate quality, and environmental regulations permit this type of installation, such a system should be considered. GWHP systems will generally be more financially attractive for larger buildings since the cost of the groundwater wells (supply and injection) does not rise linearly with capacity.
- Vertical GCHPs: Vertical Ground-coupled heat pump systems are usually limited to buildings with six stories or less due to the static pressure limitations for the GHX pipes [ASHRAE, 1995]. It is possible to use stronger GHX pipes but they are more expensive and difficult to work with. Generally, when a system's cooling capacity exceeds 350 to 700 kW, the surface of a typical parking lot will not be sufficient to accommodate the GHX without supplemental heat rejection. Vertical GCHPs are common in residential applications, particularly where drilling costs are low.
- Horizontal GCHPs: Horizontal Ground-coupled heat pump systems do not have the height limitations and pipe requirements imposed on vertical systems. However, they require larger land area and, generally, when the system's cooling capacity exceeds 35 to 70 kW, the surface of a typical parking lot will not be sufficient to accommodate the GHX without supplemental heat rejection. Horizontal systems can usually offer the lowest initial costs but will also have lower seasonal efficiencies because of lower ground temperature. These characteristics are often well suited for residential applications.

The most cost-effective installations of ground-source heat pump systems normally occur in new construction, where the building's design can be planned to maximise GSHP system benefits, as mentioned in the background section of this manual. Retrofit installations should also be considered but may have longer payback periods. In case of retrofit situations where the building heating/cooling system is to be upgraded/replaced, the financial benefits of GSHP projects will improve due to the "credits" described below.

For all ground-source heat pump projects, "credits" for material and labour costs that would have been spent on a "conventional" heating and cooling system have to be accounted for. The user

[1] A reminder to the user that the range of values for cost items mentioned in the manual are for a 2000 baseline year in Canadian dollars. Some of this data may be time sensitive so the user should verify current values where appropriate. (The approximate exchange rate from Canadian dollars to United States dollars and to the Euro was 0.68 as of January 1, 2000).

will have to determine these initial costs in order to obtain a plausible financial evaluation of the GSHP project. These credits will also apply to engineering and design, some development costs and some annual costs. Grey input cells are provided to allow project decision-makers to keep track of credit items when preparing the project cost analysis.

Type of analysis

The user selects the type of analysis from the drop-down list. For a "Pre-feasibility analysis," less detailed and lower accuracy information is typically required while for a "Feasibility analysis," more detailed and higher accuracy information is usually required.

To put this in context, when funding and financing organisations are presented with a request to fund an energy project, some of the first questions they will likely ask are "how accurate is the estimate, what are the possibilities for cost over-runs and how does it compare financially with other options?" These are very difficult to answer with any degree of confidence, since whoever prepared the estimate would have been faced with two conflicting requirements:

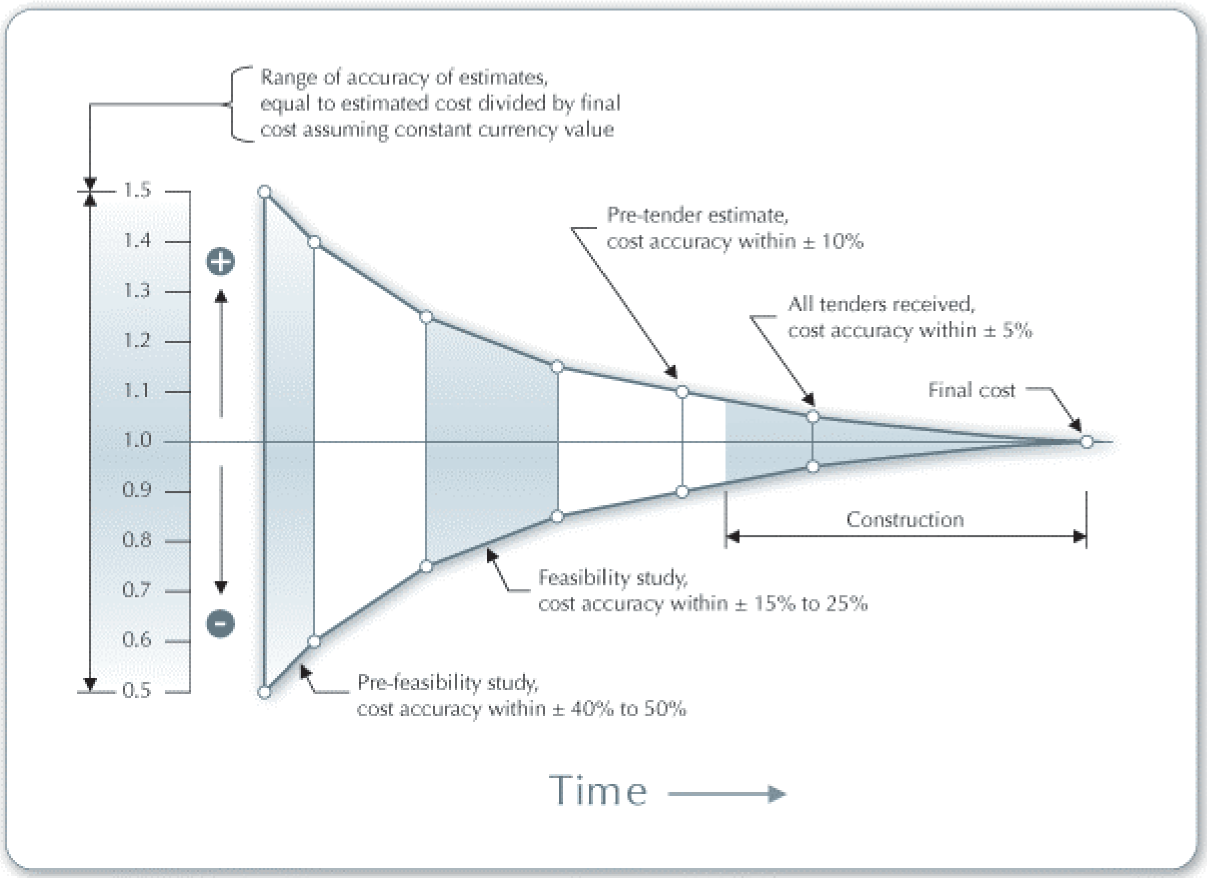
- Keep the project development costs low in case funding cannot be secured, or in case the project proves to be uneconomic when compared with other energy options.
- Spend additional money and time on engineering to more clearly delineate potential project costs and to more precisely estimate the amount of energy produced or energy saved.

To overcome, to some extent, such conflicts, the usual procedure is to advance the project through the following four stages:

- Pre-feasibility analysis
- Feasibility analysis
- Development (including financing) and engineering
- Construction and commissioning

Each stage could represent an increase of a magnitude or so in expenditure and a halving of the uncertainty in the project cost-estimate. This process is illustrated, for hydro projects, in the Accuracy of Project Cost Estimates figure [Gordon, 1989].

At the completion of each step, a "go or no go" decision is usually made by the project proponent as to whether to proceed to the next step of the development process. High quality, but low-cost, pre-feasibility and feasibility studies are critical to helping the project proponent "screen out" projects that do not make financial sense, as well as to help focus development and engineering efforts prior to construction. The RETScreen Clean Energy Project Analysis Software can be used to prepare both the initial pre-feasibility analysis and the more detailed feasibility analysis.



Accuracy of Project Cost Estimates [Gordon, 1989]

Currency

To perform a RETScreen project analysis, the user may select a currency of their choice from the "Currency" cell in the *Cost Analysis* worksheet.

The user selects the currency in which the monetary data of the project will be reported. For example, if the user selects "$," all monetary related items are expressed in $.

Selecting "User-defined" allows the user to specify the currency manually by entering a name or symbol in the additional input cell that appears adjacent to the currency switch cell. The currency may be expressed using a maximum of three characters ($US, £, ¥, etc.). To facilitate the presentation of monetary data, this selection may also be used to reduce the monetary data by a factor (e.g. $ reduced by a factor of a thousand, hence k$ 1,000 instead of $ 1,000,000).

If "None" is selected, all monetary data are expressed without units. Hence, where monetary data is used together with other units (e.g. $/kWh) the currency code is replaced with a hyphen (-/kWh).

The user may also select a country to obtain the International Standard Organisation (ISO) three-letter country currency code. For example, if Afghanistan is selected from the currency switch drop-down list, all project monetary data are expressed in AFA. The first two letters of the country currency code refer to the name of the country (AF for Afghanistan), and the third letter to the name of the currency (A for Afghani).

For information purposes, the user may want to assign a portion of a project cost item in a second currency, to account for those costs that must be paid for in a currency other than the currency in which the project costs are reported. To assign a cost item in a second currency, the user must select the option "Second currency" from the "Cost references" drop-down list cell.

Some currency symbols may be unclear on the screen (e.g. €); this is caused by the zoom settings of the sheet. The user can then increase the zoom to see those symbols correctly. Usually, symbols will be fully visible on printing even if not fully appearing on the screen display.

Cost references

The user selects the reference (from the *Cost Analysis* worksheet) that will be used as a guideline for the estimation of costs associated with the implementation of the project. This feature allows the user to change the "Quantity Range" and the "Unit Cost Range" columns. The options from the drop-down list are: "Canada - 2000," "None," "Second currency" and a selection of 8 user-defined options ("Enter new 1," "Enter new 2," etc.).

If the user selects "Canada - 2000" the range of values reported in the "Quantity Range" and "Unit Cost Range" columns are for a 2000 baseline year, for projects in Canada and in Canadian dollars. This is the default selection used in the built-in example in the original RETScreen file.

Selecting "None" hides the information presented in the "Quantity Range" and "Unit Cost Range" columns. The user may choose this option, for example, to minimise the amount of information printed in the final report.

If the user selects "Second currency" two additional input cells appear in the next row: "Second currency" and "Rate: 1st currency/2nd currency." In addition, the "Quantity Range" and "Unit Cost Range" columns change to "% Foreign" and "Foreign Amount," respectively. This option allows the user to assign a portion of a project cost item in a second currency, to account for those costs that must be paid for in a currency other than the currency in which the project costs are reported. Note that this selection is for reference purposes only, and does not affect the calculations made in other worksheets.

If "Enter new 1" (or any of the other 8 selections) is selected, the user may manually enter quantity and cost information that is specific to the region in which the project is located and/or for a different cost base year. This selection thus allows the user to customise the information in the "Quantity Range" and "Unit Cost Range" columns. The user can also overwrite "Enter new 1" to enter a specific name (e.g. Japan - 2001) for a new set of unit cost and quantity ranges. The user may also evaluate a single project using different quantity and cost ranges; selecting a new range reference ("Enter new 1" to "Enter new 8") enables the user to keep track of different cost scenarios. Hence the user may retain a record of up to 8 different quantity and cost ranges that can be used in future RETScreen analyses and thus create a localised cost database.

Second currency

The user selects the second currency; this is the currency in which a portion of a project cost item will be paid for in the second currency specified by the user. The second currency option is activated by selecting "Second currency" in the "Cost references" drop-down list cell. This second unit of currency is displayed in the "Foreign Amount" column.

If the user selects "$," the unit of currency shown in the "Foreign Amount" column is "$."

Selecting "User-defined" allows the user to specify the currency manually by entering a name or symbol in the additional input cell that appears adjacent to the currency switch cell. The currency may be expressed using a maximum of three characters ($US, £, ¥, etc.). To facilitate the presentation of monetary data, this selection may also be used to reduce the monetary data by a factor (e.g. $ reduced by a factor of a thousand, hence k$ 1,000 instead of $ 1,000,000).

If "None" is selected, no unit of currency is shown in the "Foreign Amount" column.

The user may also select a country to obtain the International Standard Organisation (ISO) three-letter country currency code. For example, if Afghanistan is selected from the currency switch drop-down list, the unit of currency shown in the "Foreign Amount" column is "AFA." The first two letters of the country currency code refer to the name of the country (AF for Afghanistan), and the third letter to the name of the currency (A for Afghani).

Some currency symbols may be unclear on the screen (e.g. €); this is caused by the zoom settings of the sheet. The user can then increase the zoom to see those symbols correctly. Usually, symbols will be fully visible on printing even if not fully appearing on the screen display.

Rate: 1st currency/2nd currency

The user enters the exchange rate between the currency selected in "Currency" and the currency selected in "Second currency." The exchange rate is used to calculate the values in the "Foreign Amount" column. Note that this selection is for reference purposes only, and does not affect the calculations made in other worksheets.

For example, the user selects the Afghanistan currency (AFA) as the currency in which the monetary data of the project is reported (i.e. selection made in "Currency" input cell) - this is the 1st currency. The user then selects United States currency (USD) from the "Second currency" input cell - this is the 2nd currency. The user then enters the exchange rate in the "Rate: AFA/USD" input cell i.e. the amount of AFA needed to purchase 1 USD. Using this feature the user can then specify what portion (in the "% Foreign" column) of a project cost item's costs will be paid for in USD.

% Foreign

The user enters the percentage of an item's costs that will be paid for in the second currency. The second currency is selected by the user in the "Second currency" cell.

Foreign Amount

The model calculates the amount of an item's costs that will be paid for in the second currency. This value is based on the exchange rate and the percentage of an items costs that will be paid for in the second currency, as specified by the user.

Initial Costs

The initial costs associated with the implementation of a ground-source heat pump project are detailed below. The major categories include costs for preparing a feasibility study, performing the project development functions, completing the necessary engineering, purchasing and installing the energy equipment, construction of the balance of system and costs for any other miscellaneous items.

Feasibility Study

Once a potentially cost-effective ground-source heat pump project has been identified through the RETScreen pre-feasibility analysis process, a more detailed feasibility analysis study may be required. This is particularly the case for larger projects, typically larger than 100 kW. Feasibility studies typically include such items as a site investigation, a soil/hydrology assessment, an environmental assessment, a preliminary project design, including loop sizing and layout, a detailed cost estimate, and a final report. Feasibility study project management and travel costs are also normally incurred. These costs are detailed in the section below.

For small projects, such as small commercial systems, the cost of the feasibility study, relative to the cost of the ground-source heat pump system, may not be justified. In this case the project proponent may choose to go directly to the engineering stage (combining some steps from the feasibility and development stages).

Note: The RETScreen Clean Energy Project Analysis Software can also be used to prepare the Feasibility Study.

Site investigation

When a GSHP system is being considered for an existing building, a site visit may be required to evaluate the site and building conditions and their suitability for installing the proposed GSHP system. For new construction, this visit may also be required to evaluate the potential of the terrain to receive the earth connection (GHX or water wells).

The visits should be conducted with a GSHP project expert and should allow for the refinement of assumptions made during the pre-feasibility study. During the visits elements such as building physical characteristics (areas, insulation levels, etc.), documentation of the existing building heating and cooling systems (for retrofit applications), location of the potential earth loop and the owner's right of access to the proposed GHX location or to the groundwater resources should be documented. Site visit time includes the time required to arrange meetings, survey the site, obtain the necessary information and any travel time (but not travel expenses - see "Travel and accommodation" below).

For a retrofit project, the time required for a site survey, detailed building and site analysis varies according to the size of the building involved and the complexity of the existing heating and cooling system. Obtaining energy consumption data can sometimes add to the time required. The time required to collect the data prior to and during the site visit typically falls between 14 to 21 hours (travel time extra) at a rate of approximately $40/h to $100/h. For new construction, where building data can be extracted from architectural or engineering drawings, the time required typically falls between 7 to 14 hours (travel time extra) at the same rate.

Site investigations involving GSHPs in permafrost-related applications are usually limited to particular applications including building foundation chilling or specialised energy transfer projects. Such projects are normally incorporated in new construction feasibility studies and require case to case cost evaluation.

Soil/hydrology assessment

While most sites are suitable for GSHP system installations, in some cases specific land or subsurface features may result in increased equipment and/or installation costs. Furthermore, in some cases a site may be judged inappropriate for any type of GSHP system. For these reasons, a soil or hydrologic assessment, depending on the proposed GSHP system type, is needed. The information collected during the assessment, and its cost, will depend on the GSHP system type.

GWHP systems will usually require the most extensive evaluation. In this case, a hydrogeological assessment has to be conducted. A typical study should be conducted by a qualified hydrogeologist and should include:

- Establishing all regulations pertinent to the installation of a groundwater system at the proposed site;
- Reviewing existing geological/hydrogeological information for the site location; and
- Subsurface investigation through test wells.

The number of test wells required is linked to the size of the proposed GWHP system. For buildings less than 3,000 m², one test well is sufficient. For larger buildings, at least two test wells should be drilled.

For GCHP systems, a geotechnical investigation can be sufficient to determine the site's suitability. However, for vertical GCHP systems, it is often valuable to have a hydrogeological investigation done. The information from the latter survey will also insure that the groundwater quality is documented prior to the installation of the vertical GCHP. This should help prevent the system's owner from being held responsible for any groundwater contamination that predated the vertical GCHP installation. A geotechnical survey for vertical GCHPs consists of test holes drilled at least 15 m below the deepest planned GHX hole. For buildings of less than 3,000 m², one test hole is sufficient. For larger buildings, two test holes should be drilled. Horizontal system geotechnical investigations consist of test pits to provide knowledge of the subsurface conditions. For GHX of less than one hectare in area, a minimum of four test pits is recommended. For GHX larger than two hectares, two test pits per hectare is recommended [ASHRAE, 1995].

The time required to carry out a soil/hydrology assessment is typically 60 to 120 hours for GWHP systems, 35 to 80 hours for vertical GCHP systems and 20 to 50 hours for horizontal GCHP systems. Typical rates for hydrogeologists or geological technicians range from $40/h to $100/h. In addition to these costs, the user should add the cost of drilling wells or boreholes or trenching of test pits.

Should soil/hydrologic assessments for isolated areas and permafrost zones be required, the typical assessment rate equals 1 to 1.5 times the conventional rate. Refer to the travel and accommodation section for additional costs. As is the case for site investigation, hydrogeological assessment may only be carried out when climatic conditions permit it.

Preliminary design

A preliminary design that combines the above information is required. In order to reduce costs, the preliminary design should be done using standard methods and existing computer design tools. The preliminary design should allow for more precise estimates of the building's loads, a zone by zone selection for the heat pumps and a more precise determination of the GHX size or groundwater flow requirement.

The cost for preparing a preliminary design will be strongly dependent on a building's size and heating and cooling system's complexity. The time required to complete the design can range from 5 to 40 hours at a rate of approximately $60/h to $100/h.

Preliminary design using GSHP in permafrost-related applications usually is limited to specific applications. Such design requires case to case evaluation. Required time will vary while the approximate rate should remain the same.

Detailed cost estimate

The detailed cost estimate for the proposed GSHP project is based on the results of the preliminary design and other investigations carried out during the feasibility study. The cost of preparing the detailed cost estimate is calculated based on an estimate of the time required by experts to complete the necessary work.

Engineering services for completing a detailed GSHP project cost estimate will range from $60/h to $100/h. The number of hours required to complete the cost estimate will range between 7 to 35 hours depending on the size of the project and the acceptable level of risk.

Report preparation

A summary report should be prepared which describes the feasibility study, its findings and recommendations. The written report will contain data summaries, charts, tables and illustrations that clearly describe the proposed project. This report should be in sufficient detail regarding costs, performance and risks to enable project lenders and other decision-makers to evaluate the merits of the project.

The cost of the report preparation is calculated based on an estimate of the time required by a professional to complete the necessary work, and should also include the time required to manage the overall feasibility study preparation. Typically, 16 to 32 hours are required at a rate of between $60/h to $100/h.

Travel and accommodation

This cost item includes all travel related costs (excluding time) required to prepare all sections of the feasibility study by the various members of the feasibility study team. These expenses include such items as airfare, car rental, lodging and per diem rates for each trip required. For local travel, a supplier may not charge for time and expenses. For isolated areas, where air travel is time consuming and expensive, it may be better to include more than one potential project in the feasibility study to spread the site visit costs over a number of projects and not just one building.

In case of isolated areas, particularly permafrost zones, rates for air travel will vary considerably. Airfares are typically twice (up to ten times in isolated permafrost areas) those for similar distances in populated areas. Since travel is a large component of the cost of doing work in isolated areas and the range of cost so variable, it is advisable to contact a travel agent with experience in arranging such travel. Accommodation rates are typically twice the going rate for modest accommodation in populated areas. Typical rates for modest hotel rooms can range from $180 to $250 per day in the more isolated areas (per diem can vary between $35 to $70).

Other

These input cells are provided to allow the user to enter cost or credit items that are not included in the information provided in the above cost category. The user must enter a positive numerical value in the "Unit Cost" column.

A cost item may be entered in the grey input cell as "Other." The user then selects "Cost" from the drop-down list in the unit column. The user can input both a quantity amount and unit cost. This item is provided to allow for project, technology and/or regional differences not specifically covered in the generic information provided.

A credit item may be entered in the grey input cell as "Credit." The user then selects "Credit" from the drop-down list in the unit column. The project may be credited for material and/or labour costs that would have been spent on the base case, or conventional, energy system. The user can input both a quantity amount and unit cost. Note that the credit item is expressed as a negative value in the "Amount" column.

Development

Once a potential ground-source heat pump project has been identified through the feasibility study to be desirable to implement, project development activities may follow. For some projects, the feasibility study, development and engineering activities may proceed in parallel, depending on the risk and return acceptable to the project proponent.

For GSHP projects, there are a number of possible project developers. Currently, a common approach is for the client to be the building owner with the developer being a local GSHP supplier who provides complete design/build services. The general contractor may also be the developer, purchasing the GSHP system on behalf of the building owner. It is also possible that an Energy Services Company (ESCO) could be the project developer, and take charge of financing and installing the GSHP system and in return receive a portion of the annual energy savings. Estimating the costs of the development phase will depend on the particular development arrangement established. Items here include costs for permits and approvals, land survey, project financing, development phase project management and any development related travel costs. These costs are detailed in the section below.

Permits and approvals

A number of permits and approvals may be required from local authorities for the construction of the project. The cost of acquiring the necessary permits and approvals is calculated based on an estimate of the time required to complete the necessary work. These agencies may include local building and electrical inspectors, fire safety inspectors, and an environmental regulating authority.

In certain isolated areas, local native band council approval may also be required. Added relative costs are minor, however time needed to obtain such approvals has to be accounted for.

The time required depends on the number of agencies involved and what is specifically required to meet their rules and regulations. The time requirement is typically 4 to 12 hours at rates ranging from $40/h to $100/h for project development staff. The user can also add to the number of hours, or unit costs, an amount to cover the actual cost of the permit. Permit costs are usually minor relative to the total project cost.

Land survey

Given the potentially large terrain occupied by the GHX in some GSHP systems, a land survey may be required to insure that the GHX is located on premises belonging to the building's owner.

Typically, the costs to survey one simple lot of 1 to 10 hectares are of the order of $750. The cost may vary if travel and accommodation costs are billed by the surveyor. Typically, a land survey will take between 0 to 30 hours at a rate of $50/h to $80/h.

Land surveying in isolated/permafrost areas may typically take the same amount of time, however travel costs, travel time and accommodation expenses have to be considered. Rates of $80 to $120 may apply.

Project financing

The time and effort required to arrange project financing will vary depending upon the project developer and client relationship. In most cases, where the client is the building owner and the developer is the product supplier, the project financing costs attributable to the project are minimal. The building owner will usually finance the project out of capital or O&M budgets and the product supplier will provide in-kind support as required to help arrange the client project financing. In the case of an ESCO developed project much more effort will likely be required to arrange financing, negotiate an energy services contract with the building owner and prepare legal documents.

The cost to obtain project financing will range from 8 to 24 hours at a rate of between $60/h to $180/h. The lower end of the range is for building owner/product supplier developed projects. The higher end of the range applies to ESCO type projects.

Project management

The project management cost item should cover the estimated expenses of managing all phases of the development of the project (excluding construction supervision).

The elapsed time for the development of a ground-source heat pump project is relatively short. Depending on the project scale, an entire project can be easily developed within a year with actual construction time only taking a few weeks. The project development management time will usually take between 20 to 40 hours at rates of between $50/h to $100/h.

Travel and accommodation

This cost item includes all travel related costs (excluding time) required to develop the project.

Other

These input cells are provided to allow the user to enter cost or credit items that are not included in the information provided in the above cost category. The user must enter a positive numerical value in the "Unit Cost" column.

A cost item may be entered in the grey input cell as "Other." The user then selects "Cost" from the drop-down list in the unit column. The user can input both a quantity amount and unit cost. This item is provided to allow for project, technology and/or regional differences not specifically covered in the generic information provided.

A credit item may be entered in the grey input cell as "Credit." The user then selects "Credit" from the drop-down list in the unit column. The project may be credited for material and/or labour costs that would have been spent on the base case, or conventional, energy system. The user can input both a quantity amount and unit cost. Note that the credit item is expressed as a negative value in the "Amount" column.

Engineering

The engineering phase includes costs for the GSHP system design, tenders and contracting, and construction supervision. If the project is awarded on a design/build basis, then all of these costs would be included in prices provided by the equipment supplier or contractor responsible for the project. If the project is awarded by tender based on specifications prepared by a consultant, then there will be engineering charges from the consultant overseeing the project and perhaps the equipment supplier.

GSHP system design

The GSHP system design includes the time required to design the GHX, or water wells, detailed layout, piping, pumping and electrical arrangement as well as the detailed design of the heat pump system and any modifications to an existing building's systems. This step includes preparing design drawings and specifications. For small GSHP systems with standard configurations, generic installation drawings can sometimes be used to minimise this cost.

The time required to prepare the system's design and detailed drawings falls between 5 to 80 hours. The lower end of the range corresponds to small commercial systems, barely larger than residential installations while the upper end of the scale corresponds to larger commercial systems. GSHP design fees usually range from $40/h to $100/h.

GSHP design used in permafrost-related applications usually is limited to specialised applications. Such design requires case to case evaluation. Required time will vary while approximate rates should remain the same.

Tenders and contracting

Upon completion of the various engineering tasks, tender documents may be required by the project developer. They are prepared for the purpose of selecting contractors to undertake the work. Once tenders are released, the contracting process is required to both negotiate and establish contracts for the completion of the project.

The time required to produce a set of bid documents will vary depending upon the complexity and the size of the project. If bid documents are required 20 to 40 hours at rates of $40/h to $100/h are possible.

Construction supervision

The construction supervision cost item summarises the estimated costs associated with ensuring that the project is constructed as designed. Construction supervision is provided either by the consultant overseeing the project or by the equipment supplier, or by the project manager. Construction supervision involves regular visits to the job site to inspect the installation.

Depending of the project size, this task can take between 15 to 40 hours at rates of $40/h to $100/h. Travel time to the site for construction supervision is in addition to the indicated range. Travel costs should be included in the "Development" section above.

Due to unusually above average travel fees and travel time, construction supervision in isolated/permafrost areas requires less frequent regular visits, but lengthier stays. Overseeing construction from start to finish should also be considered.

Other

These input cells are provided to allow the user to enter cost or credit items that are not included in the information provided in the above cost category. The user must enter a positive numerical value in the "Unit Cost" column.

A cost item may be entered in the grey input cell as "Other." The user then selects "Cost" from the drop-down list in the unit column. The user can input both a quantity amount and unit cost. This item is provided to allow for project, technology and/or regional differences not specifically covered in the generic information provided.

A credit item may be entered in the grey input cell as "Credit." The user then selects "Credit" from the drop-down list in the unit column. The project may be credited for material and/or labour costs that would have been spent on the base case, or conventional, energy system. The user can input both a quantity amount and unit cost. Note that the credit item is expressed as a negative value in the "Amount" column.

Energy Equipment

The energy equipment, as defined here, includes, when applicable, the system's heat pumps, water well pumps, circulating pumps, heat exchanger, anti-freeze solution, drilling, trenching, GHX pipes, valves and fittings and transportation costs. All cost figures are installed costs and include overhead and profit. The user may refer to the RETScreen Online Product Database for supplier contact information in order to obtain prices or other information required.

Some specific cost items such as those for electrical equipment and controls and transportation costs are not listed in this section. It is assumed that these costs are equivalent to those of a conventional heating and cooling system and have negligible impact on the incremental cost of a GSHP system.

In cases where heavy or specialised construction machinery may be required specifically for the GSHP system, and not locally available such as in certain isolated areas, transportation costs should be accounted for in the "Other" cost item.

Heat pumps

The baseline unitary cost of a GSHP is approximately $235 per kW of cooling capacity. However, the cost depends on the selected efficiency, as shown in the table below. The user may refer to the RETScreen Online Product Database for supplier contact information in order to obtain prices or other information required.

Heat Pump Efficiency Level	Typical Cost $/kW
Standard	$235
Medium	$270
High	$330

Cost of Ground-Source Heat Pumps

The total cooling capacity, based on the building's block load, is automatically copied from the *Energy Model* worksheet. The unit cost may be lower if large heat pumps are used while it may be higher for smaller ones. A typical standard efficiency heat pump of only 3.5 kW of cooling capacity can cost over $570 per kW while a 25 kW unit will be about $200 per kW. The user should keep in mind that commercial systems may require a total installed capacity higher than the evaluated block load capacity.

Well pumps

The cost of well pumps is estimated based on the pump power requirement (in kW). The power requirement is calculated in the model and automatically transferred to the *Cost Analysis* worksheet. The main types of pumps used in GWHPs are submersible pumps and lineshaft pumps. For smaller systems (15 L/s or less), submersible pumps will usually be the lowest initial cost option. For larger systems, lineshaft pumps usually become more advantageous.

Unit costs of both types of pumps will primarily be sensitive to the pump design flow rate. Typical costs for both types of pumps are presented in the table below.

Flow Rate L/s	Submersible $/kW	Lineshaft $/kW
3	$ 1,700	$ 3,400
15	$ 750	$ 850
30	$ 450	$ 425

Cost of Well Pumps

Circulating pumps

The cost of circulating pumps is estimated based on the pump power requirement (in kW). The power requirement is calculated in the model and automatically transferred to the *Cost Analysis* worksheet. Circulating pumps are required for both GCHP and GWHP systems.

Unit costs of circulating pumps will vary depending on the pump design power demand. Typical costs for circulating pumps are presented in the table below.

Capacity kW	Typical Cost $/kW
0.2	$ 1,900
1	$ 1,100
4	$ 500
10	$ 350
20	$ 250

Cost of Circulating Pumps

Circulating fluid

The cost of circulating fluid is estimated based on the volume of antifreeze solution required (in cubic meters). The volume is calculated in the model and automatically transferred to the *Cost Analysis* worksheet. Any antifreeze solution used in the building loop, either for GCHPs or GWHPs is not considered in the volume calculation done by the model. Only the GHX loop volume is considered.

It is quite common for GCHPs to reach below freezing temperature conditions during winter operations. When such cases are likely, an antifreeze solution must be used in the GHX loop. Common antifreeze solutions used are: calcium chloride, ethanol, ethylene glycol, methanol, propylene glycol, potassium acetate, potassium carbonate and sodium chloride.

Each type of fluid has its advantages and disadvantages which are well documented [ASHRAE, 1995]. The use of antifreeze in GCHPs is regulated by different government agencies in many countries and proper verification is required before considering any such fluids. The typical cost ($/m³) for propylene glycol ranges from $2,400 to $3,000.

It is important to note, that in some areas the use of particular types of antifreeze solutions is not permitted by local authorities, therefore it is well advised to be well informed about the regulations prior to deciding which fluid to use.

Plate heat exchangers

The plate heat exchanger cost is estimated based on the heat pump system cooling capacity (in kW). The capacity is calculated by the model and automatically transferred to the *Cost Analysis* worksheet. The most widely used type of heat exchangers in GWHP system is plate type. These heat exchangers are efficient, compact, easy to maintain and affordable. The typical costs range between $7/kW to $20/kW of installed cooling capacity depending on heat exchanger size.

Trenching and backfilling

Trenching for a horizontal GHX can be done with a backhoe, a chained excavator, a vibratory plough or even a bulldozer for large fields. The unit cost of trenching and backfilling can be influenced by factors such as trench depth, soil type, presence of obstacles (e.g. boulders) and the number of turnarounds. The backfilling process is critical for good GHX performances and integrity. Backfill material should not contain any large rocks and sand should be used where the pipes are located.

The typical costs for trenching and backfilling, for a 1.8 m deep trench, are presented in the table below. The length of trench is calculated in the model and copied automatically from the *Energy Model* worksheet. Permafrost conditions can make trenching costs in isolated areas significantly higher. In isolated areas, construction machinery can sometimes be rented locally but rental costs may be up to 1.5 times standard costs.

Trench Width m	Typical Cost Range $/m
0.15	$4.00 to $6.00
0.61	$4.00 to $6.00
0.91	$5.00 to $9.00

Cost of Trenching and Backfilling (excluding turnarounds)

Typical costs for a turnaround will vary from $40 to $70 per turnaround.

Drilling and grouting

Drilling for vertical GHX or GWHP systems can be done with conventional drilling equipment such as rotary drills, cable tool drills and air drills. The unit cost of drilling is closely linked to soil type. Drilling in hard rock formations will be more costly and require more time. Wellbore or borehole diameter also influences the cost of drilling and grouting. Vertical boreholes can be smaller in diameter, typically 0.1 to 0.15 m, than water wells, which can range anywhere from

0.15 to 0.4 m depending on flow rates. Grouting of wells and vertical holes is done by using special material, the most common being high solids bentonite. The grout is used to prevent surface water from contaminating aquifers or to prevent one aquifer from contaminating an adjacent aquifer.

The typical costs ($/m) of drilling and grouting are presented in the table below. The required drilling length is calculated in the model and copied automatically from the *Energy Model* worksheet. This length accounts for injection wells. Therefore, when considering a standing well system, the unit cost should be divided by two since they do not require injection wells.

Soil Type	0.1 m Bore	0.15 m Bore	0.25 m Bore
Fine Gravel, Soft Rock	$11.00 to $15.00	$12.00 to $16.00	$15.00 to $19.00
Medium Rock	$12.00 to $17.00	$13.00 to $18.00	$16.00 to $21.00
Hard Rock	$15.00 to $27.00	$12.00 to $28.00	$19.00 to $32.00

Cost of Drilling and Grouting

The unit costs shown in the table are for an average grouting of 6 m for a typical 76 m bore or well depth. If the entire bore has to be grouted, this will add an extra $1.15/m, $2.60/m and $6.60/m for the 0.1, 0.15 and 0.25 m diameter bores respectively. Local regulations may require entire boreholes to be grouted. Grouting the entire borehole will also reduce the heat transfer efficiency and results in increased total borehole length.

Trenching costs for headers between the borehole, or wells, and the building are not considered explicitly in the model and the user can enter these costs in the "Other" cost item.

Ground HX loop pipes

The model uses 32 mm nominal diameter polyethylene pipes (Series 160) for performance calculations. The typical costs for this pipe varies between $1.50 to $3.50 per linear meter. The table below shows typical pipe costs for diameters that might be used for other loops such as the building loop, headers, etc. The pipe length is calculated in the model and automatically transferred to the *Cost Analysis* worksheet.

Pipe Diameter mm	Cost Range $/m
14	$0.75 to $1.50
25	$1.00 to $2.50
38	$2.50 to $4.00
51	$3.50 to $5.00
76	$5.50 to $7.00

Cost of Pipes

Header pipe costs are not explicitly calculated in the model but the user may enter this cost in the "Other" cost item. The header cost will depend on the distance between the building and the GHX or water wells and the pipe diameter.

Fittings and valves

All fittings and valves on the earth or water connection loop are usually thermally fused to insure the integrity of the assembly. The table presents average costs of typical fittings used in GSHP systems. The typical cost range for fittings and valves is $8 to $20 per kW of cooling capacity.

Fitting Type	Cost $/unit
Elbow – 2.54 mm dia.	$3.50
Elbow – 3.81 mm dia.	$6.00
Reducer – 3.81 mm dia.	$9.50
U-bend – 5.8 mm dia.	$41.00
Elbow – 5.8 mm dia.	$8.00

Cost of Fittings

Other

These input cells are provided to allow the user to enter cost or credit items that are not included in the information provided in the above cost category. The user must enter a positive numerical value in the "Unit Cost" column.

A cost item may be entered in the grey input cell as "Other." The user then selects "Cost" from the drop-down list in the unit column. The user can input both a quantity amount and unit cost. This item is provided to allow for project, technology and/or regional differences not specifically covered in the generic information provided.

A credit item may be entered in the grey input cell as "Credit." The user then selects "Credit" from the drop-down list in the unit column. The project may be credited for material and/or labour costs that would have been spent on the base case, or conventional, energy system. The user can input both a quantity amount and unit cost. Note that the credit item is expressed as a negative value in the "Amount" column.

Balance of System

The balance of system for a ground-source heat pump project typically includes only a few items such as the supplemental heating system, the supplemental heat rejection system and the cost of the building loop piping, valves, fittings and insulation. It is assumed that other cost components, such as for the required duct-work or transportation costs, are similar to those for a conventional system and will have a negligible impact on the incremental cost of a GSHP system.

All cost figures are installed costs and include overhead and profit.

Supplemental heating system

As discussed in the energy model description, a ground-source heat pump system may require a supplemental heating system to meet the peak period demand. This supplemental system can take many forms, from electric duct heaters to gas, or oil furnaces. Typical costs for various supplemental heating systems can be obtained from local HVAC contractors or from cost data handbooks [Means, 1998].

The supplemental heating system cost is estimated based on the required capacity (in kW). The required supplemental heating capacity is calculated by the model and copied automatically from the *Energy Model* worksheet.

Supplemental heat rejection

As discussed in the energy model description, a GSHP system may require a supplemental heat rejection system to meet the peak period demand. This supplemental system usually consists of a cooling tower. Typical costs for cooling towers can be obtained from local HVAC contractors or from cost data handbooks [Means, 1998].

The cost of the supplemental heat rejection system is estimated based on the required capacity (in kW). The required supplemental heat rejection capacity is calculated in the model and copied automatically from the *Energy Model* worksheet.

Internal piping and insulation

This cost item covers all piping, fittings, valves and insulation required for the building loop. The Cost of Pipes table presents pipe costs while the Cost of Fittings table presents typical costs for fittings and valves. Insulation costs are shown in the table below.

Pipe Diameter mm	Cost Range $/m
14	$11.00
25	$11.25
38	$12.00
51	$12.50
76	$14.00

Cost of Pipe Insulation

The typical cost range for internal piping and insulation is $20 to $70 per kW of cooling capacity.

Other

These input cells are provided to allow the user to enter cost or credit items that are not included in the information provided in the above cost category. The user must enter a positive numerical value in the "Unit Cost" column.

A cost item may be entered in the grey input cell as "Other." The user then selects "Cost" from the drop-down list in the unit column. The user can input both a quantity amount and unit cost. This item is provided to allow for project, technology and/or regional differences not specifically covered in the generic information provided.

A credit item may be entered in the grey input cell as "Credit." The user then selects "Credit" from the drop-down list in the unit column. The project may be credited for material and/or labour costs that would have been spent on the base case, or conventional, energy system. The user can input both a quantity amount and unit cost. Note that the credit item is expressed as a negative value in the "Amount" column.

Miscellaneous

This category is for all of the miscellaneous costs that occur during a project and have not been taken into account in the previous sections. For GSHP projects these costs can include training and contingencies.

Training

When the installation is complete, the system must be commissioned by a system expert, often in the presence of the building owner. The commissioning involves a trip to the building site. This trip normally includes the final inspection and necessary training for the operation of the system. For residential projects, this step is still required but to a lesser extent. The adequate training of operators and, when applicable, of maintenance personnel is fundamental to the successful deployment of any technology. The time required for this task is typically 8 to 16 hours for commercial/industrial systems and 1 to 4 hours for residential applications. The applicable rates range from $40/h to $100/h. In isolated areas the time required for this task can be substantially greater given the particular nature of the application. Travel and accommodation costs must also be accounted for.

Contingencies

A contingency allowance should be included to account for unforeseen annual expenses and will depend on the level of accuracy of the O&M cost subsection. It is common practice to carry a contingency allowance for at least the replacement of the most expensive component subject to catastrophic failure. The contingency allowance is calculated based on an estimated percentage of the system's cost. It typically ranges from 2 to 15%.

Annual Costs (Credits)

There will be a number of annual costs associated with the operation of a ground-source heat pump system. These could include property taxes and insurance, O&M labour and travel and accommodation expenses. In addition, costs for electricity consumption and peak load demand (or credit, for cases where the peak demand is reduced) will also be incurred. These costs are detailed below.

Grey input cells are also provided to allow the user to enter a cost or credit item that is specific to the project and not included in the generic information provided.

O&M

Property taxes/Insurance

Generally, GSHP systems should not increase property taxes. In some cases, a community may even provide a tax incentive for GSHP installations. The owners of a GSHP system may choose to insure the cost of the system. This will include fire insurance, public liability insurance and accident insurance to cover repairs in the event of accidental damage. This cost can be estimated by contacting an insurance broker.

O&M labour

Ground-source heat pump systems usually have a lower maintenance cost than conventional systems. This cost is best expressed in terms of $ per floor area (m^2) and will range from $1.00/$m^2$ to $3.00/$m^2$ compared to $2.00/$m^2$ to $4.00/$m^2$ for a conventional system.

GSHPs used in permafrost applications may require particular maintenance. Such costs should be estimated on a case by case basis.

Travel and accommodation

For larger GSHP systems in isolated locations, it is possible that an annual allowance may be required for travel, room and board costs associated with annual maintenance and inspection by a system expert.

Other

These input cells are provided to allow the user to enter cost or credit items that are not included in the information provided in the above cost category. The user must enter a positive numerical value in the "Unit Cost" column.

A cost item may be entered in the grey input cell as "Other." The user then selects "Cost" from the drop-down list in the unit column. The user can input both a quantity amount and unit cost. This item is provided to allow for project, technology and/or regional differences not specifically covered in the generic information provided.

A credit item may be entered in the grey input cell as "Credit." The user then selects "Credit" from the drop-down list in the unit column. The project may be credited for material and/or labour costs that would have been spent on the base case, or conventional, energy system. The user can input both a quantity amount and unit cost. Note that the credit item is expressed as a negative value in the "Amount" column.

Contingencies

A contingency allowance should be included to account for unforeseen annual expenses and will depend on the level of accuracy of the O&M cost subsection. It is common practice to carry a contingency allowance for at least the replacement of the most expensive component subject to catastrophic failure. The contingency allowance is calculated based on an estimated percentage of the system's cost. It typically ranges from 2 to 15%.

Fuel/Electricity

Electricity

This item represents the total electrical energy required to run the GSHP system on an annual basis, both for heating and cooling purposes, and includes any parasitic electricity used for pumps. The user enters the price of electricity ($/kWh) for the specific location in the unit cost cell.

Incremental electricity load

In the case of a small commercial application, there is a potential for a reduction in demand charges due to lowered peak electricity requirements. The model calculates the incremental peak electricity load, at any point during the cooling or heating season, between the GSHP system and the conventional heating and cooling system, as defined in the *Energy Model* worksheet.

The user enters the average demand charge ($/kW on a yearly basis) for the specific building in the unit cost cell. The incremental electricity load is assumed to be credited or charged to the building's owner for the entire year.

The auxiliary heating load is assumed to be electric only where the base case fuel type is electricity.

Periodic Costs (Credits)

This section is provided to allow the user to specify the periodic costs associated with the operation of the system over the project life. Grey input cells are provided to allow the user to enter the name of a periodic cost and periodic credit item. The user must enter a positive numerical value in the "Unit Cost" column.

A periodic cost represents recurrent costs that must be incurred at regular intervals to maintain the project in working condition. A periodic cost item is entered in the grey input cell. The user then selects "Cost" from the drop-down list in the unit column. The interval (in years) over which the periodic cost is incurred is entered in the period column. The amount of the cost incurred at each interval is entered in the unit cost column.

The project may also be credited for periodic costs that would have been incurred over the project life of the base case, or conventional, energy system. The periodic credit item is entered in the grey input cell. The user then selects "Credit" from the drop-down list in the unit column. The interval (in years) over which the periodic credit is incurred is entered in the period column. The amount of the credit incurred at each interval is entered in the unit cost column. Note that the credit item is expressed as a negative value in the "Amount" column.

End of project life

The user enters the value of the project at the end of its life. This amount is also commonly referred to as the salvage value (or disposal value). If the salvage value of the project at the end of its life is positive, then the user selects "Credit" from the drop-down list in the unit column in order to express this item as a negative value. However, if the costs of remediation or decommissioning that must be incurred at the end of the project life exceed the salvage value, then the user must select "Cost" from the drop-down list. The user must enter a positive numerical value in the "Unit Cost" column.

Note: At this point, the user should go to the optional *GHG Analysis* worksheet.

Blank Worksheets (3)

These worksheets are provided to allow the user to prepare a customised RETScreen project analysis. For example, the worksheets can be used to enter more details about the project, to prepare graphs, to perform a more detailed sensitivity analysis and to create a custom database. The user may also use these worksheets to develop a companion model to RETScreen.

Financial Summary

As part of the RETScreen Clean Energy Project Analysis Software, a *Financial Summary* worksheet is provided for each project evaluated. This common financial analysis worksheet contains six sections: **Annual Energy Balance**, **Financial Parameters**, **Project Costs and Savings**, **Financial Feasibility**, **Yearly Cash Flows** and **Cumulative Cash Flows Graph**. The Annual Energy Balance and the Project Costs and Savings sections provide a summary of the *Energy Model*, *Cost Analysis* and *GHG Analysis* worksheets associated with each project studied. In addition to this summary information, the Financial Feasibility section provides financial indicators of the project analysed, based on the data entered by the user in the Financial Parameters section. The Yearly Cash Flows section allows the user to visualise the stream of pre-tax, after-tax and cumulative cash flows over the project life. The *Financial Summary* worksheet of each Workbook file has been developed with a common framework so as to simplify the task of the user in analysing the viability of different projects. This also means the description of each parameter is common for most of the items appearing in the worksheet.

One of the primary benefits of using the RETScreen software is that it **facilitates the project evaluation process for decision-makers**. The *Financial Summary* worksheet, with its financial parameters input items (e.g. avoided cost of energy, discount rate, debt ratio, etc.), and its calculated financial feasibility output items (e.g. IRR, simple payback, NPV etc.), allows the project decision-maker to consider various financial parameters with relative ease. A description of these items, including comments regarding their relevance to the preliminary feasibility analysis, is included below.

Annual Energy Balance

The summary items here are calculated and/or entered in the *Energy Model* and *GHG Analysis* worksheets and transferred to the *Financial Summary* worksheet.

Project name

The user-defined project name is entered for reference purposes only in the Energy Model worksheet, and it is copied automatically to the *Financial Summary* worksheet.

Project location

The user-defined project location is entered for reference purposes only in the *Energy Model* worksheet, and it is copied automatically to the *Financial Summary* worksheet.

Heating energy delivered

The *Energy Model* worksheet calculates the heating energy delivered (MWh) by the project. This energy displaces the heating energy that would have otherwise been delivered by the conventional, or base case, system. The heating energy delivered is used in conjunction with the avoided cost of heating energy and the base case heating system seasonal efficiency to calculate the heating energy savings.

Cooling energy delivered

The *Energy Model* worksheet calculates the cooling energy delivered (MWh) by the project. In cases where the building is air-conditioned, this energy displaces the cooling energy that would have otherwise been delivered by the conventional, or base case, system. The conventional, or base case, air-conditioner is assumed to be run by electricity. The cooling energy delivered is used in conjunction with the retail price of electricity and the base case air-conditioner seasonal COP to calculate the cooling energy savings. Obviously, these savings only occur if the base case system provides air-conditioning.

Heating fuel displaced

The heating fuel displaced is the type of heating energy displaced by the addition of the project. The heating fuel type selected in the *Energy Model* worksheet is transferred here. The heating fuel displaced is used in the calculation of the heating energy savings. The following types of fuels are available in the model: Natural gas, Propane, Diesel (#2 oil), #6 oil, Electricity and Other.

Electricity required

The *Energy Model* worksheet calculates the electricity required (MWh) to run the ground-source heat pump system during heating and cooling seasons. This value is then used to calculate the annual cost of fuel/electricity.

Incremental electricity load

The model calculates the maximum incremental electricity load (kW) at any point during the cooling or heating season resulting from the replacement of the base case heating and/or cooling system by the ground-source heat pump system. This value, calculated in the *Energy Model* and *Cost Analysis* worksheets, is used to calculate the annual cost of fuel/electricity resulting from the addition of the ground-source heat pump system.

The potential increase in demand charges caused by an incremental electricity load will occur to the extent that the incremental electricity load from the ground-source heat pump project will translate into an equivalent overall increased electricity load for the building studied. Therefore, an overall increase implies that the peak electricity load for heating or cooling coincides with the overall peak load for the building. Inversely, a negative incremental electricity load could result in a reduction in demand charges and in turn, in a reduction of the annual cost of fuel/electricity.

Net GHG emission reduction

The model calculates the net annual average GHG emission reduction in equivalent tonnes of CO_2 per year (t_{CO_2}/yr) resulting from the installation of the system instead of the base case, or baseline, heating system. This value is calculated in the *GHG Analysis* worksheet and is copied here automatically.

Net GHG emission reduction - credit duration

The model calculates the cumulative net greenhouse gas (GHG) emission reduction for the duration of the GHG credit, in equivalent tonnes of CO_2 (t_{CO2}), resulting from the implementation of the project instead of the base case, or baseline, system. This value is calculated by multiplying the appropriate net annual GHG emission reduction by the GHG reduction credit duration.

Net GHG emission reduction - project life

The model calculates the net project life GHG emission reduction for the duration of the project, in equivalent tonnes of CO_2 (t_{CO2}) resulting from the installation of the project instead of the base case, or baseline, heating and cooling system. This value is calculated by multiplying the net annual GHG emission reduction by the project life.

Financial Parameters

The items entered here are used to perform calculations in this *Financial Summary* worksheet. Values for each parameter will depend on the perspective of the user (e.g. building owner vs. energy services company (ESCO)).

Avoided cost of heating energy

The user enters the avoided cost of heating energy. The avoided cost of heating energy is used in conjunction with the heating energy delivered, the heating value and the base case heating seasonal efficiency (appearing in the *Energy Model* worksheet) to calculate the annual heating energy savings. The model escalates the avoided cost of heating energy yearly according to the energy cost escalation rate starting from year 1 and throughout the project life. Note that the avoided cost of energy unit for propane is expressed in terms of liquefied propane.

GHG emission reduction credit

The user enters the GHG emission reduction credit per tonne of CO_2 (t_{CO2}). It is used in conjunction with the net GHG emission reduction to calculate the annual GHG emission reduction income.

Preliminary estimates predict the market price of GHG emission reduction credits in the USA will range from $US 4 to $US 95 per tonne of CO_2, with $5 to $8 per tonne being the most likely range [Sandor, 1999]. As of 2003, the global market price has typically been in the range of $US 3 to $US 5 per tonne of CO_2.

The value entered is assumed to be representative of year 0, i.e. the development year prior to the first year of operation (year 1). The model escalates the GHG emission reduction credit value yearly according to the GHG credit escalation rate starting from year 1 and throughout the project life.

GHG reduction credit duration

The user enters the GHG reduction credit duration (year). This value typically represents the number of years for which the project receives GHG reduction credits. It is used to determine the annual GHG reduction income.

GHG credit escalation rate

The user enters the GHG credit escalation rate (%), which is the projected annual average rate of increase in the GHG emission reduction credit over the life of the project. This permits the user to apply rates of inflation to the market price of GHG emission reduction credits which may be different from general inflation.

Retail price of electricity

The retail price of electricity is transferred from the *Cost Analysis* worksheet. This value is used in conjunction with the electricity required to run the ground-source heat pump system in order to calculate the system annual cost of fuel/electricity. The model also uses this value in conjunction with the cooling energy delivered and the seasonal air-conditioner COP to calculate the annual cooling energy savings obtained when the base case system provides air-conditioning.

This value is assumed to be representative of year 0, i.e. the development year prior to the first year of operation (year 1). The model escalates the retail price of electricity yearly according to the energy cost escalation rate starting from year 1 and throughout the project life.

Demand charge

The demand charge is transferred from the *Cost Analysis* worksheet. The model uses this value in conjunction with the incremental electricity load to calculate the annual cost of fuel/electricity resulting from the ground-source heat pump project.

The demand charge must be expressed on an annual basis given that the resulting additional charge from a positive incremental electricity load or inversely, the credit from a negative incremental electricity load, is shown and treated by the model as an annual amount. The user must enter 0 in all cases when demand charges are not imposed by the utility or when any incremental electricity load resulting from the project does not result in the same change in the peak electricity load of the whole building.

The value entered is assumed to be representative of year 0, i.e. the development year prior to the first year of operation (year 1). The model escalates the demand charge value yearly according to the inflation rate starting from year 1 and throughout the project life.

Energy cost escalation rate

The user enters the energy cost escalation rate (%), which is the projected annual average rate of increase for the cost of energy over the life of the project. This permits the user to apply rates of inflation to fuel/electricity costs which are different from general inflation for other costs. For example, North American electric utilities currently use energy cost escalation rates ranging anywhere from 0 to 5% with 2 to 3% being the most common values.

Inflation

The user enters the inflation rate (%), which is the projected annual average rate of inflation over the life of the project. For example, inflation for the next 25 years in North America is currently forecasted to range between 2 and 3%.

Discount rate

The user enters the discount rate (%), which is the rate used to discount future cash flows in order to obtain their present value. The rate generally viewed as being most appropriate is an organisation's weighted average cost of capital. An organisation's cost of capital is not simply the interest rate that it must pay for long-term debt. Rather, cost of capital is a broad concept involving a blending of the costs of all sources of investment funds, both debt and equity. The discount rate used to assess the financial feasibility of a given project is sometimes called the "hurdle rate," the "cut-off rate," or the "required rate of return." The model uses the discount rate to calculate the annual life cycle savings. For example, North American electric utilities currently use discount rates ranging anywhere from 3 to 18% with 6 to 11% being the most common values.

Project life

The user enters the project life (year), which is the duration over which the financial feasibility of the project is evaluated. Depending on circumstances, it can correspond to the life expectancy of the energy equipment, the term of the debt, or the duration of a power/heat purchase or energy service agreement. Although the model can analyse project life's up to 50 years, the project life of a well designed ground-source heat pump system typically falls between 20 and 30 years.

Debt ratio

The user enters the debt ratio (%), which is the ratio of debt over the sum of the debt and the equity of a project. The debt ratio reflects the financial leverage created for a project; the higher the debt ratio, the larger the financial leverage. The model uses the debt ratio to calculate the equity investment that is required to finance the project. For example, debt ratios typically range anywhere from 0 to 90% with 50 to 90% being the most common. In cases where the ground-source heat pump cost is incorporated into the cost of a house and tied to its mortgage, the debt ratio will likely be between 50 and 75%.

Debt interest rate

The user enters the debt interest rate (%), which is the annual rate of interest paid to the debt holder at the end of each year of the term of the debt. The model uses the debt interest rate to calculate the debt payments. For example, at a minimum the debt interest rate will correspond to the yield of government bonds with the same term as the debt term. A premium is normally added to this rate (the "spread") to reflect the perceived risk of the project.

Debt term

The user enters the debt term (year), which is the number of years over which the debt is repaid. The debt term is either equal to, or shorter than the project life. Generally, the longer the term, the more the financial viability of an energy project improves. The model uses the debt term in the calculation of the debt payments and the yearly cash flows. The term of the debt normally falls within a 1 to 25 year range. It should not exceed the estimated project life.

Income tax analysis?

The user indicates by selecting from the drop-down list whether or not income tax should be factored into the financial analysis. If the user selects "Yes" certain input fields will be added to allow the user to customise the income tax analysis according to the specific circumstances of the project. In some situations, the after-tax return of a project can be more attractive than its pre-tax return. For ground-source heat pumps installed in private homes and paid for by the home-owner, it is likely that the user would select "No" given all cash flows would come from after-tax money.

The income tax analysis allows the model to calculate after-tax cash flows and after-tax financial indicators. In all cases, the model assumes a single income tax rate valid throughout the project life and applied to net income. Note that the analysis is based, among others, on net initial and annual costs, i.e. any credits entered in the *Cost Analysis* worksheet for these two categories are not treated separately. This leads to a reasonably accurate tax analysis unless the initial and/or annual credits are of the same order of magnitude as the corresponding costs and fall under a different depreciation schedule for tax purposes.

Effective income tax rate

The user enters the effective income tax rate (%), which is the effective equivalent rate at which the net income derived from the project is taxed. For example, in most jurisdictions, this would correspond to the combined federal, provincial/state and/or local income tax rates for businesses. Net taxable income is derived from the project cash inflows and outflows assuming that all revenues and expenses are paid at the end of the year in which they are earned or incurred.

The effective income tax rate is assumed to be constant throughout the project life. Note that sales tax should be considered in the "Initial Costs" section of the *Cost Analysis* worksheet and that property tax should be considered in the "Annual Costs" section.

Loss carryforward?

The user indicates by selecting from the drop-down list whether or not losses are carried forward, i.e. whether or not a loss (a negative taxable income) in a given year can be used to lower taxes owed in that same year or can be deferred to offset profits from future years. If the user selects "Yes," losses are carried forward and applied against taxable income in the following years, thereby reducing the income tax owed up to the accumulated losses, years after the losses occur. If the user selects "No," losses are not carried forward but rather lost and thereby never used to offset any other year taxable income. If the user selects "Flow-through," losses are not carried forward but rather used in the year in which they occur and applied against profits from sources other than the project (or qualify and generate a refundable tax credit), thereby reducing the income tax owed in the years in which losses occur.

Whether losses must be carried forward or not will depend on the tax laws in the jurisdiction in which the project is located. The "Flow-through" situation is typically the most advantageous for the project owner and can contribute to make profitable a project which would not appear financially attractive on a pre-tax basis.

The model does not allow losses to be carried backward and does not set a limit on the number of years for carryforwards.

Depreciation method

The user selects the depreciation method from three options in the drop-down list: "None," "Declining balance" and "Straight-line." This selection of the yearly depreciation of assets is used in the model in the calculation of income taxes and after-tax financial indicators. The user should select the method accepted by the tax departments in the jurisdiction of the project. The difference between the "End of project life" value and its undepreciated capital costs at the end of the project life is treated as income if positive and as a loss if negative.

When "None" is selected, the model assumes that the project is fully capitalised at inception, is not depreciated through the years and therefore maintains its undepreciated value throughout its life.

When "Declining balance" is selected, the model assumes that the capitalised costs of the project, as specified by the depreciation tax basis, are depreciated at the depreciation rate. The portion of initial costs not capitalised is deemed to be expensed during the year of construction, i.e. year 0.

When "Straight line" is selected, the model assumes that the capitalised costs of the project, as specified by the depreciation tax basis, are depreciated with a constant rate over the depreciation period. The portion of initial costs not capitalised is deemed to be expensed during the year of construction, i.e. year 0.

For both declining balance and straight-line depreciation, the model assumes that the full depreciation allowed for a given year is always taken. Also, the model does not incorporate the half-year rule used in some countries and according to which depreciation is calculated over only half of the capitalised cost during the first year of operation of the equipment.

Depreciation tax basis

The user enters the depreciation tax basis (%), which is used to specify which portion of the initial costs are capitalised and can be depreciated for tax purposes. The remaining portion is deemed to be fully expensed during the year of construction (year 0).

For example, if a ground-source heat pump project costs $2,000 to evaluate (feasibility study) and develop, and $8,000 to design (engineering), build, install and commission, the user could enter 80% as the depreciation tax basis in order to depreciate only the engineering, energy equipment, balance of system and miscellaneous costs while the feasibility and development costs would be fully expensed during year 0.

Depreciation rate

The user enters the depreciation rate (%), which is the rate at which the undepreciated capital cost of the project is depreciated each year. The depreciation rate can vary widely according to the class of assets considered and the jurisdiction in which the project is located.

Depreciation period

The user enters the depreciation period (year), which is the period over which the project capital costs are depreciated using a constant rate. The depreciation period can vary widely according to the class of assets considered and the jurisdiction in which the project is located.

Tax holiday available?

The user indicates by selecting from the drop-down list whether or not the project can benefit from a tax holiday. If the user selects "Yes," the tax holiday applies starting in the first year of operation, year 1, up to the tax holiday duration. The income tax calculation for the development/construction year, year 0, is not affected.

Tax holiday duration

The user enters the tax holiday duration (year), which is the number of years over which the tax holiday applies, starting in the first year of operation, year 1. For example, in India, certain renewable energy projects are given a five-year tax holiday.

Project Costs and Savings

Most of the summary items here are calculated and/or entered in the *Cost Analysis* worksheet and transferred to the *Financial Summary* worksheet. Some calculations are made in the *Financial Summary* worksheet.

Initial costs

The total initial costs represent the total investment that must be made to bring a project on line, before it begins to generate savings (or income). The total initial costs are the sum of the estimated feasibility study, development, engineering, energy equipment, balance of system and miscellaneous costs and are inputs in the calculation of the simple payback, the net present value and the project equity and debt.

It is important to note that the range of possible costs listed throughout RETScreen do not include sales taxes. In a number of jurisdictions, clean energy project project costs are often exempt from sales taxes. Users will have to consider these costs for their region when preparing their evaluations. For example, if in a particular region sales tax is applicable to the cost of a ground-source heat pump project then the user must add the amount of sales tax to the cost of the project chosen from the proposed range of values.

Feasibility study

The feasibility study item represents the sum of the costs incurred to assess the feasibility of a project. It is net of any "credits" for not having to develop the base case project. Considerable detail is provided in the *Cost Analysis* worksheet for estimating the sub-costs for feasibility studies. This is done because it will help the project proponent better estimate the costs of the next investment required, which is the investment in a feasibility study. However for smaller projects, the RETScreen analysis may be sufficient to move to the development and engineering phase or to construction.

Note: The RETScreen Clean Energy Project Analysis Software can also be used to prepare the Feasibility Study.

Development

The development item typically represents the sum of the costs incurred to bring a project to the detailed design and construction stage, once its feasibility has been proven. It is net of any "credits" for not having to develop the base case project.

Engineering

The engineering item typically represents the sum of the costs of the design activities required to go from the development stage to the construction stage of a project. It also includes costs for construction supervision. It is net of any "credits" for not having to develop the base case project.

Energy equipment

The energy equipment item typically represents the sum of the purchasing and installation costs of the energy equipment, less any "credits" for not having to purchase or install base case equipment.

Balance of System

The balance of system item represents the sum of the purchasing, construction and installation costs of all the elements of the energy system other than the equipment costs less any "credits" for not having to purchase or install base case equipment.

Miscellaneous

The miscellaneous item includes all the costs not considered in any of the other initial costs categories that are required to bring a project to the operational stage.

Incentives/Grants

The user enters the financial incentive; this is any contribution, grant, subsidy, etc. that is paid for the initial cost (excluding credits) of the project. The incentive is deemed not to be refundable and is treated as income during the development/construction year, year 0, for income tax purposes.

For example, in Canada the Renewable Energy Deployment Initiative (REDI) may provide a 25% contribution for certain renewable energy systems used for heating and cooling applications. The contribution is 40% for systems installed in Canada's remote communities. More information may be obtained from the REDI Website or by calling 1-877-722-6600.

Annual Costs and Debt

The total annual costs are calculated by the model and represent the yearly costs incurred to operate, maintain and finance the project. It is the sum of the O&M costs, the fuel/electricity costs and debt payments. Note that the total annual costs include the reimbursement of the "principal" portion of the debt which is not, strictly speaking, a cost but rather an outflow of cash. These costs are described briefly below.

O&M

The operation and maintenance (O&M) costs are the sum of the annual costs that must be incurred to operate and maintain the energy system, in excess of the O&M cost required by the base case energy system. The model uses the O&M cost to calculate the total annual costs and the yearly cash flows.

Fuel/Electricity

The annual cost of fuel/electricity to run the ground-source heat pump system is transferred from the *Cost Analysis* worksheet. It represents the sum of the costs of electricity and of demand charges when relevant. It includes costs for both heating and cooling operation. It also includes the electricity required to run auxiliary equipment such as pumps and fans.

Debt payments - debt term

The model calculates the debt payments, which is the sum of the principal and interest paid yearly to service the debt. Whereas debt payments are constant over the debt term, the principal portion increases and the interest portion decreases with time. In that respect, it is similar to the yearly annuity paid to reimburse the mortgage of a house. Debt payments are calculated using the debt interest rate, the debt term and the project debt.

Annual Savings or Income

The total annual savings represent the yearly savings realised due to the implementation of the project. From the perspective of an independent heat/power producer or an energy services company, these "savings" will be viewed as "income." It is directly related to the avoided cost of heating and cooling energy derived from implementing the project.

Heating energy savings/income

The model calculates the heating energy savings which represent the additional cost that would have been incurred if this heating energy had been delivered by the base case energy system. The heating energy savings are equal to the product of the heating energy delivered, the cost and heat of combustion of the heating energy avoided divided by the base case system seasonal heating efficiency. The yearly value of heating energy savings is escalated at the energy cost escalation rate.

Cooling energy savings/income

The model calculates the cooling energy savings which represent the additional cost that would have been incurred if this cooling energy had been delivered by the base case energy system. The cooling energy savings are equal to the product of the cooling energy delivered, with the retail price of electricity divided by the base case air-conditioner seasonal COP. In cases where the base case system does not included air-conditioning, the cooling energy savings are set to zero. The yearly value of cooling energy savings is escalated at the energy cost escalation rate.

GHG reduction income - duration

The model calculates the GHG emission reduction income which represents the income (or savings) generated by the sale or exchange of the GHG emission reduction credits. It is calculated from the annual net GHG emission reduction and the GHG emission reduction credit value. The yearly value of GHG emission reduction income is escalated at the GHG credit escalation rate.

Periodic Costs (Credits)

The periodic costs and periodic credits entered by the user in the *Cost Analysis* worksheet are transferred here.

The model escalates the periodic costs and credits yearly according to the inflation rate starting from year 1 and throughout the project life. From an income tax perspective, periodic costs and credits are treated as operating expenses rather than capital investments and are therefore fully expensed in the year they are incurred.

End of project life - Cost/Credit

The value of the project at the end of its life entered by the user in the *Cost Analysis* worksheet is transferred here. This amount is also commonly referred to as the salvage value (or disposal value).

The salvage value entered is assumed to be representative of year 0, i.e. the development/construction year prior to the first year of operation (year 1). The model escalates the salvage value yearly according to inflation rate starting from year 1 and up to the end of the project life (i.e. the schedule year reported in the model).

For tax purposes, the difference between the project salvage value and its undepreciated capital costs at the end of the project life is treated as income if positive and as a loss if negative.

Financial Feasibility

The results provide the decision-maker with various financial indicators for the proposed project.

Pre-tax Internal Rate of Return and Return on Investment

The model calculates the pre-tax internal rate of return (%), which represents the true interest yield provided by the project equity over its life before income tax. It is also referred to as the return on investment (equity) (ROI) or the time-adjusted rate of return. It is calculated by finding the discount rate that causes the net present value of the project to be equal to zero. Hence, it is not necessary to establish the discount rate of an organisation to use this indicator. An organisation interested in a project can compare the internal rate of return of the project to its required rate of return (often, the cost of capital). The IRR is calculated on a nominal basis, that is including inflation.

If the internal rate of return of the project is equal to or greater than the required rate of return of the organisation, then the project will likely be considered financially acceptable (assuming equal risk). If it is less than the required rate of return, the project is typically rejected. An organisation may have multiple required rates of return that will vary according to the perceived risk of the projects. The most obvious advantage of using the internal rate of return indicator to evaluate a project is that the outcome does not depend on a discount rate that is specific to a given organisation. Instead, the IRR obtained is specific to the project and applies to all investors in the project. The model uses the pre-tax yearly cash flows and the project life to calculate the internal rate of return.

After-tax Internal Rate of Return and Return on Investment

The model calculates the after-tax internal rate of return (%), which represents the true interest yield provided by the project equity over its life. It is also referred to as the return on investment (equity) (ROI) or the time-adjusted rate of return. It is calculated by finding the discount rate that causes the net present value of the project to be equal to zero. Hence, it is not necessary to establish the discount rate of an organisation to use this indicator. An organisation interested in a project can compare the internal rate of return of the project to its required rate of return (often, the cost of capital). The IRR is calculated on a nominal basis, that is including inflation.

If the internal rate of return of the project is equal to or greater than the required rate of return of the organisation, then the project will likely be considered financially acceptable (assuming equal risk). If it is less than the required rate of return, the project is typically rejected. An organisation may have multiple required rates of return that will vary according to the perceived risk of the projects. The most obvious advantage of using the internal rate of return indicator to evaluate a project is that the outcome does not depend on a discount rate that is specific to a given organisation. Instead, the IRR obtained is specific to the project and applies to all investors in the project. The model uses the after-tax yearly cash flows and the project life to calculate the internal rate of return.

Simple Payback

The model calculates the simple payback (year), which represents the length of time that it takes for an investment project to recoup its own initial cost, out of the cash receipts it generates. The basic premise of the payback method is that the more quickly the cost of an investment can be recovered, the more desirable is the investment. For example, in the case of the implementation of a Ground-Source Heat Pump energy project, a negative payback period would be an indication that the annual costs incurred are higher than the annual savings generated.

The simple payback method is not a measure of how profitable one project is compared to another. Rather, it is a measure of time in the sense that it indicates how many years are required to recover the investment for one project compared to another. **The simple payback should not be used as the primary indicator to evaluate a project**. It is useful, however, as a secondary indicator to indicate the level of risk of an investment. A further criticism of the simple payback method is that it does not consider the time value of money, nor the impact of inflation on the costs.

On the other hand, the payback period is often of great importance to smaller firms that may be cash poor. When a firm is cash poor, a project with a short payback period, but a low rate of return, might be preferred over another project with a high rate of repayment, but a long payback period. The reason is that the organisation may simply need a faster return of its cash investment. The model uses the total initial costs, the total annual costs (excluding debt payments) and the total annual savings, in order to calculate the simple payback. The calculation is based on pre-tax amounts and includes any initial cost incentives.

Year-to-positive cash flow

The model calculates the number of years to positive (cumulative) cash flow, which represents the length of time that it takes for the owner of a project to recoup its own initial investment out of the project cash flows generated. The year-to-positive cash flow considers project cash flows following the first year as well as the leverage (level of debt) of the project, which makes it a better time indicator of the project merits than the simple payback. The model uses the year number and the cumulative after-tax cash flows in order to calculate this value.

The year-to-positive cash flow differs from the discounted payback indicator in that it considers the nominal value of future cash flows rather than the discounted value of future cash flows.

Net Present Value - NPV

The model calculates the net present value (NPV) of the project, which is the value of all future cash flows, discounted at the discount rate, in today's currency. NPV is thus calculated at a time 0 corresponding to the junction of the end of year 0 and the beginning of year 1. Under the NPV method, the present value of all cash inflows is compared against the present value of all cash outflows associated with an investment project. The difference between the present value of these cash flows, called the NPV, determines whether or not the project is generally a financially acceptable investment. Positive NPV values are an indicator of a potentially feasible project. In using the net present value method, it is necessary to choose a rate for discounting cash flows to present value. As a practical matter, organisations put much time and study into the choice of a discount rate. The model calculates the NPV using the cumulative after-tax cash flows. In cases where the user has selected not to conduct a tax analysis, the NPV calculated will be that of the pre-tax cash flows.

Annual Life Cycle Savings

The model calculates the annual life cycle savings (ALCS) which is the levelized nominal yearly savings having exactly the same life and net present value as the project. The annual life cycle savings are calculated using the net present value, the discount rate and the project life.

Benefit-Cost (B-C) ratio

The model calculates the net benefit-cost (B-C) ratio, which is the ratio of the net benefits to costs of the project. Net benefits represent the present value of annual revenues (or savings) less annual costs, while the cost is defined as the project equity.

Ratios greater than 1 are indicative of profitable projects. The net benefit-cost (B-C) ratio, similar to the profitability index, leads to the same conclusion as the net present value indicator.

Calculate GHG reduction cost?

The user indicates by selecting from the drop-down list whether or not the project GHG emission reduction cost should be calculated. In order to calculate the true economic cost (not the financial cost) of GHG emission reductions, a number of other parameters such as the GHG emission reduction credit, debt ratio, etc. should be set to 0. In addition "Income tax analysis" should be set to "No" and other taxes should also be set to 0. This option is more applicable to economists as it requires a careful analysis of assumptions used.

GHG emission reduction cost

The model calculates the GHG emission reduction cost. The GHG emission reduction cost is calculated by dividing the annual life cycle savings (ALCS) of the project by the net GHG emission reduction per year. For projects with a net increase in GHG emission, the GHG emission reduction cost is irrelevant and hence not calculated.

Project equity

The model calculates the project equity, which is the portion of the total investment required to finance the project that is funded directly by the project owner(s). The project equity is deemed to be disbursed at the end of year 0, i.e. the development/construction year. It is calculated using the total initial costs, the initial cost incentives and the debt ratio.

Project debt

The model calculates the project debt, which is the portion of the total investment required to implement the project and that is financed by a loan. The project debt leads to the calculation of the debt payments and the net present value. It is calculated using the total initial costs and the project equity.

Debt payments

The model calculates the debt payments, which is the sum of the principal and interest paid yearly to service the debt. Whereas debt payments are constant over the debt term, the principal portion increases and the interest portion decreases with time. In that respect, it is similar to the yearly annuity paid to reimburse the mortgage of a house. Debt payments are calculated using the debt interest rate, the debt term and the project debt.

Debt service coverage

The model calculates the debt service coverage for each year of the project and reports the lowest ratio encountered throughout the term of debt. The debt service coverage is the ratio of the operating benefits of the project over the debt payments. This value reflects the capacity of the project to generate the cash liquidity required to meet the debt payments. It is calculated by dividing net operation income (net cash flows before depreciation, debt payments and income taxes) by debt payments (principal and interest).

The debt service coverage is a ratio used extensively by the potential lenders for a project to judge its financial risk. The model assumes that the cumulative cash flows are used to finance a sufficient debt service reserve before any distributions to the shareholders.

Yearly Cash Flows

Pre-tax

The model calculates the net pre-tax cash flows, which are the yearly net flows of cash for the project before income tax. It represents the estimated sum of cash that will be paid or received each year during the entire life of the project. Note that the initial costs are assumed to occur at the end of year 0 and that year 1 is the first year of operation of the project. Annual costs and savings given in the *Financial Summary* worksheet, which reflect amounts valid for year zero, are thus escalated one year in order to determine the actual costs and savings incurred during the first year of operation (i.e. year 1).

After-tax

The model calculates the net after-tax cash flows, which are the yearly net flows of cash for the project after income tax. It represents the estimated sum of cash that will be paid or received each year during the entire life of the project. Note that the initial costs are assumed to occur at the end of year 0 and that year 1 is the first year of operation of the project. Annual costs and savings given in the *Financial Summary* worksheet, which reflect amounts valid for year zero, are thus escalated one year in order to determine the actual costs and savings incurred during the first year of operation (i.e. year 1).

Cumulative

The model calculates the cumulative cash flows, which represent the net after-tax flows accumulated from year 0. It uses the net flows to calculate the cumulative flows.

Cumulative Cash Flows Graph

The cumulative cash flows are plotted versus time in the cash flows graph. These cash flows over the project life are calculated in the model and reported in the Yearly Cash Flows table.

Greenhouse Gas (GHG) Emission Reduction Analysis

As part of the RETScreen Clean Energy Project Analysis Software, a *GHG Analysis* worksheet is provided to help the user estimate the greenhouse gas emission reduction (mitigation) potential of the proposed project. This GHG emission reduction analysis worksheet contains four main sections: **Background Information**, **Base Case System (Baseline)**, **Proposed Case System (Project)** and **GHG Emission Reduction Summary**. The Background Information section provides project reference information as well as GHG global warming potential factors. The Base Case Electricity System and Base Case Heating and Cooling System sections provide a description of the emission profile of the baseline system, representing the baseline for the analysis. The Proposed Case Heating and Cooling System section provides a description of the emission profile of the proposed project, i.e. the ground-source heat pump project. The GHG Emission Reduction Summary section provides a summary of the estimated GHG emission reduction based on the data entered by the user in the preceding sections and from values entered or calculated in the other RETScreen worksheets (e.g. annual energy delivered). Results are calculated as equivalent tonnes of CO_2 avoided per annum. This is an optional analysis - inputs entered in this worksheet will not affect results reported in other worksheets, except for the GHG related items that appear in the *Financial Summary* and Sensitivity worksheets.

Greenhouse gases include water vapour, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3) and several classes of halo carbons (that is, chemicals that contain carbon together with fluorine, chlorine and bromine). Greenhouse gases allow solar radiation to enter the Earth's atmosphere, but prevent the infrared radiation emitted by the Earth's surface from escaping. Instead, this outgoing radiation is absorbed by the greenhouse gases and then partially re-emitted as thermal radiation back to Earth, warming the surface. Greenhouse gases that are most relevant to energy project analysis are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O); these gases are considered in the RETScreen GHG emission reduction analysis.

The *GHG Analysis* worksheet with its emission related input items (e.g. fuel mix, fuel conversion efficiency) and its calculated emission factor output items (e.g. GHG emission factor), allows the decision-maker to consider various emission parameters with relative ease. However, the user should be aware that this ease of use may give a project developer a too optimistic and simplified view of what is required in setting a baseline for a proposed project. As such, it is suggested that the user **take a conservative approach in calculating the baseline emission factor for the project**, particularly at the pre-feasibility analysis stage. In order to determine the net benefits of obtaining carbon finance for the project, the user can evaluate the project twice, once including the value of the carbon credits and the associated transaction costs and once without, and then compare the results.

Use GHG analysis sheet?

The user indicates by selecting from the drop-down list whether or not the optional *GHG Analysis* worksheet is used to conduct an analysis of GHG emission reduction.

If the user selects "Yes" from the drop-down list, then the user should complete the *GHG Analysis* worksheet. Certain input fields will be added to the *Financial Summary* worksheet in order to calculate the GHG emission reduction income and cost.

If the user selects "No" from the drop-down list, then the user should go directly to the *Financial Summary* worksheet.

Type of analysis

The user selects the type of analysis from the two options in the drop-down list: "Standard" and "Custom." "Standard" analysis uses many pre-defined parameters in the calculations whereas "Custom" analysis requires that these parameters be entered by the user.

Background Information

Project name

The user-defined project name is entered for reference purposes only in the *Energy Model* worksheet, and it is copied automatically to the *Financial Summary* worksheet.

Project location

The user-defined project location is entered for reference purposes only in the *Energy Model* worksheet, and it is copied automatically to the *GHG Analysis* worksheet.

Global Warming Potential of GHG

The model indicates the global warming potential of methane (CH_4) and nitrous oxide (N_2O). If the user selects the "Custom" type of analysis, different values from the default values provided may be entered by the user. Researchers have assigned Global Warming Potentials (GWPs) to greenhouse gases to allow for comparisons of their relative heat-trapping effect. The higher the global warming potential of a gas the greater the contribution to the greenhouse effect. For example nitrous oxide is 310 times more effective than carbon dioxide at trapping heat in the atmosphere.

GWPs of gases are defined as a unit multiple of that given to carbon dioxide (CO_2), which is assigned a reference value of 1 (i.e., the GWP of CO_2 is 1 and the GWP of N_2O is 310). The default values are those defined by the Revised Intergovernmental Panel on Climate Change (IPCC) Guidelines for Greenhouse Gas Inventories, 1996.

Base Case Electricity System (Baseline)

To perform the RETScreen GHG emission reduction analysis for the project, the user will need to define the baseline (also called base case or reference case) electricity system. Often this will simply imply defining a "proxy" plant and its associated fuel.

For example, in North America when preparing a GHG emission reduction analysis for a GSHP project where central-grid electricity is used, it is often reasonable to assume that a combined-cycle natural gas power plant is the proxy plant. In this case the user need only select "Natural gas" as the fuel type with a 100% fuel mix and use the default "T & D losses" of 8%. For the case of an isolated-grid, a diesel genset would likely be the "proxy" power plant with "Diesel (#2 oil)" chosen as the fuel type.

It is also possible to define the grid and the mix of the different power plants with their respective fuels, fuel mix and different T & D losses (e.g. distributed generators such as photovoltaics will have lower T & D losses). This information is usually available through the local electric utility, the utility regulator and/or through government. For example, the United States Environmental Protection Agency (US-EPA) provides "The Emissions & Generation Resource Integrated Database" called E-GRID. This is a database featuring environmental characteristics of electric power generation in the US, including fuel mix. This database is available free of charge at the E-GRID Website.

To illustrate this alternative analysis method, for a ground-source heat pump project based in Nova Scotia, Canada, the provincial government might determine the baseline to be the weighted average of the current generation mix. This can be calculated by simply entering the current fuel mix into the grid along with the appropriate emissions coefficient. For this example and with information provided by Natural Resources Canada, the user would select the following fuel types and associated fuel mix: coal with 78% of the fuel mix, large hydro with 9%, #6 oil with 5%, natural gas with 5% and biomass with 3% of the fuel mix and T & D losses of 8% for all fuel types.

Some users may prefer to perform a much more detailed analysis of the GHG reduction potential of the project (e.g. an economist working for a public utility commission). The model allows for a more detailed analysis regarding T & D losses and using the "Custom" option under the "Type of analysis" drop-down list, the user can prepare an even more detailed analysis regarding emission factors, etc.

If the user has access to dispatch information from the local utility, the Base Case Electricity System table can be used to model the marginal fuel use on the grid, which may more accurately represent the fuels and the emissions that are being displaced by the proposed project. For example, if dispatch information shows that the fuel used on the margin is natural gas 85% of the time and fuel oil 15% of the time, the user would enter these details into the base case table along with the corresponding GHG coefficients. The resulting baseline is often referred to as the "operating margin."

Another baseline option, referred to as the "build margin" can be calculated by modeling recent capacity additions, for example, the 5 most recent plants that have been added to the grid. The build margin can be modeled in the base case table by entering recent capacity additions along with their relative generating capacities (scaled to total 100%) and appropriate GHG coefficients.

It is suggested that the user take a conservative approach in calculating the baseline emission factor for the project, particularly at the pre-feasibility analysis stage.

Fuel type

The user selects the fuel type from the options in the drop-down list. The RETScreen software can model the GHG emissions of any electricity supply system. The fuel type is the fuel(s) or power plant(s) which will be displaced by the proposed project. If the user selects one of the fuel types from the drop-down list, default emission factor and fuel conversion efficiency values will be inserted into the row inputs of the table. The default emission factors and conversion efficiencies of various fuel types are given in the following table [Fenhann, J., 1999], [Fenhann, J., 2000] and [The Danish Energy Agency, 1999].

For "Custom" projects, if a specific fuel type is not included in the drop-down list, the user may choose "Other" and manually enter values for the remainder of the row inputs. The order in which reference fuels or power plants are listed in this table is irrelevant.

Fuel type	CO_2 emission factor (kg/GJ)	CH_4 emission factor (kg/GJ)	N_2O emission factor (kg/GJ)	Fuel conversion efficiency %
Coal	94.6	0.0020	0.0030	35%
Natural gas	56.1	0.0030	0.0010	45%
Nuclear	0	0	0	-
Large hydro	0	0	0	-
#6 oil	77.4	0.0030	0.0020	30%
Diesel (#2 oil)	74.1	0.0020	0.0020	30%
Geothermal	0	0	0	-
Biomass (wood)	0	0.0320	0.0040	25%
Small hydro	0	0	0	-
Wind	0	0	0	-
Solar	0	0	0	-
Propane	63.1	0.0010	0.0010	45%

Default Emission Factors and Conversion Efficiencies

Fuel mix

The user enters the fuel mix (%) of the base case electricity system for each fuel type. Units are given as percentages of total electricity supplied. Note that the user should verify that the sum of all fuel types listed in the fuel mix column equals 100%.

CO_2, CH_4 and N_2O emission factors

(Custom analysis)

The user enters the CO2, CH4 and N2O emission factors for the different fuel types. They represent the mass of greenhouse gas emitted per unit of energy. Emission factors will vary for different types and qualities of fuels, and for different types and sizes of power plants. For grid-connected projects, the user should enter factors representative of large generating plants. On the electricity mix row at the bottom of the table, the model calculates the equivalent emission factors for the global electricity mix and per unit of electricity delivered. The electricity mix factors thus account for a weighted average of the fuel conversion efficiencies and T & D losses of the different fuel types.

For each fuel type selected, units are given in kilograms of gas emitted per gigajoule of heat energy generated (kg/GJ). For the global electricity mix shown on the bottom row of the table, units are given in kilograms of gas emitted per gigajoule of end-use electricity delivered.

For more information on determining GHG emission factors, see the revised IPCC Guidelines for National Greenhouse Gas Inventories. CO2 emission factors for many fuels are included on page 1.13 of the IPCC Reference Manual. CH4 and N2O emission factors for a number of fuels are included on pages 1.35 and 1.36 of the IPCC Reference Manual.

CO_2, CH_4 and N_2O emission factors

(Standard analysis)

The model provides the CO2, CH4 and N2O emission factors which represent the mass of greenhouse gas emitted per unit of energy. Emission factors will vary for different types and qualities of fuels, and for different types and sizes of power plants. The default factors provided are those which are representative of large power plants that feed a central electricity grid. On the electricity mix row at the bottom of the table, the model calculates the equivalent emission factors for the total electricity mix and per unit of electricity delivered. The electricity mix factors thus account for a weighted average of the fuel conversion efficiencies and T & D losses of the different fuel types.

For each fuel type selected, units are given in kilograms of gas emitted per gigajoule of heat energy generated (kg/GJ). For the total electricity mix shown on the bottom row of the table, units are given in kilograms of gas emitted per gigajoule of end-use electricity delivered.

For more information on determining GHG emission factors, see the revised IPCC Guidelines for National Greenhouse Gas Inventories. CO2 emission factors for many fuels are included on page 1.13 of the IPCC Reference Manual. CH4 and N2O emission factors for a number of fuels are included on pages 1.35 and 1.36 of the IPCC Reference Manual.

The default values provided by the model are given in the Default Emission Factors and Conversion Efficiencies table.

Fuel conversion efficiency

(Custom analysis)

The user enters the fuel conversion efficiency for the selected fuel type. The fuel conversion efficiency is the efficiency of energy conversion from primary heat potential to actual power plant output. This value is used to calculate, for each fuel type, the aggregate GHG emission factor and therefore is only relevant for fuel types which actually produce greenhouse gases (i.e. with non-zero CO2, CH4 and N2O emission factors).

For example, a typical coal-fired power plant could have a fuel conversion efficiency of 35%, which indicates that 35% of the heat content of the coal is transformed into electricity fed to the grid.

Units are given as a percentage of primary heat potential (gigajoules of heat) to actual power plant output (gigajoules of electricity). Fuel types which emit no GHGs (e.g. solar) have a default value of 100%.

Fuel conversion efficiency

(Standard analysis)

The model provides the fuel conversion efficiency for the selected fuel type. The fuel conversion efficiency is the efficiency of energy conversion from primary heat potential to actual power plant output. This value is used to calculate, for each fuel type, the aggregate GHG emission factor and therefore is only relevant for fuel types which actually produce greenhouse gases (i.e. with non-zero CO2, CH4 and N2O emission factors).

For example, a typical coal-fired power plant could have a fuel conversion efficiency of 35%, which indicates that 35% of the heat content of the coal is transformed into electricity fed to the grid.

Units are given as a percentage of primary heat potential (gigajoules of heat) to actual power plant output (gigajoules of electricity). Fuel types which emit no GHGs (e.g. solar) have a default value of 100%.

The default values provided by the model are given in the Default Emission Factors and Conversion Efficiencies table.

Transmission and distribution losses

The user enters the transmission and distribution (T & D) losses (%) of the base case electricity system, which includes all energy losses between the power plant and the end-user. This value will vary based on the voltage of transport lines, the distance from the site of energy production to the point of use, peak energy demands, ambient temperature and electricity theft. In addition, T & D system type (e.g. AC vs. DC) and quality may also influence losses. The model calculates the weighted average of the T & D losses of the global electricity mix on the bottom row of the table.

Units are given as a percentage of all electricity losses to electricity generated. It is reasonable to assume T & D losses of 8 to 10% in modern grids in industrialised countries and 10 to 20% in grids located in developing countries.

GHG emission factor

The model calculates the GHG emission factor for each reference fuel type. Values are calculated based on the individual emission factors, the fuel conversion efficiency and the T & D losses. The weighted GHG emission factor for the total electricity mix is calculated on the bottom row of the table.

Units are given in tonnes equivalent of CO_2 emission per megawatt-hour of end-use electricity delivered (t_{CO_2}/MWh).

Base Case Heating and Cooling System (Baseline)

The base case heating and cooling system, or baseline system, represents the system to which the ground-source heat pump is compared. The base case heating and cooling system is defined in terms of its fuel types, its emissions of GHG and its conversion efficiencies.

Note that in all cases, the base cooling system is assumed to be powered by electricity using the base case electricity mix system.

The base case system is normally referred to as the reference or baseline option in standard economic analysis.

Fuel type

The fuel type of the base case heating system entered by the user in the *Energy Model* worksheet is transferred to the *GHG Analysis* worksheet.

The fuel type of the base case cooling system is assumed to be powered by electricity in all cases.

Fuel mix

The base case heating and cooling systems are assumed to be fuelled by a single source of energy and the fuel mix is therefore set to 100%.

CO_2, CH_4 and N_2O emission factors

(Custom analysis)

For the base case heating system, the user enters the CO2, CH4 and N2O emission factors corresponding to the heating fuel type selected. If the heating fuel type is electricity, emission factors of the base case electricity mix are used. For the base case cooling system, CO2, CH4 and N2O emission factors for the base case electricity mix are used.

CO2, CH4 and N2O emission factors represent the mass of greenhouse gas emitted per unit of energy generated. Emission factors will vary for different types and qualities of fuels, and for different types and sizes of heating equipment.

For each fuel type selected, units are given in kilograms of gas emitted per gigajoule of heating or cooling energy generated (kg/GJ).

For more information on determining GHG emission factors, see the revised IPCC Guidelines for National Greenhouse Gas Inventories. CO_2 emission factors for many fuels are included on page 1.13 of the IPCC Reference Manual. CH_4 and N_2O emission factors for a number of fuels are included on pages 1.35 and 1.36 of the IPCC Reference Manual.

CO_2, CH_4 and N2O emission factors

(Standard analysis)

For the base case heating system, the model provides the CO2, CH4 and N2O emission factors corresponding to the heating fuel type selected. If the heating fuel type is electricity, emission factors of the base case electricity mix are used. For the base case cooling system, CO2, CH4 and N2O emission factors for the base case electricity mix are used.

CO2, CH4 and N2O emission factors represent the mass of greenhouse gas emitted per unit of energy generated. Emission factors will vary for different types and qualities of fuels, and for different types and sizes of heating equipment. The default factors provided are those which are representative of large heating plants. For smaller plants and for greater accuracy, the user may select the "Custom" type of analysis and specify the emission factors.

For each fuel type selected, units are given in kilograms of gas emitted per gigajoule of primary heating or cooling energy generated (kg/GJ).

For more information on determining GHG emission factors, see the revised IPCC Guidelines for National Greenhouse Gas Inventories. CO_2 emission factors for many fuels are included on page 1.13 of the IPCC Reference Manual. CH_4 and N_2O emission factors for a number of fuels are included on pages 1.35 and 1.36 of the IPCC Reference Manual.

The default values provided by the model are given in the Default Emission Factors and Conversion Efficiencies table.

Fuel conversion efficiency

The base case heating and cooling system fuel conversion efficiencies are entered by the user in the Energy Model worksheet and are transferred to the GHG Analysis worksheet. The fuel conversion efficiency represents the annual average efficiency of energy conversion from primary heat potential to actual heating, or cooling, energy output. This value is used to calculate, for each fuel type, the aggregate GHG emission factor and therefore is only relevant for fuel types which actually produce greenhouse gases (i.e. with non-zero CO2, CH4 and N2O emission factors).

Units are given as a percentage of actual space heating and cooling energy output (gigajoules of heating/cooling energy) to primary heat potential (gigajoules of heat or electricity).

GHG emission factor

The model calculates the GHG emission factor for the base case heating and cooling systems. Values are calculated based on the individual emission factors and the fuel conversion efficiency.

Units are given in tonnes equivalent of CO_2 emission per megawatt-hour of end-use space heating and cooling energy delivered (t_{CO_2}/MWh).

Proposed Case Heating and Cooling System (Ground-Source Heat Pump)

The proposed case heating and cooling system, or mitigation system, is the proposed project. It is defined in terms of its fuel types, its emissions of GHG and its conversion efficiencies. Note that in all cases, the ground-source heat pump is assumed to be electricity-driven using the base case electricity system.

The proposed case system is normally referred to as the mitigation option in standard economic analysis.

Fuel type

The fuel type of the ground-source heat pump is assumed to be electricity for both heating and cooling.

Fuel mix

The fuel mix of the ground-source heat pump is assumed to come from a single source, i.e. electricity, and is thus set to 100%.

CO2, CH4 and N2O emission factors

The model provides the CO_2, CH4 and N_2O emission factors corresponding to the fuel type, i.e. electricity used to drive the ground-source heat pump. These values correspond to the electricity mix of the base case electricity system.

For each fuel type selected, units are given in kilograms of gas emitted per gigajoule of electricity used by the ground-source heat pump in both the heating and cooling mode (kg/GJ).

Fuel conversion efficiency

The model calculates the fuel conversion efficiency in the Energy Model worksheet and the value is transferred to the GHG Analysis worksheet. The fuel conversion heating and cooling efficiencies are equivalent to the "Seasonal heating COP" and the "Seasonal cooling COP" respectively, as they appear in the Energy Model worksheet.

The fuel conversion efficiency represents the annual average efficiency of energy conversion from electricity to actual space heating and cooling energy output. This value is used in conjunction with the CO_2, CH4 and N_2O emission factors to calculate the aggregate GHG emission factor for the proposed project.

Units are given as a percentage of actual space heating or cooling energy output (gigajoules of heating/cooling energy) to electricity input (gigajoules of electricity).

GHG emission factor

The model calculates the GHG emission factor for the proposed ground-source heat pump system. Values are calculated based on the individual CO_2, CH4 and N_2O emission factors and the fuel conversion efficiency.

Units are given in tonnes equivalent of CO_2 emission per megawatt-hour of end-use space heating and cooling energy delivered (t_{CO_2}/MWh).

GHG Emission Reduction Summary

Based on the GHG emission data entered, the model calculates the annual reduction in GHG emissions when the base case system is displaced with the proposed case system.

Base case GHG emission factor

The model transfers the base case GHG emission factor calculated in the base case heating and cooling system (baseline) section. This value represents the amount of GHG emitted per unit of space heating and cooling energy delivered for the base case system. The GHG emission factor for the base case cooling system is assumed to be zero in cases with no air-conditioning.

Units are given in tonnes equivalent of CO_2 emission per megawatt-hour of space heating and cooling energy delivered (t_{CO_2}/MWh).

Proposed case GHG emission factor

The model transfers the proposed case GHG emission factor calculated in the proposed case heating and cooling system section. This value represents the amount of GHG emitted per unit of space heating and cooling energy delivered if the ground-source heat pump is installed.

Units are given in tonnes equivalent of CO_2 emission per megawatt-hour of space heating and cooling energy delivered (t_{CO_2}/MWh).

End-use annual energy delivered

The model displays the end-use annual energy delivered, as calculated in the *Energy Model* worksheet.

Units are given in megawatt-hours of space heating and cooling energy delivered (MWh).

Annual GHG emission reduction

The model calculates the annual reduction in GHG emissions estimated to occur if the proposed project is implemented. The calculation is based on emission factors of both the base case and the proposed case system and on the end-use annual energy delivered.

Units are given in equivalent tonnes of CO_2 emission per year (t_{CO2}/yr).

Note: At this point, the user should complete the *Financial Summary* worksheet.

Sensitivity and Risk Analysis

As part of the RETScreen Clean Energy Project Analysis Software, a *Sensitivity and Risk Analysis* worksheet is provided to help the user estimate the sensitivity of important financial indicators in relation to key technical and financial parameters. This standard sensitivity and risk analysis worksheet contains two main sections: **Sensitivity Analysis** and **Risk Analysis**. Each section provides information on the relationship between the key parameters and the important financial indicators, showing the parameters which have the greatest impact on the financial indicators. The Sensitivity Analysis section is intended for general use, while the Risk Analysis section, which performs a Monte Carlo simulation, is intended for users with knowledge of statistics.

Both types of analysis are optional. Inputs entered in this worksheet will not affect results in other worksheets.

Use sensitivity analysis sheet?

The user indicates, by selecting from the drop-down list, whether or not the optional *Sensitivity and Risk Analysis* worksheet is used to conduct a sensitivity analysis of the important financial indicators.

If the user selects "Yes" from the drop-down list, the sensitivity analysis section will open and the user should complete the top part of the worksheet. The user will need to click on "Calculate Sensitivity Analysis" button to get the results.

Perform risk analysis too?

The user indicates, by selecting from the drop-down list, whether or not the optional risk analysis section is used to conduct a risk analysis of the important financial indicators, in addition to the sensitivity analysis. In the risk analysis section, the impact of each input parameter on a financial indicator is obtained by applying a standardised multiple linear regression on the financial indicator.

If the user selects "Yes" from the drop-down list, then the risk analysis section will open and the user should complete the lower-half of the worksheet. The analysis will be performed on the financial indicator selected by the user in the "Perform analysis on" input cell at the top-right. The user will need to click on "Calculate Risk Analysis" button in the Risk Analysis section at the lower-half of this worksheet to get the results.

Project name

The user-defined project name is entered for reference purposes only in the *Energy Model* worksheet, and it is copied automatically to the *Sensitivity* worksheet.

Project location

The user-defined project location is entered for reference purposes only in the *Energy Model* worksheet, and it is copied automatically to the *Sensitivity* worksheet.

Perform analysis on

The user selects, from three options in the drop-down list, the financial indicator to be used for both the sensitivity and risk analyses. Modifying the selection in this cell will change the results in the worksheet.

After-tax Internal Rate of Return and Return on Investment

The model calculates the after-tax internal rate of return (%), which represents the true interest yield provided by the project equity over its life. It is also referred to as the return on investment (equity) (ROI) or the time-adjusted rate of return. It is calculated by finding the discount rate that causes the net present value of the project to be equal to zero. Hence, it is not necessary to establish the discount rate of an organisation to use this indicator. An organisation interested in a project can compare the internal rate of return of the project to its required rate of return (often, the cost of capital). The IRR is calculated on a nominal basis, that is including inflation.

If the internal rate of return of the project is equal to or greater than the required rate of return of the organisation, then the project will likely be considered financially acceptable (assuming equal risk). If it is less than the required rate of return, the project is typically rejected. An organisation may have multiple required rates of return that will vary according to the perceived risk of the projects. The most obvious advantage of using the internal rate of return indicator to evaluate a project is that the outcome does not depend on a discount rate that is specific to a given organisation. Instead, the IRR obtained is specific to the project and applies to all investors in the project. The model uses the after-tax yearly cash flows and the project life to calculate the internal rate of return.

Year-to-positive cash flow

The model calculates the number of years to positive (cumulative) cash flow, which represents the length of time that it takes for the owner of a project to recoup its own initial investment out of the project cash flows generated. The year-to-positive cash flow considers project cash flows following the first year as well as the leverage (level of debt) of the project, which makes it a better time indicator of the project merits than the simple payback. The model uses the year number and the cumulative after-tax cash flows in order to calculate this value.

The year-to-positive cash flow differs from the discounted payback indicator in that it considers the nominal value of future cash flows rather than the discounted value of future cash flows.

Net Present Value - NPV

The model calculates the net present value (NPV) of the project, which is the value of all future cash flows, discounted at the discount rate, in today's currency. NPV is thus calculated at a time

0 corresponding to the junction of the end of year 0 and the beginning of year 1. Under the NPV method, the present value of all cash inflows is compared against the present value of all cash outflows associated with an investment project. The difference between the present value of these cash flows, called the NPV, determines whether or not the project is generally a financially acceptable investment. Positive NPV values are an indicator of a potentially feasible project. In using the net present value method, it is necessary to choose a rate for discounting cash flows to present value. As a practical matter, organisations put much time and study into the choice of a discount rate. The model calculates the NPV using the cumulative after-tax cash flows. In cases where the user has selected not to conduct a tax analysis, the NPV calculated will be that of the pre-tax cash flows.

Sensitivity range

The user enters the sensitivity range (%), which defines the maximum percentage variation that will be applied to all the key parameters in the sensitivity analysis results tables. Each parameter is varied by the following fraction of the sensitivity range : -1, -1/2, 0, 1/2, 1. This value is used in the sensitivity analysis section only.

The sensitivity range entered by the user must be a percentage value between 0 and 50%.

Threshold

The user enters the threshold value for the financial indicator selected. The threshold is the value under which (for the "After tax IRR and ROI" and "Net Present Value - NPV") or over which (for "Year-to-positive cash flow") the user considers that the proposed project is not financially viable. Results which indicate an unviable project, as defined by the user threshold, will appear as orange cells in the sensitivity analysis results tables. This value is used in the sensitivity analysis section only.

Click here to Calculate Sensitivity Analysis

The "Click here to Calculate Sensitivity Analysis" button updates the sensitivity analysis calculations using the input parameters specified by the user (i.e. "Perform analysis on" and "Sensitivity range" input cells). The sensitivity analysis tables are updated each time the user clicks on this button.

The sensitivity analysis calculations can take up to 15 seconds to run depending on the Excel version and the speed of the computer. When the sensitivity analysis is updated, the button disappears.

If the user makes any changes to the input parameters, or navigates through any of the other worksheets, the button will reappear. The user will then have to click on the button to update the sensitivity analysis calculations so that the results reflect the changes.

Sensitivity Analysis for...

This section presents the results of the sensitivity analysis. Each table shows what happens to the selected financial indicator (e.g. After-tax IRR and ROI) when two key parameters (e.g. Initial costs and Avoided cost of heating energy) are varied by the indicated percentages. Parameters are varied using the following fraction of the sensitivity range : -1, -1/2, 0, 1/2, 1. Original values (which appear in the *Financial Summary* worksheet) are in bold in these sensitivity analysis results tables.

Results which indicate an unviable project, as defined by the user threshold, will appear as orange cells in these sensitivity analysis results tables.

All parameter values used for the calculations are taken from the *Financial Summary* worksheet and all the sensitivity variations are evaluated at the level of that worksheet. This is a partial limitation of this sensitivity analysis worksheet since some parameter values are calculated from inputs in other worksheets, but those inputs are not changed. However, for most cases, this limitation is without consequence. If required, the user can use the blank worksheets (Sheet1, etc.) to perform a more detailed analysis.

Risk Analysis for...

This section allows the user to perform a Risk Analysis by specifying the uncertainty associated with a number of key input parameters and to evaluate the impact of this uncertainty on after-tax IRR and ROI, year-to-positive cash flow or net present value (NPV).

The risk analysis is performed using a Monte Carlo simulation that includes 500 possible combinations of input variables resulting in 500 values of after-tax IRR and ROI, year-to-positive cash flow or net present value (NPV). The risk analysis allows the user to assess if the variability of the financial indicator is acceptable, or not, by looking at the distribution of the possible outcomes. An unacceptable variability will be an indication of a need to put more effort into reducing the uncertainty associated with the input parameters that were identified as having the greatest impact on the financial indicator.

Avoided cost of heating energy

The avoided cost of heating energy is automatically transferred from the *Financial Summary* worksheet to the *Sensitivity* worksheet.

The user enters the avoided cost of energy range. The range is a percentage corresponding to the uncertainty associated with the estimated avoided cost of heating energy value. The higher the percentage, the greater the uncertainty. The range specified by the user must be between 0 and 50%. The range determines the limits of the interval of possible values that the avoided cost of heating energy could take.

For example, a range of 10% for an avoided cost of heating energy of $0.09/kWh means that the avoided cost of heating energy could take any value between $0081/kWh and $0.099/kWh. Since $0.09/kWh is the estimated value, the risk analysis will consider this value as being the most probable and the minimum and maximum values as being the least probable, based on a normal distribution.

If the avoided cost of heating energy is known exactly by the user (no uncertainty), the user should enter a range of 0%.

Initial costs

The total initial cost is transferred automatically from the *Financial Summary* worksheet to the *Sensitivity* worksheet.

The user enters the initial costs range. The range is a percentage corresponding to the uncertainty associated with the estimated initial costs value. The higher the percentage, the greater the uncertainty. The range specified by the user must be between 0 and 50%. The range determines the limits of the interval of possible values that the initial costs could take.

For example, a range of 10% for initial costs of $30,000 means that the initial costs could take any value between $27,000 and $33,000. Since $30,000 is the estimated value, the risk analysis will consider this value as being the most probable and the minimum and maximum values as being the least probable, based on a normal distribution.

If the initial costs are known exactly by the user (no uncertainty), the user should enter a range of 0%.

Annual costs

The annual cost is transferred automatically from the *Financial Summary* worksheet to the *Sensitivity* worksheet, but does not include debt payments.

The user enters the annual cost range. The range is a percentage corresponding to the uncertainty associated with the estimated annual costs value. The higher the percentage, the greater the uncertainty. The range specified by the user must be between 0 and 50%. The range determines the limits of the interval of possible values that the annual costs could take.

For example, a range of 10% for an annual cost of $800 means that the annual cost could take any value between $720 and $880. Since $800 is the estimated value, the risk analysis will consider this value as being the most probable and the minimum and maximum values as being the least probable, based on a normal distribution.

If the annual costs are known exactly by the user (no uncertainty), the user should enter a range of 0%.

Debt ratio

The debt ratio is automatically transferred from the *Financial Summary* worksheet to the *Sensitivity* worksheet.

The user enters the debt ratio range. The range is a percentage corresponding to the uncertainty associated with the estimated debt ratio value. The higher the percentage, the greater the uncertainty. The range specified by the user must be a percentage value between 0% and the lowest percentage such that the debt ratio will always fall between 0 and 100%. The range determines the limits of the interval of possible values that the debt ratio could take.

For example, a range of 10% for a debt ratio of 70% means that the debt ratio could take any value between 63 and 77%. Since 70% is the estimated value, the risk analysis will consider this value as being the most probable and the minimum and maximum values as being the least probable, based on a normal distribution.

If the debt ratio is known exactly by the user (no uncertainty), the user should enter a range of 0%.

Debt interest rate

The debt interest rate is automatically transferred from the *Financial Summary* worksheet to the *Sensitivity* worksheet.

The user enters the debt interest rate range. The range is a percentage corresponding to the uncertainty associated with the estimated debt interest rate value. The higher the percentage, the greater the uncertainty. The range specified by the user must be between 0 and 50%. The range determines the limits of the interval of possible values that the debt interest rate could take.

For example, a range of 10% for a debt interest rate of 20% means that the debt interest rate could take any value between 18 and 22%. Since 20% is the estimated value, the risk analysis will consider this value as being the most probable and the minimum and maximum values as being the least probable, based on a normal distribution.

If the debt interest rate is known exactly by the user (no uncertainty), the user should enter a range of 0%.

Debt term

The debt term is automatically transferred from the *Financial Summary* worksheet to the *Sensitivity* worksheet.

The user enters the debt term range. The range is a percentage corresponding to the uncertainty associated with the estimated debt term value. The higher the percentage, the greater the uncertainty. The range specified by the user must be a percentage value between 0% and the lowest percentage such that the debt term will always fall between 1 year and the project life. The range determines the limits of the interval of possible values that the debt term could take.

For example, a range of 10% for a debt term of 20 years means that the debt term could take any value between 18 and 22 years. Since 20 years is the estimated value, the risk analysis will consider this value as being the most probable and the minimum and maximum values as being the least probable, based on a normal distribution.

If the debt term is known exactly by the user (no uncertainty), the user should enter a range of 0%.

GHG emission reduction credit

The GHG emission reduction credit is automatically transferred from the *Financial Summary* worksheet to the *Sensitivity* worksheet.

The user enters the GHG emission reduction credit range. The range is a percentage corresponding to the uncertainty associated with the estimated GHG emission reduction credit value. The higher the percentage, the greater the uncertainty. The range specified by the user must be a percentage value between 0 and 50%. The range determines the limits of the interval of possible values that the GHG emission reduction credit could take.

For example, a range of 10% for a GHG emission reduction credit of $\$5/t_{CO_2}$ means that the GHG emission reduction credit could take any value between $\$4.5/t_{CO_2}$ and $\$5.5/t_{CO_2}$. Since $\$5/t_{CO2}$ is the estimated value, the risk analysis will consider this value as being the most probable and the minimum and maximum values as being the least probable, based on a normal distribution.

If the GHG emission reduction credit is known exactly by the user (no uncertainty), the user should enter a range of 0%.

Click here to Calculate Risk Analysis

The "Click here to Calculate Risk Analysis" button updates the risk analysis calculations using the input parameter ranges specified by the user. Clicking on this button starts a Monte Carlo simulation that uses 500 possible combinations of input variables resulting in 500 values of the selected financial indicator. The impact graph, the median, the minimum and maximum confidence levels, and the distribution graph are calculated using these results and updated each time the user clicks on the button "Click here to Calculate Risk Analysis."

The risk analysis calculations can take up to 1 minute to run depending on the Excel version and the speed of the computer. When the risk analysis is updated, the button disappears.

If the user makes any changes to the input range values, or navigates through any of the other worksheets, the button will reappear. The user will then have to click on the button to update the risk analysis calculations so that the results reflect the changes.

Impact graph

The impact graph shows the relative contribution of the uncertainty in each key parameter to the variability of the financial indicator. The X axis at the bottom of the graph does not have any units, but rather presents a relative indication of the strength of the contribution of each parameter.

The longer the horizontal bar, for a given input parameter, the greater is the impact of the input parameter on the variability of the financial indicator.

The input parameters are automatically sorted by their impact on the financial indicator. The input parameter at the top (Y axis) contributes the most to the variability of the financial indicator while the input parameter at the bottom contributes the least. This "tornado graph" will help the user determine which input parameters should be considered for a more detailed analysis, if that is required.

The direction of the horizontal bar (positive or negative) provides an indication of the relationship between the input parameter and the financial indicator. There is a positive relationship between an input parameter and the financial indicator when an increase in the value of that parameter results in an increase in the value of the financial indicator. For example, there is usually a negative relationship between initial costs and the net present value (NPV), since decreasing the initial costs will increase the NPV.

In some cases, there is insufficient data to properly plot the graph. For example, when the year-to-positive cash flow is immediate, the result is not a numerical value, and therefore these values cannot be plotted.

Median

The model calculates the median of the financial indicator. The median of the financial indicator is the 50th percentile of the 500 values generated by the Monte Carlo simulation. The median will normally be close to the financial indicator value calculated in the *Financial Summary* worksheet.

Level of risk

The user selects from the drop-down list the acceptable level of risk for the financial indicator under consideration. The options are: 5%, 10%, 15%, 20% and 25%.

The level of risk input is used to establish a confidence interval (defined by maximum and minimum limits) within which the financial indicator is expected to fall. The level of risk represents the probability that the financial indicator will fall outside this confidence interval.

The limits of the confidence interval are automatically calculated based on the median and the level of risk, and are shown as "Minimum within level of confidence" and "Maximum within level of confidence."

It is suggested that the user select a level of risk of 5 or 10%, which are typical values for standard risk analysis.

Minimum within level of confidence

The model calculates the "Minimum within level of confidence," which is the lower limit of the confidence interval within which the financial indicator likely falls. It is the percentile of the distribution of the financial indicator corresponding to half the level of risk defined by the user. For example, for a "Minimum within level of confidence" value of 15% IRR, a level of risk of 10% means that 5% (half the level of risk) of the possible IRR values are lower than 15%.

Maximum within level of confidence

The model calculates the "Maximum within level of confidence," which is the upper limit of the confidence interval within which the financial indicator likely falls. It is the percentile of the distribution of the financial indicator corresponding to 100% minus half the level of risk. For example, for a "Maximum within level of confidence" value of 25% IRR, a level of risk of 10% means that 95% of the possible IRR values are lower than 25%.

Distribution graph

This histogram provides a distribution of the possible values for the financial indicator resulting from the Monte Carlo simulation. The height of each bar represents the frequency (%) of values that fall in the range defined by the width of each bar. The value corresponding to the middle of each range is plotted on the X axis.

Looking at the distribution of financial indicator, the user is able to rapidly assess its' variability.

In some cases, there is insufficient data to properly plot the graph. For example, when the year-to-positive cash flow is immediate, the result is not a numerical value, and therefore these values cannot be plotted.

Bar graph

The bar graph summarises the maximum and minimum financial indicator values that can be expected according to the level of risk defined by the user.

Product Data

Some of the product data requirements for the model are provided in the RETScreen Online Product Database. To access the product database the user may refer to "Data & Help Access." The product database provides information on the equipment associated with the project. From the online product database dialogue box the user may obtain product specification and performance data, as well as company contact information.

The product database sorting routine starts by using the "Design criteria" selected by the user in the *Energy Model* worksheet. From the dialogue box the user selects the GSHP COP Range, followed by the Region, Supplier and Model. The data can be pasted from the dialogue box to the spreadsheets by clicking on the "Paste Data" button. Only data that are in **bold** are pasted to the spreadsheets; all other data are for reference purposes only. Data entered using the product database may be **overwritten**, i.e. the user may prefer to use other data and can manually enter values into the spreadsheets. "Other information" such as product weight and/or dimensions, is provided to help the user prepare the study. The product database contains a link to the Websites of some product suppliers. In the case where the Website link cannot be activated the user should try using another browser or can contact the supplier by other means (email, fax, etc.).

Note: To see all the suppliers listed in the product database and their contact information, the user can choose "Any" from the "GSHP COP Range" input cell.

The product database is distributed for informational purposes only and does not necessarily reflect the views of the Government of Canada nor constitute an endorsement of any commercial product or person. Neither Canada nor its ministers, officers, employees or agents make any warranty in respect to this database or assumes any liability arising out of this database.

Product manufacturers interested in having their products listed in the product database can reach RETScreen® International at:

RETScreen® International
CANMET Energy Technology Centre - Varennes
Natural Resources Canada
1615 Lionel-Boulet, P.O. Box 4800
Varennes, Quebec, CANADA J3X 1S6
Tel: +1-450-652-4621
Fax: +1-450-652-5177
E-mail: rets@nrcan.gc.ca

Weather Data

This database includes some of the weather data required in the model. To access the weather database the user may refer to "Data & Help Access." While running the software the user may obtain weather data from **ground monitoring stations** and/or from **NASA's satellite data**. Ground monitoring stations data is obtained by making a selection for a specific location from the Online Weather Database dialogue box. NASA's satellite data is obtained via a link to NASA's Website from the dialogue box.

Ground Monitoring Stations Data

From the dialogue box, the user selects a region, then a country, then a sub-region (provinces in Canada, states in the United States and N/A in the rest of the countries), and finally a weather station location. The weather station usually corresponds to the name of a city/town within the selected country. From the dialogue box the data can be pasted to the spreadsheets by clicking on the "Paste Data" button. Only data that are in **bold** are pasted to the spreadsheets; all other data are for reference purposes only. Data entered using the online weather database may be **overwritten**; i.e. the user may prefer to use other data and can manually enter values into the spreadsheets. As an alternative the user can use the NASA satellite data, particularly for the case when the project location is not close to the given weather station location.

NASA Global Satellite Data

A link to the NASA Surface meteorology and Solar Energy Data Set Website is provided in the online weather database dialogue box. The user is able to select the data required for the model by clicking on a region on the world map illustrated on the NASA Website. The location is narrowed down to a "cell" within a specified latitude and longitude. The user may simply copy and paste this data to the RETScreen spreadsheets or manually enter these values.

NASA and CETC - Varennes are co-operating to facilitate the use of NASA's global satellite solar data with RETScreen and to develop a new global weather database (see Surface meteorology and Solar Energy Data Set for the tool). This work is sponsored as part of NASA's Earth Science Enterprise Program and is being carried out at the NASA Langley Research Center and at CETC - Varennes. This collaboration provides RETScreen users access (free-of-charge) to satellite data (e.g. the amount of solar energy striking the surface of the earth, global temperatures and wind speeds), simply by clicking on links in either the RETScreen software or the NASA Website. These data had previously only been available from a limited number of ground monitoring stations and are critical for assessing the amount of energy a project is expected to produce. The use of these data results in substantial cost savings for users and increased market opportunities for industry while allowing governments and industry to evaluate regional renewable energy resource potential.

Cost Data

Typical cost data required to prepare RETScreen studies are provided in the RETScreen Online Cost Database and in the Online Manual. This database is built into the "right-hand column" of the *Cost Analysis* worksheet. Data are provided for Canadian costs with 2000 as a baseline year. The user also has the ability to create a custom cost database.

The user selects the reference (from the *Cost Analysis* worksheet) that will be used as a guideline for the estimation of costs associated with the implementation of the project. This feature allows the user to change the "Quantity Range" and the "Unit Cost Range" columns. The options from the drop-down list are: "Canada - 2000," "None," "Second currency" and a selection of 8 user-defined options ("Enter new 1," "Enter new 2," etc.).

If the user selects "Canada - 2000" the range of values reported in the "Quantity Range" and "Unit Cost Range" columns are for a 2000 baseline year, for projects in Canada and in Canadian dollars.

Selecting "None" hides the information presented in the "Quantity Range" and "Unit Cost Range" columns. The user may choose this option, for example, to minimise the amount of information printed in the final report.

If the user selects "Second currency" two additional input cells appear in the next row: "Second currency" and "Rate: 1st currency/2nd currency." In addition, the "Quantity Range" and "Unit Cost Range" columns change to "% Foreign" and "Foreign Amount," respectively. This option allows the user to assign a portion of a project cost item in a second currency, to account for those costs that must be paid for in a currency other than the currency in which the project costs are reported. Note that this selection is for reference purposes only, and does not affect the calculations made in other worksheets.

If "Enter new 1" (or any of the other 8 selections) is selected, the user may manually enter quantity and cost information that is specific to the region in which the project is located and/or for a different cost base year. This selection thus allows the user to customise the information in the "Quantity Range" and "Unit Cost Range" columns. The user can also overwrite "Enter new 1" to enter a specific name (e.g. Japan - 2001) for a new set of unit cost and quantity ranges. The user may also evaluate a single project using different quantity and cost ranges; selecting a new range reference ("Enter new 1" to "Enter new 8") enables the user to keep track of different cost scenarios. Hence the user may retain a record of up to 8 different quantity and cost ranges that can be used in future RETScreen analyses and thus create a localised cost database.

Training and Support

The user can obtain current information on RETScreen Training & Support at the following Website address: www.retscreen.net/e/training/.

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