Ground Loop Design™

Geothermal Design Studio

User's Manual

(English)

GLD™ Premier Financial 2009 Edition for Windows®

Gaia Geothermal

www.gaiageo.com

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Ground Loop Design^{TM} Premier Financial Edition 2009 User's Guide

The Ground Loop Design^{TM} Premier Financial 2009 Edition User's Manual
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Software Versions Available

Three versions of GLD™ are available. The program always is available for download on the web at www.gaiageo.com. For sales and program upgrade information, contact sales@gaiageo.com.

Version features include:

Features	Commercial: Premier Finance	Commercial: Premier	Residential
Design Studio	●	●	●
StudioLink System	●	●	●
Maximum Peak Loads	no limit	no limit	200 kBtu/hr
Borehole Module	●	●	●
Horizontal Module	●		●
Surface Water Module	●		●
Average Block Loads Module	●	●	
Zone Manager Loads Module	●		●
Heat Pump Add/Edit Module	●	●	
Preloaded Pump Library	●	●	●
Monthly Temp Calculations	●		
Boiler/Cooling Tower Hybrids	●	●	
Fixed Length Design Mode	●		●
Graphing Functions	●		
English or Metric Units	●	●	●
English/Metric Units Conversion	●		●
Borehole Data Importer	●	●	
Loads Data Importer	●	●	●
Standard Reports	●	●	●
Advanced Reports	●		
Enhanced User Interface	●	●	
Automatic Fluids Data Entry	●	●	●
Data Reference Files	●	●	●
Customization Options	●	●	●
Interactive Help	●	●	●
Multiple Languages	●	●	●
LEAD PLUS PLUG-IN			●
Finance/Emissions Module	●		

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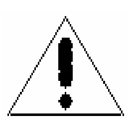
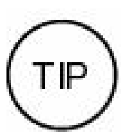
The following symbols are used in this document to highlight certain information and features included in the **User's Guide** and **GLD** software program.



This caution symbol notifies the user that care must be taken at the specified location.

This star-shaped symbol highlights new features in Premier Version 5.0



The round symbol highlights suggestions for using the program more effectively or for improving designs.

Contents

Chapter 9: The Finance Module.......……….......……………………139

PREFACE

Before You Begin

This chapter describes the typical uses and users of the software. It also describes the installation procedure and hardware and software requirements for the Ground Loop Design (GLD)^{TM} program. Additionally, the chapter introduces the licensing system.

Introduction: Typical Uses and Users

GLD^{TM} Premier Financial Version 2009 is intended as a Design Studio for professional HVAC designers and engineers working in the area of geothermal applications. It is primarily designed for use with light-commercial or commercial installations, since the calculations take into account long-term thermal effects that often determine the necessary design requirements. Additionally, the loads representation employed in GLD's Zone Management system allows for detailed equipment selection and specific load distribution data to maximize calculation accuracy.

The Premier Financial Version of GLD^{TM} includes three design modules: one for vertical borehole, one for horizontal and one for surface water (pond, lake, etc.) installations. It also includes two loads modules, one for average block loads and one for the more detailed zone model. The loads data can be shared between modules using GLD's unique linking system. In addition, loads data from external loads programs as well as from Excel files conveniently can be imported into the loads modules. The Premier Financial Version also now includes a financial module for conducting financial and emissions analyses of various HVAC systems.

Because of the extensive customization and override features included in the software, GLD is suited ideally for both standard and non-standard applications, which can involve significant variations in equipment, loads, and operational parameters for each zone in the design. The user, who may prefer to add his or her specific images or data sheets, has the freedom to customize the data reference files. In addition, the program is optimized for hybrid systems as well as for the addition of boilers and cooling towers to loopfield designs.

With instant, direct metric/English unit conversions and foreign language capabilities, GLD is a truly international program. With GLD, communicating project parameters, equipment requirements and loads data with coworkers, partners, and vendors anywhere in the world is efficient and easy. The program provides a framework for international standardization.

System Requirements for Running GLD

This section lists the hardware and software requirements for running GLD.

Hardware Requirements

A full installation has the following minimum hardware requirements:

- 1 GB RAM (2 GB recommended)
- 150 MB hard disk space (300 MB recommended)
- Intel Core 2 Duo Processor

Software Requirements

GLD has the following software requirements:

- System running under Windows®
- Netscape Navigator® or Internet Explorer®

Operating System Requirements

GLD will operate under Windows 9X/ME/NT/2000/XP/VISTA.

Internet Browser Requirements

An Internet browser is required only for viewing the data reference files, and not for general program operation. To access the data reference files, at least one of the following browsers is necessary:

- Netscape Communicator Version 5.0 or later.
- Internet Explorer Version 5.0 or later.

Installation Procedure

If you have problems installing GLD, please visit the support page at http://www.gaiageo.com or contact your distributor. Note that you can also download GLD from the internet at http://www.gaiageo.com. The downloadable version always will be the most recent release.

Initial Installation

For CD versions of GLD, installation should start automatically. If not, the software may be installed by clicking on the **Setup.exe** file included on the disk.

The program is set to install in the folder:

(Main Drive):\Program Files\Gaia Geothermal\GLD Premier

If desired, the user can specify a different location during the installation sequence.

Installation of Updated Versions or Re-Installation

If the user re-installs or replaces the software with a more recent version, the user either can uninstall the program (see ***Note*** below) or can just update a current version (versions subsequent to Version 2.0). To completely remove a version, go to the Windows Start Menu → Settings → Control Panel → Add/Remove Programs and choose to remove "GLD". After removing the program, please conduct the new installation as described above. As long as the user does not manually delete folders, existing work files, pumps, and zone files will not be affected.

Note:

The file **"Pumplist.gld"** in the **\GLD\pumps** folder will be overwritten upon re-installation. If the user has added pumps other than those originally included with the program, *this file should be copied or moved to a backup directory* prior to removal and re-installation. After re-installation, the **Pumplist.gld** file can be returned to the **\GLD\Pumps** folder *or* the desired contents can be added to the contents of the new **Pumplist.gld** file using a simple text editor like **Notepad.exe**. The format of the file is provided below.

Pumplist.gld

```
Pump List File
Number of Manufacturers (Integer)

First Manufacturer Name (Text)
Street Address (Text)
City, State, Zip (Text)
Country (Text)
Telephone Number (Text)
Number of Different Series for this Manufacturer (Integer; Example: 2)
Series #1 Name (Text)
Series #1 filename without .hpd extension (Text)
#Date Entered# (Text; Example: #2001-10-05#)
Series #2 Name (Text)
Series #2 filename without .hpd extension (Text)
#Date Entered# (Text; Example: #2001-10-06#)

Second Manufacturer Name (Text)
Street Address (Text)
…
```

Alternatively, any pump files not included with the setup package may be added from within the program itself using the method described in Chapter 2, under *Adding Pump Sets Obtained from External Sources*.
The actual original heat pump data files (*.hpd), will not be deleted unless their names are identical to those being installed. Thus, all data can be recovered even if the previous version of the **Pumplist.gld** file is overwritten. However, this will either involve editing the **Pumplist.gld** file manually to include the customized data, or identifying those files within the program itself. In general, if there are only a few pump sets to add, working within the program may be best. If there are many, cutting and pasting from the old file using a text editor may prove to be more efficient (Remember to modify the number of manufacturers if necessary!).

If the user has created customized heat pump sets, it may be wise to make a backup of all data files prior to removal and re-installation.

Additionally, *customized* ***data reference files*** *should be backed up* before any user-modified GLD menu HTML documents are replaced. The linked HTML documents themselves will not be overwritten.

Program Licensing

This section describes the USB dongle and license transfer options available in GLD Premier Finance 2009 Edition.

Software License Dongle

Your GLD software license is stored on the USB dongle that came with your program. This dongle enables you effortlessly to transfer GLD from one computer to another. Please be careful not to misplace this dongle. Lost dongles can not be replaced without the purchase of a new license.

If the dongle is not attached to your computer, GLD will function as a trial version, which is fully functional except for a few design parameters that are locked at certain values.

When you insert the dongle into a free USB port on your computer for the first time, your computer most likely will recognize the dongle and after a few seconds, the dongle light will turn on. When it turns on, your license will activate. However, if your computer indicates that the dongle is "new hardware" you have two options for installing the dongle driver:

How to Install the Dongle Driver:

Windows Vista, XP and Windows 2000 users with internet access:

If your computer has access to the internet, your computer can automatically install the drivers. Follow along with the Windows new hardware wizard to install the drivers. The process takes a few minutes. When the installation is complete, the dongle light will turn on.

All other users:

Via Windows Explorer, navigate to:
(Main Drive):\Program Files\Gaia Geothermal\GLD\Extras

In the Extras folder you will find a HASPUserSetup.exe program.

Run the program to install the dongle driver. When the installation is complete, the dongle light will turn on.

After Dongle Installation is Complete:

Now that the dongle is installed, you can access the full functionality of the GLD version that you purchased. If you remove the dongle, the program will revert to demo mode. If you reattach the dongle, the program will reactivate again.

How To Transfer the Program Between Computers

The dongle licensing system allows the user to transfer the license from one computer to another. If a user decides to transfer GLD from one computer to another, all he or she has to do is the following:

- Install GLD onto the target computer.
- After the "demo version" of the program is running on the new computer, attach the dongle and follow the above instructions regarding dongle driver installation.

CHAPTER 1

GLD Overview

This chapter is an introduction to the GLD Premier Financial 2009 Edition software package. It introduces new features, the Design Studio, the Heat Pump and Loads Modules, the Borehole, Horizontal and Surface Water Design Modules, the reporting functions, and the data reference files. There is also an explanation of the theoretical and experimental basis for the program's calculations.

General Program Features

GLD Premier Financial 2009 Edition is a "Geothermal Design Studio" that provides the user with a freedom that single-purpose software cannot offer. The program is modular and permits flexibility in the designing process and customization based on designer preferences. Additionally, it has an English/metric unit conversion option, providing applicability to the widest range of equipment and customers. Because the software is available in different languages, it is truly international in its ability to traverse national borders as well as language and cultural barriers.

New in Premier Financial 2009 Edition

GLD Premier Financial 2009 Edition adds a range of features to the program including:

- The finance module. This new module enables designers to model and estimate the hard and soft costs associated with geothermal systems. From expected future $C0_2$ emissions costs to the installation costs, annual and lifetime operating and maintenance costs of geothermal, hybrid, and more standard HVAC systems, the module provides designers with the control, flexibility and ease-of-use associated with previous versions of GLD.

Furthermore, it enables decision makers to compare simultaneously the financial profiles of multiple systems.

- Four new professional reports

The Design Studio

The studio is the desktop work area in which the designer conducts his or her project analyses and establishes the basis for designs. When additional projects are desired, new windows may be opened or existing projects may be loaded. The Loads modules hold and display the information for the particular installation. Other windows may be opened concurrently. For example, one window may be used to edit or to modify heat pump data, another to calculate equivalent full load hours, and still others to provide easily accessible graphs or charts that may be required repeatedly through the course of a design. Similar design plans can be compared directly, or entirely different designs can be created and varied. All of the information a designer needs exists in one convenient location within GLD.

Besides opening and closing windows and taking care of file management, the studio desktop menu and toolbar include control features which can be applied to more than one different type of project. For example, the English/metric unit conversion tool can convert a single window without affecting the rest of the open windows. Project reports can also be printed from the studio desktop.

Customization

GLD offers the user a great deal of freedom in how he or she enters and uses information. Rather than conforming designs to the software, this software package allows some modification and variation in its included features.

Some of the most common areas of customization in GLD include the entry of loads and the selection of equipment. Although fully automatic modes are available, the user also has the ability to customize or override the automatic features. For example, detailed load information may be included for precision designs, while extremely limited data is enough for rough calculations. Additionally, if the data are available, the designing engineer can enter his or her own pump sets to take full advantage of the automatic selection procedures. Also, different families of pumps can be used within a single project, and even individual pumps not included in the pre-defined pump sets can be employed as required.

Another area where customization is possible is in the data reference files, which are based on HTML. With a simple HTML editor the user can include any tables, data, pictures, graphs, charts, or any other useful information that meets the user's needs. User-added files can supplement or replace the data reference files already provided with GLD.

Metric/English Units

One of the intrinsic features in GLD is the English/metric unit conversion capability. The English/metric option can be used not only to compare values, but it also can be used to quickly make use of specific equipment or loads data supplied in only one format.

Because the reports and data reference files automatically recognize the selected units, users can obtain different reports and data lists depending on the state of the Design Studio. Presentation and comparison of project information between different engineers and designers is now a straightforward process.

Internationalization

The final major feature of GLD is the international component. Because the program is multi-language capable, users easily can communicate accurate results and design parameters across borders, even when the designers are not proficient in the technical language of their foreign counterparts.

Currently, Japanese, Chinese, Korean, Italian, Spanish, Russian, Czech, Lithuanian, French and Romanian versions are available. Figure 1.1 is a screenshot from the Korean version (metric).

Figure 1.1 Korean Version of GLD

Heat Pump and Zone/Loads Modules Introduction

The underlying framework of GLD is based on three modules that permit flexibility in the addition and modification of components related to geothermal designs. The first is the heat pump module, which takes a representative amount of data from the heat pump specifications and then uses it for the automatic pump selection features. The second and third are the average block and zone loads modules, which provide organized methods for entering the heat gains or losses for an installation. Because the heat pump and loads modules are closely related, users can match heat pumps to the loads automatically or manually.

An advantage of this design is that the heat pump selection and the loads modules can be connected directly with the various design modules available in the studio. **Therefore, one type of loads and heat pump data can be used for all designs.**

Heat Pump Module

In GLD, heat pump data can be entered into a separate module that keeps track of all of the pumps stored in the GLD's Heat Pump Database. Families of heat pumps from various manufacturers can be added to the existing pump set maintained by the user. In this way, heat pump data obtained from any source easily can be included within the software to take advantage of the automatic equipment sizing features of GLD.

Recent data from popular heat pump manufacturers is included with GLD. However, any pump set can be added to the list. The heat pump model only requires that certain data from heat pump specification sheets, or from software provided by the manufacturer, be entered into the *Edit/Add Heat Pumps* module. The model in GLD requires the input of a minimum of six data points for both heating and cooling modes. These data points relate capacity and power to the inlet source temperature and are fit using a polynomial line to provide an accurate model for the equipment for any given design parameters. By including additional data from different source flow rates and/or different inlet load temperatures and flow rates, higher levels of accuracy are possible.

The *Edit/Add Heat Pumps* module is covered in detail in Chapter 2.

Zones/Loads Modules

GLD employs two different types of load input schemes. With the Zone Manager Loads module, users can perform a detailed analysis. With the Average Block Loads module, users can make quick estimates without performing detailed component design work. In Premier Financial 2009 Edition, users can optionally add monthly loads data to the Average Block Loads and then calculate month-by-monthly inlet temperatures in a Borehole Design module. These stand-alone modules are linked to design modules using the *Studio Link* system (Chapter 3). Both modules can import loads data from commercial loads programs and Excel files.

Zone Manager Loads Module

TIP

Component-style designs often are more appropriate for geothermal installations, particularly when equipment is available in various sizes. The units can be placed near or within the locations to be conditioned. With regard to water source heat pumps, it is often much easier to bring water lines to the equipment instead of providing ductwork or long load lines from a centralized source.

TIP

When considering geothermal applications, the precision of the zone/loads model is crucial because it relates directly to the extent of external heat exchanger installation. Heat exchanger costs impact the overall costs of a project. Additionally, a unit that is called only when necessary or is well matched to a zone will be more efficient than a larger unit that may cycle more often.

Inputs for GLD's Zone Manager Loads module include peak load information for each of the zones in an installation at different periods during the day. These loads data can be matched automatically to heat pumps stored within GLD's Heat Pump Database. Therefore, ideal and rapid sizing is possible. As with the Average Block Loads module, the annual running time also may be included for a buried heat exchanger. This loading information can be simple or complex, depending on the level of detail the designer desires. To facilitate this model, the zones can be viewed either independently or together on the summary panel.

Average Block Loads Module

For quick estimates and general calculations, there is no need to do a full zone analysis for a project. In these cases, designers can quickly enter data and consider approximate designs using the Average Block Loads module.

The average block model takes peak data from up to four time periods during the peak day, and then uses a generalized form of the automatic pump selection sequence to match a particular type of pump to an entire installation. For buried heat exchangers, the model also uses weekly and annual operational time as parameters. The hours can be computed from monthly loads data using the Equivalent Hours Calculator (Chapter 3).

In GLD Premier Financial Edition 2009, users have the option of calculating month-by-month inlet temperatures in the borehole design module. Performing these calculations requires detailed monthly loads data and therefore the average block module in the Premier Financial 2009 Edition now accepts the input of monthly total and peak loads for both heating and cooling. Note that these data are necessary for calculating month-by-month inlet temperatures.

Loads modules are covered in detail in Chapter 3.

Design Modules

The GLD Geothermal Design Studio consists of the following three design modules:

- The **Borehole Design Module** – In fixed temperature mode, this module models the lengths of bore required for a vertical borehole exchanger system. In fixed length mode, it models the inlet temperatures for a user-defined borehole field length. Additionally, the borehole design module can model and graph the monthly inlet temperatures for the design (if monthly loads data have been input into the Average Block loads module).

- The **Horizontal Design Module** – This module determines the length of piping required for a horizontal/slinky exchanger system.

- The **Surface Water Design Module** - This module determines the length of piping required when a closed loop of pipe inserted into a body of water acts as the heat exchange medium.

All three modules utilize the same loads module formalism, and are linked to loads modules using the *Studio Link* system.

All three modules also include a new, expanded user interface function as can be seen in figure 1.2. By double clicking on any of the tabbed panels (Results, Fluid, Soil, U-Tube, etc.) an expanded calculation view appears which enables the designer both to see the calculated results immediately after any parameter has been modified and also to access the parameters that are most commonly adjusted during the design optimization process.

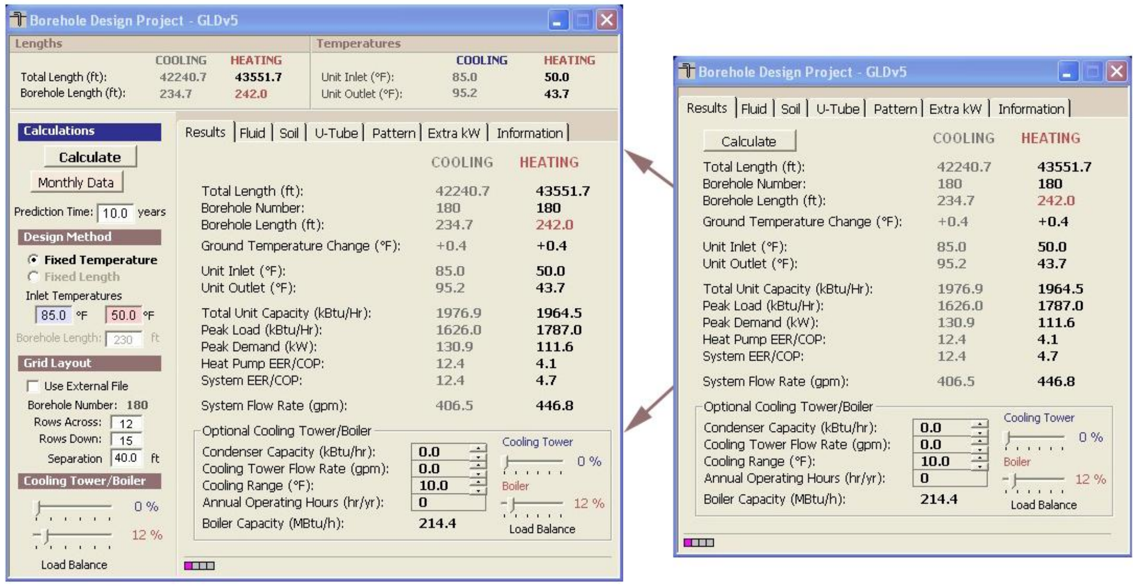


Fig. 1.2 Expanded Interface

Borehole Design Module

Description

The Borehole Design module allows the user to enter various parameters with respect to the desired vertical borehole system. Input is arranged in panels corresponding to the type of input as shown in figure 1.3. Key design parameters can be modified quickly in the expanded user interface as well (see figure 1.2, above).

Fig. 1.3 Borehole Design Panel List

Using these seven panels (*Results, Fluid, Soil, U-Tube, Pattern, Extra kW, and Information)*, the user enters the project-specific information.
After the user enters all parameters, the software calculates results based on the input data. Within this framework, it is straightforward and easy to make changes and conduct new calculations.

In Version 5.0, the Borehole Design module allows for two types of design methodologies: **fixed temperature** and **fixed length** designs. Fixed temperature designs should be familiar to users that upgraded from earlier versions of GLD. Fixed temperature refers to the design process in which users specify target inlet temperatures (designers set, or fix, the temperatures themselves) and then have the program calculate results such as the required bore length, the outlet temperatures and the coefficient of performance (COP), etc., based on the input data.

With fixed length designs, designers specify the required borefield length by inputting the number of boreholes in the design and then defining the borehole length (fixing the total design length) After entering these data as well as the other design parameters, the software calculates results such as, the inlet and outlet temperatures and the coefficient of performance (COP), etc., based on the input data. The fixed length feature is well suited for designing when land resources are limited, when a designer wishes to quickly reverse engineer a system, etc.

Additionally, when the borehole design module is linked to an Average Block loads module that has monthly loads data entered, the program can calculate and report monthly inlet temperatures for both fixed temperature and fixed length designs.

A more complete description about how to enter data and perform calculations in the Borehole Design module is provided in Chapter 4.

Theoretical Basis

To continue providing geothermal system designers with the widest range of flexibility, two separate theoretical models now are included within the GLD framework. The first model, and the original one used in all previous versions of the software, is based on the cylindrical source model and allows for quick but accurate length or temperature calculations based on limited data input. The second is based on a simple line source theory, but is more detailed in its ability to generate monthly temperature profiles over time given monthly loads and peak data. This second model is popular in some academic and institutional circles, and it is now included so that users can directly compare the two models' results using an identical input data set. Although the outputs of the two models do not always agree, they do give the designer more information on which to base a final system design.

The vertical bore length equations used in the primary model in the Borehole Design module are based upon the solution for heat transfer from a cylinder buried in the earth. The method was developed and tested by Carslaw and Jaeger (Carslaw and Jaeger, 1947). The solution yields a temperature difference between the outer cylindrical surface and the undisturbed far field soil temperature. Ingersoll suggested using the equation and its solution for the sizing of ground heat exchangers in cases where the extraction or rejection occurs in periods of less than six hours (where the simple line source model fails) (Ingersoll, 1954). The borehole module's equations include the suggestions of Kavanaugh and Deerman, who adjusted the methods of Ingersoll to account for U-tube arrangement and hourly heat variations (Kavanaugh and Deerman, 1991). It also employs the borehole resistance calculation techniques suggested by Remund and Paul to account for pipe placement, grout conductivity, and borehole size (Paul, 1997).

Additionally, the software calculates the amount of energy absorbed by or withdrawn from the ground using the load information collected from the individual zones and their relationship to the equipment selected.

The calculations find the conditions for long-term, steady state operation of borehole fields based on the desired heat pump inlet temperatures. In order to provide an optimum design and prevent system failure, the combination of parameters must allow for proper extraction or dissipation of energy from or to the earth at the location of interest.

For the first model, the most complete description of the calculations and input data can be found in Chapter 3 of the book, *Ground Source Heat Pumps - Design of Geothermal Systems for Commercial and Institutional Buildings,* by S.P. Kavanaugh and K. Rafferty, 1997. In extensive tests, this model consistently proved to be the most accurate when compared with calibrated data from actual installations (Hughes and Shonder, 1998).

The second model within the Borehole Design module is based on the solution to the purely heat conductive problem in a homogenous medium, which was solved by approximating the borehole as a finite line sink (Eskilson, 1987). The steady state solution relates to the case where heat is extracted continuously from the borehole without ever exhausting the heat source, making it a fully renewable source of energy.

As implemented in GLD, the difference between the second model and the first is that with the second model, it is possible to calculate the evolution of the borehole wall temperature over time when a constant heat extraction rate (Q) is extracted from the borehole. It makes use of a dimensionless "G-function" concept to model the temperature variations, taking into account the ratio of the borehole radius and length and the physical layout of the bore field. GLD also employs its own internal borehole superposition model, allowing users to define the borehole layout in a gridfile, import the gridfile into the program and then automatically determine the required G-function.

Because of increased data entry requirements for the monthly and peak loads data in the second model, it is only applicable when used in conjunction with the Average Block Loads module (where only one set of monthly loads data is required per installation). Use of the Zone Manager is limited to the original cylindrical source theoretical model. The other design modules currently do not make specific use of the monthly loads data except in the reduced, “equivalent hours” form.

Horizontal Design Module

Description

The Horizontal Design module, similar to the Borehole Design module, allows the user to enter parameters necessary to describe a horizontal buried pipe and trench configuration. Again, the interface is arranged in panels corresponding to the type of input. Key design parameters also can be modified quickly in the expanded user interface as well (see figure 1.2, above).

After the user enters all parameters, the software calculates results such as the required trench and pipe lengths, the inlet and outlet temperatures, the coefficient of performance (COP), etc., based on the input data.

The input information is organized into seven panels, as shown in figure 1.4.

Fig. 1.4 Horizontal Design Panel List

Using these seven panels (*Results, Fluid, Soil, Piping, Configuration, Extra kW, and Information)*, the user enters the project-specific information.

A more complete description about how to enter data and perform calculations in the Horizontal Design module is provided in Chapter 5.

Theoretical Basis

The horizontal trench length equations used in the Horizontal Design module are based upon the Carslaw and Jaeger solution for heat transfer from cylinders buried in the earth, as described in the single vertical case above. Again, this method properly models shorter time periods of heat extraction or rejection, where the simple line source model fails. Since a number of pipes may be buried in close proximity, this model must be modified to account for all mutual pipe interactions. A major benefit derived from using this model, besides its ability to accurately assess heat-transfer, is that both the horizontal and the vertical design modules can operate under the same loads formalism.

In 1948, Ingersoll and Plass demonstrated that the Kelvin line source theory could be used to estimate the change in temperature of a buried pipe in which heat is being absorbed or rejected (Ingersoll and Plass, 1948). In a ground coupling system, an apparent thermal resistance between the circulating fluid and the undisturbed ground dominates the overall resistance. In 1985, in the *ASHRAE Design/Data Manual for Ground-Coupled Heat Pumps,* Parker et. al. outlined a method by which this "field resistance" or "soil resistance" could be estimated and applied to determine piping and trench length requirements for a buried pipe system. In the case of horizontal pipe systems located near the ground surface, the mathematics necessitate the inclusion of "mirror image" pipes into the calculations. These "mirror image" pipes are located the same distance above the surface as the buried pipes are below it. In a multiple pipe system, the soil temperature in the vicinity of any single pipe is determined by both the undisturbed earth temperature and by the thermal interference from other pipes in the same and in adjacent trenches. (Parker, Bose, and McQuiston, 1985).

The current Horizontal Module effectively employs a combination of the cylindrical model of Carslaw and Jaeger and the multiple pipe methodology of Parker et. al. Additionally, as in the Borehole Module, the equations also include modifications suggested by Kavanaugh and Deerman that adjust the methods of Ingersoll to account for physical arrangement and hourly heat variations (Kavanaugh and Deerman, 1991). However, time-step-based rates of rejection and extraction also previously were discussed in some depth by Parker et. al.

The two "Slinky" options available on the Configuration panel partially are based on the above formalism. Because of the complexity of the solution to the heat transfer equation for coiled loops of pipe, the design procedure used for the "Slinky" options is actually only a theoretical approximation. This approximation is recommended in *Closed-loop Geothermal Systems: Slinky Installation Guide* and is based on a specific set of tests conducted on 36" diameter Slinky coils (Jones, 1995). In the approximation, the program first calculates the total trench length required for a single U-Tube buried at the specified trench depth. It then divides the calculated length by 250 ft and multiplies the result by a factor determined from both the run fraction and the Slinky pitch (distance between adjoining loops). The horizontal Slinky configuration employs the same calculation procedure as that of the vertical. However, in the case of the horizontal Slinky, the U-tube depth is lowered such that the average depth of the vertical Slinky would be equal to that of a flat horizontal Slinky. The pitch and run fraction function is obtained from a two-dimensional interpolation over the surface determined from the experimentally determined data points provided in the Slinky manual.

Surface Water Design Module

Description

The Surface Water Design module allows the user to enter various parameters concerning the body of water (lake, pond, river, etc.) system. As in the Borehole Module, inputs are arranged in panels that relate to the type of input. After the user enters all parameters, the software calculates the required pipe length, the circuit number, the inlet and outlet temperatures and the COP, etc., based on the design specifications. Again, within this framework, it is straightforward to make changes and recalculate results, especially when using the expanded user interface.

The input information is organized into seven panels, shown in figure 1.5.

Fig. 1.5 Surface Water Design Panel List

These seven panels include *Results, Fluid, Soil, Piping, Surface Water, Extra kW* and *Information*. The panel names and many of the panel input parameters differ from those of the Borehole Design module.

A more complete description about how to enter data and perform calculations in the Surface Water Design module is provided in Chapter 6.

Theoretical Basis

To determine the length of pipe necessary for different surface water systems, experiments were conducted for different size pipes in coiled and "slinky" configurations for both heating and cooling modes (Kavanaugh, 1997). GLD uses a polynomial fit of this experimental data to determine the amount of pipe necessary for different loading conditions.

Additionally, coefficients are used to take into account the effect of the heat transfer in the lengths of the header and the branch piping that are in both the water and the soil between the installation and the submerged circuits. The program combines all factors so that the loop system provides the source inlet temperature at the heat pump requested by the designer.

Because the circuit layout is of primary importance to the designer concerned with pumping losses, the head loss estimation feature for different piping configurations is included in the Surface Water Design module. Users can quickly explore different layouts to determine the optimum design in terms of both heat transfer and circulation pump energy losses.

A description of some of the calculations and the input data can be found in Chapter 7 of the book, *Ground Source Heat Pumps - Design of Geothermal Systems for Commercial and Institutional Buildings,* by S.P. Kavanaugh and K. Rafferty, 1997.

Financial Module

The financial module is the newest module in GLD. The finance module models both “hard” and “soft” costs associated with geothermal and standard HVAC systems, enabling designers and decision makers to compare simultaneously the financial profiles of geothermal and standard HVAC systems. See Chapter 9 for a full description of the financial module.

Additional Modules

GLD’s Design Studio has the potential for additional modules that may be included in later versions. These modules would also be able to take advantage of the Design Studio’s heat pump and loads models.

Reports

GLD’s reporting features allow the designer to make hardcopies of both the data entered and the resulting calculations. These reports are design records, and are valuable when communicating the design to others involved in the projects.

Project Reports

Every design module has associated project reports, which can be printed at any time from the Design Studio desktop. The project report contains all the project information, and includes the parameters chosen, the calculation results, and the name of the zone file used. Both concise and detailed versions of the report are available.

Monthly Inlet Temperature Reports

Monthly inlet temperature reports can be printed from the Design Studio desktop after calculating inlet temperatures in the borehole design module. The reports contain heat transfer, power, borehole temperature, Tf (fluid temperature), exiting water temperature, entering water temperature, minimum entering water temperature and maximum entering water temperature for each month of the design. The four reports include a concise temperature report, a detailed temperature report, and a report that offers all project parameters, loads data and temperature data and a report that offers project parameters and loads data.

Zone Reports

A ‘print’ button in the loads modules allows the designer to print the loads-related information in various formats. Because the zones contain information about the zones, the loads, and the equipment, it is often necessary to obtain reports of the information in separate as well as combined documents.

For example, at one time, a designer may want to quickly see all of the zones with their loads and corresponding equipment. At other times, the designer may only need to see a list of the equipment for each zone. GLD offers five different zone report options including:

- A concise zone report
- A detailed zone report
- An equipment list report
- A loads report
- A zone names report

Finance Reports

A ‘print’ button in the finance modules allows the designer to print the finance-related information in various formats.

GLD offers four different finance report options including:

- A concise finance report
- A detailed finance report
- A concise inputs report

- A detailed inputs report

Reports are described in detail in Chapter 7.

Data Reference Files

To access the data reference files the user must have an internet browser present in the GLD-enabled computer. The program will work without the browser, but the data reference files may not be accessible.

Metric and English reference files are included with GLD. These files aid in the correct verification and entry of the various parameters. The three main topics/design aids currently included under the *Tables* menu in the Design Studio are *Fluid Properties, Soil Properties,* and *Pipe Properties*. A convenient *Conversions* table with metric/English conversions in two different formats is included for reference as well. Reference files can be opened and left as open windows on the desktop, and the user can refer to them as necessary during the design process.

Realizing that designers and engineers have their own preferred resources, GLD employs the HTML browser model so that the user has ultimate control over the reference files. The designer simply creates a basic HTML file containing customized data, pictures, graphs, charts, etc. and then modifies the included top level HTML files to link to their pages. The system requires a very basic knowledge of HTML, but it offers an extremely flexible system for user customization.

Detailed information on reference files and sample HTML can be found in Chapter 8.

Program Help and Support

GLD contains a comprehensive, searchable database of help topics. Access this feature from the Design Studio *Help* menu. Through the *Help* menu it is also possible to access the latest web resources and updates. If these resources do not answer your question, please contact your vendor for support.

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Paul, N. *The Effect of Grout Thermal Conductivity on Vertical Geothermal Heat Exchanger Design and Performance.* M.S. Thesis, South Dakota State University. 1996.

CHAPTER 2

Adding/Editing Heat Pumps

To effectively use any of the design modules included with GLD, it is important to understand how the system models heat pump data. For the purpose of adding new or editing existing heat pumps to GLD's Heat Pump Database, the Add/Edit Heat Pumps Module is included as a separate module in the Design Studio. This chapter describes the theory of the module and gives an example of how to enter heat pump data. A more detailed example can be found online, and accessed through the *Help* menu web resources option.

Heat Pump Model

Description

For convenience, the Loads modules in GLD predict how heat pump characteristics will vary with changes in the input design parameters. If the designer changes the inlet source or load temperatures, or the system flow rate, the capacity and power data of the units may also change. The easiest and most accurate way of realizing these changes is to employ an internal model, which the software uses to update the pump data automatically. Using GLD, the designer can concentrate on the effects of variations without worrying about how the individual pumps in various zones will react to such changes.

The heat pump model employed in GLD reproduces the complete operational data of any particular unit when supplied with a few representative data points selected from across the range of interest. Data for each pump can be entered into the model and grouped together under manufacturer and series headings. The data need only be input once, and then can be used repeatedly for subsequent modeling sessions. Pump data is stored permanently in the '**pumps**' directory. Many popular pumps from major manufacturers already are included with the program.

In both heating and cooling modes, the *minimum* data required is the capacity and power variations with source inlet temperature. To increase the modeling accuracy, these same variations have to be included at a second flow rate. Even more accurate results can be obtained if correction factors are provided for variations in the load inlet temperature and flow rate. The level of accuracy depends both on the amount of data available and the time the designer wants to invest.

Note that GLD's heat pump module allows for both water-to-air and water-to-water pumps.

Theoretical Basis

Capacity and Power

Heat pump capacities and power requirements vary smoothly but significantly for differing source inlet temperatures. Three points taken along both the capacity vs. temperature and power vs. temperature curves are fit to a polynomial equation to model these variations. The resulting calculated coefficients are then used to generate capacity or power values for any given source inlet temperature.

The basic polynomial equation used for fitting has the form:

$$y = a + bx + cx^2,$$

where a, b, and c are the three coefficients calculated from the fitting routine. For the capacity case, 'y' represents the capacity and 'x' is the desired temperature. For the power-input determination, 'y' is the power and 'x' again is the temperature. **Be aware that these coefficients do change for metric and English units.**

The software stores coefficients for each pump, and then uses the coefficients with the source inlet temperatures chosen by the designer to determine the unit capacity and power.

Flow Rate

To model the effect of the source flow rate on the calculated capacity and power, data from a second flow rate are used. Generally speaking, with different flow rates the shape of the capacity and power curves does not change significantly, but is shifted up or down by a constant factor. This factor is determined for each of the three temperature data points and averaged over those input to obtain the linear flow factor, which is shown on the input screen.

Once the flow factor is determined, the linear capacity or power change per flow unit may be calculated. The program then calculates a new capacity or power at any specified flow rate using the initial values already known from the stored data.

If no data points are entered for a second flow rate, the flow factor is assumed to be the constant value of 1.0. This means that the capacity and power will not vary with changes in flow rate.

Considering the size of the variations (generally only a few percent), this simple model is accurate enough for most pumps. A completely accurate model of the flow rate variations for all possible pumps would require significantly more data entry.

Load Side Corrections

The GLD Edit/Add Heat Pumps module also can include corrections to the capacity or power that result from variations in the load side inlet temperature or flow rate. They are entered as correction factors across the desired temperature or flow range. The software again uses the polynomial fitting to model these correction factors. In these cases, a four-coefficient model is used to better model the types of variations that may occur. Three to five points are allowed as data input.

Again, if load side correction data are not included, there will be no capacity or power variations with load temperature or flow, and all correction factors will be 1.0, the standard value.

The load side temperature range will generally be considerably different for water-to-air and water-to-water pumps. GLD suggests different initial temperature ranges when the user chooses the water-to-air or the water-to-water pump type option.

Entering Data into the Add/Edit Heat Pumps Module

The user opens the Edit/Add Heat Pumps module from the Design Studio Heat Pumps menu. Note that one module can be open at a time.
When the module opens, there are two selection boxes present in the upper pane, while no pump data is displayed in the lower pane. In the left box, the user can choose to select either one of the manufacturers from the list of existing manufacturers or 'New Series'. If a manufacturer is selected, the associated list of pump series available for that particular manufacturer appears in the box on the right. When a series is chosen, the data for that series appears in the lower panel.

Creating a New Series and/or Manufacturer

If the user chooses 'New Series' from the manufacturer list on the left, the lower pane becomes active with another selection box that requests direction as to whether to use an existing manufacturer or to create a 'New Manufacturer'. After the user makes a selection, the panel changes to show information about the manufacturer and series. The manufacturer information will be editable if the series belongs to a new manufacturer. The Edit/Add Heat Pumps module with an open 'Pump Information' panel is shown in figure 2.1.

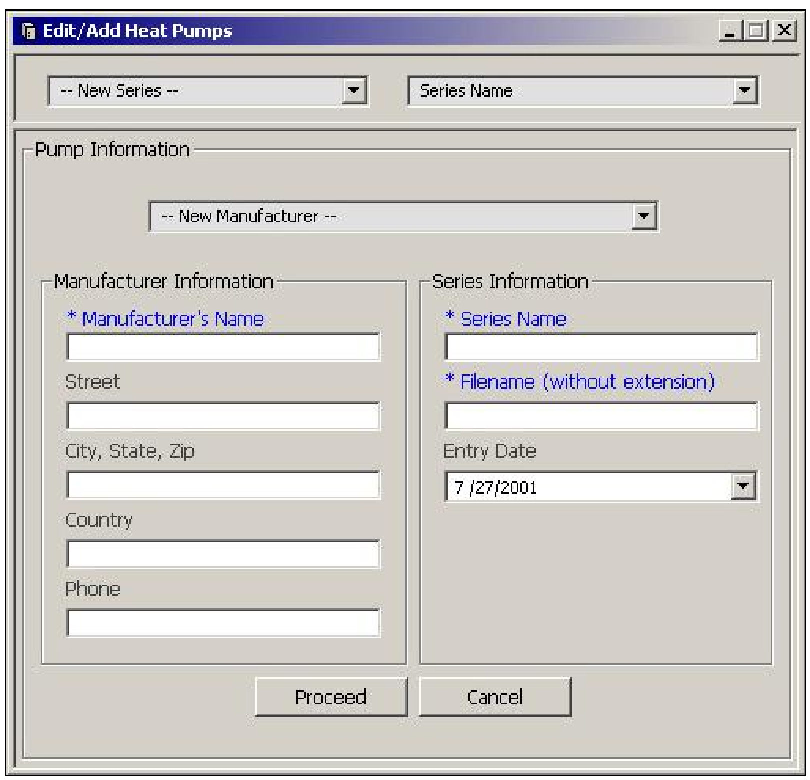

Fig. 2.1 Pump Information Panel

After the user enters all the data and clicks the 'Proceed' button, all of the information for the series being added will be stored in the **Pumplist.gld** file. **Note that the information marked with an asterisk must be included before the user is allowed to proceed.**

Editing Pump Data

Once the new pump series information is entered, or an existing pump series is selected from the upper pane, the Pump Edit pane will appear in the lower pane of the Edit/Add Pumps module, as shown in figure 2.2. There are two sub-panes. The left sub-pane is a list of the pumps already included in the series. The right sub-pane is a series of tabbed panels that contain the data for each pump on the list. In the case of a new series, both the list and the panel section will be empty until a new pump is created. The name of the current manufacturer and series are shown in the selection boxes in the upper pane.

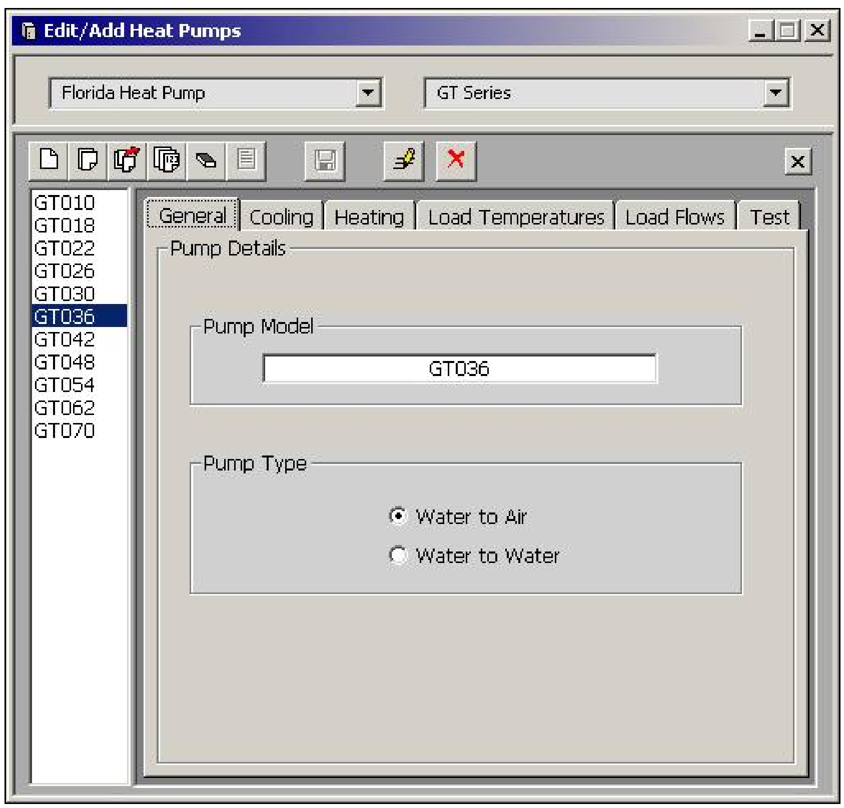

Fig. 2.2 Pump Edit Pane

Pump Series Controls

The Pump Series control buttons, shown in figure 2.3, are found above the list and the pump data panels. They include the Pump Edit controls (*New*, *Copy*, *Remove*, *Reorder*, and *Clear*,) the pump *Save* control, the *Edit Pump Information* control, and the *Delete Series* control.

Fig. 2.3 Pump Series Controls

Pump Edit Controls

The Pump Edit Control buttons are designed to work directly with the pump list. New pumps are added by pressing the *New* button. Copies of existing pumps are added with the *Copy* button. *Remove* is used to remove a pump from the list. *Reorder* is pressed to reorganize the list, both alphabetically and numerically. *Clear* is used to delete all pumps from the current list. **Be careful not to accidentally delete pumps.**

Save Control

The *Save* control button can be used at any time to save the current pump information.

Edit Pump Information Control

The *Edit Pump Information* control button allows the user to edit both the series and the manufacturer information for a given pump. **Note, however, that if the manufacturer information is changed, it will change for every series connected to that manufacturer.** 'Proceed' or 'Cancel' will return the user to the Pump Edit Pane.

Delete Series Control

The *Delete Series* control button deletes the current series. If the series is the only series of a manufacturer, the manufacturer also will be deleted automatically.

Note: The actual heat pump file (.hpd) will not be deleted from the* ***pumps*** *directory. If necessary, the series can be restored by creating a 'New Series'. The user need only provide the appropriate manufacturer and series name, and use the deleted '.hpd' filename for the pump set 'Filename'. Incomplete fields will be recreated from the *.hpd file. If the original file no longer* *exists, the program creates a new *.hpd file. Incidentally, the same system can be used to add new pump sets obtained from external sources as described below.*

General Information

The General panel is the first panel a user sees when he or she decides to input data for a new pump. It has an input box for the name of the pump, and in the 'Pump Type' area, the user selects whether the pump should be classified as a water-to-air or a water-to-water pump. An example of the pump *General* panel is shown in the lower right pane of figure 2.2.

Capacity, Power, and Flow Rates

The capacity, power, and flow rate information pertaining to the source side flow for both heating and cooling are entered into the two tabbed panels labeled *Cooling* and *Heating* in the Pump Edit pane. An example of the *Cooling* panel is shown below in figure 2.4. The *Heating* panel follows an identical format, although the temperatures will be different.

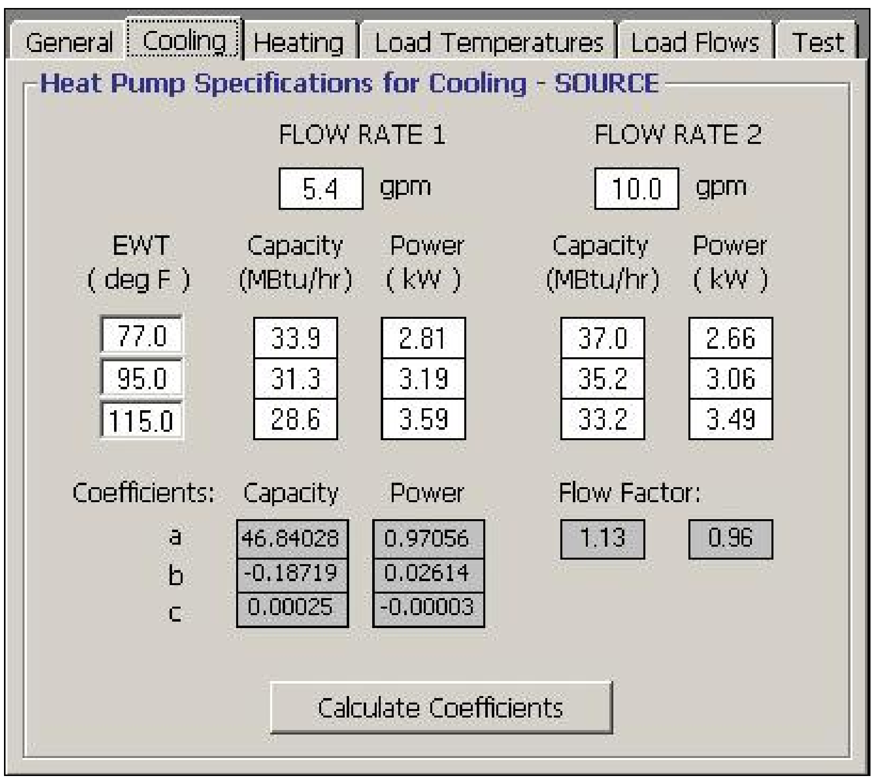

Fig. 2.4 Heat Pump Specifications – Cooling

As can be seen from the figure, the source entering water temperature (EWT) is listed to the left, and the capacity and power requirement of the unit at different flow rates are listed to the right. Once the values are input, the coefficients and flow factor can be calculated from the entered data. The *Calculate Coefficients* button turns red when values are changed, indicating that new coefficients must be calculated before proceeding.

Note: If data for only one flow rate are available, only the first capacity and power requirement data must be included, under the section entitled 'FLOW RATE 1'. The data under 'FLOW RATE 2' can be left as zeroes, and the program will ignore them, leaving the flow factor as 1.0.

Load Side Corrections

Corrections resulting from variations in inlet temperatures and flow rates on the load side can be entered in the *Load Temperatures* and *Load Flows* tabbed panels of the Pump Edit pane. If these corrections are not added, the factors remain at 1.0 and input variations in load temperature or flow rate will have no effect on calculated capacities and/or input power. Time permitting, however, it is best to include as much information as possible from what the manufacturer provides.

Load Temperatures Panel

The *Loads Temperatures* panel is where corrections for variations in the load inlet temperature are input. Both the cooling and heating information (taken at the average or standard source temperature and flow rate, and the average load flow rate) are entered on the same panel, an example of which is shown in figure 2.5.

The factors shown in figure 2.5 were calculated from a manufacturer's list of capacities provided for the different temperatures, using the capacity at the selected temperature as the numerator and the capacity at 67°F for cooling (70°F for heating) as the denominator. The 67°F (70°F) capacity values were those used for the inlet source data on the *Cooling* and *Heating* tabbed panels described previously. Occasionally, manufacturers will provide capacity values at the standard temperature with a table of correction factors that can be entered into the GLD *Load Temperatures* panel directly.

Notice how in figure 2.5 five points of data are included for cooling but only three are included for heating. The software requires a minimum of three data points for its coefficient calculation. More data may be input if desired. **However, no boxes may be left blank!** *Other temperature* ***and*** *coefficient values must* *be set to zero in this case.* As a convenience, '0' buttons are included to quickly set rows to zero.

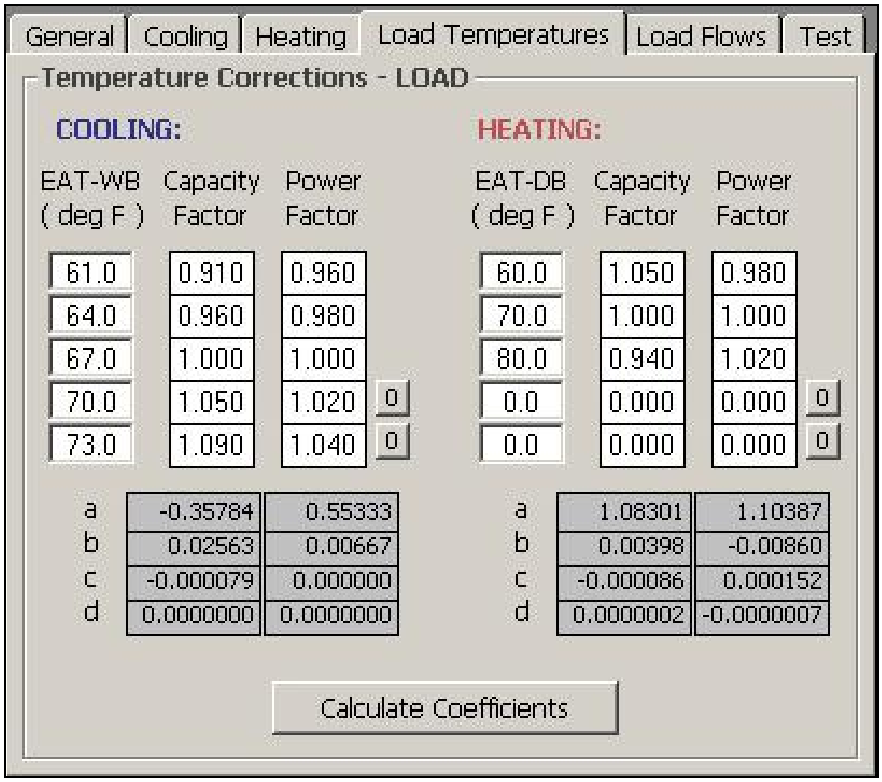

Fig. 2.5 Heat Pump Load Temperatures Panel

Note: If correction factors are unknown or unnecessary, they can all be left at the constant value of 1.0, which is the initial condition that exists when a new pump is first added.

Load Flows Panel

Similar to the *Load Temperatures* panel, the *Load Flows* panel allows the user to enter corrections for variation in load side flow rates. **The system used here is different, however**. Every pump is assigned a *nominal* flow rate, and the data is input as percentages of the nominal flow rate. A sample *Load Flows* panel is shown in figure 2.6.

To get a capacity factor at a flow rate of 80 percent of nominal, for example, the capacity of the unit at 80 percent of nominal would be divided by the capacity at the nominal flow rate. The procedure is identical for the power factors. Data is usually taken at standard source temperatures and flows, and at the standard load temperature. Quite often, the manufacturer provides lists of these variations that can be input directly.

Once again, a minimum of three points is necessary for the coefficient calculations, and '0' buttons are provided for quickly setting the unused rows to zero. **Remember - boxes must be set to 0 if they are not used!**

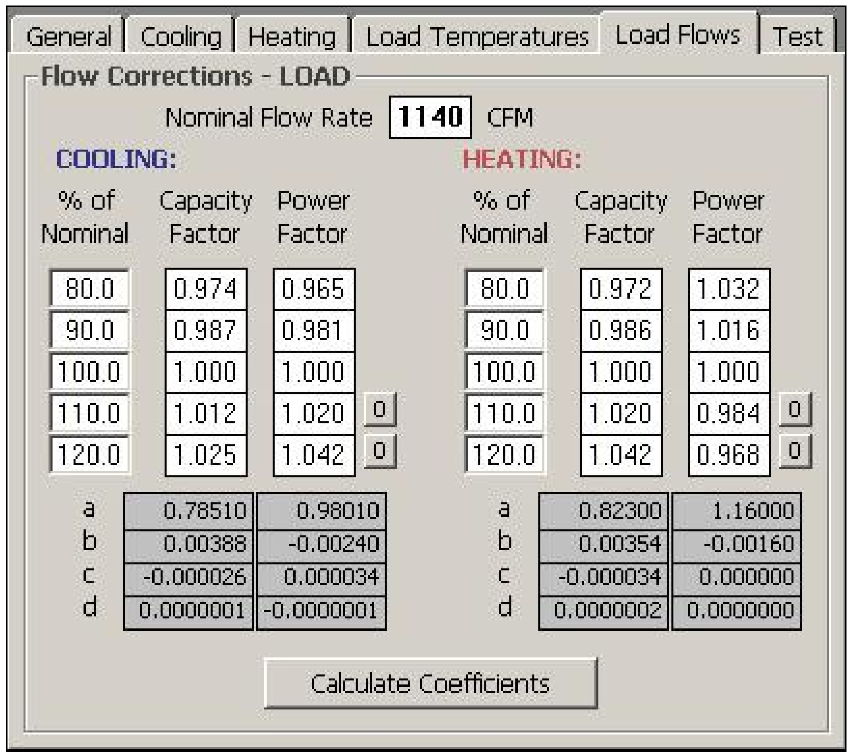

Fig. 2.6 Heat Pump Load Flows Panel

Testing Input Data

The *Test* panel is provided as a final check after a pump's data has been input into the Heat Pump module. Without testing the data directly, there is no way to know if mistakes were made during the input process.

A sample Test panel is shown in figure 2.7. As can be seen from the figure, both source and load entering water and air temperatures, as well as flow rates, can be edited directly. Clicking the "Test" button performs the calculation to see what capacity, power, and EER/COP result from the chosen input parameters. Average values are used initially, but by varying the parameters the designer can see how well the newly created model matches the data set used for data entry.

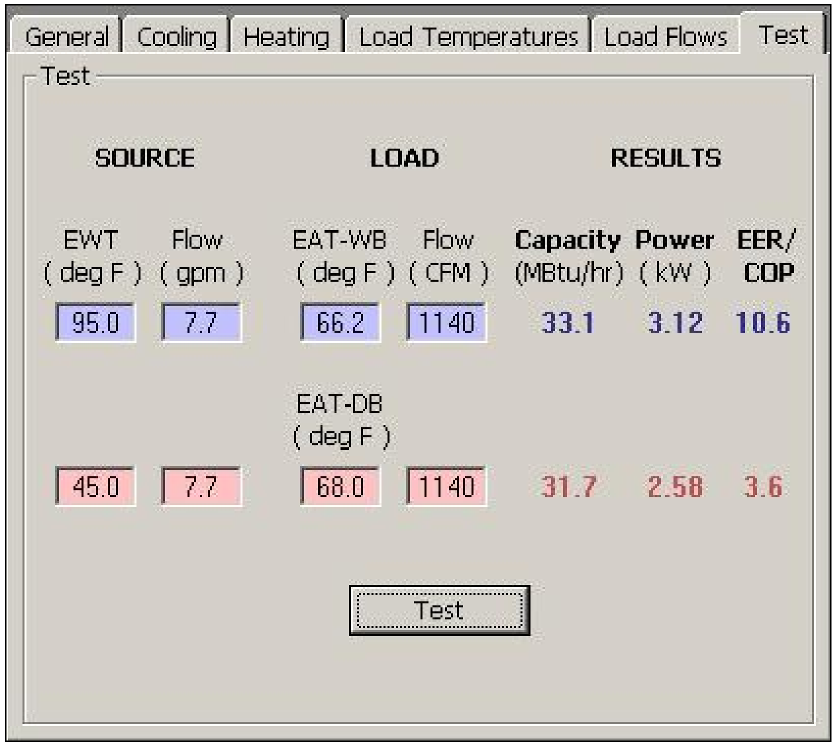

Fig. 2.7 Heat Pump Test Panel

Often, any input errors will be evident immediately from the test (by comparing the test results with the input sheet). Additionally, the user can use this test to make certain that the pump data are accurate over the particular range of temperatures, flows, etc. that he or she typically uses, and then modify the data if necessary.

Exiting the Edit/Add Heat Pumps Module

After editing or adding heat pumps, and calculating all necessary coefficients, the user should make sure that the pumps are saved by clicking the *Save* button on the Pump Series control bar. When the pumps are securely saved, the *Save* button will become disabled.

Clicking the close button in the upper right hand corner of the lower pane closes the Pumps Edit Pane, and clicking the close button in the upper right hand corner of the Edit/Add Heat Pumps window closes the Edit/Add Heat Pumps module. Closing without saving edited data will initiate a dialog box that reminds the user to save the data before closing.

Heat Pump File Descriptions

There are two types of files created by the Edit/Add Heat Pumps module. The first is the **Pumplist.gld** file, which maintains the current master list of manufacturers and the series associated with those manufacturers. The **Pumplist.gld** file also includes the filenames (without the '.hpd' extension) of the heat pump data files associated with the individual series.

The second type of file is the '.hpd', heat pump data file, for each individual series of pumps. This file type keeps track of all the data input by the user as well as the pump names and the coefficients calculated within the module. Since '.hpd' files cannot be deleted by the program (unless they are accidentally overwritten), many difficulties usually can be overcome by just adding new pump sets or, if necessary, editing the **Pumplist.gld** file directly. The format of the **Pumplist.gld** file is given in the Preface, page 3.

Adding Pump Sets Obtained From External Sources

To provide the greatest amount of flexibility to the user, GLD allows the user to obtain heat pump data files (*.hpd files) from external sources. For example, a heat pump set may be copied from a fellow designer, or even downloaded from a participating heat pump manufacturer's website.

Since the original **Pumplist.gld** file does not contain a reference to the externally obtained data set, it must be added manually. The procedure for this is as follows:

1. Place the '*.hpd' file into the **\GLD\pumps** folder.
2. Add a 'New Series'.
    a. If the series belongs to an existing manufacturer, choose the appropriate manufacturer.

    b. If the series belongs to an unlisted manufacturer, choose 'New Manufacturer' from the list.
3. Provide the 'Series Name' and 'Manufacturer Name', as required.
4. Under 'Filename', **type the *existing* filename** of the series to be added. Note- the existing filename is the *.hpd file the user just put into the pumps folder in step 1 above.
5. Click "Proceed".

GLD will open the heat pump file for editing and will include it in its Heat Pump Database. Additionally, if this is a new manufacturer, any included manufacturer information will become visible for this pump set. Since the **Pumplist.gld** file has been modified, it will register the new pumps for use in all modules opened afterwards.

Other Resources

For additional information and specific instructions on how to enter pump data step-by-step, please visit the following website:

http://www.gaiageo.com/webresources.htm

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CHAPTER 3

Loads and Zones

All of the calculations performed in GLD fundamentally are based on loads provided by the designer. This chapter describes the unique GLD loads system, and how to enter the loads in both the Zone Manager and the Average Block loads modules. Additionally, it explains the pump matching capabilities and operation both in automatic and in manual modes. At the end of the chapter there is an explanation of how to import external loads files as well as a brief review of the program's loads input methodology.

The GLD Loads Model

The intrinsic flexible nature of the GLD Geothermal Design Studio appears again in the loads models the software employs: the user is not limited to a single style of loads input. Similar to the design modules, a designer can choose between different types of loads input schemes based on the level of complexity he or she desires and the time he or she wishes to invest. These loads modules are then 'linked' to one or more design modules using the GLD Studio link system. Currently, two loads modules are available, the Zone Manager Loads module and the Average Block Loads module

The Zone Manager Loads module is provided for designers who desire a full analysis capability. Loads are input as separate zones, and each zone is matched with a particular pump. This mode is more valuable when users require thorough designs.

The Average Block Loads module offers a rapid system of entering whole systems information for users who do not require or desire to input the data for a fully zone-divided installation. Rather than matching specific pumps to each zone, the Average Block Loads module uses a particular, user-defined style of pump (or COP) and matches it in an average way to the entire installation. Although the input scheme is simpler, the design calculations are identical to those of the more complex Zone Manager Loads module. In fact, on average, if identical values could be placed in both the Zone Manager and Average Block loads modules, identical calculated bore lengths would result.

the Average Block Loads module optionally can accept monthly loads (total and peak) data. When the user inputs these data, the program can later calculate the monthly inlet temperatures in the borehole design module.

Zone Files

Zone (loads) files are stored as ***.zon** files in the GLD '**zones'** directory. They have a general format that can be read into any loads module, and they **can be used simultaneously** in different design modules. However, if this is done, it may be wise to save any changes under different filenames.

Both loads modules are stand-alone entities. **The files are entirely independent of project design files**. This means that an entire installation loading design can be entered, matched with pumps, optimized, and saved without ever opening a design module. This is valuable for users who wish to keep the loads entry and pump selection completely separate from the studio's geothermal design modules. Now users can work on designs and load inputs at different times, and can use the same loads files for various projects/styles of project.

New zone files can be created by clicking the '*New'* button in any loads module, or by clearing all of the current loads information with the *Clear* button, followed by the '*New'* button. The designer provides a filename when the zone file is saved.

Zone files can be opened and saved using the *Open* and *Save* buttons on the Loads panel.

The Zone Manager Loads Module

For commercial, non-centralized installations, it is often necessary to divide loads into separate zones that individually are served by specific heat pumps. This type of system has many advantages including lower installation and service costs as well as a highly accurate method of matching the loads to the heat exchanger. From the time-specific loads data that the user provides, GLD determines the maximum heating and cooling loads of the entire system, and then uses these values to calculate the length of heat exchanger required.

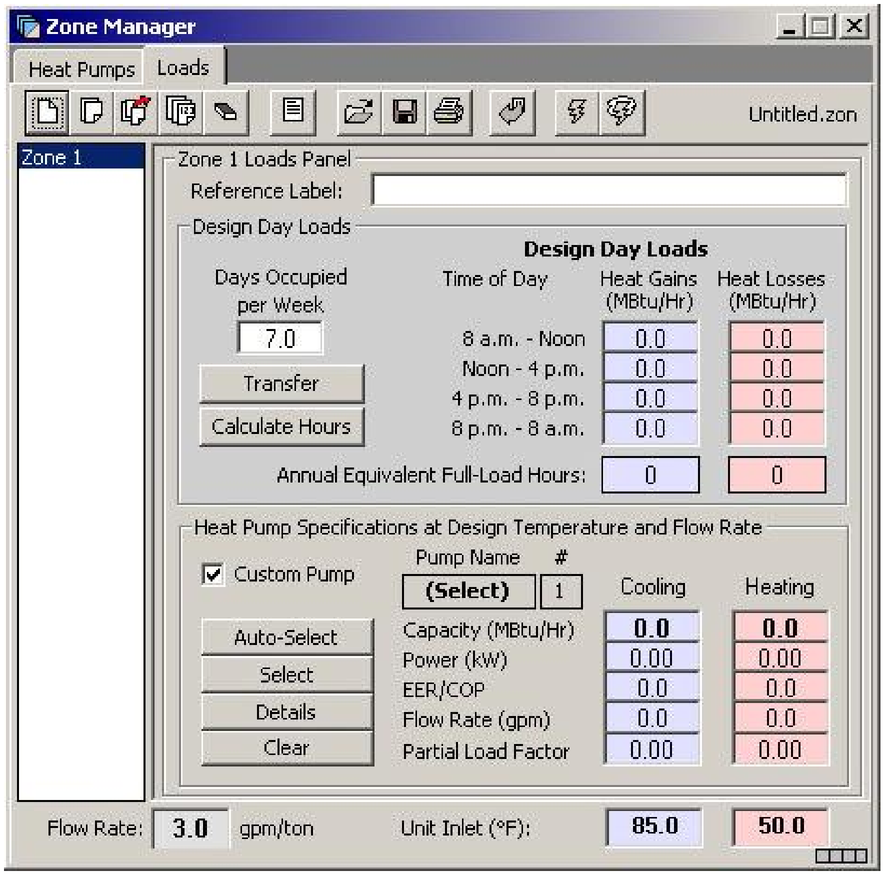


Fig. 3.1 Zone Manager Loads Module, Main View

The Zone Manager loads module can be opened either from the *Loads* Menu or by clicking the Zone Manager toolbar button. An example of the module opened to the *Loads* tabbed panel is shown in figure 3.1. The *Heat Pumps* tabbed panel will be discussed shortly.

In the *Main View*, Zones in GLD are organized in a list on the left side of the *Loads* tabbed panel. Each zone panel contains information relating to the working zone, including a zone name, the loading information, and the information about any heat pumps selected for that zone. Selecting a different zone name in the zone list changes the working zone.

Using the list, the designer can bring up and modify any particular zone by clicking on its name. An essentially equivalent but more compact summary of the input data can be obtained in the *Summary View*, obtained by clicking on the *Summary View* toggle button. Different representations of zone data can also be printed as reports.

Managing Zones in the *Loads* Tabbed Panel

The buttons along the top of the *Zone Manager* are used to work with the zones. A closer view is shown in figure 3.2.

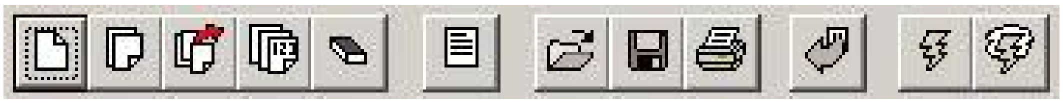
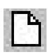


Fig. 3.2 Zone Manager Control Buttons

The five buttons on the left side are zone-editing controls, and they include *New*, *Copy*, *Remove*, *Renumber*, and *Clear*. A *Summary* view of all the zones can be obtained by hitting the sixth, or *Summary View,* toggle button. The next three buttons are the *Open* and *Save* buttons, for opening and saving the zone files, and the *Print* button, for printing various zone reports. The next button is the *Import Loads* button, a description of which can be found towards the end of this chapter under "Importing Loads Data from External Programs." The final two buttons on the far right are for pump selection across the entire set of zones, and include *Auto-Select All* and *Update/Reselect,* which are discussed in more detail below.

 *New* and  *Copy*

A new zone may be created at any time from the *Loads* panel by clicking the *New* button. Identical zones may be created from any existing zone by bringing up that zone's data window and clicking the *Copy* button.

 *Remove* and  *Clear*

Zones also can be deleted from the list. Any zone can be removed from the list by bringing up the zone's data window and pressing the *Remove* button. To delete all of the zones in the list, press the *Clear* button.

 *Renumber*

If several zones are added or removed from the list, click the Renumber button to reorganize the zones. This button renumbers the existing zones from one, starting with the first zone in the current list.

 Summary View Toggle Button

With the *Summary View* toggle button, the user can at any time simultaneously look at the group of zones. This view provides lists of the heat pump data in both cooling and heating modes as well as collective information about the set of chosen pumps. This information includes the peak loads and when they occur, and the total combined capacity, the peak demand, and the average efficiency of the selected equipment. Although individual pumps cannot be added or removed in the *Summary View*, changes made across the entire pump selection are directly observable. A sample *Summary* panel is shown in figure 3.3. Note that more than one type of pump series is listed.

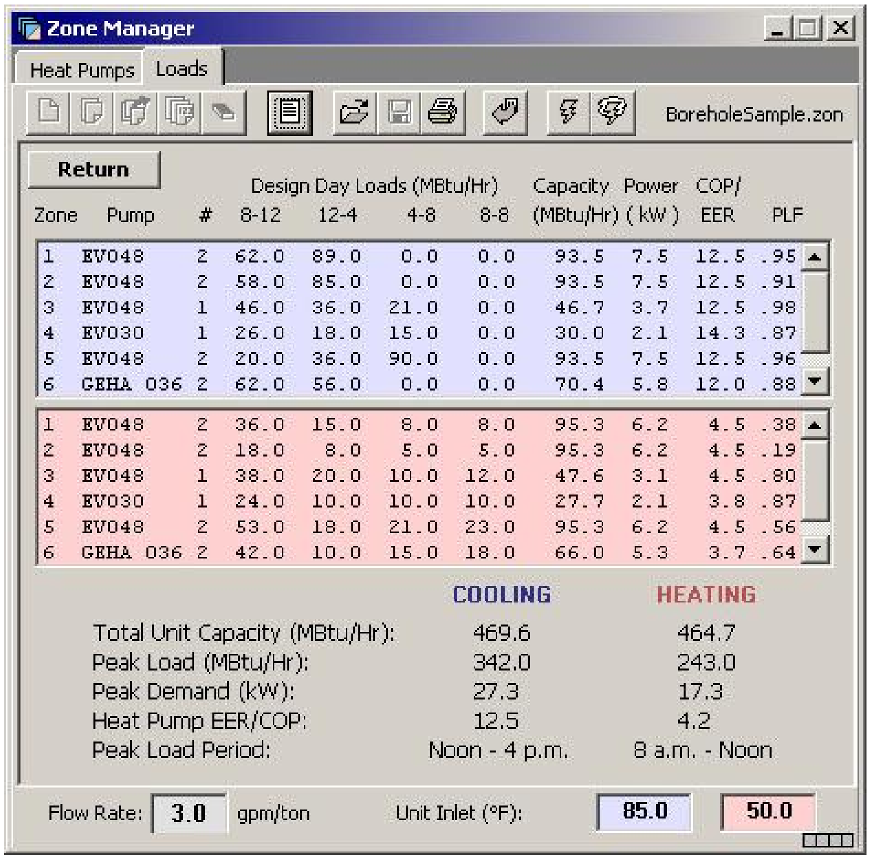


Fig. 3.3 Zone Manager Summary View

Entering Loads

Loads can be entered directly in the individual zone data windows back in the M*ain View* of the *Loads* tabbed panel. A sample entry is shown in figure 3.4. The GLD loads input methodology may be new for some designers. Consequently, an additional and alternative description of the methodology can be found at the end of this chapter.

Design Day Loads

According to the model that GLD uses, average peak load data for every hour of a twenty-four hour day can be included if desired. However, for simplification, average peak loads for the design day, or the day of heaviest usage in the year for both cooling (heat gains) and heating (heat losses) modes of operation, can be input for up to four separate times of the day. These include morning (8 a.m. to 12 noon), afternoon (12 noon to 4 p.m.), evening (4 p.m. to 8 p.m.) and night (8 p.m. to 8 a.m.). **This method of input not only provides the total load, but also identifies when the equipment will be in use for the heat exchanger calculations.**

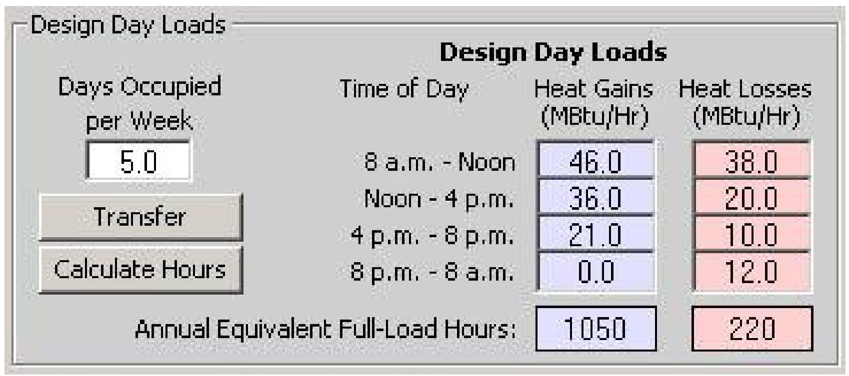


Fig. 3.4 Sample Loads Input Data

If only one peak value during the day is provided to the designer, it can be entered into one or several of the time slots, depending on how the loads will be expected to change during the course of a day. Slightly reduced values can be added for off-peak hours if the building still will be in operation but not at full load. Insignificant time slots can be left at zero.

Note: If only one peak load value is provided per zone, the designer will need to be consistent in placing it in the same time slot for every zone. This is because the software loops through all of the zones to determine which time of day has the highest loading requirements prior to performing its calculations.

If only cooling or only heating loads data are to be used, all of the non-used slots **should remain as zeroes**. Only the side with the loads provided will be calculated.

Annual Equivalent Full-Load Hours

The hours entered into the lower section of figure 3.4 are determined from detailed annual loads data for the system being designed. They represent the annual number of hours the system will be running if operating at full load, and are a measure of the system running time.
This system is used both to limit the amount of data the user must enter and to simplify the calculations. It is identical to methods that require input of all the

monthly data but more concise, since it represents the total energy input to the ground in terms of the peak load. Month-to-month variations are not necessary in the annual/monthly/daily pulse model used in GLD.

For example, if a loading report provides the number of Btus required by this zone each month, the hours per month will be obtained by dividing the monthly Btu requirement by the peak Btu/h value. The resulting number will be the monthly equivalent full-load hours. To get the annual full-load hours, the value will need to be obtained for every month that required heating or cooling, and then combined to finally get the annual equivalent heating or cooling hours.

TIP

If exact values are not available, an estimate should be made with regard to the expected running time of the unit in each particular zone. Estimates of time must be reduced, of course, from actual running time since the 'annual equivalent full-load hours' represents the running time if the system were operating continuously at full load, which is not generally the case.

Equivalent Hours Calculator

NEW

To aid in this calculation, GLD includes the *Equivalent Hours Calculator*, found in the *Tools* menu, or obtainable directly by clicking the 'Calculate Hours' button. Figure 3.5 shows a view of the Equivalent Hours Calculator.

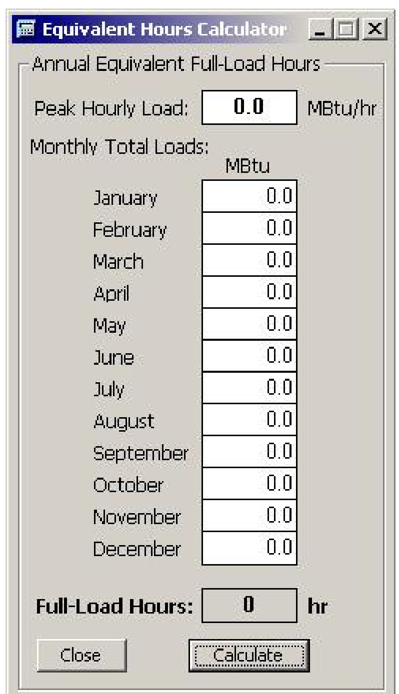


Fig. 3.5 Equivalent Hours Calculator

Remember that although the vertical bore length calculation results are not extremely dependent on the running hours within one zone for multi-zone designs, the total number of running hours across the zones can certainly affect the required bore length. The user should attempt to enter the running hours as accurately as possible.

Equivalent hours are unnecessary for a surface water design, since long-term buildup effects are unimportant. If a loads module is linked to a Surface Water Design module, the hours will not be visible.

Days per Week

This value represents the occupation of the installation, in days per week. The building in the example is only occupied during weekdays, so the value 5.0 was entered. Decimal values can be used for partial occupations, and the amount can vary between zones.

Again, the occupation is unnecessary for a surface water design, since long-term buildup effects are unimportant. If a loads module is linked to a Surface Water Design module, the days per week will not be visible.

Pump Matching and Selection

Every zone has heat pump equipment associated with it. Equipment matching and selection is done within the zone data window, in the lower section entitled, "Heat Pump Specifications at Design Temperature and Flow Rate". In this section, the designer has three choices when matching a pump to a zone:

- Automatic selection based on the active heat pump series
- Manual selection from a list of all available pumps
- Custom input of pump data

Once selected, the zone retains all of the information associated with the pump chosen. This information includes the pump name, the number of pumps, and the capacity, power consumption, EER/COP, flow rate, and partial load factor in both cooling and heating modes. If obtained from the list of available pumps, detailed information is also available, including the manufacturer and series name, the pump type, and the inlet load temperatures.

Figure 3.6 shows the pump selection section of the zone data window with sample data matched to the loads data of figure 3.4.

Several buttons can be found in the pump selection section. These include *Auto-Select, Select, Details,* and *Clear.* A checkbox is also included to indicate when the pump is a 'custom pump', or a pump not included in GLD's internal list of pumps.

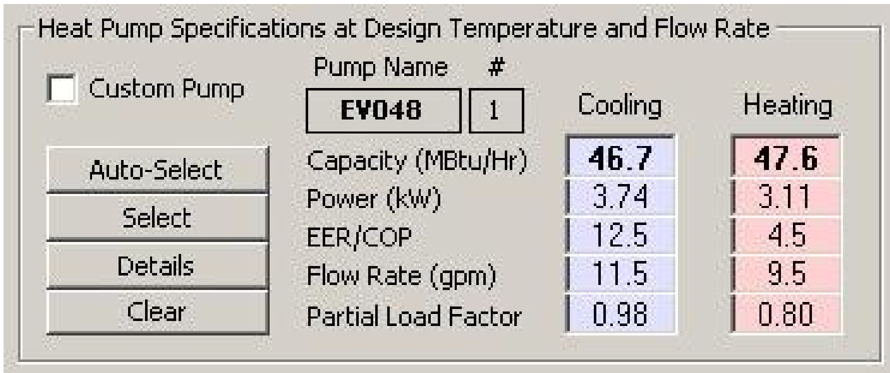


Fig. 3.6 Sample Pump Selection Section with Data

Auto-Select

This option is by far the easiest method of matching a pump to the loads in a particular zone. By clicking the *Auto-Select* button, GLD utilizes the information stored for the active pump series and determines which pump within the list is best suited to the zone in question. If the listed pumps are too small for the zone loads, the software increases the number of pumps of each size until an acceptable match is achieved.

The pump selection process uses information from the Zone Manager loads module. This includes the chosen inlet source temperature, the flow rate, the heat pump series, and the initial inlet load temperatures. The flows and load temperatures can be entered at the bottom of the module, and the active heat pump series and load temperatures may be changed on the *Heat Pumps tabbed* panel.

Manual Select

If an automatically selected heat pump is for any reason undesirable, or a different pump series from the same manufacturer, or even from a different manufacturer is required, the *Select* button may be used. This button allows the designer to choose any of the stored pumps. As with the *Auto-Select* button, all of the associated fields are calculated automatically once the pump is selected.

When the *Select* button is pressed, the selection panel appears, as shown in figure 3.7. After a pump is chosen, pressing *Select Pump* will place the pump in the zone and automatically calculate all of the associated parameters. *Cancel* will return the user to the main display without changing any pumps.

Note: Unlike with Auto-Select*, a pump that is manually selected may or may not match the loads in the zone. It is the responsibility of the designer to make sure the pumps match the zones.*

Fig. 3.7 Pump Selection Panel

Details

Specific details about a given pump may be obtained by clicking the *Details* button. Additionally, the details panel is where the designer may vary the loads input temperatures or flows for that particular pump. *After the user presses the return button, variations in the input load temperature will affect the pump parameters listed on the main pump selection area.* A sample details panel is shown in figure 3.8.

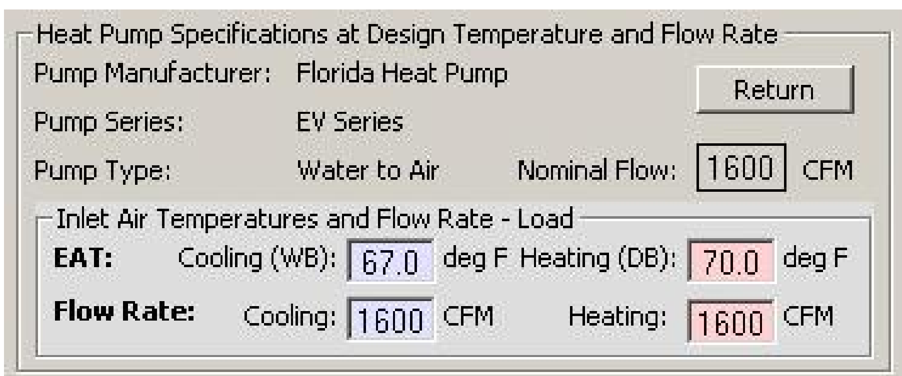


Fig. 3.8 Pump Details Panel

Clear

Pressing the *Clear* button clears the current pump in a zone. All values are reset to the initial state, allowing the user to reselect or enter a pump for the zone.

Custom Pump (Customization)

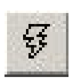
If the designer must include a heat pump unit that is not stored in GLD's Heat Pump Database, he or she may add customized pumps simply by entering values directly into the boxes on the pump selection section of the zone data window. When the user does this and overrides the automatic selection features, a check appears next to the "Custom Pump" label, indicating that the pump information is from an external source. The details section will no longer contain information about the pump manufacturer, series, or type.

The calculation portion of GLD will require at least the capacity and power data to utilize the pump properly. *The actual COP used in the calculations is determined from the capacity and the power, not the input text box.* Other information may be added for the designer's reference.

Note: When a custom pump is included, its values will remain unchanged during the designing process. ***Variations in inlet source or load temperatures, or system flow rate, will not affect a customized pump's data.***

Automatic Heat Pump Selection Options for the Entire Zone Set

Two controls are included with GLD that allow for an automatic selection of pumps throughout the entire set of zones. This feature is useful when the pump set needs to be compared or changed, or when modifications are required throughout the existing set. These controls are necessary so that large sets of pumps can be changed or updated without having to step through each individual zone.



Auto-Select All Pumps

The *Auto-Select All Pumps* control performs the same function as the *Auto-Select* button in the pump selection section of the zone data window, except it performs the selection sequentially through all of the zones. It uses the active heat pump series selected on the *Heat Pumps* tabbed panel.

Note: Auto-Select All Pumps *will overwrite all currently selected pumps,* ***including custom pumps***.

Update/Reselect Current Pumps

The *Update/Reselect Current Pumps* control reselects the pumps in all zones after determining the current series used in each particular zone. For example, if most of the pumps belonged to the same water-to-air series, but one was a water-to-water pump, this control would determine the difference and update the pumps accordingly.

Note: Custom pumps are not affected when the Update/Reselect Current Pumps *control is activated.*

Working Series Selection in the Heat Pumps Tabbed Panel

Figure 3.9 Shows the Zone Manager opened to the *Heat Pump* tabbed panel. This panel is used to specify the working series for all of the automatic selection features described for the *Loads* tabbed panel. In the *Heat Pump* tabbed panel, the user simply selects the pump series that he or she intends to use for the matching session. The selection may be changed at any time without affecting previously automatically selected units. **However, if the 'Auto-Select All Pumps' button on the *Loads* panel is pressed, every zone will be replaced with the current working series**. Additionally, in this panel the user may define an inlet load temperature to be used in any automatic selection.

Choosing the Active Series

The active heat pump series is the series of heat pumps used by the *Auto-Select* features in the *Loads* panel.

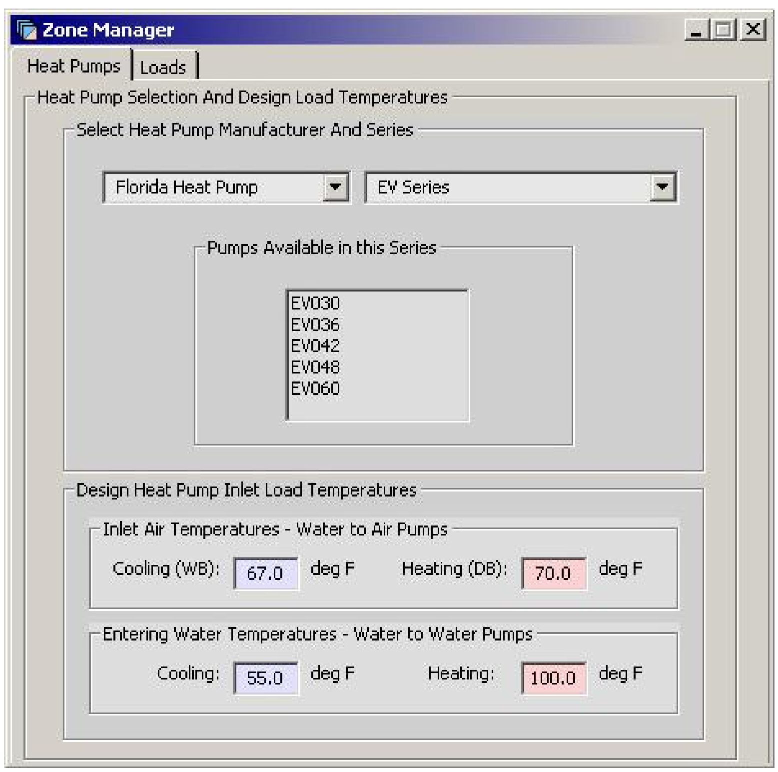


Fig. 3.9 Heat Pumps Tabbed Panel

It represents the primary heat pump family utilized by the designer for a particular project. Although this is the primary series, other pumps may still be selected for certain zones using either the *Select* button or by defining a custom pump. To choose a pump series, select a manufacturer, followed by the desired series of that manufacturer. A list of available pumps appears in the list box.

Inlet Load Temperatures

Values for the initial inlet load temperatures for both water-to-air and water-to-water pumps may be entered in the appropriate boxes. If necessary, these values may be changed for individual pumps in the *Loads* panel. For water-to-air pumps, 'WB' refers to "Wet Bulb" and 'DB' refers to "Dry Bulb" temperatures.

The Average Block Loads Module

If detailed zone-style modeling is unnecessary for an initial calculation, or if information is incomplete for a component-based design, or if the user desires to calculate monthly inlet temperatures for a borehole design, the Average Block loads module is a better option than the Zone Manager (and in the case of monthly inlet temperatures, the only option). The required input consists of only a single set of loads, which represents the entire installation. This single set of loads data optionally can be entered in a new month-by-month loads screen for inlet temperature calculations.

The pump matching model in the Average Block module is slightly different from the model for the individual zones. A single pump type is selected from the GLD Heat Pump Database to approximate the average pump characteristics of the installation. For example, if the designer is planning to use the highest efficiency pumps, a pump in a series with a higher coefficient of performance (COP) might be chosen over a lower efficiency pump. If specific pump characteristics are required, they can be input directly, overriding the automatic functions.

Two views of the Average Block Loads Module are shown in figures 3.10 and 3.11. Although it resembles a single zone in the *Loads* tabbed panel of the Zone Manager loads module, it has some differences: there is a monthly loads button, there is no list of zones, and the pump matching section has a different format.

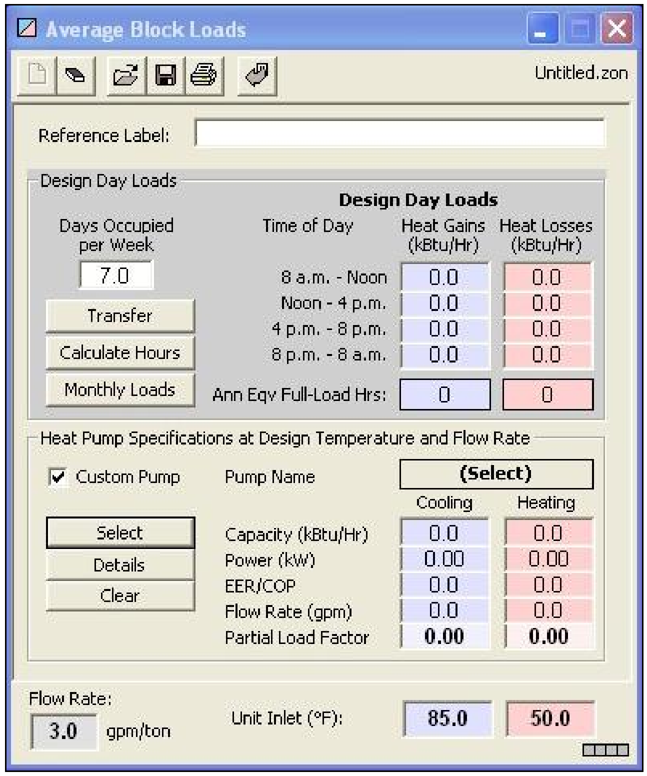


Fig. 3.10 Average Block Loads Module

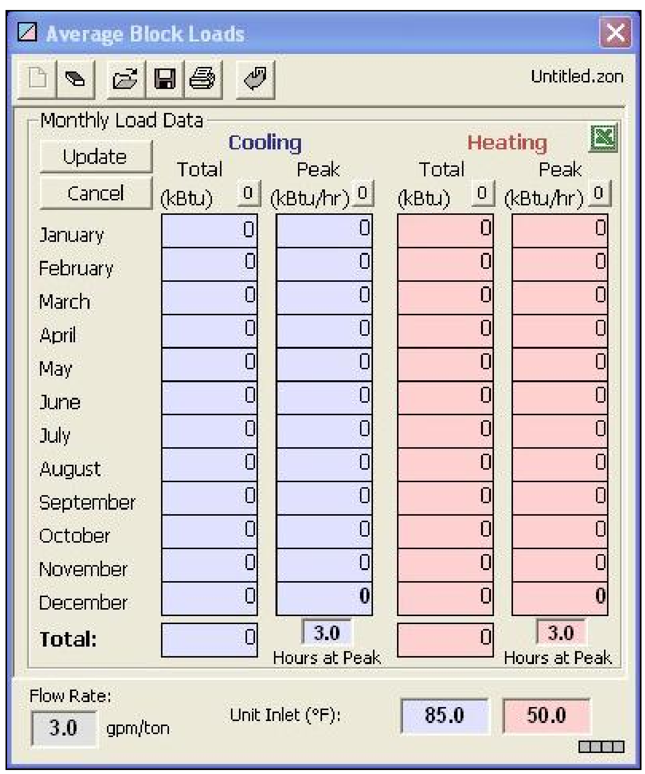


Fig. 3.11 Monthly Loads Input Boxes in Average Block Module

Managing the Average Block Loads

The buttons along the top of the *Average Block Loads* module are used to work with the single panel of loads information. A closer view is shown in figure 3.12.

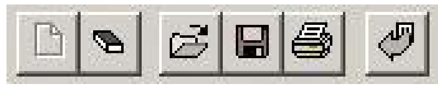
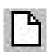


Fig. 3.12 Average Block Loads Module Controls

The buttons on the left are zone-editing controls, and include only *New* and *Clear*. To the right are the *Open* and *Save* buttons, for opening and saving the zone files, along with the *Print* button, for printing various zone reports. The last button on the right is the *Import Loads* button which is explained towards the end of this chapter. Unlike the Zone Manager, there are no Auto-Select buttons.

 *New*

A new set of loads data may be created initially by clicking the *New* button. Since only one panel is allowed, this button becomes disabled after a new set appears. It is re-enabled when the set is cleared.

 *Clear*

To delete all of the current information, press the *Clear* button.

Entering Loads

The method of entering loads data into the Average Block is nearly identical to the method used in the Zone Manager. There are two main differences. The first is that the summed loads values may be larger than the smaller values used in individual zones. Refer to the Zone Manager Entering Zones section or the end of this chapter for specific details about the *Design Day Loads*, *Annual Equivalent Full-Load Hours*, and *Days Occupied per Week* sections. Note that the Annual Equivalent Full-Load Hours can be calculated for the entire installation using the *Equivalent Hours Calculator*.

The second difference is that the loads data entry method has been expanded to accept monthly loads data. Monthly loads data are necessary for calculating monthly inlet temperatures in the borehole design module. **Note that adding monthly loads is necessary only if a designer wishes to calculate monthly inlet temperatures for a vertical borehole heat exchanger.**

Monthly Loads

To access the monthly loads data input panel as seen in figure 3.13, click on the *Monthly Loads* button.

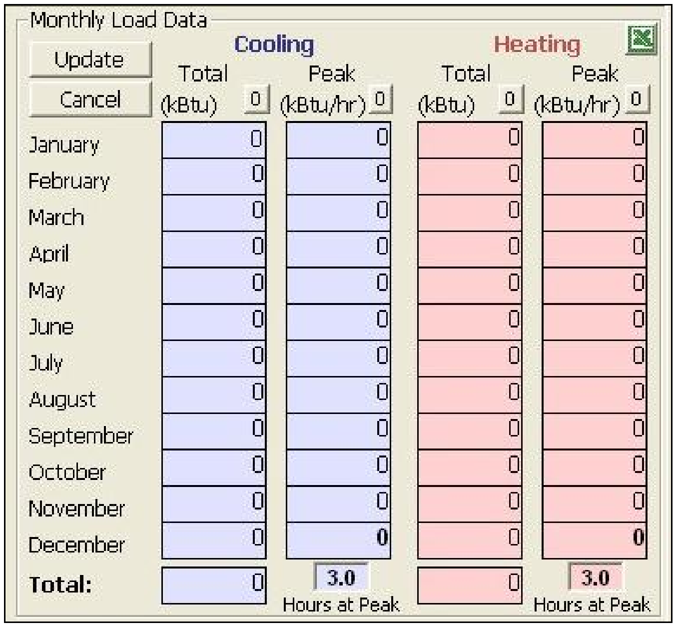


Fig. 3.13 Monthly Loads Input Boxes

There are three ways to enter the loads data:

- Manually enter the total and peak cooling and heating loads in the appropriate boxes.
- Copy and paste from Excel using the Excel icon button. See later in this chapter for how to format the Excel file. Note that with Version 5, formatting has changed!
- Import a commercial loads file or excel file using the loads import button (see below)

If necessary, hit the “zero box” at the top of each column to reset all values to “0”.

In the last row of the peak cooling and peak heating columns, there are two input boxes for the number of hours the system is expected to operate at the peak. The initial value is set at **3.0** hours and shown in bold face. Only the Monthly Data, or second model of the Borehole Design module uses this “Hours at Peak” value in its calculations. The other modules and models utilize the 4 or 8 hour time period already fixed in the Design Day Loads section.

After entering the loads data, hit the *Update* button to return to the main loads panel screen. Notice that the program automatically converts the monthly loads into the design day format following the calculations described on pages 65-66.

Pump Selection

Although the selection process is identical to selection in the Zone Manager loads module, the results are slightly different. Figure 3.14 shows the result after selecting a pump, and then modifying the *partial load factor* to 0.9 on the dominant load (Heat Gains) side.

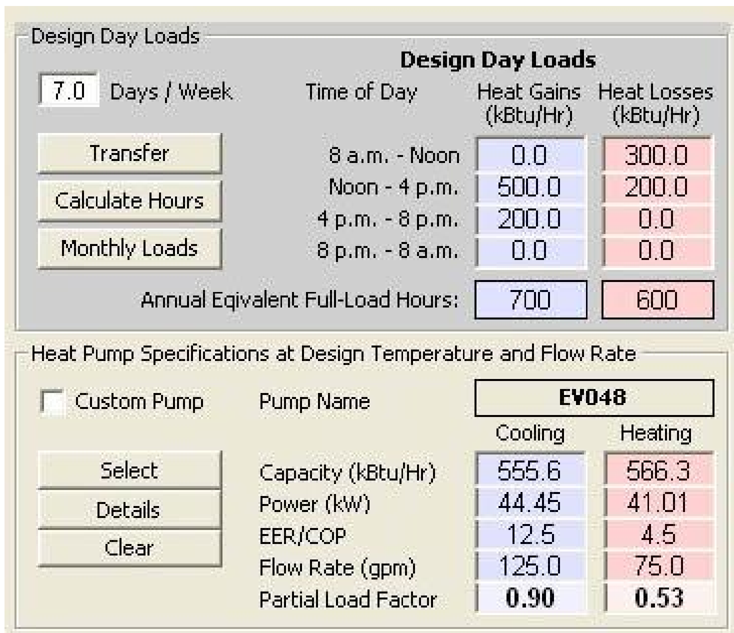


Fig. 3.14 Average Block Loads Pump Selection

In this case, an average pump was selected for the zone, and that pump was given a partial load factor of 1.00 for the dominant cooling side. Since the partial load factor, the ratio between the peak loads and the total equipment capacity, varies depending on designer preference, it can have any value of 1.0 or less. Additionally, the partial load factor will remain constant as the continuous update feature modifies the pump values due to changes in the temperature or the flow rate. The partial load factor plays a small role in the heat exchanger length determination calculations.

Details and Clear

The Details and Clear buttons and the Details panel operate in the same way as they do in the Zone Manager Loads module. However, one difference is that no variation of the load flow rates is permitted in the Details panel.

Custom Pump (Customization)

Checking the Custom Pump check box allows an override of all automatic pump selection features. The user can input any data desired, although once again the COP used in the calculations is calculated from the capacity and the power, not taken from the text box list.

Pump Continuous Update Feature

The *Update/Reselect Current Pumps* control is called automatically when changes are made to either the inlet source temperature or the system flow rate from within the Zone Manager, the Average Block Loads module, or the design modules. In this way, the designer does not have to worry about updating the pumps already matched to zones in GLD.

However, the designer must be aware that sometimes this may result in a new pump size assignment due to capacity changes related to variations in temperature or flow. If this is problematic, custom pumps may be used to lock pump values into a zone. However, for proper modeling, any customized pumps must be edited separately by the designer after the design parameters have been established.

The Studio Link System

The *Studio Link* system is a powerful feature in GLD that gives users the ability to link or to unlink the loads modules to or from the design modules. When a loads module is linked to a Borehole, Horizontal or Surface Water Design module, all of the data in that loads module is transferred to the design module. Once the connection is established, the pertinent information is stored within the design module, which makes transfers in from or out to the loads module as necessary. Since the information is now held in the design module, it is possible to add multiple design modules with only a single loads module open. When studio links are established, the information shown in the loads module will correspond to the active design project.

As long as a link is active, design modules retain information about the type of link and the filename of the associated zone '.zon' file. This information is stored in saved project '.gld' files, so that the appropriate loads module can be opened and loaded when a project file is opened.

 Making a Link

The most direct method of making a link between a loads and a design module is to open both modules to be linked, activate (click on) the design module, and then press the 'Link' button on the toolbar. Another option is to choose "Link" from the GLD *Loads* menu. If there is only one type of loads module open, a link will be established with that module. If more than one type of loads module is open, GLD will query the user for his or her linking preference.

Alternative systems for linking exist, but they are more indirect. For example, if only one unlinked design module is present, a link may be established from any open loads module, since GLD automatically recognizes the user's intention. If more than one unlinked design module exists, however, pressing the link button from an active loads module will have no effect.

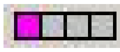
The link status lights in the corners of the modules indicate when a link has been formed. Colors indicate the type of link. Link status lights are described in more detail below.

 Unlinking

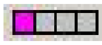
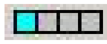
To break a link between modules, simply activate (click on) the design module to be disconnected and click the 'Unlink' button on the toolbar. Equivalently, the user can choose "Unlink" from the GLD *Loads* menu. The link will be broken, and all related loads information for the design module will be cleared. However, the information still exists in the loads module, and can be recovered by linking again if necessary.

If only one design module is linked to a particular loads module, unlinking from the loads module is also possible. If more than one linked design window is open, however, clicking the unlink button from a loads module will have no effect, since GLD cannot determine which project should be disconnected.

The link status lights in the corners of the modules indicate when links are broken. Link status lights are described in more detail below.

 Studio Link Status Lights

Studio Link status lights are used to indicate when links are made, when data transfer occurs, and when links are broken. They are located in the lower left hand corner of the design modules, and the lower right hand corner of the loads modules.

  Connection Established - First Light from Left

The light furthest to the left indicates both whether or not a connection is established and the type of connection. If the light is off, no connection is established. Magenta indicates a link to an Average Block Loads module, while light blue indicates a link to a Zone Manager loads module.

 Receiving Data - Second Light from Left

The second light from the left indicates when the module is receiving data from the other module. It is green in color.

 Sending Data - Third Light from Left

The third light from the left indicates when the module is sending data to the other module. It is yellow in color.

 Broken Connection – Rightmost Light

The light on the right turns red whenever a connection is broken. It turns off again when connections are reestablished.

Importing Loads Data From External Programs

With GLD, users easily can import loads data from both commercial loads programs and Excel files directly into the loads modules. Import commercial loads programs data by clicking on the *Import* button found in both the Average Block and the Zone Manager loads modules and import Excel files data by using the ‘Import Loads’ command from the Design Studio *Loads* menu.

Since calculation programs express results in a number of different ways, GLD edits the input data so that it matches the Design Day formalism used in the Loads Modules. Occasionally, however, the data from external loads programs do not have the hour-by-hour level of detail that GLD can accept. In these cases, the designer or GLD must make modifications to the imported data to assure that the proper level of detail is retained. In this way the program can be certain to calculate the appropriate heat exchanger size. These modifications are explained later.

Using the Import Button for Commercial Loads Programs Files

To import a file from a commercial loads program, the user can click on the Import button from any loads module. This automatically opens the file dialog box in the "zones" folder, and displays all files that can be imported. When the user selects a valid import file, the program automatically transfers the data into the current open zone of the active loads module. Note that any previously existing loads will be overwritten. At the same time the data is transferred into the loads module, an *Import Loads* window is opened, showing the imported data in detail. This window is shown in figure 3.15, and its corresponding loads entry is shown in figure 3.16. Note that in the Average Block loads module, imported monthly total and peak data are automatically imported into the monthly loads input boxes as seen in figure 3.13.

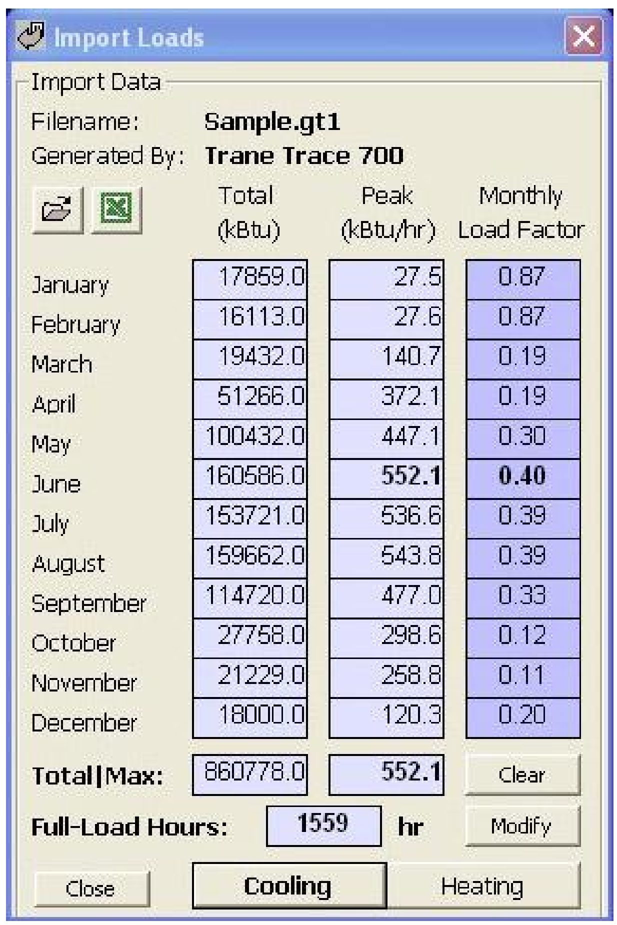


Fig. 3.15 Import Loads Window

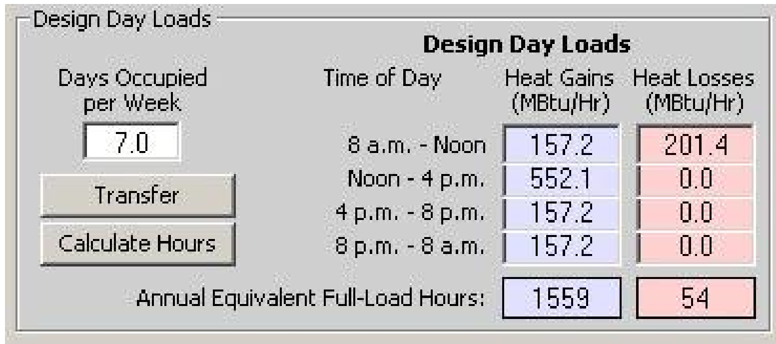


Fig. 3.16 Results of Importing

The Import Loads window displays the imported data, the filename, and the name of the program that generated the file. Total loads and peak demand data are presented on separate screens for cooling and heating. Use the buttons on the bottom of the window to toggle between the two. On the right is the monthly partial load factor, calculated by GLD. The data can be modified directly in the Import Loads window or by hitting the "Modify" button the user can open the file in the Equivalent Hours Calculator, where the data can be edited as well. The user can transfer the modified data into the loads module by pressing the "Transfer" button. When both the Calculator and the Import Loads windows are open, the program first will ask the user from which window, the Calculator or the Import Loads window, he or she wishes to transfer data. The program then prompts the user to decide to which loads, heating or cooling, the data should be transferred.

Using the Import Loads Command for Excel Data

The easiest way to import data from an Excel file is by using the 'Import Loads' command found in the Design Studio *Loads menu*. Select 'Import Loads' and an Import Loads window similar to that in Fig 3.13 will appear. GLD expects the Excel data to be in the following column order and units. Note that GLD can accept a maximum of 12 data rows per column. **Also note that the column order is different from the column order in previous versions of GLD**:

Month	Total Cooling	Peak Cooling	Total Heating	Peak Heating
	1000 BTU	1000 BTU/hr	1000 BTU	1000 BTU/hr
January				
…				
December				

To import the Excel data, simply highlight the four columns in the Excel spreadsheet and copy them onto the clipboard (Ctrl-C). **Note: highlight only the numeric data. DO NOT highlight the column and row descriptions.** Then in the Import Loads window click on the *Excel* icon. The data will be imported. Data can be modified (if necessary) and transferred into the loads modules following the method described above in "Using the Import Button for Commercial Loads Programs Files."

TIP

Note that it is possible to import a single column of data. Following the column order listed above, put the single column of data in the correct position. Fill the remaining columns with zeros and then copy all four columns to the clipboard.

When Imported Data is Not Detailed Enough: How the Program Modifies External Loads Files

In the case of a loads program that generates only total monthly loads and peak monthly demand, nothing is known about the daily hour-by-hour transfer of heat to or from the installation. This information is important in the Borehole and Horizontal Design modules because the hourly data ultimately determines the contributions to the daily and monthly pulses of heat to the ground (GLD performs calculations based on daily, monthly and annual heat pulses). In this type of situation, GLD will use the peak demand and total monthly loads to determine a monthly partial load factor (PLFm) for the peak design month, where

PLFm = (actual run time per month) / (run time if at full load per month).

Once the program calculates the PLFm, it automatically determines the relationship between off-peak period loads and peak period loads to assure that the monthly partial load factor matches that of the imported data. The program assumes that the peak demand occurs during the top four-hour period, multiplied by the number of days in the month. If the total heat gains or losses provided for the peak month still exceed this value, the remainder of the total monthly loads are evenly split between the other time periods in the day, making up the remaining 20 hours. If not, the demands of all other periods are set to 0. The peak and its time block will be used for the daily pulse. The monthly pulse utilizes the data in the off-peak periods to recalculate the PLFm. A sample PLFm calculation is presented below.

Assume the monthly calculation gives a total monthly load in January of 10000 KBtu (kWh), and the corresponding peak demand from noon to four p.m. is 30 KBtu/hr (kW). In this case, the monthly partial load factor is:

PLFm = 10000 KBtu / (30 KBtu/hr * 24hr * 31 days) = 0.448

If this value is to be transferred correctly into the Design Day Loads boxes in the loads modules, the 0.448 must remain the same. Noon to four p.m. represents four hours out of twenty-four in a day. Loads not included in that four-hour period must be included in the other twenty hours of the day. The following equation is used to determine the relationship between off-peak loads and peak loads so that the PLFm is maintained (Note that this automatic calculation also assumes that the installation is running 7 days per week, and changes the 'Days per Week' value to reflect this. If other occupation times are desired, the values will need to be changed manually to reflect proper distribution over the course of a month):

PLFm =

(Days per Week / 7 days) x
((4 hr x [Peak Demand 8-12am]
+ 4 hr x [Peak Demand 12-4]
+ 4 hr x [Peak Demand 4-8]
+ 12 hr x [Peak Demand 8pm-8am]) / (24 hr x [Top Peak Demand]))

0.448 =

(7 days per Week/ 7days) x
((4 hr x 30 KBtu/hr)
+ (4 hr x Y)
+(4 hr x Y)
+(12 hr x Y) / (24 hr x 30 KBtu/hr))

or, solving for Y:

Y = (((30 KBtu/hr x 24 hr) x 0.448) – (30 KBtu/hr x 4hr)) / 20 hr

Y = (322.56 KBtu – 120 KBtu) / 20 hr

Y = 10.128 KBtu/hr

To preserve the partial load factor when transferring into the Design Day Loads, 30 KBtu/hr has to be transferred to the noon to four p.m. block as expected. The 10.128 KBtu/hr needs to be transferred into each of the other three blocks, which represent the other 20 hours of the day.

GLD performs the monthly partial load and the full-load hours calculations automatically when it imports a file containing only monthly and peak loads data. However, if the designer knows more specific details about the installation in question, he or she may want to place those loads more precisely in the actual in-use periods of the day, and consider also the daily occupation of the installation (i.e. not in use on weekends, etc.). However, as long as the peak demand and partial monthly load factor remain the same, the calculated length will also remain the same, no matter what the representation, since the daily and monthly pulses remain unchanged.

Review of Loads Entry in GLD

The loads input methodology in GLD is not as complicated as it first may appear to be. This system has been chosen for two main reasons: First, the advanced mathematical model the program employs allows the loads to be broken into hourly pulses throughout the day of peak demand (the 'Design Day'), which should provide a better overall accuracy in the calculations. Second, GLD uses full-load equivalent hours to reduce the total amount of data entry.

GLD also accepts monthly total and peak loads in the average block loads module. These data are only necessary for monthly inlet temperature calculations in the borehole design module. The mathematical model the program employs for these calculations requires the more detailed monthly loads data.

Design Day Loads

The 'Design Day' heat gains and losses are simply the average hourly peak demands of the installation over the different periods of the day. Although the program could include all 24 hours of the day separately, it instead uses three 4-hour periods and one 12-hour period to simplify input. These average hourly loads can be entered directly into the corresponding entry box. The soil resistance models employed by the program actually use this data to determine the daily and monthly transfer of energy into the soil. This is because the model assumes that there are different resistances associated with the annual, monthly, and daily pulses of heat being transferred.

If an installation is not being used at night, for example, the demand for the 12 hour period might be set to 0.

Annual Equivalent Full-Load Hours

Because complete loads entry could be extensive, especially in applications with more than a few zones, GLD limits the necessary data by compacting all of the monthly loads into a single number, the "Annual Equivalent Full-Load Hours". This number effectively represents all of the monthly total loads data (KBtu or kWh), in terms of the peak demand value (KBtu/hr or kW). The advantage is that a single value is used instead of twelve (one for each month of the year).

The full-load hours calculation procedure is straightforward. Simply sum the monthly total loads for all of the months (Kbtu or kWh), and divide by the peak demand (KBtu/hr or kW). The resulting number, the *annual equivalent full-load hours*, then has the units of hours. To put it another way, think of the *annual equivalent full-load hours* as the total number of hours the system would be running in a year if it ran at full capacity the whole time.

To help with this calculation, the program offers the "Equivalent Hours Calculator" as one of the standard tools included in the Geothermal Design Studio. If the designer knows the monthly total loads and peak demand, he or she can simply input them into the boxes provided in the calculator. Pressing 'Calculate' then determines the hours, according to the summation and division described above. When the user presses the 'Transfer' button in any loads module **when the calculator is showing**, the values will be transferred directly into the loads module, as previously described.

Surface Water Design Loads

The Surface Water Design Module does not require the loads input detail of the other design modules. Since there is no long-term build-up of heat in the water, the only values that are actually required are the peak demand of the installation. All other values may be set to zero, or included simply for reference.

CHAPTER 4

The Borehole Design Module

This chapter describes the features and operation of the Borehole Design module. This module is used in the design of vertical borehole systems. It is one of the three design modules included with GLD.

Overview

A design is only as good as the quality of the data that goes into it. This is certainly the case with the GLD Borehole Design module. Although GLD utilizes the best theoretical models available today, the most accurate results will naturally result from the most accurate input parameters. Because the calculations conducted here involve the combination of a large number of input parameters, **care must be taken to assure that proper values are verified before use**. Assuming that reasonable values are provided to the software, the software will provide reasonable results.

General Features

To aid in the data entry process, the Borehole Design module in GLD consists of a set of panels, grouped by subject, through which the designer can enter and edit the input variables efficiently. For example, parameters related to utility costs are listed on the *Utility Costs* panel, while piping choices are listed on the *U-tube* panel. The idea is that everything related to a project is presented simultaneously and is easily accessible at any time during the design process. In the expanded user interface mode, which can be expanded by double clicking on any of the tabs, the most commonly modified parameters as well as calculation results are always visible, as seen below in figure 4.1.

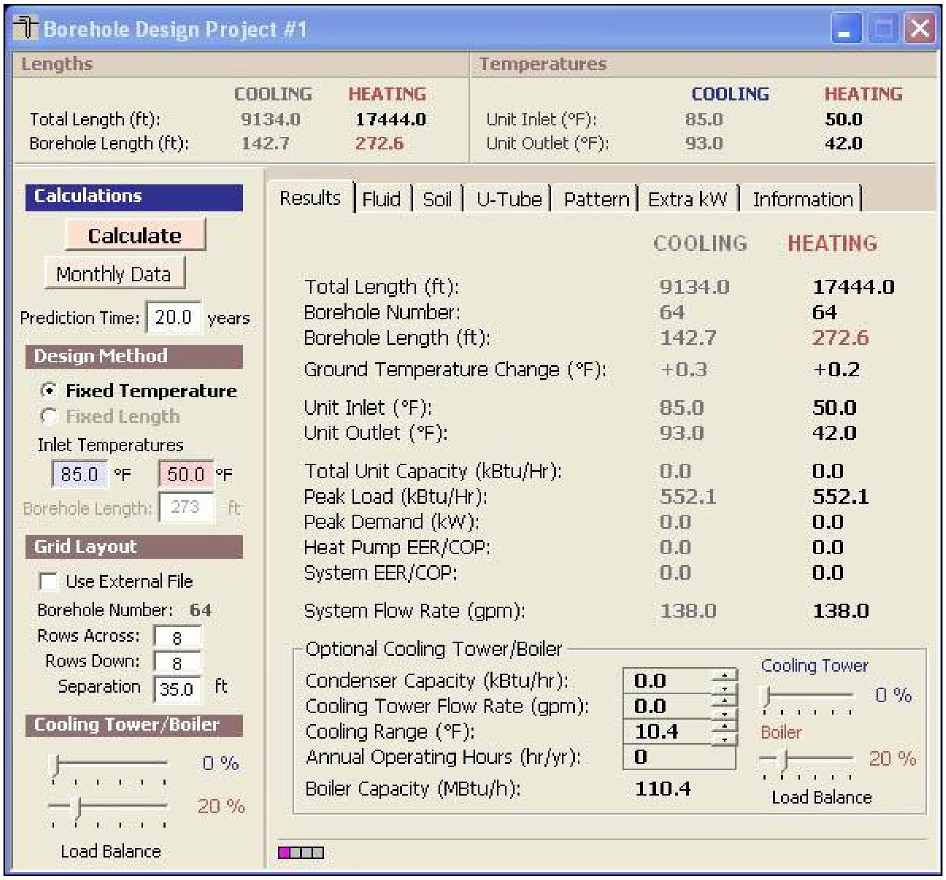


Fig. 4.1 Expanded User Interface

The Borehole Design module includes several additional features:

- Metric and English unit conversion
- Printed reports of all input and calculated data
- Convenient buttons to bring up tables and calculators
- A 'Calculate' button used to refresh the calculations
- A 'Monthly Data' button used to calculate monthly inlet temperatures
- A 'Graphing' button used to graph inlet temperature data within the Design Studio
- Boiler and cooling tower hybrids

Opening Projects

There are two ways to open Borehole Design projects. One is by using the 'New Borehole' command from the Design Studio *File* menu or toolbar, and the other is by opening an existing Borehole Design project (***.gld**) file. Files cannot be opened if other modules with the same name are already open. As many files can be opened as the system's memory permits.

 New Projects

New projects may be opened at any time from the Design Studio by choosing 'New Borehole' from either the Design Studio *File* menu or the toolbar. New projects open with standard parameter values that must be edited for new projects. The module opens directly into the Information panel, through which the designer enters information about the new project.

In new projects, no loads files (*.zon) are loaded. The user must create a new loads file or open an existing loads file into one of the loads modules. Links may be established using the Studio Link system described in Chapter 3.

 Existing Projects

Existing projects may be opened at any time from the Design Studio by choosing 'Open' from the Design Studio *File* menu or toolbar. The file automatically opens into a new Borehole Design Project module.

If a loads file (*.zon) is associated with the loaded project, the loads file automatically will be loaded into the appropriate loads module and opened along with the project file. However, if the associated loads file cannot be found, the user will be notified and the automatic file loading will not occur.

Saving Projects

Projects may be saved at any time using 'Save' or 'Save As' from the Design Studio *File* menu or by clicking the save button on the toolbar. When the user closes the program or module, the program automatically asks the user if he or she wants to save the project and associated loads files.

Typical Operation

Although each user will have his or her own unique style, the typical operation of the Borehole Design module would include the following steps:

1. Enter Loads and select pump in either the Average Block Loads module or the Zone Manager module
2. Form a link between the loads module and the design module
3. Modify step-by-step the input parameters listed in each panel
4. Perform initial calculation
5. Modify various parameters and recalculate to determine the effects of the modifications
6. Add an optional boiler/cooling tower
7. Establish an optimal system
8. Save and/or print the project and associated zone file

Entering Data into the Tabbed Panels

GLD's innovative tabbed panel system provides for easy organization of and direct access to the relatively large number of design parameters associated with a particular project. This section describes the *Information, Extra kW, Pattern, U-Tube, Soil, Fluid, and Results* panels (See Chapter 3 for a discussion of Loads entry).

Information

The contents of the *Information* panel are shown in figure 4.2. All of the descriptive information related to the project is stored in this panel. This primarily includes the names of the project and designer and the dates. Reference data concerning the client also can be included on this page, so that all relevant project information is in one convenient location.

In addition to generalized project information, specialized comments can be included in the 'Comments' section of the *Information* panel. This area allows the designer to make any notes particular to the specific project that may not necessarily fit under any of the other topics provided.

All of the data in the information panel is optional, but completing the page is recommended for the sake of organization. Reports utilize the project information as a way of distinguishing one project from another.

Except for the dates, the information panel input boxes contain only text, and any desired format may be used when filling out the form.

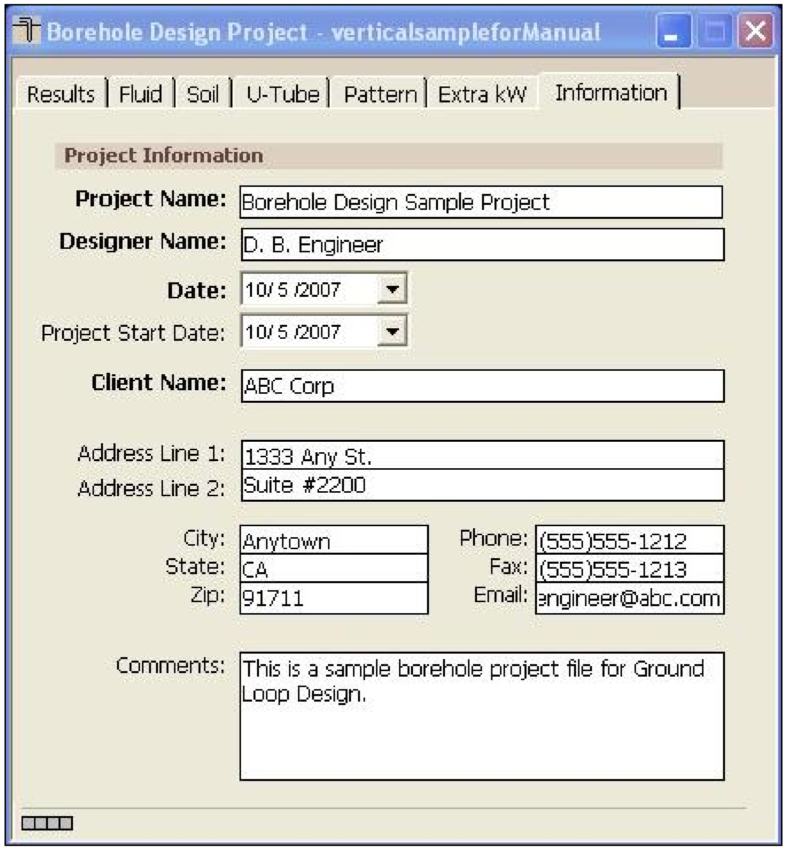


Fig. 4.2 ***Information*** **Panel Contents**

Extra kW

Additional energy that is utilized by the system can be entered in the *Extra kW* panel. The entry boxes are shown in figure 4.3.

This panel is included for entire system average efficiency calculations. The top entry box, “Circulation Pumps”, is for the energy required by the system circulation pumps. The middle entry box, “Optional Cooling Tower”, is for the energy required by a cooling tower (if used). The lower entry box, “Additional Power Requirements”, is for all other elements (besides the heat pump units) in the system that may require energy input. For example, heat recovery units require additional energy that can be recorded in this box so that it can be used in the overall calculation of the System EER/COP.

In the ‘Circulation Pumps’ section, the ‘Required Input Power’ is calculated from the ‘Pump Power’ required by the pump(s) for the system in question and the average ‘Pump Motor Efficiency’. It is not possible to edit the ‘Required Input Power’ values directly. However, if the pump motor efficiency is set to 100%, the ‘Pump Power’ and ‘Required Input Power’ will be the same.

Fig. 4.3 *Extra kW* Panel Contents

If an optional cooling tower is used for hybrid applications, the demands of the pump and fan may be included on this panel. The tower pump is selected based on the water flow and the total head (these also determine the horsepower). The required fan horsepower and motor efficiency may also be entered to include the demand of the fan. *Generally, cooling tower inputs are left at zero initially, and then modified once the program suggests the cooling tower size and flow rate.*

The 'Additional Power' may be included as necessary.

Note: To make a kilowatt entry in the 'Pump Power' box, switch to metric units, enter the kilowatt value, and then return to English units.

Pump Power Calculator

If the pump efficiency, system flow rate and head loss are known, the *Pump Power Calculator* can be used to determine the pump power. An image of the pump power calculator is shown in figure 4.4.

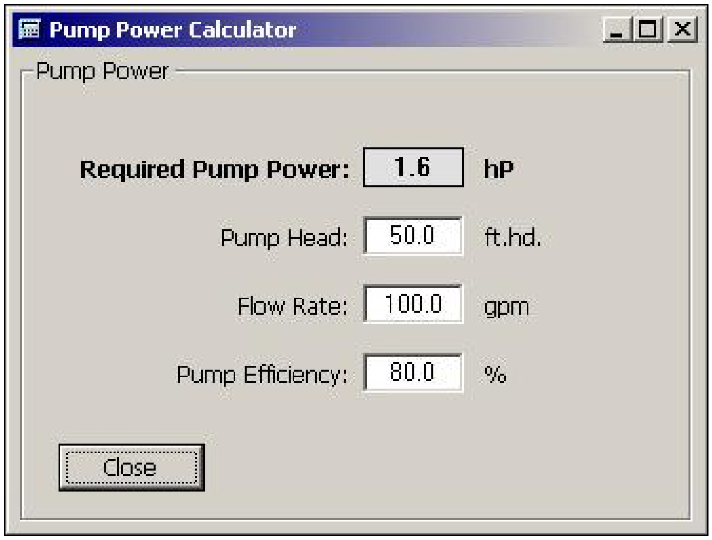


Fig. 4.4 Pump Power Calculator

Pattern

Information pertaining to the ground field arrangement is in the *Pattern* panel. This includes the vertical boreholes pattern, the borehole separation, the optional selection of external grid files, the number of boreholes per parallel loop, and the fixed borehole length design option. The input screen is shown in figure 4.5. Pattern, borehole separation and external grid file data also are visible and adjustable in the expanded user interface, as seen in figure 4.6.

Vertical Grid Arrangement

The standard Borehole Design module is configured to accept equally spaced borehole patterns based on an x, y coordinate system. For rectangular systems, users can enter the pattern directly into the *rows across* and *rows down* boxes. For non-rectangular systems, see external grid files, below.

Separation between Vertical Bores

This value is the center-to-center distance between adjacent bores. For optimal use of space, the current calculations allow only one spacing distance between vertical bores in either direction.

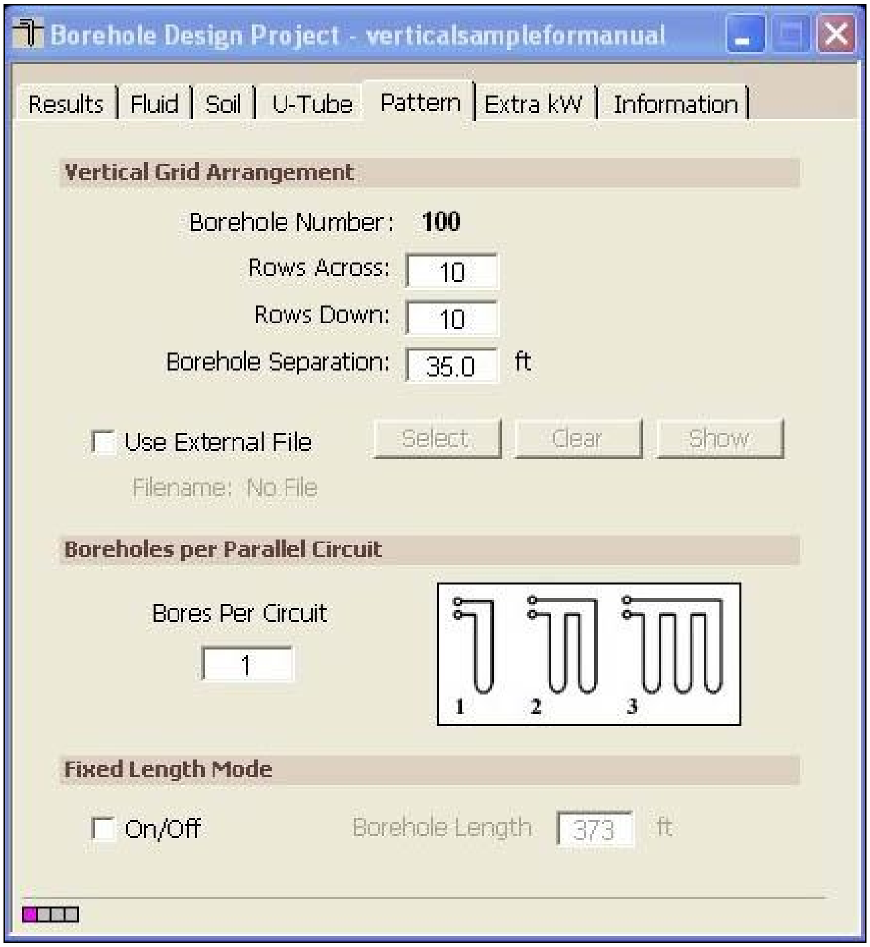


Fig. 4.5 *Pattern* Panel Contents

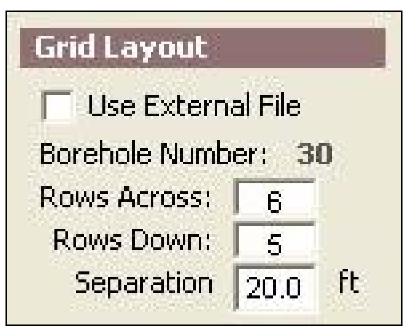


Fig. 4.6 *Pattern* Data in Expanded User Interface

External Grid Files

For non-rectangular and potentially non-equally spaced systems, users have the option of creating and then importing an external grid data file that contains the x, y coordinates for each borehole in the system.

User-designated grid files must follow this format:

Sample *GridData.txt* created in text editor

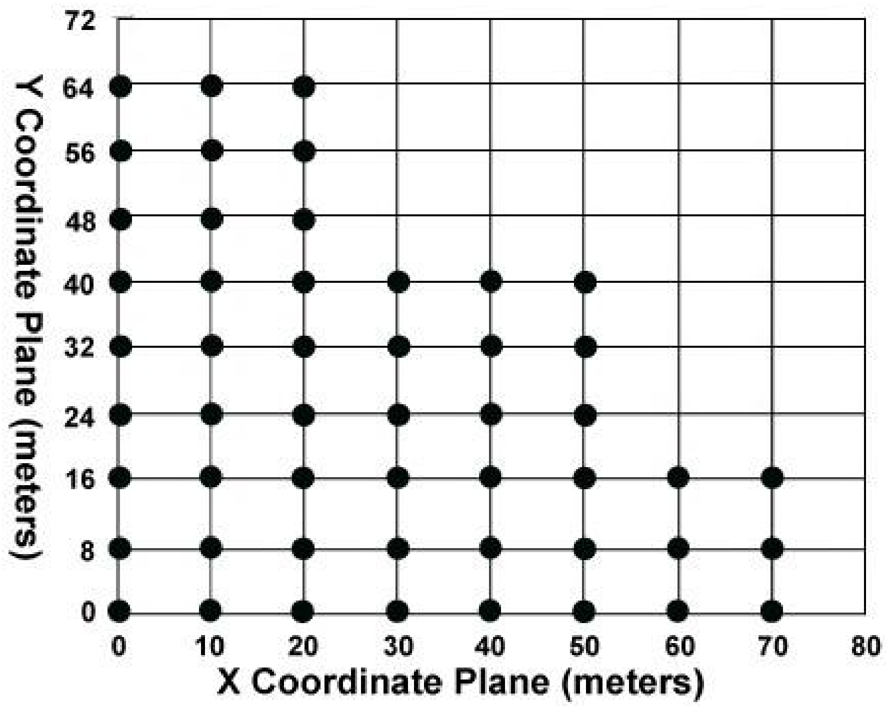
```
Metric
0,0
0,10
10,0
10,10
0,20
20,0
20,20
10,20
20,10
30,0
30,10
30,20
30,30
20,30
10,30
0,30
```

This sample grid file was manually created in a text editor. As can be seen, the first line indicates whether a Metric (meters) or English (feet) units coordinate plane is specified. The next line indicates the x, y coordinates of the first borehole. The line after that indicated the x, y coordinates of the second borehole, etc. This particular sample has 16 boreholes spaced at 10 meter intervals.

Below can be found a recommended three step protocol for creating grid files:

1) First, lay out your proposed borehole field on a x,y grid similar to the ones shown. Doing so will decrease the chance of errors when creating a grid file.

Sample X, Y grid



Note that this grid is in meters and that each black dot represents a borehole.

2) Open up a text editor and in the first line of a new text file, specify whether the grid file is in metric or English units. Since this grid is in meters, the first line of the grid file should say "Metric".

3) In the text file begin listing the boreholes in the grid file as can be seen below. Note that the first borehole is at the origin (0,0).

Grid file for sample X,Y grid

```
Metric
0,0
0,8
0,16
0,24
0,32
0,40
0,48
0,56
0,64
10,0
10,8
etc…
```

After a grid file is created, it must be saved in the following folder:

Gaia Geothermal\GLD\Grid Files

so that the GLD program can find the grid file.

After creating and saving a grid file, load it into the heat exchanger module by first checking the *Use External File* checkbox and then hitting the 'Select' button to choose the desired file as seen in figure 4.7.

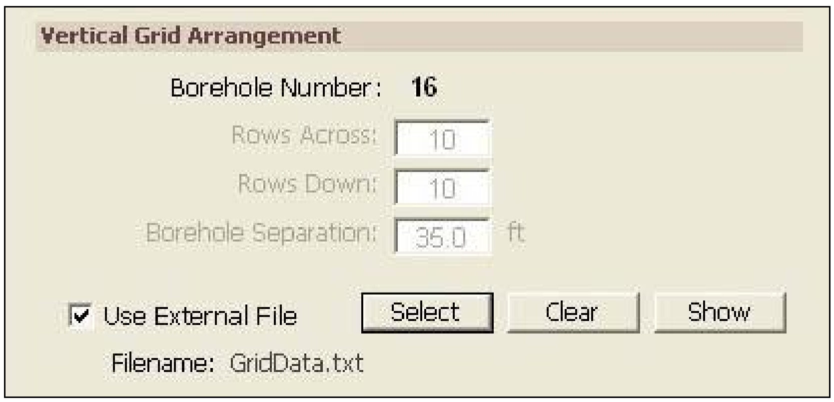


Fig. 4.7 Selecting an External Grid File

The file name will appear directly below the checkbox. In this case, the filename is GridData.txt. When a valid grid file has been selected, the number of boreholes in the file is displayed and the standard *rows across*, *rows down* and *borehole separation* text boxes become inactive. If GLD is unable to read the grid file (for example, if the formatting is incorrect), then GLD will revert to the standard rectangular grid (rows across and rows down). Click the *Show* button to review the selected grid file at any time.

When a gridfile is selected, it is indicated in the expanded user interface, as seen in figure 4.8.

Fig. 4.8 Use of External File Indicated in Expanded User Interface

Boreholes per Parallel Loop

The 'number of boreholes per parallel loop' refers to the piping arrangement within the borehole pattern. The calculation will give slightly different bore lengths depending on whether one, two, or more boreholes are included in one parallel circuit. Remember that pumping costs will increase as the pipe lengths per parallel circuit become longer.

Fixed Length Mode

By selecting fixed length mode, the designer can specify the loop field length (*number of boreholes* x *length per borehole*) and have GLD calculate the entering water temperatures. When in fixed length mode, it is important to note that both cooling and heating lengths are identical, unlike in the fixed temperature mode (where designers specify temperatures and calculate lengths). The expanded user interface displays the design mode (fixed temperature or fixed length) as well as adjustable parameters associated with each mode. For the fixed temperature mode, the entering water temperatures can be adjusted, while for the fixed length mode, the borehole length can be modified. This can be seen in figure 4.9.

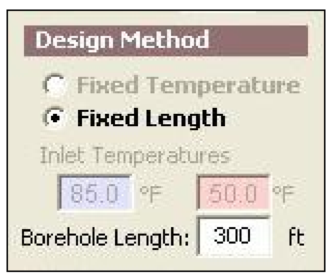


Fig. 4.9 Design Method in Expanded User Interface

U-Tube

The *U-Tube* panel contains information related to the pipe and bore. The main purpose of the panel is to obtain a value for the borehole thermal resistance. Calculated according to the method of Paul and Remund (Paul, 1996), the thermal resistance calculation takes into account the pipe parameters and positioning, the borehole diameter, and the grout thermal conductivity. If desired, an experimentally determined value of the borehole resistance also may be entered into the textbox, which then overrides all calculations. The panel contents are shown in figure 4.10.

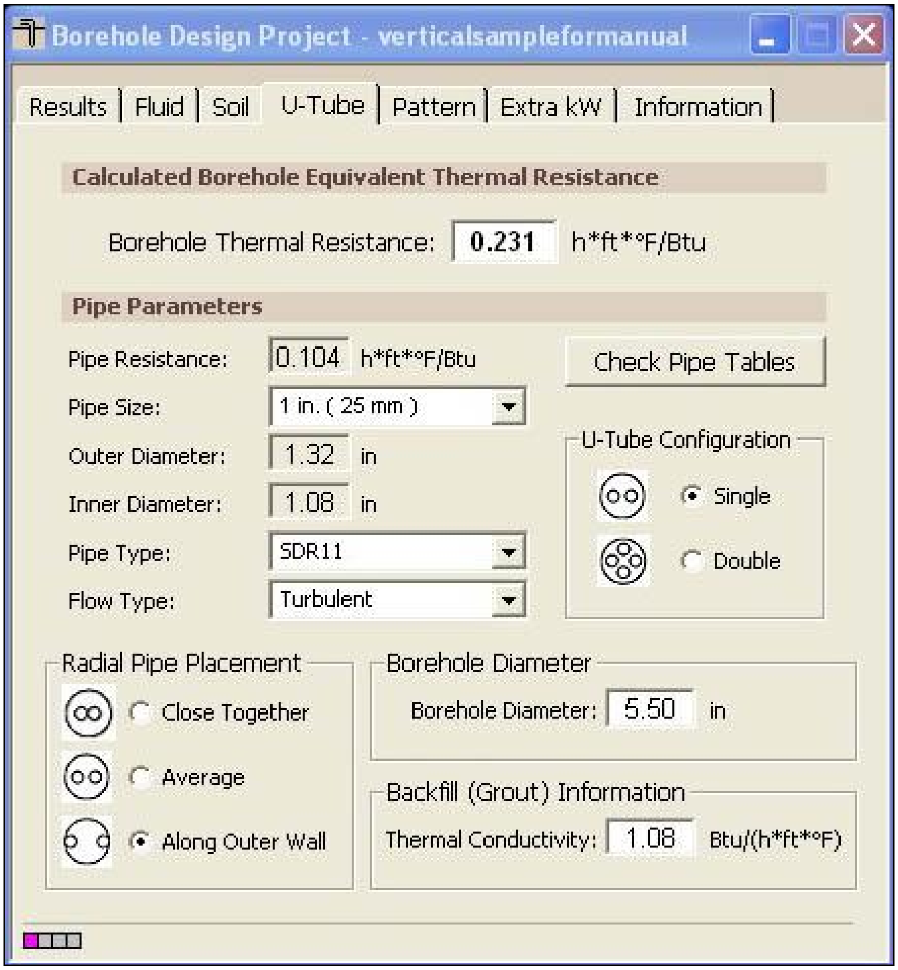


Fig. 4.10 ***U-Tube*** **Panel Contents**

Pipe Parameters

The pipe parameters are entered in the 'Pipe Parameters' section. They include the pipe resistance and pipe outside diameter, followed by the configuration and placement of the pipe in the bore.

GLD calculates the convective resistance using the Dittus-Boelter correlation for turbulent flow in a circular tube (Incropera and DeWitt, 1990). The calculations use average values of the Reynolds number to represent the different types of flow, with values of Re = 1600, 3150, or 10000 for laminar, transition, and turbulent, respectively. The calculations also use average values of viscosity and the Prandtl number for water, taken at a temperature of 70°F.

Using the standard expression for resistance of a hollow cylinder (Incropera and DeWitt, 1990), the program can calculate an approximate value for the pipe resistance. It assumes HDPE pipe with a conductivity of 0.225 Btu/h”ft*F.

The pipe resistance varies with the pipe style and flow. The user can select the size and type of pipe from the appropriate selection boxes. If another pipe diameter is required, it can be entered directly into the text boxes as needed.

Note: By pressing the ‘Check Pipe Tables’ button, the ‘Pipe Properties’ tables will open.

If the user wants to enter an experimentally determined pipe resistance, or requires more precise calculations, he or she can enter these values directly into the ‘Pipe Resistance’ text box, overriding all pipe resistance calculations.

The user also selects the U-tube configuration and radial pipe placement for the designed installation. A single U-tube refers to two pipes placed in the bore, while a double U-tube refers to four pipes placed in the bore. The radial pipe placement can be one of the following:

- **Close together** - 1/8” average distance between the pipes
- **Average -** pipes are centered at a point halfway between the wall and the center of the bore
- **Along outer wall -** pipes are against the outer wall

Illustrations are included to clarify the choices.

Note: The ‘Double’ U-tube configuration at this stage is added more for reference than for practical use. Currently, the values GLD uses are based on experimental data and a new theoretical model accounting for a lower pipe and convective resistance, and a larger displacement of the grout. Designers should be aware of this fact, and remember that a ‘single’ U-tube is the standard option.

Borehole Diameter and Backfill (Grout) Information

The user can enter the borehole diameter and the grout thermal conductivity directly into their respective text boxes. **If cuttings are used for the backfill, the average soil conductivity should be entered here.**

Soil

Input parameters relating to the soil are located in the *Soil* panel, as shown in figure 4.11. These include the average ground temperature, the soil thermal properties and the modeling time period.

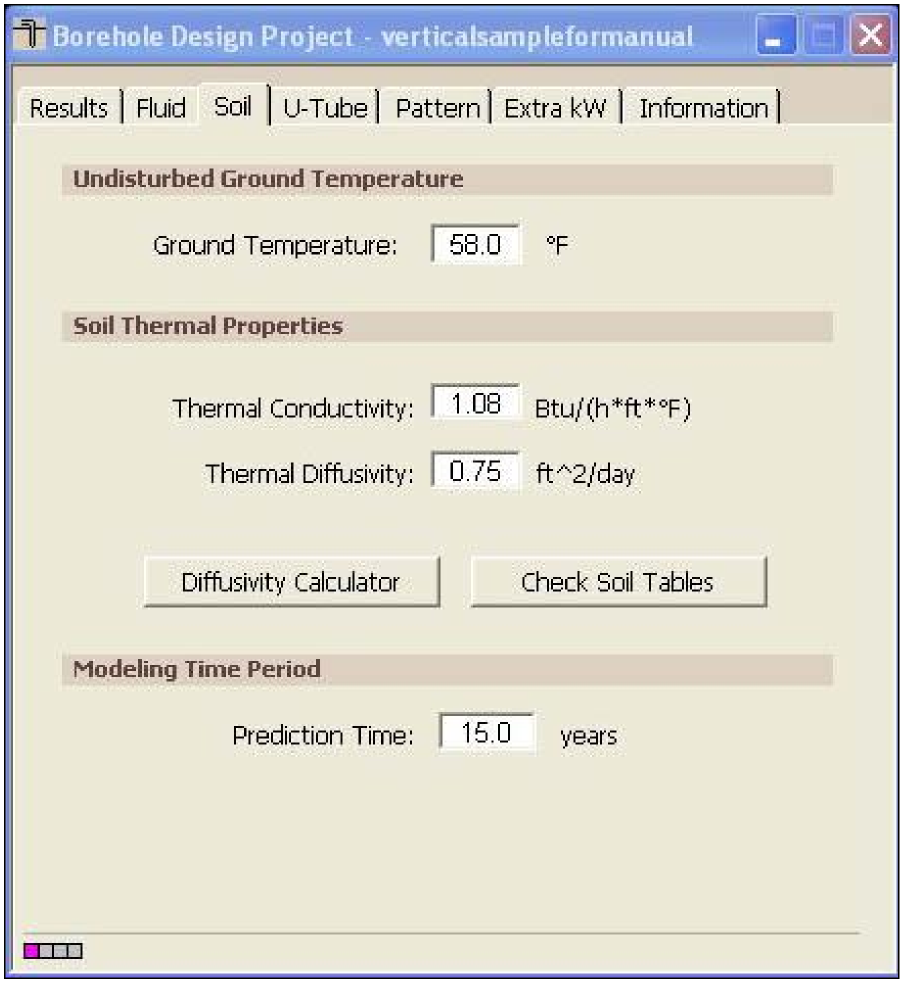


Fig. 4.11 ***Soil*** **Panel Contents**

TIP

The undisturbed ground temperature refers to the temperature of the soil below the surface layer, where there is no longer a seasonal swing. This value may be determined from regional data or by recording the actual stabilized temperature of water circulated through pipe in a test bore.

The soil thermal properties are a little harder to define, and care must be taken to provide accurate values, especially for the thermal conductivity. The thermal diffusivity relates to the density of the soil and its moisture content. Typical values of thermal conductivity and diffusivity for sand, clay, and different types of rocks can be found in the 'Soil Properties' tables. However, it is recommended that soil tests are performed to obtain these values. *The thermal conductivity in particular has a large effect on the calculated bore length, and should be determined with care through in-situ tests or comparison with other projects installed in the local vicinity. GLD does not encourage the use of ex-situ data.*

Diffusivity Calculator

For the designer's assistance, GLD includes a *Diffusivity Calculator* that can be used to determine the actual diffusivity if all the soil parameters are known. It requires knowledge of the thermal conductivity, the dry specific heat and density, and the moisture level in the soil. An image of the diffusivity calculator is shown in figure 4.12.

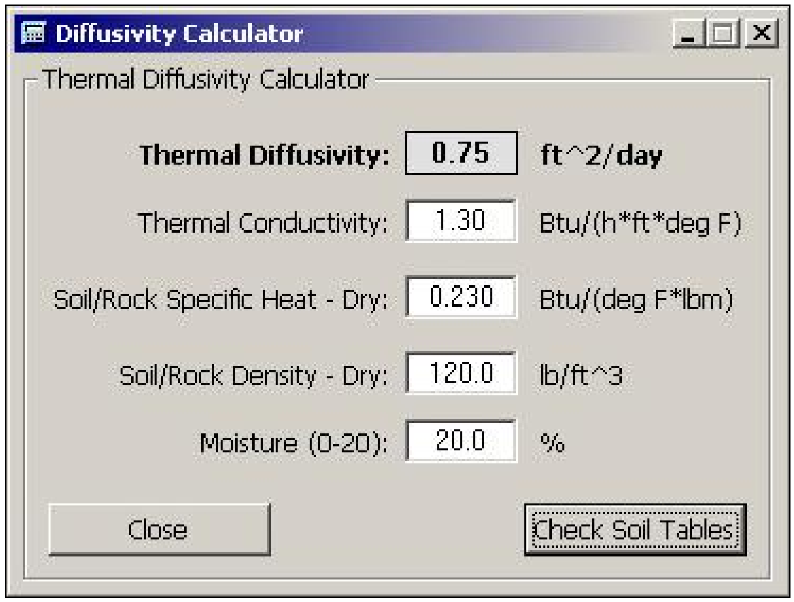


Fig. 4.12 Diffusivity Calculator

Modeling time Period

TIP

In GLD, ten years is used as a standard length of time for the ground temperature to stabilize, although longer time periods may be entered if desired. When excessive ground water movement is known to occur, one year is sometimes used as the modeling time period. In this case, it is assumed that the ground temperature stabilizes in a single year due to the neutralizing effects of the ground water movement.

The modeling time/prediction time period can also be viewed and modified in the expanded user interface, as seen in figure 4.13.

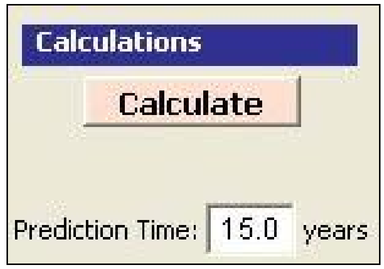


Fig. 4.13 Design Prediction Time in Expanded User Interface

Fluid

The circulating fluid parameters may be entered in the *Fluid* panel. A sample input screen is shown in figure 4.14. Note **that automatic fluid data entry mode** is available as an option in this version of GLD.

Design Heat Pump Inlet Fluid Temperatures

The heat pump inlet fluid temperatures are included in the *Fluid* panel. The designer can input the desired inlet source temperatures for both heating and cooling here. *When changes are made to these values, the heat pumps in all zones are updated automatically.* **Since the new calculated equipment capacities can lead to changes in selected equipment, the designer must be aware of the changes**. Customized pump values must be manually adjusted.

The inlet fluid temperatures also can be viewed and modified in the expanded user interface, as seen in figure 4.9 above. **Note: inlet temperatures can only be modified in fixed temperature mode.**

Design System Flow Rate

The system flow rate per installed ton is included on the *Fluid* panel. *This is the system flow rate per ton of peak load, not installed capacity* (This is because it is assumed that all units will not be running at full load simultaneously, even in the peak load condition).

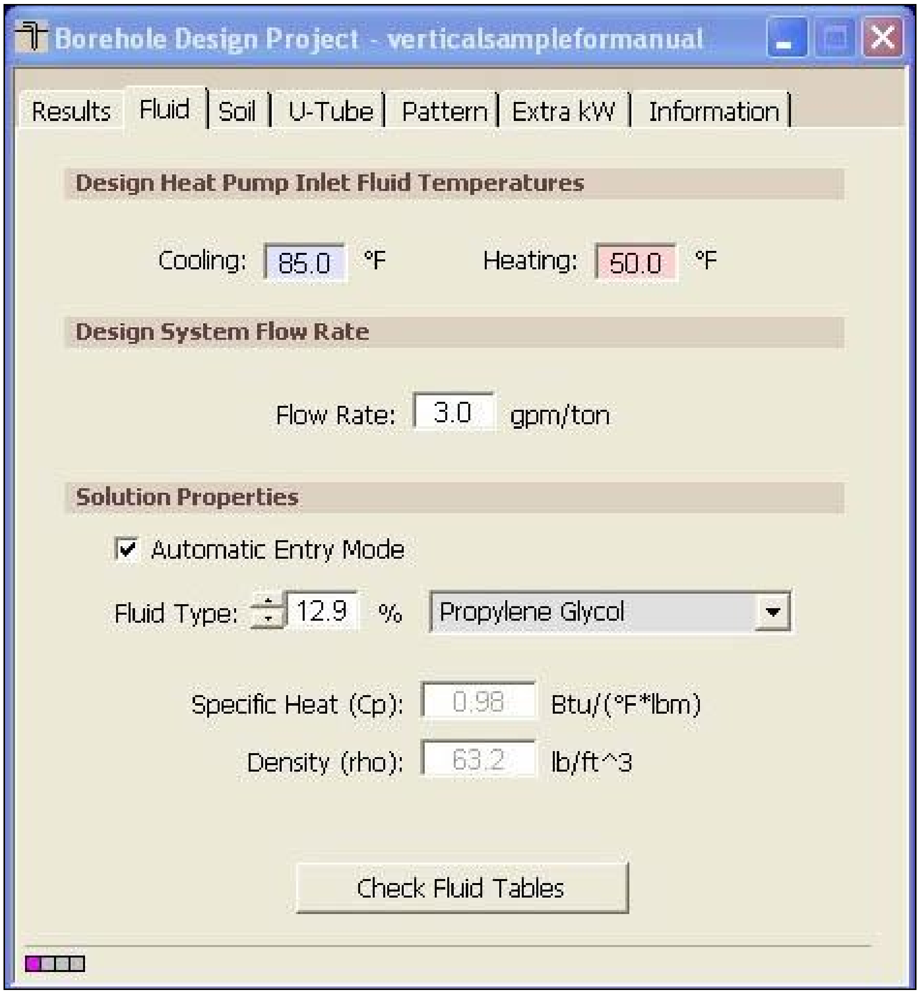


Fig. 4.14 ***Fluid*** **Panel Contents**

Optimized systems generally operate in the range from 2.5 to 4.0 gpm/ton, while the ideal system flow rate is somewhere around 3.0 gpm/ton. Again, if the flow rate is changed, the selected heat pumps are updated in the loads modules.

Solution Properties

Solution properties are also included in the *Fluid* panel. These include the *specific heat* and *density* of the circulating fluid. Also, a reference label is included so that the designer knows the percentage of antifreeze and antifreeze type; ***however, this reference label is not currently linked to the other input parameters.***

The specific heat and density values of the antifreeze are used for the calculation of the heat pump outlet temperature, which in turn is used for the bore length calculation.

Additionally, the viscosity of the solution may affect the flow type in the pipe, which was selected on the *U-Tube* panel. The designer must be aware of any changes made.

In **automatic entry mode**, the user first selects the fluid type and then selects the desired freezing temperature. GLD automatically displays the specific heat and density for the fluid selection. When the automatic entry mode checkbox is marked, the program is in automatic entry mode.

In **manual entry mode**, the user manually selects and inputs the specific heat and density for the target solution as seen in figure 4.15. When the automatic entry mode checkbox is unmarked, the program is in manual entry mode.

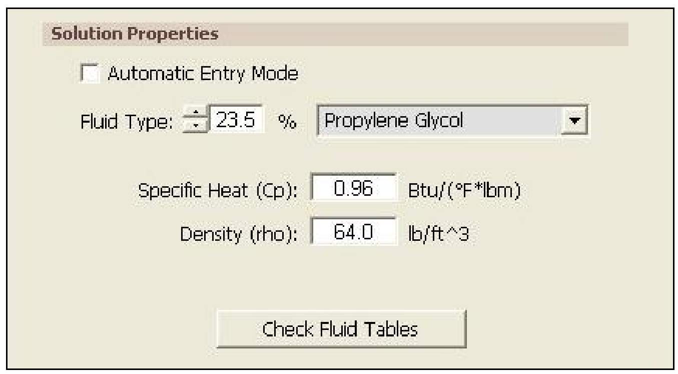


Fig. 4.15 Manual Entry Mode for Solution Properties

Note: Since solution properties vary considerably and non-linearly with type and percentage of additive, GLD does not include detailed automatic antifreeze information for all conditions. Generalized tables of data may be found in the 'Fluid Properties' tables. ***It is recommended that the designer manually enter the desired values in the input text boxes.***

Results

All results for both the heating and the cooling calculations can be viewed at any time on the *Results* panel. After all data has been entered or any changes have been made, the user can calculate interim or final results using the 'Calculate' button. A sample screen for this panel can be seen in figure 4.16. The 'Calculate' button is also available in the expanded user interface, as seen in figure 4.13. In addition, when monthly loads have been input into the Average Block loads module, a 'Monthly Data' button will be available to calculate monthly inlet temperatures.

The two lists on the *Results* panel are for heating and cooling. Although all of the numbers shown are valid and respond to changes, the side with the longer required length is printed in bold type so that it stands out. The longer length determines the installation size and for this reason the shorter-length system results lose relevance. In fixed length mode, since both heating and cooling are of equal length, neither side is highlighted.

The Calculate panel is divided into two sections. On the top is the reporting section, which presents the calculation results. The lower "*Optional Cooling Tower/Boiler*" section is included to assist in the sizing of a cooling tower and/or boiler. This is a convenient tool for hybrid-type designs, which may be desirable when the cooling length exceeds that of heating or when the heating length exceeds that of cooling. The cooling tower and boiler options are discussed in more detail below.

Calculate Button Results

TIP

The reporting section is further separated into five subsections. The first deals with the bores, including the total length, the borehole number, and the borehole length for one bore. A common way to adjust the borehole length to a desired value is to change the borehole number or pattern on the *Pattern* panel.

The second subsection presents the long-term ground temperature change with respect to the average ground temperature of the installation. Remember that only the temperature change listed in bold has any relevance. However both temperature changes will be equal if the cooling and heating loads to the ground are equal.

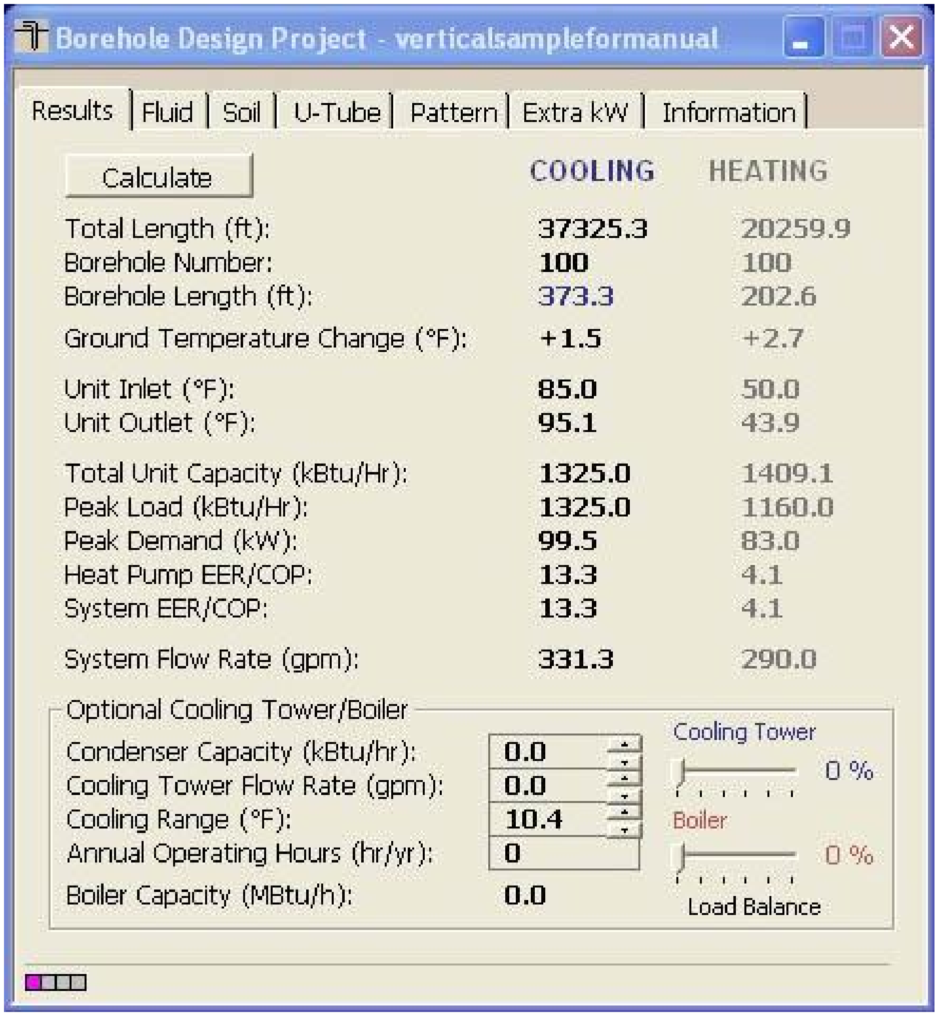


Fig. 4.16 *Results* Panel Contents

The third subsection of the report lists the heat pump inlet and outlet temperatures of the circulating fluid.

The fourth subsection lists the total unit capacity, the peak loads and demand of all the equipment, and the calculated heat pump and system efficiencies. The peak load is the maximum and is determined from whichever time period across all the zones has the highest load. The peak demand includes all pumps and external energy requirements, including those listed in the *Extra kW* panel**.**

Finally, the system flow rate is listed in its own subsection. The system flow rate is calculated from the peak load divided by 12,000 Btu/ton, and then multiplied by the flow rate (in gpm/ton) chosen on the *Fluid* panel. It represents the flow rate from the installation out to the buried pipe system.

Calculation results for lengths and temperatures are always available in the expanded user interface as well, as seen in figure 4.17. Calculations can be formed at any time in the expanded user interface, as well.

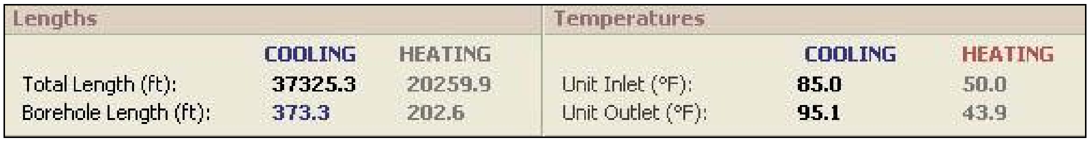


Fig. 4.17 Calculation Results in Expanded User Interface

Monthly Data Button Results

If monthly loads data have been input in the Average Block loads module, users can have GLD calculate monthly inlet temperatures for a user defined modeling time period (see soil tabbed panel and figures 4.11 and 4.13).

After hitting the ‘Calculate’ button, users can hit the “Monthly Data’ button in either the standard or the expanded user interface to calculate monthly inlet temperatures. Depending on the modeling time period and the computer resources, this calculation may take several seconds to complete. After the calculation is done, maximum entering and exiting fluid temperatures for both the heating and cooling sides are displayed in purple, as shown in figures 4.18 and 4.19.

Note that the inlet temperatures that result for the monthly data calculations are not always equal to the initial temperatures selected in the fixed temperature mode or calculated in the fixed length mode. This is because the program is using the more detailed data set in a stepwise manner to calculate the temperature buildup over time. The differences that result are due to differences in the theoretical model methodology.

Additionally, after hitting the ‘Monthly Data’ button, the graphing icon button will appear. In addition, a TempData.txt file that contains the temperature data is generated and can be found in the GLD folder. If necessary, data from this file can be imported in Excel.

Note: Monthly data can be calculated for boiler/cooling tower systems by first hitting calculate, then adding the boiler/cooling tower, and then hitting the Monthly Data button.

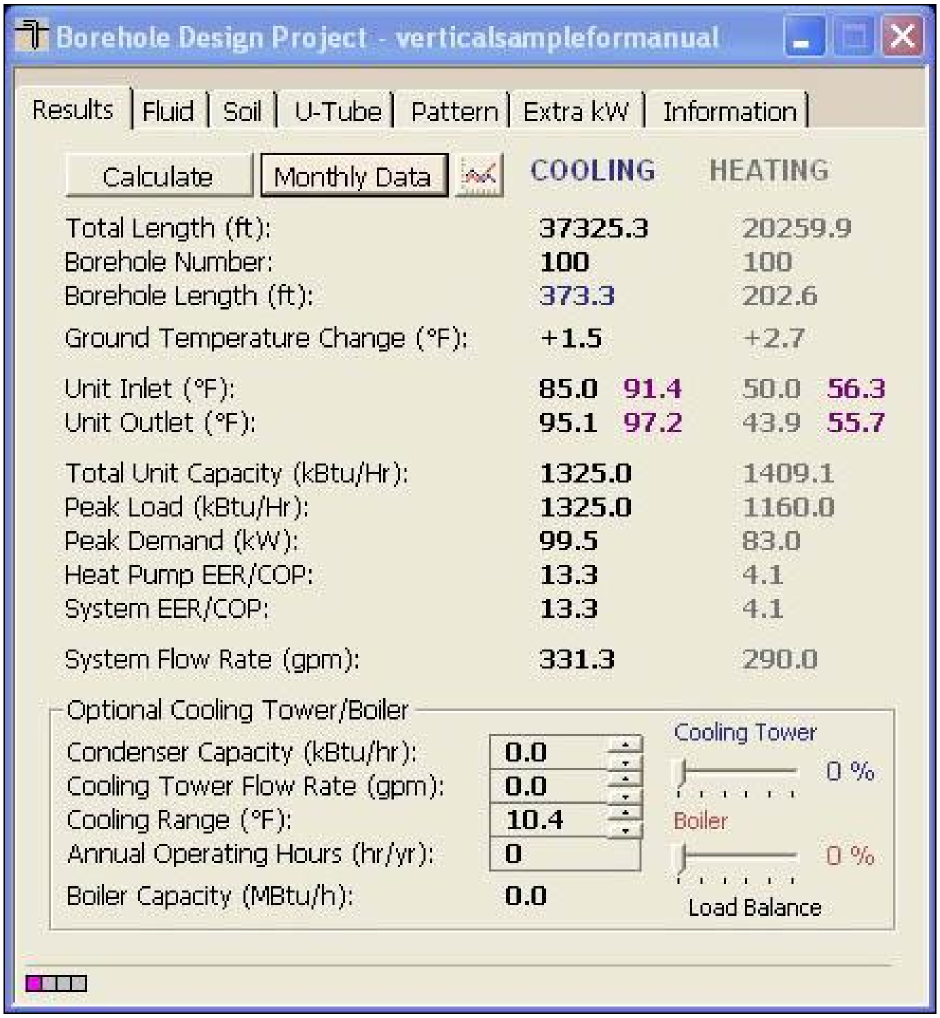


Fig. 4.18 Monthly Inlet Temperature Primary Results

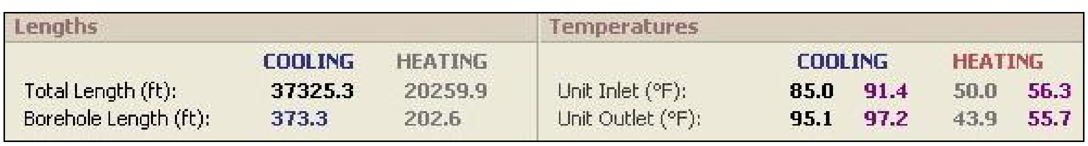


Fig. 4.19 Monthly Inlet Temperature Primary Results in Expanded User Interface

The Graph Icon Button

After calculating the monthly inlet temperatures, the designer can click on the graph button in either the standard or expanded user interface to view a graph of the monthly inlet temperatures, as seen in figure 4.20.

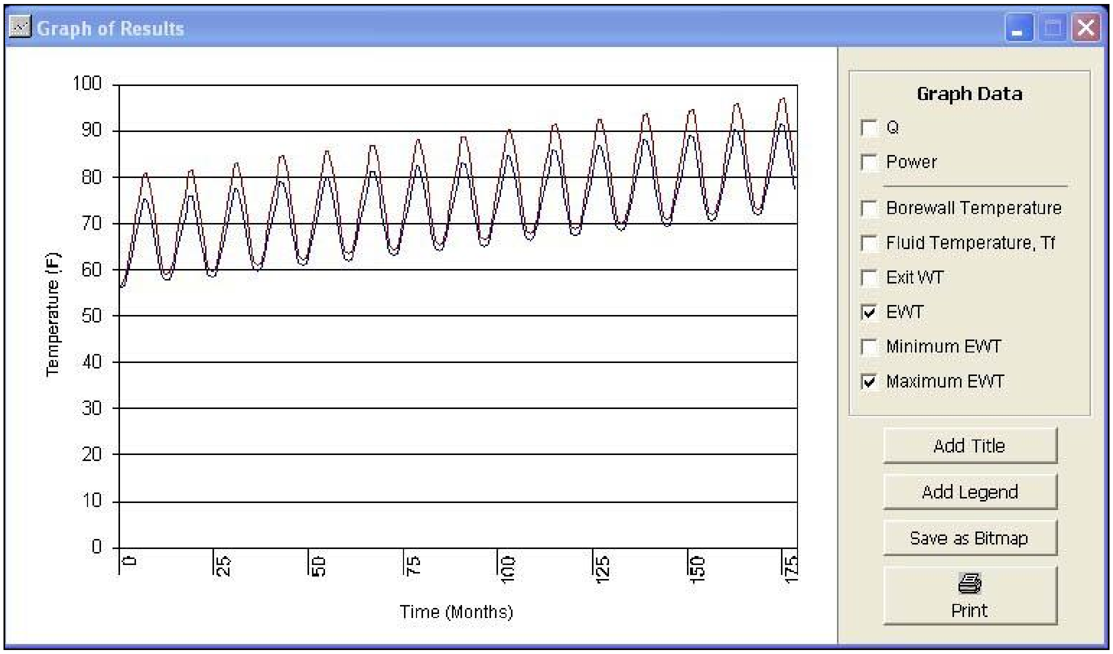


Fig. 4.20 Graph of Monthly Inlet Temperatures

Within the graph, the designer can choose which data to view, save, and/or print. Options include: Q (heat transferred to or from the ground), power, borehole temperature, fluid temperature (Tf, the average temperature of fluid in the borehole calculated as the average of exiting and entering temperatures), exiting water temperature, entering water temperature, and minimum (a variation of the average calculated from the application of short term heating loads) and maximum (a variation from the average calculated from the application of short term peak cooling loads) entering water temperatures. The designer can also add a title and legend to the graph. More than one graph can be open at the same time, enabling designers to quickly compare different designs. Saved graphs can be found in the GLD/Graph Images folder.

Optional Cooling Tower and Boiler Section

Cooling towers and boilers can be added to designs via the sliders that are located on both the *Results* panel (figure 4.16) and in the expanded interface, as seen in figure 4.21. The Cooling Towers and Boilers can be run independently or together in order to balance required lengths or temperatures.

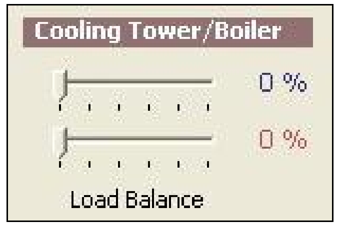


Fig. 4.21 Cooling Tower and Boiler Controls in Expanded User Interface

Cooling Towers

Although typically not recommended because of increased running and maintenance costs, the user may elect to add a cooling tower to a cooling-dominated geothermal system to reduce the total boring lengths, and therefore the total initial installation costs. To facilitate this design choice, *GLD* offers the cooling tower, or "hybrid", option.

In any case where the calculated boring lengths for cooling are longer than those for heating, the difference in the lengths can be eliminated through the use of a cooling tower tied in parallel to the geothermal ground loop. This requires that either the cooling tower capacity is chosen such that both the peak load and the annual load to the ground are balanced or if a full balance is unnecessary, a capacity is chosen that allows for downsizing the loop to an acceptable length.

To aid in the sizing process, a *Load Balance* control is provided in the Optional Cooling Tower section of the Calculate panel. Although clicking the slider control can initiate a valid calculation or recalculation, the slider control generally is employed after initial calculations have been conducted. The *Load Balance* is a slider-based control that represents a percentage of the total cooling load, both instantaneous (peak) and annual. For example, a *100% Load Balance* would be equivalent to saying that the entire cooling load of the system would be handled by the cooling tower. Conversely, a *0% Load Balance* would mean that no cooling tower is employed.

In a typical design it is difficult to predict exactly how much load balance or what size of cooling tower is necessary to match the cooling and heating lengths. However, using the *Load Balance* slider control, the designer can optimize the system to the lengths desired by directly controlling the amount of cooling load to be handled by the cooling tower.

TIP

In the case where the designer desires the shortest length possible, the design requires a perfect balance of the heating and cooling loads to the ground. The length from this perfect balance would be the minimum length required to adequately cover the heating load requirement. **To accomplish this, the *Load Balance* slider needs to be adjusted to the percentage value where the calculated cooling and heating bore lengths are approximately equivalent.**

TIP

Note: As expected, the Long Term Ground Temperature Change for both heating and cooling should be ***identical*** *in a perfectly balanced system.*

In other cases, the designer just may seek a reduction in the total required system length rather than a perfect balance. Using the slider control, the designer can select the desired length and then note the required cooling tower condenser capacity (as calculated by the program).

Once the required cooling tower capacity is determined, the designer can further modify the various cooling tower parameters to match them to his or her own system. The standard equation used in the program (Francis, 1997) is:

Condenser Capacity (Btu/hr)

= Flow Rate (gpm) x 500 x Temperature Difference (°F),

where the 500 is used for pure water, and represents a factor derived from:

Specific Heat of Water (1.0) x 60 min/hr x Density (8.33 lb/gal) = 500

(Note that GLD actually calculates this factor from the input fluid properties on the *Fluids* panel, although pure water is a logical choice for most cooling-dominated applications.)

For example, if the cooling range is increased above the initial minimum value, the capacity of the condenser also is increased, reducing the total number of operating hours. However, in the same case, decreasing the required flow rate is another option which would keep the condenser capacity and operating hours unchanged. The only limitations are the required temperature difference and the minimum condenser capacity needed to meet the chosen design length. With GLD, users have the flexibility to choose the parameters that fit best in their designs.

Boilers

In GLD, boilers are similar to cooling towers except that they are added in order to reduce the overall heating load on the system. In this case, the user may actually reduce the peak and annual heating loads by the flat percentage defined by the slider value. The required boiler capacity and the modified peak loads applied to the loop field are shown on the panel, but no other inclusion electrical or fuel costs for the boiler are included in the calculation report. The expected heat pump power is also reduced by the same percentage, in order to estimate a real system.

Printing Reports

Reports of the active project can be printed at any time from the Design Studio using the toolbar print button or from the *File* menu → *Print*.

Two project reports and four monthly inlet temperature reports are available. In the concise and detailed reports, information printed includes all of the input parameters from the design module, along with the associated results. In the concise and detailed reports, the zone and loads information is not included with the report, and must be printed separately from the *Loads* panel. The filename of the ***.zon** file associated with the project report is also listed on the reports. The other four inlet temperature reports offer different combinations of input parameters, loads and monthly inlet temperatures that designers can choose among depending on their reporting needs.

More information on reports can be found in Chapter 7.

References

Francis, E., Editor. *Refrigeration and Air Conditioning, 3rd Edition.* Air-Conditioning and Refrigeration Institute. p.186. Prentice Hall, New Jersey, 1997.

Incropera, F. and Dewitt, D. *Introduction to Heat Transfer, 2nd Edition.* p. 456, p. 98. John Wiley and Sons, New York. 1990.

Paul, N. *The Effect of Grout Thermal Conductivity on Vertical Geothermal Heat Exchanger Design and Performance.* M.S. Thesis, South Dakota State University. 1996.

CHAPTER 5

The Horizontal Design Module

This chapter describes the features and operation of the Horizontal Design module. This module is used in the design of near-surface horizontal systems. It is one of the three design modules included with GLD.

Overview

As with the Borehole and Surface Water Design modules, the calculations made in the Horizontal Design module involve the combination of a large number of input parameters. **Care must be taken to assure that proper values are verified before use**. Assuming that reasonable values are provided to the software, the software will provide a reasonable result.

General Features

The Horizontal Design module in GLD also includes a set of panels, grouped by subject, through which the designer can enter and edit the input variables in a straightforward and efficient manner. For example, parameters related to trench configuration are listed on the Configuration panel, while piping choices are listed on the *Piping* panel. Everything related to a project is presented simultaneously and easily is accessible throughout the design process. In the expanded user interface mode, which can be expanded by double clicking on any of the tabs, the most commonly modified parameters as well as calculation results are always visible, as seen below in figure 5.1.

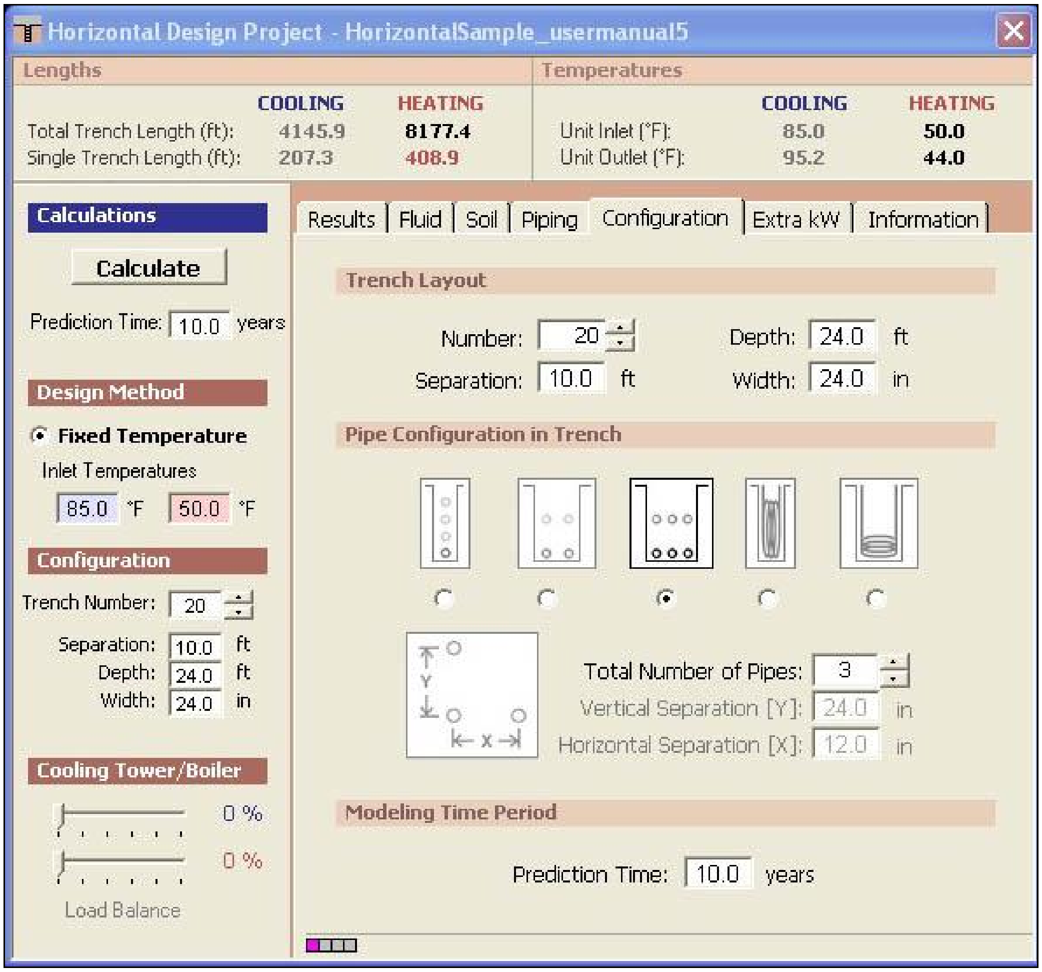


Fig. 5.1 The Expanded User Interface

The Horizontal Design module includes several additional features:

- Metric and English unit conversion
- Printed reports of all input data and calculated results
- Convenient buttons to bring up tables and calculators
- A 'Calculate' button used to refresh the calculations
- Boiler and cooling tower hybrids

Opening Projects

There are two ways to open Horizontal Design projects. One is by using the 'New Horizontal' command from the Design Studio *File* menu or toolbar, and the other is by opening an existing Horizontal Design project (***.gld**) file. Files cannot be opened if other modules with the same name are already open. As many files can be opened as the system's memory permits.

New Projects

New projects may be opened at any time from the Design Studio by choosing 'New Horizontal' from either the Design Studio *File* menu or the toolbar. New projects open with standard parameter values that must be edited for new projects.

In new projects, no loads files (*.zon) are loaded. The user must create a new loads file or open an existing loads file into one of the loads modules. Links may be established using the Studio Link system described in Chapter 3.

Existing Projects

Existing projects may be opened at any time from the Design Studio by choosing 'Open' from the Design Studio *File* menu or toolbar. The file automatically opens into a new Horizontal Design Project module.

If a loads file (*.zon) is associated with the loaded project, the loads file automatically will be loaded into the appropriate loads module and opened along with the project file. However, if the associated loads file cannot be found, the user will be notified and the automatic file loading will not occur.

Saving Projects

Projects may be saved at any time using 'Save' or 'Save As' from the Design Studio *File* menu or by clicking the save button on the toolbar. When the user closes the program or module, the program automatically asks the user if he or she wants to save the project and associated loads files.

Typical Operation

Although each user will have his or her own unique style, the typical operation of the Horizontal Design module would include the following steps:

1. Enter Loads and select pumps in either the Average Block Loads module or the Zone Manager module
2. Form a link between the loads module and the design module
3. Modify step-by-step the input parameters listed in each panel
4. Perform initial calculation
5. Modify various parameters and recalculate to determine the effects of the modifications
6. Add a optional boiler/cooling tower
7. Establish an optimal system

8. Save and/or print the project and associated zone file

Entering Data into the Tabbed Panels

GLD's innovative tabbed panel system provides for easy organization of and direct access to the relatively large number of design parameters associated with a particular project. This section describes the *Information, Extra kW, Configuration, Piping, Soil, Fluid, and Results* panels. The *Information* and *Extra kW* panels are identical to those included in the Borehole Design module described in Chapter 4, so the reader is referred there for detailed information. See Chapter 3 for a discussion of Loads entry.

Configuration

Information pertaining to the trench configuration is in the *Configuration* panel. This includes the trench layout, the pipe configuration in the trenches, and the modeling time. The input screen is shown in figure 5.2. Trench number, separation, depth and width options also are visible and adjustable in the expanded user interface, as seen in figure 5.3.

Trench Layout

This is the section where the user enters all parameters regarding the physical size and placement of the trenches. The number of trenches may be modified at any time using the up-down arrows, and "Separation" refers to the center-to-center distance between adjacent trenches. The program assumes all trenches will be equal in separation, length, depth and width. Note that if the selected piping configuration does not fit into the selected trench size, the program will automatically adjust the size of the trench to accommodate the selection.

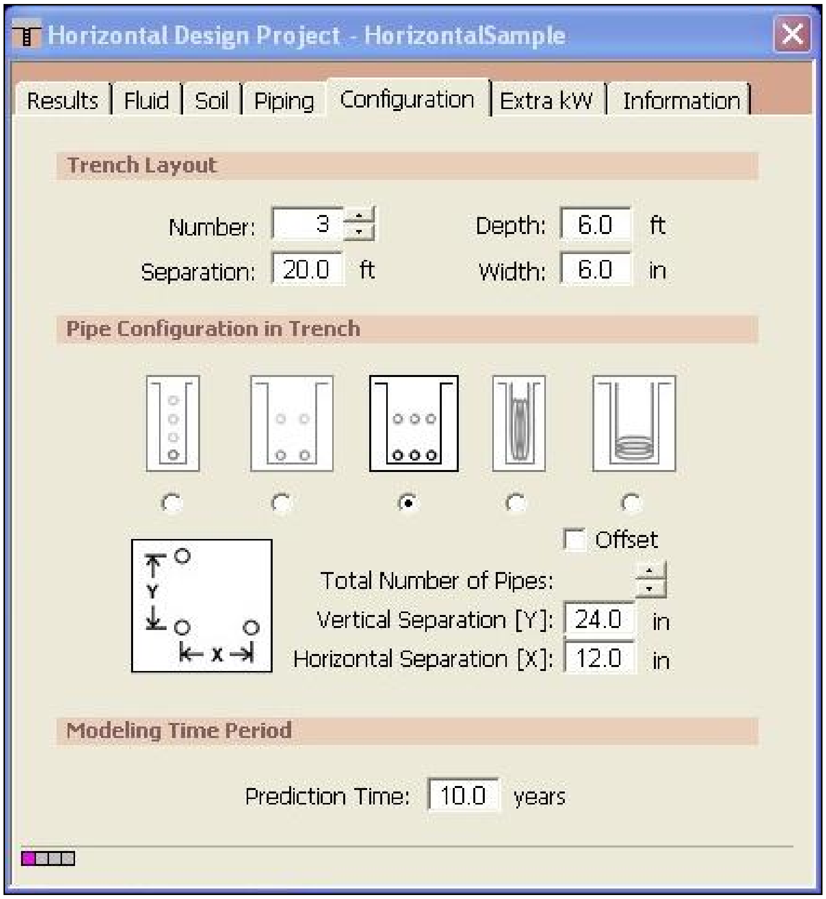


Fig. 5.2 Configuration Panel Contents

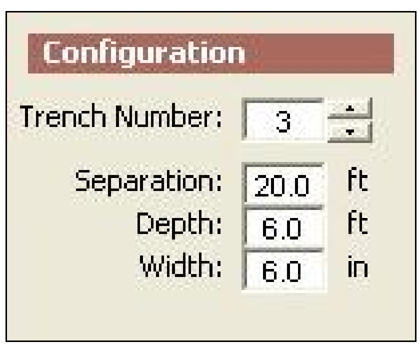


Fig. 5.3 Configuration Controls in Expanded User Interface

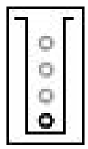
Pipe Configuration in Trench

The designer defines the physical arrangement of pipe in the trenches in this section.

STRAIGHT PIPE CONFIGURATIONS

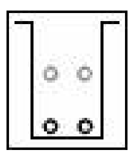
In the case of the three straight-pipe configurations, the user also provides the total number of pipes and the horizontal [X] and vertical [Y] separation of the pipes in the trench. An additional offset, meaning a horizontal shift between adjacent vertical layers, can be included if desired.

Single-Pipe Vertical Alignment



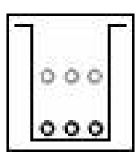
In this arrangement, the user creates a single column of pipes. The number of pipes chosen defines how many layers will be included. Each pipe is separated from its neighbor by the given vertical separation [Y], starting from the bottom of the trench. If the 'Offset' box is checked, each pipe layer will be shifted from the pipe layer below by the given horizontal separation [X].

Two-Pipe Vertical Alignment



In this arrangement, the user creates two-pipe layers. The number of pipes chosen defines how many layers will be included (2, 4, 6, etc.). Each vertical layer is separated from the one above or below by the given vertical separation [Y]. If the 'Offset' box is checked, each pipe layer will be shifted from the pipe layer below by one-half the given horizontal separation [X/2].

Three-Pipe Vertical Alignment



In this arrangement, the user defines three pipe layers. The number of pipes chosen defines how many layers will be included (3, 6, 9, etc.). Each vertical layer is separated from the one above or below by the given vertical separation [Y]. If the 'Offset' box is checked, every layer will be shifted from the layer below by one-half the given horizontal separation [X/2].

SLINKY PIPE CONFIGURATIONS

In the case of the horizontal and vertical slinky configurations, the user

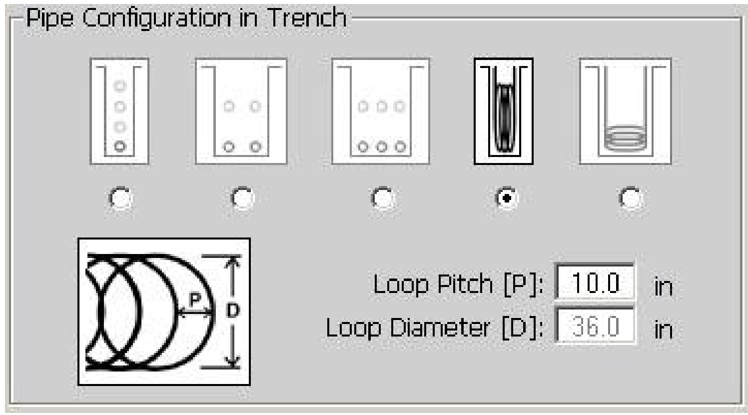
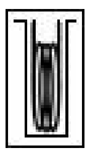


Fig. 5.4 Slinky Variables

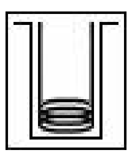
may define the pitch and diameter of the Slinky. Because of the limited model employed, the pitch must be between 10 and 56 inches, and the diameter must be 36 inches. See figure 5.4.

Vertical Slinky



In this arrangement, the slinky is placed vertically within a trench and is resting at the bottom. The trench may be as narrow as the pipe and soil allow.

Horizontal Slinky



In this arrangement, the slinky is placed horizontally at the bottom of the trench. The minimum trench width depends on the slinky diameter.

Modeling time Period

In GLD, ten years is used as a standard length of time for ground temperature stabilization, although longer or shorter time periods may be entered if desired. In the case of horizontal systems, a single year or less is often chosen since the interaction with the atmosphere or sunlight generally reduces the long-term buildup or reduction of soil temperatures. Long-term thermal effects are more commonly associated with vertical bores. The modeling time/prediction time period can also be viewed and modified in the expanded interface as seen in figure 5.5

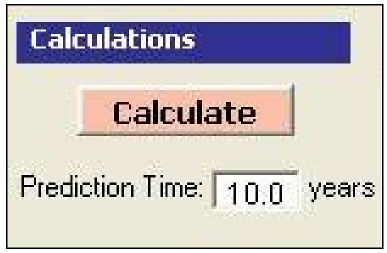


Fig. 5.5 Prediction Time Controls in Expanded User Interface

Piping

The *Piping* panel contains all the information related to the particular pipe chosen for the buried heat exchanger. The program uses information about the pipe size and flow type to determine the associated pipe resistance, which ultimately is used in the length calculations. The input screen for the piping panel is shown in figure 5.6.

Pipe Parameters

The pipe characteristics are entered in the ‘Pipe Parameters’ section. They include the pipe resistance, the inside and outside pipe diameter, and the pipe and flow type.

As in the Borehole Design module, GLD calculates the convective resistance using the Dittus-Boelter correlation for turbulent flow in a circular tube (Incropera and DeWitt, 1990). The calculations use average values of the Reynolds number to represent the different types of flow, with values of Re = 1600, 3150, and 10000 for laminar, transition, and turbulent, respectively. The calculations also use average viscosity values and the Prandtl number for water, taken at a temperature of 70^{o}F.

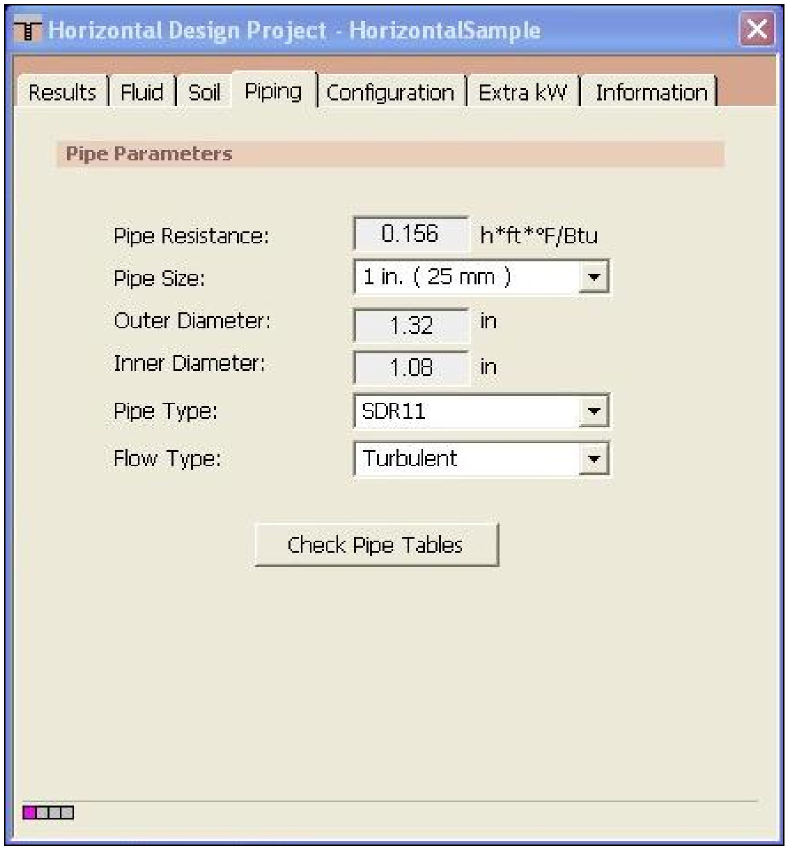


Fig. 5.6 *Piping* Panel Contents

Using the standard expression for resistance of a hollow cylinder (Incropera and DeWitt, 1990), the program calculates an approximate value for the pipe resistance. It assumes HDPE pipe with a conductivity of 0.225 Btu/h"ft*F.
The pipe resistance varies with the pipe style and flow. The user can select the size and type of pipe from the appropriate selection boxes. **If another pipe diameter is required, it can be entered directly into the text boxes as needed.**

Note: By pressing the 'Check Pipe Tables' button, the 'Pipe Properties' tables will open.

If the user wants to enter an experimentally determined pipe resistance, or requires more precise calculations, he or she can enter these values directly into the 'Pipe Resistance' text box, overriding all pipe resistance calculations.

Soil

Input parameters relating to the soil are located in the *Soil* panel, as shown in figure 5.7. These include the average ground temperature, the soil thermal properties, and the ground temperature corrections at a given depth.

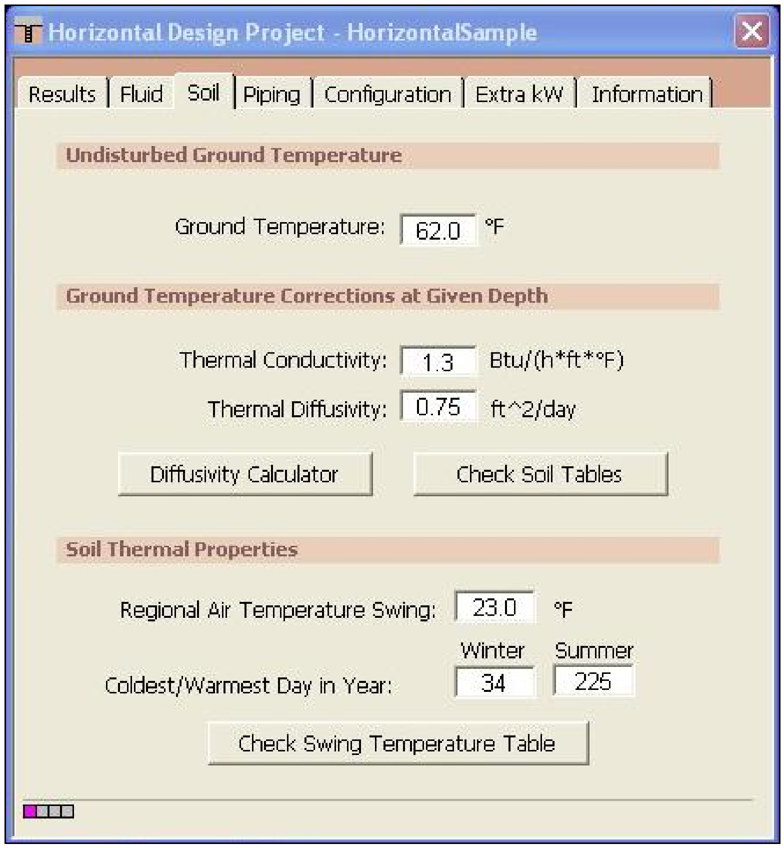


Fig. 5.7 *Soil* Panel Contents

Undisturbed Ground Temperature

TIP

The undisturbed ground temperature refers to the temperature of the soil below the surface layer, where there is no longer a seasonal swing. This value may be determined from regional data or by recording the actual stabilized temperature of water circulated through pipe in a test bore.

Soil Thermal Properties

The soil thermal properties are a little harder to define, and care must be taken to provide accurate values, especially for the thermal conductivity. The thermal diffusivity relates to the density of the soil and its moisture content. Typical values of thermal conductivity and diffusivity for sand, clay, and different types of rocks can be found in the 'Soil Properties' tables. However, it is recommended that designers perform soil tests to obtain these values. *The thermal conductivity in particular has a large effect on the calculated bore length, and should be determined with care through in-situ tests or comparison with other projects installed in the local vicinity. GLD does not encourage the use of ex-situ data.*

Diffusivity Calculator

For the designer's assistance, GLD includes a *Diffusivity Calculator* that can be used to determine the actual diffusivity if all pertinent soil parameters, including the thermal conductivity, the dry specific heat and density, and the moisture level in the soil, are known.

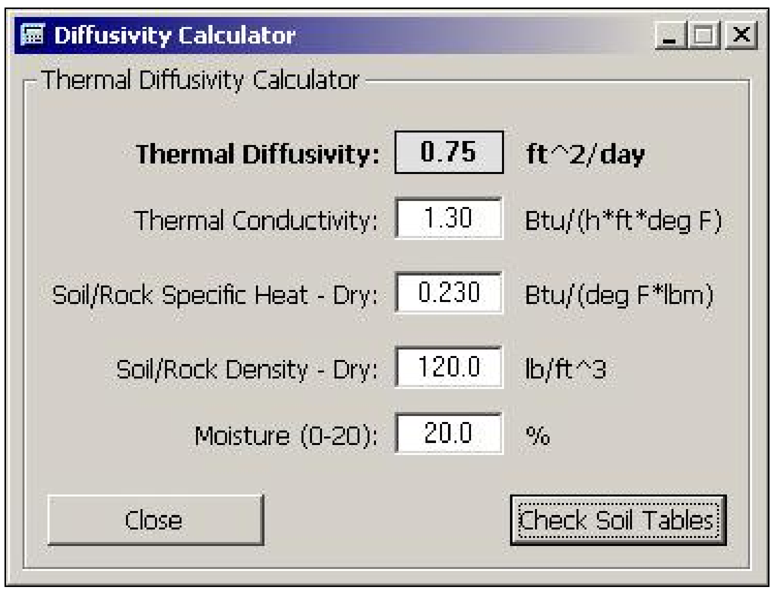


Fig. 5.8 Diffusivity Calculator

Ground Temperature Corrections at Given Depth

In a horizontal configuration, the ground temperature around buried pipes can vary significantly simply due to the proximity to the surface. To account for this variation at different depths, the regional 'Swing' temperature and phase shift are used in a sinusoidal equation. The program determines the depth of each pipe in the chosen configuration, and then calculates the expected temperature at that depth.

Regional Air Temperature Swing

This is the temperature swing for the location of interest. It is a measure of the average temperature variation of the region during the warmest and coolest months as compared to the yearly average temperature. Regions with temperate climates have a lower temperature swing than regions that have large differences between summer and winter temperatures.

Coldest/Warmest Day in Year

These are the actual days of the year, on a 365-day scale, when the temperature is usually coldest or warmest. For example, if February 3 is approximately the coldest day of the year, the value entered will be ‘34’ (31 days in January, plus 3 days of February).

Fluid

The circulating fluid parameters may be entered in the *Fluid* panel. A sample input screen is shown in figure 5.9. In the expanded user interface, fluid temperatures can be viewed and modified at any time, as seen in figure 5.10.

Design Heat Pump Inlet Fluid Temperatures

The heat pump inlet fluid temperatures are included in the *Fluid* panel. The designer can input the desired inlet source temperatures for both heating and cooling here. *When changes are made to these values, the heat pumps in all zones are updated automatically.* **Since the new calculated equipment capacities can lead to changes in selected equipment, the designer must be aware of the changes**. Customized pump values must be adjusted manually.

Design System Flow Rate

The system flow rate per installed ton is included on the *Fluid* panel. *This is the system flow rate per ton of peak load, not installed capacity* (This is because it is assumed that all units will not be running at full load simultaneously, even in the peak load condition).

TIP

Optimized systems generally operate in the range from 2.5 to 4.0 gpm/ton, while the ideal system flow rate is somewhere around 3.0 gpm/ton. Again, if the flow rate is changed, the selected heat pumps are updated in the loads modules.

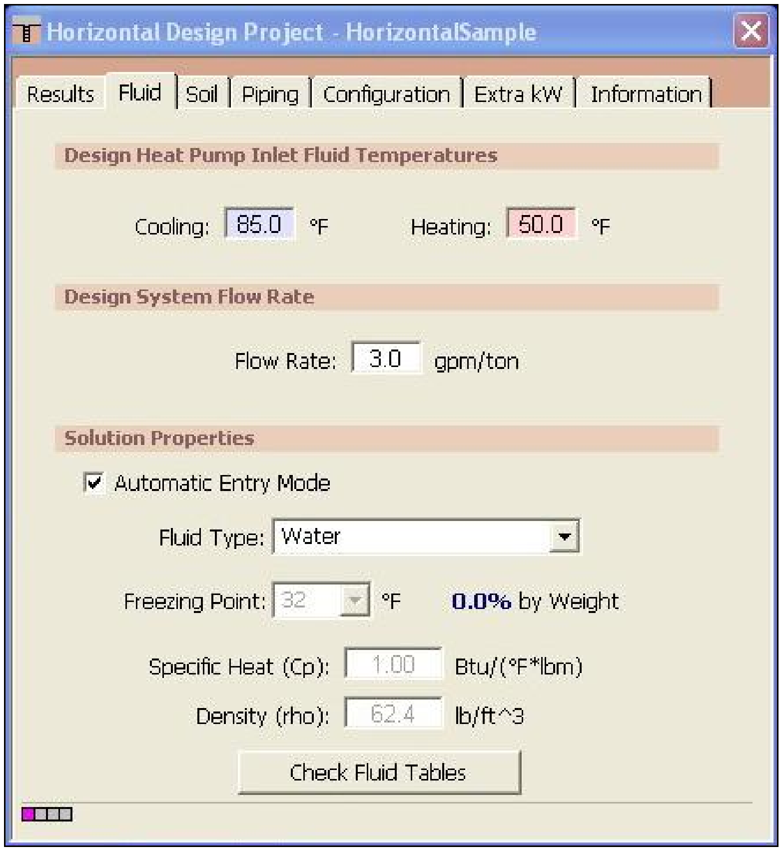


Fig. 5.9 *Fluid* Panel Contents

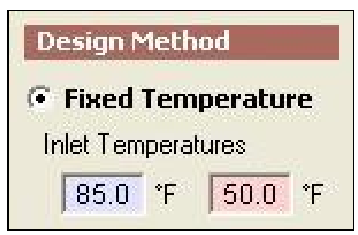


Fig. 5.10 Inlet Temperatures in Expanded User Interface

Solution Properties

Solution properties are also included in the *Fluid* panel. These include the *specific heat* and *density* of the circulating fluid. Also, a reference label is included so that the designer knows the percentage of antifreeze and antifreeze type; ***however, this reference label is not currently linked to the other input parameters.***

The specific heat and density values of the antifreeze are used for the calculation of the heat pump outlet temperature, which in turn is used for the trench length calculation.

Additionally, the viscosity of the solution may affect the flow type in the pipe, which was selected on the *Piping* panel. The designer must be aware of any changes made.

In automatic entry mode, the user first selects the fluid type and then selects the desired freezing temperature. GLD automatically displays the specific heat and density for the fluid selection.

In manual entry mode, the user manually selects and inputs the specific heat and density for the target solution.

Note: Since solution properties vary considerably and non-linearly with type and percentage of additive, GLD does not include detailed automatic antifreeze information for all conditions. Generalized tables of data may be found in the 'Fluid Properties' tables. ***It is recommended that the designer manually enter the desired values in the input text boxes.***

Results

All results for both the heating and the cooling calculations can be viewed at any time on the *Results* panel. After all data has been entered or any changes have been made, the user can calculate interim or final results using the 'Calculate' button. The 'Calculate' button is also available in the expanded user interface, as see in figure 5.5.

A sample screen for the *Results* panel can be seen in figure 5.11. Results are also displayed in the expanded user interface, as see in Figure 5.12.

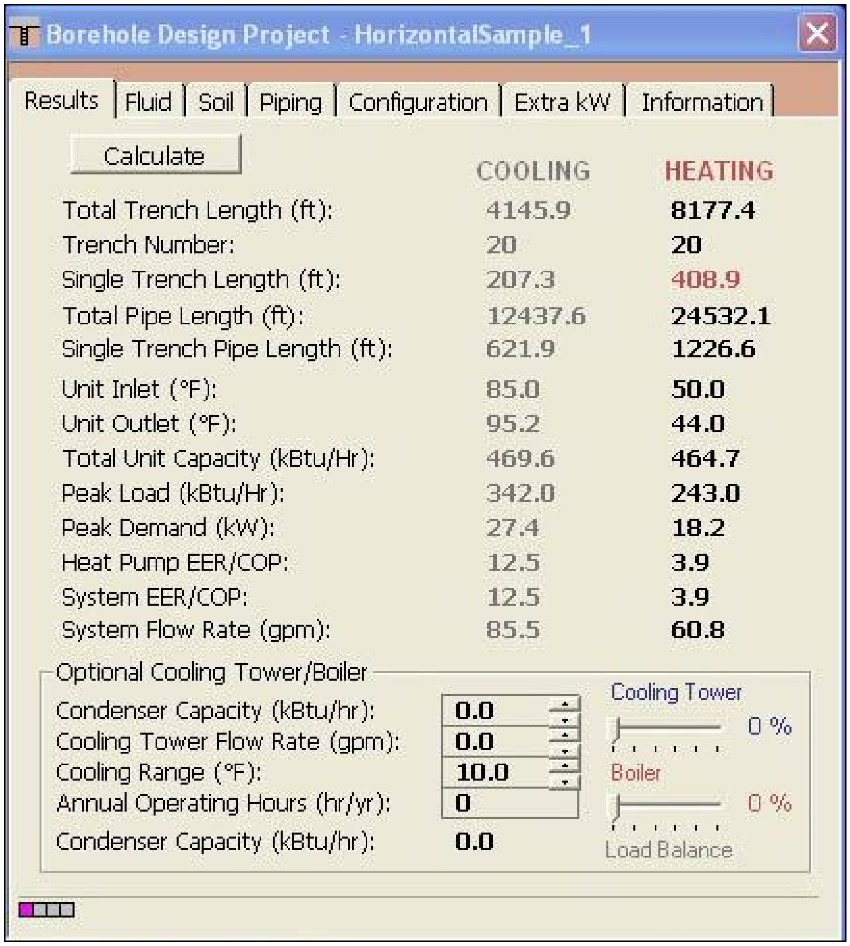


Fig. 5.11 *Results* Panel Contents

Fig. 5.12 Results Display in Expanded User Interface

The two lists on the *Results* panel are for heating and cooling. Although all of the numbers shown are valid and respond to changes, the side with the longer required length is printed in bold type so that it stands out. The longer length determines the installation size and for this reason the shorter-length system results lose relevance.

The Results panel is divided into two sections. On the top is the reporting section, which presents the calculation results. The lower "*Optional Cooling Tower/Boiler*" section is included to assist in the sizing of a cooling tower and/or boiler. This is a convenient tool for hybrid-type designs, which may be desirable when the cooling length exceeds that of heating or when the heating length exceeds that of cooling. The cooling tower and boiler options are discussed in more detail below.

Reporting Section

TIP

The reporting section is further separated into several subsections. The first deals with the trenches, including the total length, the number of trenches, and the length for one trench. A common way to adjust the trench length to a desired value is to change the trench number on the *Configuration* panel.

The associated pipe length, both total and for a single trench, directly follow the reported trench lengths. The pipe lengths are a function of the selected configuration of pipe in the trench, so the length of trench is always less than the length of pipe when anything other than a single pipe configuration is chosen.

The following subsection of the report lists the heat pump inlet and outlet temperatures of the circulating fluid.

The next subsection lists the total unit capacity, the peak loads and demand of all the equipment, and the calculated heat pump and system efficiencies. The peak load is the maximum and is determined from whichever time period across all the zones has the highest load. The peak demand includes all pumps and external energy requirements, including those listed in the *Extra kW* panel**.**

Finally, the system flow rate is listed in its own subsection. The system flow rate is calculated from the peak load divided by 12,000 Btu/ton, and then multiplied by the flow rate (in gpm/ton) chosen on the *Fluid* panel. It represents the flow rate from the installation out to the buried pipe system.

Optional Cooling Tower and Boiler Section

Cooling towers and boilers can be added to designs via the sliders that are located on both the *Results* panel (figure 4.16) and in the expanded interface, as seen in figure 5.14. The Cooling Towers and Boilers can be run independently or together in order to balance required lengths or temperatures.

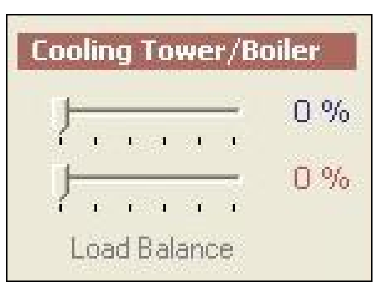


Fig 5.14 Cooling Tower and Boiler Controls in Expanded User Interface

Cooling Towers

Although typically not recommended because of increased running and maintenance costs, the user may elect to add a cooling tower to a cooling-dominated geothermal system to reduce the total boring lengths, and therefore the total initial installation costs. To facilitate this design choice, *GLD* offers the cooling tower, or "hybrid", option.

In any case where the calculated trench lengths for cooling are longer than those for heating, the difference in the lengths can be eliminated through the use of a cooling tower tied in parallel to the geothermal ground loop. This requires that either the cooling tower capacity is chosen such that both the peak load and the annual load to the ground are balanced or if a full balance is unnecessary, a capacity is chosen that allows for downsizing the loop to an acceptable length.

To aid in the sizing process, a *Load Balance* control is provided in the Optional Cooling Tower section of the Calculate panel. Although clicking the slider control can initiate a valid calculation or recalculation, the slider control generally is employed after initial calculations have been conducted. The *Load Balance* is a slider-based control that represents a percentage of the total cooling load, both instantaneous (peak) and annual. For example, a *100% Load Balance* would be equivalent to saying that the entire cooling load of the system would be handled by the cooling tower. Conversely, a *0% Load Balance* would mean that a cooling tower is not employed.

In a typical design it is difficult to predict exactly how much load balance or what size of cooling tower is necessary to match the cooling and heating lengths. However, using the *Load Balance* slider control, the designer can optimize the system to the lengths desired by directly controlling the amount of cooling load to be handled by the cooling tower.

In the case where the designer desires the shortest length possible, the design requires a perfect balance of the heating and cooling loads to the ground. The length from this perfect balance would be the minimum length required to adequately cover the heating load requirement. **To accomplish this, the *Load Balance* slider needs to be adjusted to the percentage value where the calculated cooling and heating bore lengths are approximately equivalent.**

Note: As expected, the Long Term Ground Temperature Change for both heating and cooling should be ***identical*** *in a perfectly balanced system.*

In other cases, the designer just may seek a reduction in the total required system length rather than a perfect balance. Using the slider control, the designer can select the desired length and then note the required cooling tower condenser capacity (as calculated by the program).

Once the required cooling tower capacity is determined, the designer can further modify the various cooling tower parameters to match them to his or her own system. The standard equation used in the program (Francis, 1997) is:

Condenser Capacity (Btu/hr)

= Flow Rate (gpm) x 500 x Temperature Difference (°F),

where the 500 is used for pure water, and represents a factor derived from:

Specific Heat of Water (1.0) x 60 min/hr x Density (8.33 lb/gal) = 500

(Note that GLD actually calculates this factor from the input fluid properties on the *Fluids* panel, although pure water is a logical choice for most cooling-dominated applications.)

For example, if the cooling range is increased above the initial minimum value, the capacity of the condenser also is increased, reducing the total number of operating hours. However, in the same case, decreasing the required flow rate is another option that would keep the condenser capacity and operating hours unchanged. The only limitations are the required temperature difference and the minimum condenser capacity needed to meet the chosen design length. With GLD, users have the flexibility to choose the parameters that fit best in their designs.

Boilers

In GLD, boilers are similar to cooling towers except that they are added in order to reduce the overall heating load on the system. In this case, the user may actually reduce the peak and annual heating loads by the flat percentage defined by the slider value. The required boiler capacity and the modified peak loads applied to the loop field are shown on the panel, but no other inclusion electrical or fuel costs for the boiler are included in the calculation report. The expected heat pump power is also reduced by the same percentage, in order to estimate a real system.

Printing Reports

Reports of the active project can be printed at any time from the Design Studio using the toolbar print button or from the *File* menu → *Print*.

The information printed includes all of the input parameters from the design module, along with the associated results. The zone and loads information is not included with the report, and must be printed separately from the *Loads* panel. The filename of the ***.zon** file associated with the project report is also listed on the report.

Two different project reports are available: concise and detailed. The concise form includes all of the design parameters, but omits some of the project information and comments. The detailed version includes the project information and comments.

More information on reports can be found in Chapter 7.

References

Francis, E., Editor. *Refrigeration and Air Conditioning, 3rd Edition.* Air-Conditioning and Refrigeration Institute. p.186. Prentice Hall, New Jersey, 1997.

Incropera, F. and Dewitt, D. *Introduction to Heat Transfer, 2nd Edition.* p. 456, p. 98. John Wiley and Sons, New York. 1990.

Paul, N. *The Effect of Grout Thermal Conductivity on Vertical Geothermal Heat Exchanger Design and Performance.*

CHAPTER 6

The Surface Water Design Module

This chapter describes the features and operation of the Surface Water Design module. This module is for the design of systems that use bodies of water, including ponds, rivers, lakes, oceans, etc. It is one of the three design modules included with GLD.

Overview

As with the Borehole and Horizontal Design modules, the calculations made in the Surface Water Design module involve the combination of a large number of input parameters. **Care must be taken to assure that proper values are verified before use**. Assuming that reasonable values are provided to the software, the software will provide a reasonable result.

General Features

The Surface Water Design module in GLD also includes a set of panels, grouped by subject, through which the designer can enter and edit the input variables in a straightforward and efficient manner. For example, parameters related to the body of water are listed on the *Surface Water* panel, while piping choices are listed on the *Piping* panel. Everything related to a project is presented simultaneously and easily is accessible throughout the design process. In the expanded user interface mode, which can be expanded by double clicking on any of the tabs, the most commonly modified parameters as well as calculation results are always visible, as seen below in figure 6.1.

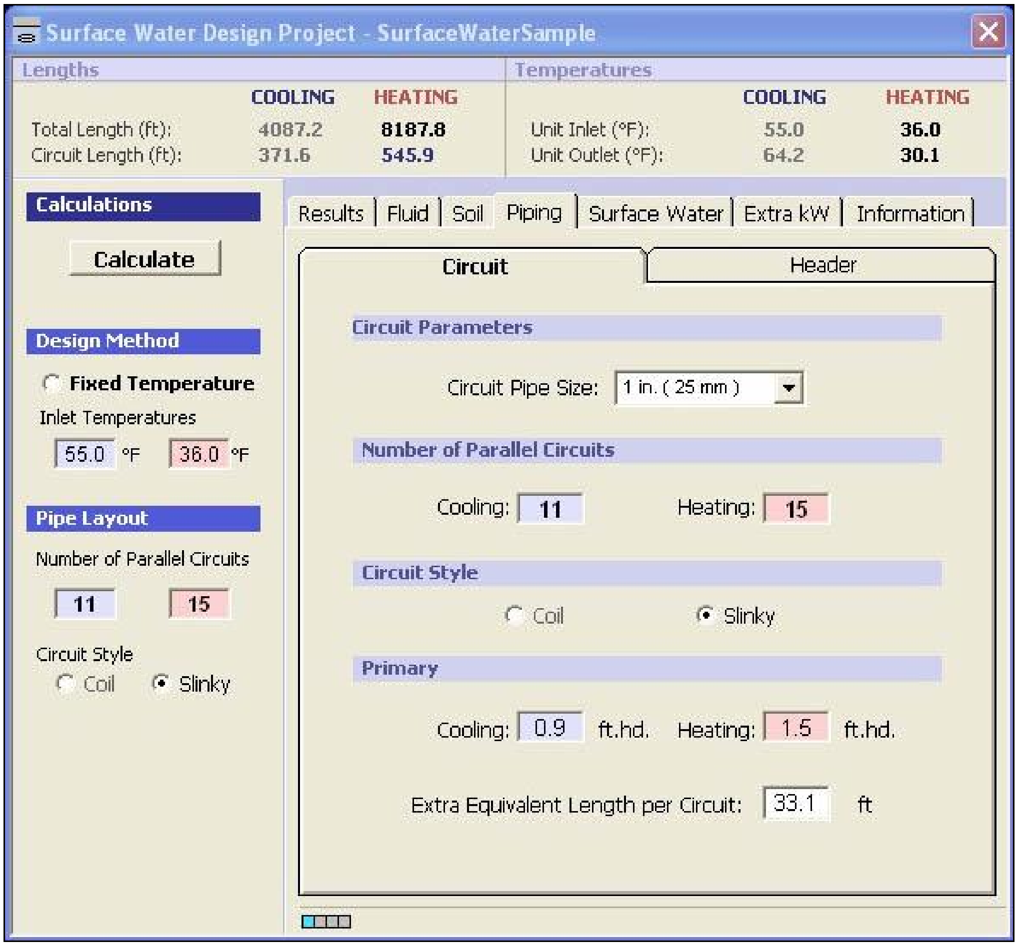


Fig 6.1 Expanded User Interface

The Surface Water Design module includes several additional features:

- Metric and English unit conversion
- Printed reports of all input and calculated data
- Convenient buttons to bring up tables and calculators
- A ‘Calculate’ button used to refresh the calculations
- A system to monitor header and branch piping head losses

Opening Projects

There are two ways to open Surface Water Design projects. One is by using the ‘New Surface Water’ command from the Design Studio *File* menu and the other is by opening an existing Surface Water Design project (***.gld**) file. Files cannot be opened if other modules with the same name are already open. As many files can be opened as the system’s memory permits.

New Projects

New projects may be opened at any time from the Design Studio by choosing 'New Surface Water' from the Design Studio *File* menu or the toolbar. New projects open with standard parameter values that must be edited for new projects.

In new projects, no loads files (*.zon) are loaded. The user must create a new loads file or open an existing loads file into one of the loads modules. Links may be established using the Studio Link system described in Chapter 3.

Existing Projects

Existing projects may be opened at any time from the Design Studio by choosing 'Open' from the Design Studio *File* menu or toolbar. The file automatically opens into a new Surface Water Design Project module.

If a loads file (*.zon) is associated with the loaded project, the loads file will be loaded automatically into the appropriate loads module and opened along with the project file. However, if the associated loads file cannot be found, the user will be notified and the automatic file loading will not occur.

Saving Projects

Projects may be saved at any time using 'Save' or 'Save As' from the Design Studio *File* menu or by clicking the save button on the toolbar. When the user closes the program or module, the program automatically asks the user if he or she would like to save the project file.

Typical Operation

Although each user has his or her own style, the typical operation of the Surface Water Design module would include the following steps:

1. Enter Loads and select pump in either the Average Block Loads module or the Zone Manager module
2. Form a link between the loads module and the design module
3. Modify step-by-step the input parameters listed in each panel
4. Perform initial calculation
5. Modify various parameters and recalculate to determine the effects of the modifications
6. Establish an optimal system
7. Save and/or print the project and associated zone file

Before You Begin

The theoretical model, which is based on experimental data and non-laminar flow, requires a minimum system flow rate of 3.0 gpm/ton in the pipes to achieve proper heat transfer. Minimum flow rates through the circuit piping also are required to maintain the non-laminar flow with different antifreeze solutions. Thus, there is a limit on the maximum recommended number of parallel circuits required in the system, which in turn determines the length of an individual circuit.

Changing the pipe size requires a change in the minimum required flow rates, which can either increase or decrease the maximum recommended number of parallel circuits and their lengths. However, this also can have substantial effects on the piping head losses, which must also be considered in order to reduce the pumping costs.

To fully optimize a system in the Surface Water Design module, **the designer thoroughly must understand the relationship between the system flow rate, the minimum required flow rates, the pipe size, the head loss per length of pipe, and the preferred number of parallel circuits**. GLD can conveniently make all the appropriate calculations, but the designer must first have a grasp of all of the individual inputs required and the relationships among them.

Finally, the surface water designing process actually involves an additional stage of optimization that is not included with the Borehole Design module. The Surface Water module includes a piping calculation component to assist the designer in selecting the best pipe sizes and circuit lengths.

Entering Data into the Tabbed Panels

GLD's innovative tabbed panel system provides for easy organization of and direct access to the relatively large number of design parameters associated with a particular project. This section describes the *Surface Water, Piping, Soil, Fluid, and Calculate* panels. The *Information* and *Extra kW* panels are identical to those included in the Borehole Design module described in Chapter 4, so the reader is referred there for detailed information. See Chapter 3 for a discussion of Loads entry.

Surface Water

Use the Surface Water panel to enter data related to the body of water being used as the heat transfer medium. Figure 6.2 shows the associated input screen.

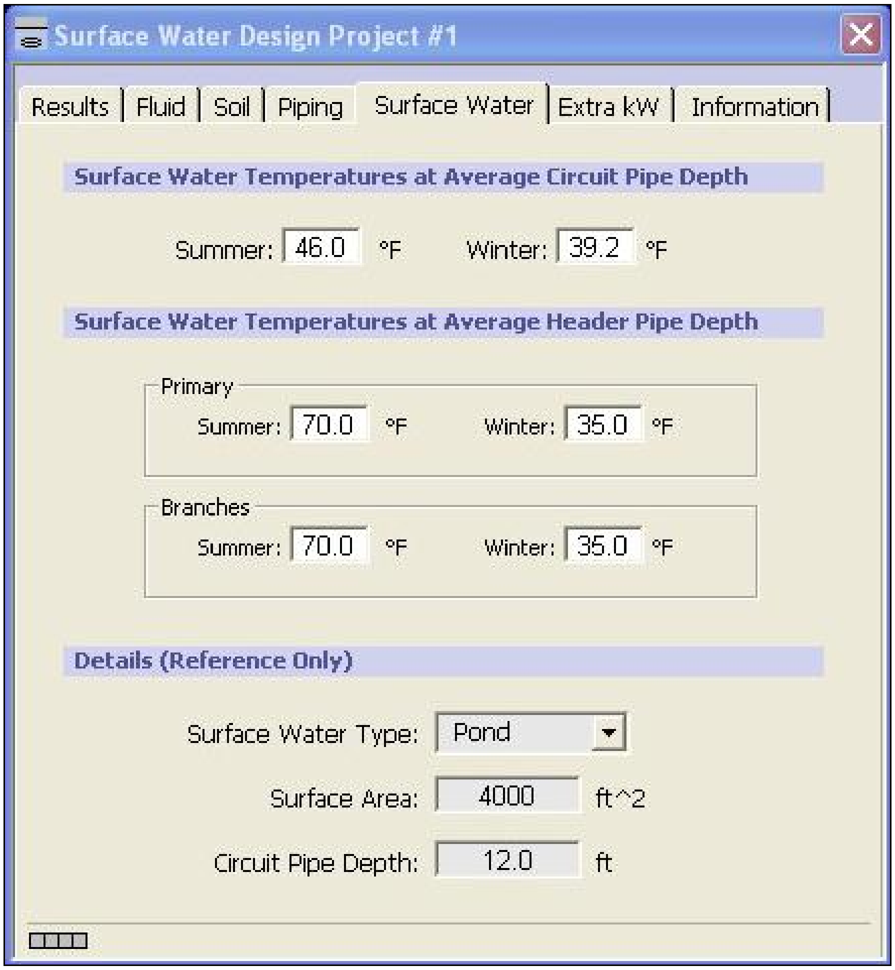


Fig. 6.2 ***Surface Water*** **Panel Contents**

Surface Water Temperatures at Average Circuit Pipe Depth

These are the temperatures in the body of water at the depth where the majority of the pipe will reside. The "Circuit Pipe" refers to the main heat exchanger portion of the pipe, and **does not include** the header pipe leading from the surface.

Temperatures in bodies of water naturally change from summer to winter. Both temperatures, at the circuit pipe depth, should be included in this section.

Surface Water Temperatures at Average Header Pipe Depth

TIP

These are the summer and winter temperatures at the average depth in the body of water where the submerged portion of the header pipes reside. "Header Pipe" refers to the section of pipe leading from the surface to the main heat exchanger (circuit) portion of the loop. Further distinctions are described below.

Primary Header

This is the standard "header", which will most likely come either directly from the installation or from a manifold that comes from the installation main supply and return lines.

Branches

These will be any branches that split from the primary headers. Generally they will be smaller in size than the primary header.

Details (Reference Only)

The surface water details are not used in any calculations. They are included for the designer's reference. Several different types of water bodies are included, but the designer can type anything in the selection box.

Piping

The *Piping* panel contains all the information related to the circuit piping and the piping selected for the primary header(s) and up to one level of branching off the primary header(s). The heat exchanger circuits actually dominate the heat transfer, but if the supply and return lines are long or exposed to different design conditions, care must be taken with the header heat transfer. The input screen for the piping circuit panel is shown in figure 6.3. Figure 6.4 is a view of the piping controls in the expanded user interface. Figure 6.5 is the input screen for the piping header panel.

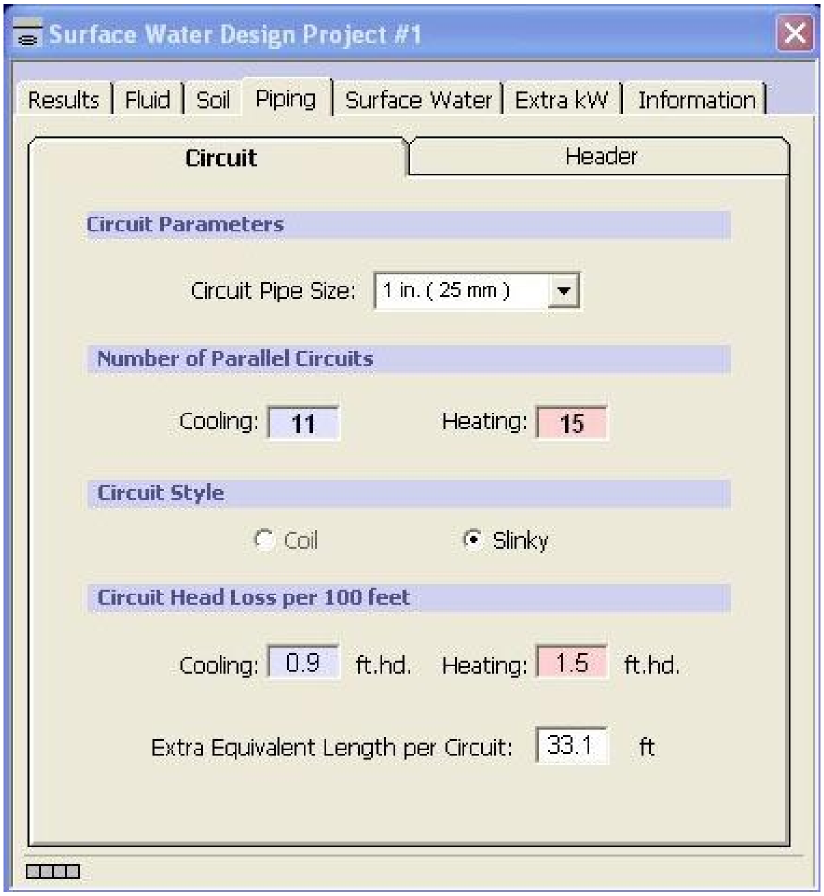


Fig. 6.3 ***Piping*** **Circuit Panel Contents**

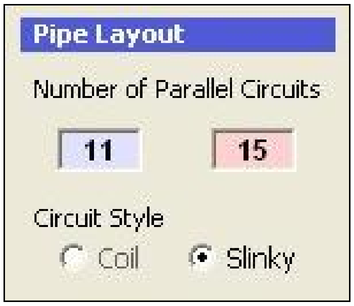


Fig. 6.4 ***Piping*** **Controls in Expanded User Interface**

Circuit Parameters

Circuit Pipe Size

TIP

This is the size of the pipe used in the primary heat transfer circuits. Although larger pipes offer better heat transfer, designers generally prefer smaller sizes (3/4", 1") because of ease of handling and lower pipe costs.

Number of Parallel Circuits

This is the number of parallel circuits required to maintain the required minimum flow rates defined by the designer. If the number of circuits entered here is greater than the allowed number of circuits, **this value will be overwritten automatically with the limiting value when the calculations are performed.**

Even if the circuits are split into equivalent groups (for example, three groups with ten circuits each), the total number of parallel circuits (the smallest unit) will not change.

Circuit Style

TIP

Both loose bundled coils and “slinky” (spread out) styles are available. If extensive spacers are used in a coil style arrangement, the slinky model may provide more accurate results, but the loose coil option will provide the more conservative results.

Circuit Head Loss per 100 feet

This is the head loss for the particular style of pipe. *These values are not entered automatically.* Instead, they come from designer’s charts. A chart in English units is included with GLD in the “Pipe Tables” section. **The designer must be aware that this value changes with pipe size, temperature, and flow rate.**

Extra Equivalent Length per Circuit

This is an average pipe length value included per circuit to take into account all fittings (elbows, tees, etc.). It is only necessary for the head loss calculations.

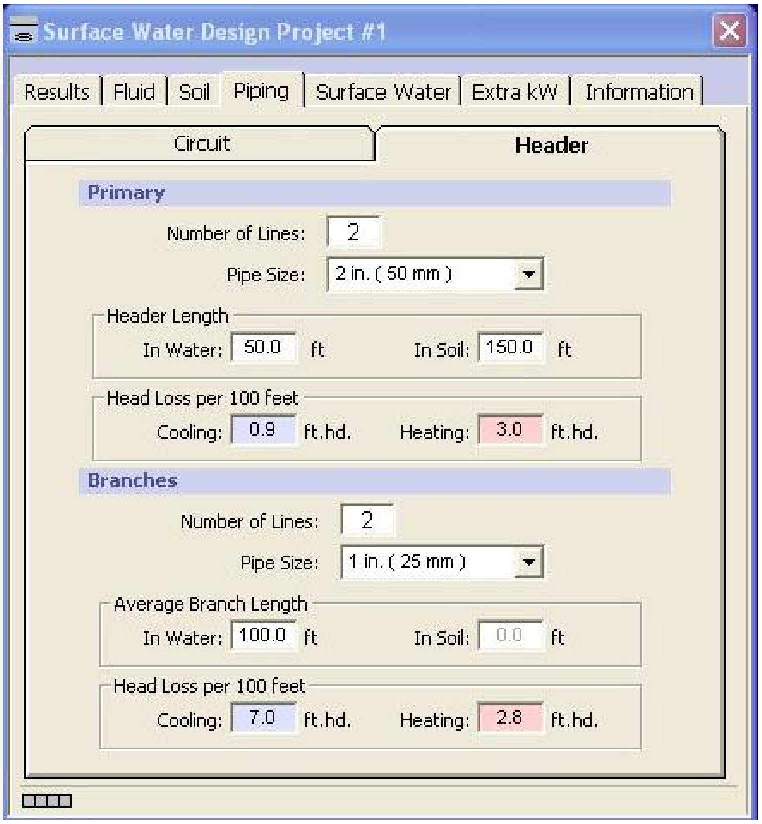


Fig. 6.5 *Piping* Header Panel Contents

Header Parameters

The GLD Surface Water module assumes that a standard supply and return line design will consist of mains, followed by a manifold that splits the mains into the headers. Headers are generally the first pipes to enter the ground or water. They can then branch off once more if necessary (branch lines). For small systems, the mains may be the headers, and there may not be branches. For larger systems, there may be many headers and multiple levels of branches.

In the *Piping* panel, the model employed allows for multiple headers and multiple first-level branches off of those headers. If further branching is required, the head loss calculations will need to be calculated and added separately. Their effect on the calculated piping length, which cannot be included, will depend on their length. **All headers are assumed to have an identical pipe size, and an approximately equivalent flow**. The same is true for the branch lines.

If there are no branches, the number of branches should be set to zero. The Surface Water Design module starts with only a single primary header.

GLD uses the header information so that the heat transfer losses or gains are taken into account. The software then uses this corrected value iteratively to modify the length of the circuit loop piping, so that the desired entering water temperature for the heat pumps is provided. These calculations depend directly on the header-depth surface water and soil temperatures obtained from the *Surface Water* and *Soil* panels.

Additionally, the program calculates the average head losses of the system when provided with the head losses per 100 ft. for each type of pipe in the system. *These values vary with pipe size, antifreeze, and flow rate.* Several graphs are provided with the program to help determine these values for pure water and standard solutions**, but the designer is ultimately responsible for making sure the appropriate values are entered**. *These head loss calculations also require the one-way length of the header, which is doubled within the program to account for both the supply and return lines.*

Because the inputs to headers and branches are similar, they are described together below.

Number of Lines

This is the number of header or branch lines in the system.

Pipe Size

This is the size of the pipe used in the primary header or branches. For pumping reasons, the size of the primary header is generally larger than the branch and circuit pipe sizes, and branches are generally larger than the circuit pipe size.

Header Length / Average Branch Length

This is the designer-defined **one-way** length of the pipe from the installation to the water line, and then from the water to the circuit pipes. Different heat transfer calculations are used for the header pipe buried in the soil and the header pipe submerged in the water.

If a primary header enters the water, it is automatically assumed that the branches have no soil component. Likewise, if branches enter the soil, it is assumed that the primary header has no water component.

Head Loss per 100 feet

This is the head loss for the particular style of pipe. *These values are not entered automatically*. Instead, they come from designer's charts. A chart in English units is included with GLD in the "Pipe Tables" section**. As mentioned above, the designer must be aware that this value changes with pipe size, temperature, and flow rate**.

Soil

The *Soil* panel is included only for the heat transfer calculations associated with the portion of the header pipe in the soil. The model uses the undisturbed ground temperature of the soil as well as several other parameters associated with the installation location to determine the temperature at pipe depth on the coolest and warmest days of the year. This temperature then is used to determine how much heat is transferred from the header pipe to the soil or vice versa.

Once the amount of heat transfer from or to the soil is known, the circuit pipe length (calculated from the surface water data) can be modified to provide fluid with the desired inlet source temperature to the heat pumps.

The *Soil* panel input screen is shown in figure 6.6.

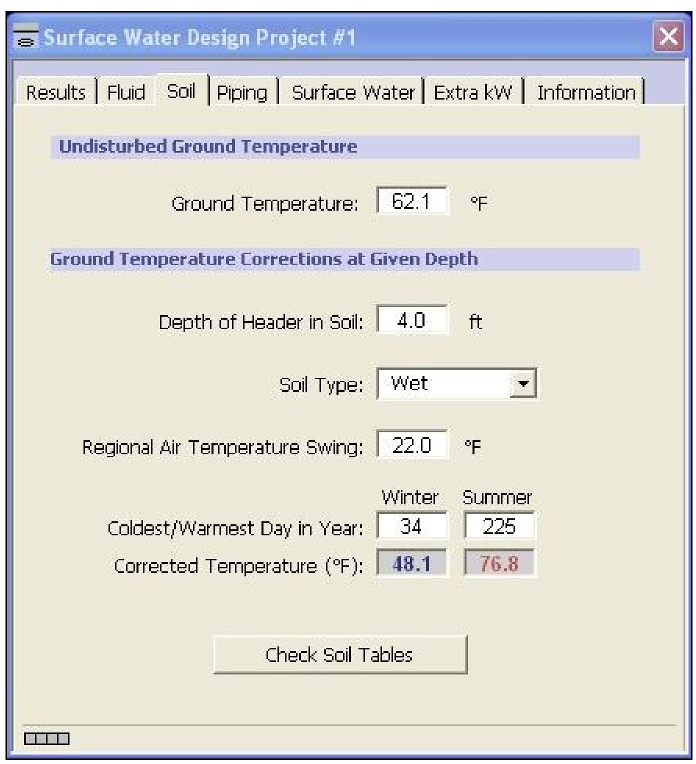


Fig. 6.6 *Soil* Panel Contents

Ground Temperature Corrections at Given Depth

Depth of Header in Soil

This is simply the average depth in the soil between the water's edge and the installation at which the primary header or branches will be buried.

Soil Type

The soil type can have one of three values: wet, dry, or average. GLD uses this to assign an approximate diffusivity value to the soil used in the temperature model.

Regional Air Temperature Swing

This is the temperature swing for the location of interest. It is a measure of the average temperature variation of the region during the warmest and coolest months as compared to the yearly average temperature. Regions with temperate climates have a lower temperature swing than regions that have large differences between summer and winter temperatures.

Coldest/Warmest Day in Year

These are the actual days of the year, on a 365-day scale, when the temperature is usually coldest or warmest. For example, if February 3 is approximately the coldest day of the year, the value entered will be '34' (31 days in January, plus 3 days of February).

The program uses these days to determine the soil temperature at the given depth at these times of the year.

Corrected Temperature

These are the corrected temperatures at the depth specified, calculated automatically from the undisturbed temperature and the other input values provided. These values are used in the heat transfer calculation between the header or branch pipes and the soil.

Fluid

The fluid panel is identical to the one described for the Borehole Design module in Chapter 4 except for one addition. That addition is the minimum required circuit flow rate in the lower 'Minimum Circuit Flow Rate and Solution Properties' section. The added section is shown in figure 6.7. As in the other modules, the inlet temperatures can be viewed and modified from the expanded interface, as seen in figure 6.8

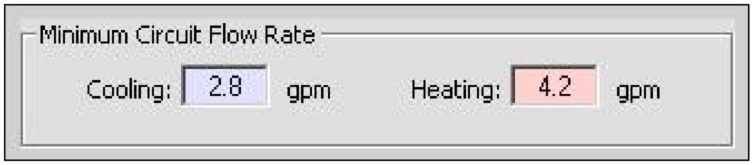


Fig. 6.7 Minimum Circuit Flow Rate Section of the *Fluid* Panel

GLD uses this information in conjunction with the system flow rate to establish the maximum number of parallel circuits. The flow rates required for non-laminar flow for several antifreeze solutions are included as a table in the 'Fluid Properties' set. **Exact values for a particular mixture may need to be determined independently by the designer**.

Note once again that changes in the inlet source temperature or the system flow rate will cause an automatic update of the selected pumps.

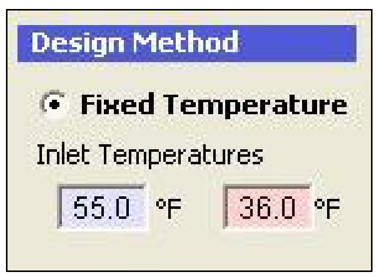


Fig. 6.8 Inlet Temperature Controls in Expanded User Interface

Results

There are several significant differences between the Surface Water Design module's *Results* panel and the Borehole Design module's *Results* panel. These differences relate to the nature of the calculations, as well as to the inclusion of the head loss calculation results. Figure 6.9 shows a typical view of the *Results* panel. Figure 6.10 shows the results display in the expanded user interface. Figure 6.11 shows the 'Calculate' button in the expanded user interface.

Again, there are two lists shown on the *Results* panel, one for heating and one for cooling. Although all of the numbers resulting from both sets of calculations are valid, the side with the longer length is printed in bold type, so that it stands out. The longer length usually determines the installation size, and for this reason the shorter-length system results lose relevance. *However, in cases where the cooling and heating lengths are similar, care must be taken to assure the safest design.*

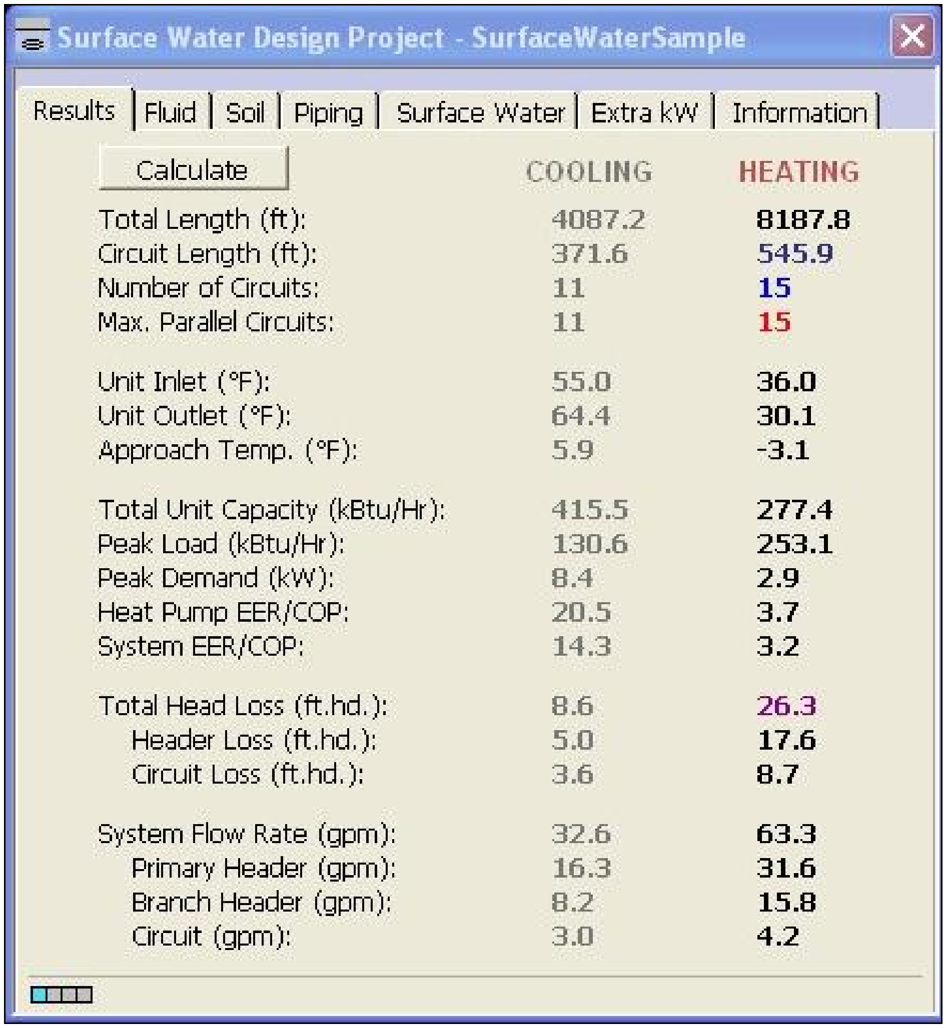


Fig. 6.9 *Calculate* Panel Contents

Fig. 6.10 Results as Displayed in Expanded User Interface

Fig. 6.11 Calculate Button in Expanded User Interface

Reporting Section

The surface water report has five sections. The first deals with the circuit pipe, and includes the total length, the length for one circuit, the number of circuits, and the maximum allowable number of parallel circuits (shown in red). If the maximum allowable number of parallel circuits exceeds the actual number of circuits, the actual number of circuits may be increased in the *Piping* panel to reduce the individual circuit lengths and thus reduce head losses. However, this type of reduction is not always necessary or desirable. Other ways of increasing the maximum allowable number of parallel circuits include changing the system flow rate or the minimum circuit flow rate for non-laminar flow.

The second section lists different temperature variables. The first two of these are Source inlet and outlet temperatures. The final variable is the approach temperature, which is the difference between the pond temperature and the desired inlet source temperature.

Note: In surface water heating applications, although the solution within the pipe may not freeze, the freezing temperature of the body of water is generally 32°F. ***If the heat pump outlet temperature is too far below this value, the water may freeze on the pipe, greatly reducing its heat transfer characteristics and potentially leading to system failure****. The designer must always pay attention to the outlet temperature value for this reason.*

As with the Borehole Design module, the third section lists the total unit capacity, the peak loads and the demand of all the equipment, followed by the calculated heat pump and system efficiencies. The peak load is the maximum, determined from whichever time period across all the zones has the highest load. The peak demand includes all pumps and external energy requirements, including those listed in the *Extra kW* panel. *Care must be exercised when equipment energy requirements listed in the Extra kW panel refer to only heating or only cooling types of equipment.* In these cases, the pump efficiency could be fine, but the system efficiency might be incorrect.

The fourth section lists the total head loss calculation results, as well as the individual losses for the header and circuit pipe. It does not include any losses for the heat pump equipment, which must be considered separately. This section is convenient for determining the optimum pumping arrangement for the system.

Finally, the system flow rate is listed along with the flow rates in the primary and branch headers, as well as the flow in the individual circuits. The system flow rate is calculated from the peak load divided by 12,000 Btu/ton, and then multiplied by the system flow rate in gpm/ton (as given on the *Fluid* panel). The primary header flow rate is calculated from the system flow rate divided by the number of primary headers, and the branch flow rate is obtained from the primary header flow rate divided by the number of branches (as given on the *Piping* panel). The circuit flow rate is obtained by dividing the system flow rate by the total number of circuits (also provided on the *Piping* panel).

Printing Reports

Reports of the active project can be printed at any time from the Design Studio using the toolbar print button or from the *File* menu → *Print*.

The information printed includes all of the input parameters from the design module, along with the associated results. Zone and loads information can be printed separately from the *Loads* panel. The filename of the ***.zon** file associated with the project report is also listed on the report.

Three different project reports are available: concise, detailed and detailed with loads. The concise form includes all of the design parameters, but leaves out some of the project information and comments. The detailed form includes the information and comments.

More information on reports can be found in Chapter 7.

CHAPTER 7

Reports

This chapter covers the report creation and printing features of GLD. It includes project, zone and financial reports.

Overview

GLD includes reporting features. These features have been added for professionals who need to keep records of their designs and communicate them to others. There are nine different report styles included within the package, and this chapter provides an explanation of as well as suggested uses for each type of report.

The Report Preview Window

When a particular report is selected, a report preview window opens to show a preview of the report. Report preview windows have a zoom feature that allows adjustment of the magnification. Additionally, reports may be sent to a printer or exported as various file types, including text and html. Multiple reports may be opened simultaneously, even if they originate from the same project.

Report preview windows do not react directly to metric/English unit conversion. Instead, a report opens with the same units used by its parent design module. If another system of units is required, the user must first change the unit system of the design module (using the Design Studio 'Units' menu), and then open a new report.

Project Reports

Project reports may be opened at any time from the Design Studio *File* menu by selecting *Print*. An option dialog box appears displaying the six types of reports that are available: *concise*, *detailed, input data with loads, concise temperature, detailed temperature, and full project*. The first two project reports are available in all three design modules. Detailed reports contain full project information, while concise reports limit the project information and exclude any comments. Detailed reports generally require multiple pages while concise reports are designed for single-page printouts. The other four project reports are associated with monthly inlet temperatures and therefore are available only with the borehole module. The user selects a preference and then clicks 'OK'.

The report does not print automatically, but instead creates the report preview window, in which the report can be reviewed prior to printing. Printing can be done by clicking on the printer icon in the upper left hand corner of the report preview window.

In general, project reports contain several main sections:

- **Information**
- **Calculation Results**
- **Input Parameters**
- **Loads (**borehole only when linked to Average Block module)
- **Monthly Inlet Temperatures** (borehole only when linked to Average Block module)
- **Comments**

Information

This section contains the information from the design module's *Information* panel. The project and designer's names, dates, client's name and address, etc. appear here. This section is included at the top of every report. Concise reports only include the project name and start date.

Calculation Results

This section lists the results of the calculations and essentially is the same information shown on the *Calculate* panel of the design module. The most important results, such as the total length of pipe required, are highlighted and boxed in order to stand out from the background. The report presents results of both the heating and the cooling calculations.

Input Parameters

This section contains all of the parameters entered by the designer during the design process. Parameters are placed into sections with names taken directly from the panels in the design modules. The filename of the zone file associated with the project is listed under the *Loads* heading.

Loads

This section contains all of the loads data entered in the Average Block loads module (peak loads and monthly loads as well, if entered). This section is only available in borehole module reports since only the borehole module is capable of calculating monthly inlet temperatures based on the input loads.

Monthly Inlet Temperatures

This section contains a summary section of the average and peak inlet temperatures followed by the month-by-month temperatures, and other associated data.

Comments

This section, at the end of the report, is reserved for any additional information that the designer would like to include with the project.

Zone Reports

Zone (or loads) reports are printed directly from the *Loads* modules. They include only the project information and data from the zones, presented in different formats. Five different zone reports exist, containing complete or specific information about the zones.

Zone reports work in conjunction with project reports, but are actually a separate entity. They are representative of the actual installation rather than the heat exchanger portion of the system. Zone delineation, loads, and equipment are separate from the heat exchanger system. It is for this reason that the designer would necessarily want to view and consider this information apart from the specific heat exchanger details. For example, if the design is a building, the zone reports will cover everything within the building, while the project report essentially will contain information about everything outside, or external to the building.

A zone report is printed from the *Loads* panel of the Zone Manager or directly from an Average Block Loads module by clicking the printer button in the controls. A dialog window appears, giving the designer the list of available report styles. After the making a choice, click 'OK' to bring up the report window.

There are five different zone reports included with GLD:

- **Detailed Form**
- **Concise Form**
- **Equipment List**
- **Loads List**
- **Names List**

Detailed Form

The *Detailed Form* zone report is the most detailed zone report. It lists all of the information included in every zone, along with full explanations of the listed parameters. The format is open and easy to read. However, as with the project reports, the detailed form produces a much longer printed report than any of the more compact versions.

Concise Form

The *Concise Form* zone report contains most of the detail of the long report, but it is packed into a smaller space. It does not include zone names, occupation days, detailed pump information (manufacturer, series, and type), or full descriptions of the items listed. It does, however, contain important information about the loads and the operational parameters of the equipment matched to those loads.

Equipment List

The *Equipment List* lists only the equipment associated with each zone. It provides detailed pump information, including name, number, manufacturer, series, and type, plus all of the operational data associated with that pump. It is an ideal report for engineers or contractors who require equipment lists but do not necessarily need to know further details about the design.

Loads List

The *Loads List* lists only the loads associated with each zone. It provides the design day loads at the different periods during the day in both heating and cooling modes. For the Borehole Design module, the Loads report includes the annual hours and weekly occupation information.

Names List

The *Names List* is just a list of the full reference names of the different zones, combined with the zone number, pump name, and number of pumps required for the zone. It makes a convenient, compact link between zone name and number, and is especially useful when the project consists of many separate zones.

NEW

Finance Reports

Finance reports are printed directly from the Finance module. They include the project information and financial data, presented in different formats. Four different finance reports exist.

A finance report is printed directly from the Finance module by clicking the printer button in the controls. A dialog window appears, giving the designer the list of available report styles. After the making a choice, click 'OK' to bring up the report window.

There are five different zone reports included with GLD:

- **Concise Form**
- **Detailed Form**
- **Concise Inputs Form**
- **Detailed Inputs Form**

Concise Form

The *Concise Form* finance report is the simplest finance report. It lists the fuel/energy usage and costs on an annual and NPV lifetime basis for only the geothermal system.

Detailed Form

The *Detailed Form* finance report is the most detailed finance report. It lists the fuel/energy usage and costs on an annual and NPV lifetime basis for both geothermal and conventional HVAC systems.

Concise and Detailed Inputs Forms

The *Concise/Detailed Inputs Forms* contain lists of all of the inputs used in the financial analysis.

Concluding Remarks

There are no data in GLD that are not expressible in a printed form. The designer can organize and share information both during the developmental stages of a project and after the design is complete.

CHAPTER 8

Tables and Reference Files

This chapter covers the tables and reference files of GLD. It starts with a description of the included files, and then explains how the user may add customized files to the existing set.

Overview

Favorite references are like a comfortable pair of worn-in sneakers. Although this software package provides some useful information in the included tables, it may never replace the old standards. Rather than trying to impose a particular system onto the users of the software, GLD employs a technologically sophisticated system that allows the user to customize the reference files as much as he or she desires. With this system a new pair of shoes feels comfortable immediately.

The reference files included with GLD are minimal, consisting of a few tables and graphs that should aid in the selection of requested parameters. All files are written in open HTML (Hypertext Mark-up Language) files. The designer can edit and add to them as he or she desires to create a customized reference library within the Design Studio environment.

As with the heat pump and loads models, the reference files model is another customizable element of the geothermal Design Studio that the user has the option to control.

Tables Included with GLD

Several tables are included with GLD. They are separated into several broad categories from which most questions will arise. These include:

- **Fluid Properties**
- **Soil Properties**
- **Pipe Properties**
- **Conversions**

The first three sections present a menu screen with hyper-links to various tables that have been included in the package. The fourth section consists of a pair of metric-to-English units conversion tables that answer most common engineering conversion problems. Below is a description of the included files.

Fluid Properties

Fluid properties refer to any data related to the circulation fluid. The five *Fluid Properties* tables in GLD are the following:

Table 1: Densities and Specific Heats of Various Solutions

Table 2: Minimum Required Flow Rate for Non-laminar Flow

(Tables 3-5 included only in English Units)

Table 3: Head Loss in SDR 11 HDPE Pipe - 20% Propylene Glycol

Table 4: Head Loss in SDR 11 HDPE Pipe - 20% Methanol

Table 5: Head Loss in SDR 11 and 17 HDPE Pipe - Pure Water

Some of these charts could have also been placed with the Pipe Properties tables, but because they vary primarily with solution type, they were placed here.

In an ideal world, the *Fluid Properties* tables would include all of the graphs, charts, and tables for all of the parameters of all possible antifreeze combinations. However, because these variations are difficult to predict for specific projects, only partial information has been included. For the most accurate designs, designers are encouraged to seek out their own favorite antifreeze combinations, and determine the specific heat, density, and minimum required flow rate for non-laminar flow.

Soil Properties

Soil properties refer to any data related to the soil. The three reference files are listed below.

Table 1: Thermal Conductivity and Diffusivity of Sand and Clay Soils

Table 2: Thermal Properties of Rocks at 77^0 F

Table 3: Earth Temperatures, Soil Swing and Phase Constants for U.S. Cities

The first two *Soil Properties* tables included with GLD provide various soil parameters, including ranges for thermal conductivity (***k***) and thermal diffusivity (α) for various types of soils.

These tables should not be considered accurate for a given location; however, they should provide the designer with a realistic range within which their own measurement results should fall.

The third table contains mean earth temperatures and other parameters for U.S. cities. This table particularly may be useful for horizontal designs.

Pipe Properties

Pipe properties refer to any data related to the piping. The *Pipe Properties* tables included with GLD are related to either the borehole thermal resistance or the pipe physical data. They are listed below.

Table 1: Thermal Conductivities of Typical Grouts and Backfills

Table 2: Pipe and Tube Dimensions

Table 3: Required Flow Rates to Achieve 2 ft/s – SDR11 Pipe

The first table provides thermal conductivities for some typical grouts. The second lists the physical dimensions (inner and outer diameter) for common pipe sizes in various types of pipe. The third, although unnecessary for the associated calculations, provides some convenient flow rates required for proper purging of a piping system.

Conversions

The Conversions table has two separate lists of metric to English conversions, placed together in one file. As already mentioned, the user can obtain multipliers for most common metric/English unit changes by going through the listed conversions.

Adding Customized Reference Files

The user can create customized reference files by editing the existing HTML files with the table lists, and making new links. The process is simple and requires only a very basic knowledge of HTML

Original Model

The original model included with GLD consists of these files:

English	Metric
FluidTables.html	**FluidTablesMetric.html**
FluidTable1.html	**FluidTable1Metric.html**
FluidTable2.html	**FluidTable2Metric.html**
FluidTable3.html	
FluidTable4.html	
FluidTable5.html	
SoilTables.html	**SoilTablesMetric.html**
SoilTable1.html	**SoilTable1Metric.html**
SoilTable2.html	**SoilTable2Metric.html**
SoilTable3.html	**SoilTable3Metric.html**
PipeTables.html	**PipeTablesMetric.html**
PipeTable1.html	**PipeTable1Metric.html**
PipeTable2.html	**PipeTable2Metric.html**
PipeTable3.html	**PipeTable3Metric.html**

To add a new file, the **FluidTables.html**, the **SoilTables.html**, or the **PipeTables.html** must be edited. The user must create a link in one of the three aforementioned *.html files to the new file (which contains the table, graph or image that the user would like to have available in GLD).

*Note: GLD requires the **FluidTables.html**, **SoilTables.html**, and **PipeTables.html** files (and their metric counterparts, **FluidTablesMetric.html**, **SoilTablesMetric.html**, and **PipeTablesMetric.html)** as the initial files when opening the associated tables. They can be edited, but if they are deleted the associated tables cannot be opened at all.*

HTML Files

HTML refers to Hypertext Mark-up Language. It is the language used on web pages, and commonly used in software to quickly provide linked information to users. HTML files can be created with an HTML editor (like those distributed with common browsers) or with a simple text editor. They must, however, follow a certain format and have a '.htm' or '.html' extension.

Editing Existing Files

Existing files may be edited by simply opening up the original file into a text editor or HTML editor, making changes, and then saving the file again. For example, if a user wishes to add a new pipe table to the list, he or she first will create the table (i.e. PipeTable4.html) and then will add a link to it on the PipeTables.html file.

Additionally, if the user wishes to add additional information to an existing table or figure, he or she only has to open the appropriate HTML file in a text editor or HTML editor and make and save the desired changes. For example, if adding a new link, **PipeTables4.html**, to the **PipeTables.html** file, one might add this new link with the name "Table 4: New Pipe Table" by typing the new link at the end of the **PipeTables.html** file into a text editor as follows (the added section is in **bold** type):

```
.
.
.
<li>
<a href="PipeTable3.html">Table 3: Required Flow Rates to Achieve
2ft/s – SDR 11 Pipe</a></li>
</ul>

<li>
<a href="PipeTable4.html">Table 4: New Pipe Table</a></li>
</ul>

</body>
</html>
```

PipeTables.html (edited version)

Making a Table

A new table can be made at any time by creating one as an HTML file. The easiest way to do this is to use an HTML editor. It is much more difficult to make a table using plain HTML in a text editor.

Although any name is valid for a table, tables can be added to the appropriate group by just extending the naming sequence already being used. For example, the name **PipeTable4.html** could be used as the name for a new file.

Adding a Picture, Graph, or Figure

If an image is stored as either ***.jpg** or ***.gif**, it can be imported into an HTML page. The HTML page can be linked directly to the GLD reference files.

As an example, let's assume that an engineer scans an image of his favorite density vs. percent solute graph for Calcium Chloride and saves it in the Help Files directory as a ***jpeg*** image, called **CaCl2Density.jpg**. A very simple HTML file can be created with a text editor, and called **FluidTable6.html**. The entire **FluidTable6.html** file would be as follows:

```
<html>
<head></head>
<body>
<img SRC="CaCl2Density.jpg" >
</body>
</html>
```

FluidTable6.html

Remember, the **FluidTables.html** file would have to be edited to include the new link to the **FluidTable6.html** file, similar to the example given in *Editing Existing Files*, above.

If everything is done properly, when 'Fluid Properties' is selected from the *Tables* menu in the Design Studio, 'Table 6' will appear as a link in the list of available tables. By clicking on the link, the CaCl2 density image, **CaCl2Density.jpg**, will appear, and can be used as a convenient internal reference.

Taking Care with Updates

Updated versions of GLD may have new reference files and new versions of **FluidTables.html**, **SoilTables.html**, or **PipeTables.html**. If this is the case, then any custom changes to these files made by the user may be overwritten during a new installation. ***Although the linked files will remain, the user is advised to make backup files of all customized reference files before new GLD installations or updates.***

Concluding Remarks

The reference files in GLD are added entirely for the user's convenience. Designers should find the customizable geothermal Design Studio an ideal and familiar environment in which they can conduct their work with the highest levels of efficiency and confidence.

CHAPTER 9

The Finance Module

This chapter describes how to use the GLD finance module, a module that models both “hard” and “soft” costs associated with geothermal and standard HVAC systems. All of the calculations fundamentally are based on data provided by the designer, providing for the greatest range of flexibility and accuracy.

Overview

When designers, architects and building owners are deciding whether or not to install a ground source heat pump system, they must consider a variety of factors including cost. Cost means different things to different people. Some think of the “hard” costs –the first costs associated with the design and installation of an HVAC system. Others think of lifecycle operating costs. In an increasingly green-focused world, still others think of environmental costs. Finally, some percentage think of the “soft” costs associated with HVAC systems- the opportunity costs associated with large vs small mechanical rooms, the varying maintenance costs associated with one system vs another, and even the water consumption costs associated with some types of systems, such as geothermal-cooling tower hybrid systems.

The Ground Loop Design financial module allows designers to model and estimate all of the aforementioned costs- from expected future $C0_2$ emissions costs to the annual and lifetime operating costs of geothermal, hybrid, and more standard HVAC systems. Furthermore, it enables decision makers to compare simultaneously the financial profiles of multiple systems.

The finance module either can be used on a stand alone basis or in conjunction with a heat exchanger system designed in GLD. On a stand alone basis, users can enter minimal data for a quick energy cost and emissions estimate or can enter detailed data for a more comprehensive financial analysis.

Users also can model the financials of a heat exchanger system designed in GLD. The program automatically transfer the applicable parameters into the finance module and reports the financial and emissions analysis. As with the other modules in Ground Loop Design, it is important to remember that the calculated results are only as good as the quality of the user-defined inputs. Assuming that reasonable values are provided to the software, the software will provide reasonable results. It is also important to note that the finance module is only an estimation tool and for a variety of reasons, installed HVAC systems may have costs and emissions that vary significantly from the estimates.

General Features

To aid in the data entry process, the Finance module in Ground Loop Design consists of a set of panels, grouped by subject, through which the designer can enter and edit the input variables efficiently. For example, parameters related to the utility costs are listed on the *Utility Costs* panel, while conventional system comparison choices are listed on the *Conventional* panel. The idea is that everything related to a single financial project is presented simultaneously and is easily accessible at any time during the design process. The tabbed panels can be seen in figure 9.1, below.

Fig. 9.1 Financial Model Panel List

The Financial module includes several additional features:

- Analyses and comparisons are based on:
    - Energy usage costs
    - $C0_2$ emissions costs
    - Water usage costs
    - Maintenance costs
    - Mechanical room lease value opportunity costs
    - Installation costs
    - Salvage values/costs
    - Tax Incentives
    - Adjustable inflation and discount rates

- Metric and English unit conversions
- Printed reports of all input and calculated data
- A 'Calculate' button used to refresh the calculations
- Quick importation and modeling of systems designed in the vertical, horizontal and pond modules
- Stand alone financial analysis capabilities
- Comparison of a geothermal system with up to four alternative systems

Theoretical Basis

The financial module analyzes a number of hard and soft costs associated with geothermal and other HVAC systems. It models these costs both for a single year and for the building lifetime.

Many of the factors required for these analyses are user-definable and the level of analysis depends on the needs of the user. If the user enters only some of the cost factors, then some costs can not be calculated or displayed. If the user enters all of the cost factors, then all of the costs can be calculated and displayed.

For the single year costs, the program sums up the various costs for a single year of operation and displays the results. For the lifetime costs, the program uses a net present value (NPV) analysis that incorporates an overall discount rate as well as inflation rates associated with different fuel types.

Opening Projects

There are two ways to open Finance projects. One is by using the 'New Finance' command from the Design Studio *File* menu or toolbar, and the other is by opening an existing Finance project (***.fin**) file from within the finance module. In the design studio, only one financial module can be open at a time.

 New Projects

New financial projects may be opened at any time from the Design Studio by choosing 'New Finance' from either the Design Studio *File* menu or the toolbar. New projects open with standard cost values that the user can modify as necessary for new projects. The module opens directly into the *Results* panel.

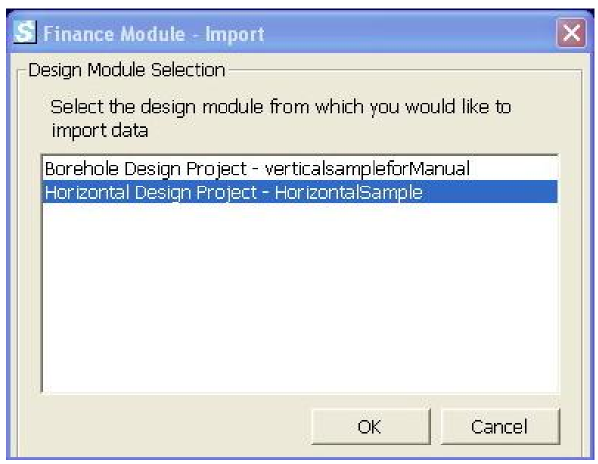
New financial projects can be for a stand-alone financial analysis or for use in conjunction with an existing heat exchanger design project. For use in conjunction with an existing heat exchanger design project, see below.

Importing Data from an Open Heat Exchanger Design Project

If a designer wishes to perform a financial and emissions analysis of a vertical, horizontal or pond project that he or she designed with GLD, he or she can do so by following these steps:

1) Open the project file (vertical, horizontal, or pond) of interest and make sure that the loads file (zone manager or average block) that is linked to the project file is open as well.
2) Push the import button on the toolbar at the top of the finance module. It looks like this:

3) A window similar to the image below will appear.



4) Select the project/design module of interest and click 'Ok'.

5) The relevant design parameters automatically will be loaded into the finance module.

Please note that if a user imports a surface water project, the user must manually enter equivalent full load hours into the geothermal tab. This is because in GLD, the surface water loads modules neither have nor require full load hours inputs (see Chapter 6 and page 156).

 Existing Projects

Existing Finance projects may be opened at any time from within the Finance module by choosing 'Open' from the Finance Module toolbar.

Saving Projects

Finance projects may be saved at any time by clicking the save button on the Finance module toolbar. When the user closes the program or module, the program automatically asks the user if he or she wants to save the finance project.

Typical Operation

Although each user will have his or her own unique method, the typical operation of the Finance module would include the following steps:

1. Open a new finance module
2. Choose metric or English units
3. If necessary, enter/modify project specific financial data in the incentives, other costs and utility costs tabbed panels
4. Either link to an open heat exchanger design file or manually enter the geothermal project data
5. In the conventional tabbed panel, choose up to 4 conventional systems to compare to the geothermal system
6. In the results tabbed panel, hit the calculate button to view the financial analysis
7. Make modifications as necessary
8. Save and/or print the finance project reports

Entering Data into the Tabbed Panels

Ground Loop Design's innovative tabbed panel system provides for easy organization of and direct access to the relatively large number of design parameters associated with a particular project. This section describes the *Incentives, Other Costs, Utility Costs, Conventional, Geothermal and Results* panels.

Incentives

Information pertaining to financial incentives for geothermal systems can be found in the *Incentive* panel as seen in figure 9.2, below. If incentives are available, users can enter the incentive as an investment tax credit percentage or as an absolute tax credit. For example, in late 2008, the U.S. Congress passed H.R. 1424 which authorizes up to $2000 in federal tax credits for residential systems and 10% federal tax credits for commercial systems. For commercial projects in the US, users can enter 10% in the investment tax credit text box. For residential projects in the US, users can enter up to $2000 in the fixed tax credit text box. Incentives are subtracted from the installation costs and reported in detail in the reports.

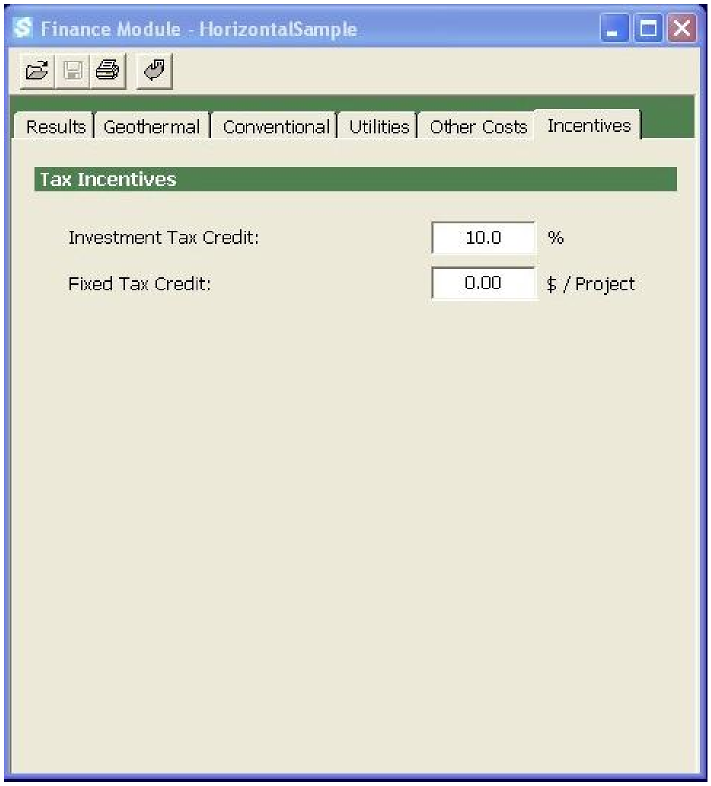


Fig. 9.2 *Incentives* Panel Contents

Other Costs

Information pertaining to a variety of hard and soft costs can be found in the *Other Costs* panel. This includes all of the baseline data for non-utility costs including $C0_2$ emissions costs, average building costs and equipment-related costs. The contents of the *Other Costs* panel are shown in figure 9.3.

All of the data entry options in the *Other Costs* panel are optional, but by entering the data, the program is able to calculate many of the hard and soft costs associated with HVAC systems.

Note that calculating the soft cost benefits of geothermal systems may help designers convince clients of the important, yet oftentimes overlooked benefits of geothermal HVAC systems.

The *Other Costs* panel is divided into three sections: emissions costs, average building costs and equipment-related costs.

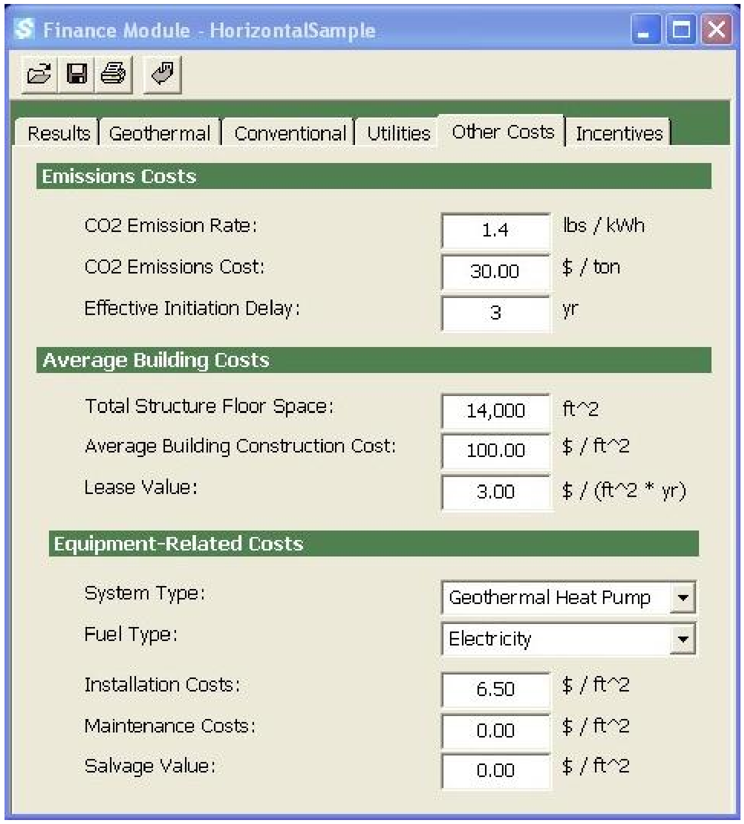


Fig. 9.3 *Other Costs* Panel Contents

Emissions Costs

As the global response to climate change intensifies, $C0_2$ emissions regimes will likely become the norm. These regimes may include cap and trade mechanisms, taxes, and other to-be-determined processes for incentivizing emissions reductions. In some countries, designers already are looking at geothermal HVAC systems both as a source of emissions credits that they can sell in the growing carbon markets for a profit as well as an attractive application of the Kyoto Protocol Clean Development Mechanism (CDM). It is likely that the Kyoto Protocol will be superceded in the next few years by a new agreement that requires even more stringent $C0_2$ emissions regimes. Additionally, local, regional and national level emissions control regimes are becoming more common. For these reasons, the finance module enables designers to determine the $C0_2$ emissions reductions associated with a geothermal system compared to a more traditional HVAC solution.

The **$C0_2$ emissions rate** is the carbon intensity per kWh of electricity generated. This rate is based on the fuel mix (coal, hydro, nuclear, etc) used to generate the electricity that will power the electrical geothermal

HVAC systems. This intensity data can be found fairly easily on state, provincial, national and NGO environmental protection websites. As the emissions rate can vary greatly, it is recommended that the designer spend a few minutes finding the appropriate rate for the project's region. In the USA, the national average is 1.34 lbs of per kWh. Detailed information on each state or province can be found on the following websites:

http://www.eia.doe.gov/oiaf/1605/ee-factors.html (USA)

http://www.ec.gc.ca/pdb/ghg/inventory_report/2005_report/a9_eng.cfm (CANADA)

The finance module enables designers to specify other energy sources besides electricity. Options include fuel oil (#2), natural gas, propane/LPG, coal (weighted average of anthracite, bituminous and semibituminous), wood and biomass. Because the $C0_2$ emissions from these fuel types tend not to vary as much as the $C0_2$ emissions associated with electrical power generation, the program uses standard $C0_2$ emissions coefficients for these other fuel types. These emissions coefficients are from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2.

The **$C0_2$ emissions cost** enables GLD to put a price tag on the $C0_2$ emitted from a range of HVAC systems. While at present time many consider this a soft cost, soon it may be a hard cost that influences investment decisions. As a result, it is especially important to consider the $C0_2$ emissions costs over a project's lifetime. While emissions costs estimates vary within the range of $5 USD/ton to $80 USD/ton, it is likely that the cost will hover somewhere around $30 USD/ton in the future.

The **effective initiation delay** is included because while at present time there are few enforced CO_2 emissions regimes, eventually $C0_2$ emissions will have a financial cost associated with them. This delay allows designers to estimate the lifetime $C0_2$ emissions costs starting at a point in the future that is defined by the effective initiation delay. For example, if the designer anticipates that 5 years from now, the $C0_2$ emissions from the HVAC system will be taxed, the designer can enter "5" into this box. When the program performs the Lifetime NPV costs of the system, it will begin including $C0_2$ emissions costs starting at year five. The effective initiation delay enables designers to maximize the accuracy of the program's calculations.

Average Building Costs

When a designer is considering the financial costs of one HVAC system versus another, it is important to remember and include overall building costs. A well designed, decentralized geothermal system may have no need for a mechanical room while a central chiller/boiler plant may require a thousand or more square feet of space. This additional space costs money to construct. In addition, the space used for a central plant has an opportunity cost- its lost rental or lease value. For these reasons, the finance module enables designers to ascertain a) the building construction cost reductions (if any) and b) the revenue generated from the additional available square footage (if any) of a geothermal system compared to a more traditional HVAC solution.

The **total structure floor space** enables designers to enter the total square footage (floor space) of the to-be-conditioned space. Please be sure not to enter the square footage of any unconditioned floor space.

The **average building construction cost** enables designers to enter the per square foot construction costs of the building.

The **lease value** is the market lease value of the floor space in $ per square foot per year terms.

Equipment Related Costs

Equipment related costs are a key ingredient in estimating overall system installation and maintenance costs as well as salvage values (if any). Typically, designers and engineers specify these costs on a per square foot (of the total conditioned space square footage) basis. The finance module can take these values into account in conjunction with the average building costs when calculating the annual and NPV lifetime costs associated with different HVAC systems.

The **system type** dropdown menu enables designers to select one of eight different types of systems including geothermal heat pumps, boilers, furnaces, air-source heat pumps, gas-fired heat pumps, air-cooled chillers, water-cooled chillers and unitary air conditioners.

The **fuel type** dropdown menu enables designers to select one of several different fuel types for the system type that the designer selected above.

Each of these system type-fuel type combinations has three optional cost parameters associated with it. These parameters include **installation costs** (per square foot), **maintenance costs** (per square foot per year) and **salvage value** (per square foot), all on a per square foot basis.

Experienced HVAC engineers oftentimes have a good rule-of-thumb estimate for the per square foot **installation costs** (including capital equipment) for a variety of HVAC systems. For geothermal systems, costs vary greatly depending on the geology, drilling conditions, type of heat exchanger utilized, etc. This makes it a bit challenging to have a "rule of thumb" for geothermal installation costs. That being said, some research has been published comparing commercial geothermal system installations costs to those of more standard systems. In particular, data collected and analyzed by Bloomquist suggest the following for vertical closed loop commercial systems:

Average installation cost	Maximum installation cost	Minimum installation cost
\$100/m^2 (\$9.3/ft^2)	\$135/ m^2 (\$12.5/ft^2)	\$36/ m^2 (\$3.3/ft^2)

Bloomquist further suggests that horizontal, closed loop systems have installation costs that are less than 50% of the cost of vertical, closed loop systems.

Below is a table adapted from Bloomquist that indicates average installation/capital costs for more standard HVAC systems:

HVAC System Type	Installation/Capital Costs
Rooftop DX with electric heating	\$52/ m^2 (\$4.8/ft^2)
Rooftop DX with gas heating	\$61/ m^2 (\$5.7/ft^2)
Air-source heat pump	\$74/ m^2 (\$6.9/ft^2)
Rooftop variable air volume (VAV)	\$86/ m^2 (\$8.0/ft^2)
Water-source heat pump with gas boiler/cooling tower	\$133/ m^2 (\$12.4/ft^2)
Central VAV with chiller, cooling tower and gas perimeter heat	\$162/ m^2 (\$15.0/ft^2)
Four-pipe fan coil unit with electric chiller and gas boiler	\$171/ m^2 (\$15.9/ft^2)

The above data are included in this manual as a convenience and general reference for Ground Loop Design software users. It is of course the responsibility of the designer to determine the exact installation cost parameters for use in the financial module.

After having selected a system type and an appropriate fuel type for the system, the user can then enter the per square foot installation cost value. If for example a user wishes to have the program perform comparisons involving both natural gas and fuel oil boilers, the user must be sure to enter the installation cost data for both types of boilers.

Please note that the finance module breaks the conventional system analysis into separate heating and cooling systems analyses. If a user wants the program to estimate installation costs for a roof DX/gas boiler system, the user must first select the unitary air conditioner, choose a fuel type and then enter the installation costs associated with the DX system. The user must then select a boiler, choose the appropriate fuel type and then enter the installation costs associated with the gas boiler. This system, while slightly more labor intensive for the user, provides for the highest degree of analysis flexibility.

Experienced HVAC engineers also oftentimes have a good rule-of-thumb estimate for the per square foot per year **maintenance costs** for a variety of HVAC systems. Once again, some research has been published comparing commercial geothermal system maintenance costs to those of more standard systems. Because younger systems have lower maintenance costs than older systems, maintenance costs increase over time. Data collected and analyzed in several studies by Bloomquist, Cane, et al., Hughes, et al. and Dohrmann and Alereza suggest the following range of maintenance costs for geothermal and conventional HVAC systems:

Below is a table on maintenance costs adapted from Hughes, et al.

HVAC System Type	Maintenance Costs
Air cooled chiller/gas fired water boiler	\$0.94/ m^2/yr (\$0.088/ft^2/yr)
Geothermal system	\$0.99/ m^2/yr (\$0.093/ft^2/yr)
Water cooled chiller/gas fired steam boiler	\$1.45/ m^2/yr (\$0.135/ft^2/yr)
Water cooled chiller/gas fired water boiler	\$2.01/ m^2/yr (\$0.187/ft^2 /yr)

Below is a table on maintenance costs adapted from Cane, et al.:

System Type	Average Age	Mean Maint Costs in 1997 dollars
Geothermal system	5	\$1m^2/yr (\$0.093/ft^2/yr)
Water source heat pump	18	\$3.3m^2/yr (\$0.31/ft^2/yr)
Packaged air-to-air	2	\$5m^2/yr (\$0.47/ft^2/yr)
Split air-to-air	24	\$4m^2/yr (\$0.37/ft^2/yr)
Reciprocating chiller	2	\$4.40m^2/yr (\$0.4/ft^2/yr)
Centrifugal chiller	20	\$5.5m^2/yr (\$0.52/ft^2/yr)
Absorption chiller	29	\$8m^2/yr (\$0.75/ft^2/yr)

Below is a third table with data based off of an analysis conducted by Dohrmann and Alereza:

System Type	Age of System (years)				
	0	2	5	10	20
Geothermal system	$\$2.2m^2/yr$ ($\$0.208/ft^2/yr$)	$\$2.3m^2/yr$ ($\$0.215/ft^2/yr$)	$\$2.4m^2/yr$ ($\$0.226/ft^2/yr$)	$\$2.6m^2/yr$ ($\$0.243/ft^2/yr$)	$\$2.96m^2/yr$ ($\$0.277/ft^2/yr$)
WLHP	$\$3.84m^2/yr$ ($\$0.36/ft^2/yr$)	$\$3.92m^2/yr$ ($\$0.367/ft^2/yr$)	$\$4.03m^2/yr$ ($\$0.378/ft^2/yr$)	$\$4.21m^2/yr$ ($\$0.395/ft^2/yr$)	$\$4.58m^2/yr$ ($\$0.429/ft^2/yr$)
DX-cooling/Electric heating	$\$4.08m^2/yr$ ($\$0.382/ft^2/yr$)	$\$4.14m^2/yr$ ($\$0.388/ft^2/yr$)	$\$4.26m^2/yr$ ($\$0.399/ft^2/yr$)	$\$4.38m^2/yr$ ($\$0.416/ft^2/yr$)	$\$4.8m^2/yr$ ($\$0.45/ft^2/yr$)
2-pipe fan coil w/ boiler and chiller	$\$5.58m^2/yr$ ($\$0.523/ft^2/yr$)	$\$5.66m^2/yr$ ($\$0.530/ft^2/yr$)	$\$5.77m^2/yr$ ($\$0.541/ft^2/yr$)	$\$5.95m^2/yr$ ($\$0.558/ft^2/yr$)	$\$6.3m^2/yr$ ($\$0.592/ft^2/yr$)
VAV w/ boiler and chiller	$\$6.77m^2/yr$ ($\$0.634/ft^2/yr$)	$\$6.84m^2/yr$ ($\$0.641/ft^2/yr$)	$\$6.95m^2/yr$ ($\$0.651/ft^2/yr$)	$\$7.13m^2/yr$ ($\$0.668/ft^2/yr$)	$\$7.5m^2/yr$ ($\$0.703/ft^2/yr$)
4-pipe fain coil with boiler and chiller	$\$7.32m^2/yr$ ($\$0.686/ft^2/yr$)	$\$7.4m^2/yr$ ($\$0.693/ft^2/yr$)	$\$7.5m^2/yr$ ($\$0.703/ft^2/yr$)	$\$7.7m^2/yr$ ($\$0.720/ft^2/yr$)	$\$8.1m^2/yr$ ($\$0.755/ft^2/yr$)

The above data are included in this manual as a convenience and general reference for Ground Loop Design software users. It is of course the responsibility of the designer to determine the exact maintenance cost parameters for use in the financial module.

After having selected a system type and an appropriate fuel type for the system, the user can then enter the per square foot per year maintenance cost value. If for example a user wishes to have the program perform comparisons involving both natural gas and fuel oil boilers, the user must be sure to enter the maintenance cost data for both types of boilers.

Please note that the finance module breaks the conventional system analysis into separate heating and cooling systems analysis. If a user wants the program to estimate maintenance costs for a roof DX/gas boiler system, the user must first select the unitary air conditioner, choose a fuel type and then enter the maintenance costs associated with the DX system. The user must then select a boiler, choose the appropriate fuel type and then enter the maintenance costs associated with the gas boiler. This system, while slightly more labor intensive for the user, provides for the highest degree of analysis flexibility.

Experienced HVAC engineers also may have a good rule-of-thumb estimate for the per square foot **salvage value** for a variety of HVAC systems. Users can enter per square foot salvage values for the different systems following the methods outlined above.

If a designer is doing a financial comparison and not getting any output results for installation costs, maintenance costs or salvage values, it is worthwhile confirming that the baseline cost data have been entered. If the data have not been entered, results can not be calculated.

Utility Costs

Input parameters relating to utility costs are located in the *Utility Costs* panel, as shown in figure 9.4. These include summer and winter utility costs for a range of fuel types, the expected annual inflation rates for each fuel type and an overall discount rate that is used in the NPV calculations.

The *Utility Costs* panel is divided into two sections: rates for common fuels and annual inflation rates.

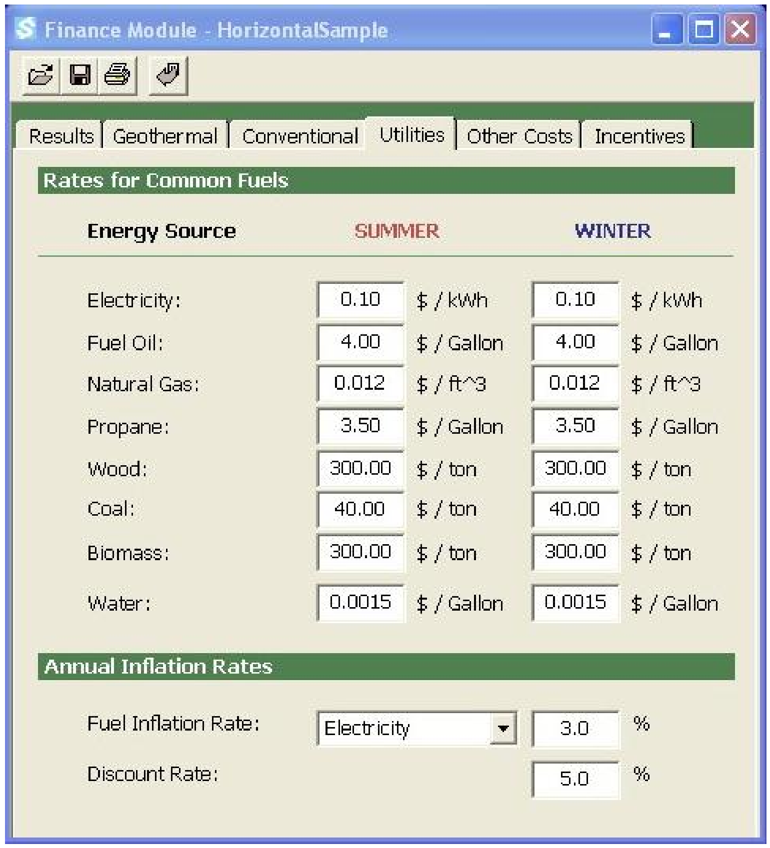


Fig. 9.4 *Utility Costs* Panel Contents

Rates for Common Fuels

The rates for common fuels can be entered in the 'Rates for Common Fuels' section. These fuels include electricity, fuel oil, natural gas, propane, wood, coal, biomass (excluding wood and wood pellets) and water. Although water is not a fuel, it is consumed in some HVAC systems (such as cooling towers) and therefore is included here for financial modeling purposes.

Note that it is essential that users enter rates for both summer and winter rates, even if they are identical. Failure to do so will result in underestimated cost results.

Annual Inflation Rates

In this section, users can enter the expected **fuel inflation rates** for each fuel type as well as the overall discount rate. Because inflation rates vary depending on fuel type, users can enter the inflation rate for each fuel type for the highest levels of modeling accuracy.

To enter the fuel inflation rate for each fuel type, the user first selects a fuel type from the dropdown menu and then enters the appropriate inflation rate. The user can then repeat the process for the other fuel types. Note that if the user selects a HVAC system but does not include a fuel inflation rate appropriate for that system, then an accurate NPV analysis cannot be performed. For example, if the user does not enter the inflation rate for fuel oil, yet selects a fuel oil boiler as part of a geothermal hybrid system, then the program will not be able to take into account the fuel oil inflation rate when performing the NPV calculations. This could lead to an inaccurate final cost analysis.

Enter the **discount rate** in the other text box. This discount rate is used in the overall NPV calculations.

Conventional

The finance module enables designers to compare the costs of a geothermal system with up to five different conventional systems. These conventional systems can include any combination of heating (boiler, furnace, air source heat pump, water source heat pump) and cooling (air cooled chiller, water cooled chiller, unitary air conditioner) equipment. After the users first selects a conventional system number (1-5) and then defines the equipment type and performance characteristics for that system number, the program determines the energy requirements and operating costs for the system. The parameters relating to the conventional system options are located in the *Conventional* panel as shown in figure 9.5.

The *Conventional* panel is broken up into two sections: alternate systems and system details.

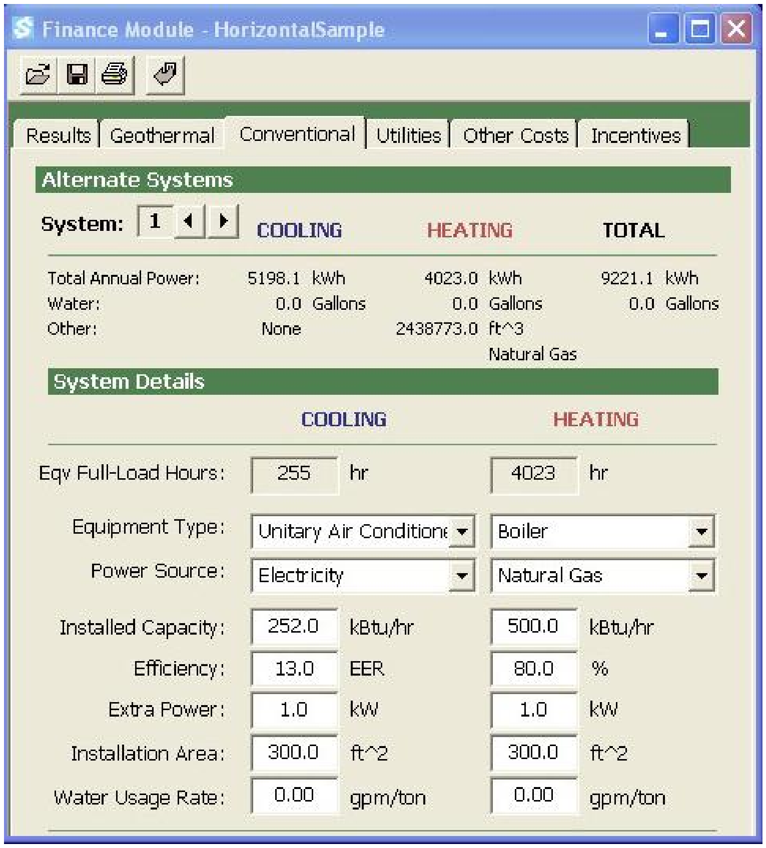
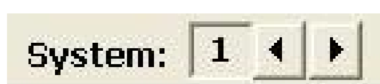


Fig. 9.5 *Conventional* Panel Contents

Alternate Systems

In this section, users can scroll through the alternate (standard HVAC) systems and see the summary of each system's energy and fuel/fuel type consumption. Users can scroll through and review each system by clicking on the left and right arrows as seen below:



Please note that if a system has not been defined (see below), power and fuel type information can not be displayed.

In general, a user will select a system (system 1, for example) and then proceed to define the system in the system details section. After defining system one, the user can choose to define another system by selecting system two and then entering the relevant information for it. The user can repeat the procedure for up to five alternate systems.

System Details

In this section, the user can enter details about the system he or she selected (system 1-5) in Alternate Systems, above. Please note that some of the details are locked out. For example, the equivalent full-load hours values cannot be changed by the user. Full load hours are entered in the *Geothermal* tabbed panel and transferred automatically into the conventional panel. This is to ensure that the comparison between the geothermal system and the conventional systems is based off of an equal number of full load hours.

Cooling

In this column, the user can enter details about the alternate cooling system(s).

Equivalent Full Load Hours

These values are transferred from the *Geothermal* panel and can not be changed by the user. If the user wishes to change these values, he or she must do so from the *Geothermal* tabbed panel.

Equipment Type

The user can select from among three cooling systems: air-cooled chillers, water-cooled chillers and unitary air conditioners. Please note that since these systems have different efficiency rating systems, the efficiency units change depending on the system selected.

Power Source

Users can select from among electricity, natural gas and propane.

Installed Capacity

Here users can enter the cooling system's *installed* capacity. Note that in general, the installed capacity for conventional systems exceeds the peak capacity of geothermal systems. This is because conventional mechanical equipment is usually significantly oversized compared to the equipment in a well designed geothermal system.

Efficiency

Here users enter the expected overall system efficiency for the selected cooling equipment. Note that the measurement units vary depending on the selected system (i.e. kW/ton for water-cooled chillers and EER for unitary air-conditioners).

Extra Power

Here users enter extra power requirements for the system (such as circulation pumps, etc).

Installation Area

In this section, users enter the floor space square footage required by the selected cooling equipment. For example, if a water-cooled chiller is selected and it requires 1000 ft^2 of mechanical room space, the user can enter 1000 ft^2 here.

Water Usage Rate

If the selected cooling equipment consumes water, the user can enter the water usage rate here.

Heating

In this column the user can enter details regarding the alternate heating system(s).

Equivalent Full Load Hours

These values are transferred from the *Geothermal* panel and can not be changed by the user. If the user wishes to change these values, he or she must do so from the *Geothermal* tabbed panel.

Equipment Type

The user can select from among four heating systems: boilers, furnaces, air-source heat pumps and gas-fired heat pumps. Please note that since these systems have different efficiency rating systems, the efficiency units change depending on the system selected.

Power Source

Users can select from among electricity, fuel oil, natural gas, propane, wood, coal or biomass (biomass excluding wood).

Installed Capacity

Here users can enter the heating system's *installed* capacity. Note that in general, the installed capacity for conventional systems exceeds the peak capacity of geothermal systems. This is because conventional mechanical equipment is usually significantly oversized compared to the equipment in a well designed geothermal system.

Efficiency

Here users enter the expected overall system efficiency for the selected heating equipment. Note that the measurement units vary depending on the selected system (i.e. % efficiency for boilers and COPs for air-source heat pumps).

Extra Power

Here users enter extra power requirements for the system (such as circulation pumps, etc).

Installation Area

In this section, users enter the floor space square footage required by the selected heating equipment. For example, if a central boiler system is selected and it requires 1000 ft^2 of mechanical room space, the user can enter 1000 ft^2 here.

Water Usage Rate

If the selected heating equipment consumes water, the user can enter the water usage rate here.

Geothermal

In this section, users enter parameters and values pertaining to the geothermal system. As mentioned previously, users have the option of importing relevant data for the financial analysis from an open heat exchanger design project. Conversely, users can manually enter the geothermal project data directly into the financial module. An overview of the *Geothermal* panel is shown in figure 9.6.

The *Geothermal* panel is divided into two sections: a summary panel and two details tabbed sub-panels.

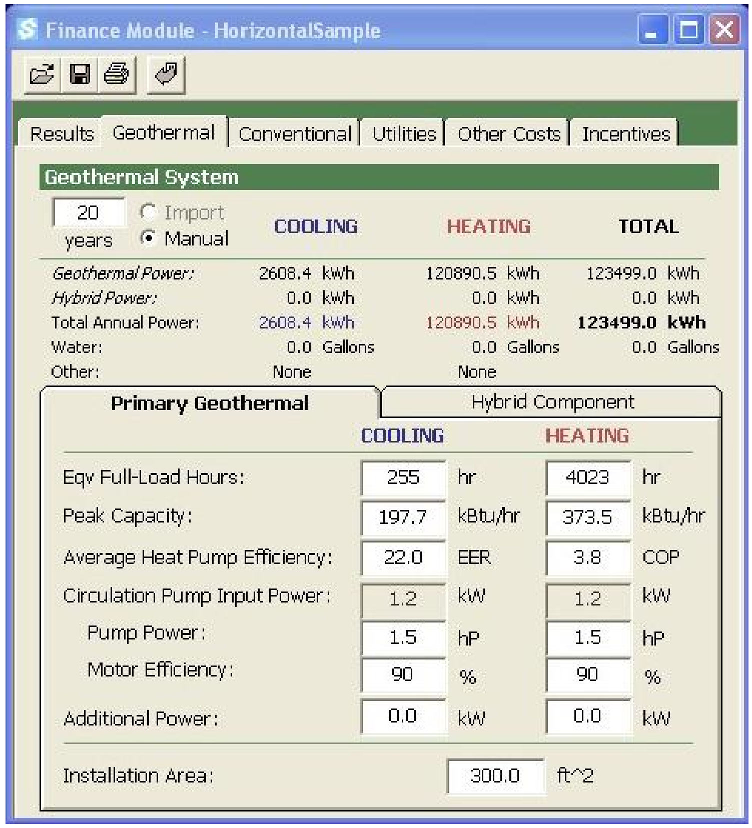


Fig. 9.6 ***Geothermal*** **Panel Contents**

Geothermal Project Power Summary Panel

The top third of the *Geothermal* panel displays several features of the geothermal system including the modeling time period, the energy usage and fuel type for the geothermal system. This can be seen below in figure 9.7.

Fig. 9.7 Geothermal Project Power Summary Panel

The modeling time period

The **modeling time period** is necessary for calculating the NPV lifetime costs of the design.

When a user imports a design project into the finance module, the modeling time period automatically is set to match the modeling time period use in the heat exchanger design. In such a case, the modeling time period is grayed out, indicating that the value was imported. If a user wishes to override this value, he or she can do so by first selecting the "Manual" option and then entering the time period of interest.

Geothermal Project Power Summary

Below the modeling time period, the user can see the program's annual energy usage estimate for the geothermal system. Results are listed in 'heating', 'cooling' and 'total' columns for ease of review.

Energy usage is divided up into the following constituent parts:

- geothermal power (the power consumed by the geothermal system)
- hybrid power (the power consumed by the hybrid system, if any)
- total annual power (a summation of geothermal and hybrid power)
- water (the amount of water, if any, consumed by the system on an annual basis)
- other (other fuel sources (natural gas, fuel oil, etc) and the annual amount consumed).

Calculated energy usage values are updated as soon as a change is made in system parameters (see below).

Geothermal System Details

The bottom two-thirds of the *Geothermal* panel displays system details related to the geothermal and hybrid system. Details of the geothermal and hybrid system (if any) can be found on separate tabbed panels. The geothermal system tabbed panel can be seen below in figure 9.8 and the hybrid component tabbed panel can be seen in figure 9.9.

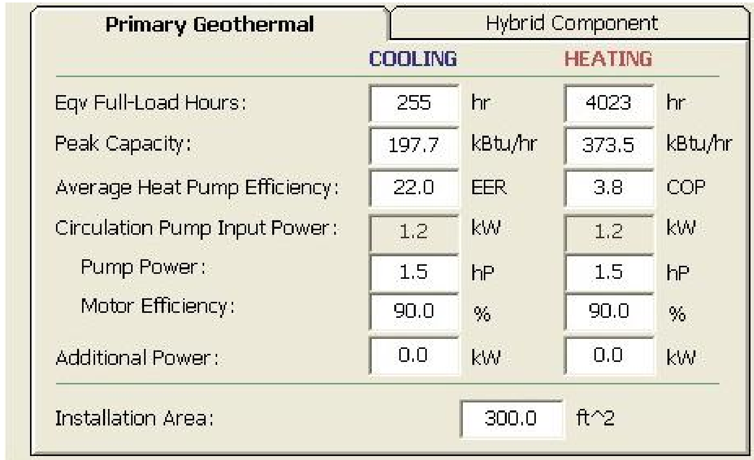


Fig. 9.8 Geothermal System Tabbed Panel

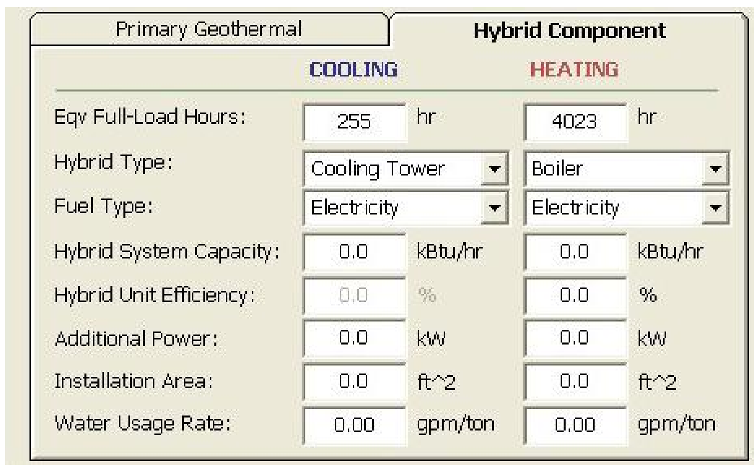


Fig. 9.9 Geothermal System Tabbed Panel

Primary Geothermal Tab

Cooling

In this column, the user can enter details about the geothermal cooling system (s).

Equivalent Full Load Hours

The user can enter the equivalent full load hours here if the user has not imported the data automatically from a heat exchanger project design.

Peak Capacity

The user can enter the peak capacity (*note that this is the peak load covered by the equipment and not the installed equipment capacity*) here if the user has not imported the data automatically from a heat exchanger project design.

Average Heat Pump Efficiency

Here the user enters the expected EER for the cooling side of the system if the user has not imported the data automatically from a heat exchanger project design.

Note that if the user has imported the data from a vertical heat exchanger project that has monthly data calculated (see chapter 4), then the imported EER is the average EER over the system lifetime and not the peak conditions EER. Generally, using the monthly data provides for a higher EER (and lower costs) since average fluid temperatures tend to be less extreme than the fluid temperatures during peak load conditions.

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Circulation Pump Input Power, Pump Power and Motor Efficiency

The circulation pump input power automatically is calculated from the pump power and motor efficiency. These values can be imported from a heat exchanger design project or manually entered.

Additional Power

The user can enter power for all other elements (besides the heat pump units) in the system that may require energy input. Again, these data can be imported from a heat exchanger project (if the data are in the project) or can be entered manually.

Geothermal Heating

In this section, the user can enter details about the geothermal heating system (s).

Equivalent Full Load Hours

The user can enter the equivalent full load hours here if the user has not imported the data automatically from a heat exchanger project design.

Peak Capacity

The user can enter the peak capacity (*note that this is the peak load covered by the equipment and not the installed equipment capacity*) here if the user has not imported the data automatically from a heat exchanger project design.

Average Heat Pump Efficiency

Here the user enters the expected COP for the heating side of the system if the user has not imported the data automatically from a heat exchanger project design.

Note that if the user has imported the data from a vertical heat exchanger project that has monthly data calculated (see chapter 4), then the imported COP is the average COP over the system lifetime and not the peak conditions COP. Generally, using the monthly data provides for a higher COP (and lower operating costs) since average fluid temperatures tend to be less extreme than the fluid temperatures during peak load conditions.

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Circulation Pump Input Power, Pump Power and Motor Efficiency

The circulation pump input power automatically is calculated from the pump power and motor efficiency. These values can be imported from a heat exchanger design project or manually entered.

Additional Power

The user can enter power for all other elements in the system (besides the heat pump units) that may require energy input. For example, heat recovery units require additional energy that can be recorded in this box so that it can be used in the overall calculation of the System *COP*. Again, these data can be imported from a heat exchanger project (if the data are in the project) or can be entered manually.

Installation Area

In this section, the user enters the floor space square footage required by the geothermal mechanical equipment. For example, if a school geothermal system is decentralized and the heat pumps are located in the ceilings above the classrooms, the user might leave this value at "0". Conversely, if the geothermal equipment is located in a small closet in each classroom, the designer could multiply the square footage of each closet by the number of closets in the school to calculate a cumulative value for entry in this text box.

Hybrid Component Tab

Cooling

In this column, the user can enter details about the hybrid component of the geothermal cooling system (s).

Equivalent Full Load Hours

The user can enter the equivalent full load hours here if the user has not imported the data automatically from a heat exchanger project design. Note that by default, the equivalent full load hours value in the hybrid panel matches the full load hours in the *geothermal* panel. If the user changes the value in the *geothermal* tabbed panel, the value in the hybrid component panel changes as well. The user does have the option though of changing this value in the hybrid tab so that it does not match the value in the *geothermal* tabbed panel.

Hybrid Type

At present time, the user has the option of selecting a cooling tower.

Fuel Type

Electricity is the only option for the cooling tower at this time.

Hybrid System Capacity

Here the user can enter the installed capacity of the hybrid system. This value automatically is entered when the user imports a heat exchanger design project (that has a hybrid component) into the finance module.

Hybrid Unit Efficiency

This value is not applicable to the cooling tower selection and is grayed out.

Additional Power

Here the user enters extra power requirements for the system (such as fans, circulation pumps, etc).

Installation Area

In this section, the user enters the floor space square footage required by the selected cooling equipment. For example, if a cooling tower requires

400 ft^2 of rooftop space, the user can enter 400 ft^2 here. Of course, if the rooftop space has no commercial value *per se*, it would be reasonable to decrease the input square footage value.

Water Usage Rate

The user can enter the water usage rate for the cooling tower here. 0.3 gpm/ton is a reasonable starting point for many systems.

Heating

In this section, the user can enter details about the hybrid component of the geothermal heating system (s).

Equivalent Full Load Hours

The user can enter the equivalent full load hours here if the user has not imported the data automatically from a heat exchanger project design. Note that by default, the equivalent full load hours value in the hybrid panel matches the full load hours in the *geothermal* panel. If the user changes the value in the *geothermal* tabbed panel, the value in the hybrid component panel changes as well. The user does have the option though of changing this value in the hybrid tab so that it does not match the value in the *geothermal* tabbed panel.

Hybrid Type

At present time, the user has the option of selecting a boiler.

Fuel Type

The user can select from among seven fuel options.

Hybrid System Capacity

Here users can enter the installed capacity of the hybrid system. This value automatically is entered when the user imports a heat exchanger design project (that is a hybrid system design) into the finance module.

Hybrid Unit Efficiency

The user can enter the boiler's thermal efficiency here.

Additional Power

Here the user enters extra power requirements for the system (such as fans, circulation pumps, etc).

Installation Area

In this section, the user enters the floor space square footage required by the selected heating equipment. For example, if the boiler requires 600 ft^2 of floorspace, the user can enter 600 ft^2 here.

Water Usage Rate

The user can enter the water usage rate, if any, for the boiler.

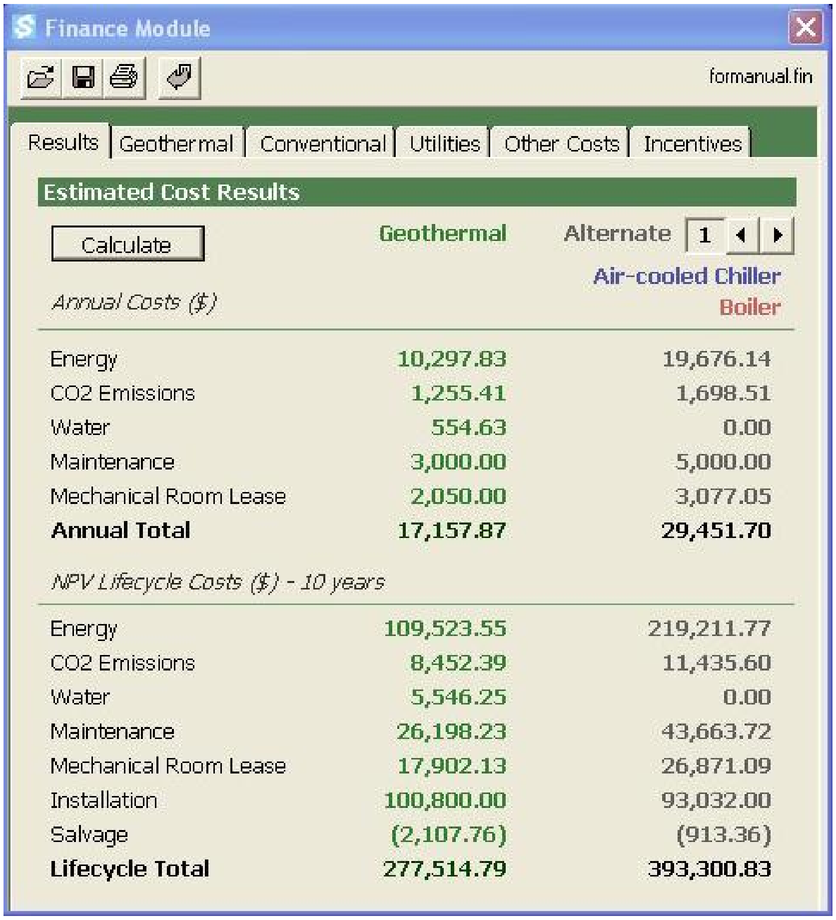
Results

All of the cost/emissions results for both the geothermal and alternate systems can be viewed at any time on the *Results* panel. After all data have been entered or any changes have been made, the user can calculate interim or final results using the 'Calculate' button. A sample screen for this panel can be seen in figure 9.10.

The Calculate panel is divided into two sections. On the top is the Annual Cost section. On the bottom is the Net Present Value (NPV) Lifecycle Costs section..

In each of the two sections, results are presented in two columns: the first is for the geothermal system and the second is for the alternate system(s). When more than one alternate system has been defined, users can scroll through the different alternate systems using the arrows.

Note that the presented costs are the summations of heating, cooling and hybrid system costs. Data are broken down into their constituent parts and displayed in the reports (see below).



Annual Costs ($)	Geothermal	Air-cooled Chiller / Boiler
Energy	10,297.83	19,676.14
CO2 Emissions	1,255.41	1,698.51
Water	554.63	0.00
Maintenance	3,000.00	5,000.00
Mechanical Room Lease	2,050.00	3,077.05
Annual Total	**17,157.87**	**29,451.70**
NPV Lifecycle Costs ($) - 10 years		
Energy	109,523.55	219,211.77
CO2 Emissions	8,452.39	11,435.60
Water	5,546.25	0.00
Maintenance	26,198.23	43,663.72
Mechanical Room Lease	17,902.13	26,871.09
Installation	100,800.00	93,032.00
Salvage	(2,107.76)	(913.36)
Lifecycle Total	**277,514.79**	**393,300.83**

Fig. 9.10 Geothermal System Tabbed Panel

Annual Costs

TIP

The annual costs section presents costs associated with running the geothermal system and alternate systems over a single year. Costs include the energy costs, $C0_2$ emissions costs, water usage costs, maintenance costs and mechanical room lease opportunity costs. Costs are reported as "0.00" if one or more of the required (and user-defined) variables used in the calculations have not been set. For example, if the user has selected a natural gas boiler as an alternate heating system but has not specified the maintenance costs for such a system, then the maintenance costs will be reported as "0.00". Upon seeing the "0.00" the user can go back to the *Other Costs* panel, input the maintenance costs, return to the *Results* page and then hit 'Calculate' again to recalculate the results.

NPV Lifecycle Costs

The NPV Lifecycle Costs section presents costs associated with running the geothermal system and alternate system over the time frame specified on the *Geothermal* tab. Costs include lifetime energy costs, lifetime $C0_2$ emissions costs, lifetime water usage costs, lifetime maintenance costs, lifetime mechanical room lease opportunity costs, installation costs and salvage value (if any) at the end of the building lifecycle. All of these lifecycle costs are calculated using the inflation and discount rates that the user has specified on the *Utilities* panel. Once again, the report will output a value of "0.00" if the user has not input the pricing parameters necessary for performing the calculation. Also please note that if any incentives have been entered into the *Incentives* tabbed panel, these values are subtracted from the overall installation costs and the net result is displayed.

Printing Reports

Financial reports can be printed at any time using the toolbar print button in the finance module.

A total of four reports, including two finance reports and two inputs reports are available. The concise finance report has information related to geothermal financials and energy usage. The detailed finance report has information related to geothermal and conventional system financials and energy usage. The concise inputs report has a truncated list of all the data inputs used in the financial calculations. The detailed inputs report has a full list of the data inputs used in the financial calculations.

More information on reports can be found in Chapter 7.

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