WATER-LOOP AND GROUND SOURCE HEAT PUMP ENHANCEMENTS

Introduction

The ability to model water loop heat pumps , in both ground coupled and conventional configurations, has been greatly enhanced in two major ways:

1. Water-source heat pump – the PVVT, PVAVS and PSZ systems can now be specified to be water-loop heat pump systems thus allowing all the options of these SYSTEM TYPEs to be available for use in modeling water –loop heat pump configurations (including variable flow, staged heating and cooling, heat recovery, ERV's, as well as sub-zone conditioning and return air plenum pathways.

2. Vertical well ground source heat exchangers – a new modeling approach has been added to more accurately model vertical wells. This new model allows the specification of grout properties, the fluid type plus a library of 42 well configurations is included..

These enhancements to the water-source and ground-source heat pump modeling capability of DOE-2.2 were supported, in part, by ClimateMaster, Inc. The new vertical well ground heat exchanger model was implemented by Xiaobing Liu of ClimateMaster. That model is based upon work by Claesson, Eskilson, Hellstrom, .et.al, at the University of Lund, Sweden and Spitler, .et.al, at Oklahoma State University.

Water-Loop Heat Pump Enhancements

The ability to model water-loop heat pump equipment has been improved by allowing the PVAVS, PVVT and PSZ systems to accept a combined specification of water cooled condenser with a heat pump heat source. No new keywords have been added to enable this feature; two existing keywords, CONDENSER-TYPE and HEAT-SOURCE, have a new combination of values that were not previously allowed.

Building Description Language Changes

SYSTEM

CONDENSER-TYPE

Takes a code-word that specifies how the condenser in packaged systems with direct-expansion cooling is cooled. Note that the program does not change any of the default performance data (such as EIR) when you change the condenser type, so you should input data representative of the unit you are modelling.

WATER-COOLED	The condenser is water cooled. You must attach the condenser to a CIRCULATION-LOOP of TYPE = CW or WLHP via the CW-LOOP keyword.. This option is not allowed when HEAT-SOURCE is HEAT-PUMP except for PSZ, PVVT and PVAVS systems; when HEAT-SOURCE is HEAT-PUMP it is then required that a CIRCULATION-LOOP of TYPE = WLHP be specified via the CW-LOOP keyword..

HEAT-SOURCE

Takes a code-word that specifies the heat source for the SYSTEM's main heating coils.

HEAT-PUMP	The source of heat is an electric air-to-air heat pump when CONDENSER-TYPE is AIR-COOLED; only for the RESYS, PSZ, PTAC, PVVT, PVAVS,

RESYS-VVT, and RESYS2 systems. The source of heat is an electric water-to-air heat pump when CONDENSER-TYPE is WATER-COOLED; only for the PSZ, PVVT and PVAVS systems. .

Ground-Source Heat Pump Enhancements

A new modeling approach, based on the G-function method, developed by researchers in Sweden and utilized in the Earth Energy Designer (EED) borehole heat exchanger design software package, has been added to more accurately model vertical wells. This new model allows the specification of grout properties, the GLHX fluid type, plus a library of 42 well configurations (EED calculated g-functions) is included..

Building Description Language Changes

GROUND-LOOP-HX

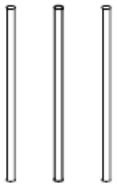
TYPE

Accepts a code-word that specifies the type of ground-coupled heat-exchanger. This keyword is required and should be the first entered. Acceptable values are:

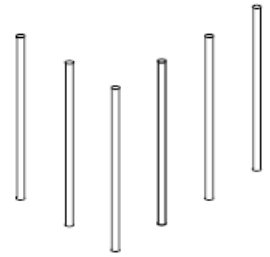
VERT-WELL-NEW	One or more vertical wells in a field of wells using the EED g-function formulation to model the wells.

CONFIGURATION

For TYPE = VERT-WELL-NEW, accepts a code-word specifying the configuration of the well-field. Acceptable entries are:

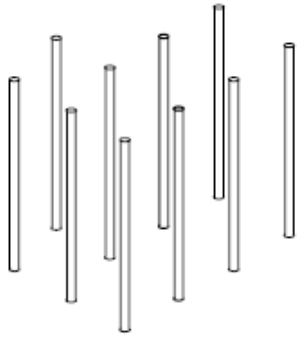
Geometry & Illustration	Configuration	# Bores
Single 	Single	1
Straight Line 	Line-Of-2	2
	Line-Of-3	3
	Line-Of-4	4
	Line-Of-5	5
	Line-Of-6	6
	Line-Of-7	7
	Line-Of-8	8
	Line-Of-9	9
	Line-Of-10	10

One L-shaped Line



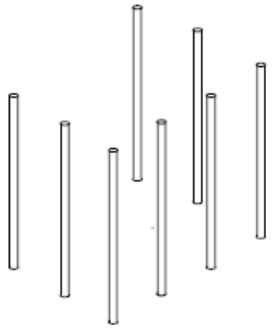
L-Config-2x2	**3**
L-Config-2x3	**4**
L-Config-2x4	**5**
L-Config-2x5	**6**

Two Parallel L-shaped Lines



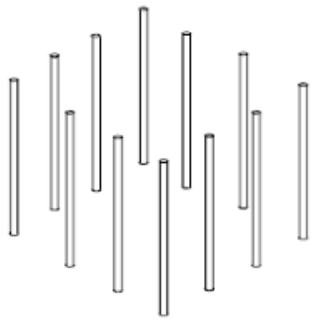
L2-Config-3x3	**8**
L2-Config-3x4	**10**
L2-Config-3x5	**12**

U-shaped Lines



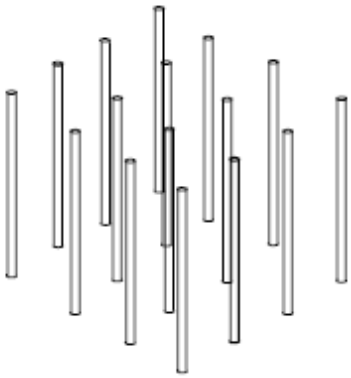
U-Config-3x2	**5**
U-Config-3x3	**7**
U-Config-3x4	**9**
U-Config-3x5	**11**

Open Rectangle



Open-Rectangle-3x3	**8**
Open-Rectangle-3x4	**10**
Open-Rectangle-3x5	**12**

Rectangle



Rectangle-2x2	**4**
Rectangle-2x3	**6**
Rectangle-2x4	**8**
Rectangle-2x5	**10**
Rectangle-2x6	**12**
Rectangle-2x7	**14**
Rectangle-2x8	**16**
Rectangle-2x9	**18**
Rectangle-2x10	**20**
Rectangle-3x3	**9**
Rectangle-3x4	**12**
Rectangle-3x5	**15**
Rectangle-3x6	**18**
Rectangle-4x4	**16**
Rectangle-4x5	**20**
Rectangle-4x6	**24**
Rectangle-4x7	**28**
Rectangle-4x8	**32**

Custom-CM	Only used when the G-FUNCTION-FROM keyword is CUSTOM. Allows election from over 300 "custom" configurations created using EED G-Funtion software and made available via the LTS_gfnc.bin library. This library can only be obtained from ClimateMaster. This codeword value requires that the G-FUNCTION-NUM keyword be set equal the integer number of the G-Function that is desired to be retrieved from the library. See G-FUNCTION-NUM for more information on this library.

G-FUNCTION-FROM

Accepts a code-word that specifies the location of the G-Functions to be used for modeling this ground-loop heat exchanger. Used for TYPE = VERT-WELL-NEW only. Acceptable entries are:

LIBRARY	Specifies that one of the 43 G-functions found in the DOE-2.2 default library, as listed under the CONFIGURATION keyword, are to be used to model the well field..
CUSTOM	Specifies that G-functions are to be retrieved from the custom library (LTS_gfnc.bin) with the specific G-functions to be used specified via the G-FUNCTION-NUM keyword.

G-FUNCTION-NUM

Accepts a integer value that specifies the G-Functions number, from the LTS_gfnc.bin library, to be used for modeling this ground-source heat exchanger.. Used for TYPE = VERT-WELL-NEW only. Only used when the G-FUNCTION-FROM keyword is CUSTOM. This library is not part of the standard DOE-2.2 release; it is produced using the Earth Energy Designer (EED) borehole heat exchanger design software package . A DOE-2.2/eQUEST compatible version of this library, containing over 300 configurations, is available; information about this library can be obtained by contacting Xiaobing Liu at ClimateMaster (405) 745-6000 x335.

DEPTH

The distance (in feet) between the ground surface and the bottom of the well. This is a required keyword.

SPACING

The distance (in feet) between the centerlines of the wells. This is a required keyword.

BOREHOLE-DIAM
The diameter (in inches) of the borehole. Used for TYPE = VERT-WELL-NEW only.

FIELD-MULTIPLIER
The number of identical fields. The program assumes that these fields do not interact with each other.

Pipe Properties
The following keywords define the properties of the pipe.

PIPE-OUTSIDE-DIA
The outside diameter in (inches) of the U-tube or pipe. Typical values for common pipe classifications are listed in the tables below. This is a required keyword.

PIPE-INSIDE-DIA
The inside diameter (in inches) of the U-tube or pipe. Typical values for common pipe classifications are listed in the tables below. This is a required keyword.

Pipe Dimensions					
Pipe Size		Pressure Ratings			
		SDR 11		SDR 17	
Size (in)	Nom. OD (in)	ID (in)	Wall Thick. (in)	ID (in)	Wall Thick. (in)
3/4	1.05	0.859	0.095	0.926	0.062
1	1.315	1.076	0.120	1.160	0.077
1-1/4	1.66	1.358	0.151	1.465	0.098
1-1/2	1.9	1.555	0.173	1.676	0.112
2	2.375	1.943	0.216	2.096	0.140

Pipe Dimensions					
Pipe Size		Pressure Ratings			
		Schedule 40		Schedule 80	
Size (in)	Nom. OD (in)	ID (in)	Wall Thick. (in)	ID (in)	Wall Thick. (in)
3/4	1.05	0.824	0.113	0.742	0.154
1	1.315	1.049	0.133	0.957	0.179
1-1/4	1.66	1.38	0.14	1.278	0.191
1-1/2	1.9	1.61	0.145	1.5	0.2
2	2.375	2.067	0.154	1.939	0.218

U-TUBE-LEG-SEP
The separation (in inches) between the outer surfaces of the tubes. For TYPE = VERT-WELL-FIELD and VERT-WELL-NEW, only. This is a required keyword.

PIPE-COND
The thermal conductivity (BTU/HR-FT-F) of the pipe. Typical values are found in the table below. This is a required keyword.

Material	Thermal Conductivity Btu/hr-ft-F
Polyethylene	0.23
Polybutylene	0.13

Fluid Properties

The following keywords define the properties of the fluid used in the GLHX pipe circuit..

FLUID

Accepts a code-word that specifies the fluid used in the circulation loop of this ground-loop heat exchanger. Used for TYPE = VERT-WELL-NEW only. Acceptable entries are:

WATER	The default..
PROPYLENE-GLYCOL	aqueous solutions of Propylene Glycol
ETHANOL	aqueous solutions of Ethylene Glycol
ETHYLENE-GLYCOL	aqueous solutions of Methanol.
METHANOL	aqueous solutions of Ethanol

ANTI-FREEZE-CONC

The concentration (in percent) of the anti-freeze fluid, as specified using the FLUID keyword, and water. Used for TYPE = VERT-WELL-NEW only.

Ground Properties

The following keywords define the properties of the ground..

REF-GRND-TEMP

The undisturbed far-field ground temperature (in degrees F) for vertical wells. For TYPE = VERT-WELL-NEW only, if this values is not specified it is calculated as the average annual outdoor dry bulb temperature using the weather file that is selected for the simulation.

REF-GRND-ADJ

The adjustment (in delta degrees F), for local conditions, to the undisturbed far-field ground temperature. Used for TYPE = VERT-WELL-NEW only.

GRND-DIFFUSIVITY

The ground diffusivity (FT2/HR). Typical values are found in the table below.

GRND-COND

The ground conductivity (BTU/HR-FT-F). Typical values are found in the table below.

> The data in the table below are compiled from following sources: Database of EED version 2.0 (Demo) (Hellstrom, et al 2000); Kavanaugh, Stephen and K. Rafferty, Ground-Source Heat Pumps, ASHRAE 1997; Soil and Rock Classification for the Design of Ground-Coupled Heat Pump Systems, IGSHPA 1989.

Description	Recommended		Description
	Conductivity	Difussivity	
	Btu/hr-ft-F	Ft^2/hr	
Amphibolite	1.7	0.0432	Igneous or metamorphic rock composed largely or dominantly of amphibole minerals.
Andesite	1.3	0.0355	Extrusive usually dark grayish rock consisting essentially of oligoclase or feldspar.
Anhydrite	2.4	0.0794	Mineral consisting of an anhydrous calcium sulfate that is usually massive and white or slightly colored.
Aplite	1.8	0.0501	Fine-grained light-colored granite consisting almost entirely of quartz and feldspar.
Arkose	1.7	0.0562	Sandstone characterized by feldspar fragments that is derived from granite or gneiss which has disintegrated rapidly
Basalt	1.0	0.0274	Dark gray to black dense to fine-grained igneous rock that consists of basic plagioclase, augite, and usually magnetite.
Breccia	1.6	0.0517	Rock consisting of sharp fragments embedded in a fine-grained matrix (as sand or clay).
Clay, dry	0.2	0.0097	Earthy material that is plastic when moist but hard when fired, that is composed mainly of fine particles of hydrous aluminum silicates and other minerals.
Clay, moist - wet	0.9	0.0258	
Claystone	1.3	0.0371	Rock composed chiefly of Clay.
Coal	0.2	0.0065	Black or brownish black solid combustible substance formed by the partial decomposition of vegetable matter without free access of air and under the influence of moisture and often increased pressure and temperature that is widely used as a natural fuel.
Concrete	0.9	0.0344	Hard strong building material made by mixing a cementing material (as portland cement) and a mineral aggregate (as sand and gravel) with sufficient water to cause the cement to set and bind the entire mass
Conglomerate	1.6	0.0517	Rock composed of rounded fragments varying from small pebbles to large boulders in a cement (as of hardened clay).
Diorite	1.5	0.0347	Granular crystalline igneous rock commonly of acid plagioclase and hornblende, pyroxene, or biotite.
Dolomite	1.9	0.0496	Limestone or marble rich in magnesium carbonate.
Dunite	2.4	0.0561	A granitoid igneous rock consisting chiefly of olivine.
Eclogite	1.7	0.0363	Any member of metamorphic rocks whose original composition is similar to that of basalt.
Gabbro	1.1	0.0283	Granular igneous rock composed essentially of calcic plagioclase, a ferromagnesian mineral, and accessory minerals.
Gneiss	1.7	0.0535	Foliated metamorphic rock corresponding in composition to a feldspathic plutonic rock (as granite).
Granite	2.0	0.0549	Very hard natural igneous rock formation of visibly crystalline texture formed essentially of quartz and orthoclase or microcline.
Granodiorite	1.9	0.0492	Granular intrusive quartzose igneous rock intermediate between granite and quartz-containing diorite with plagioclase predominant over orthoclase.
Gravel, dry	0.2	0.0103	Loose rounded fragments of rock.
Gravel, saturated	1.0	0.0291	
Gypsum	0.9	0.0310	Widely distributed mineral consisting of hydrous calcium sulfate that is used especially as a soil amendment and in making plaster of paris.
Ignimbrite	1.7	0.0554	Hard rock formed by solidification of chiefly fine deposits of volcanic ash.
Limestone, marly	1.3	0.0371	Rock that is formed chiefly by accumulation of organic remains (as shells or coral), consists mainly of calcium carbonate, is extensively used in building, and yields lime when burned.
Limestone, massive	1.6	0.0472	
Limestone, oolitic	1.4	0.0404	
Marble	1.5	0.0504	Limestone that is more or less crystallized by metamorphism, that ranges from granular to compact in texture, that is capable of taking a high polish, and that is used especially in architecture and sculpture.

Description	Recommended		Description
	Conductivity	Difussivity	
	Btu/hr-ft-F	Ft^2/hr	
Marl	1.2	0.0354	Loose or crumbling earthy deposit (as of sand, silt, or clay) that contains a substantial amount of calcium carbonate.
Marl, clayey/argillaceous	1.2	0.0352	
Marl, dolomitic	1.3	0.0371	
Peat	0.2	0.0070	Partially carbonized vegetable tissue formed by partial decomposition in water of various plants.
Pegmatite	1.7	0.0554	Coarse variety of granite occurring in dikes or veins.
Peridotite	2.3	0.0574	Any of a group of granitoid igneous rocks composed of ferromagnesian minerals and especially olivine.
Quartzite	3.5	0.1107	Compact granular rock composed of quartz and derived from sandstone by metamorphism.
Rhyolite	1.9	0.0609	Very acid volcanic rock that is the lava form of granite.
Rock Salt	3.1	0.1744	Crystalline compound NaCl that consists of sodium chloride.
Sand, dry	0.2	0.0111	Loose granular material that results from the disintegration of rocks, consists of particles smaller than gravel but coarser than silt.
Sand, dry compacted	0.7	0.0274	
Sand, frozen	1.2	0.0517	
Sand, moist	0.6	0.0215	
Sand, saturated	1.4	0.0372	
Sandstone	1.3	0.0446	Sedimentary rock consisting of usually quartz sand united by some cement (as silica or calcium carbonate).
Shale	1.2	0.0354	Fissile rock that is formed by the consolidation of clay, mud, or silt, has a finely stratified or laminated structure, and is composed of minerals essentially unaltered since deposition.
Schist	1.8		Metamorphic crystalline rock that has a closely foliated structure and can be split along approximately parallel planes.
Silt, dry	0.2	0.0097	Loose sedimentary material with rock particles usually 1/20 millimeter or less in diameter.
Silt, moist - wet	1.0	0.0317	
Siltstone	1.4	0.0404	Rock composed chiefly of indurated silt
Slate	1.2		Dense fine-grained metamorphic rock produced by the compression of various sediments (as clay or shale) so as to develop a characteristic cleavage.
Syenite	1.5	0.0420	Igneous rock composed chiefly of feldspar.
Till (boulder clay, moraine)	1.2	0.0369	Unstratified glacial drift consisting of clay, sand, gravel, and boulders intermingled.
Tonalite	1.6	0.0436	
Trachyte	1.6	0.0517	Usually light-colored volcanic rock consisting chiefly of potash feldspar.
Tuff	0.6	0.0388	Rock composed of the finer kinds of volcanic detritus usually fused together by heat.

Grout Properties

The following keywords define the properties of the grout (backfill) material.

GROUT-COND

The thermal conductivity (Btu/Hr-Ft-F) of the grout. Used for TYPE = VERT-WELL-NEW only. Typical values are listed in the table below.

Description	Thermal Conductivity
	Btu/hr-ft-F
Grouts without Additives	
Bentonite 10%, frozen	0.8
Bentonite 10%, in water	0.4
Bentonite 20%, in water	0.3
Bentonite 40%, frozen	0.5
Bentonite 40%, in water	0.3
Bentonite, dry	0.1
Clay, dry	0.2
Clay, moist - wet	0.9
Concrete	0.9
Gravel, dry	0.2
Gravel, saturated	1.0
Sand, dry	0.2
Sand, dry, compacted	0.7
Sand, frozen	1.2
Sand, moist	0.6
Sand, saturated	1.4
Silt, dry	0.2
Silt, moist - wet	1.0
Till	1.2
Thermally Enhanced Grouts	
20% Bentonite -40% Quartzite	0.9
30% Bentonite -30% Quartzite	0.8
30% Bentonite -30% Iron Ore	0.5
60% Quartzite -Flowable Fill (Cement + Fly Ash + Sand)	1.1

The above data are compiled from following sources:

Database of EED version 2.0 (Demo) (Hellstrom, et al 2000).

Kavanaugh, Stephen and K. Rafferty, Ground-Source Heat Pumps, ASHRAE 1997.