GSHP Modelling in ESP-r/HOT3000

This document outlines the ground source heat pump model incorporated into the ESP-r/HOT3000 source code. The following sections describe the model and the modelling approach, detail the modifications made to the ESP-r/HOT3000 source code to incorporate the GSHP models, and finally describe the testing and validation of this model.

GSHP Model

The ground source heat pump model was developed by Caneta Research Inc, and is detailed in the Caneta reports: '*Water Source Heat Pump Data for HOT3000 – Milestone #1*', '*HOT3000 Fortran GSHP Algorithms'*.

The model created by Caneta consists of two loops: the ground loop and the heat pump loop. The ground loop model is used to calculate the temperature of the water entering the heat pump (the entering water temperature – EWT). The operation of the heat pump loop is a function of the heat pump capacity and the entering water temperature.

Ground Loop

For the initial implementation into ESP-r/HOT3000, four ground loop configurations are available for simulation:

- Vertical single U-tube per bore hole,
- Horizontal 4-pipe, 2x2 arrangement,
- Horizontal 2-pipe, side-by-side arrangement, and
- Horizontal slinky arrangement

The user specifies which ground loop configuration is being modelled in the GSHP input file. For information on this input file format, please see '*GSHP Input File Format for ESP-r/HOT3000*', April 2002.

The function of the ground loop calculation is to determine the EWT. This calculation is performed on a daily basis – independent of the simulation timestep – as the minimum timestep for which the algorithms defined in '*Earth-Coupled Heat Transfer*' are applicable is a day.

The required inputs for the EWT temperature calculation are: the ground loop configuration, the daily load on the ground loop, the ground properties, the piping properties and configuration, and the exterior conditions. The daily load on the ground loop is calculated within the ESP-r/HOT3000 building simulation whereas the other inputs are specified in the `*gshp` file.

It should be noted that since a heating load in the house will result in an energy draw from of the ground, it will be represented as a negative load on the ground, and a cooling load in the house will be represented as a positive load on the ground.

Within this ground-loop calculation, there are two time loops – the so-called i-loop and j-loop. The j-loop is contained within the i-loop and it is designed to take into account the effects of the heating-up and cooling-down of the ground due to the loads on the ground loop. The routines in the j-loop are performed recursively for each day starting at the beginning of the simulation to the current day each timestep, i.e., for the simulation of day 4, the j-loop will cycle through days 1, 2, 3, and 4.

The fluid circulating in the ground loop is a 15% propylene glycol/water solution – and it is assumed to be freeze-protected until at least –10°C. If the EWT drops below –10°C, a message is issued to the user.

Heat Pump

The GSHP heat pump model incorporated into ESP-r/HOT3000 is very similar to the existing ASHP model. For this reason, the existing ASHP routines were used wherever possible.

The differences between the modelling of a ground-source or water-source heat pump and an air-source heat pump are as follows:

- Calculation of the capacity and coefficient of performance,
- Accounting for the cyclic performance, and
- Calculation of the circulation pump power.

The capacity and coefficient of performance (COP) of an air-source heat pump is dependent on the external conditions and the condenser airflow rate. Conversely, the performance of the water-source heat pump is based on the entering water temperature (EWT). Therefore, modifications to the heat pump model currently available in ESP-r/HOT3000 were required for GSHP simulation. New functions were created to calculate the operating capacity and COP based on the correlations for EWT derived from '*Simplified Energy Analysis Algorithms for GSHP Systems for HOT2000*'.

The cyclic performance of a GSHP is also dependent on the EWT. Currently, ASHP are classified as either 'typical', 'good', or 'poor' with their part-load characteristics defined accordingly. For GSHPs, correlations for part-load performance are defined based on the EWT and the degradation coefficient. These correlations are defined in '*Water Source Heat Pump Data for HOT3000 – Milestone #1*'.

A GSHP requires a pump to circulate the heat transfer fluid through the ground and into the heat pump unit. The pump power is calculated based on the heat pump capacity and the ground loop configuration. The correlation between the circulation pump power and the heat pump capacity is defined in '*Water Source Heat Pump Data for HOT3000 – Milestone #1*', December 2001. The user is not required to input the pump power.

Simulation Parameters

For the simulation of GSHP systems in ESP-r/HOT3000, it was determined by Caneta that the ideal start-up period is 10 days. This start-up period is required to precondition the ground properties. The user will be allowed to specify any length of start-up period up to a maximum of 10 days, for an annual simulation.

Note on simulation days: For the GSHP ground loop simulation, the variables `Day` and `iPeriod` represent the days of the simulation. For simulations beginning on January 1st WITH NO STARTUP, these variables will be numbered as 1, 2, 3, up to 365. Conversely, for simulations beginning on January 1st WITH STARTUP, these variables will be numbered as 366, 367 up to 730.

Output of Results

The standard H3K output facilities were updated to incorporate the GSHP components. The heat pump loop components, with the exception of the pump, are included in the ASHP outputs. A new output was created to record the monthly energy consumption of the GSHP pump.

Incorporating the GSHP Model into ESP-r/HOT3000

The following sections detail the modifications made to the ESP-r/HOT3000 source code to incorporate the Caneta models. The first section lists the modifications made to existing ESP-r/HOT3000 subroutines while the second section describes the new subroutines created for the GSHP modelling.

Modifications to existing subroutines

Several existing ESP-r/HOT3000 subroutines required modification to incorporate the GSHP model. These include:

MZINPT *(esrubps/input.F)*

If `*gshp` is defined in the .cfg file, then call the `GSHPINPUT` subroutine.

MZNUMA *(esrubps/bmatsv.F)*
If a GSHP system is being modelled, call the `GSHPSIM` subroutine once every day, after zone and hourly calculations – at the end of the `do 40` loop.

ERSYS *(esrucom/esystem.F)*
If `*gshp` is present in the `.cfg` file, then the GSHP flag (`common/gshpinfo/igshp`) and input file name (`common/gshpfile/gshpfile`) common block variables are set.

EMKCFG *(esrucom/emkcfg.F)*
Modified to allow for the recognition of the `*gshp` flag in the `.cfg` file.

SCSYS *(esrucom/scsys.F)*
Modified to allow for the recognition of the `*gshp` flag.

HVACINPUT (*cetc/hvacinput.F)*
If the HVAC system is a GSHP then call `ASHP_INPUT` – the HVAC input file for GSHP systems is identical to that for ASHP systems, only the variable `ihvac_type = 8`.

In addition, a new `isys_type` variable was defined. `isys_type` classifies the ASHP system as "typical", "good", or "poor" and then defines the correlation coefficient for part load performance accordingly. Conversely, for a GSHP system, the part load performance is a function of entering water temperature. Therefore, if `isys_type = 4`, then a GSHP system is being modelled and the values of `ahp`, `bhp`, `chp`, and `dhp` are initially set to `0.0`.

These values will be defined in the subroutines `GSHP_HEAT_COEFF` and `GSHP_COOL_COEFF`, called from `HVACSIM`.

START_HVAC_SIM *(cetc/hvacsim.F)*
If a GSHP system is being modelled, then call `HVACSIM`. This step was required because the GSHP model requires that the HVAC loads be calculated during the start-up period, and this is not done for standard HVAC simulations.

HVACSIM *(cetc/hvacsim.F)*
If a GSHP system is being modelled, call to `GSHP_load` to sum the daily heating and cooling loads.

In addition, if a GSHP system is being modelled in heating mode and there is a heating load call `GSHP_HEAT_COEFF` – to calculate the part load coefficients. If the GSHP system is being modelled in cooling mode and there is a cooling load, call `GSHP_COOL_COEFF`.
Note: the remainder of the `HVACSIM` calculations remains unchanged.

hvac.h (include/hvac.h)
The maximum number of HVAC systems types (`max_hvac_types`) was increased to 8 to allow for the GHSP definition.

Creation of new subroutines

Caneta developed several new subroutines to model ground source heat pump systems. To incorporate these subroutines into the ESP-r/HOT3000 structure required that the subroutines be modified to not only use ESP-r/HOT3000-calculated values, but also to read data in the same format as typical ESP-r/HOT3000 subroutines. In addition, the creation of new subroutines, functions, and modules was required.

The required modifications to the Caneta-developed subroutines were:

(i) Using standard ESP-r/HOT3000 read statements for all variables located in input files.
(ii) Creating modules to contain the "global" variables used in several subroutines - to avoid the lengthy subroutine call statements.
(iii) Reading in the zone heating and cooling loads from the ESP-r/HOT3000 building simulation. Because the ESP-r/HOT3000 simulation timesteps are hourly (or sub-hourly), these values were summed over the simulation day.

GSHP_INPUT *(cetc/gshp_module.F)*,
V1_INPUT (*cetc/gshp_module.F)*,
HS_ INPUT (*cetc/gshp_module.F)*, and
SL_INPUT(*cetc/gshp_module.F)*
These modules were created to store all the input data for the GSHP models. `GSHP_INPUT` stores system-independent input data, while all store system-specific data.

GSHP_DAILY *(cetc/gshp_module.F)*,
This module was created to store all daily values for the summed loads and the entering water temperature.

GSHPINPUT *(cetc/gshpinput.F)*
This subroutine controls the reading of the required input data for the GSHP system from the `*.gshp` file. GLOBAL_READ *(cetc/gshpinput.F)* reads the general input applicable to all systems. Depending on which system is being modelled; the model-specific input-reading subroutine is then called:
V1_READ *(cetc/gshpinput.F)*,
HS_READ *(cetc/gshpinput.F)*,
H4_READ *(cetc/gshpinput.F)*, or
SL_READ *(cetc/gshpinput.F)*
The data read in from the `*.gshp` file is saved into the `GSHP_INPUT`, `V1_INPUT`, `HS_INPUT`, and `SL_INPUT` modules.

GSHP_init *(cetc/gshpinput.F)*
This initialization of the GSHP variables is performed once per simulation.

GSHP_HEAT_COEFF *(cetc/gshpsim.F)* and
GSHP_COOL_COEFF *(cetc/gshpsim.F)*
Determines the degradation coefficients for a ground source heat pump based on entering water temperature. Calls GSHP_COEFF *(cetc/gshpsim.F)* to calculate the part-load performance coefficients.

GSHP_load *(cetc/gshpsim.F)*
This subroutine is called once per timestep, and performs a summation on the heating a cooling loads.

GSHPSIM *(cetc/gshpsim.F)*
This is the main ground loop simulation subroutine. It is called once per simulation day from `MZNUMA`. `GSHPSIM` calls `GSHP_init` and depending on the GSHP system being modelled, one of:
HEATXVI *(cetc/gshpsim.F)*,
HEATXH4 *(cetc/gshpsim.F)*,
HEATXHS *(cetc/gshpsim.F)*, or
HEATXSL *(cetc/gshpsim.F)*
The GSHP system-specific subroutines calculate the entering water temperature for the simulation day.

GSHP_pump_power *(cetc/gshpsim.F)*
This function returns the amount of pumping power required to circulate the heat transfer fluid through the ground loop. It is set to `GSHP_pump_energy` in `ASHP_HEATING` and `ASHP_COOLING`. `GSHP_pump_energy` is saved to the module `HVAC_OUTPUT`.

GSHP_COP (*cetc/gshpsim.F*)
This function returns the heat pump coefficient of performance (COP) at operating conditions. This value is a function of the steady state COP as well as the entering water temperature (EWT).

GSHP_CAP (*cetc/gshpsim.F*)
This function returns the heat pump capacity at operating conditions. The operating capacity is a function of the steady state capacity as well as the entering water temperature (EWT).

Testing and Validation

Validation of the GSHP model was performed by Caneta and outlined in their report '*HOT3000 Fortran GSHP Validation Report*'.

Also tested was the incorporation of Caneta's GSHP model into ESP-r/HOT300. Three rounds of testing were performed.

The first round included reading in the heating and cooling loads used by Caneta to validate the EWT calculation and implementation. The following graphs show the correlation in results for two systems – a vertical ground loop and a slinky loop.

It can be seen that for the vertical loop, the correlation is very close, whereas for the slinky loop, the results are very close until mid-summer when they start to diverge slightly.

The second set of testing included running a set of simulations whereby the Caneta loads were applied to an adiabatic zone via infiltration. System-specific weather files were created to simulate the required heating and cooling loads for a one-zone building with a specified amount of infiltration air. The results from these tests mirrored the results obtained from the above cases.

The third set of testing was performed to ensure that the incorporation of the GSHP model would not impact the results for ESP-r/HOT3000 simulations that don't use the model. For this, two test cases were run with both the standard version of bpsh3k and with the version compiled including the GSHP coding. The SL5 results were identical.

References

Caneta Research Inc., '*Water Source Heat Pump Data for HOT3000 – Milestone #1*', Report for CETC, December 21, 2001.

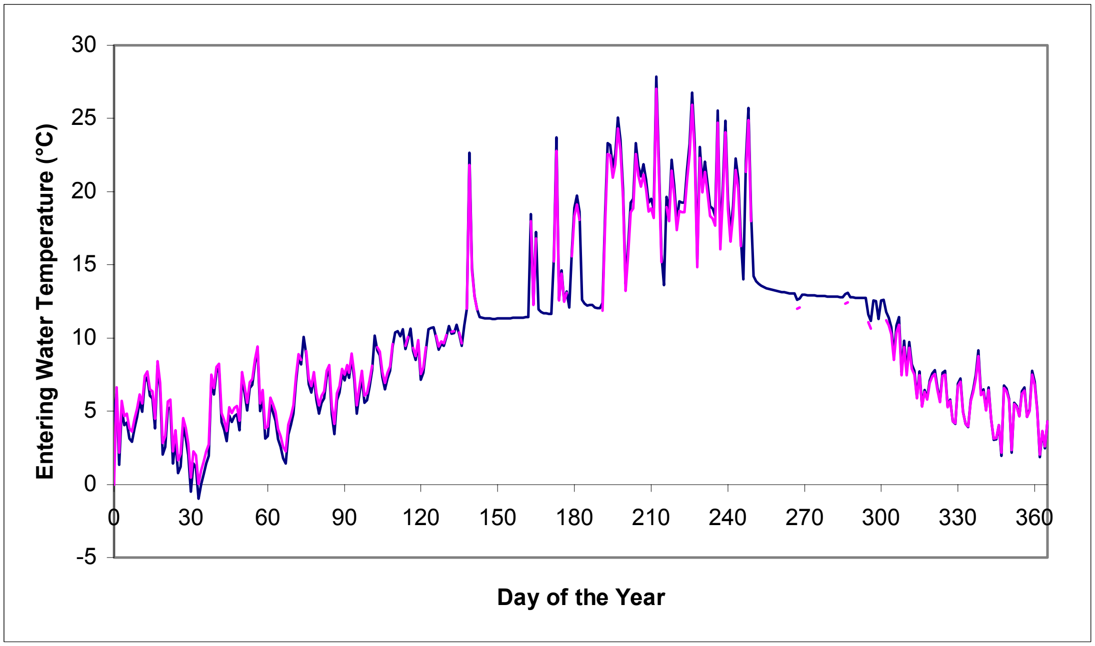
Caneta Research Inc., '*HOT3000 Fortran GSHP Algorithms',* Report for CETC, November 28, 2001.

Caneta Research Inc., '*HOT3000 Fortran GSHP Validation Report',* Report for CETC, December 18, 2001.

Caneta Research Inc., '*Simplified Energy Analysis Algorithms for GSHP Systems for HOT2000*', March 1994.

P. Hart and R. Couvillion, **Earth-Coupled Heat Transfer**.

J. Purdy, '*GSHP Input File Format for ESP-r/HOT3000*', April 5, 2002.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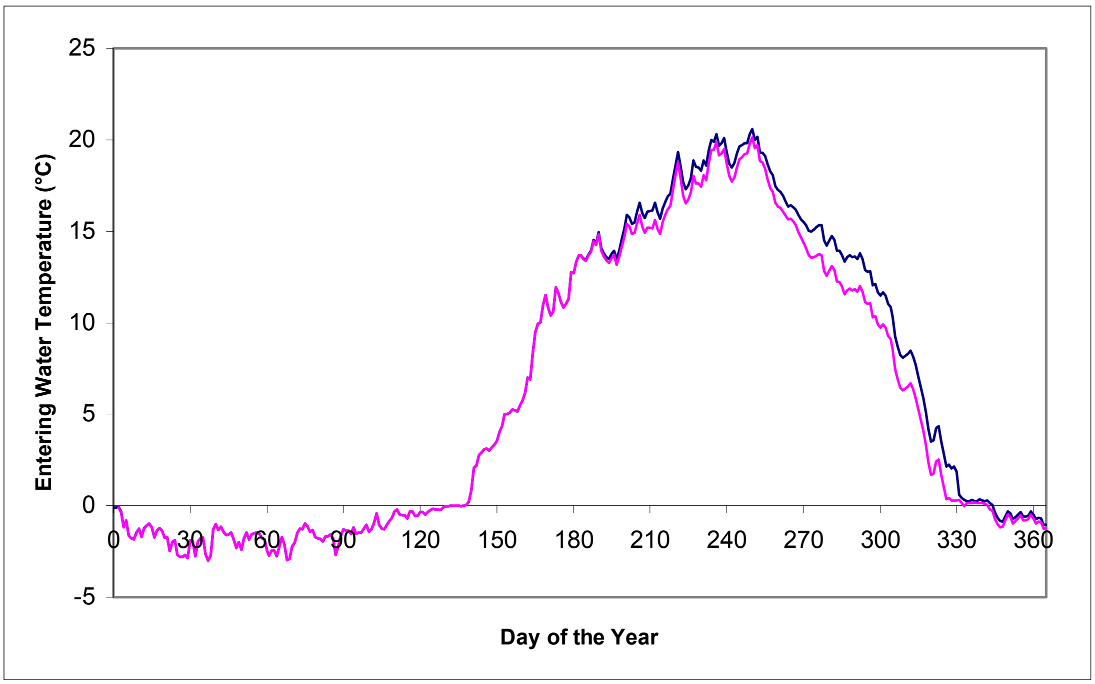
Day of the Year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Day of the Year