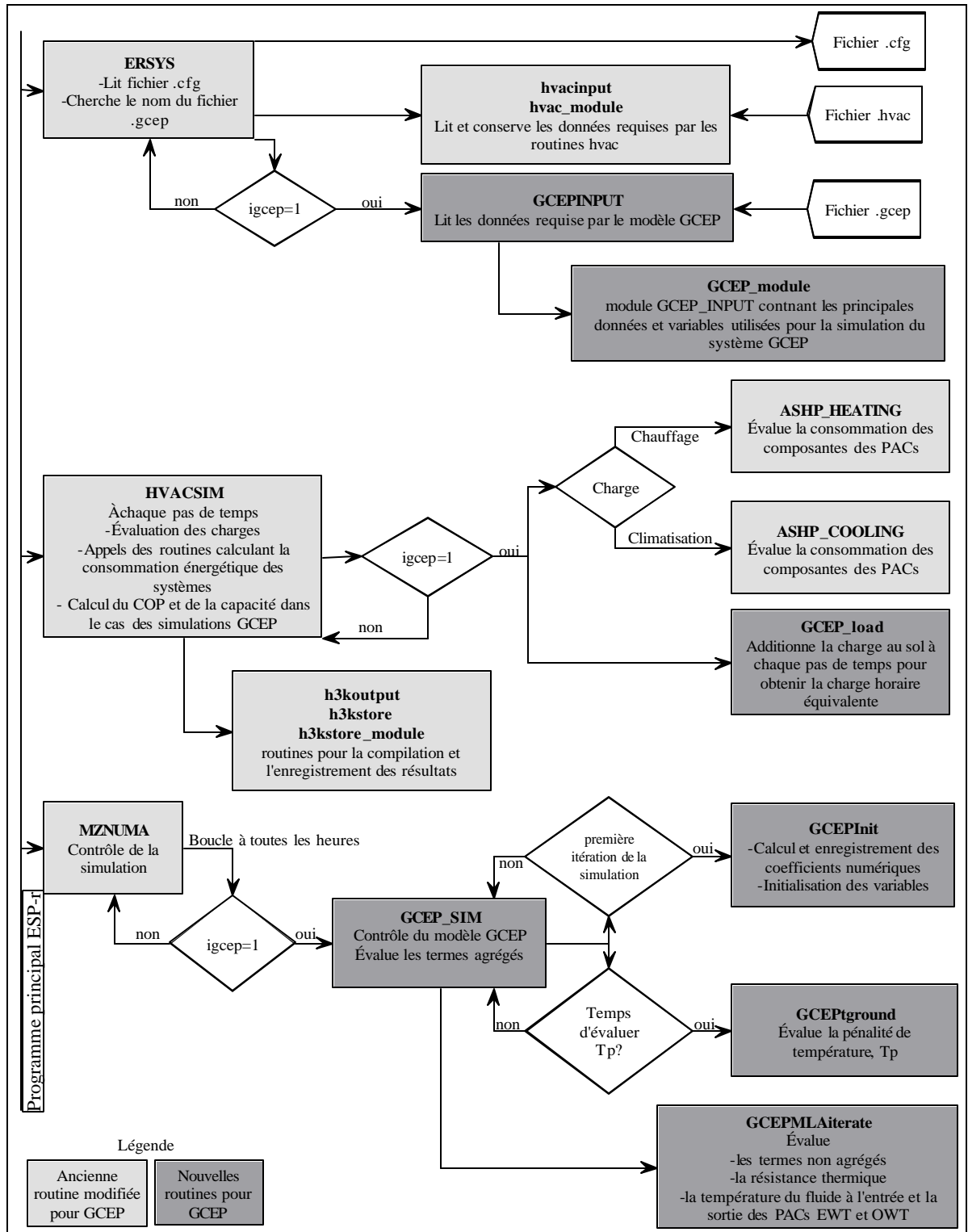# GCEP Model

The GCEP (Ground Coupling Ecole Polytechnique) model does hourly simulations of rectangular borfields.

Integration of the GCEP model to ESP-r

The following flowchart shows the GCEP model's structure in ESP-r. The three main routines that control the execution of a GCEP simulation are:

- ERSYS detects the presence of a GCEP input file and activates a flag indicatig the presence of a GCEP simulation (igcep=1). Calls the GCEPINPUT routine which reads the GCEP input file and stores the inputs in the GCEP module where they are accessible to the rest of the model.
- HVACSIM compiles the zone loads and distributes them to the various HVAC systems routines, evaluates consumption of these systems and calls the routines that compile and save these consumptions. For the GCEP systems, this routine calls the GCEP_load routine which adds the loads at each time step to obtain the total load for an hour.
- MZNUMA calls the routines which model the HVAC systems. This routine calls the GCEP_SIM routine, which controls the evaluation of the borefield behaviour (the GCEP model), at each hour.

ERSYS
-Lit fichier .cfg
-Cherche le nom du fichier .gcep

Fichier .cfg

hvacinput
hvac_module
Lit et conserve les données requises par les routines hvac

Fichier .hvac

non — igcep=1 — oui

GCEPINPUT
Lit les données requise par le modèle GCEP

Fichier .gcep

GCEP_module
module GCEP_INPUT contnant les principales données et variables utilisées pour la simulation du système GCEP

ASHP_HEATING
Évalue la consommation des composantes des PACs

Chauffage

Charge

HVACSIM
Àchaque pas de temps
-Évaluation des charges
-Appels des routines calculant la consommation énergétique des systèmes
- Calcul du COP et de la capacité dans le cas des simulations GCEP

igcep=1 — oui

Climatisation

ASHP_COOLING
Évalue la consommation des composantes des PACs

non

GCEP_load
Additionne la charge au sol à chaque pas de temps pour obtenir la charge horaire équivalente

h3koutput
h3kstore
h3kstore_module
routines pour la compilation et l'enregistrement des résultats

première itération de la simulation

non

oui

GCEPInit
-Calcul et enregistrement des coefficients numériques
-Initialisation des variables

MZNUMA
Contrôle de la simulation

Boucle à toutes les heures

non — igcep=1 — oui

GCEP_SIM
Contrôle du modèle GCEP
Évalue les termes agrégés

Temps d'évaluer Tp?

non

oui

GCEPtground
Évalue la pénalité de température, Tp

Programme principal ESP-r

Légende

Ancienne routine modifiée pour GCEP

Nouvelles routines pour GCEP

GCEPMLAiterate
Évalue
-les termes non agrégés
-la résistance thermique
-la température du fluide à l'entrée et la sortie des PACs EWT et OWT

Many modifications to the ESP-r source code were made. Some of the changed files are shown in light grey on the flowchart. Some files not shown on the flowchart were also modified. A complete description of the changed files is given at the end of this document.

The capacity and COP of the system are evaluated using the fluid temperature at the heat pumps' inlet from the previous hour. Since this temperature does not vary significantly enough to have a noticeable impact on COP and capacity from hour to hour, the influence on results is small.

Nevertheless, the infrastructure allowing the integration of an iteration process between the COP, the ground load and the fluid temperature is in place. The GCEP_SIM routine performs the operations that must be made once every hour. The GCEP_MLAiterate routine performs the operations necessary to do an iteration. It is therefore possible to iterate between GCEP_MLAiterate and a heat pump model if it becomes convenient to do so.

GCEP data file format

The GCEP data file has the '.gcep' extension. It contains only numerical values. Every line corresponds to data which have common traits. Values are placed beside each other on a line with one or more blank spaces as separators. The following table describes the position and signification of each value in the file.

GCEP data file format

Position on the line	Variable Name	Units	Description
1st line : Ground properties			
1	*k_s*	W/m°C	Ground thermal conductivity
2	*Alpha_s*	m²/day	Ground thermal diffusivity
3	*Rho_s*	kg/m³	Ground density
2nd line : Grout Properties			
1	*k_g*	W/m°C	Grout thermal conductivity
3rd line : Boreholes dimensions			
1	*D_bore*	m	Borehole diameter
2	*Deapth_bore*	m	Borehole depth
4^{rth} line : Borefield arrangement			
1	*N_bor_x*		Number of boreholes in the X direction
2	*N_bor_y*		Number of boreholes in the Y direction
3	*L_bor_x*	m	Distance between 2 borehole in the X direction
4	*L_bor_y*	m	Distance between 2 borehole in the Y direction
5th line : Pipes arrangement			
1	*Tube_ Case*		Disposition of the pipes in the boreholes. The dispositions are presented in the following figure. **1 U tube** 1 = disposition A, 2 = disposition B, 3 = disposition C **2 U tubes** 4 = disposition A, 5 = disposition B, 6 = disposition C
2	*TypeTubes*		Used pipes (1 to 12 described in next table)
3	*K_t*	W/m°C	Pipe wall thermal conductivity
4	*Pipe_length*	m	Total length of pipes in the system
6th line : Fluid properties			
1	*K_f*	W/m°C	Fluid thermal conductivity
2	*Rho_f*	kg/m³	Fluid density
3	*Cp_f*	J/Kg°C	Fluid specific heat
4	*Mu_f*	kg/ms	Fluid dynamic viscosity
7th line : Reference temperatures			
1	*Tg_ND*	°C	Undisturbed ground temperature (at infinite distance)
2	*Tg_init*	°C	Initial ground temperature

The following figure shows the tube disposition accounted by the model: A=pipes at the borehole centre, C=pipes at the borehole wall, B=pipes midway between the centre and the wall. The B configuration is more often encountered in reality while the A configuration is more conservative for calculations.
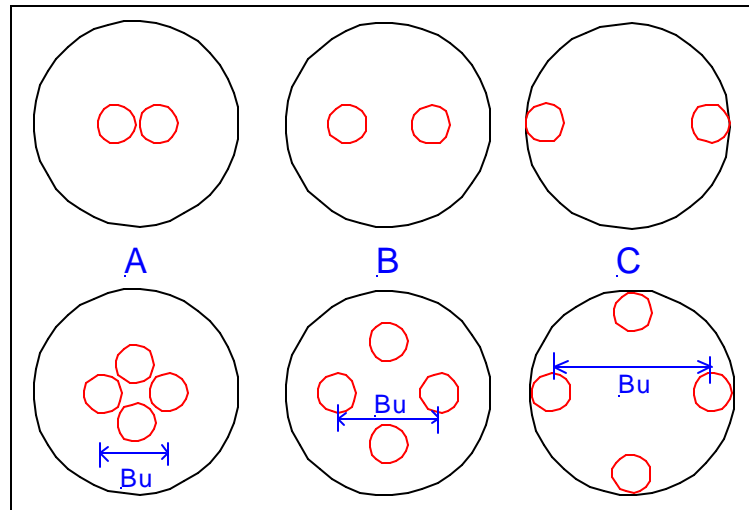
The following table shows pipes accounted for by the model. It consists in a selection of pipes generally used for geothermal applications.

Inside and Outside diameter of commonly used pipes

No	Name	$D_{p,o}$ (cm)	$D_{p,i}$ (cm)
1	¾" SDR-11	2.67	2.18
2	1" SDR-11	3.34	2.73
3	1¼" SDR-11	4.22	3.45
4	25 mm SDR-11	2.50	2.04
5	32 mm SDR-11	3.20	2.60
6	40 mm SDR-11	4.00	3.26
7	¾" SDR-135	2.67	2.27
8	1" SDR-135	3.34	2.85
9	1¼" SDR-135	4.22	3.59
10	25 mm SDR-135	2.50	2.04
11	32 mm SDR-135	3.20	2.62
12	40 mm SDR-135	4.00	3.40

GCEP model integration

Integration of the GCEP model is verified by doing an ESP-r simulation and comparing the temperatures predicted to those calculated by the same model under CA-SIS for the same conditions. Those conditions are described in the following table. Ground thermal loads are calculated by ESP-r for a building in the Ottawa region. The load profile is presented in the bottom section of the figures presenting the results.

Data used for the verification of the GCEP model

Variable name	Value	Units	Description
k_s	1.3	W/m°C	Ground thermal conductivity
$Alpha\_s$	0.0561	m²/day	Ground thermal diffusivity
Rho_s	1021	kg/m^3	Ground density
k_g	2.6	W/m°C	Grout thermal conductivity
D_bore	0.152	m	Borehole diameter
$Deapth\_bore$	100	m	Borehole depth
N_bor_x	3		Number of boreholes in the X direction
N_bor_y	3		Number of boreholes in the Y direction
L_bor_x	8	m	Distance between 2 borehole in the X direction
L_bor_y	8	m	Distance between 2 borehole in the Y direction
$Tube\_ Case$	2		Disposition of the pipes in the boreholes (1 to 6)
$TypeTubes$	2		Used pipes (1 to 12)
k_t	0.42	W/m°C	Pipe wall thermal conductivity
$pipe\_length$	1800	m	Total length of pipes in the system
k_f	0.49	W/m°C	Fluid thermal conductivity
Rho_f	1022	kg/m³	Fluid density
Cp_f	3960	J/Kg°C	Fluid specific heat
Mu_f	855×10^{-6}	kg/ms	Fluid dynamic viscosity
Tg_ND	10	°C	Undisturbed ground temperature (at infinite distance)
Tg_init	10	°C	Initial ground temperature

The top part of the following figure presents calculated fluid temperatures at the outlet of the borefield. The temperatures predicted by the GCEP model are exactly the same as those predicted by the same model implemented in CA-SIS (called TYPE93). We can therefore affirm that the implantation is successful.

The model is also compared to the GSHP (Ground Source Heat Pump) model that is already implanted in ESP-r. The GSHP model uses the Hart and Couvillon (1986) method. It doesn't account for thermal interference among boreholes and evaluates temperatures once a day (every 24 hours). Since thermal loads are relatively weak on the 9 boreholes, thermal interference has a small influence and comparison between the two models (GSHP and GCEP) is pertinent. Temperatures calculated with the GSHP model are represented by triangles on the figure. Since there is good agreement between temperatures calculated by both models, it can be assumed that they are valid.
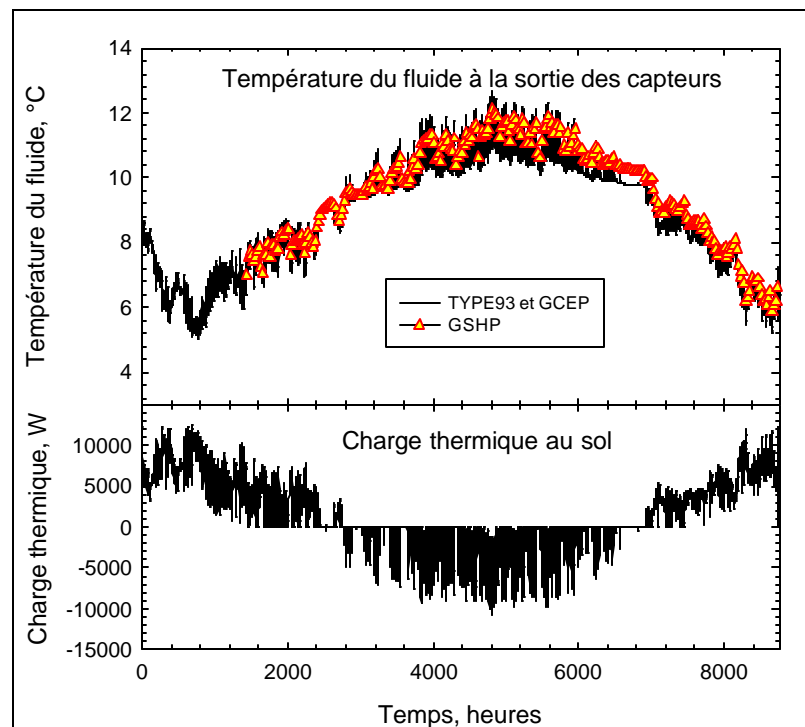
Verification of the integration of the GCEP model

Modifications to the ESP-r source code

The following modifications were made to the ESP-r source code to allow detection of a GCEP data file, calls to the GCEP routines during the simulation and saving of the GCEP calculation results.

Modifications to the bmatsv.F file

This file contains the mznuma routine which controls the numerical simulation. The GCEP_SIM routine is called from mznuma every hour to evaluate the behaviour of the ground coupling and the fluid temperatures. The following modifications are made to bmatsv.F :

1   Declaration of the flag indicating the presence of the GCEP data file
2   Call to the GCEP_SIM routine every hour
3   End of the simulation: Erase all binary files created at the beginning of the simulation to contain the data used for the numerical calculations of ground heat transfer.

Modifications to hvacsim.F

This file manages loads on the different zones and evaluate the load on the main and secondary systems. It also evaluates the energy consumption of the different systems and their components. GCEP_load, the routine which sums the loads at each time step and determines the hourly load, is also called from this file.   The following modifications were made to hvacsim.F :

1   Declaration of the GCEP flag

2   Call to the HVACSIM routine which manages calculations of the loads and energy consumption when the GCEP flag is activated.

3   Use of the GCEP_INPUT module which contains the data used for the GCEP calculations

4   Calculation of the heating energy consumption and the secondary system consumption for a GCEP system.

5   Calculation of the cooling energy consumption for a GCEP system

6   COP calculation and call to the GCEP_load routine to add the ground load to the hourly ground load.

7   Adding of the GCEP pumping consumption to the call to the H3KSTORE_HVAC_Packaged_DATA routine which manage the saving of simulation results.

Modifications to ashp.F

This file calculates the heat pump consumption in heating mode. The following modifications were made to it:

1   Use of the GCEP_INPUT module containing the variables used for the simulation of the GCEP system

2   Declaration of the variable GCEP_HP_mode which will be initialised to 1 for heating mode and –1 for cooling mode.

3   Assignation of the GCEP_HP_mode variable and calculation of the heat pump capacity.

4   Evaluation of the Heat Pumps COP

Modifications to ashp_cooling.F

This file evaluates the consumption of the heat pumps in cooling mode. The following modifications are done to this file:

1. Use of the GCEP_INPUT module containing the variables used for the simulation of the GCEP system
2. Declaration of the variable GCEP_HP_mode which will be initialised to 1 for heating mode and –1 for cooling mode.
3. Assignation of the GCEP_HP_mode variable and calculation of the heat pump capacity.
4. Evaluation of the Heat Pumps COP

Modifications to hvac_module.F

This file contains data used for the calculation of HVAC systems consumption. The following changes were made to it :

1. Declaration of the GCEP_pump_energy variable, the GCEP system pump consumption

Modifications to hvacinput.F

This file reads the hvac data file and initialise variables in the file hvac_module.F. The following modifications were done to it:

1. Inform the user that ihvac_type(i) initialised to 9 means that the system in question (i) is a GCEP system

2   Allow reading of ihvac_type values of 9, the value 9 representing a GCEP system

3   Call the ASHP_INPUT routine which initialise data relative to the heat pumps

4   Inform the user that isys_type=4, used for GSHP systems, is also used for GCEP systems

5   Inform the user that the correlation coefficients are initialised for a GCEP system (isys_type=4)

Modifications to input.F

This file defines the configuration of the building for simulation ends. The following modifications were done to it:

1   Declaration of the GCEP flag

2   Call to the GCEPINPUT routine which initialises the module containing the data on the GCEP system

Modifications to scsys.F

This files verifies if a GCEP data file is present. The following modifications were done to it:

1   Declaration of the GCEP data file

2   Declaration of the GCEP data file's name

3   Initialisation of the GCEP flag

4   Reading of the GCEP data file name

Modifications to emkcfg.F

This file creates a system configuration file. The following modifications were done to it:

1. Declaration of the GCEP flag
2. Writing in the configuration file of the presence of the GCEP data file

Modifications to bps.F

This file initialises the user terminal, the climate data base and show the main menu. The following modifications were done to it:

1. Insertion of the GCEP module (GCEP_module.F) containing the ddata on the GCEP system

Modifications to esystem.F

This file reads the configuration file. The following modifications were done to it:

1. Declaration of the GCEP data file
2. Declaration of the GCEP data file name
3. Initialisation of the GCEP flag
4. Verification of the GCEP data file

<u>Modifications to h3koutput.F</u>

This file saves results. The following modifications were done to it:

1. Addition of a GCEP_PUMP MJ column in the level 5 output file
2. Writing of the monthly consumption of the GCEP pump (fGCEP_pump_energy_monthly) in this column

<u>Modifications to h3kstore.F</u>

This file stocks results and transform them in the required format to save them to a file. The following modifications were done to it:

1. Initialise fGCEP_pump_energy_monthly(imonth) at 0
2. Add fGCEP_pump_energy, the consumption of the GCEP pump during the time step, to the list of variables received by the H3KSTORE_HVAC_Packaged_DATA routine
3. Declaration of fGCEP_pump_energy in the routine
4. Addition of fGCEP_pump_energy to the pump monthly consumption (fGCEP_pump_energy_monthly)

<u>Modifications to h3kstore_module.F</u>

This module contains variables used to save results. The following modifications were done to it:

1. Déclaration of fGCEP_pump_energy_monthly