IMPLEMENTATION OF A MODEL THAT COUPLES A CENTRAL GROUND SOURCE HEAT PUMP AND A BOILER FOR SIMULATION USING THE EE4 CBIP COMPLIANCE CHECKING SOFTWARE

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ABSTRACT

Commercial building HVAC systems that integrate a central ground source heat pump with a backup boiler (combo systems) are becoming increasingly more popular in Canada. Natural Resources Canada (NRCan) has developed and implemented a combo system model into EE4 CBIP, the compliance checking software for the Office of Energy Efficiency's (OEE) Commercial Building Incentive Program (CBIP). Considerations in the development and implementation of such a model into EE4 CBIP were: DOE2.1e simulation engine constraints, approximating the heat pump using an electric boiler with corrected COP's accounting for several heat pumps working in sequence, validation methodology, and issues in modelling the reference case for compliance. Future work involves expanding the model to estimate energy savings from using central ground-source heat pumps for preheating domestic hot-water.

INTRODUCTION

In 1997, Canada's Model National Energy Code for Buildings (MNECB) was published. To help users determine compliance of their buildings using the performance path option, the EE4 CODE software was developed.

Soon after, NRCan launched the Commercial Buildings Incentives Program (CBIP), a program that requires that a building be 25% more efficient than the MNECB requirements to qualify for government financial incentives. A spin-off software called EE4 CBIP was developed and is currently being maintained by NRCan's CANMET Energy Technology Centre (CETC) to determine compliance with the program. The reader is directed to the various references (Calla et al. 2004, Beausoleil-Morrison et al. 2001, and Calla et al. 2001) at the end of this paper for additional background information on EE4 and the CBIP program. EE4 CBIP is continuously evolving to support models that reflect or approximate real-life HVAC systems.

Central ground-source heat pump systems for space heating are attractive given the higher COP that can be achieved when the ground is used as a heat sink or source. British Columbia and Manitoba are provinces where these systems have increased in popularity in recent years. In fact, about 15 building submissions that use central ground-source heat pump systems are made to the OEE CBIP Program every year.

Given the high cost of ground-source heat pumps, some of these systems are purposefully under-sized to reduce the capital investment needed at the start. In this case, a backup boiler is installed and deployed for when the heating load can not be met by the heat pump. When the heating load exceeds the capacity of the heat pump, both the heat pump and the boiler can be controlled to operate together to meet the load. The heat pump can also be turned off when it can not meet the full load and the boiler deployed instead to meet the total heating demand.

Another incentive for installing backup boilers with central ground-source heat pumps is to reduce operating cost. There are situations when the local price of electricity rises to the point where it is more economical to run a fuel boiler than a central ground-source heat pump to meet the heating load. This new trend created the need for representing these types of systems in commercially available modelling software for energy analysis and incentive calculations for different organisations (NRCan, Hydro-Quebec, etc.). Our goal was to develop a modelling methodology that accurately represents this system using the DOE2.1E engine.

DOE2.1E offers the possibility of modelling distributed unitary heat pumps on a closed loop using either a boiler/cooling tower combination or a ground heat exchanger to reject or add energy from or into the loop. However, it is not possible to add an auxiliary boiler in addition to the ground heat exchanger or to use a central water-to-water ground source heat pump with auxiliary heating. The work-around method presented in this article was developed to represent a hybrid system consisting of central ground source heat pump(s) with auxiliary heating (combo system).

MODELLING AND SIMULATION

Modeling Background of Other Simulation Programs with Respect to Combo Systems

The TRNSYS (Klein et al. 2004) building energy simulation program has models for most of the HVAC components that can be used to build a mechanical system. These component models are connected together to form a network that operates based on certain control actions. Available component models are: boilers, ground-source heat pumps, heat exchangers, pipes, and pumps. These can be connected together based on the appropriate control actions to form a central ground-source heat pump system with boiler backup. TRNSYS is used mostly for research projects where users want full control over the parameters that define the performance of the HVAC system they are modeling. Most users who are interested in modeling commercial HVAC systems choose to use tools such as DOE-2 or eQuest, which require a much smaller time investment to create a working model.

eQuest is a building energy analysis tool which contains a wizard for creating the building, a wizard for energy efficiency measures, and a graphical display results module. eQuest uses an enhanced version of the DOE-2 simulation engine. This widely used tool for modeling HVAC systems in commercial buildings does not have the capability to model a central ground source heat pump system with a boiler backup given that this HVAC system is not common in the United States.

EnergyPlus (Crawley et al. 2004) is a modular building energy simulation tool based on the best features of the BLAST and DOE-2.1E simulation engines. Similar to TRNSYS, EnergyPlus has models for many HVAC components that can be connected together in a network to form a complete building mechanical system with an associated control action. EnergyPlus also has all the component models needed to assemble a central ground-source heat pump system with a boiler backup supplying cold and hot water to fan coils inside the space. The backup boiler of the heat pump can be controlled so that it turns on when the heat pump can not meet the total load. The option also exists to have the boiler and the heat pump operate together to meet the load. Another control option is to shut down the heat pump and have the boiler meet 100% of the total heating load.

EE4 CBIP Modelling Strategy

A work-around method capable of accurately representing complex ground source heat pump systems in EE4 was necessary since no built-in systems in DOE2.1E were designed to model central water-to-water ground source heat pumps with auxiliary heating. It consists of using an electric boiler with a corrected efficiency (equivalent to the COP) to represent the heating mode of the GSHP and a conventional chiller for the cooling mode.

The Model in Heating Mode

Since the electric boiler is a central component located in the PLANT module in DOE2.1E, it is possible to use it to represent the GSHP in the heating mode. Boilers with other fuel types can be used to represent the backup heating equipment. Different control sequences for the two boilers can be implemented using the LOAD-MANAGEMENT command. Also, the hot-water produced by these equivalent boilers can be used by all the hydronic central systems using the HOT-WATER command as the heating source.

Because of the relatively stable temperature of the ground over the year, the nominal efficiency (COP) of a GSHP is also relatively constant. It is possible to obtain acceptable results by using a constant COP corresponding to the yearly average value calculated according to heat pump manufacturer's specifications and local ground temperature conditions. The electric boiler used to represent the GSHP in the heating mode has an efficiency, which does not vary with the heating load. However, a GSHP COP varies with part-load. Therefore, a new routine was implemented in EE4 that applies a correction factor calculated with the approximate number of hours at different part loads according to the EIR FPLR performance curve used by DOE2.1E.

In DOE2.1E, the EIR FPLR performance curve is used to adjust the steady-state Energy-Input Ratio EIR to account for the degradation related to part-load performance of the heat pump. . The corrected Energy-Input Ratio EIR is calculated as follows:

$$\text{EIR}_{corr} = \frac{[\text{EIR FPLR}] \times [\text{EIR}]}{[\text{PLR}]} \quad (1)$$

Where:
EIR FPLR is the part load ratio coefficient (third degree PLR function)
EIR is the nominal Energy Input Ratio defined as the ratio of the steady-state electricity input to the heating capacity.
PLR is the part load ratio (value between 0 and 1) equal to the ratio of the actual load on the heat pump to the steady-state heating capacity of the unit.

With this correlation, it is possible to approximate the yearly average EIR of the GSHP by evaluating the number of hours at which the GSHP operates at different part load ratios. To do so, the temperature of 18 °C is used as the equilibrium temperature (no

heating) and the peak load coincides with the lowest outside air temperature encountered in the region of interest. An hourly weather file is used for the calculations. As an example, in the region of Montreal, a GSHP with a nominal COP of 3.0 (EIR of 0.333) could have the following part load operation as specified in Table 1:

Table 1: Example of a heat pump part load operation

PLR	EIR-FPLR	EIR$_{corr}$	Hours
0.1	0.14	0.47	611
0.2	0.26	0.44	881
0.3	0.38	0.42	893
0.4	0.49	0.41	1254
0.5	0.59	0.40	679
0.6	0.69	0.38	658
0.7	0.78	0.37	591
0.8	0.86	0.36	346
0.9	0.93	0.35	187
1	1.00	0.33	54

In this case, the yearly weighted average EIR would be 0.3909 (COP of 2.558). This value represents a 15% decrease of the nominal efficiency of the heat pump. The correction factor is thus 0.85.

Since several heat pumps working in sequence usually improve the overall efficiency of the system, the correction factor had to be modified to take this phenomenon into account. The same exercise has been carried out by distributing the load among several heat pumps. Figure 1 illustrates the correction factors calculated when 1 to 10 heat pumps are used in sequence:

The correction factor routine in EE4 was established by incorporating a correlation using these values. Two control options are modelled between the central ground-source heat pump and the backup boiler through the DOE2.1E LOAD-MANAGEMENT command. The parallel operation specifies that the heat pump is used to meet the heating load up to its maximum capacity. Higher heating loads are then met by the heat pump and the boiler operating together. For the sequential (alternating) operation, the heat pump is used to meet the load up to its maximum heating capacity. In this case, heating loads higher than the capacity of the heat pump are met only by the backup boiler.

When an electric boiler is implemented in DOE2.1E, a default value of 2 % of the boiler capacity is used to represent energy losses and boiler auxiliary equipment leading to additional energy consumption. This situation is not acceptable when the equivalent boiler is used to represent a GSHP. The E-HW-BOILER-LOSS command is then set to zero to eliminate the auxiliary energy consumption.
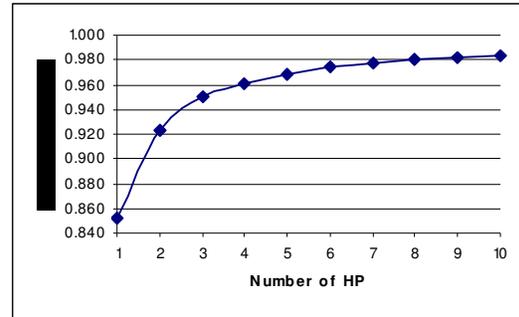

Figure 1: COP correction factor vs. the number of sequencing heat pumps

The Model in Cooling Mode

The cooling mode of the GSHP is represented by a conventional chiller in DOE2.1E using a 0 consumption air type condenser. The ground loop water temperature entered by EE4 users does not vary substantially over the year, hence the cooling COP is set to be an average value based on manufacturer data and local monthly ground temperature. It is to be noted that average ground temperatures for different parts of Canada are provided to EE4 users through the website (http://buildingsgroup.nrcan.gc.ca/ee4/english/manual/index.php). Because a conventional air-cooled chiller would face higher condensing temperature variations, the chiller performance curves in DOE-2 CAP-FT (capacity correction) and EIR-FT (Energy Input Ratio correction) are set to a constant value of 1. These curves usually adjust the nominal capacity and the Energy-Input Ratio as a function of the temperature outside of the condenser and evaporator of the chiller. In the simulation, the only variation of the chiller efficiency occurs because of the part load conditions encountered over the year. The performance curve used to take this effect into account is the EIR-FPLR performance curve.

Heating/Cooling Balance Effect on Ground Temperature

When GSHP systems are designed, great care should be taken in considering the yearly heating and cooling energy balance. Too much heat extraction from the ground could lead to a temperature decrease over the years, affecting the performance of the GSHP. Many types of software are used to determine the number of boreholes needed while taking this energy balance into consideration. The sizing of the ground heat exchanger is left to the designers and our modeling work assumes correct design practices. In EE4, ground loop temperatures currently vary on a monthly basis only and these monthly temperatures are assumed to be the same every year. Hence, this

energy balance was not part of the scope of this phase of our work since the work-around method we apply is based on the guidelines of the EE4 modeling manual. This, could of course be, a topic for future enhancement of the model.

Circulation Pump Consumption

In the DOE2.1E input file, the characteristics (pressure drop. flow, efficiency, etc.) of the primary pumps (ground loop side) and the secondary pumps (building side) are entered by using, in the PLANT-PARAMETERS command, the HCIRC and CCIRC keywords. In EE4, it is currently assumed that the hot water and cold water pumps are on continuously regardless of whether there is a call for heating or cooling. The same assumption is made for the primary and secondary pumps of the central ground-source heat pump loop.

Validation Results

Currently EE4 users have only one option to model central ground source heat pump systems; using unitary heat pump units in each of the conditioned zones. In the cooling mode, the unitary heat pumps reject heat from the space into a common water loop. Heat is added to the water loop in the heating mode. The inlet temperature to the water loop is set by the user to the average monthly ground temperature. The capacity and COP of the unitary heat pumps are entered by the user at ARI rating conditions for ground-source heat pump systems. These two performance parameters of the unitary heat pumps are modified within DOE-2 to account for operating temperatures and part-load performance.

With no auxiliary heating device (100 % GSHP), the results of the new alternative method, proposed in this paper for modeling central ground-source heat pump systems, should be similar to those generated by the conventional approach of EE4 that uses unitary GSHP. In the case of 100% GSHP, the equivalent boiler and chiller COPs represent a weighted average COP of all the unitary heat pumps entered in the original EE4 file that uses unitary heat pump units. In the new workaround procedure that we have implemented in EE4, fan coils using hot water and chilled water for heating and cooling, respectively, are used instead of the unitary heat pumps.

Figure 2 shows results from an EE4 simulation of a 2350 m^2 public school using 100% GSHP for heating and cooling. These EE4 results are obtained using unitary GSHP units. The Figure also contains results for the same building using the new method for modeling GSHP systems proposed in this paper. The differences in the results are primarily due to the fact

that the new proposed approach for central GSHP systems uses a constant average COP as opposed to the variable COP used to model unitary heat pump systems. In addition, there is an uncertainty associated with the part-load correction factors presented in Table 1.
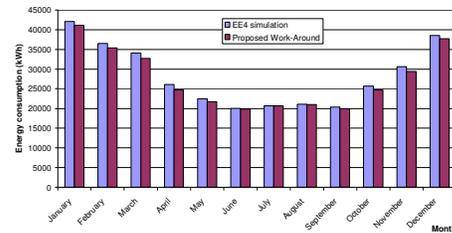

Figure 2: Validation results of a 2350 m² school located in Montreal

The difference between the annual energy consumption calculated with the proposed work-around and the results obtained with the original EE4 calculations is less than 3 %.

The same validation procedure was carried out with a *fictional* building (modelled as a school) tested in 5 different Canadian cities: Montreal, Edmonton, Halifax, Toronto and Vancouver. The cooling and heating capacities of the systems were adjusted to the peak load of the area of interest. Also, for the EE4 model, the entering water temperature (ground loop water temperature) was changed according to those specified in the EE4 modelling guide (http://buildingsgroup.nrcan.gc.ca/ee4/english/manual/index.php) for these specific cities.

When the results of the new work-around method are compared to those generated by EE4, a difference varying between less than 1 % and 2,8 % is observed, depending on the location. These values represent the total energy consumption difference between the EE4 (unitary GSHP) and the modified building (equivalent boiler) located in Montreal and Vancouver, respectively. The results for the other cities fall within these values. Usually, the new method tends to slightly increase the energy used for heating and decrease the energy used for cooling. The latter phenomenon (cooling energy difference) requires that the model be revisited in order to make it more representative of the reality. However, since the cooling energy represents an average of 5% to 15% of the global energy consumption of a typical Canadian building, this energy consumption difference is less critical than the heating component. We should not forget that this method is a work-around that permits the use of DOE2.1E to represent a system that is not currently supported. This means that average values have to be taken instead of real performance curves that could vary performance parameters on an hourly basis and according to

physical data (ex.: ground loop temperature). Other programs like TRNSYS could potentially better represent the reality because of their flexibility and capability to use more correlations. The results in table 2 are taken from the BEPU report generated by DOE2.1E for the *fictional* building located in Montreal:

Table 2: Comparison between EE4 and the Work-around method for GSHP as relates to space heating and space cooling (taken from the DOE2.1E BEPU reports)

EE4 results	Work-around method results
| ```
ENERGY TYPE:     ELECTRICITY
SITE UNITS:          KWH
CATEGORY OF USE
---------------

SPACE HEAT          72047.
SPACE COOL          29553.
PUMPS & MISC        28903.
.
.
.
                 ----------
TOTAL              245365.
``` | ```
ENERGY TYPE:     ELECTRICITY
SITE UNITS:          KWH
CATEGORY OF USE
---------------

SPACE HEAT          75079.
SPACE COOL          26272.
PUMPS & MISC        29206.
.
.
.
                 ----------
TOTAL              245367.
``` |

In table 2, the total energy consumption difference between the two buildings is less than 1 %. In this case, energy use for heating is about 4,2 % higher with the work-around method, but the energy use for cooling is about 11 % lower. As mentioned previously, the latter case needs further work in order to be more accurate. However, 11 % of the cooling energy represents merely 1,3 % of the total building energy consumption. Also in table 2, a slight difference occurs between pump energy consumption in the two cases. As explained in the section *Circulation Pump Consumption,* conventional chilled water and hot water pumps are used in DOE-2 to represent the primary and secondary pump of the central ground-source heat pump system. For the conventional unitary GSHP represented by EE4, only one circulation pump is used to represent all the pumps. This means that an equivalent flow and pressure drop have to be used for this single pump associated with the EE4 GSHP units to represent the two pumps of the central system, leading to a slight energy consumption difference (about 1 %). Considering the numbers of simplifications in the modelling procedures and assumptions used (ex. Constant COP), these numbers seem reasonable for a first phase implementation of this model in EE4.

Table 3 represents the use of an auxiliary gas boiler sized at 30 % of the peak load and the GSHP sized at 70% of the peak load. When the ground-source heat pumps reach their maximum capacity, the boiler kicks in to provide the extra required heating energy. 251 m³ of natural gas (2 640 kWh_{eq}[1]) are used to provide this energy. The new total energy

consumption is 247 297 kWh_{eq}, representing a 0,8 % increase. With the new proposed method for modeling central ground-source heat pumps, it is possible to have a good idea of a cost effective solution considering energy savings and capital cost of the systems.

Table 3: Extract from the DOE2.1E BEPU Report (modeling an auxiliary gas boiler)

```
ENERGY TYPE:     ELECTRICITY   NATURAL-GAS
SITE UNITS:          KWH           M3
CATEGORY OF USE
---------------
SPACE HEAT          74369.          251.
SPACE COOL          26272.            0.
```

Since the model uses some average values (ex.: COP), it is expected that the results will show slight differences when compared to EE4 results using unitary GSHP. However, the overall behaviour of the work-around method is quite satisfactory and the possibility of modeling an auxiliary heating system is very interesting for energy analysis purposes. Further work will include improvement in the determination of the COP to better represent the real operation of GSHP.

IMPLEMENTATION ISSUES IN EE4

GUI Changes

In order to accommodate modeling this new combination system, a new tab has been added to the EE4 Plant dialogue entitled "Combination Ground Source Heat Pump". The fields on this new tab become active only if the user has checked a new checkbox field on the Central Heating Tab of the Plant dialogue entitled "Model a Combination Ground Source Heat Pump". If this field is checked, we also disable all fields on the Central Cooling tab of the Plant dialogue and do not permit the explicit definition of a chiller and chilled-water circulation pumps. Instead, we implicitly define a chiller for the DOE2 proposed file using Cooling capacity and COP characteristics as specified by the user for the ground source heat pump's cooling mode.

When the user models this type of system, the boiler is defined in the same fashion as before from the Central Heating Tab of the Plant dialogue. This boiler is used to represent the backup boiler of the system.

Figure 3 shows the new Combination Ground Source Heat Pump tab of the Plant dialogue along with the various new fields.

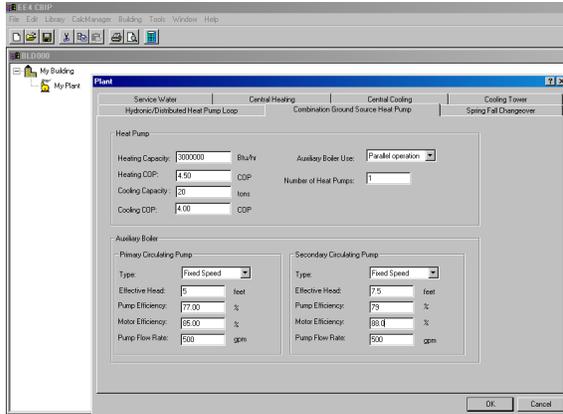[1] Equivalent kWh – conversion factor 10,52 kWh_{eq}/m³

Figure 3: GUI Implementation of the Mode

We allow the auxiliary boiler use to be modeled in either of two operating modes: parallel or alternate operation. With the parallel operation option, the ground source heat pump will initially cycle on to meet the heating load. If the heat pump capacity is insufficient to meet the heating load, then the boiler will kick in to provide supplemental heat in conjunction with the heat pump. With the alternate operation option, the heat pump will initially kick in and if the heat pump capacity is insufficient to meet the heating load, then it will cycle off and the entire heating load will be taken up by the boiler.

The heating and cooling capacities and COP's that we ask for in the Combination Ground Source Heat Pump Tab are not COP values set at ARI conditions. They should be values corresponding to the expected operating conditions of the building (average value corresponding to the average ground temperature of the building location) and according to manufacturers specifications.

For the purposes of the CBIP programme and obtaining associated credits, we ask the user to document the evaluation of the COP. We ask the user to obtain the monthly ground temperatures from the EE4 modeling procedure manual that we compile and maintain with every new release of the EE4 software.

The average heating capacity and COP should be evaluated according to the estimated heating period only. For example, if there is no heating during the summer, the summer monthly ground temperatures should not be used for the evaluation of the average COP. Taking into account these temperature (usually higher than in the winter time) for the annual average value, the heating COP will be higher, leading to higher energy savings. For an EWT (entering water temperature - ground side) variation of 20F, the heating COP of a water-to-water heat pump varies about 25%-30%, depending on model and capacity.
We ask the user to apply the same methodology for the average cooling COP.

For simplicity, we recommend that the user enter one of the RETScreen (http://cetc-varennes.nrcan.gc.ca/en/retscreen.html) derived average COP's based upon the efficiency level of the GSHP (standard efficiency = 2.8, medium efficiency = 3.2, high efficiency = 4.0) based upon ARI 330 testing.

We also allow multiple heat pumps to be defined. It should be noted that the heating capacity and cooling capacity are the capacities of each of the heat pumps.

Issues with the Reference Fuel

Before implementation of this new combo systems feature, EE4 would use the same fuel as the proposed case for the reference building boiler fuel (as selected from the EE4 interface).

Modeling this new combination system added a new complexity. The reference fuel can no longer be assumed to be the same as the boiler fuel in the proposed case. Take, for example, the case where the boiler fuel is selected as natural gas whereas the heat pump is working on electricity. The fuel that should be used for the reference case would have to be the fuel of the system that satisfies the greatest heating load during the year. Would that be the fuel used by the heat pump or the boiler?

In order for us to determine the reference case fuel, we were required to search the PS-D report of the DOE2 results file after the proposed case run to determine which fuel was used most to heat the building. We then added new logic so that the reference boiler fuel could be set based on this comparison.

This new routine was only necessary when the user chose to model a combination ground source heat pump with an auxiliary boiler. If this was not the case, the status quo for selecting the reference heating fuel was maintained.

Issues with Modeling 2 Electric Boilers

Another limitation with the DOE2 simulation engine was encountered when the user chooses to model the ground source heat pump in conjunction with an electric boiler. DOE2 can not properly model 2 electric boilers. Although, the energy consumption is added up correctly, the total costs for electricity use is not added properly. In order to overcome this, we were required to define one of the electric boilers as using "Other" as a fuel source instead of "Electricity". An electricity meter is then attached to this "Other" fuel. This then allows both electric boilers to be modeled in a roundabout way so that all

electrical use is considered in the tallying up of energy costs for electricity.

Testing Issues

As is with the implementation of all new features of significant complexity, we required significant testing to make sure our logic was working as intended with the DOE2 simulation engine. We came across various snags which we had to address. We came across the following snags:

- Ensured that the alternate and parallel operations as specified by the user were translated to the proper DOE-2 BDL syntax under the LOAD-MANAGEMENT command.
- Ensured that reference fuel selection for other system types had not been affected by these combo system-specific changes.
- Ensured that we had not adversely affected how the other 16 HVAC systems were being modeled or that no adverse affects were introduced with the addition of this new feature.
- Ensured that proper performance curves are assigned to the boiler and chiller used to represent the heat pump. The performance curves for the auxiliary boiler were checked to make sure that they were not inadvertently modified.
- It was verified that all user inputs related to the central ground-source heat pump system were properly mapped to the DOE-2 input files. This also included applying the proper part-load correction factors to the nominal heating COP entered by the user.

Future Work

Another use of the GSHP application under consideration for the next version of EE4 is preheating of domestic hot water (DHW). In this case, a similar methodology is used to model the energy consumption of the GSHP. An equivalent boiler is used and the fraction of the energy taken by the GSHP is transferred to the PLANT using the PROCESS-HW-POWER and PROCESS-HW-SCH commands in DOE2.1E. The fraction taken by the GSHP is determined by the temperature at which the water is preheated. The GSHP leaving water temperature usually does not exceed 43°C and the DHW temperature is usually set at about 60°C. The capacity fraction taken by the GSHP is calculated as follows:

$$F = \frac{\left(T_{pre} - T_{in}\right)}{\left(T_{out} - T_{in}\right)} \qquad (2)$$

Where:

T_{pre} is the preheating water temperature (ex.: 43°C)
T_{out} is the final outlet water temperature (ex.: 60°C)
T_{in} is the entering water temperature (ex.: 13°C)

The capacity taken by the GSHP for the preheating of the water is then:

$$P_{gshp} = F \times P_{tot} \qquad (3)$$

Where:
P_{gshp} is the preheating capacity of the GSHP
P_{tot} is the total capacity needed to heat the water from T_{in} to T_{out}

When a central GSHP is used, the preheating of the DHW is accomplished by the same central equipment, modeled as an equivalent electric boiler in the PLANT section. The balance is taken by the conventional DHW heater defined in the SYSTEM section (PLANT-ASSIGMENT).

Similarly when unitary GSHPs are used (conventional approach in EE4), an equivalent electric boiler is added in the PLANT section. The COP and the capacity of this equipment should reflect the heat pump manufacturer's specifications and local ground conditions.

In both cases, the calculated capacity taken by the GSHP (equation 3) is entered in DOE2.1E with the PROCESS-HW-POWER command. The same schedule as the DHW is used and defined with the PROCESS-HW-SCH command.

Since part of the DHW load is taken by the PLANT (preheating with GSHP), the energy consumption in the DOE2.1E BEPU report is divided in two separate sections: SPACE HEAT and DOMHOT WATER. The results shown in table 4 were taken from two different simulations. The first one uses a conventional electric DHW heater and the second uses GSHP preheating:

In this case, the energy savings are 7 015 kWh, representing a 3 % overall energy consumption reduction.

This work-around method was not implemented in the upcoming EE4 release version 1.60 because of a lack of time. However, the next release of EE4 will most probably include it.

Future improvement of the model will require revisiting the calculation of the correction factors for the COP since these factors were derived assuming

that the capacity of the heat pump is equal to the estimated peak load at the lowest temperature in the weather file. Given that a backup boiler is required, this indicates that the heat pump is most probably not sized to meet the peak load. Improving the model will require determining correction factors for different sizes of the heat pump (25% of peak load, 50% of peak, etc.). The peak load calculation procedure in EE4 would then be used to determine the best correction factor to apply for the COP.

Table 4: Example of DHW preheated by a GSHP (DOE2.1E BEPU reports)

Without GSHP preaheating		With GSHP preheating	
ENERGY TYPE :	ELECTRICITY KWH	ENERGY TYPE : SITE UNITS :	ELECTRICITY KWH
CATEGORY OF USE		CATEGORY OF USE	
---------------		---------------	
AREA LIGHTS	50790.	AREA LIGHTS	50790.
MISC EQUIPMT	6221.	MISC EQUIPMT	6221.
SPACE HEAT	111744.	SPACE HEAT	116288.
SPACE COOL	9044.	SPACE COOL	9044.
PUMPS & MISC	4247.	PUMPS & MISC	4263.
VENT FANS	18508.	VENT FANS	18508.
DOMHOT WATER	31992.	DOMHOT WATER	20416.
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TOTAL	232545.	TOTAL	225530.

CONCLUSION

The implementation of the Combo System Model in EE4 CBIP approximates the central ground source heat pump in heating mode by modeling an electric boiler using an adjusted COP (EIR) and a conventional chiller in cooling mode using a zero-consumption air type condenser.

The backup boiler could be electricity or fuel-fired. In the case of electricity, a DOE2.1e constraint required us to apply a workaround to properly tally up electrical energy costs.

The model was validated by comparing its predictions to a conventional unitary heat pump system. This validation procedure was repeated for 5 different Canadian cities: Montreal, Edmonton, Halifax, Toronto and Vancouver with very good agreement between the results for the two systems.

For compliance-checking purposes, it was necessary to ensure that the reference case fuel was the fuel which was used most for heating in the proposed case. The original procedure was to use the same boiler fuel for both proposed and reference cases. The fact that two possible fuel types would be possible for the boilers in the proposed case made it necessary to use this new methodology.

Extensive testing was carried out to make sure that no adverse affects were introduced into the proper modelling of the conventional unitary ground source heat pumps or the 16 different HVAC systems already supported by EE4.

Future work in EE4 will focus on integration of the central GSHP with domestic hot water systems and revisiting calculation of correction factors for COP.

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