HEATSTORE

Validation report of system integration modelling

Prepared by: Mariëlle Koenen, TNO
Can Tümer, TNO
Charlotte Rey, Storengy
Geoffroy Gauthier, PlanEnergi

Checked by: Mariëlle Koenen, TNO
Marc Perreaux, Storengy, WP5 lead

Approved by: Holger Cremer, TNO, HEATSTORE coordinator

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HEATSTORE (170153-4401) is one of nine projects under the GEOTHERMICA – ERA NET Cofund aimed at accelerating the uptake of geothermal energy by 1) advancing and integrating different types of underground thermal energy storage (UTES) in the energy system, 2) providing a means to maximise geothermal heat production and optimise the business case of geothermal heat production doublets, 3) addressing technical, economic, environmental, regulatory and policy aspects that are necessary to support efficient and cost-effective deployment of UTES technologies in Europe.

This project has been subsidized through the ERANET cofund GEOTHERMICA (Project n. 731117), from the European Commission, RVO (the Netherlands), DETEC (Switzerland), FZJ-PtJ (Germany), ADEME (France), EUDP (Denmark), Rannis (Iceland), VEA (Belgium), FRCT (Portugal), and MINECO (Spain).

About HEATSTORE

High Temperature Underground Thermal Energy Storage

The heating and cooling sector is vitally important for the transition to a low-carbon and sustainable energy system. Heating and cooling is responsible for half of all consumed final energy in Europe. The vast majority – 85% - of the demand is fulfilled by fossil fuels, most notably natural gas. Low carbon heat sources (e.g. geothermal, biomass, solar and waste-heat) need to be deployed and heat storage plays a pivotal role in this development. Storage provides the flexibility to manage the variations in supply and demand of heat at different scales, but especially the seasonal dips and peaks in heat demand. Underground Thermal Energy Storage (UTES) technologies need to be further developed and need to become an integral component in the future energy system infrastructure to meet variations in both the availability and demand of energy.

The main objectives of the HEATSTORE project are to lower the cost, reduce risks, improve the performance of high temperature (~25°C to ~90°C) underground thermal energy storage (HT-UTES) technologies and to optimize heat network demand side management (DSM). This is primarily achieved by 6 new demonstration pilots and 8 case studies of existing systems with distinct configurations of heat sources, heat storage and heat utilization. This will advance the commercial viability of HT-UTES technologies and, through an optimized balance between supply, transport, storage and demand, enable that geothermal energy production can reach its maximum deployment potential in the European energy transition.

Furthermore, HEATSTORE also learns from existing UTES facilities and geothermal pilot sites from which the design, operating and monitoring information will be made available to the project by consortium partners.

HEATSTORE is one of nine projects under the GEOTHERMICA – ERA NET Cofund and has the objective of accelerating the uptake of geothermal energy by 1) advancing and integrating different types of underground thermal energy storage (UTES) in the energy system, 2) providing a means to maximize geothermal heat production and optimize the business case of geothermal heat production doublets, 3) addressing technical, economic, environmental, regulatory and policy aspects that are necessary to support efficient and cost-effective deployment of UTES technologies in Europe. The three-year project will stimulate a fast-track market uptake in Europe, promoting development from demonstration phase to commercial deployment within 2 to 5 years, and provide an outlook for utilization potential towards 2030 and 2050.

The 23 contributing partners from 9 countries in HEATSTORE have complementary expertise and roles. The consortium is composed of a mix of scientific research institutes and private companies. The industrial participation is considered a very strong and relevant advantage which is instrumental for success. The combination of leading European research institutes together with small, medium and large industrial enterprises, will ensure that the tested technologies can be brought to market and valorised by the relevant stakeholders.

1 Introduction

Models are per definition simplifications of the systems that they represent. Model validation is the process of comparing the predictions to real world observations, and it is needed to confirm that the predictions are as accurate as needed for their purpose. If a model is not as accurate as needed, the model needs to be calibrated. Calibration (or model matching) implies the adaptation of model parameters to improve the comparison between model prediction and observations in an iterative approach.

The intention of the current report was to validate the system integration models developed in work package 3 of the HEATSTORE project using monitoring data from the demonstration sites. Unfortunately, the demonstration sites are not as advanced yet. Only one of the sites for which system integration modelling has been performed has become operational within the timeframe of the HEATSTORE project, which is the Dutch HT-ATES site in Middenmeer, The Netherlands. But even for this site, monitoring data relevant for the model validation is not yet available. The current report therefore describes the intended validation methodology for each of the demonstration sites.

2 HT-ATES case study in The Netherlands – Middenmeer

2.1 HT-ATES description

At Agriport in Middenmeer, the Netherlands, the HT-ATES system to serve the heat network for the greenhouse horticulture has become operational in the spring of 2021. The HT-ATES stores geothermal heat from three deep geothermal systems in the summer, to be produced in the winter. A schematic overview of the network is shown in Figure 2.1. For a more detailed description of the use case definition, as well as the modelling details and results please refer to Allaerts et al. (2021).

Figure 2.1 a) Schematic overview of the heat network, with the locations of the geothermal sites, the biomass plant, the HT-ATES wells and the heat pump; b) coupling of HT-ATES to the greenhouses.

2.2 Model validation

2.2.1 CHESS – HT-ATES (proxy) Model

2.2.1.1 Description

As described in Allaerts et al. (2021), the HT-ATES system was included as a proxy model for the Middenmeer demonstration site in the system integration model code CHESS. The proxy CHESS HT-ATES model uses coefficients that are tuned ("model matching") to mimic the results of a more sophisticated simulation model from DoubletCalc3D on the HT-ATES system. With this proxy model, CHESS is fed with heat produced from the ATES system using a pre-set loading and unloading scheme.
More recently, in the Dutch WarmingUP research programme (www.warmingup.info), a direct coupling between CHESS and DoubletCalc3D was realised. The direct coupling allows the (simulated) management of the HT-ATES operations (loading and unloading of the system) by the external heat supply and demand simulations in CHESS instead of the pre-set scheme. This is highly beneficial in the conceptual design phase of a heat network with HT-ATES as flexible component.

The model simulations were performed with the proxy model using a pre-set loading and unloading scheme. The real life operational scheme is based on the heat availability and is different from the pre-set scheme. For model validation purposes, the CHESS-ATES simulation, either with the ATES proxy model or the coupled CHESS-DoubletCalc3D model, should be performed again, based on the actual scheme.

2.2.1.2 Required Measurement Data

The HT-ATES model as part of the heat network needs to be validated by the volumes and temperature of the water going in and out of the aquifer. In Figure 2.2, the locations of the proposed temperature (TT) and flowrate (FT) transmitters are shown on the ATES side flow lines. Temperature sensors should ideally be located as close as possible to the respective wells for model validation purposes.

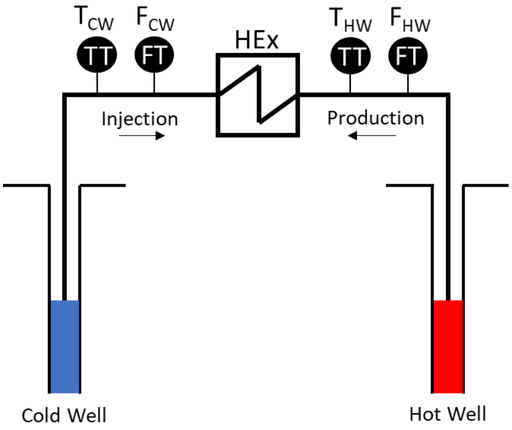


Figure 2.2. Illustration of measurement locations.

The predicted production temperatures of the ECW Middenmeer ATES model indicate a large variation over time and are integrally dependent on the previous injection rates and temperatures. Therefore, the proposed temperature and flow measurements are recommended to take place during at least 1 injection and production cycle. At the site, both flow and temperature measurements are taken every 10 seconds. This is more than sufficient for model validation purposes. Essentially, a sampling rate of once per hour would be sufficient and it would be easier for data handling.

2.2.1.3 Model Validation

New simulations should be performed using the actual operational scheme of the system. The actual scheme is very different from the scheme used in the design phase of the system, and appears to be highly dependent on the heat demand in summer and hence on the weather conditions. Relatively cold weather in summer results in higher heat demand and hence less heat for storage than predicted. Since the actual scheme will be input to the model (pre-set) for validation purposes, either the proxy model or the directly coupled model can be used. Yet, since the directly coupled model will be used in the future for conceptual design purposes, it is advised to use this model from now on.

Note that the hydrothermal model validation of the HT-ATES system itself is reported in Diaz-Maurin and Saaltink (2021) and is based on distributed temperature sensors (DTS) within the monitoring well.

For reference, please see the model validation effort of the proxy model vs. the hydrothermal model in DoubletCalc3D presented in D 3.3.

2.2.2 CHESS - Flow and Thermal Solver

2.2.2.1 Description

For the validity of the constructed CHESS flow-thermal model, the following technical aspects should be assessed;

1. Pressure drop in the piping system : This gives an indication on the accuracy of the predicted flow and pressure field. The assumed pipe roughness for the piping is a major contributor to the (in)accuracy of the prediction.
2. Thermal loss in the system : This gives an indication on the accuracy of the predicted temperature field. The assumed insulation value for the piping is a major contributor to the (in)accuracy of the prediction.

2.2.2.2 Required Operational Conditions

Both pressure drop and thermal losses are coupled to the flowrates in the system and the largest values of pressure drop and thermal losses will originate from the largest and smallest flowrates in the system, respectively. Hence, it is advised to conduct the pressure drop measurements during high load hours/days (winter daytime) and the thermal loss (temperature drop) measurements during the low load hours/days (summer night time). For the ECW Middenmeer case, these conditions take place during January and July respectively.

System solutions, presented in Allaerts et al. (2021), indicate an ideal flow controller to be present in the system during the entire year; flowrate in the system is linearly coupled to the consumer demands such that the temperature difference (deltaT = 85 °C – 33 °C = 52 °C) over the consumers remain the same. It should be noted that any variation from this control strategy could generate differences between the simulations and measurements, especially for cases with lower loads (summer time). In order to also account for the influence of the control strategy, flowrate measurements are also proposed in section 2.2.2.3.

2.2.2.3 Required Sensor Data

At maximum capacity, the maximum pressure drop over the entire system will be dictated by how much flowrate is being fed to the critical (most distant) consumer, Helderman, seen in Figure 2.3. For the pressure drop measurements, one could think of two different measurement approaches;

1. Pressure transmitters up- and downstream the main supply pump near the geothermal wells,
2. Pressure transmitter downstream the main supply (circulation) pump combined with a pressure transmitter at the arrival to the critical consumer (upstream the differential pressure control valve).

The difference between the pressure readings in option (1), will provide the total pressure drop over the system (i.e. total pump head, as denoted in Figure 2.3) and will be the sum of pressure loss over the supply and return pipelines leading to the critical consumer as well as the differential pressure control valve setting at the consumer (usually a value of 0.2 to 0.5 bar). The alternative, option (2), will provide the pressure loss over the supply line. These instantaneous pressure readings should be combined with a flow reading at the supply lines and should be executed when flowrates in the system are stable (less than ± 1% fluctuation in 5 minutes).

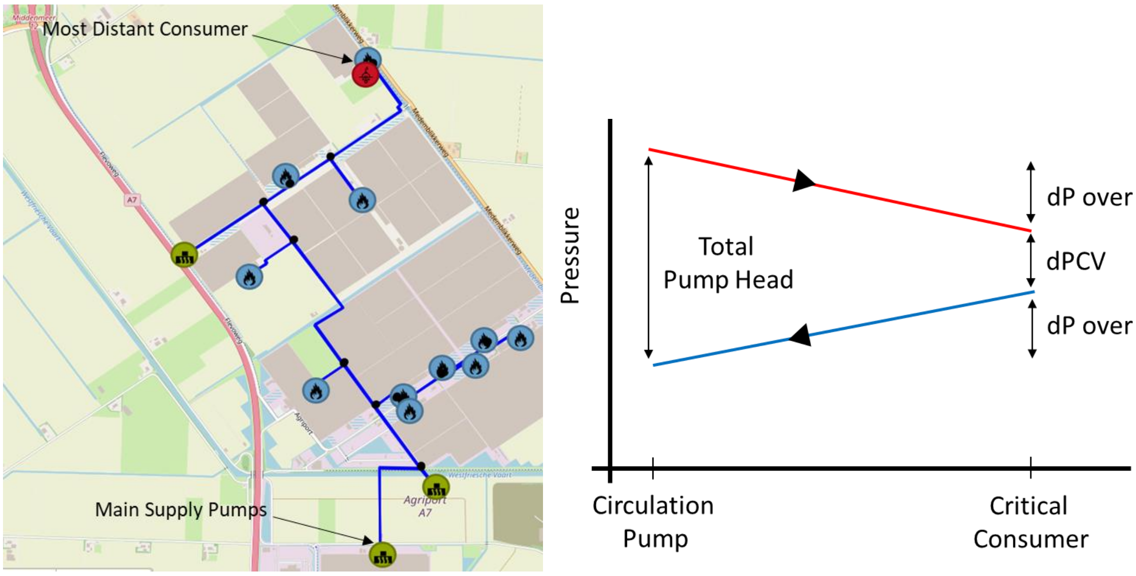


Figure 2.3. The flow system in ECW Middenmeer and the evolution of the pressure drop over the pipelines.

For the temperature drop measurements, a temperature transducer should be used at the outgoing (supply) pipe at the Geothermal wells and another one at the arrival of this supply line at the distant consumer. The temperature drop readings should ideally be done at the same time along with the pressure/flow measurements after the temperatures reach stable levels (less than ± 1% fluctuation in 5 minutes).

2.2.2.4 Model Validation approach

As mentioned, the flow thermal solver should be validated at two different time periods; winter (January for ECW Middenmeer) during daytime (highest thermal loads) and summer (July for ECW Middenmeer) during night time. These two periods will provide the largest and smallest pressure drops and thermal loses over the system. CHESS results of ECW Middenmeer are listed for these time periods in Table 2.1. Note that these values need to be updated after new simulations with the actual HT-ATES operational scheme have been performed.

For reference, please see the model validation effort (vs. measurements done with the DCS system of ECW Middenmeer vs. CHESS results), presented in Allaerts et al. (2021).

Table 2.1. CHESS simulation results of the system.

Time	**Total Consumption in Heat Grid** [MW]	**Flowrate to Helderman** [m^3/hr]	**Total Pump Head** (except dPCV) [bar]	**Temperature Drop** (Geothermal wells to Helderman) [°C]	**Tsoil** [°C]
January	31.7	42.44	6.23	1.33	5.3
July	4.74	8.05	0.194	6.56	17.1

Defining a general criterion on the magnitude of allowed deviations between simulations and measurements is not straightforward. Such criteria can only be case-specific and must keep the interests of the stakeholders in mind. For instance, while operating with similar overall demands and flowrate (2nd and 3rd columns of Table 2.1), deviations of total pump head (simulations vs measurements, 4th column of Table 1) will affect operational costs of the supply pumps linearly. Similarly, deviations of temperature drop (simulations vs measurements, 5th column of Table 1) will affect the amount of heat production linearly (and in turn the costs of the supply pumps). Hence, the overall error should be judged based on how much error could be allowed on certain key performance indicators, e.g. operating expenditure or heat loss.

Furthermore, as was mentioned in section 2.2.2.1, roughnesses and insulation values of the piping could be used to calibrate the flow prediction (pressure drop) and the thermal prediction (temperature drop), respectively.

3 PTES case study in Denmark – Dronninglund

3.1 Case study description

For a detailed description of the complete energy system in Dronninglund, please refer to Gauthier (2021).

The main elements of the district heating system of Dronninglund, as of 2021, are the following:

- A thermal solar collector field of 37,500 m^2 (gross area).
- A 60,000 m^3 water volume Pit Thermal Energy Storage (PTES) system.
- 4 gas engines, for a total capacity of 3.6 MW_{th}.
- 2 gas boilers for a total capacity of 11 MW_{th}.
- A 10 MW_{th} bio-oil boiler.
- A newly installed 5.5 MW_{th} (heating capacity) air-water heat pump, that can also cool down the PTES.

Locations of the solar heating part of the system (including the PTES) and of the heat pump are shown in Figure 3.1.

The solar heating system of Dronninglund was implemented in 2 phases. The first phase was implemented in 2014 and consisted of the solar collector field, the PTES and an absorption heat pump. The auxiliary heat production units already installed were 4 gas engines and a bio-oil boiler, respectively with a capacity of 6 MW_{th} and 10 MW_{th}. The air-water electrical heat pump was later installed, in 2021, after decommissioning of the absorption heat pump. The PTES has been in use since March 2014.

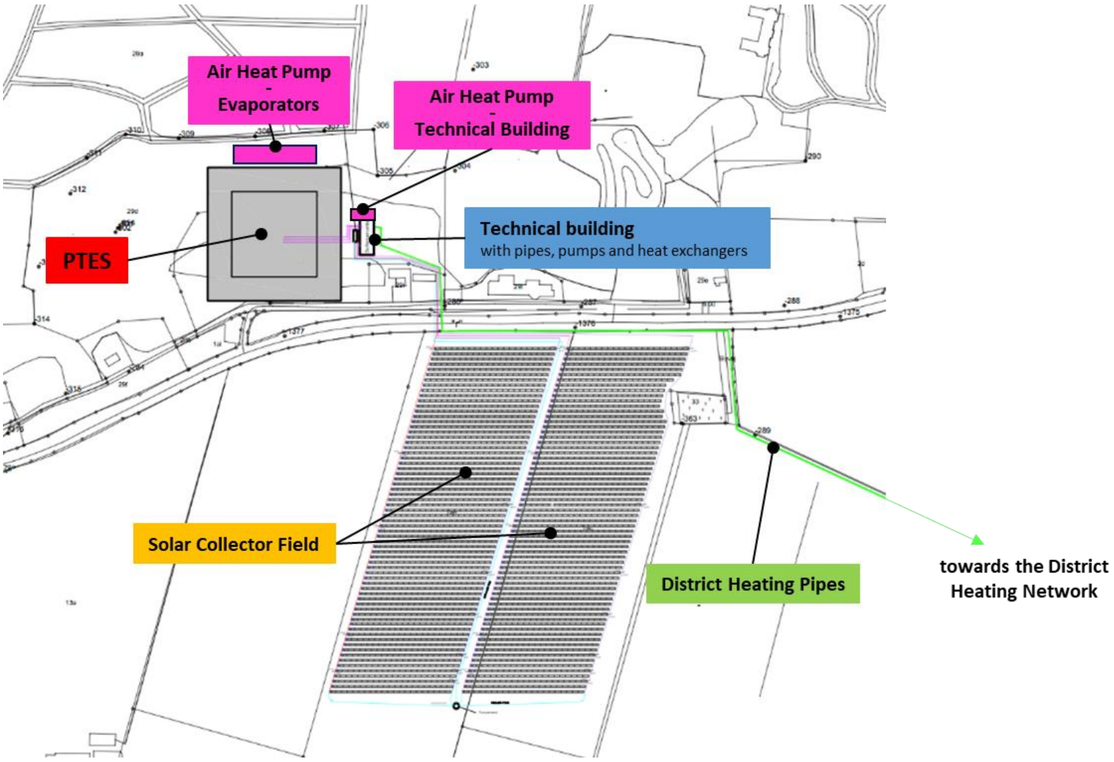


Figure 3.1. Schematic aerial view of the solar and heat pump part of the heating system in Dronninglund.

3.2 System integration model

The software program TRNSYS has been chosen for system modelling of the current heating system of Dronninglund. TRNSYS is an Energy System Simulation (ESS) software used to simulate the behaviour of transient systems. It contains a library of energy systems components (pumps, valves, pipes, solar collectors, heat pumps, wind turbines and photovoltaic panels) and an engine (also called kernel) capable of solving the system energy balance, based on how components are connected with each other, iteratively for each given timestep. In TRNSYS the timestep goes from one hour down to one millisecond.

This tool is ideal for system calculations involving underground storage as it can include very detailed models for each component and will solve the interaction between all components. It can for instance model accurately the performance of PTES or BTES systems including heat exchange to the soil and the air, and thus provide realistic results for heat losses, temperatures inside the storage, charge and discharge efficiencies, etc. It has been used by PlanEnergi in the past to make system design calculations (see Gauthier (2021)) as well as heat storage modelling validation against measurements (see Gauthier (2020)).

Generally speaking, the more the model runs automatically, using fixed control strategies, the more flexible and realistic it should be, because it will not be influenced by measurement uncertainties and errors. This being said, it would be interesting to compare the results obtained with a model running mostly on fixed control strategies and another one running mostly on measured parameters.

PTES-Type 1300 & 1301 (TESS library)
Knowledge of the geometry of the PTES, together with the results from the calibration study carried out in Gauthier (2020) enable a realistic modelling of the PTES in TRNSYS. The most adequate component for that matter would be, as concluded in Gauthier (2020), Type 1300 and 1301, developed by TESS, with the appropriate geometry (see Figure 3.3) and calibration parameters. This component is the combination of two Type, one modelling the water part of the storage (Type 1300) and the other modelling the soil part of the storage (Type 1301). The storage water is modelled as 1D (see Figure 3.4) and the soil domain as 2D. Type 1300+1301 approximates the inverted truncated pyramid geometry of the PTES in Dronninglund with an inverted truncated cone geometry (axial symmetry, see Figure 3.2).

Main geometry parameters for the PTES TRNSYS model (shown in Figure 3.4) are the following:
- R_{ext}: insulation extension length over the soil next to the storage.
- R_{far}: distance of the conductive soil boundary condition to the insulation extension end.
- R_{top}: radius of the top of the truncated cone.
- R_{bot}: radius of the bottom of the truncated cone.
- D_{depth}: depth of the buried storage (0 if storage not buried, which is the case in Dronninglund)
- Height: water depth of the storage
- D_{deep}: depth of the conductive soil boundary condition underneath the bottom of the storage.

The energy balance and temperatures inside the storage and in the soil surrounding the storage are solved at each timestep using the finite difference method. For the details regarding the setup of this component, please refer to Gauthier (2020).

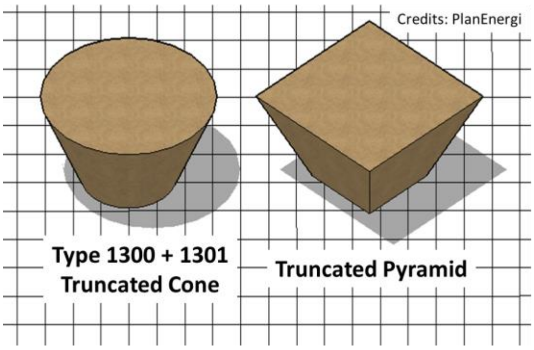


Figure 3.2. Heat storage geometry used by the TESS component “Type 1300+1301” compared with actual geometry of the PTES in Dronninglund.

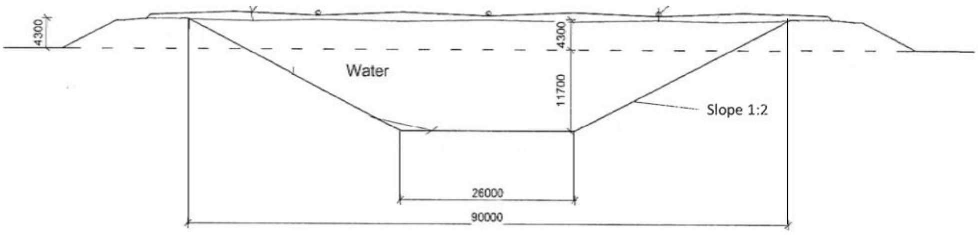


Figure 3.3. Main geometry parameters of the PTES in Dronninglund.

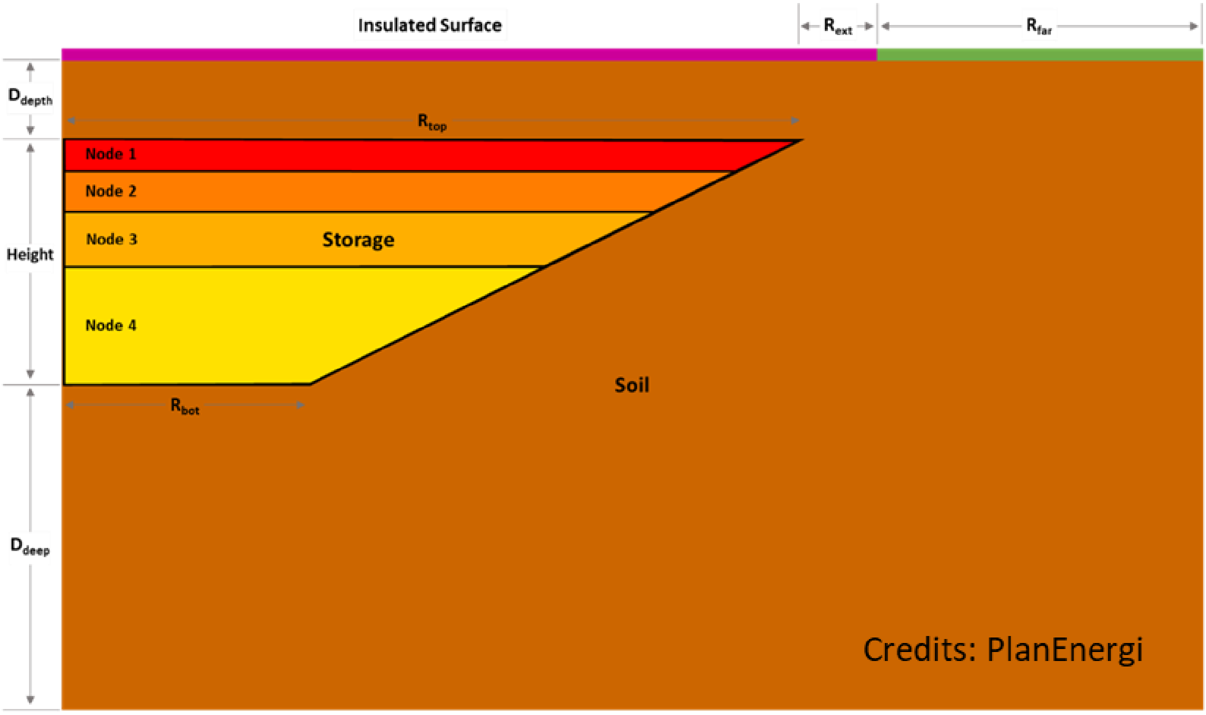


Figure 3.4. Main parameters used by Type 1300 & 1301, example of implementation with 4 water nodes for the water domain discretization.

Control strategy of the PTES could be fixed and enable most encountered operations modes of the actual PTES, but also be able to run based on measured flows. For instance, for simplification reasons, a fixed control strategy has often been set the PTES to receive all the heat produced by the solar collector field, and solar heat is, in this case, exclusively discharged from the PTES (see Figure 3.5). But it is also possible to implement in the model a mode in which the solar heat bypasses the PTES, or partially charges the PTES and is partially sent to the district heating network (see Figure 3.6). These different control strategies in the model (with or without PTES bypass option) could be tested and it would be interesting to see which ones provide the system energy balance closest to the measurements, with the heating contribution of each element. The “best” behaving model would be the one where yearly contribution of the solar collector field, the heat pump, the PTES and the auxiliary heaters are closest to the measured yearly contribution of those heat sources. For the PTES, the heat charged into and discharged from the PTES would ideally be as close as possible to the measured charged and discharged heat, as well as the heat losses.

Another modelling option is to run the model operating the PTES based exclusively on measured flows coming into and out of the PTES. This method is, however, more uncertain as the measurements can be flawed, but could be investigated and compared with a fixed control strategy.

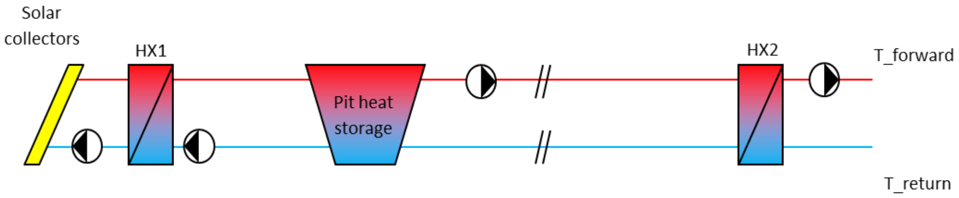


Figure 3.5. Principle diagram of a simplified solar loop model, where all solar heat produced goes to the PTES.

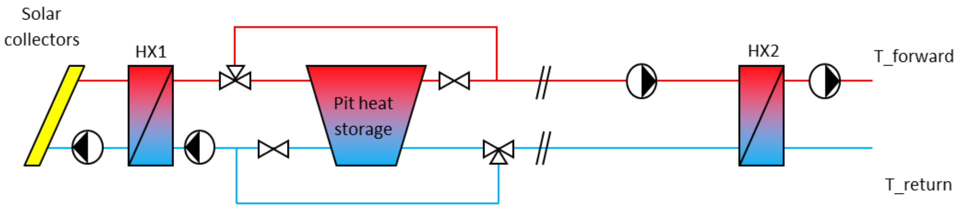


Figure 3.6. Principle diagram of a more detailed solar loop model, with an option to send solar heat directly to the district heating network.

Solar collector field-Type 1290 (TESS library)

Type 1290 is a component for solar collectors developed by TESS. It models accurately the thermal performance of a flat plate solar collector, using all known parameters from the installed solar collectors: optical parameters (η0, a1, a2, b0, b1), thermal properties (collector capacitance and fluid heat capacity), arrangement (number of collectors in series, orientation, slope). This component uses as inputs:

- Ambient air temperature (dry bulb temperature).
- Sky temperature (can be calculated based on ambient air temperature).
- Inlet temperature (provided from the solar heat exchanger, another component of the model).
- Inlet flowrate (see pump description below).
- Beam radiation on the tilted surface.
- Sky diffuse radiation on the tilted surface.
- Ground diffuse radiation on the tilted surface.

This component would be used together with the weather data (see following section) to calculate the heat produced by the solar collector field. It can be used with an external pump component, which can be easily modelled by a user-input equation block (a set of user-input equations). The pump would be implemented with given temperature target levels and the possibility to cool down the storage at night if the top PTES temperature exceeds a given threshold. The solar collectors should be linked to the PTES, but also enable a direct connection to the district heating network grid.

Air-water heat pump

The heat pump could be modelled from an equation block, giving the COP as a function of inlet temperatures. This information can be extracted from the technical datasheet of the heat pump. Since the heat pump can run both on air and on the PTES as a heat source, a fixed control strategy should also be implemented in the model and match the actual control strategy chosen for the implemented heat pump.

Pipes and heat exchangers

For pipes and heat exchangers connecting the solar heating system to the main district heating system (gas engines, gas boilers, bio-oil boilers, district heating pipes), standard TRNSYS components can be used.

Main district heating system

Gas engines, gas boilers, bio-oil boilers, and heat consumption (or load) in the district heating network can be divided into two groups: a first group would consist of the auxiliary heat sources, and another group of the heat consumption of the network together with the forward/return temperatures from the district heating network.

A control strategy should be established and based on the availability of the heat originating from the gas engines, gas boilers and bio-oil boilers. This could be achieved as a first step by establishing realistic and fixed control rules, and a second step could consist of determining the use of each heat source on measurements. The main role of the auxiliary heat sources is to increase the temperature of the water coming from the solar heating system to the required forward temperature.

For the heat load, either predicted values or actual measurements can be used as inputs to the model, depending on the status of the energy system; design or operational.

The main system components are shown in the schematic diagram in Figure 3.7.

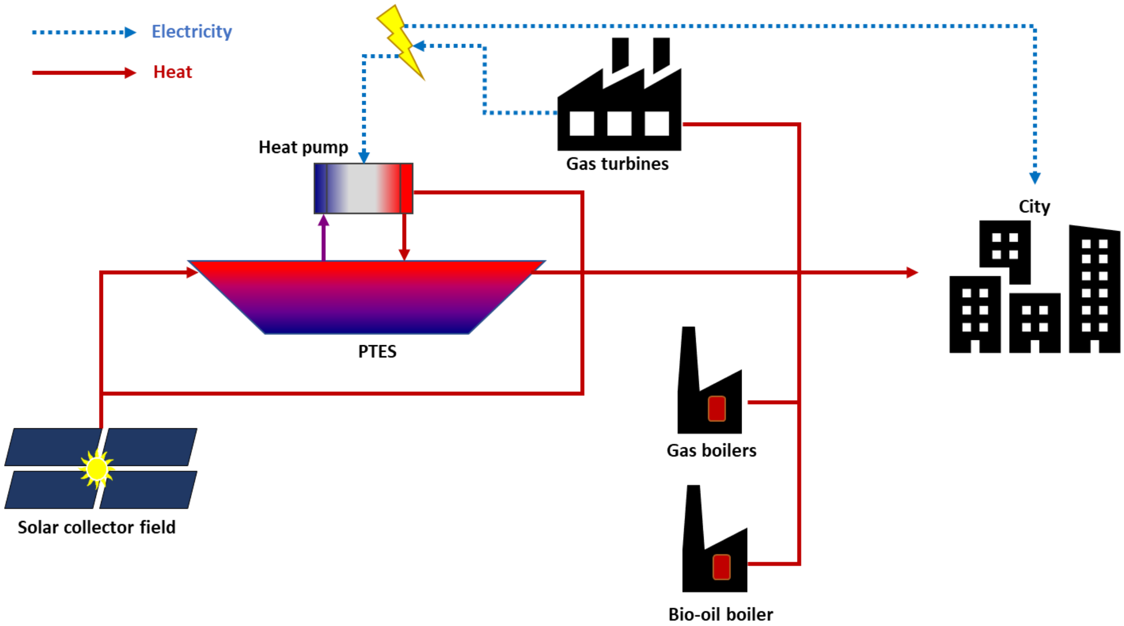


Figure 3.7. Schematic showing the main elements of the system model for Dronninglund and which elements they can deliver heat (and electricity) to.

3.3 Model validation approach

3.3.1 Required data

As mentioned above, validation of the model could be achieved in two successive steps. The first one consists in running the model with only the necessary inputs (weather data, heat demand profile) and let the fixed control strategies run the model. This step provides valuable information about how close a system design model can get compared with actual operations of the system. With measured data used as inputs, then the difference between design heat balance and measured heat balance can no longer be attributed to the difference in boundary conditions. For instance, in Gauthier (2021), design system calculations for Dronninglund have been compared with measured system energy balance. A satisfying accordance was found between the two, but the total heat demand used in the model, as well as the total solar radiation were much higher than what was measured during the first years of operation of the system. This difference is possibly due to the difference in boundary conditions, but it is impossible to know how much that plays in the observed difference.

Then a second step would make use of as many inputs as possible and see if the annual energy balance corresponds to the measurements. This second step enables validation of the modelled system energy balance, when provided with real-condition inputs. The first step requires fewer data inputs (only the necessary inputs, see below).

Then, system model validation can be done on two different levels of details:

- A first level which is overall energy/heat balance of the system.
- A second level where each component is more carefully studied, including operating temperatures.

The second level of detail can help understand what makes the model more or less close to the measurements. It can be used for example to compare the temperatures inside the PTES, the COP of the heat pump for different operating conditions, or the yield of the solar collector field for different irradiation and air temperature conditions. In this sense, the second level of detail is much more cumbersome, and would probably not be carried out entirely in practice. It also requires the model to use a larger amount of data inputs (second step described above).

Table 3.1 illustrates the different model validation steps and the kinds of model validation achievable with these steps.

Table 3.1. Different simulation steps and corresponding possible levels of detail for model validation.

Simulation step	Overall energy balance model validation	Individual component model validation
1- Running model with only necessary inputs	Yes	No
2- Running model with measured flowrates and temperatures	Yes	Yes

3.3.1.1 Input data

For the model to run, a minimum (and necessary) amount of input data is required. The solar collector field, the PTES and the heat pump need meteorological conditions, and the load from the district heating network requires forward and return temperatures, as well as a flowrate (or a power heat load which can be translated into a flowrate). This data is required for the simulation referred to previously as "first step".

Ideally, to validate the model, these inputs should come from measurements, and can be fed to the TRNSYS model. This is illustrated in Figure 3.8. The inputs should have a maximum timestep of 1h, and if not should be interpolated to provide hourly values, since TRNSYS cannot calculate with longer timesteps.

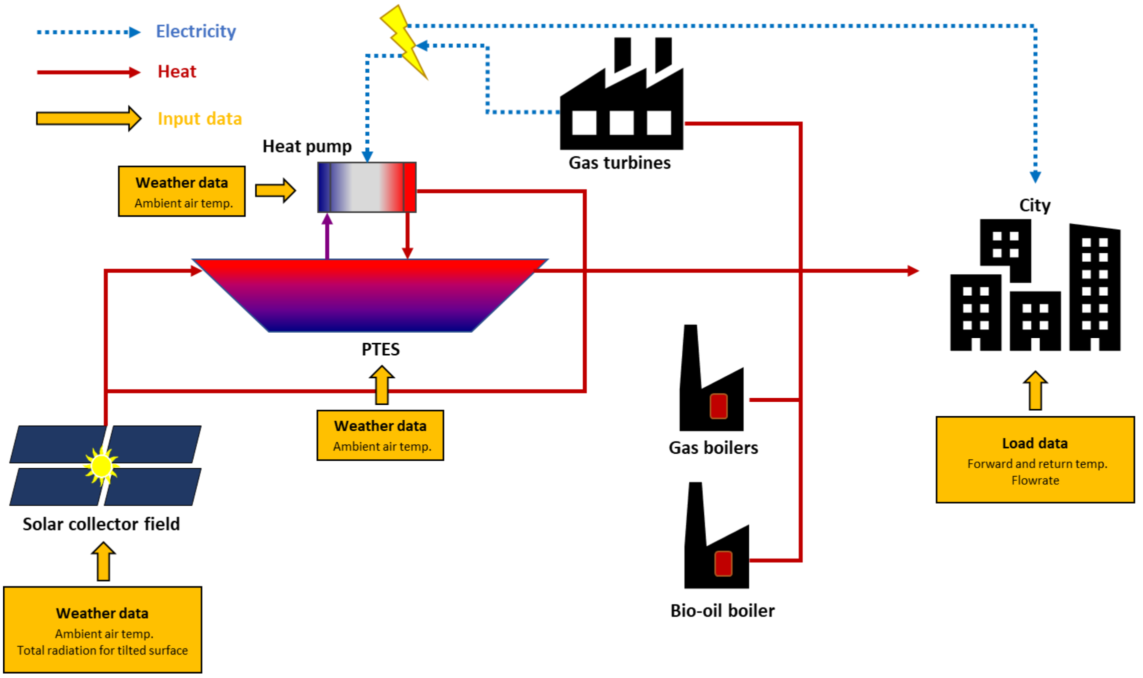


Figure 3.8. Schematic showing the main elements of the system model for Dronninglund and which elements they can deliver heat to, together with their necessary input data.

Then, the model can run with more inputs (temperatures and flowrates for different components), and this "second step" would enable to study the model with even more realistic conditions, but not necessarily provide better results compared with measured system energy balance, because measured data contains inaccuracies that can cause inaccuracies in the heat balance of the system. This effect has been observed using data for model validation in Gauthier (2020) and Diaz-Maurin and Saaltink (2021) for the PTES in Dronninglund.

3.3.1.2 Data required for validation of overall system energy balance

As a first level of detail, we would validate the overall energy balance of the system. To do this, we would need to calculate the amount of heat produced or consumed by each element of the system, as well as the heat losses of the system.

For the gas turbines, the gas boilers and the bio-oil boilers, knowledge of the amount of heat delivered to the grid should be gathered.

For the solar collector field, knowledge of the amount of heat produced and where it is sent to (whether the heat is sent to the PTES only, the grid only, or both) should be gathered.

For the PTES, charged and discharged energy should be gathered, together with the energy content, in order to evaluate the heat losses.

For the heat pump, the amount heat delivered at the condenser, the energy absorbed (and from which source, whether it is air or water from the PTES) at the evaporator and the electricity consumption should be gathered.

Ideally, measurements should be obtained for each hour (if possible) and then summed. Table 3.2 gives an overview of all the necessary information for model validation in terms of overall system energy balance.

Table 3.2 also presents the information which could be used for a more detailed validation of the model, where each component is studied in more detail, using more inputs for the simulation (see description in Table 3.1).

The extra/optional inputs can also be used, as mentioned in section **Error! Reference source not found.**, to study how t he model runs with measured flowrates and temperatures for various individual components and compare the overall system energy balance results obtained when running the model with and without those inputs (see Table 3.1).

Table 3.2. List of the required data for model validation, and the different level of detail required.

Component(s)	Measurement	Required for overall system validation	Required for detailed system validation
Gas turbines Gas boilers Bio-oil boilers	Heat delivered to the District heating network (DHN)	Yes	Yes
	Flowrates		Yes
	In/outlet temp.		Yes
Gas turbines	Electricity produced		
Heat pump	Heat delivered to the DHN	Yes	Yes
	Heat taken from the air		Yes
	Heat taken from/sent to the PTES	Yes	Yes
	Electrical consumption		Yes
	Evaporator in/outlet temp.		Yes
	Evaporator flowrate		Yes
	Evaporator mode		Yes
	Condenser in/outlet temp.		Yes
	Condenser flowrate		Yes
Solar collector field	Heat delivered to the DHN	Yes	Yes
	Heat delivered to the PTES	Yes	Yes
	Flowrates		Yes
	In/outlet temp.		Yes
PTES	Heat delivered to the DHN	Yes	Yes
	Heat received form the SCF	Yes	Yes
	Heat received from/sent to the heat pump	Yes	Yes
	Internal energy content	Yes	Yes
	Flowrates		Yes
	In/outlet temp. for each in/outlet pipe		Yes

3.3.2 Model validation

For model simulation, two steps have already been described: a first step with a minimum number of inputs used for the model, and a second step where most components run based on measured data inputs. In the first step, the model runs based on fixed control strategies (and not actual operations data).

On the first step, Gauthier (2020) and Gauthier (2021) present the comparison between system design calculations and the monitoring results from the first year of operation of the early heating system in Dronninglund. The two, although in the same order of magnitude, are quite far from each other (20% underestimation of the solar heating contribution), which can be explained by:

- The use in the model of typical meteorological year weather data, which differs significantly from the weather conditions observed in 2014 in Dronninglund.
- A yearly heat load of 36,170 MWh while design parameters were set to 40,000 MWh.
- The PTES had to be cooled down because the CHP had a lot of operating hours in the spring of 2014, which means that the PTES wasn't discharged as much as it was supposed to, resulting in extra heat losses.
- The model assumes a simplified charge/discharge of the PTES (as in Figure 3.5), where the actual system has the possibility of sending solar heat directly to the district heating network (as in Figure 3.6).

Validation should be done over one year of measured data, and with measured data used as inputs. Since the PTES model is initialised at the start of the simulation with a non-preheated soil, the simulation time should be more than one year (to leave time for the PTES component to heat up the soil around it, and start with the proper initial conditions). This could be achieved by using historical measurement data as inputs to the charge/discharge of the PTES for the first years of simulation. Only the last year would be used for comparison with measurements.

The validation procedure is illustrated in Figure 3.9, in the case of the first simulation step (use of necessary measurements as inputs to the model). Valid input data for the PTES operations can be retrieved as far as 2017, and could be used to make 3 years of preheating calculations on the PTES. Reliable system energy balance measurements are also available from 2017, but since the PTES would not be properly preheated in the model, year 2020 should be used alone for model validation.

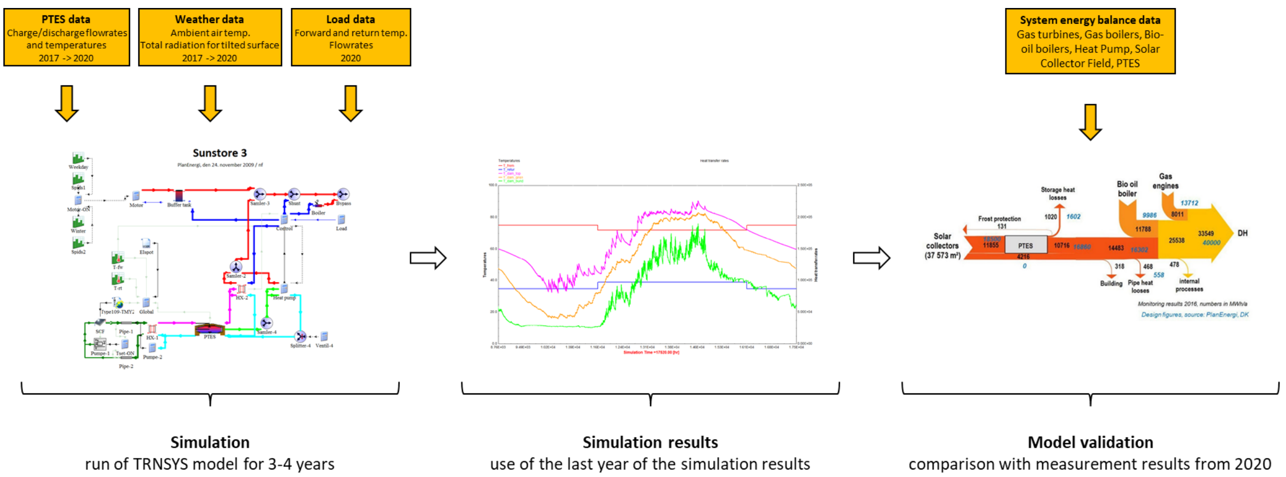


Figure 3.9. Graphical representation of the model validation procedure (pictures extracted from Gauthier (2021)).

Based on the results from a first simulation with the TRNSYS model, the same procedure could be repeated using:

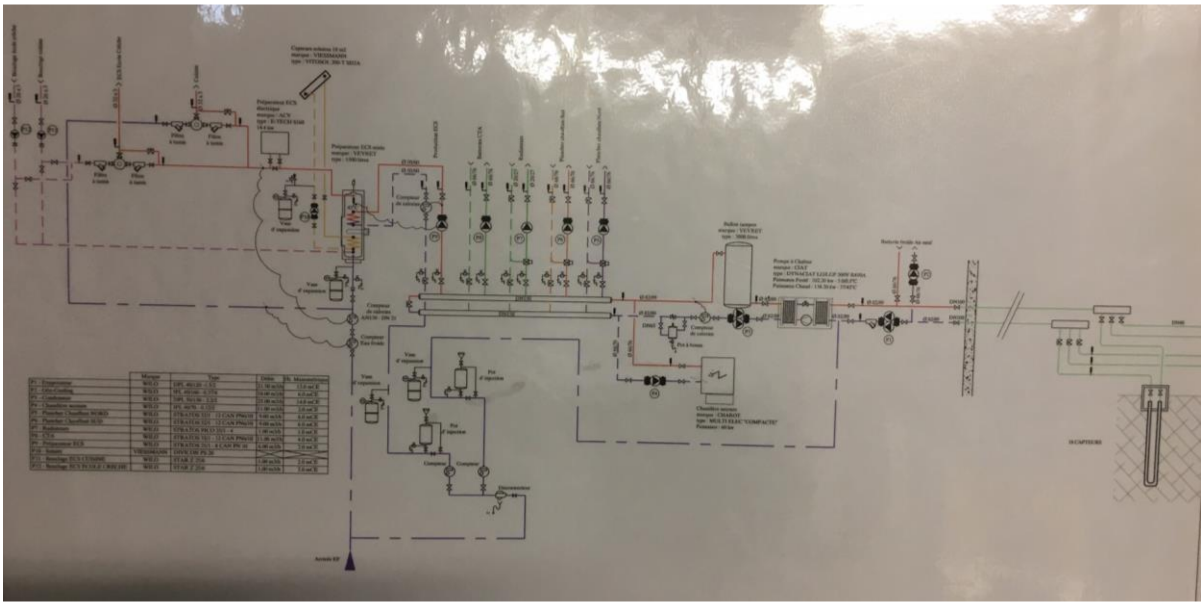
- Different setup parameters in the model components.
- Different number of PTES preheating years.
- Individual components (PTES, solar collectors, heat pump) measurements as inputs.

These extra simulations could be used to analyse where the model behaves according to measurements and where it deviates from them. The end result of such a study is an improved knowledge of strengths and weaknesses of a given TRNSYS model containing a certain number of components and can be used to improve the prediction accuracy of system integration and system design models. Such a study has, however, not been carried out in the present project, due to a lack of time to gather the proper data and build up the corresponding TRNSYS model. Previous system models could not have been reused because the energy system of Dronninglund has evolved significantly since the first TRNSYS model was developed.

4 BTES case study in France – BTESmart Vallin-Fier, Annecy

4.1 BTES case study description

The updated version of the BTESmart project is in Annecy, France. A borehole heat exchangers field (18 BHEs/100 m each) was built in 2012 under the playgrounds of the school “Vallin-Fier”, to heat and cool the buildings. The system has been in operation for almost 10 years. After nearly 10 years, the temperature measurements showed that the soil temperature was decreasing for many reasons, one of them being that no geocooling was used to recharge the underground during summer including the non-use of geocooling, as initially planned. The BTESmart Vallin-Fier project consists in



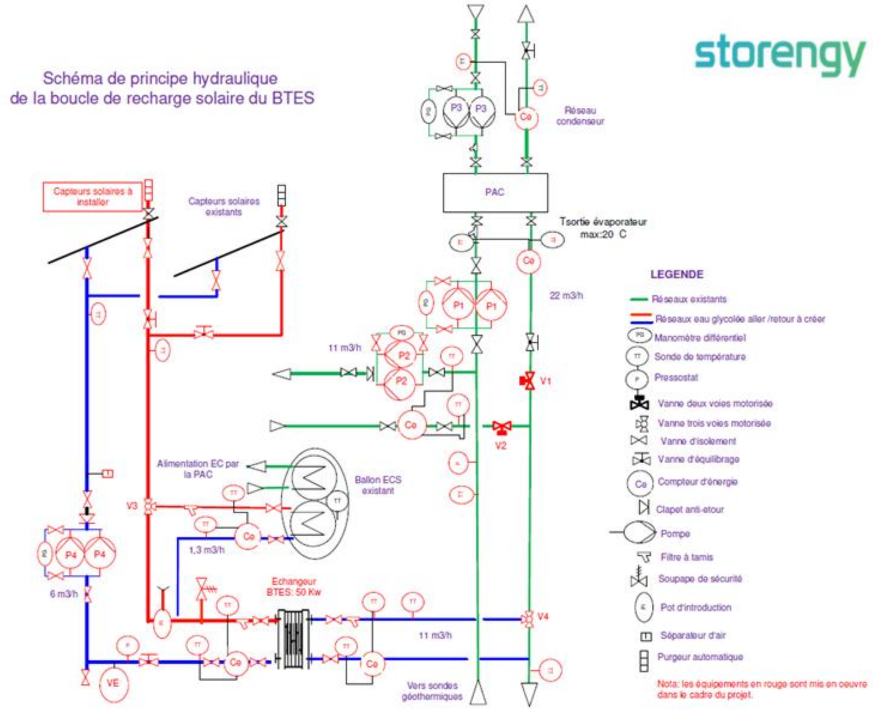


Figure 4.1 : Hydraulic diagram of existing facility (top) and changes that will be done (BTESmart project).

converting this geothermal facility into a real heat storage, by connecting it to solar thermal panels to recharge the underground, mainly during summer.

The actual hydraulic diagram and the changes to carry out are represented in Figure 4.1.

4.2 System integration model methodology

In Allaerts et al. (2021), a theoretical system with geothermal BHEs and solar thermal panels was modeled, using TRNSYS.
As agreed with the National Funding Agency, due to the change of pilot site during the Heatstore project, the tasks and deliverable 5.4 will be done in the frame of a national extension.
The work to be done will consist of:

- Adding the new TRNSYS type with two independent hydraulic circuits, described in the deliverable 5.3, to the TRNSYS model developed in the BTESmart Vallin-Fier project.
- Compare it with recorded data.

4.3 Model validation approach

4.3.1 Required data

New sensors (mainly for temperature and energy) will be installed on site. The settings for switching the devices on/off will also be used to make the model as realistic as possible.

4.3.2 Model validation

In the TRNSYS model, the real heating, domestic hot water and cooling needs will be entered. The model validation will then consist in comparing the following parameters (modelled vs. measured): the temperatures in and out of the BTES, the switch on/off of the HP and the solar energy collected.

5 Final remarks

Unfortunately, validation of system integration models could not be done within the HEATSTORE framework due to delays at the demonstration sites. This report describes shortly the plans and methodologies for validation once sites are operational and data becomes available.

The system integration models, which were developed in work package 3, have been applied to predict and optimize the design and operations of the heat networks for the demonstration sites. Assumptions or predictions related to a.o. the energy supply and demand were used as input, whereas the actual conditions are or will be different. The heat storage in the first months of operation at the Middenmeer site in the Netherlands show that actual storage can be very different from predicted values, and is related to the weather conditions affecting heat demand. Model 'validation' of the model in the prediction and design mode can give valuable information regarding how accurate a system design model can predict actual operations of a system. This basically includes comparison of heat energy balances between model and system. For the purpose of actual model validation, the model should be re-run using all operational input data once the system is in operation, presenting a digital twin. Flow, pressure and temperature measurements at various locations along the system should be compared to the model results. Any significant deviations between model and system can be used to finetune uncertain model parameters, such as pipe roughness and heat capacity or insulation of system components (heat exchanger, pipes, valves).

6 References

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