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Design Framework and Laboratory Experiments for Slinky-Loop Type Ground Source Heat Exchangers and Integration of Novel Heat Pump Designs for Retrofitting Projects

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ABSTRACT

Slinky-loop collectors, spiral heat exchangers and earth baskets are interesting for using geothermal technologies in retrofitting projects, particularly when drilling of vertical borehole heat exchangers is not possible. However, up to now no engineering design tools or field capacity tests exist for these systems, leading to a low employment of these systems. Within the H2020-project GeoFit we develop calculation tools and test protocols for geothermal designers, based on comprehensive laboratory experiments as well as dynamic simulations of the heat transfer to test the performance of different slinky-loop type ground source heat exchangers (GHEX) under different conditions in a climate chamber. The data of these experiments and simulations will then be used to develop an engineering tool for these types of collectors. The work on the GHEX design will go hand in hand with the development of suitable heat pumps for selected retrofitting cases. One system under development is a gas-fired hybrid adsorption/compressor heat pump suitable for size-reduced GHEX compared to pure compressor heat pump systems. The second concept is an electrically driven system based on an advanced electrical driven heat pump cycle which is optimized to utilize a maximum of renewable thermal energy from the GHEX.

1. INTRODUCTION

The building sector is responsible for the 40% of the total energy consumption and represents about a third of Europe's CO_2 emissions. Heating and cooling account for 50% of this annual energy consumption and almost half of EU buildings have boilers installed before 1992, with an efficiency rate of below 60%. Moreover, refurbishment rate for energy renovation of existing buildings is currently below 1%. Shallow geothermal has a great potential in Europe, but its adoption is hindered by long installation time and cost, technical difficulty in coupling heat pumps with existing high temperature heating systems, and the risk of structural damages or disruption caused by drilling activities.

GEOFIT is an integrated industrially driven action, funded by the H2020 program and carried out by 24 partners across EU, aimed at deployment of cost effective enhanced geothermal systems (EGS) on energy efficient building retrofitting. This entails the technical development of innovative EGS and its components, namely non-standard heat exchanger configurations, a novel hybrid heat pump and electrically driven compression heat pump systems and set of heating and cooling components to be integrated with the novel GSHP concepts, all specially designed to be applied in energy efficient retrofitting projects.

One of the challenges addressed in this project is that for several novel ground heat exchanger configurations (slinky, earth-basket, shallow spiral heat exchangers) no engineering design tools or field capacity tests are in existence. Such calculation tools and test protocols for the geothermal designer will therefore be developed in this project. Within this framework, we carry out extensive laboratory experiments accompanied by dynamic simulation of the heat transfer to test the performance of different slinky-loop type ground source heat exchangers (GHEX) under different conditions in a climate chamber. Four types of downscaled GHEX will be put in three different types of soil in 1m³ boxes. The thermal behavior of the soils and the implications on the performance of the GHEX will be tested at three temperature levels, two levels of heat injection, two levels of heat extraction and with two different loop pitches per GHEX type under the controlled atmosphere of the climate chamber. The combination of all parameters results in 432 variations. The most promising GHEX systems will then be installed in real-life size in field experiments. The lab and field experiments will be essential for the design framework and the development of an engineering tool for the optimization of GHEX design for different retrofitting settings (see Subchapter 2).

The work on the GHEX design will go hand in hand with the development of suitable heat pumps for selected retrofitting cases. One system under development is a gas-fired hybrid adsorption/compressor heat pump suitable for size-reduced GHEX compared to pure compressor heat pump systems. The second concept is an electrically driven system based on an advanced electrical driven heat pump cycle which is optimized to utilize a maximum of renewable thermal energy from the GHEX. The novelties lie in the use of Low GWP refrigerants as well as the use of Aluminum heat exchangers for cost reduction. So far, no residential ground source heat pump system exists where these technologies (LGWP, Aluminum HEX) were combined. Both systems will be tested in the lab and in selected demo cases to adjust them for the usage in building retrofitting markets (see Subchapter 3).

2. DESIGN FRAMEWORK FOR NOVEL GROUND (SLINKY/EARTH BASKET) TYPE SHALLOW HEAT EXCHANGERS

The state of the art of the GHEX is characterized by different types of probes which differ in depth of placement, shape and size. The GHEX has the purpose of exchanging as much heat as possible with the ground, referring to the high thermal capacity of the soil, even if the conductivity is not so high. The soil presents a temperature profile that changes seasonally in the first 10-13 meters of depth, assuming a temperature similar to that of the external environment, but under this level, the soil temperature assumes constant yearly profile equal to the yearly average external temperature (Figure 1).

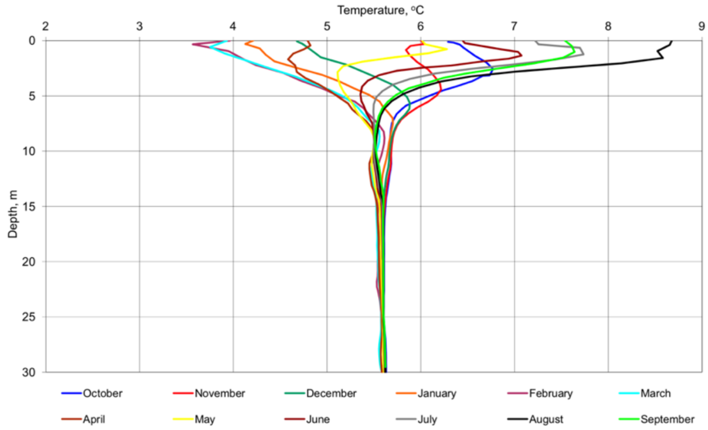


Figure 1: Seasonal ground temperature distributions

On the difference of seasonal temperature profile, is based the different approach between shallow GHEX and vertical GHEX. Vertical GHEX are well described in the literature and the heat exchanger with the ground can be modelled by several mathematical methods which are the basis for commercial designing tools. On the other hand, shallow GHEXs and helix GHEXs are theme of numerous scientific papers but there aren't commercial tools that can be used in particular application as can be a building retrofitting.

2.1 Laboratory experiments setup

To carry out the laboratory experiments we use different sizes of HD-PE big boxes (Figure 2). The high one, for our vertical basket and the long horizontal box for each of our other GHEX types (horizontal basket, vertical flat-lying and horizontal flat standing. The chart illustrated below shows the different variations, types and sizes of the mentioned resources we use and additionally, three soil-types (gravelly-sandy, saturated sandy and loamy-clayey) that are needed to measure the thermal behavior of our modified slinky loop-types and basket collectors. The collectors consist of an HD-PE HEX-support (grid) which is at one hand combined with a heat output HD-PE-tube for our spiral baskets and on the other hand used with a heat input heating cable for the flat-lying and standing loop types.

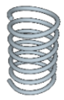
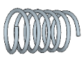
Big boxes (L x W x H)	GHEX Loop-types	Soil-types
1x (1200 x 800 x 1510 mm) 	• Vertical basket 	• gravelly-sandy (cable sand)  • saturated sandy (sieved humus)  • loamy-clayey 
1x (2400 x 800 x 850 mm) 	• Horizontal basket  • Vertical flat lying  • Horizontal flat standing 	

Figure 2: Investigated configurations for the test setup of laboratory experiments

The HD-PE grid which is surrounded by the tube is 120 cm high, has a diameter of 36 cm inside the basket and a loop pitch (distance between single loops) from about 10 cm. It has a high-temperature resistance (-40 °C/+80 °C) which is necessary for our heating cable (-20 °C/+80 °C). The specific power of the heating section reaches about 40 W/m but can be regulated by a power controller.

2.2 Measuring and Monitoring Strategy

PT1000 and SMT100 Moisture sensors are used for monitoring where the amount and positions of the sensors depend on the GHEX type. Primary objective of all setups is the measurement of horizontal and vertical temperature gradients in the soil. Two operation modes - heating and cooling will be tested. For cooling mode, a SensorTran© DTS-based fiber optic cable is mounted next to the heating cable, in different soil layers parallel to the GHEX and next to the container inner surface. The difference of the arrangement in heating mode is that the fiber optic cable is installed inside the PE tube. The installation of PT1000 and SMT100 in the soil remains the same. Raw data of all sensors and calculated temperature and moisture values are logged with LabView for further evaluation.

For the cooling mode, a heating cable will be used to simulate the energy transfer (from the building) to the soil. The rated power of the cable is 40W/m and it is regulated by a power-controller based on phase angle control adjustable by 0-10VDC. The setup allows four constant power levels 10, 20, 30 and 40W/m. The electrical energy source operates with European standard 230VAC, 50Hz. A residential meter, model 382-M made by Kampstrup, is used for monitoring the energy input to the heat exchanger. This type of meter meets all current standards to measure active and reactive energy. The meter provides a class A S0-interface according to DIN43864 which is used for counting energy units. To evaluate the soil and HEX characteristics, temperature levels and moisture content are monitored overall the container/box. All sensors except the glass fiber optic cable are connected to different I/O bus converters based on an RS485 network.

A schematic of the laboratory measurement setup is depicted in Figure 3. This figure shows the setup for the cooling mode of a heat pump simulated with the heating cable.

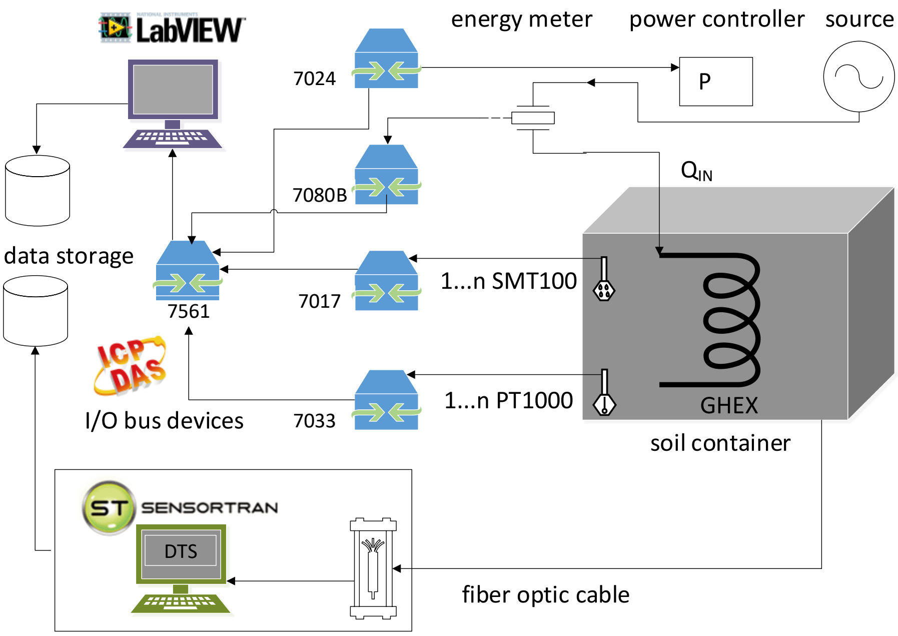


Figure 3: Schematic measurement setup

The following types of converters and sensors are used for the setup:

- ICP CON I-7561: USB to RS232/422/485 converter. Interface for communication between the Windows 7 operating system and the ICP bus network.
- ICP CON I-7017: Analog input module with 8 differential input channels. Interface for SMT100 sensors which measure moisture [vol.% H_2O] and temperature [°C] at the same time. For the lab setup, the moisture value is relevant.
- ICP CON I-7033: 3-channel Resistance Temperature Detector (RTD) input module. Interface for 2-wire PT1000 temperature sensors.
- ICP CON I-7080B-G: high-speed counter unit with 2 inputs and 2 digital output channels. Interface for counting pulses from energy meter to measure energy input to heat exchanger. This value is converted into [W] and [kWh].
- ICP CON I-7024: Analog output module with 4 channels. A 0-10VDC signal is used to control the power controller.

<u>Temperature sensors:</u>

- The RTD-sensors (PT1000) are based on a 2-wire connection and meet tolerance standards according to EN 60751 class B.

A calibration process of each sensor is done via a calibration furnace and meets the ITS-90 standard. Each PT1000 sensor has a specific correction factor which is taken into account during the measuring process in LabView.

- Distributed Temperature Sensing System SensorTran 5100 with glass fiber optics:

Raman spectra distributed temperature sensing (DTS) by fiber-optic cables has recently shown considerable promise for the measuring and monitoring of surface and near-surface hydrologic processes such as groundwater-surface water interaction, borehole circulation, snow hydrology, soil moisture studies, and land surface energy exchanges. DTS systems uniquely provide the opportunity to monitor water, air, and media temperatures in a variety of systems at much higher spatial and temporal frequencies than any previous measurement method [Tyler et al, 2009]. Temperature resolution approaching 0.01°C per meter is possible with long integration times if the DTS device itself is protected from changes in temperature [Selker et al., 2006a]. A typical spatial resolution is between 0,5-1m for Rayleigh based computation such as the Sensortran 5100.

This real-time data provides a baseline for further CFD-simulation models. This system is a standalone measurement setup and is not connected to the LabView computer. Data will be evaluated separately.

Moisture sensors:

The SMT100 sensors work on Frequency Domain Reflectometry (FDR) and are factory calibrated with an accuracy of ±3 % (vol.% H_2O) for mineral soils, average salinity and a moisture range of 0-50 vol. % H_2O.

To simulate the heating mode of a heat pump, the heating cable is replaced by an HD-PE tube with 20mm outer diameter. To regulate the energy flow, the electrical source, the power controller and energy meter are replaced by a circulation thermostat type Julabo FP51. This device allows accurate control of the fluid temperature and mass flux of the brine. It has an RS485 interface which is used to connect with LabView. Temperatures from -51 to +200°C are possible at a cooling power of max. 2kW. The amount of energy which is detracted (QOUT) is calculated in LabView based on mass flux and temperatures (TIN and TOUT). During the measurements, the box with soil and the HEX remains in a climate chamber while all the measuring equipment and PCs is situated outside.

Error! Reference source not found. shows how the GHEX (orange) and the fiber (turquoise) placed in the box for the first experiment with the heating cable. 24 PT1000 and 12 SMT100 sensors measure the data in the pink quarter of the box. The distances vary depending on the distance between box edge and GHEX and are centered. To align the GHEX and the cables to the required geometry, a total of three baskets made of a plastic grid and iron rods are used. The heating cable and the fiber optic cable are attached to the baskets. The baskets are not shown in the figure. The fiber optic cable is run directly on and parallel to the GHEX on an inner and an outer basket. To increase the number of temperature measurement points along the cable, the cable is routed twice close to each other. In addition, the inner walls of the box are also measured with the cable to determine the boundary condition. The iron rods are removed after filling with sediment in order to avoid influencing the thermal conductivity.

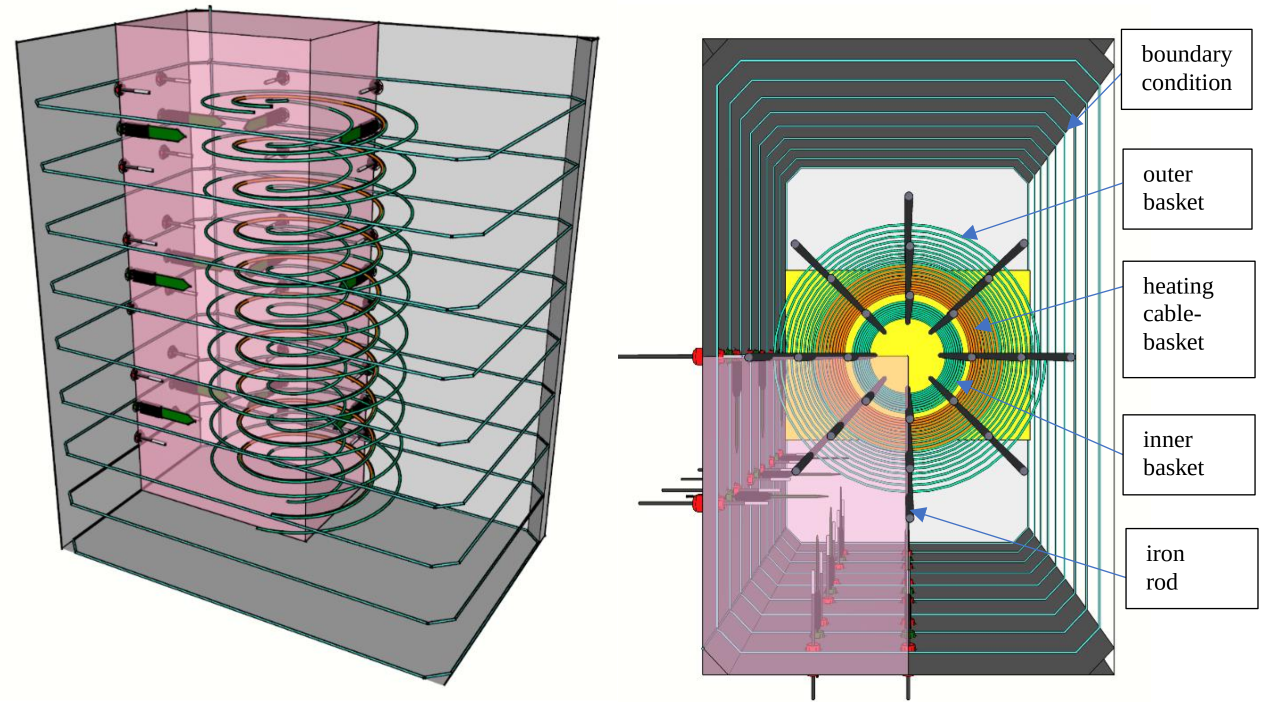


Figure 4: 3D rendering of the experimental setup

The yellow area in the right view represents a wooden base plate in which the iron bars are aligned. It is also visible that due to the symmetry of the structure, the measurement data of the pink cuboid can be scaled to the remaining volume.

2.3 First results of laboratory experiment test runs

The first experiment simulates the cooling operation of a heat pump with a vertical spiral GHEX and 100 % cable sand. Instead of just one long fibre optic cable, a total of four individual cables as short as possible were used to facilitate the evaluation of the data. The cables were supposed to measure the boundary condition and the three baskets separately. Although the cables were calibrated in advance, a high signal noise occurred during the measurements of different temperatures in the soil. An attempt to improve the measurement data by increasing the value of the software parameters such as measurement duration, number of traces and number of pulses per measure cycle failed. A further attempt to recalibrate the cables during operation also showed no improvement in signal noise. The results also showed that the longest cable (60 m) had significantly lower signal noise compared to the shorter cables (30 m and 40 m). Typically, DTS systems are used for longer distances such as boreholes and oil pipelines. However, since no minimum distances were specified in the literature found or in the manufacturer's manual, and this problem did not occur to such an extent during calibration, short lengths were used. Furthermore, the number of measuring points per meter is physically and systematically limited to two points per meter. Therefore, the experiment was aborted, and the setup reworked.

In the second experiment, the four fiber optic cables were replaced with one long cable (128 m) to minimize the signal noise, as originally planned. Furthermore, the cable was doubled per section respectively basket to increase the number of measuring points. In addition, the number of iron rods was doubled to ensure that the baskets were as circular as possible since the shape can become unstable when the container is filled with sediment.

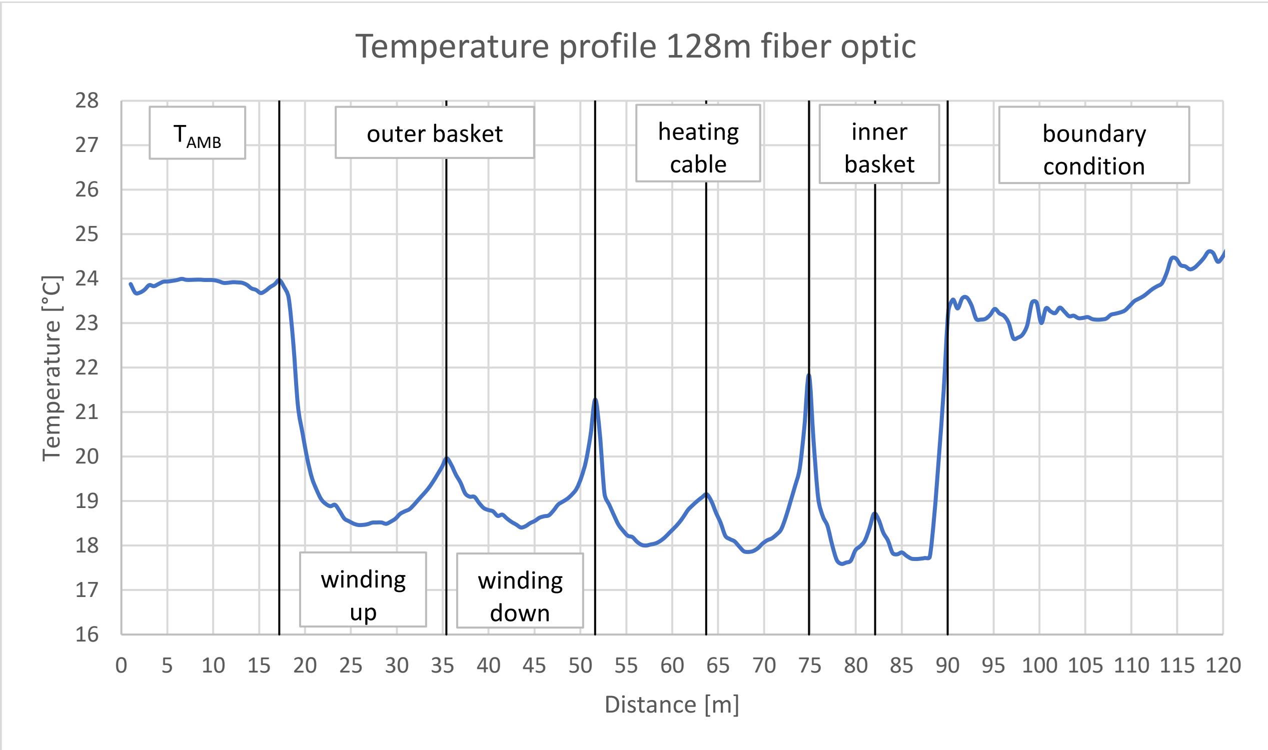


Figure 4: Temperature profile fiber optic

Figure 1Figure 4 Figure 4: Temperature profile fiber opticshows the first measurement results of the second setup with the 128 m long fiber optic cable. The temperature curve represents a momentary recording of the sediment box without conditioning the environment. The ambient temperature in the laboratory was between 23.5 and 24.5 °C. The sediment in the centre of the box had a temperature of approx. 17 °C. The course from right to left represents the route of the cable and thus the respective sections or baskets. The distance 90-120m corresponds to the inner walls of the box (boundary condition). Section 75-90 m shows the temperature profile of the inner basket. The peak at 82.5 m corresponds to the turning point of the double winding (down and up) of a basket located near the warmer container floor. This can also be seen with the other two baskets (heating cable & outer basket). Section 50-75 m represents the heating cable. After each double winding of a basket, the fibre optic cable was led out of the sediment to the surface in order to facilitate the evaluation and allocation of the distances to the measuring points along the cable which can be seen at 75 m. The value is minimally lower than the ambient temperature since most probably no measuring point in the loop was in direct contact with T_{AMB}. Section 0-16 m corresponds to the distance between the measuring station and the test setup in the climatic chamber, which can be up to 15 m. Furthermore, a slight difference in the minimum temperatures per section can be seen, which corresponds to the difference between the ambient and the core temperature of the box.

Based on the knowledge gained so far regarding measurement setup, handling and DTS system, further tests and controlled scenarios will be measured and evaluated. After the extensive calibration and test runs, the full measurement program of all envisaged scenarios and variations will start in November 2019. The results of the measurements and the simulations will be presented at the World Geothermal Congress 2020.

2.4 Development of an engineering design tool for GHEX

The purpose of this task is to provide a robust design framework for consultants and installers with regard to an optimal design of different types of ground source heat exchangers. This will be based on an in-depth analysis of the systems-design for different application types (single houses, collective systems such as apartment buildings, utility and also retrofit and newly built situations including nZEB). To develop codes that are useful for the designer the requirements are:

- The main governing processes should be included in sufficient detail.
- The code needs to be able to solve for length or surface of GHEX required to accommodate a given load within set fluid temperature boundaries.
- The code needs to run sufficiently fast to allow the design to proceed smoothly and allow sensitivity and optimization to be performed.

For vertical borehole heat exchangers and, to a lesser extent for horizontal ground heat exchangers, design methods have been developed and implemented in tools such as Earth Energy Designer, EWS or GLHEPRO. For slinky-type heat exchangers and earth baskets at present no practical and reliable calculation method exist. The development of such calculation method is not trivial as (1) The geometry is much more complex (2) These systems are regularly allowed to freeze the surrounding ground, therefore phase change has to be considered (3) During heat dissipation (cooling operation) the near-surface soil humidity gradient may be affected (4) The seasonally varying near-surface temperature gradient (to depth of ± 10 meters below surface) needs to be accounted for. In this task, such tools will be developed and translated to engineering tools for system design.

The approach adopted within the Geofit project is to develop models with a high level of spatial and temporal detail and a high order of complexity to study different key-aspects of the heat transfer problem. These models will consider the local (fluid flow in an individual heat exchanger and surrounding ground) as well as global problem (heat flow between adjacent ground heat exchangers, groundwater flow effects). The main computational methods used will be Fluent, FEFLOW and Thermal Resistance – Heat Capacitance networks.

The basis for the development can be summarized as:

- Laboratory scale and field-scale experiments to provide reference data set for model validation and process analysis.
- Detailed 3D model analysis of slinky and earth-basket type heat exchangers using coupled heat and mass transfer
- Models based on finite volume or finite element methods.
- Development of a simpler but accurate model-based (lumped capacitance / thermal resistance model) that will allow a dynamical system design analysis
- Development of engineering tools based on finite line source solutions, G-function generator and heat exchanger thermal resistance calculations.

As a third example, one may consider the fact that in many new developments the number of individually designed and constructed systems increases in such a way that thermal interactions between neighbouring systems is unavoidable and would need to be considered. However, this is not possible with the available calculation methods as these are not able to analyse different systems in a common framework (e.g. it is not feasible to integrate different energy usage types, different number and depths of heat exchangers). Moreover, as a designer one does not usually have the necessary information about the neighbouring systems. Again, an integrated systems-design approach is needed. In addition, new working fluids will be developed and integrated in this effort.

In summary, the specific objectives of this task are:

- Develop an integrated design framework for ground source energy systems that can be used by planners, construction companies and installers to select the optimal solution of ground source heat exchanger and define the key-design parameters.
- Based on the system analysis performed for the integrated design framework a benchmarking tool will be developed
- Provide fundamental experimental data on the performance of slinky-type and earth basket type heat exchangers and the interaction with the surrounding ground volume in laboratory and field-scale experiments.
- Develop a modelling methodology for the detailed analysis of slinky and earth basket type heat exchangers
- Develop an engineering calculation tool for the sizing of slinky- and earth basket type heat exchangers

2.5 Simulation of slinky-loop and earth basket type collectors

Thermal parameters of the ground and GHEX materials are essential for the simulation and design of GHEX, e.g. the thermal conductivity, density, heat capacity. For fluids, also the viscosity is of importance. The following parameters are sensitive for the final design of GHEX systems and have therefore to be considered carefully:

- Ground thermal conductivity
- Ground heat capacity
- Undisturbed vertical ground temperature profile
- Surface temperature (seasonally varying)
- Mass flow through porous media
- Energy exchange per time unit (note that in single stage systems the thermal capacity may exceed the energy demand of the user, cycling of the heat pump occurs)
- Maximum thermal capacity
- Minimum and maximum allowed temperature in the heat exchanger
- Mass flow rate per unit time

- Medium freeze point, heat capacity, thermal conductivity, viscosity (all temperature dependent)
- Ground heat exchanger properties (pipe diameter, wall thickness, conductivity, borehole diameter, backfilling thermal conductivity, backfilling heat capacity, loop topology (OR: thermal resistance)

A CFD simulation methodology is developed to be able to predict the behavior and interaction of slinky-loop and earth basket type collectors. For the detailed simulations ANSYS Fluent is used to solve the underlying equation set. In a first step, the tube is substituted by a thermal heat source (in analogy to experiments performed with a hot wire), in a second step the fluid flow inside the tubes is accounted for by solving the Navier-Stokes equations. In both cases the transient and space heat source boundary conditions is directly imported from the transient and position dependent temperature data of the probes in the tube and along the wire. The outer boundary conditions at the box walls is also available as a position dependent and transient data set. With these boundary conditions and equi-thermal initial conditions the full equation set is defined. Solution of the equations yield the transient spatial temperature and humidity distribution in the whole box, which is compared to discrete temperature and humidity probes positioned in the experiment. Beside single loops also the interaction of two loops will be assessed by detailed simulations and compared to the experimental data. Figure 5 shows the schematics of the numerical setup with a single heat exchanger tube. Transient boundary conditions are available from the experiment on horizontal (purple) and vertical (yellow and red) box walls as well as on the tube (orange). Temperature and humidity data from the experiment will be compared at predefined locations (symbolized by blue spheres).

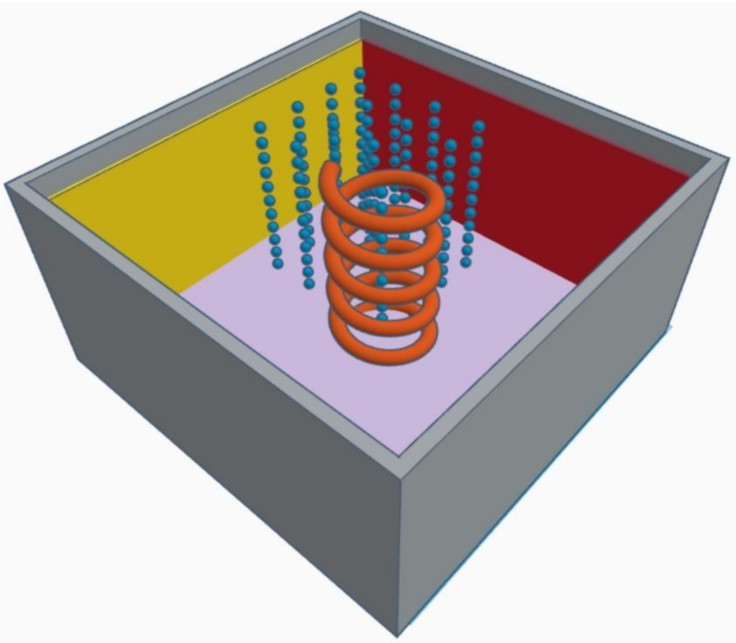


Figure 5: Schematic CFD setup (3D spring model by Reece Pallet, England (thingyverse)

3. DEVELOPMENT AND INTEGRATION OF HEAT PUMPS FOR RETROFITTING PURPOSES

3.1 General aspects

The integration of ground systems with heating/cooling solutions and heat pumps to achieve maximum performance and highest system efficiencies is a great challenge that demands a solution. In order to find the best solution for each pilot site with respect to increased supply temperatures compared to a new building, different heat pump configurations are analyzed. The model-based approach allows a precise and accurate component design, but more important, it makes us capable to establish an optimal control strategy, not only for the heat pump itself but also for the entire system (ground source heat exchanger, heat pump, building).

A heat pump is a device that transfers heat energy from a heat source to a so-called heat sink. External energy is used to perform the work of transferring energy from the heat source to the heat sink. In GEOFIT we use two different heat pump technologies:

- Hybrid system with coupled adsorption and vapour compression cycle
- Electrical driven vapour compression cycle

The **hybrid heat pump** concept consists of the union of three main components: a gas boiler, an adsorption unit and a vapour compression unit. The gas boiler represents the heat source to drive the adsorption cycle, which is then coupled to the compression cycle for space heating and cooling purposes. Ground source heat exchanger represent the heat source/sink for the operation of the two heat pumps unit.

The most common design of an **electrical driven vapour compression cycle** consists of four main components, a condenser, an expansion valve, an evaporator and a compressor. The working fluid circulating through these components is called refrigerant. In general, the system efficiency is given by the coefficient of performance (COP). The COP is the ratio of useful heat output to work required. The useful output can either be heating, cooling or both. Especially for heating purposes, the COP usually exceeds 1 because, instead of just converting work to heat, it pumps additional heat from a heat source to where the heat is required.

3.2 Modeling based development approach

The operation of a geothermal heat pump system is intrinsically dynamic, due to the variation of the user demand, the temperature of the soil and the heat pump. To simulate such kind of systems, three main approaches can be applied (Sangi et al., 2019):

- Physical modelling: detailed heat and mass transfer equations are defined;
- Black box approach: totally empirical, based on performance maps of the components;
- Grey box approach, consisting in the mixing of the previous two approaches.

In literature, several examples of the simulation of ground-source heating systems can be found, using a physical/thermodynamical approach (Choi et al., 2014; Lubis et al., 2011) or a dynamic physical approach (Sangi et al., 2019), but the vast majority applies an empirical or semi-empirical approach, with TRNSYS as the most used simulation environment (Di Bella et al., 2018; Morrone et al., 2014; Zurmuhl et al., 2019). At the same time, even for adsorption and vapour compression heat pumps, a vast literature exists, based on either dynamic or empirical approaches (Alibabaei et al., 2016; Bava and Furbo, 2017; Deutz et al., 2018; Tangwe et al., 2014). Coupling of the various components is usually realised by means of co-simulation, e.g. integrating TRNSYS and MATLAB, which significantly reduces flexibility and speed of the simulations. In the present case, Modelica language, within the Dymola environment, was chosen for the dynamic model of the system, since it was proven as a reliable tool for the simulation of complex energy systems, including adsorption chillers and heat pumps (Bau et al., 2014; Lanzerath et al., 2015; Schicktanz and Núñez, 2009), heat pumps (Graber et al., 2010; Ling et al., 2014; Mortada et al., 2012) and geothermal systems (Sangi et al., 2019). Commercial TIL and TIL Media libraries were used and integrated with self-developed components to ensure a reliable and fast evaluation of the design of the system.

3.3 Hybrid heat pump system

The coupling of an adsorption and a vapour compression unit within the hybrid heat pump system gives a certain flexibility in operation modes. In order to find the best solution for each pilot site integration, we evaluate three configurations. Figure 6 shows the basic hybrid heat pump concept.

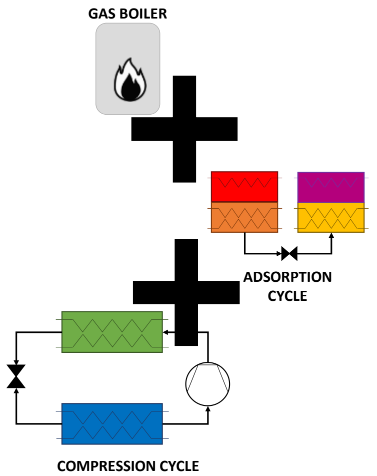


Figure 6: GEOFIT hybrid heat pump concept.

a) ***Series operation of the evaporator loops of the two chillers, direct space heating from heat pumps***: in this configuration, the gas boiler provides heat for the adsorption process, adsorption heat, condensation heat from the adsorption module and condensation heat of the vapour compression heat pump represent the useful space heating effect, and the GSHEX represents the evaporation heat source. The operation of adsorption unit only or both adsorption and vapour compression units depends on ambient conditions and the user demand. The heat provided by the GSHEX is provided to the adsorption module and subsequently, in series, to the vapour compression module. The main advantage of such a configuration is the simpler layout; on the other hand, however, if the temperature of the ground is quite low (e.g. 10°C), the outlet temperature from the evaporator of the adsorption unit can be as low as 5-6°C, while the outlet temperature from the vapour compression unit can be near 0°C, thus requiring a water/glycol mixture as heat transfer fluid to avoid freezing.

b) ***Series operation of the evaporator loops of the two chillers, indirect space heating from heat pumps***: compared to the previous case, the difference of this layout is in the connection to the building heating system: an additional heat exchanger is used, controlled by a mixing valve. In this case, the hot water loops from the heat pumps and the hot water outlet from the desorber of the adsorption unit are mixed. The aim is to compensate for the discontinuous power of the adsorption chiller (Vasta et al., 2018) and therefore supplying a more constant inlet temperature to the user, at the expenses of a more complex layout.

c) ***Parallel operation of the evaporator loops of the two chillers, direct space heating from heat pumps***: compared to case (a), in this configuration, the evaporator loops of the two heat pumps are connected in parallel, to avoid freezing problems. An additional motorised valve is needed to achieve proper operation.

3.4 Electrical driven vapour compression system

The design of the electrical driven vapour compression system is based on the specific requirements in the case of building retrofitting. As working fluid, a Low Global Warming Potential (GWP) refrigerant (e.g. R1234ze(E)) with a GWP smaller than 10 will be used. The system will include alternative cost-effective heat exchangers to be used with the Low GWP refrigerant like plate heat exchangers made of a material cheaper than Copper.

The final heat pump configuration will be a trade-off between complexity of machinery and efficient operation. Usually a more complex heat pump cycle is more efficient but has the disadvantage of higher invest costs. One favorable heat pump configuration is a twin-cycle system which basically consists of two heat pumps with different condensation temperatures but with the same temperature on the source side. Alternatively, a single-stage configuration which uses a significantly larger condenser for enhanced subcooling is also analyzed. Both systems allow a more efficient operation compared to state-of-the-art heat pump systems in the case of building retrofitting.

So far, no residential ground source heat pump system exists where these technologies (Low GWP, cost-efficient heat exchangers) were combined. Figure 7 shows the schematic view and the representation within the system environment for a Single-Stage system.

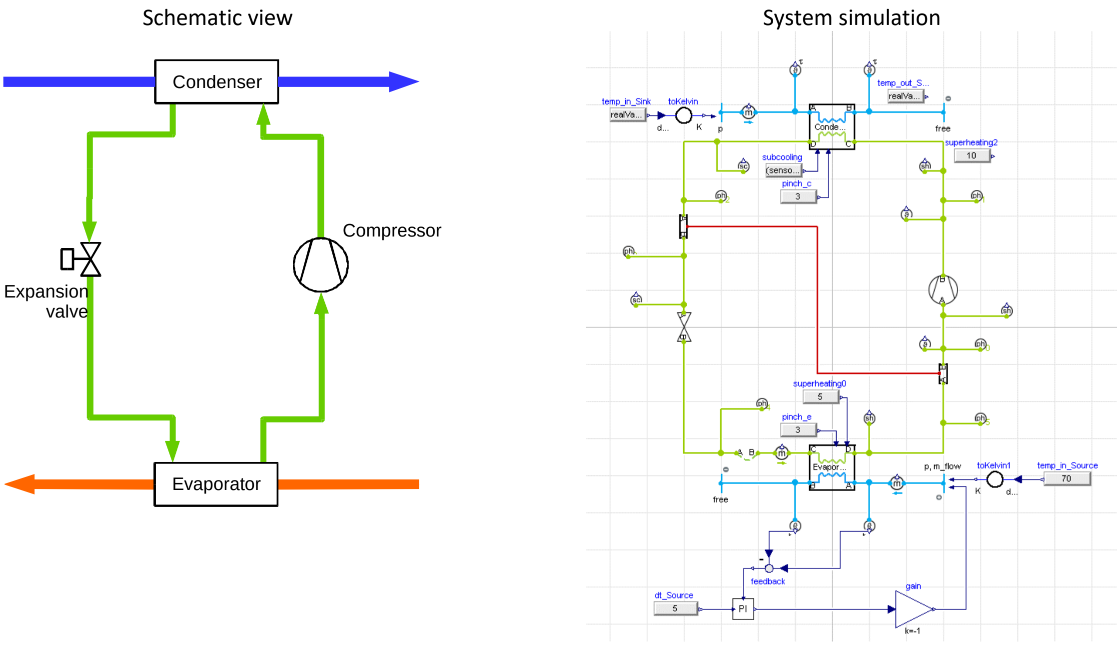


Figure 7: Schematic view of the electrical driven vapor compression system (left) and its representation inside the simulation environment (right).

4. OUTLOOK

At the end of the demonstration phase in the GEOFIT project, the action will increase the commercial attractiveness of geothermal energy in combination with ground source heat pumps and therefore increase the penetration of this renewable source in building retrofitting.

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REFERENCES

Alibabaei, N., Fung, A.S., Raahemifar, K., 2016. Development of Matlab-TRNSYS co-simulator for applying predictive strategy planning models on residential house HVAC system. Energy Build. 128, 81–98. https://doi.org/10.1016/J.ENBUILD.2016.05.084

Bau, U., Lanzerath, F., Gräber, M., Graf, S., Schreiber, H., Thielen, N., Bardow, A., 2014. Adsorption energy systems library - Modeling adsorption based chillers, heat pumps, thermal storages and desiccant systems, in: Proceedings of the 10th International Modelica Conference. Lund. https://doi.org/10.3384/ECP14096875

Bava, F., Furbo, S., 2017. Development and validation of a detailed TRNSYS-Matlab model for large solar collector fields for district heating applications. Energy 135, 698–708. https://doi.org/10.1016/J.ENERGY.2017.06.146

Choi, J., Kang, B., Cho, H., 2014. Performance comparison between R22 and R744 solar-geothermal hybrid heat pumps according to heat source conditions. Renew. Energy 71, 414–424. https://doi.org/10.1016/J.RENENE.2014.05.057

Deutz, K.R., Charles, G.-L., Cauret, O., Rullière, R., Haberschill, P., 2018. Detailed and dynamic variable speed air source heat pump water heater model: Combining a zonal tank model approach with a grey box heat pump model. Int. J. Refrig. 92, 55–69. https://doi.org/10.1016/J.IJREFRIG.2018.05.022

Di Bella, G., Sapienza, A., Vasta, S., Lombardo, G., 2018. Design of a geothermal plant to heat a waterpark swimming pool: Case study of tramutola (Basilicata, Italy). Eur. J. Electr. Eng. 20, 539–557. https://doi.org/10.3166/ejee.20.539-557

Graber, M., Kosowski, K., Richter, C., Tegethoff, W., 2010. Modelling of heat pumps with an object-oriented model library for thermodynamic systems. Math. Comput. Model. Dyn. Syst. 16, 195–209. https://doi.org/10.1080/13873954.2010.506799

Lanzerath, F., Bau, U., Seiler, J., Bardow, A., Bardow, E., 2015. Optimal design of adsorption chillers based on a validated dynamic object-oriented model. Sci. Technol. Built Environ. 21, 248–257. https://doi.org/10.1080/10789669.2014.990337

Ling, J., Qiao, H., Alabdulkarem, A., Aute, V., Radermacher, R., 2014. Modelica-based Heat Pump Model for Transient and Steady-State Simulation Using Low-GWP Refrigerants. Int. Refrig. Air Cond. Conf. 1–9.

Lubis, L.I., Kanoglu, M., Dincer, I., Rosen, M.A., 2011. Thermodynamic analysis of a hybrid geothermal heat pump system. Geothermics 40, 233–238. https://doi.org/10.1016/J.GEOTHERMICS.2011.06.004

Morrone, B., Coppola, G., Raucci, V., 2014. Energy and economic savings using geothermal heat pumps in different climates. Energy Convers. Manag. 88, 189–198. https://doi.org/10.1016/J.ENCONMAN.2014.08.007

Mortada, S., Zoughaib, A., Clodic, D., Arzano-Daurelle, C., 2012. Dynamic modeling of an integrated air-to-air heat pump using Modelica. Int. J. Refrig. 35, 1335–1348. https://doi.org/10.1016/j.ijrefrig.2012.03.009

Sangi, R., Jahangiri, P., Müller, D., 2019. A combined moving boundary and discretized approach for dynamic modeling and simulation of geothermal heat pump systems. Therm. Sci. Eng. Prog. 9, 215–234. https://doi.org/10.1016/J.TSEP.2018.11.015

Schicktanz, M., Núñez, T., 2009. Modelling of an adsorption chiller for dynamic system simulation. Int. J. Refrig. 32, 588–595. https://doi.org/10.1016/J.IJREFRIG.2009.02.011

Tangwe, S., Simon, M., Meyer, E., 2014. Mathematical modeling and simulation application to visualize the performance of retrofit heat pump water heater under first hour heating rating. Renew. Energy 72, 203–211. https://doi.org/10.1016/j.renene.2014.07.011

Vasta, S., Palomba, V., La Rosa, D., Mittelbach, W., 2018. Adsorption-compression cascade cycles: An experimental study. Energy Convers. Manag. 156, 365–375. https://doi.org/10.1016/j.enconman.2017.11.061

Zurmuhl, D.P., Lukawski, M.Z., Aguirre, G.A., Law, W.R., Schnaars, G.P., Beckers, K.F., Anderson, C.L., Tester, J.W., 2019. Hybrid Geothermal Heat Pumps for Cooling Telecommunications Data Centers. Energy Build. https://doi.org/10.1016/J.ENBUILD.2019.01.042