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Hybrid Ground Source Heat Pump Systems - Review

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ABSTRACT

The Ground coupled heat pump (GCHP) systems consist of underground thermal energy storage and any type of heat pump. These systems can be used for heating and/ or for cooling. Their efficiency is very good if the building's heating and cooling loads are well balanced on an annual basis. Unfortunately, in warm-climate or cold-climate areas there is always an imbalance and consequently there is a domination of either cooling or heating loads. In both cases a larger area of borehole heat exchangers (BHEs) is needed, which reduces the system's efficiency. A good solution to the problem is to diminish the capital costs by means of a heat rejecter or a heat absorber, thus obtaining hybrid GCHP (HGCHP) systems. Many different components can be a part of this type of systems - solar collectors, storage with phase change materials, heat rejecters, borehole thermal energy storage as well another type of heat pump.

The work presents a review of many hybrid GCHP systems constructed and used all over the world. Additionally the experience of some members of the Bulgarian research team and their international cooperation is discussed. The existing problems by using this technology and the future progress are commented, too.

1. INTRODUCTION

There is still no specific answer to the question what a hybrid system is - it is usually a combination of at least two types of installations (they can contain both electrical and mechanical parts).

In the last years a type of combined heat pump system has become very popular - it can contain several types of heat pumps and is connected to the ground with heat exchangers. This provides heating, cooling and domestic hot water (DHW) for different buildings. These types of systems are called hybrid GSHP (HGSHP) systems.

Normally the systems are designed for building's heating and cooling loads which are well balanced on an annual basis. Of course it is not possible to have exact balance - every time there is available domination of heating or cooling load (Figure 1). Thus the length of the ground heat exchanger must be changed which leads to lower system's efficiency (Ramamoorthy et al, 2001).

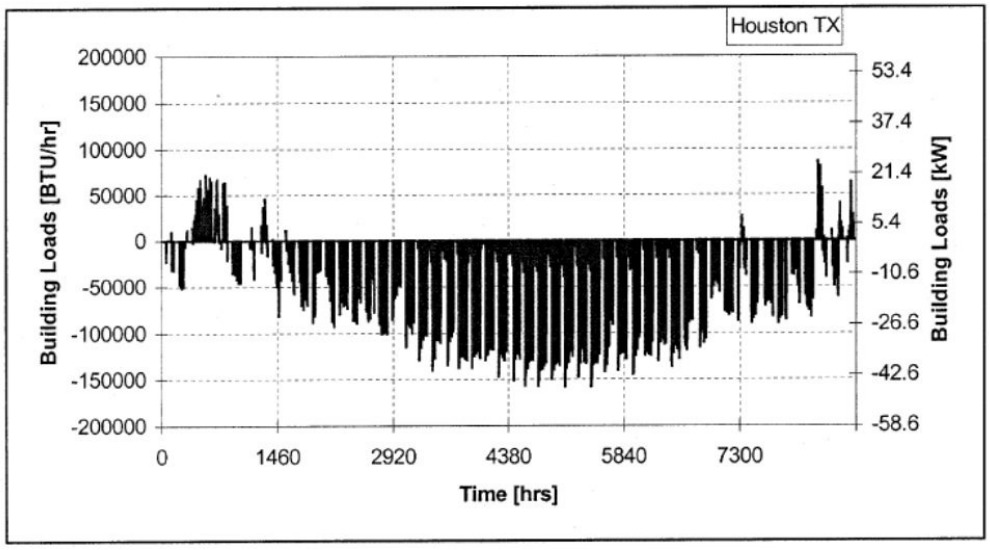


Figure 1: Annual building loads for climatic conditions typical of Houston in Ramamoorthy et al (2001).

Three main categories of the GSHPs are specified by ASHRAE (1999): ground water heat pump (GWHP) systems, surface water heat pump (SWHP) systems, and ground-coupled heat pump (GCHP) systems (Figure 2) in Yang et al (2010). The (GCHP) systems are connected with heat exchanger under the ground vertically (borehole heat exchanger, BHE) or with heat exchanger in horizontal trenches (called horizontal heat exchanger).

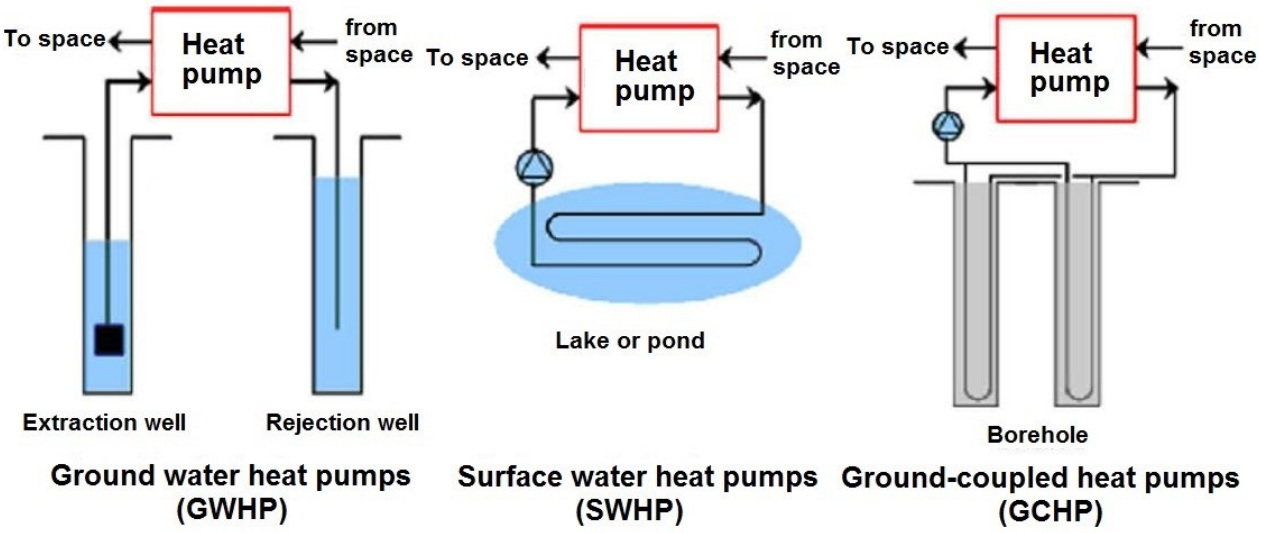


Figure 2: Scheme of ground source heat pumps in Yang et al (2010).

The article presents several types of HGCHP systems. Here is the list of them - HGCHP system with solar collectors (Yang et al, 2010), HGCHP system with cooling tower (Yi et al, 2008), HGCHP system with a DHW heating system (Cui et al, 2008), HGCHP system for building cooling with several heat pumps (Pardo et al, 2009) and solar heat pump heating system with latent and stratified thermal storages (Trinkl, 2006). Some installation examples of the Bulgarian team from Plovdiv are commented, too (ground heat exchanger coupled with phase change materials - Bottarelli et al, 2015 and 2013) and a hybrid GCHP installation in Plovdiv (Toshkov et al, 2014 and Stoyanov et al, 2013).

2. DESCRIPTION OF SEVERAL HYBRID GCHP SYSTEMS

2.1 HGCHP Systems with Solar Collectors

Let us suppose that there is available heating-dominated climate. Thus the number of the boreholes (size of the borehole heat exchanger) must be relative big, which leads to decreasing of his efficiency and more capital costs. The solution in this case is to incorporate in the system solar collectors which will be used to augment the soil temperature. The installation view is presented in Figure 3 (Yang et al, 2010).

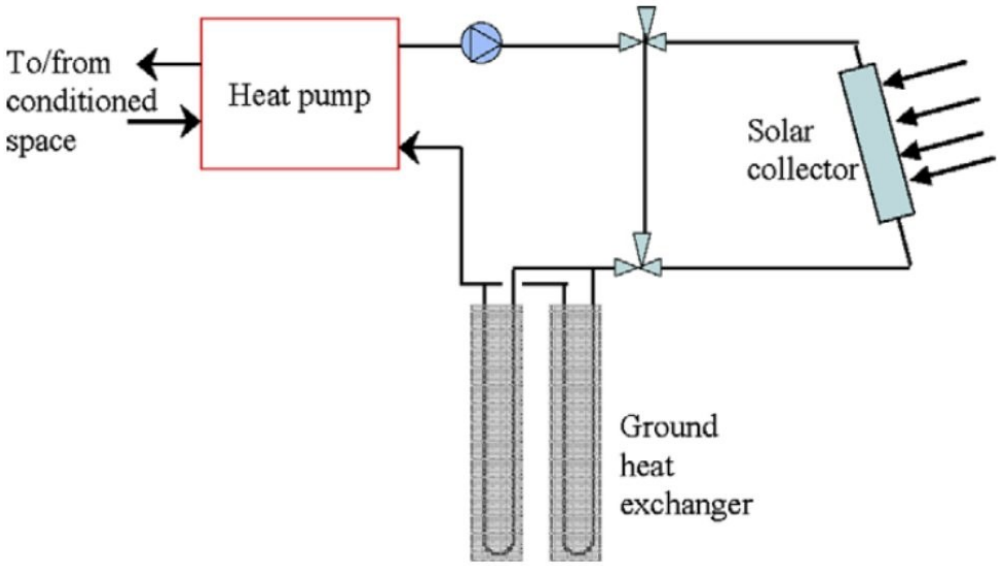


Figure 3: Schematic diagram of a HGCHP system with solar collectors (Yang et al, 2010).

2.2 HGCHP Systems with Cooling Tower

The number of the boreholes (size of the borehole heat exchanger) must be bigger if we have cooling-dominated climate. It leads to decreasing of the system efficiency and more capital costs like in the heating-dominated climate. Then heat rejecters/ cooling tower can be integrated in the installation (Figure 4) (Yi et al, 2008).

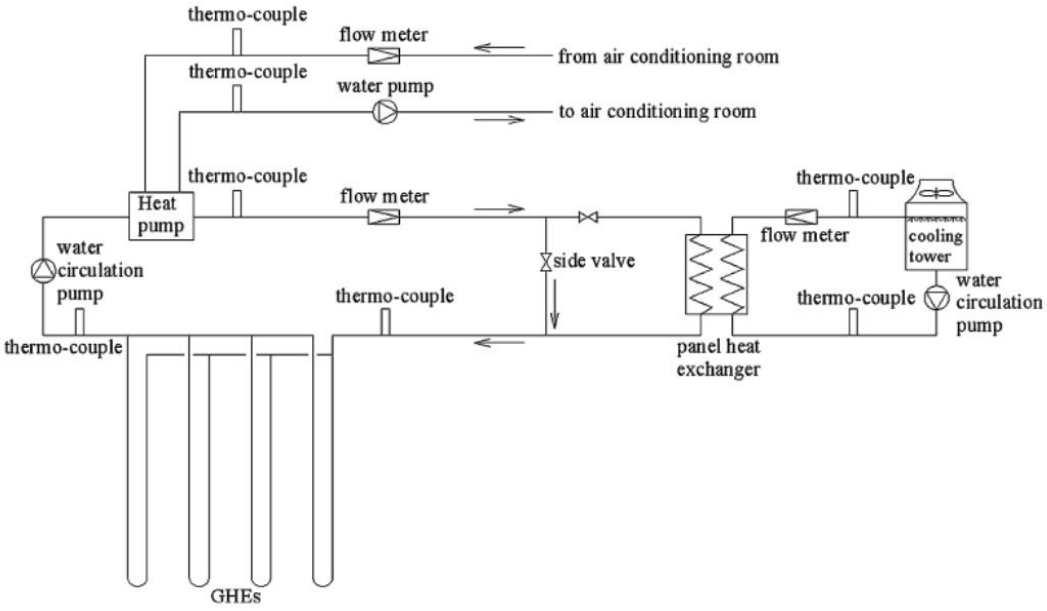
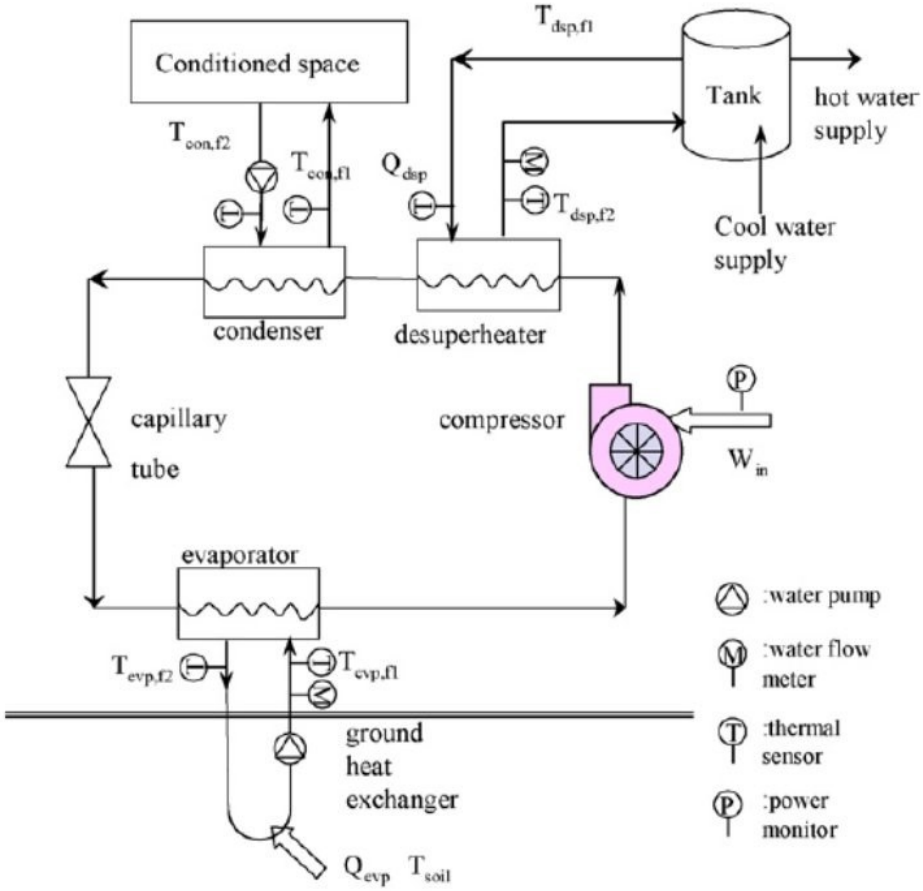


Figure 4: Schematic diagram of a HGCHP with cooling tower (Yi et al, 2008).

2.3 HGCHP Systems with a DHW Heating System

Relative high temperature is needed by the domestic hot water (DHW) production. As mentioned above, the HGCHPS can work in some different regimes like heating, cooling and DHW production. A small HGCHPS was produced in Hong Kong for operation in four modes - cooling with DHW production, cooling only, heating with DHW production and heating only. This is possible because of the device called desuperheater which is mounted near the heat pump compressor (Figure 5) (Cui et al, 2008).



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Figure 5: Schematic diagram of the HGCHP with a DHW heating system (Cui et al, 2008).

2.4 Hybrid Ground Coupled Heat Pump System for Building Cooling with Several Heat Pumps

Pardo et al. (2009) present various HGCHP systems for cooling of building in regions with dominated cooling load (in this case Valencia, Spain). Here are some main components of the installation: air to water heat pump (AWHP), air fan (AF), thermal storage device (TSD), ground heat exchanger (GHE), internal and external water pumps (IWP, EWP), water to water heat pump (WWHP) and storage water pump (SWP).

One of the proposed hybrid systems (configuration B) is shown in Figure 6. This installation is used in regions with a long cooling season (in this case in Valencia, Spain). Two heat pumps are used - AWHP and WWHP (it is connected with the ground). The first one is switched on during the night (there is lower temperature of the air compared with the ground). It charges the TSD, which cool is used during the day. The ground heat pump is switched on during the day when the capacity of the storage in not enough. When needed, the WWHP is switched on additionally with the aim to decrease the temperature. The by-pass connection near the storage is used when the outlet fluid storage temperature is higher than the inlet fluid storage temperature. Compared with the other 2 variants of the systems, the AWHP is also used here to satisfy directly the thermal load.

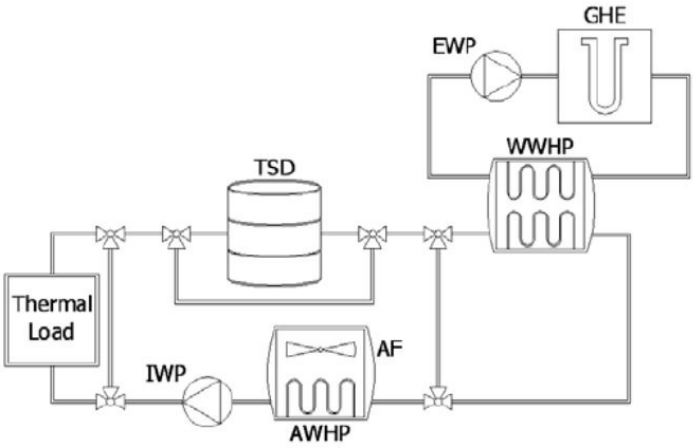


Figure 6: Hybrid configuration type B (Pardo et al, 2009).

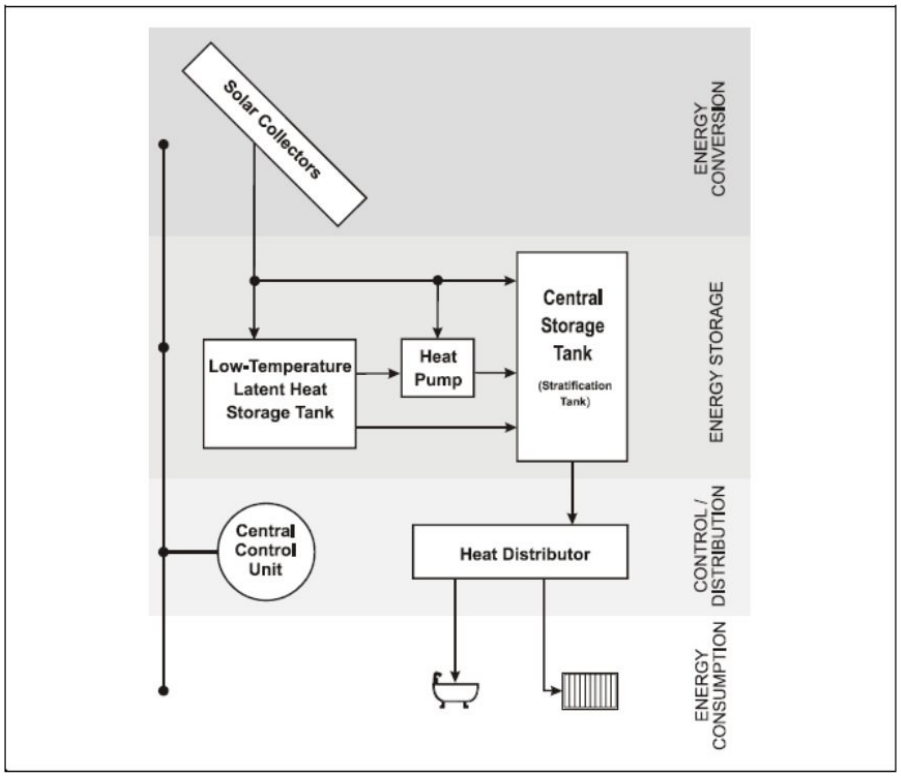


Figure 7: Solar heat pump heating system with latent and stratified thermal storages (Trinkl, 2006).

2.5 A Domestic Solar Heat Pump Heating System with Latent and Stratified Thermal Storages

Another variant of HGCHP system is presented in Trinkl (2006). It consists of solar thermal collectors, heat pump, stratification tank, latent heat thermal energy storage tank with low-temperature, heat distributor and central control unit (Figure 7). The latent storage has water as a medium (it can have a temperature down to -5°C). The heat from the solar collector can enter directly the stratification tank or the latent storage (depending on the available solar radiation). When needed the heat pump can transfer the

energy of the latent storage to a usable temperature level (+35°C to +50°C) in the stratification tank. The authors have focused on two purposes - heating system development and latent heat store development.

3. BULGARIAN TEAM EXPERIENCE ON HYBRID THERMAL SYSTEMS

Some Bulgarian scientists from Plovdiv started in 2005 the creation and investigation in Plovdiv of GCHP system (Technical University of Sofia, Plovdiv Branch and Plovdiv university Paisii Hilendarski). Some of them have international experience in the same field. Several HGCHP systems are discussed below.

3.1 Ground Heat Exchanger Coupled with Phase Change Materials (PCMs)

A scientific team proposed to mix the micro-encapsulated PCMs directly with the backfill material which is close to the ground heat exchanger (GHE) or to install them in a surrounding shell (Bottarelli et al, 2015). Use of the PCMs incorporated with GHEs may meet some instantaneous heating demand by a GCHP, thus reducing the sudden heating or cooling wave upon the ground. Therefore, the peak temperature would be lower with the same GHE length, or the GHE length could be shorter with the same peak temperature. The performance of the novel GHE design with PCMs is currently being analyzed by means of an experimental setup and a numerical approach.

The model domain considers a cross-section which consists of a PCM layer and a large part of the surrounding soil. The PCM layer is a mix of micro-encapsulated paraffin, water and soil with specified mass ratios. The coupling sketch of one-half symmetric model domain of a GHE with a heat pump is shown in Figure 8.

The application has been evaluated through numerical modeling to solve transient heat transfer using effective heat capacity method. Annual performance has been simulated by taking into account the estimated energy requirement for an assumed residential building located in Northern Italy. According to hourly time series boundary conditions and annual performance, the simulation results show that the use of PCMs is able to smooth the thermal wave in the ground, to improve the coefficient of performance of the heat pump (COP) and, if suitably sized, to prevent thermal depletion in winter by charging the PCMs naturally in summer with a shallow GHE.

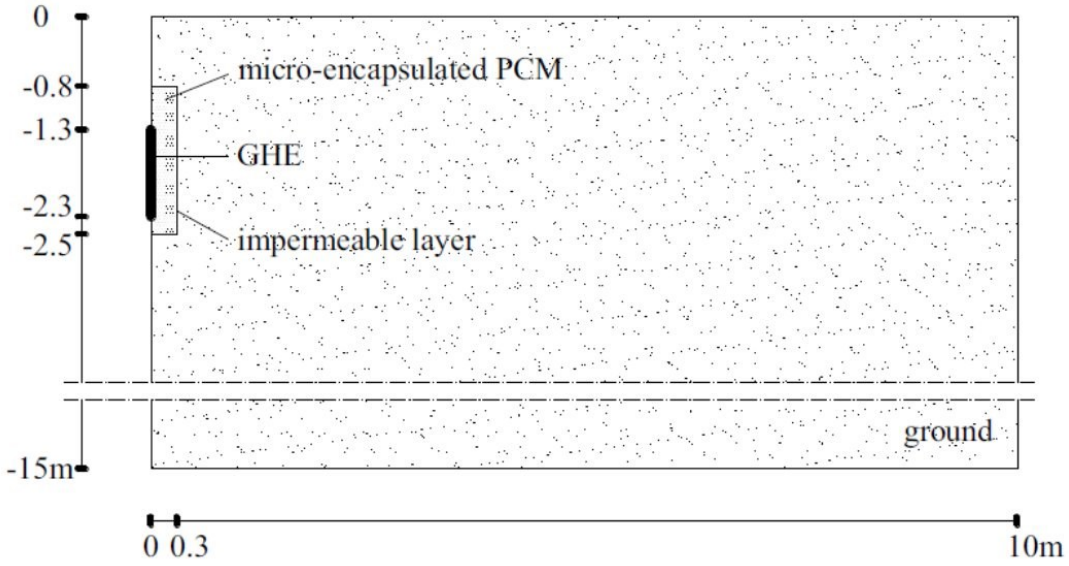


Figure 8: Coupling sketch of one-half symmetric model domain of a GHE with a heat pump (Bottarelli et al, 2015).

In order to assess the PCM effect on the thermal behavior of GHEs, a finite element model was implemented to simulate the heat transfer performed by a GHE with and without a PCM layer attached to its surface. The numerical tool used here is commercial software (COMSOL V4.3a), in which the heat transfer problem is solved for a soil section where the GHE is buried. To analyze the suppression of heat wave by the PCM, the GHX was assumed to be operating according to a daily schedule, in which ON/ OFF periods are alternated (Bottarelli et al, 2013).

Figure 9 also shows the measurement points, which are placed at 0, 50 and 100 mm away from the flat panel. The first point is for the temperature measurement at the interface between the GHE and the PCM layer, while the other two points show the temperature of the ground at different distances.

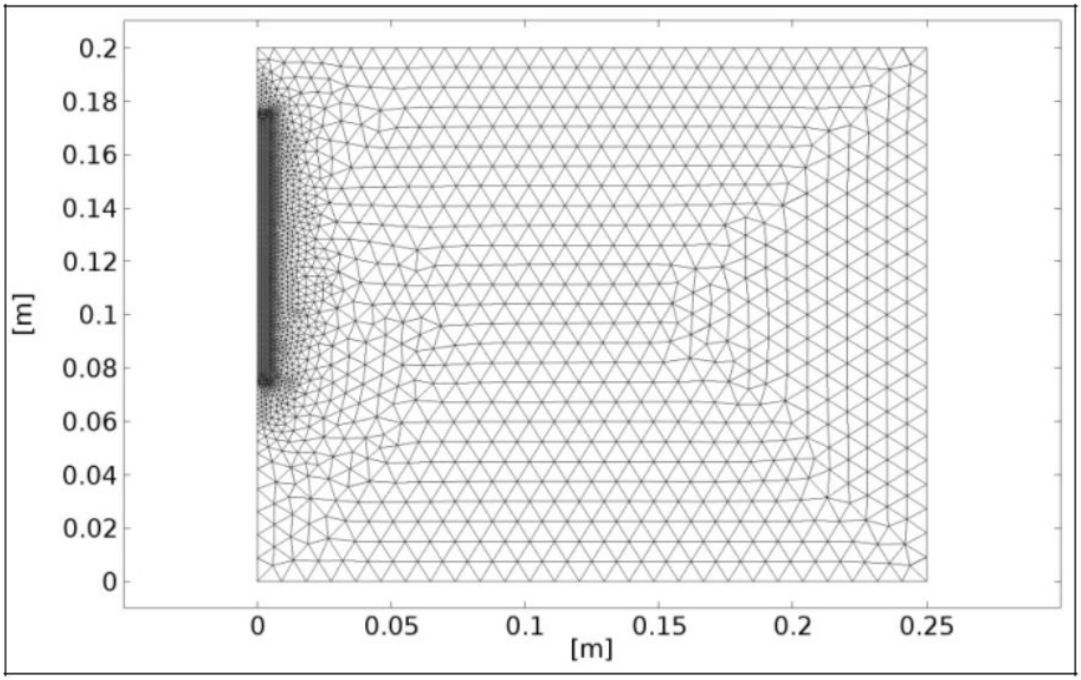


Figure 9: Meshed domain of the model (Bottarelli et al, 2013).

3.2 Hybrid GCHP Installation in Plovdiv, Bulgaria

A test installation with solar collectors charging a phase change material (PCM) storage, borehole storage and a heat pump was developed recently at the Technical University of Sofia, Plovdiv Branch. The main goal of the team is to perform different modes with the installation using the different storages. A photograph of the interior section of the hybrid installation is shown in Figure 10.



Figure 10: Interior laboratory view of the hybrid installation.

The scheme of the installation is presented in two figures by strategic reasons (Figure 11 and 12). Sophisticated methods for analysing an obtained data set have been used by implementing a Supervisory Control and Data Acquisition (SCADA) system, which also allowed remote control and supervision via Internet.

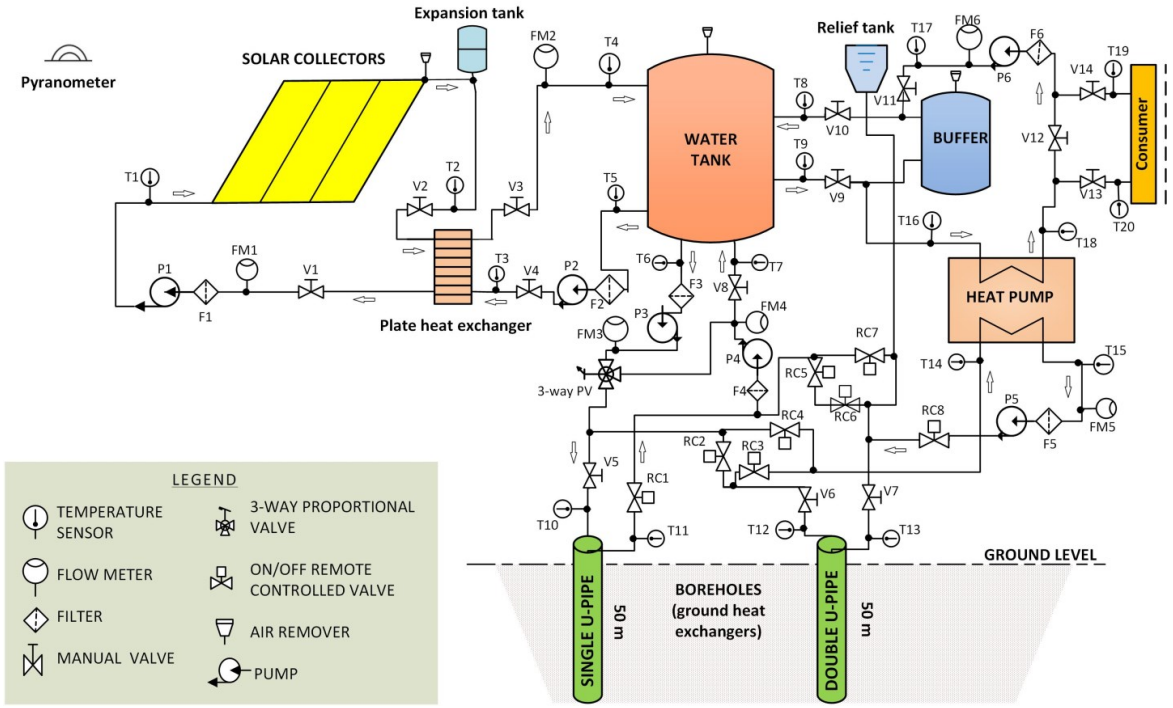


Figure 11: Set-up of the hybrid Ground Coupled Heat Pump system with solar collectors (Toshkov et al, 2014).

The installation containing borehole heat exchangers consists of the following main parts:

Solar collectors: flat glazed type, PK Select-CL "Sunsystem" Ltd - Bulgaria, 3 pieces each with 2.15m² absorption surface of copper, coefficient of absorption/ reflection – 95%/5%, heat carrier – 20% water-propylene-glycol solution. The collectors are coupled in parallel scheme on the roof of the building and equipped with thermal regulator, pump station WILLO-SOLAR 20/6 (P1), expansion tank 12 dm³, power supply unit IN-100K and air remover. The produced heat power of about 600 kWh/m²/year is supplied to the next element of the system - the plate heat exchanger (Toshkov et al, 2014).

Brazed plate heat exchanger: GEA type GBS-100M-20 with 20 plates 74x204 mm, overall heat exchange surface and power are 0.3 m² and 40 kW respectively (Figure 11). The maximum flow rate is till 4 m³/h, outputs and inputs have a size of 3/4 inch. The heat from the solar loop is transferred to water storage tank through plate exchanger by means of pump (P2).

The other part of the installation (containing latent storage) is used to study a latent heat accumulator charged by solar energy, which is a part of developed hybrid system for air conditioning (Figure 12). Various paraffins will be used in the latent heat accumulator as PCM (Stoyanov et al, 2013). Eight species of paraffins were selected as the most appropriate (in price and technical parameters). They were purchased and tested. As a result of the experiments 3 types of paraffins (with the highest latent heat) were selected - E46, E53 and ECP.

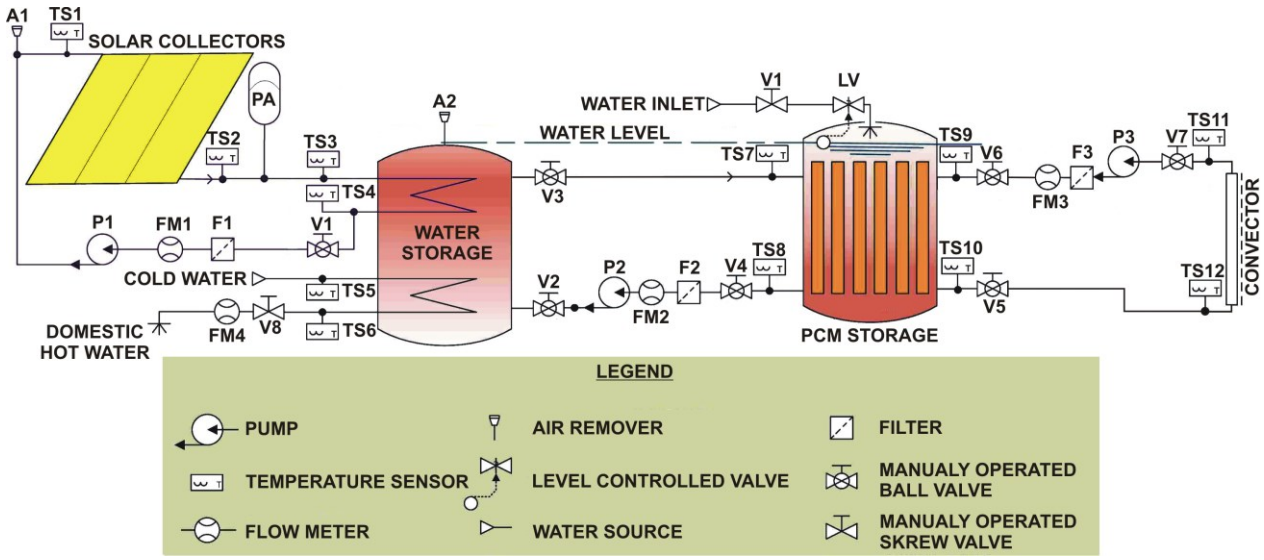


Figure 12: Set-up of the installation containing storage with phase change materials (Stoyanov et al, 2013).

Some containers are situated in the storage. They contain the different types of paraffin (there is an opportunity to change the paraffins and the containers). The tank and the containers of the storage are made of stainless steel grade AISI 304 L (Figure 13). The number of the containers is 39. They have a rectangular cross section with the following dimensions: 80 x 50 x 1,5 mm. They are coaxially disposed in the storage. There are two concentric circles - one external with 26 pieces and another internal with 13 pieces containers. Brackets are placed in the tank for relief insertion and removal of the containers - both in the upper and lower part. The brackets provide reliable fixing of the containers in the storage. The brackets are fixed to the threaded perforations of the concentric situated bearing rings on the inner and outer circle of the containers. The bracelets on the lower row are welded to the tank bottom; at the same time the bracelets on the upper row are fixed to the storage by means of 3 studs (the difference between every two studs is 120°).

The thermal storage has 3 outputs (they are centrally located on the bottom of the tank). Additionally are available 3 inputs which are located in 120° angle on its periphery. The storage is insulated with mineral wool having a thickness of **d**=50 mm.

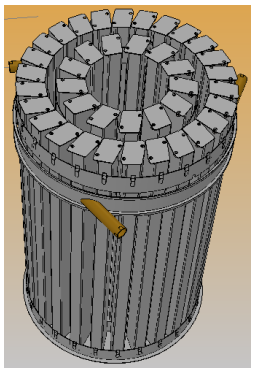


Figure 13: Inner construction of the latent thermal storage (Stoyanov et al, 2013).

Several modes can be performed with the above described installation (the first 5 regimes have been already realised in the laboratory of TU Sofia, Plovdiv Branch).

- charging of the water storages;

- charging of the borehole storage;

- direct solar heating;

- ground-coupled heat pump heating;

- solar-assisted heat pump heating;

- ground-coupled heat pump cooling.

- production of domestic hot water;

- combined usage of the different storages (water storage, borehole storage and latent accumulator).

CONCLUSIONS

The most important conclusions connected with the hybrid geothermal systems are as follows:

1. The most effective use of GCHPs is for combined heating (in winter) and cooling (in summer).

2. Hybrid installation combines technical and economic advantages of different installation components (decreasing of the initial system costs and improving the performance of the HGCHP system).

3. Selection of appropriate components of HGCHP is directed to different climates and regions.

4. The well designed HGCHP systems adjust the unbalanced loads of heating and cooling in the buildings.

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