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# Long term experience and research on hybrid thermal systems

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There are different types of hybrid thermal systems. The term "Hybrid system" usually refers to at least two types of installations. They possess elements such as a Phase Change Material (PCM) storage, a heat pump, solar collectors, heat rejecters, a seasonal water storage and an underground thermal energy storage, which can be combined with an electrical apparatus (e.g. Photovoltaic/ Thermal.(PV/T) collectors) and a second heat pump. The aim of the hybrid thermal installation is to improve the system's energy efficiency. The article discusses different configurations of hybrid thermal systems. At the same time the article presents the long experience of the members of the scientific team at the Plovdiv Branch of the Technical University of Sofia and the research they have done on hybrid thermal systems. The prospects for future developments are also mentioned.

**Keywords:** hybrid thermal systems, renewable energy sources, underground thermal energy storages

## INTRODUCTION

A thermal system is a unit that consists of several components. There are not only thermal elements inside the aggregate - electrical and mechanical parts are available, too. What a hybrid system is, still remains without a concrete answer. Usually the term "Hybrid system" refers to at least two types of installations.

There is a great variety of hybrid thermal systems. Three types are presented in this article, namely the solar hot water supply system with a phase change material (PCM) and water hybrid storage system [1], the renewable energy sourced hybrid heating system combined with a latent heat storage and a heat pump [2] and the hybrid photovoltaic/ thermal (PV/T) system [3].

Other very popular type of hybrid thermal systems in the last decades is the Ground Source Heat Pump (GSHP) system. It contains underground thermal energy storages and one or more heat pumps of different possible types. If we combine them with another kind of equipment with the aim of improving the system's performance, we get the so-called hybrid GSHP (HGSHP) systems. A number of these HGSHPs are an object of discussion in this paper: HGSHP systems with solar collectors [4], HGSHP systems with hot water supply [5], HGSHP systems with supplemental heat rejecters [5], Hybrid storage systems for seasonal thermal energy storage in solar district heating [6], Cool thermal energy storage (BTES-PCM) for peak shaving [7] and Hybrid ground-coupled heat pump systems for air conditioning [8].

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Some of the members of the scientific team at the Technical University of Sofia, Plovdiv Branch, participated in the design, construction and study of several hybrid thermal installations. The charging and discharging of a hybrid installation with solar collectors and Borehole Thermal Energy Storage Systems (BTES) [9], a novel ground heat exchanger coupled with phase change materials [10], a hybrid PV/T system at TU-Sofia, Plovdiv Branch [11], and a hybrid GSHP installation in Plovdiv [12] are presented in the current work.

## HYBRID THERMAL SYSTEMS

Although there is a big variety of hybrid thermal systems, only three of them are discussed below. They do not include any underground device, but the installations contain components such as PCM storage, heat pump, high temperature solar collectors and even a combination with electrical facility (for example PV/T solar collector) - system elements which have not been used much in the past, but are becoming more and more popular during the last three decades.

### *Solar hot water supply system with a PCM/ water hybrid storage system*

Nagano et al. [1] propose an installation with evacuated solar collectors and a PCM storage for domestic hot water (DHW) production [1]. It has three heat-pipe type vacuum tube solar collectors (VSC), which contain 70 vacuum tubes with a total collector area of 7 m². The storage system consists of a water storage (250 l) and a PCM storage (76 l). The PCM used is a mixture of $Mg(NO_3)_2$•$6H_2O$ and $MgCl_2$•$6H_2O$, which has a melting temperature of 59,7 °C and a heat of fusion of 161,2 kJ/kg (Fig.1).

The charging mode includes the operation of circulation pump (4) during the day. The pump moves a brine mixture through the PCM and the water storages. The pump is switched ON when the temperature difference between the collector inlet temperature of the brine and the outlet water tank temperature of the brine is higher than 3°C. After leaving the solar collectors (1) the brine heats first the PCM device (3) and then is delivered to the water storage (2). A by-pass pipeline is used to directly charge the water storage tank, if the collector outlet brine temperature is lower than the PCM temperature (the corresponding magnetic valves (6) are switched ON or OFF after receiving temperature regulator signals).

The discharging mode occurs during the night. About 500 l tap water is delivered to the bottom of the hot water tank. The water is heated initially in the water tank and after that it enters the PCM storage for additional heating to a higher temperature. The final needed temperature is about 42°C. If the outlet water temperature is higher than 42°C, a mixing with tap water takes place - the temperature sensor sends a signal to the magnetic valve (8). If the described system cannot produce water with a temperature of 42°C, an auxiliary heating source is used for additional heating.

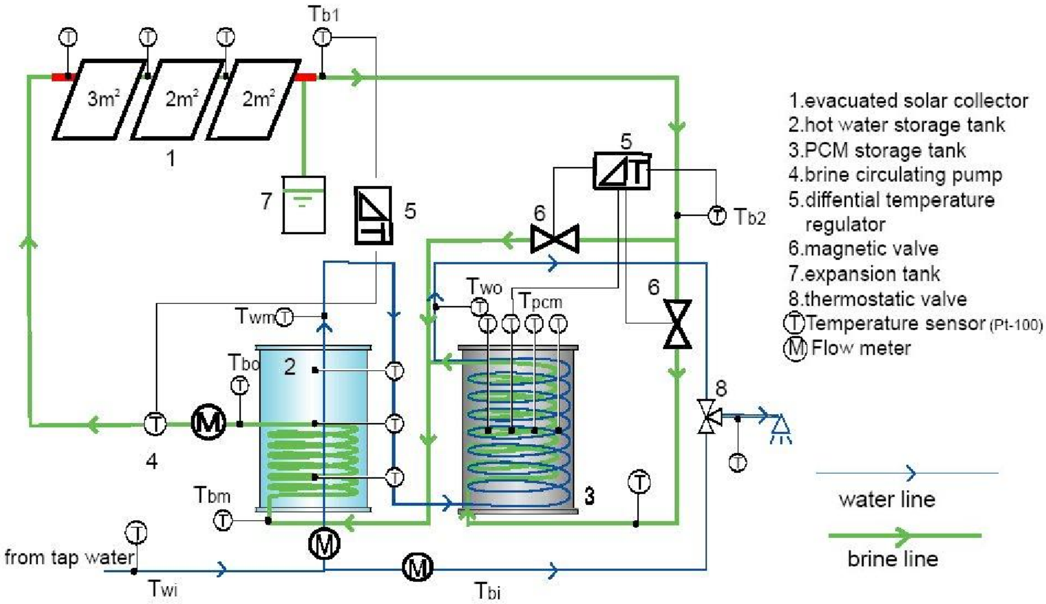


**Fig.1.** Solar hot water supply system with a PCM/ water hybrid thermal energy storage system [1]

*Renewable energy sourced hybrid heating system combined with latent heat storage*

A hybrid thermal system is set up at the Davutpasha Campus in Turkey. The installation contains three main components - solar collectors (SC), a heat pump (HP) and a latent heat storage (LHS) [2]. It is used for heating the Yildiz Renewable Energy Building (YREB).

Fig.2 shows the installation setup. In addition to the SC, HP and the LHT accumulation tank (AT), a wall heating system is available. The two installed flat plate solar collectors have a total surface area of 3,24 m². The collectors, with a theoretical efficiency of 85%, are connected to the latent storage serially. The on-off controlled circulating cycle pump has an electrical power of 100W. The latent heat storage has a steel construction and is painted black. Its external size is 0,22 m³. The paraffin is enclosed in a case with a volume of 0,063 m³. The PCM used is paraffin with a melting point between 42 and 44 °C. The working fluid delivered by the solar collectors circulates around the paraffin case within the latent heat storage. Additionally, there is a water gap in the middle of the storage with a diameter of 0,1m.

The latent storage is charged by the heat delivered from the solar collectors during the daytime. A circulating pump is switched ON if the water temperature in the latent storage is higher than 45 °C. In this way it delivers the water to the well-insulated water storage (AT). The temperature in the AT must be 45°C because the temperature regime of the wall heating is 45–35 °C. If the outlet water LHT temperature is lower than 45°C, the water is delivered to the heat pump with the aim of raising its temperature. The heat pump does not work if the water temperature in the water tank is higher than 45°C. This leads to relatively big energy savings. The computer software DALI (Data Acquisition and Logging Interface) and TELECONTROL are used to show the temperatures at the different measuring points. A comprehensive experimental energy and exergy analysis of the system components, as well as of the system as a whole, has been performed.

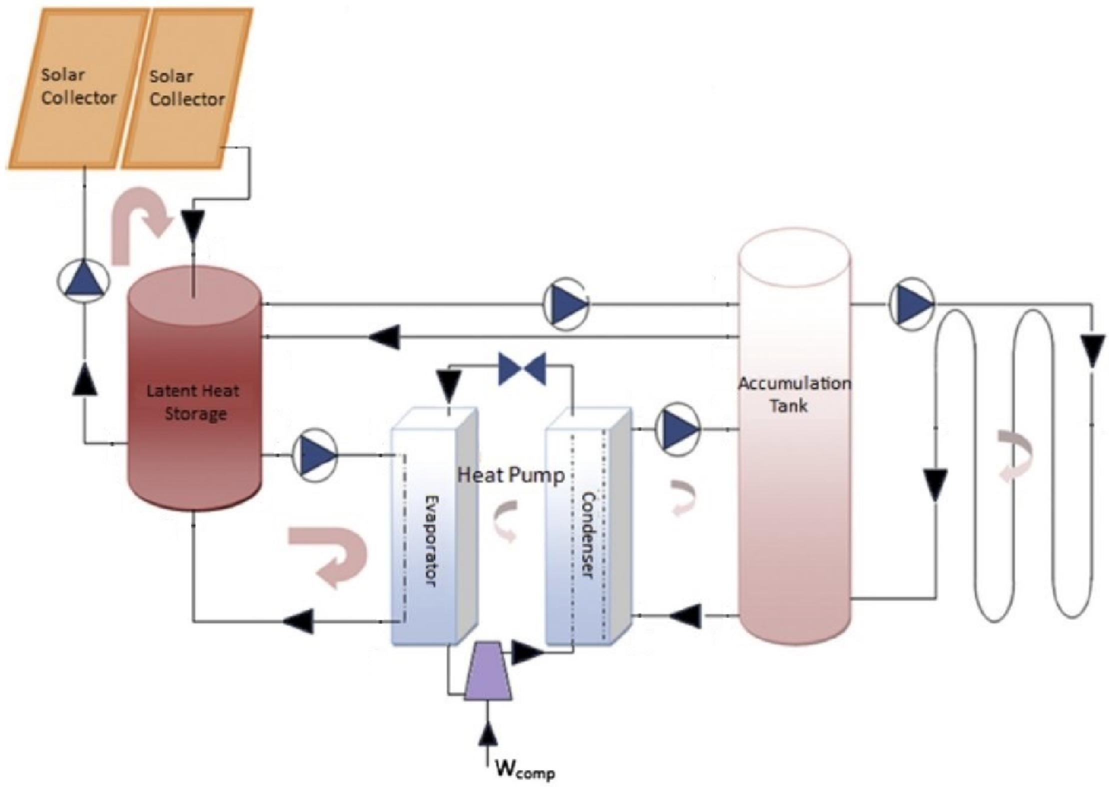


**Fig.2.** Renewable energy sourced hybrid heating system combined with latent heat storage [2]

*Hybrid PV/ T systems*

A combination of collectors which produce both heat and electricity is not uncommon. These solar collectors are called photovoltaic - thermal (PV/T) collectors. Such a collector construction has the following advantages [3]:

- the electrical efficiency of the combined PV/T collector is higher than that of the plain photovoltaic panel;
- the uniformity on the roof typical for the PV/T collectors is better compared to a separate thermal collector and a PV panel;
- the mounting of one instead of two installations is a precondition for reducing the capital expenses.

There are nine design concepts available. They can be divided in four different groups [3]. Their sketches are presented in Fig.3:

**1. Sheet-and-tube PV/T-collectors** (Fig.3A). A metal serpentine pipe of any kind is placed on the back side of the standard simplest photovoltaic panel. When this pipe is covered with an insulation, a Sheet-and-tube construction of a PV/T-collector is produced.

**2. Channel PV/T-collectors** (Fig.3B). There is a channel with a liquid which has direct contact with the PV area. The use of water can diminish the electrical efficiency with up to 4%. An additional disadvantage is the level of liquid transparency which leads to a further decrease in efficiency.

**3. Free flow PV/T-collectors** (Fig.3C). In this construction the additional glass layer between the gas and the liquid, which is available in the Channel PV/T-collector construction, is missing. Thus the two different fluids are mixed. However, one disadvantage is the higher evaporation leading to additional decrease in efficiency. The losses due to fluid transparency are similar to the channel PV/T-collectors.

**4. Two-absorber PV/T-collectors** (Fig.3D). There are two PV panels. The upper one must be transparent. There are also two water channels. Thus the liquid (eventually water) passes through the upper channel and exits through the lower one.

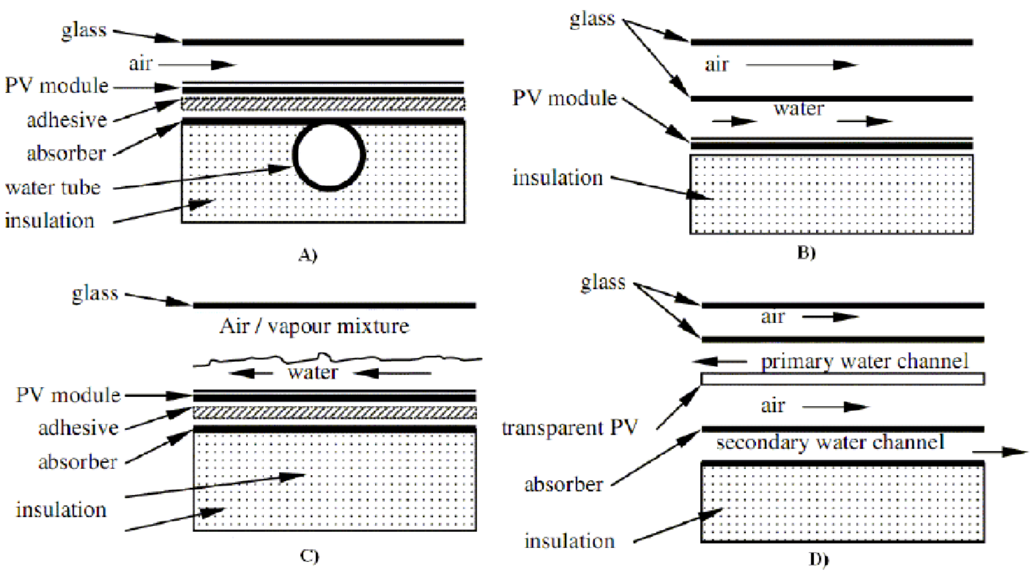


**Fig.3.** Different types of water cooled flat PV/T collectors [3]

## HYBRID GSHP SYSTEMS

The Ground source heat pump (GSHP) systems consist of an 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 (Fig.4). In both cases a larger area of borehole heat exchangers (BHEs) is needed, which reduces the system's efficiency [13]. A good solution to the problem is to diminish the capital costs by means of a heat rejecter or a heat absorber, thus obtaining the so-called hybrid GSHP (HGSHP) systems.

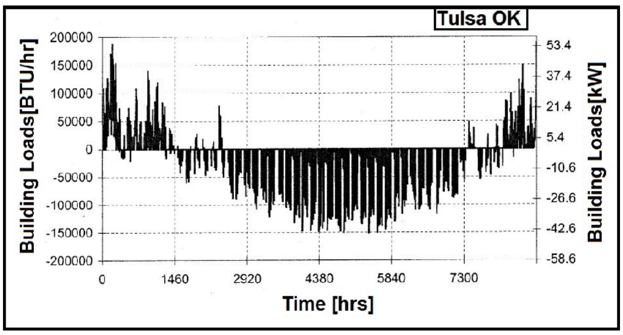


**Fig.4.** The region of Tulsa, Oklahoma with a relatively moderate climate (cooling loads are negative and heating loads are positive) [13]

Seven different constructions of HGSHP systems are discussed below. They possess additional components such as solar collectors, heat rejecters, a seasonal water storage, a PCM storage or an additional heat pump.

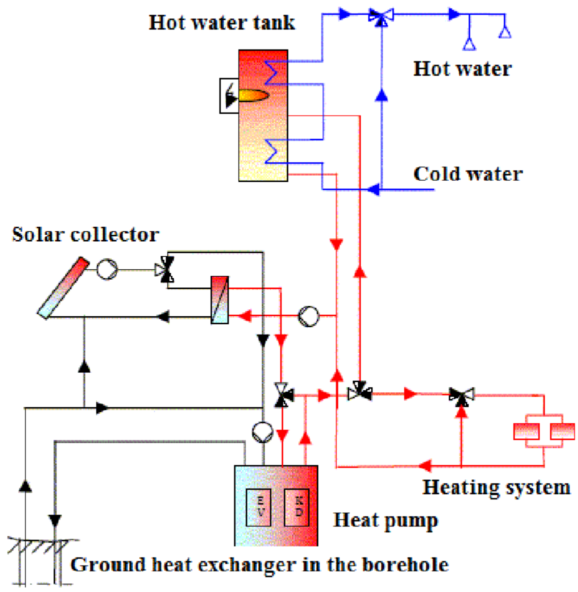


**Fig.5.** Example of a system with solar collectors in combination with a ground-source heat pump [4]

### *HGSHP systems with solar collectors*

About 40 years ago the ground was used only as a heat source. The practice shows that there is a heat depletion at the place of use. That means that in regions where more heating is needed the inlet fluid temperature in the heat pump evaporator is going to decrease in the course of a long period of time. The use of solar collectors for example is a good opportunity to raise the temperature of the used ground area. So the capital costs (in this case the number of the BHEs) will decrease significantly. An example of a system with solar collectors which are combined with a heat pump and borehole heat exchangers is presented in Fig.5.

*HGSHP systems with hot water supply*

The production of domestic hot water (DHW) requires higher temperature. Heat is normally produced by burning fossil fuels or using electrical heaters. One interesting opportunity is the DHW production by means of HGSHP systems during a cooling season. A device called desuperheater (a small additional heat exchanger) can be installed near the heat pump compressor [5]. In this way the excess heat obtained by condensation is used to heat a certain amount of DHW (Fig.6).

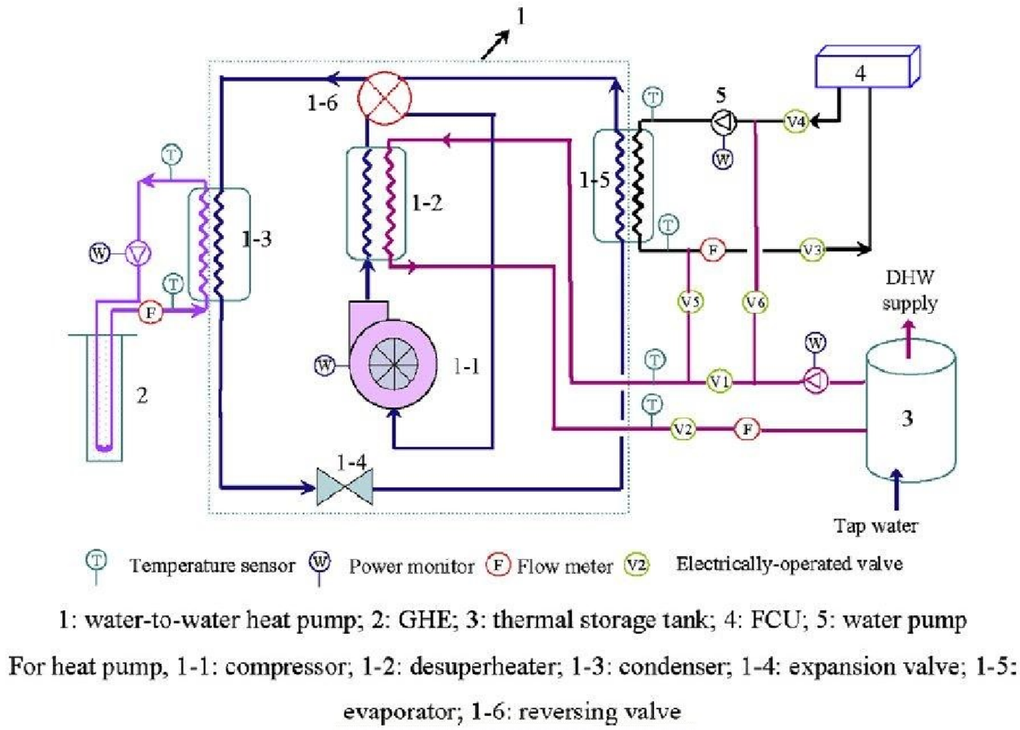


**Fig.6.** Schematic diagram of the HGSHP with a DHW heating system [5]

*HGSHP systems with supplemental heat rejecters*

Assuming that the building is in a region with dominating cooling regime such as Tulsa, Oklahoma (Fig.4). HGSHP systems can be used in this case. However, it is better to have an additional cooler during the cooling season (in order to avoid the capital cost for more BHEs). A good solution in this case is to include a cooling tower with the aim of cooling the BHEs which are connected to the condenser of the GSHP [5]. An example of this type of system is shown in Fig.7. The HGSHP system has a cooling tower which is connected in series with the ground loop (there is a heat exchanger between the boreholes and the cooling tower).

*Hybrid storage system for seasonal thermal energy storage in solar district heating*

There are different types of seasonal thermal storages that are constructed under the ground. The convective storage with water as a medium is called pit storage. The conductive storage type with the soil as a medium is called duct storage (or borehole thermal energy storage, BTES). There is also a mixed type of underground storage - it is called aquifer thermal energy storage [14].

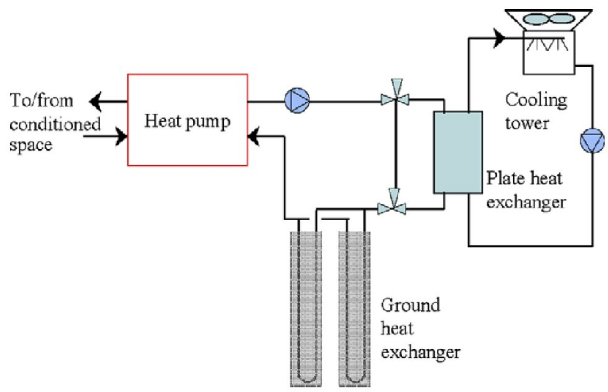


**Fig.7.** Schematic diagram of a HGSHP with cooling tower [5]

The convective storage can be heated up to 90°C (this is the requirement for implementing solar district heating). In addition, its medium can be used as a working fluid. Unfortunately the construction of a storage of this type is relatively expensive. The BTES is, to the contrary, relatively less flexible than the convective storage (there is an additional exchange process from soil to fluid and vice versa), but its construction costs are lower than the costs of building a convective storage.

A combination of the above-mentioned storages is suggested in Müller and Reuss [6]. It consists of a pit storage which is surrounded by a number of boreholes (BTES). There is no need for expensive insulation for the pit storage - the thermal losses reduce drastically due to the heat that is directed to the surrounding boreholes (Fig.8). On the other hand, the low potential heat coming from the solar collector is delivered to the BTES (if its outlet temperature is not high enough and thus not appropriate for the pit storage). The described storage combines the economical and operational advantages of both the convective and the conductive storage types.

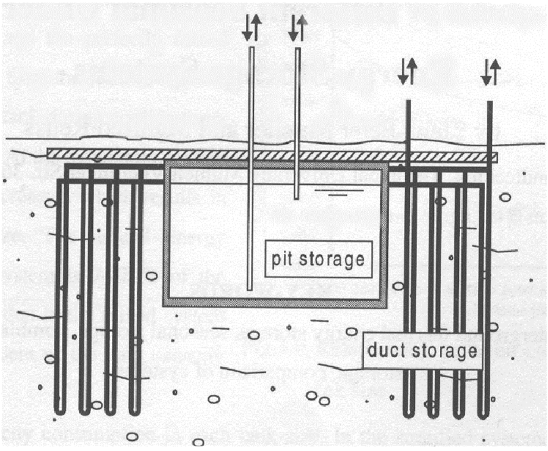


**Fig.8.** Hybrid pit/ duct store [6]

*Cool thermal energy storage (BTES-PCM) for peak shaving*

Underground thermal energy storages (UTESs) are used in Sweden in cooling mode during the summer. The BTES systems are usually connected to mechanical chillers with the aim of covering the cooling peak load in the afternoon. The use of a PCM storage can replace the chillers and avoid the relatively high electrical energy consumption. The set-up of such a system is presented in Fig.9. The BTES is presented in the diagram as a seasonal storage which is charged by using heat pumps for cooling in winter. After that, in the summer, the stored cooling is used to cool the buildings. Unfortunately there are peak loads in the afternoon. The installation that includes a PCM storage is designed for peak shaving. That means that the PCM storage is charged for about 6 hours at night using the BHEs at an approximate rate of 50 kW. This cooling is used in the afternoon (for about 3 hours) when the PCM storage is discharged with a rate of 100 kW.

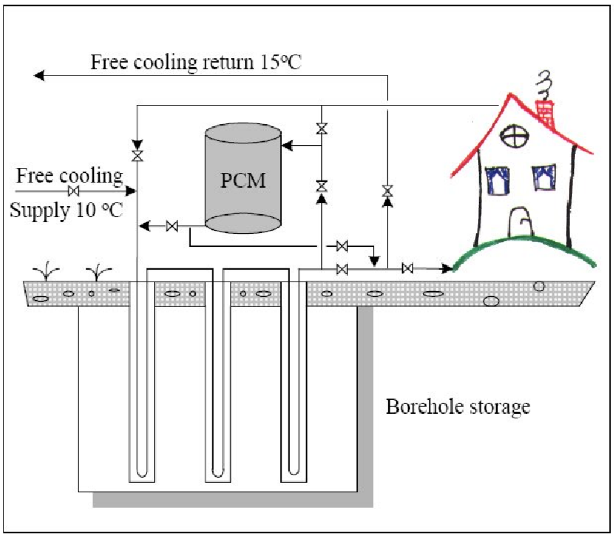


**Fig.9.** A combined BTES-PCM cool storage air conditioning system [7]

*Hybrid ground coupled heat pump system for air conditioning*

Several layouts of hybrid ground coupled heat pump systems for air conditioning are presented in Pardo et al. [8]. The main installation elements are a water to water heat pump (WWHP), an air to water heat pump (AWHP), a thermal storage device (TSD), an air fan (AF), a ground heat exchanger (GHE), an internal as well as an external water pump (IWP, EWP) and a storage water pump (SWP).

Fig.10 shows one of the proposed hybrid systems (configuration A). The aim of the installation is to cool the buildings in regions where the cooling season is longer than the heating season (e.g. Valencia, Spain). Two types of heat pumps are used because they are connected to cold sources which have different temperatures during the day and during the night.

The presented configuration has an AWHP which is switched on during the night because the air temperature then is lower than the ground temperature. This is how the TSD is loaded. The IWP is switched on during the day with the aim of cooling the building. If its capacity is not enough, the WWHP is switched on. The by-pass connection near the storage is used when the outlet fluid storage temperature is higher than the inlet fluid storage temperature.

The proposed configuration is expected to improve the system energy efficiency during the cooling season in regions with dominating cooling loads.

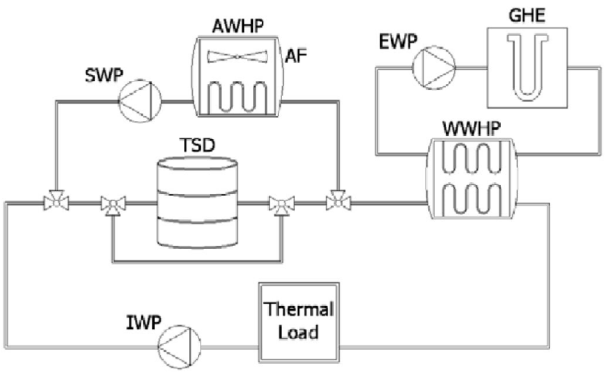


**Fig.10.** Hybrid configuration type A [8]

## BULGARIAN TEAM EXPERIENCE ON HYBRID THERMAL SYSTEMS

A scientific team was created at the Technical University of Sofia, Plovdiv Branch, in 2005. Its long experience includes work in the field of Renewable Energy Sources. The main subject of investigation was hybrid thermal systems and their components. Several of the team members had previous or parallel work in the same research area with other research groups abroad. Several hybrid systems in different types of studies are presented below.

### *Charging and discharging of hybrid installation with solar collectors and BTES*

A hybrid installation with solar collectors and Borehole Thermal Energy Storage (BTES) was set up in 2003 at the "Solar Energy Laboratory" of the Technical University Federico Santa Maria (UTFSM) in Valparaiso, Chile with the participation of Prof. A. Georgiev [9]. The shallow Borehole Heat exchanger (BHE) was used to carry out an in situ determination of ground thermal conductivity λ, borehole thermal resistance $R_b$ and undisturbed soil temperature. This technique is commonly known as Thermal Response Test (TRT). The first stage of the setup preparation included three perforations along a line to a depth of about 22 m followed by the implementation of the TRT.

At the second stage of the setup preparation, just after completing the TRT, the installation was remodelled. Three solar collectors with a total active area of about 4,4 m² were connected to the BTES. This configuration of the installation was used to charge the ground by means of solar energy (natural experiment). This charging took place in the course of 29 days (from 18th of August to 16th of September 2003).

After the charging cycle a new modification was introduced to the hydraulic system. One loop of a cross-flow water-water heat exchanger was connected to the BHE circuit instead of the solar collectors, while the other loop fed the heat exchanger with tap water (Fig.11). An old automobile radiator was adapted to work as the cross-flow water-water heat exchanger. The discharging mode started on the 17th of September and ended on the 30th of September 2003. The corresponding temperatures and flow rates as well as the solar insolation were measured and recorded during the second and third stages of the study.

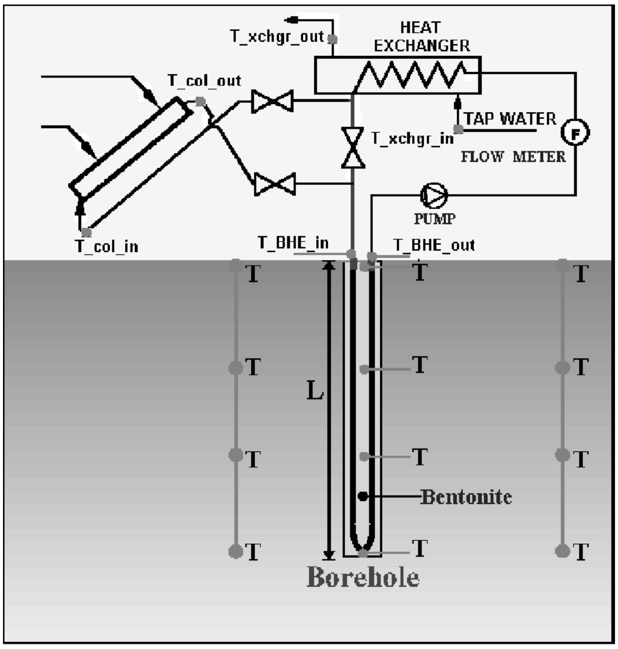


**Fig.11.** Diagram of the test installation during charging and discharging [9]

### *Novel ground heat exchanger coupled with phase change materials*

Employing Phase Change Materials (PCMs) is an effective measure to store thermal energy and it may also be used as an effective method to smooth the thermal wave generated from the operation of a GSHP. The approach is known when the PCMs are introduced directly in a tank within a closed loop, especially for vertical closed loop. However, using a tank containing PCMs could be an expensive solution for the horizontal closed loop ground heat exchanger (GHE) system, due to the low energy performance of the PCMs. Moreover, the heat transfer may not be effective for the bulky PCM tank.

The international scientific team proposed to mix the micro-encapsulated PCMs directly with the backfill material which is close to the GHE or to install them in a surrounding shell [10]. Use of the PCMs incorporated with GHEs may meet some instantaneous heating demand by a GSHP, 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 analysed by means of an experimental setup and a numerical approach.

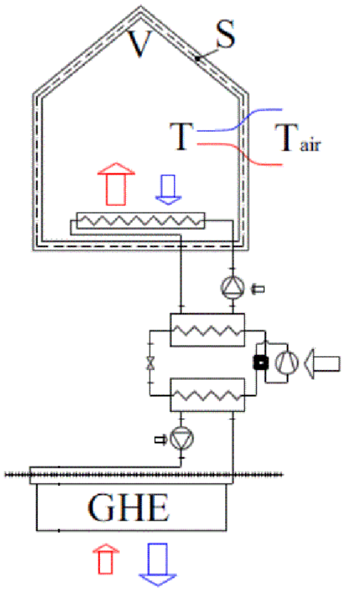


**Fig.12.** Coupling sketch of one-half symmetric model domain of a GHE with a heat pump [10]

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 Fig.12.

The application has been evaluated through numerical modelling 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.

*Hybrid PV/ T system at TU-Sofia, Plovdiv Branch*

An installation for testing of photovoltaic (PV) solar panels was set up in 2010 at the Technical University of Sofia, Plovdiv Branch (Fig.13). The main parts of the installation are a combined PV/T solar panel 1 and an ordinary photovoltaic solar panel 12. A circulation pump 2 is used to move the cooling fluid through the combined panel and the thermostat tank 3 - it is used to maintain a constant temperature through the PV/T panels. A PT100 Signal Conditioner 5 is used to measure the temperature. The signal is then sent to a data logger 6 and processed using a Laptop or a personal computer 7. An integrated solarimeter/ anemometer 8 is used to measure the global solar radiation and the wind velocity. The pyrheliometer 9 measures the direct solar radiation by means of the sun-following system (sun tracker) 10 and the direct solar radiation measurement unit 11. The current/ voltage signal conditioners 13 are utilized to measure the electrical power obtained from the sun [11].

The experiment was carried out during 2 days – 26 and 27 of May 2010. 7 tests were done. Each test had a duration of about 15 min. The following parameters were measured: intensity of the global solar radiation (using the integrated solarimeter), ambient temperature, flow rate, inlet and outlet fluid temperature trough the PV/T panel, thermal power produced by the PV panel and electrical power produced by the PV/T panel. The produced thermal power from the PV/T panel, the ratio of electrical power produced by PV/T panel to PV panel and the ratio of thermal to electrical power produced by PV/T panel were calculated.

The test results show that:

- the gained thermal power in the PV/T panel is about 9 times higher than the gained electrical power in the temperature interval (20 till 50°C);
- the effect of the increased electrical production in the PV/T panel is relatively stable over a long temperature interval;
- the cooled PV/T panel produces about 3% more electricity than the PV panel in the whole temperature interval.

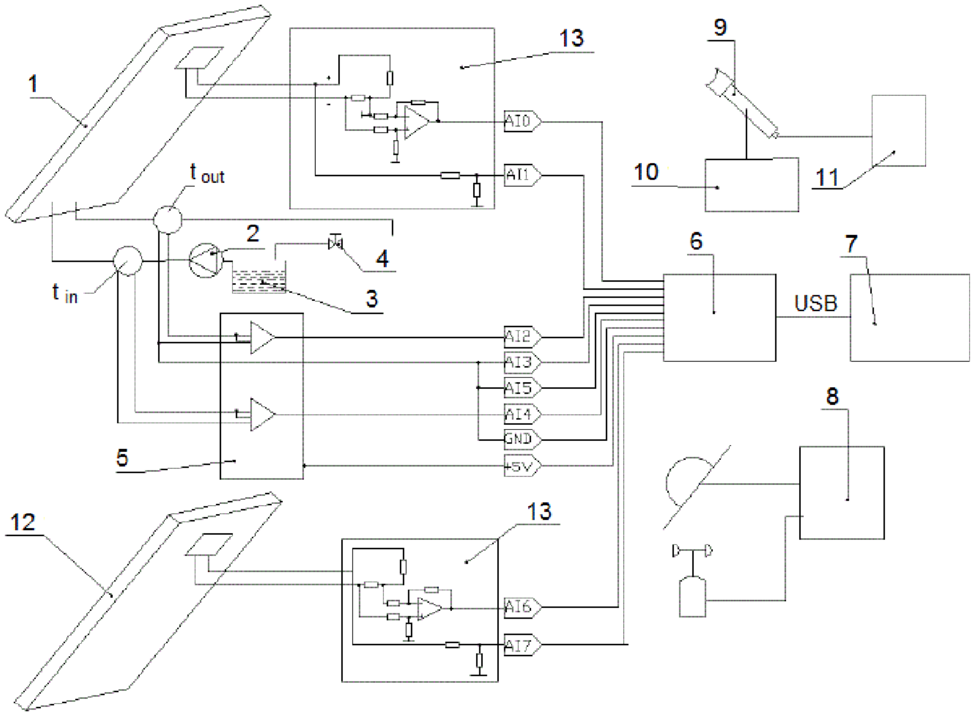


**Fig.13.** Installation setup of PV/T system in Plovdiv [11]

*Hybrid GSHP installation in Plovdiv*

In 2013 a test installation with solar collectors charging a phase change material (PCM) storage, a borehole storage and a heat pump was developed at the Technical University of Sofia, Plovdiv Branch. The main aim of the scientific team was to evaluate different types of phase change materials that could potentially be used in domestic heating, cooling and hot-water systems for daily accumulation storage. A ground borehole heat exchanger loop was also added. A photograph of the interior section of the hybrid installation is shown in Fig.14.


**Fig.14.** Interior laboratory view of the hybrid installation

In the experiments a large number of parameters (temperatures, flow rates, solar radiation values, electrical consumption etc.) have to be logged and monitored for a long period of time. 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. The National Instruments LabView package was used in this study to develop user-friendly virtual instrumentation for the research.

**1. Construction of the system**

The installation is located in Plovdiv, Bulgaria, at the campus of the Technical university of Sofia, on the 4-th floor. Its test setup is presented in Fig.15. The main components of the installation are: solar collectors (SC), a hot-water storage (200 l), a latent heat storage (300 l), a water-water heat pump (inverter type), a cold-water storage (150 l), two borehole heat exchangers (BHEs), two expansion tanks, a flat panel heat exchanger and a fan-coil convector [12]. The installation is designed to ensure that there is no pressure in the PCM storage tank, which allows the sensors to be easily placed inside.

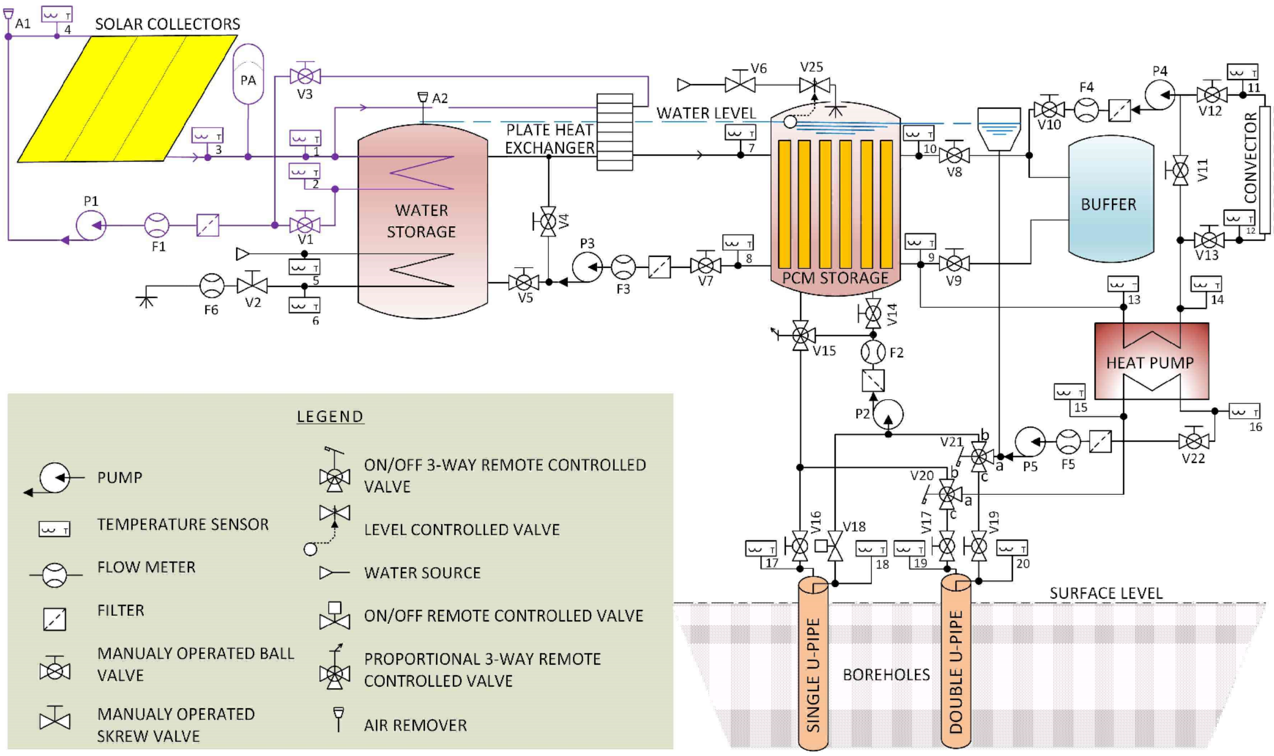


**Fig.15.** Diagram of the hybrid installation (GSHP with SC and PCM storage) [12]

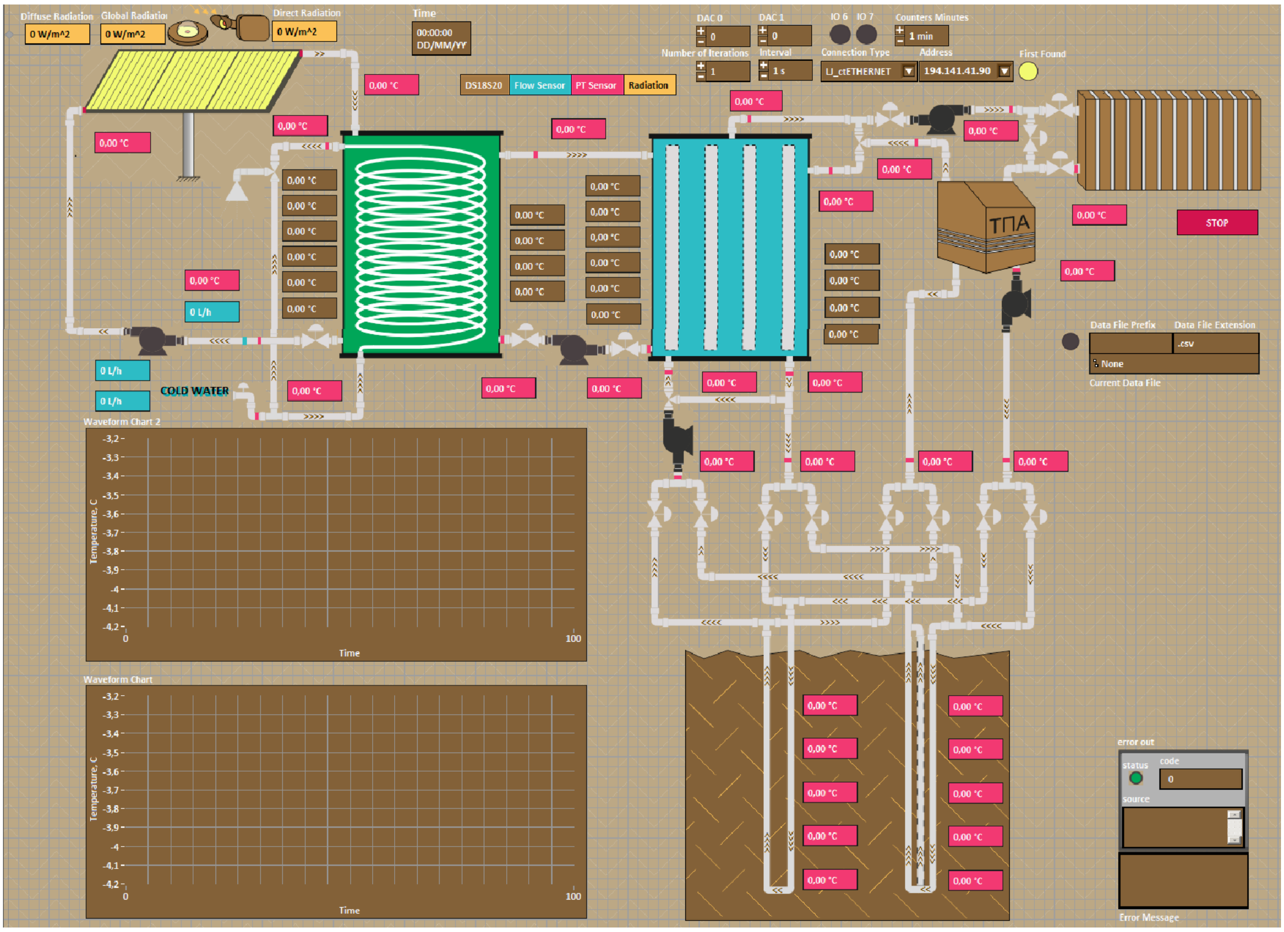


**Fig.16.** The LabVIEW Supervisory Control Screen for the hybrid system installation [12]

The indoor heating and cooling area is about 25 m² (one room). The borehole drilling was performed near the building in October 2011. Two boreholes were perforated - the first one has a single U-pipe and the second one has a double U-pipe design. The depth of the boreholes is 50 m each. Their diameter is 165 mm. Six Pt100 sensors were put in each borehole at different depths (50, 40, 30, 20, 10 and 1,5 m). The solar collectors which are mounted on the roof are filled with propylene glycol.

The storage tanks are thermally insulated (insulation with a thickness of 100 mm is used). The PCM (paraffin) is set into 39 rectangular metal boxes, which sink in the water inside the PCM storage tank. Paraffin is chosen because of its high number of recharging cycles and excellent chemical and thermal stability.

**2. Measurement and control requirements**

The system complexity demands a lot of measurement points for a long period of time in order to obtain a suitable data set that allows correct thermal and energy process analyses. The number of measurement points can be approximated depending on which specific sensor or instrument type was used.

An interactive human machine interface (HMI) gives researchers the opportunity to monitor all the process and control parameters. This system is well adapted to analyse processes in the fields of solar assisted BHE and PCM storage systems.

The operator console is designed as a PC-based station linked via USB or wireless Internet connection to a DAQ board. Depending on the type of experiment conducted, a different virtual instrument screen was prepared. The instrument screen which allowed the study of PCM storage and BTES is shown in Fig.16. It ensures that the experiment is being remotely monitored and controlled in real time [12].

The solar pyrheliometer Kipp & Zonen CH 1 (mounted on the sun tracker system) and the pyranometer Kipp & Zonen CMP 6 are used for measuring of the beam and global solar radiation correspondingly. The diffuse radiation component is calculated by a virtual instrument and all three component values are displayed in the upper left corner of the screen.

All measurement data are logged and permanently stored on the hard disk drive for future analysis. The system allows to remotely monitor and control the process through the Internet.

**3. Different regimes for system operation**

Seven different regimes are possible for system operation:

- Mode 1 (charging of the water storages);
- Mode 2 (charging of the borehole storage);
- Mode 3 (direct solar heating);
- Mode 4 (ground-source heat pump heating);
- Mode 5 (solar-assisted heat pump heating);
- Mode 6 (production of domestic hot water, DHW);
- Mode 7 (ground-source heat pump cooling).

Modes 1 to 5 have been implemented during a time period of about three months in 2014.

## CONCLUSIONS

Here are the most important conclusions regarding hybrid thermal systems:

1. If any component is to be added to an existing installation, it has to improve the system's energy efficiency.

2. The scientific team of the Technical University Sofia, Plovdiv Branch, has long experience in the research and development of hybrid thermal installations and some of their components. Their future activity can be directed as follows:

- well-designed hybrid thermal system (correct choice of the installation components);
- creation and validation of mathematical models allowing simulation of different hybrid installations and operation modes;
- regime optimisation of the already known hybrid systems with regard to different climate conditions;
- use of new and more effective materials in the system elements.

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