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Review

Literature Review and Case Study on Underfloor Heating Using Heat Pump and Solar Thermal Collector

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Abstract

This study explores the design, integration, and performance of underfloor heating systems coupled with heat pumps and solar thermal technologies. A thorough literature review is conducted, covering the historical development of floor heating from ancient civilizations to modern applications using PEX-based hydronic systems. It provided a comprehensive overview of various heat pump classifications—including ground-source (horizontal, vertical, closed-loop, and open-loop) and air-source systems—and their operating principles. This study also examines the role of solar thermal collectors in enhancing energy efficiency and reducing reliance on conventional energy sources. A focused analysis of a hybrid system combining photothermal and photovoltaic floor heating, demonstrated the potential for significant energy savings and improved indoor thermal comfort. The findings suggest that such integrated systems offer a sustainable alternative to traditional heating methods, reducing both fossil fuel consumption and environmental pollution. The review highlights key design considerations, performance parameters, and the promising applicability of phase change materials (PCMs) for thermal energy storage in modern building heating systems.

Keywords: Underfloor heating system; photovoltaic solar; heat pump and energy efficiency.

1. Introduction

Floor heating is the best innovation in the history of the heating system. In 1200 BC, these types of central heating were first applied in Anatolia, The Greeks and Romans heated their baths by turning warm air from the oven into a plenum below the floor. In the last few centuries, Chinese and Koreans even used a foundation a couple of centuries B.C. Today, the applications of hydronic floor systems based on PEX-type plastic platforms have increased significantly in residential buildings. Heating based on an air distribution system is less popular than traditional heating, but air flow through the building materials has been studied by different ways. The performance and economy of a residential, hybrid air-based system with air collector and hollow-core dome were examined by Short and Kutscher [1] Howard [2] studied the environmental engineering of a thermal air-core storage system and practical applications for concrete steel maceration units (CMU). The alignment of nuclear airflow was low-speed. The effects of hollow-core concrete dome thermal storage were investigated by Radu zmeureanu, Paul Fazio [3]**.** Miroslaw Zukowski [4] presented analysis and numerical forecasts of heat and pressure drop characteristics for floor and ventilation ducts. The test results were used for validation of the models. Between computer simulation and performance data measured, an acceptable accuracy was achieved. As the software program for air-distribution systems underfloor, the analysis method was used. The software was precious and correct.

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Heba Al Maleh and Hussen Ali Tine. [5] investigated and installed in the renewable power lab a solar floor heating system. The plan was compared with Trnsys's theoretical results with Trnsys and the experimental results. Thermal losses and measurement failures were so closely taken into account. Finally, the project's feasibility to achieve saving and reimbursement was calculated.

Heba Al Maleh et al [6] used for residential applications where working windows frequently fulfill the ventilation requirements and cooling was not compulsory. Other applications include large, open buildings, including aircraft hangars, where ground heating was much cheaper than heating the entire air volume.

Ye Zhang et al.[7] proposed new system was implemented at the Urumqi office building in China. The method includes three units: the VPCTESD (thermal energy storage device) for the heat pipe solar heater, and the heating system. Experimental development of the influence of solar collector heat efficiency, water intake and outlet, local heat connectivity methods and thermal power of this system.

Ioan Sarbu and Calin Sebarchievici [8] discussed the vapor compression-based HP systems briefly with CO_2 emissions of the electro-compressor, as well as energy, heat comfort and environmental impact comparing the various heating systems in their calculation of the corresponding thermodynamic cycle, the performance coefficient (COP) and HP emissions. The radiator and radiation heating system energy efficiencies in a workroom linked to a GCHP were tested in an experimental study. The main performance parameters (COP and CO_2 emissions) were obtained for one month of operation of the GCHP system and a comparative analysis was carried out.

Ahmad El Mays et al. [9] submitted a study of the application of a phase-change material white petroleum jelly with an underfloor electric heating system. A prototype for a well-insulated house had been built. In relative cold weather, the thermal behavior of the use of phase change material was investigated. Results indicate that average ambient temperature of 14°C reduced the electrical consumption due to latent heat stored in PCM by six hours by an average.

Khem Raj Gautam and Grom Bruun Andresen. [10] investigation examined whether SAHP can achieve its objective of minimizing auxiliary energy dependence, improving the COP of the heat pump and efficiency of collectors, all at a low cost.

Maria T. Plytaria et al. [11] an inspection was carried out on a solar-assisted floor heating system with a built-in phase change material PCM layer. The case studied concerns a 100 m2 building for the Athens site (Greece).

Ansuini et al. [12] explained of how they had expanded the use of granulated PCM and the production and/optimization of radiant 80. PCM delivers a great deal of energy storage power in the different types of solar collector’s flat plate, photovoltaic and thermal photovoltaic.

Mazo et al. [13] developed model to simulate a PCM floor heating system that was pumped by a heat pump, thus lowering the cost of electric energy consumption.

Evangelos Bellos et al. [14] simulated the transient system simulation (TRNSYS) tool providing a wide range of user-functional features for solar energy system simulations. The TRNSYS default values specify several parameters of the evaluated structures. The solar collectors, heat pumps and other instruments that had been collected from the TRNSYS Library, which in many simulations had been very popular up to now. The heating system consists of flat plate collectors, storage tanks and an auxiliary system for providing additional demands for heating when there was insufficient solar power. To improve storage capacity and reduce heating loads, the PCM layer was used for the underfloor heating system. PCM-layer cases were energetically and financially investigated above floor tubes, underfloor tubes and without PCM. The collection capacity, system performance, auxiliary energy consumption, solar cover and indoor temperature profile are presented.

Waleed A. Abdelmaksoud.[15] the paper examines a solar heating system where a flat-plate collector supplies hot water to a chamber representing a residential building. The system uses a storage tank and circulates water through copper pipes beneath the floor to raise indoor temperature. Its thermal performance and economic feasibility were evaluated through 15-minute interval measurements during an 8-hour test in January 2022.

2. Systems of heat pump

2.1 Heat pumps principle operating

Several definitions of the heat pump can be found in the literature. Still, they are equally important - cooling machines where low-temperature heat is transmitted to high-temperature heat transfer fluids by using energy to convert the machine's workplace. In literature, we can find many definitions of the heat pump. However, this is equally important – a cooling machine that supplies high-temperature heat transfer fluids with energy to convert the working medium of a device. Figure (1) represents the schematic diagram of a heat pump [16].

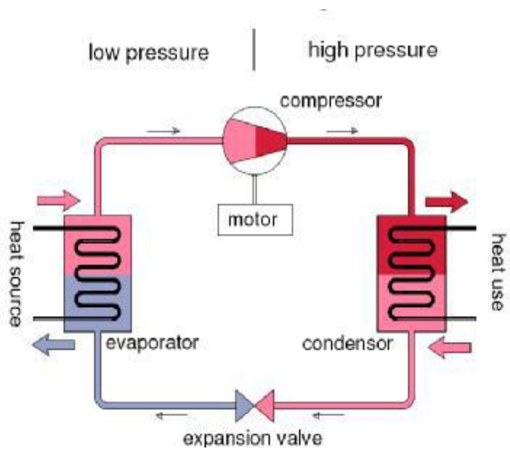

Figure 1. Diagram of a compression heat pump.

2.2 Heat pump classification

The heat pump is heated at low temperatures, like air, water, soil or wastewater. The heat pump type depends on the type of source with low temperatures and the type of heating system source. Heat transfer from air to air, water to water, water to water, ground to air and water. Heat transfer in a heat pump system can take place [17].

- **Concerning the direction of the heat exchanger, systems divide on**

a) Horizontal network system. Wide areas without rock or big rocks and a minimum soil depth of 1.5 m require horizontal collectors. In a single trench, several pipes can also be laid. "The quantity of trench needed can also be reduced when the pipe is placed in a series of coils that overlap vertically or horizontally on the base of a wider trench"[18]. A disadvantage is the inapplicability of these systems for construction or other purposes for areas with pipes. The vertical design is figuratively seeded (2).

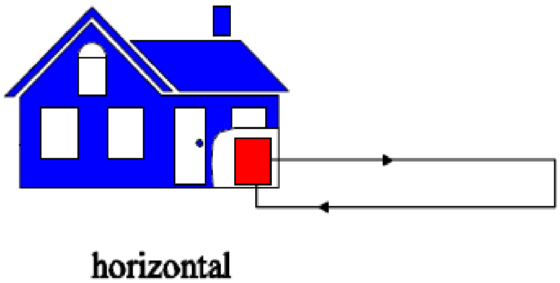

Figure 2. Heat exchanger of horizontal ground.

b) Vertical borehole systems. A coolant is pumped through several vertical drills, "which collect heat and increase the fluid temperature". In places where land is

confined, vertical collectors are often used. For instance, they are inserted into boreholes with a diameter of between 100 and 150 mm and a depth of between 50 m and 150 m. Vertical systems are more costly than horizontal systems and require fewer pipes and pumping energy. After the installation, this system causes minor damage than flat[19]. The system is shown in figure (3) with vertical heat exchangers.

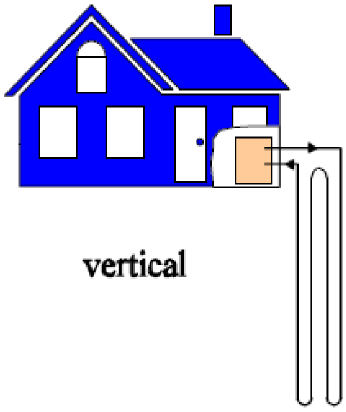

***Figure 3*. Heat exchanger of vertical ground.**

c) The system is open-loop. Open-loop is based on a source of groundwater. Once this groundwater is used, it is returned to the ground. This technology is recognized to be very cost-effective; thus, GSHP systems open loop have been the most common until recently. The inconveniences are that the availability of water is limited. Fouling and corrosion can become a problem depending upon the water quality, especially in the field of groundwater use [20]. The open-loop system principle is illustrated in figure (4).

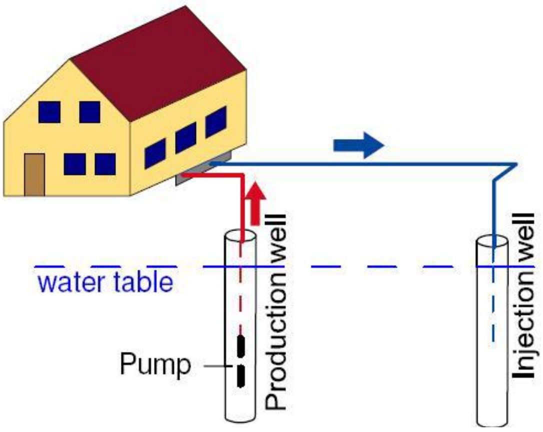

Figure 4. System of open-loop.

d) Systems with closed-loop (Ground Coupled systems). These systems consist of a sealed loop of a pipe buried in the ground horizontally or vertical [21]. Figure (5) and figure (6) show closed-loop systems.

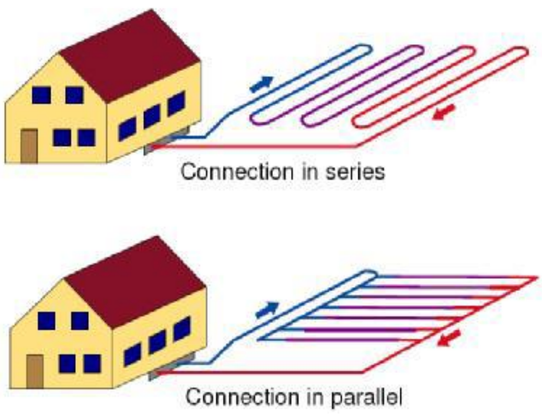

Figure (5): System of horizontal closed-loop

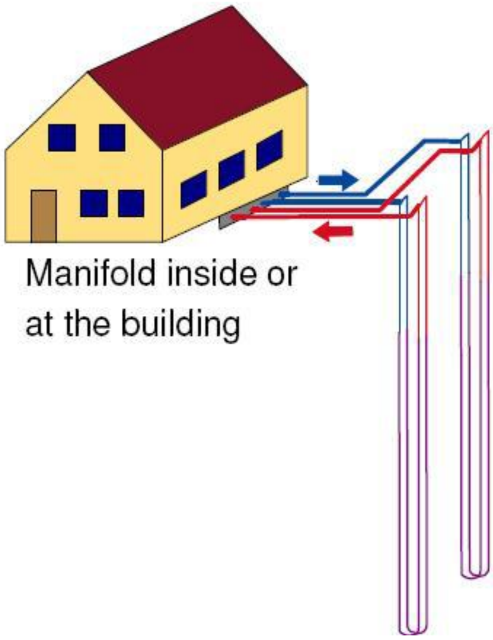

Figure 6. System of vertical closed-loop

2.3. Usage in residential properties underfloor heating

Underfloor warming, the heating system is used as a heat emitter for the floor surface. The surface of the floor is heat transferred from the tube system inside the base. The heat transfer process combines heat radiation and low convective currents in underfloor heating systems [22].

When considering systems using a Ground Source Heat Pump, it must be borne in mind that the quality and productivity of the heat pumps depend on many parameters. The primary and main parameter of the GSHP work is the soil's energy potential.

The following parameters affect the soil's energy potential: geological conditions of the area; types of soils involved in the heat exchange process; depth of the soil's water; soil moisture/12/. The soil humidity influences soil heat exchange, as the water has significant heat conductivity coefficients. But in 4/, there is an opinion that groundwater has no significant impact on ground heat swapping, and the main parameter for calculations is the thermal conductivity of the ground.

However, a wetland thermal conductivity is more significant than a dryland thermal conductivity. It means a maximum of 50 per cent higher collector loops for the soil of low thermal conductivity than for high thermal conduciveness. The ground also has great significance. The heat capacity and thermal resistance are different for each soil and, secondly, depending on the types of soils or rocks for the other technologies used in drilling operations. "The biggest difference between soil and rock is that rock has considerably higher thermal conductivity values. The parameters of the ground area, such as soil cover depth, soil type and rock type, are essential to determine before designing the process. Without the importance of ground temperature and thermal conductivity, a proper assessment of the ground heat transfer cannot be calculated.

3. Heating systems under the floor heating systems for the underfloor

Energy consumption in the construction division has risen in recent years and is nearly 40% of the world's energy consumption [23]. Specific heating consumption ranges from 15 kWh/m^2 to 100 kWh/m^2 for typical buildings [24]. Alternative energy sources such as solar electricity are promising to meet the energy requirements of buildings in whole or in part [25]. In Greece, the potential for solar radiation differes from 1400 kWh/m^2 to 1800 kWh/m^2, and Athens has an intermediate value of 1600 kWh/m^2 [14]. This solar potential promises a large percentage to meet the heating energy needs of Greek buildings. Solar energy can be used in household hot water production or the construction sector for space heating applications. Besides, solar collectors, in many cases, are built-in in solar-only or hybrid systems in tank storage or heat pumps [26].

4. Selected systems

The system selected includes a range of hugely efficient components for the seasonal mismatch of solar radiation and heat require in the building and combined systems using both direct-use glazed collectors and non-glazed heat absorber systems (S.A.) as heat. The system includes a direct-use application of solar thermo-radiation (S.C.) for heat generation. Besides, systems that only use solar pumps with a salt buffer as cold pump as a thermal source are, comparison and evaluation with the conventional air/water heat pump system (A/W-HP) [27].

For all variants, the systems chosen under reference conditions use the following options:

- Moderate climate.
- The defined domestic hot water tapping profile.
- Either the reference building definition for space heating and domestic hot water.

The oriented and sloping surface of the roof as possible was defined, either covering the solar thermal absorber zone, a photovoltaic panel area, a PVT area or a mixture of those components. In this simulation study, the photovoltaic generators provide the generated power to the grid. Besides, all electricity consumed is removed from the grid. Therefore, no storage of electricity is considered; only the annual energy balance is evaluated. The authors know very well how the energy storage system for thermal and electricity is handled but focus on the design of thermal energy supply systems.

4.1 Direct solar heat generation

The maximum direct solar thermal generation leads to a minimum demand from the electric grid externally supplied end energy [27]. As shown in figure (7). Since the thermal collectors cover the total area of the roof, there is no room for the generation of photovoltaic power.

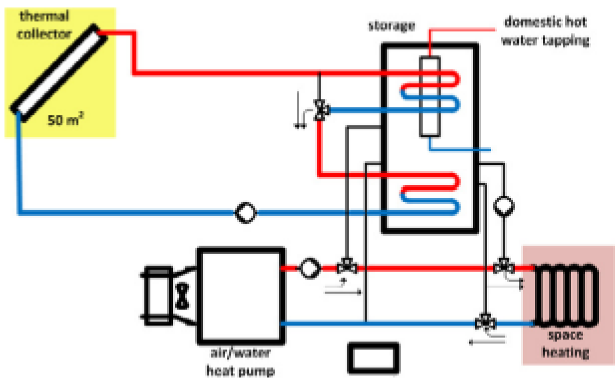

Figure 7. Direct solar heat generation.

4.2 Heat pump and photovoltaic

The system only provides heat for space heating and heat water with the air/water heat pump, as shown in figure (8). For electricity generation, a photovoltaic generator utilizes the entire applicable roof surface. The P.V. and the heat pump are not directly connected. This system shows the influence of a minimum source temperature of 0°C, one product from the ice storm on the heat pump's source-side, since the system simulation environment is not currently provided with a validated ice storage model [27].

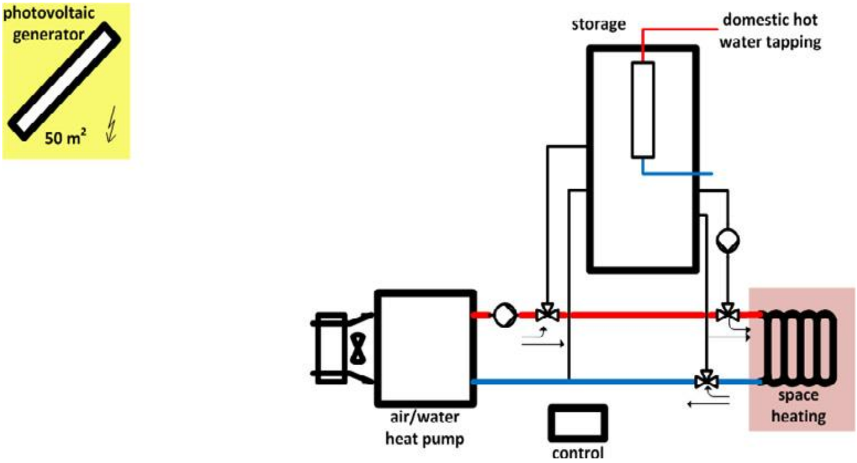

Figure 8. Heat pump and photovoltaic system.

4.3 Small solar thermal side-by-side with photovoltaic

Combines an air-/water heat pump with a minor solar thermal system and a photovoltaic electricity generation from covered platform collectors for heating and hot water [27]. As illustrated in figure (9). Besides, an air/water heat pump provides heat as a backup.

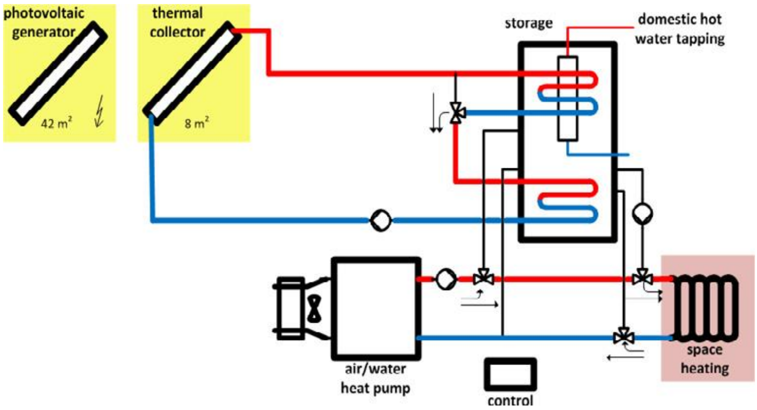

Figure 9. Small solar thermal side-by-side with a photovoltaic system.

4.4 Uncovered thermal absorber with heat pump

The one and only heat source of a salt/water heat pump (B/W-HP) is an uncovered heat absorber, and it provides heat directly to the storage tank, as shown in figure (10). The total roof area covered by the thermal absorber is not considered a photovoltaic generator.

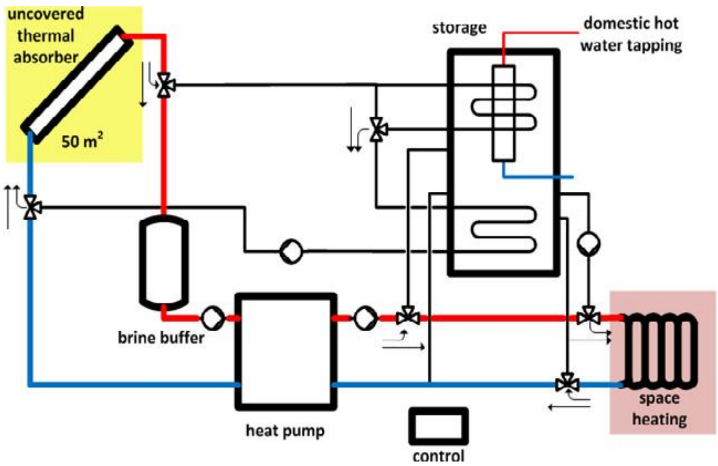

Figure 10. Uncovered thermal absorber with heat pump system.

5. Design of Solar Heating and Heat Pump systems

The display scheme enables these systems to be represented in a simplified graphical manner. Centre places represent the major components of the scheme (e.g. solar or heat pumps); the squares were representing renewable energy sources, e.g. solar or geothermal energy sources, are represented at top rank by squares; the extra energy required, e.g. electricity, is represented by the left level of the court; the heating plants served, e.g. DHW, are represented by the heating system. Different arrows connecting the respective squares depict the energy flows. Since the scheme is based on squares, the "square view" of SHPS was designated. The Square View provides the reader with a clear overview of system components and power flows within a short period. It does not provide detailed information on hydraulic connections; it does not contain any data on the size of any part. In the following figure, you can see the structure of the unbiased view (11) [28].

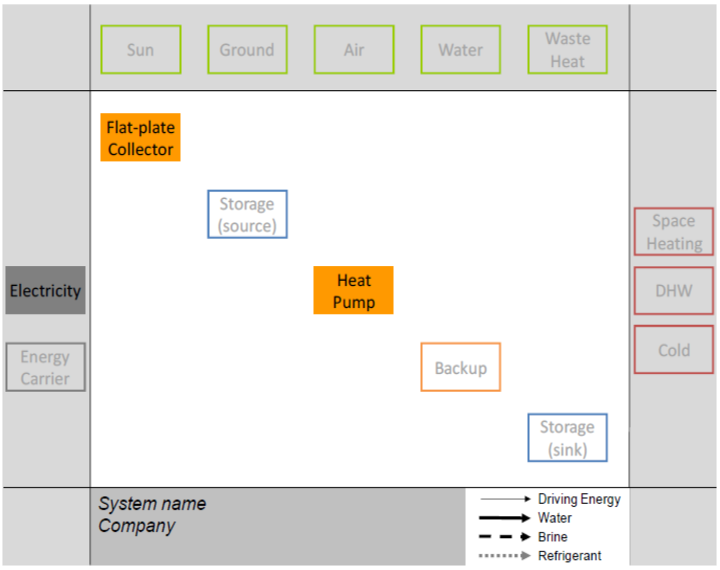

Figure 11. Diagram structure showing the main elements, heat sources, thermal sinks and another electricity carrier in a solar heat pump assisted system.

Structural diagrams and unified hydraulic drawings are compiled for each system to record information on the primary hydraulic connections. The suitable hydro mechanism and an unbiased view of SHPS are presented as examples in the following figure (12). A list of specific primary properties was collected for structure, enabling systems to be classified. One distinctive aspect was a subdivision using the heat source used by the heat pump. As the only heat source, and aero thermal heat source and solar thermal collector are shown in the following examples from systems using a geothermal heat source. Examples of air ventilation systems and water exhaust air systems (e.g. soil, lake, rivers) as a heating source could be recorded.

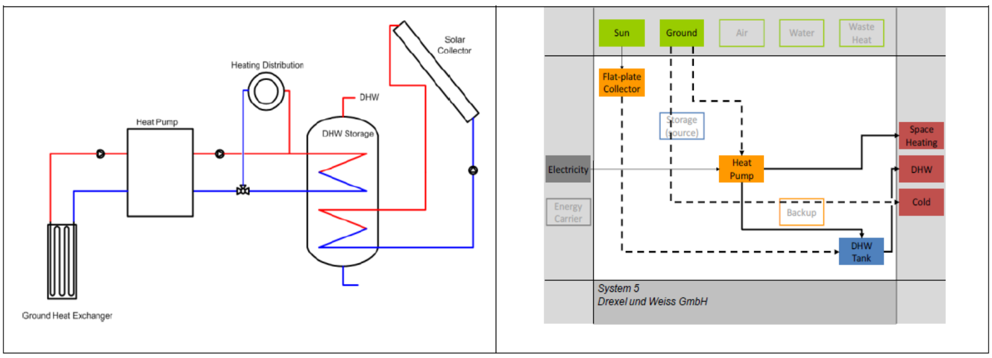

Figure 12. Unified (left) hydraulic system and an SHPS "square view" (right) visualization scheme. Geothermal heat is used as a heat source, whereas solar and heat pumps are only connected "parallel."

The solar thermal collector is the only heat source for the system, another type of system. Specific collectors that can also operate as efficient heat exchangers with ambient air under reduced or no solar radiation conditions must be used in these systems.

An example of an SHPS fitted with a hybrid solar col

lector connected to a combi DHW storage system and a storage unit including phase change material (water/ice shown in the example) used for low-temperature heat storage is given in the following figure (13). A system that applies unglazed solar collectors is illustrated in figure (14). The solar collectors are connected directly to the heat pump in this case [28].

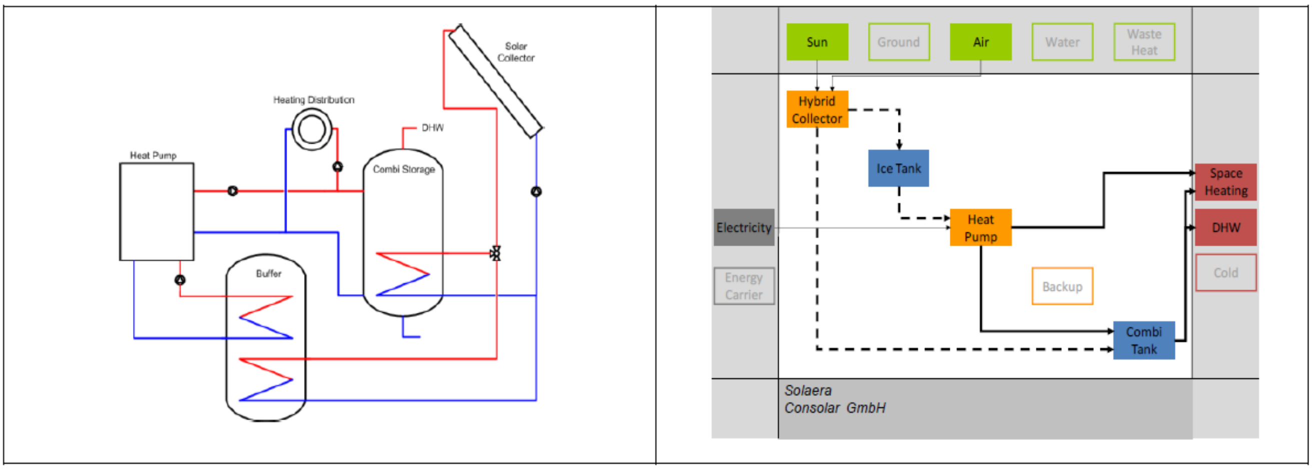

Figure 13. Unified (left) hydraulic and square (right) SHPS view. Only a solar thermal collector as the heat source is used for the system shown. The DHW tank and ice/water buffer storage are fed via a hybrid collector

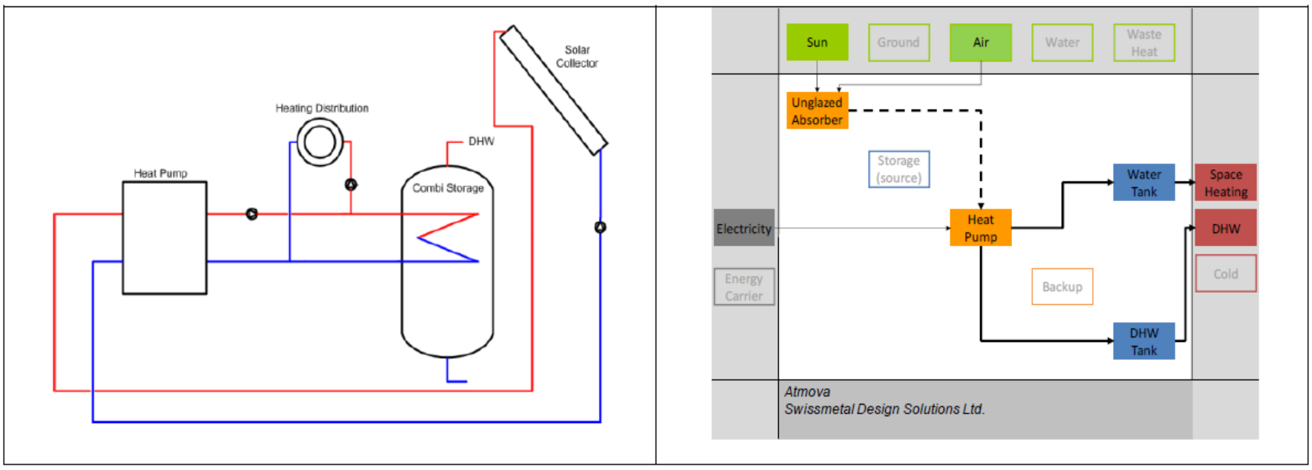

Figure 14. Unified (left) hydraulic and square (right) SHPS view. An unglazed collector is only used as the heat source for the heat pump in this system.

6. Case study: In this paper selected the analysis of Lian Zhang and Baowen Cao [23]

6.1 Heating system design

A dual system co-ordinates operation is designed to combine a thermal heating system with a photovoltaic radiation heating system. The idea is to develop a photovoltaic system. The solar heating system converts solar energy into heat energy and heats the soil via hot water pipes placed on the floor. Thus, the solar thermal system converts solar energy into heat energy. Photovoltaic power systems heat the A.C. heating cables laid in the floor in a photovoltaic floor heating system to supply the room with heat energy[29]. The system's overall design is shown (15).

The solid bold and black line is the radiant heating system for the photothermal floors, and the only solid line is the photovoltaic heating system for the floors. A.C. heating cables and water pipes are evenly connected to the room floor with a humidity and temperature sensor. The temperature of the room can be set and regulated. The solar hot water pump heats the water, circulated through the heat collection pump in the water tank, in a thermal floor radiant heating system. The indoor warm water circulating through the heat supply pump is another circuit of the water tank.

To collect and monitor temperature, flow and energy data, the heat collection circuit and Heat Power Circuit are equipped with temperature sensors and flow transmitters, respectively. Installed in the water tank is a level transmitter that assists the controller in determining whether to start the electromagnetic water supplement valve. The top of the tank has an exhaust pipe to maintain the water tank's normal pressure. The base of the tank is equipped with a drainage blow valve that provides long-term stability.

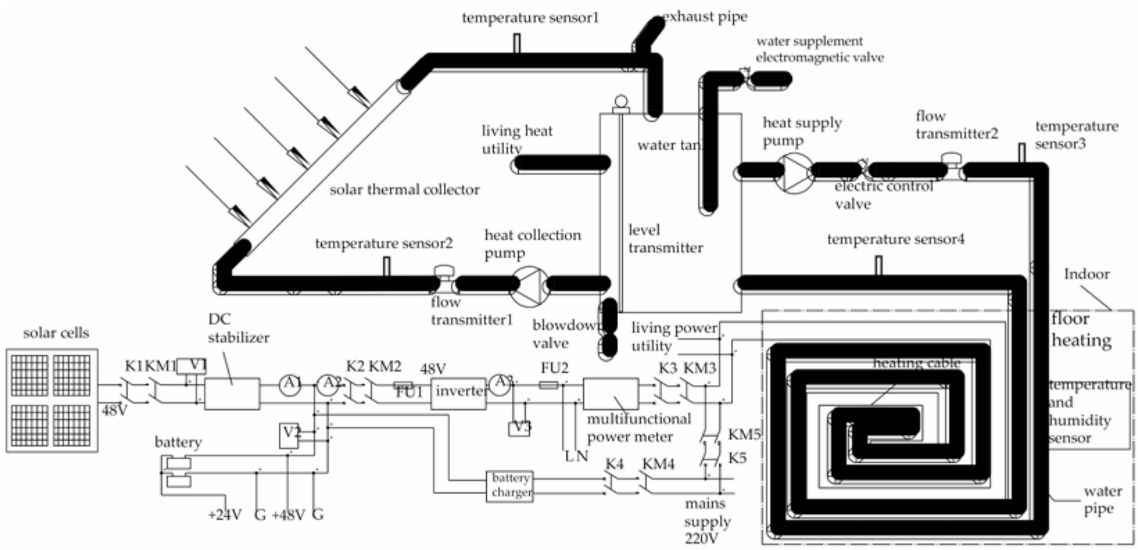

Figure 15. The overall design of the system [29]

6.2 Indoor temperature distribution

A vast difference in temperature between the maximum and minimum indoor temperature tables can be shown in table (1) There are some reasons:

- The minimum test point is set by the wall and near the floor, meaning the heat source is quite far away.
- The maximum test point in the middle of the heating system with less heat loss and a lower temperature change is relatively high. The maximum temperature is measured.

Table 1. Temperature measurement points.

Temperature (°C)	0	0.6m	1.2m	1.8m	2.4m
Minimum	**24.13**	**25.69**	**25.7**	**25.66**	**25.2**
Maximum	**29.96**	**26.94**	**26.92**	**26.89**	**26.71**
Average	**27.21**	**26.27**	**26.25**	**26.25**	**25.97**
The max temperature difference	**5.83**	**1.25**	**1.22**	**1.23**	**1.51**
Standard Deviation	**1.8737**	**0.3587**	**0.3563**	**0.3633**	**0.4323**

6.3 Indoor temperature change rate

The photovoltaic radiant heating system heating and cooling speed are the fastest between the three different heating systems. At the set temperature (20°C), and the indoor temperature is reduced to the initial value by less than 1800 s, the indoor temperature reaches over 3600 s. The thermal inertia of the photovoltaic floor heating system's thermal cables could be responsible for the result. The photovoltaic floor radiation heating system meets the setting temperature

demand in the longest possible time, reflecting the most significant electricity consumption photovoltaic floor radiant heating system's most significant electricity consumption.
The indoor temperature change in the three separate heating systems is shown in Figure (16).

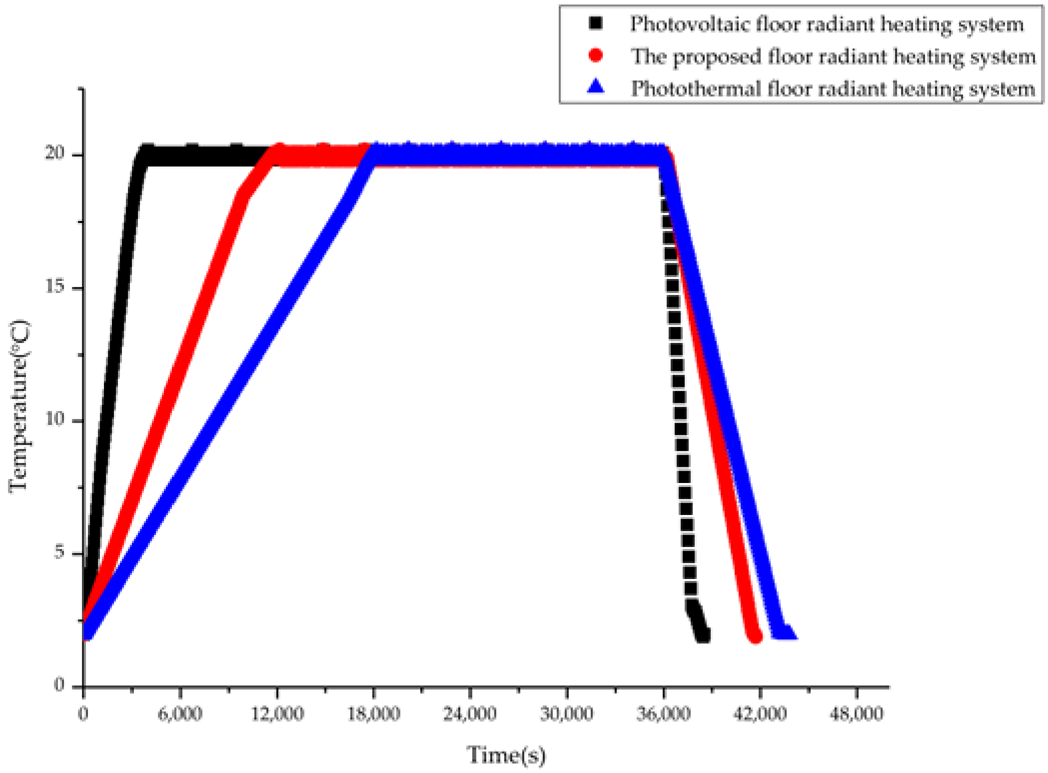

Figure (16): "Indoor temperature changes of the three different heating systems[29]."

7. Conclusion

Energy substitution technology has been used in many areas in the development of renewable energy. This research suggests that solar energy replaces conventional power as renewable: a solar-powered solar radiant heating system is coupled with a radiant heating system from the floor. This study proposes and studies the photothermal radiant heating systems from the floor. From the previous studies that were mentioned in this research that in the future the global trend will be to use underfloor Heating System as an alternative energy for many reasons, including the depletion of fossil energy sources as well as to reduce pollution from the previous studies that were mentioned in this research that in the future the global trend will be to use as an alternative energy for many reasons, including the depletion of fossil energy sources as well as to reduce pollution.

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