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An Approach for Combining of Solar Heating System with Ground Source Heat Pump System

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Abstract: As a viable technology in the heating systems for building, renewable energy systems have received a lot of attention. However, renewable energy system's performance depends on environmental conditions and might be gradually reduced by extensive and long-term activity. Underground heat storage is one of the most commonly used methods of energy systems and some approaches have been proposed and carried out to reduce the energy consumption of building heating systems. However, not all of the proposed approaches are effective in terms of efficiency and performance. Therefore, this paper is to study and analyze the effectiveness of combining the Solar Heating system (SHS) with Ground Source Heat Pump System (GSHPS) to improve the performance of the heating system and increase heating transfer. TRNSYS simulation software is used to perform the simulation. The simulation is carried out to study the solar heating system and the solar heating system combined with underground storage. The obtained results show that the developed heating system with underground storage is more efficient and better in performance than using solar heating systems individually.

Keywords: TRNSYS, Solar Heating System, Underground Storage

1. Introduction

Nowadays, the systems of renewable energy are signifying sustainable and energy-saving methods in buildings. Besides, energy utilization in heating buildings has a big proportion of whole energy consumed in cold areas. Principally, the heating energy utilization occupies a great portion of the total energy consumption in buildings. It is around 70% of the whole building's energy consumption. Some alternative energy sources, such as geothermal energy and solar energy, have a large growth for supplying buildings with energy. Typically, geothermal energy and solar energy have a massive ability to increase renewable energy and are rapidly utilized in heating buildings [1, 26]. During recent years, a great number of solar thermals have been utilized abundantly. As for the process of solar heating, several researchers conducted analysis and discussion of the solar systems from various perspectives and gave some worthy constructive suggestions [2, 27]. The solar heating system could provide about 88% of the building load and save up to 61.5% of the heating costs. The researches, on the other hand, have been focusing primarily on thermal performance analysis and process optimization [3, 28].

In China, the demand for heating buildings is nearly 43% of the whole energy requirement. As a method to get significant energy saving. In this case, it needs to increase indoor thermal heating of passive techniques for buildings, especially in winter and also consent to the heating systems declining. The ideal energy demand for the heating and the saving of energy related to the utilization of the solar heating system have been considered. The solar collectors are considered as the main energy source for heating in winter climates, and an underground source heat pump has been used to optimize the heating system of the building.

In some areas, the period of cold climate is quite long, nearly half of the year, so that the consumption of the energy is huge and raising the energy inflexibility level. As a result of rough solar energy resources, such areas have ardent solar radiation in the summertime. In spite of that the radiation of solar in the wintertime is so weak. Therefore, the conception of combining SHS with GSHPS storage to save and increase the transfer of the heating through the wintertime is taking great importance. For that reason, this paper is to study and analysis the combination of both the solar system and underground energy storage and the effectiveness of such combined systems.

It is organized as follows: section 2 is to summarize the literature related to the building's heating approaches. Section 3 discusses the structure and mechanism of our approach and section 4 is to represent the implementation and the evaluation of obtained results. In section 5, we summarized the proposed approach.

2. Related Work

Building a heating system is a hot research topic and has attracted a lot of attention. Different authors have proposed different approaches.

Chen et al. [4] carried out a statistical analysis of the solar-assisted ground-coupled heat pump system in northern China for the supplying heat of the building. They suggested that the SAGCHP system combines the solar collector system with the GCHP system by means of a storage tank and a plate heat exchanger to provide all of the hot water for residential use and heating buildings. The results of their simulation showed the solar collector area is the target to optimize the system at 40 m^2 with a borehole depth of approximately 264 m. At this point, the total annual heat extraction and the hot water constraint, about 75%, can be supplied using solar energy. Both Yang et al.[5] and Lizana et al.[21] they proposed a numerical simulation method for the performance of SGSHPS in the various heating modes, including the single GSHP modes, combined operating mode, night and day alternative mode of service and heat-feeding alternative for U-tube solar. The experimental results showed that the system performance can be improved during the day with the help of solar energy and increasing solar energy for the combined operating mode. GHE can be stored in the ground during the day to enhance the GSHP function at night.

Moreover, the combination of GSHP and solar collectors to minimize electricity requirements in the system is suggested. The simulations were designed to identify the advantages of integrated systems with solar heat and to find the best approaches for designing and operating systems. According to the authors, there are three main reasons why solar panels must be installed into a heat pump system from the ground source. One is to minimize energy usage and the others are to increase borehole temperature and to reduce net heat extraction. The experimental results showed that when the solar heating was being used in the summer to build up Domestic Hot Water (DHW) and to regenerate the boreholes during the winter, the optimum goal was achieved [12, 25]. Mehrpooya et al. [13] investigated a corresponding solar and GSHP thermal collector for heating greenhouses. The main goal is to simultaneously examine the process from an economic and technological perspective. The results showed that there is a significant seasonal show of 4.14 coefficients with a 50m length boiler. The number of boreholes used is 3 and a 9.42m^2 solar collector area. Yan et al.[8] used legislation to minimize the marginal utility approach, to achieve the total net savings of energy in the life cycle. The results showed that the optimized tank volume depends heavily on the collector area, while the tank volume has very limited effects on the optimization of the collectors' area. The results also showed that the energy efficiency of structures of various sizes can be measured effectively.

Eicher et al. [6] used the life cycle impact assessment (LCIA) approach to the SHP system. To supply hot domestic water (HDW) and space heating (SH). The purpose of this research is to evaluate the environmental impacts of the energy and material used in the implementation of the serial SHP and to identify areas for improvement through the application of the "cradle-to-grave" approach to system evaluation. This study showed that the environmental impact, due to materials, is not negligible compared to the use of operating resources based on the type of SHP system. To improve the environmental quality of SHP, SHP technology includes not only enhancing the efficiency of the SHP system and the electricity supply mix but also increasing the quantity and improving the type of materials used. The results showed that SHP has fewer environmental effects than electrical systems. Matrawy et al. [9] introduced thermal analysis and optimization of the components of the solar water heating system based on the seasonal and annual system performance analyzes. A graphic method for optimization was created. The developed method was used to estimate the optimum dimensions when extracting a daily amount of hot water (175L) at 60°C. The final results showed that the optimum area (A) and volume (V) are 16m^2 and 700L, respectively, with the specified load specifications and a solar factor of 70%. Chung et al. [14] proposed an annual central solar heating system with two sets of collectors, a light-sized tank and two thermal loads, the loads represent an office building and greenhouse for agricultural research in order to achieve better efficiency during the winter climate. The simulation tests showed 50% to 80% more solar fractions than other inland areas. The system under construction has a 184m^2 collector area (A) and 600 m^3 of storage volume (V).

Çomakli et al. [7] suggested the relationship between the entire area of the solar collector and the volume of the storage tank used for collecting solar thermal energy. To achieve their idea, the data obtained from the experiments carried out under the climatic conditions are used to create a numerical system at MATLAB. The results demonstrated that the output of the collector decreases when the storage tank volume increases and the ratio of the tank storage volume and collector area should be usually between the volume of 50 L/m^2 and 70 L/m^2 of the collector area to the tank storage volume, which would range from 35% to 45%. The purpose of there is to improve the life-cycle energy analysis of solar water heating systems and maximize the size of the system. Hobbi et al. [10] proposed the use of a solar flat plate collector based on regional hot water needs for an approach to solar water heating systems circulation. The specification includes the collector area, the type of fluid, the collector mass flow rate, the volume and height of the storage tank, the heat exchanger capacity, the size and length of the connecting tubes, the material and the thickness of the absorption of the plate, the number and size of the riser tubes, and the tube spacing. The results showed that the designed system could provide 83% to 97% and 30% to 62% of the demand for hot water in summer and winter, respectively, by using solar energy.

A combination of a geothermal reversible heat pump with heat and cooling thermal solar collector and domestic hot water output was identified to offer an alternative technical solution that leads to a reduction in operating costs in comparison with traditional fossil-fuel solutions. Thermal solar collectors were used to reduce boreholes and investment costs [11, 22-24].

3. Proposed Approach

In this paper, integrating solar systems with an underground storage approach is proposed in order to increase the efficiency and performance of the building's heating system. An experiment of the solar heating system of Baoding city, Hebei province, north China, and simulation of combining solar heating with underground storage is implemented. Our approach employs solar dish collectors and underground storage to heat and enhance the thermal comfort of the building, as shown in Figure 2.

Apart from the fact that energy use in buildings has an enormously important responsibility for a proportion of total energy in cold areas. Figure 1 shows that the process of heating building with two methods. The first one is using a solar dish collector with a tank of volume 80m^3 and the second one is using underground borehole heat storage.

3.1. Solar Heating with Solar Dish Collector

The collectors used are solar dish collectors with water as the operating fluid such as the solar water heater (SWH). The parameters of the collector dish are provided below in Table 1.

Table 1. *Collector parameters.*

Parameter	Value
Aperture diameter	4 m
Dish depth	0.3 m
Rim angle	55 degree
Focal length	1.5 m
Collector system errors	10 mrad
Beam spread with errors	0.085 m
Focal image width	0.156 m

The system contains 10 solar collectors. Hence, the aluminum reflector is chosen to be used as a reflector in the collector. Spherical aluminum reflectors are presumed for this system in order to obtain as much solar radiation as possible. The obtainable mirror area of the dish collectors is 370m^2. Therefore, the spherical aluminum covers the entire mirror area of the collector to optimize solar radiation output of the dish collectors. In addition, the supply temperature from collectors is decreased in the tank with a volume of 80m^3 connected with the collector through in and out pipes. This is attributed to the thermal insulation of the tank and the distribution pipes are investigated to decrease the temperature transfer of the system. A pump is used to circulate fluid through the systems. Figure 2 demonstrates the mechanism of the system. The solar dish collector collects the heat in order to heat the fluid water coming to the tank connected with the solar dish through PE100 pipes. The hot water flows from the collector to the tank again through PE100 pipes. The hot water stored in the tank flows into the building through a steam boiler heating system as distributed in the building for the purpose of increasing the temperature of its surrounding environment. The circulated water is pumped again to the collector through the tank. The water starts again as mentioned above. Ultimately, more accurate building structural models are used in the proposed approach.

3.2. Combined Solar Heating with Underground Storage

To substitute the lost temperature in the tank and taking advantage of the geothermal heat, we combine the solar system with underground storage. The solar system combined with underground storage is able to supply heat efficiently and effectively. The proposed approach exploits the geothermal heat for the purpose of increasing the transfer of heat to the building.

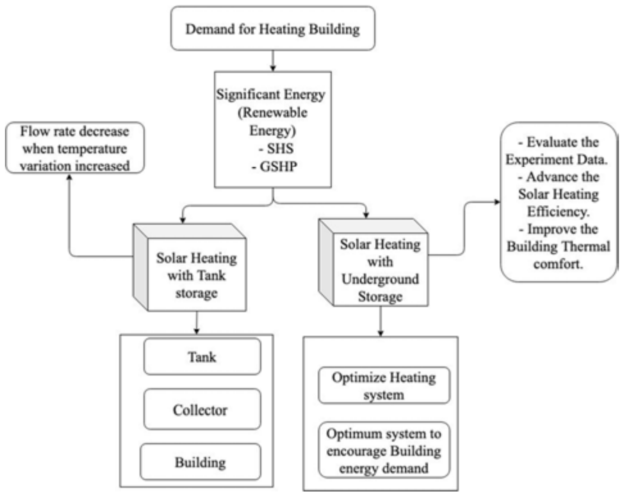

Figure 1. *Renewable Energy uses For Heating Building.*

The borehole depth is represented by d in millimeters, the material of the vertical buried pipe is PE100, Inner diameter of buried pipe is represented by IR in millimeters, external diameter of buried pipe is represented by OR in millimeters, borehole diameter R in millimeters, the stratum structure is mainly clay and silt and the optimum velocity range is (0.3 – 0.6 m/s). In the heat transfer model adopted in the design, it is assumed that the buried pipes are arranged symmetrically in the borehole. To isolate the pipes from the ground heat exchanger tubing, rubber-plastic insulation material with a wall thickness of 20 mm is used to minimize the potential heat loss caused by the contact of the pipes with the walls of the borehole. another aspect of the proposed design of borehole thermal resistance, the average distance between buried pipes and the backfilling material and thermal conductivity can be determined based on the factors mentioned above. In order to increase the energy and reduce the imbalance of underground heat load, the number and space of buried pipes should be increased appropriately when the area of the borehole is sufficient. It is also recommended that the distance of the buried pipe should be 5m.

4. Proposed Approach Implementation and Evaluation

This section presents the implementation and evaluation of the proposed approach. The proposed approach has been implemented and executed using TRNSYS. As mentioned above, the proposed approach for the heating building consists of two methods. The first one with the solar dish collector. The second one is the combination of the solar dish collector with underground storage.

4.1. Experimental Parameters

For the implementation of the proposed design, we used the Baoding office building with a geometrical area of 4630m^2. The other parameters of the building are described in Table 2. This area is equipped with a ground source heat pump (GSHP) system and a solar heating system. The environmental conditions of both systems are also described in Table 2. The heat is obtained from the underground by a ground heat exchanger with a length of 105m.

Table 2. *Main characteristics of the studied building and dish collectors.*

Parameter	Value
Area	4630 m^2
Height of the Building	22 m
U (Glazing)	2.78 W m^{-2} K^{-1}
U (Roof)	1.0 W m^{-2} K^{-1}
U wall	0.59 W m^{-2} K^{-1}
U basement floor	0.93 W m^{-2} K^{-1}
Heating degree-days	18°C
Glass g-value	0.64°C
T (winter set point)	18°C
Metabolic rate	1.2 met
Thermal load related to the office electrical equipment	49.67 w/m^2
Clothing factor	1.5 (Clo)
Wind speed	18 m/s
Heat load	230 kW
Negative heat (rejected)	49.67 w/m^2
Flow rate	15 L/h
Water temperature supply/return	75/50°C
Building rotation	6°C
Air change (ACH)	0.1
Infiltration leakage	0.1 1/h
The humidity of supply air	50%
Dish collector area	37 m^2
Collector efficiency	65%
Tank volume	80 m^3

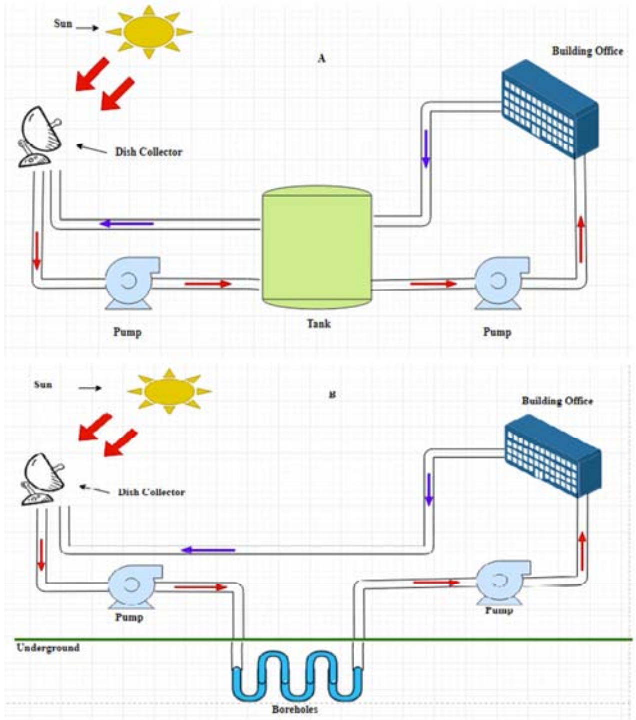

Figure 2. *System diagram.*

4.2. Simulation Environment

For performing the simulation, we used TRNSYS software. It is highly adaptable simulation software. It depends on the setting used to simulate the transient system behavior and it has definitely several popular modules currently used in the software. Many simulations can be carried out independently for the recognizable experimental setting. Figure 3 shows the simulation of the system's solar heating flow chart using the PCP collector instead of using a solar dish collector, including the same input parameters, output parameters, fan coil (type 753c), pumps, tank, underground heat storage, weather data, and distinctive parameters function. The output devices include a printer and a real-time oscilloscope. Simulation results are generally printed as an excel file via the printer, which is loaded as statistics from internal documents or can be shown in real-time on the screen of the computer.

To apply the heating system, we used a collector, tank storage and an additional heating source. The collector is the most significant element of this simulation platform. It can be used to determine the efficiency of the system. The additional heating source can be used to verify the temperature sustainability at a fixed value, especially when solar energy is not adequate. The additional heating source starts operating when the inlet temperature is below the setpoint value.

TRNSYS is divided into two separate components: the first component is an interface represented by TRANSYS Build and the second one is TRNSYS Studio represented by several "Types" (small objects written in Fortran or C++). TRNSYS studio is based on full weather data sustainability, including hourly temperature variations, solar radiation, wind velocity, and relative humidity. Besides, it is able to supply the energy demands of each hour during the day. Table 1 shows the thermal properties of the building materials that are used in the simulation of the building as input and no attention was given to internal gains and ventilation systems.

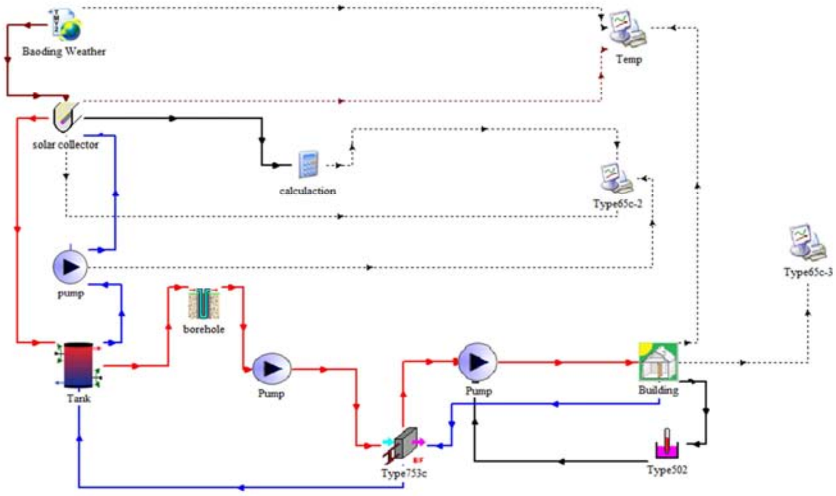

Figure 3. *TRNSYS simulation flow chart of the solar heating system using PCP collector.*

5. Study Result and Evaluation

In this section, we present experimental measurements on building heat systems by solar collectors and the simulation of combining solar collectors with underground heat storage for heating building using the TRNSYS simulation platform.

5.1. Experiment Results of the System Using Tank Storage

5.1.1. Solar Collector's Temperature

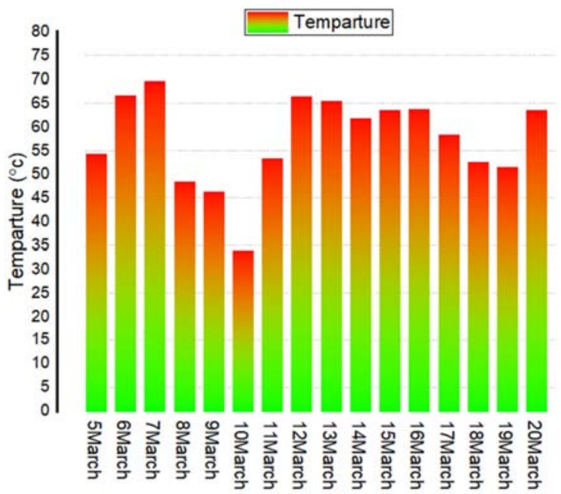

Figure 4. *The solar collector's temperature (° C) in the morning time.*

Figures 4 and 5 show the performance of the solar collector heating system based on experimental measurements for 10 solar collectors. The temperature of the solar collectors has been shown throughout the winter period, from 5 March to 20 March. Although there are temperature variations from the solar collectors. The temperature supplied by each collector is typically less than 80°C. For this system, the temperature of the solar collector was measured two times a day, morning as shown in Figure 4 and evening as shown in Figure 5. The temperature represented by Figures 4 and 5 is the average temperature for 10 solar collectors, each one with an efficiency of 65% and the dish collector area of 37 m^2.

For the current system, heat is generated in the solar collector and circulated through hot water to heat the building. For each room, the steam boilers heating system is fixed. The 4-inch distribution pipes have a length of 65 m, and the air temperature around the pipes is 9°C. the water flow velocity is 0.45m/s, with nominal parameters. The consequence of the high-temperature deviation of the hot water is ranging from 30°C to 75°C and the energy used for the building heating system is limited.

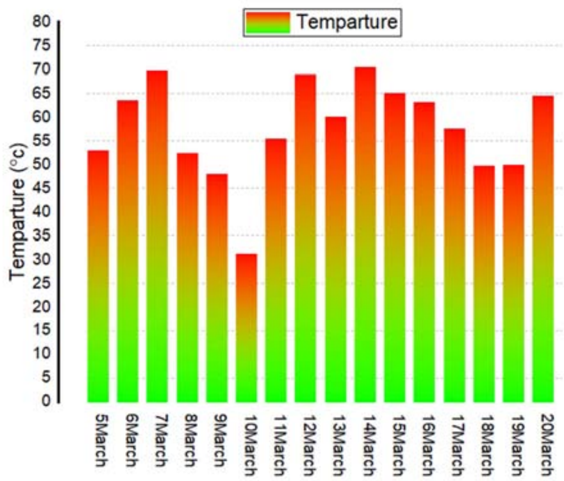

Figure 5. *The solar collector's temperature (°C) in the evening time.*

To handle the loss of heat during circulation through the structure, the distributed pipes are wrapped with isolators.

According to Figures 4 and 5, we notice that as the incident energy increases to the solar collector, the temperature increases as well with taking into account the temperature of the collector during the day from (5 March to 20 March) and the solar collector's surrounding environment temperature of the sky (acquired as an occupation of the muddiness of the sky), which was recorded as the temperature of the sky from the natural environment of China.

5.1.2. Tank Temperature

The Temperature Inlet to the Tank

There are several ways of energy savings in heating systems. One of them is in the tank. Figure 6 shows the tank temperature from solar collectors. the supply temperature from collectors is decreased in the tank with a volume of 80m^3. Therefore, the tank and distribution pipes are thermally insulated and investigated to decrease the temperature transfer of the system.

To improve the performance of the heating systems, the flow rate of the system is equipped with a flow pump from the collector to the tank, and a thermostat is provided to control the start/stop of the circulation pump when the temperature of the building reaches the setpoint temperature.

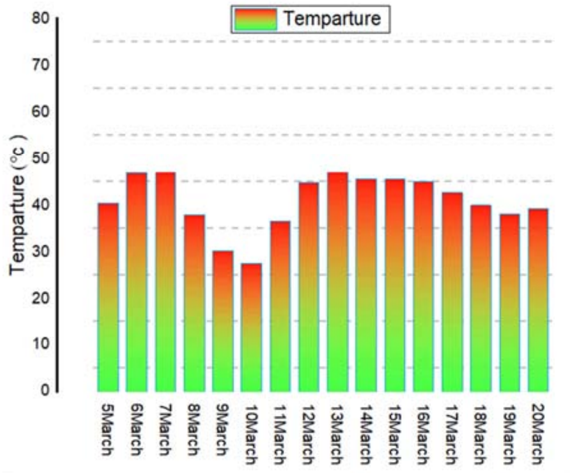

Figure 6. *The temperature (°C) inlet to the Tank.*

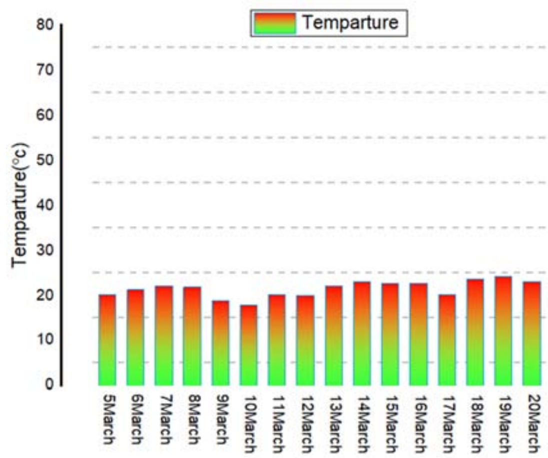

Figure 7. *The temperature (°C) outlet from the Tank.*

The temperature variation between the collectors and the tank is attributed to the volume of the tank and the distance from the collector to the tank.

The Temperature Outlet from the Tank

The stability of the supplied temperature used in the heating system is actually increased by lowering the temperature drop level. Therefore, the higher stability and energy performance of the heating system is often achieved by lowering both the temperature supply and the temperature drop simultaneously. In addition, the thermal comfort of this system is compared based on TRNSYS simulation software and the obtained results show that their efficiency accomplished with temperature outlet measurements form tank, as shown in Figure 12.

An experiment is carried out to investigate the temperature of the outlet from the storage tank as in Figure 7, which shows that the temperature of the outlet from the tank is between 18°C and 25°C and the thermal efficiency of the tank is 83.6%. The mass transfer contained in the tank is apart from the mass flowing in and out from the tank. However, experimental effects showed that the measurement of the tank through the stored water flow in and out of the tank showed a negligible temperature variance in the direction of the radiates.

5.1.3. Building Temperature

Figures 8 and 9 represent the temperature of the building in the morning and afternoon, respectively. The variation of the temperature drops on the basis of the characteristics of the building and the temperature out from the tank for the different values of the distributed temperature.

Figure 8 represents the temperature of the building in the morning. It shows that the flow rate is reduced when the variation between input water temperature to the building and output water temperature from the tank increases. The tank also involves heat transfer with various processes, such as heat conduction through the tank wall, and the energy consumption is usually influenced by the activity of the residents of the building and the surface material of the floor.

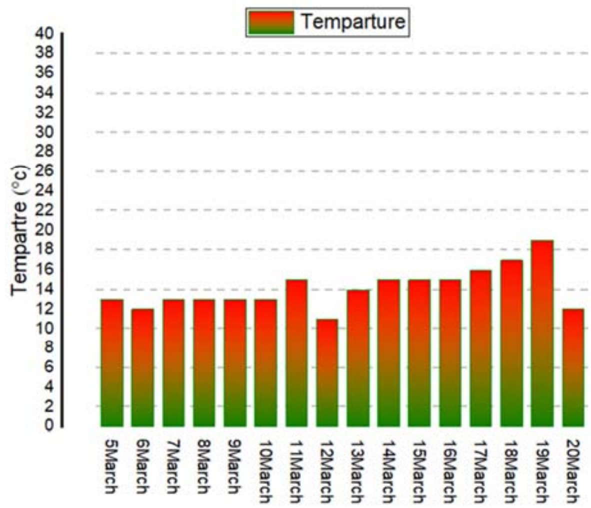

Figure 8. *Building temperature (°C) in the morning.*

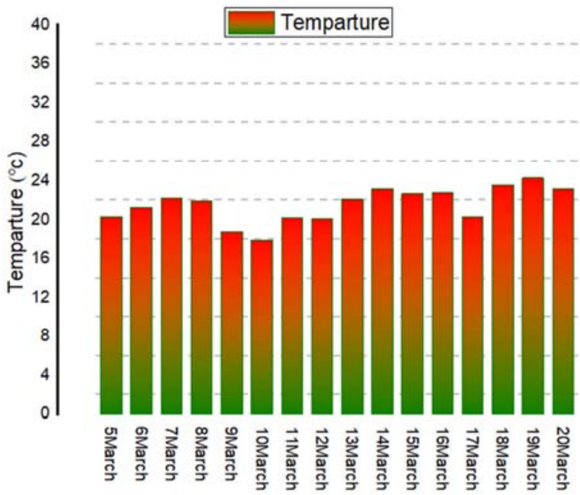

Figure 9. *Building temperature (°C) in the afternoon.*

Figure 9 represents the temperature of the building in the afternoon. The results show that the building temperature in the afternoon is higher than the temperature in the morning for the building.

In this paper, TRNSYS simulation and ground heat pump systems are recommended for advancing the effectiveness of the solar heating system.

5.2. TRNSYS Simulation Results of the System with Underground Storage

5.2.1. Solar Collector's Temperature

In order to characterize the system as a whole, the parabolic solar collector has been designed in TRNSYS. Figure 10 shows the output temperature from the solar collector.

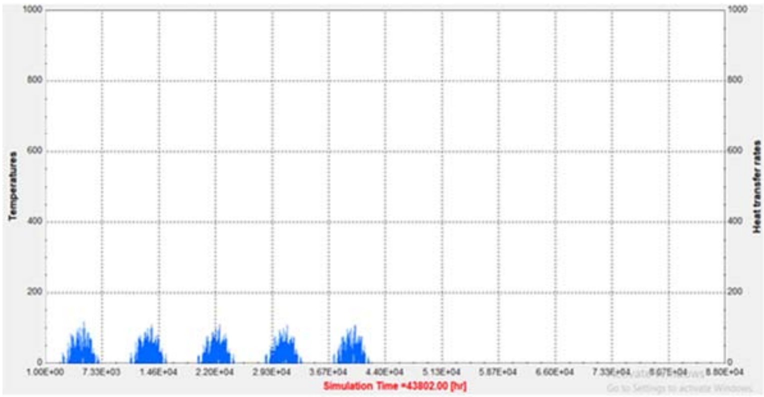

Figure 10. *The solar collector temperature (°C) simulated with TRNSYS.*

TRNSYS was used to simulate the temperature outlet for the solar collector based on weather data and radiation data generated by Meteonorm as an inclusive meteorological reference, especially for the place where actual measurements are taken with climate stations [16].

Through the TRNSYS simulation system, the results are illustrated in Figure 10. The heat received by the solar collectors is enhanced by solar energy, but in an attempt to maintain an outlet's temperature at a set value and the auxiliary heating supply must provide more energy.

5.2.2. Temperature Inlet to the Building

The activities of building occupants and the underground surface substance influence energy consumption. Figure 11 shows the temperature inlet to the building based on TRNSYS; the transient simulation time is presented in the x-axis (hrs.), while the y-axis presents temperature (°C) inlet to the building.

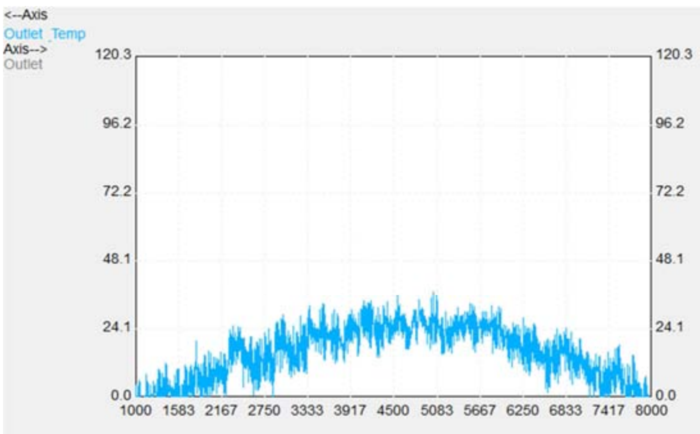

Figure 11. *Temperature (°C) inlet to the building.*

These results compared to Figures 8 and 9 show that the simulation outcome is much higher than the experiment result for the building temperature. This, in turn, means that the inlet temperature distribution of the building is improved by adopting the underground heat storage.

5.2.3. Building Air Temperature and Tank Outlet Temperature

Figure 12 shows the simulated temperature stability of the building through the time to analyze the load from temperature currents. As we notice, the building temperature is lower than the surrounding equipment temperature at around 4°C. Figure 7 shows the temperature outputs from the experiment set-up (18 - 25°C) and the error, such as measurement error, is obtained. The simulation results show that the building air temperature is between 18.4°C and 22°C. The transient simulation time is presented in the x-axis (hrs.), while the y-axis presents building air temperature (°C) and Tank Outlet Temperature (°C) at the same time.

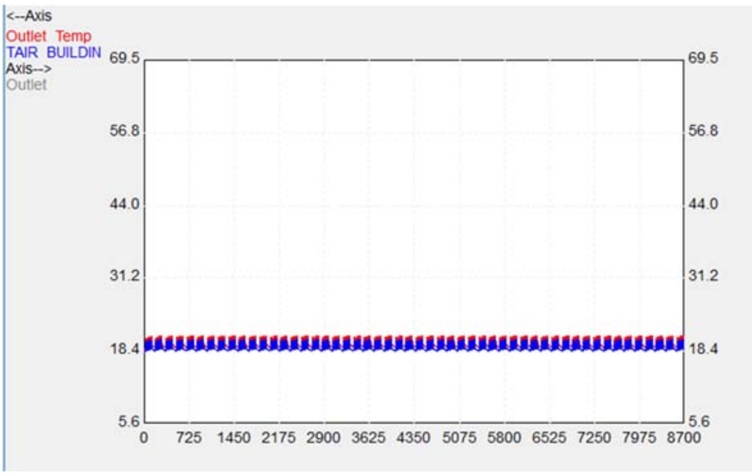

Figure 12. *Building Air Temperature (°C) and Tank Outlet Temperature (°C).*

5.2.4. Building Air Temperature and Fan Outlet Temperature

The ambient air is heated with fan coil to produce hot air to be distributed through the building. During the start and stop of the fan coil unit, a sudden temperature change is detected, and when the fan coil is not in operation, the temperature of the fan coil unit will follow the average temperature of the tank, which is also influenced by the tank volume and tank thermal loss.

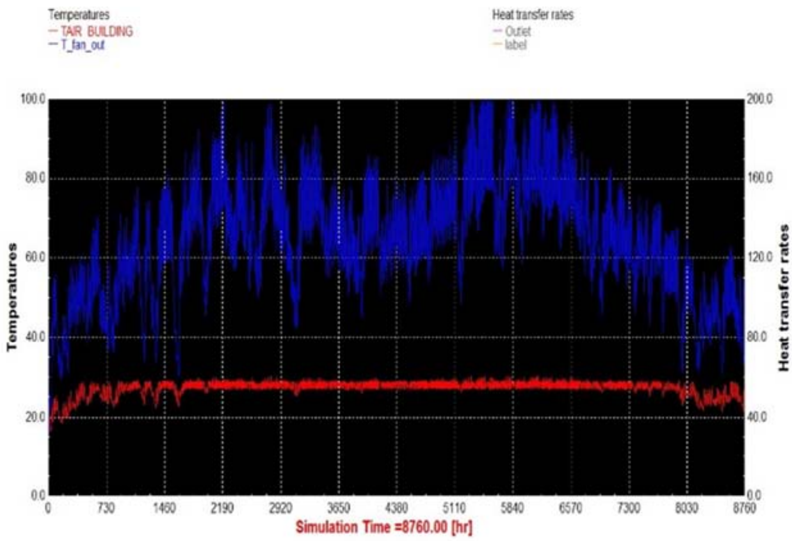

Figure 13. *Building Air Temperature (°C) and Fan Outlet Temperature (°C).*

Figure 13 shows the detailed simulation results for the air temperature and the fan coil temperature outlet for the building of simulation time 8760 hrs. In case of an increase in the fan flow rate, the building air temperature increases and when the fan coil has a flow rate of hot water, the fan coil air temperature is increased. The results also demonstrated that the heat absorbed by the fan coil increased as flow rates increased.

5.2.5. Building Heat Transfer Rate

The ground storage model is used to improve heat transfer through the ground. As shown in Figure 14, the simulation results are for 8760 hrs. It shows the thermal transfer frequency of the borehole outlet containing the 48 borehole heat exchangers with d=105mm, IR=26mm, OR=32mm, R=135mm, as well as the heat differences of ground and tank water storage systems. It is often concluded that the fluid's temperature outlet increases over time as the ground loads in function. The outlet fluid temperature differences are also considerably bigger in comparison to the variances in heat transfer. However, over time heat transfer gradually improves.

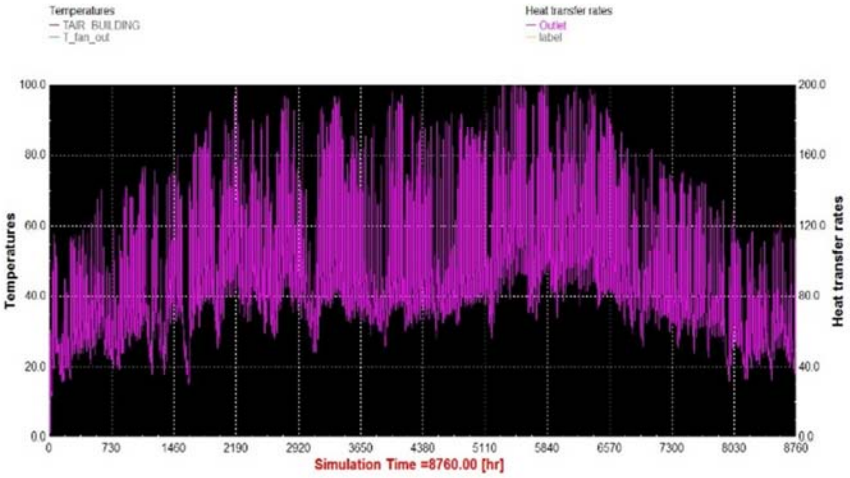

Figure 14. *Building Heat Transfer rate.*

Finally, the results show that the collectors supply high temperature to the system and the thermal comfort is compared based on TRNSYS software. It is found that the efficiency is accomplished with the temperature outlet from the tank. TRNSYS is used for advancing the effectiveness of the combined solar heating system with underground heat storage. The simulation results are much higher than the experiment results for the building temperature. This means that the system is improved by adopting the underground heat storage.

6. Conclusion

In this paper, an approach is proposed to combine the solar heating system with underground heat storage to improve heat transfer and decrease heat loss. The proposed approach is based on two parts. The first part consists of the solar thermal collector and tank connected with each other through PE100 pipes. The second part is comprised of underground boreholes to act as energy storage and increase heat transfer. The proposed approach is compared with the solar heat system without boreholes. Based on the obtained results, we noticed that the proposed approach is better in terms of heat transfer and system performance.

The proposed approach was based on the experimental analysis for the solar heat system and simulation for the solar heat system combined with the underground boreholes. The obtained results demonstrate that there is a remarkable improvement in the combined system in terms of the system efficiency and performance as well as an increase in the thermal comfort of the building. Nevertheless, it is far from ideal that the underground storage heat pump is not suitable for every model because the solar energy resource and collector efficiency are different, but it is possible to be achieved by the correct design parameters based on the similar way described in this paper through the TRNSYS simulation framework. Although the proposed approach has achieved good results in heating of the building, the future work will focus on investigating the increase in the diameter and number of boreholes as well as the placement of the solar collectors to the boreholes.

Nomenclature

TRNSYS	Transient System Simulation program
SHS	Solar Heating System
GSHPS	Ground Source Heat Pump System
SWH	Solar Water Heater
Mard	Milliradian
U	Coefficient
T	Temperature (°C)
Clo	Cloth
CPC	Compound Parabolic Collectors

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