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The Study of Thermostat Impact on Energy Consumption in a Residential Building by Using TRNSYS

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ABSTRACT

The present study investigates the effectiveness of thermostat control strategy in cooling energy consumption in residential buildings. To evaluate the energy consumption, two scenarios including a residential zone with and without the thermostat control system are assumed. The TRNSYS software provides an efficient numerical tool to model and evaluate a cooling system. Furthermore, since solar-powered cooling systems for residential air-conditioning are receiving growing and significant interest, a hot-water fired absorption chiller coupled with evacuated tube collectors is considered as the cooling system. The results reveal that the cooling systems consume a large amount of energy in hot climate zones without employing the thermostatic control. Therefore, cooling energy has great potential for a significant saving in hot climates. It is illustrated that the thermostat strategy has an obvious impact on such energy saving. In the current study, employing the thermostat in 90 m^2 residential building results in saving energy by up to 36 %.

1. INTRODUCTION

Optimizing and controlling energy consumption in residential building sections has become an important issue worldwide. Energy unions follow strategies to achieve fundamental approaches to decarbonizing energy systems. These approaches are solely achieved by employing more integrated and sustainable ways to produce and deliver energy. Buildings sector consumes 30 % and 55 % of global energy demand and global electricity demand, respectively [1-6]. The buildings and building construction sectors combined are responsible for nearly 40 % of the total direct and indirect CO_2 emissions [1-6]. Even though sustainable building technology is developing significantly nowadays, improvements are still slow and properly adjusted with a growing buildings sector demand. It is worth mentioning that energy demand for buildings and construction industry sectors continues to surge by nearly 3 % per year.

Space heating and cooling consume a significant amount of energy, up to 75 % of the total energy demand [3]. Therefore, energy saving in this section has effective impacts on improving energy efficiency. Renewable air conditioning technologies offer an applicable option among the available ones to manage this high growth energy demand. These technologies reduce the consumption of primary energy sources such as fossil fuels. Among the renewable heating and cooling technologies, solar-assisted cooling systems have illustrated to be a trustworthy and efficient alternative. This class of renewable air-conditioning systems can be driven by a low-grade heat source. Furthermore, studies have illustrated that other strategies, such as the thermal-conscious energy control, can be significantly effective in reducing the amount of energy consumption besides the application of solar-powered air conditioning systems in the residential buildings.

The usage of thermostatic strategy to obtain thermal control in a residential building results in two essential improvements: growth in thermal comfort and energy saving. The application of the thermostat causes the indoor temperature to adjust to the desired level, while the occupants are psychologically satisfied to have this opportunity to manage their environmental conditions. Furthermore, this strategy offers several advantages such as simplicity, low-cost, and ease of operation that can result in the wide employment of this technology.

The application of the thermostat demonstrates that energy consumption for thermal comfort can be reduced significantly. Previous studies proved that significant energy saving could be achieved, up to 30 % and 23 % for heating and cooling systems, respectively [7, 8]. The resultant economic impact is 15-40$ saving by 0.56 ^oC lowering setting for U.S. residential building. Simulation of a residential building in the North America climates suggests that lowering the thermostat temperature level, 2-4 ^oC for 8h per night, saves 5-15 % on the energy bill annually [8], even the amount of energy saving remarkably depends on the employed thermostatic strategy and climate zone. Nowadays, many researchers consider using a programmable thermostat to achieve maximum energy saving in conjunction with maximum thermal comfort. The smart zoning of thermostatic loads was investigated to improve the occupant-building interaction and adjust it to occupancy schedules and sudden weather-changing conditions [9]. Luca et al. assessed the impact of the programmable thermostatic valve in a centralized heating system to evaluate the building energy demand [10]. The study of the actual energy saving by the utilization of thermostatic valves in a residential building illustrated that energy saving ranged between 7.1 % and 23.3 % [11]. The other study of an old residential building in Italy showed the usage of thermostatic valve resulted in the reduction of energy demand by up to 10 % [12]. Considering the occupants' presence and behavior

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demonstrated that the control schemes based on these two important parameters could save the energy up to 20-50 % for heating and 10-25 % for cooling [13-15].

This study represents the impact of employing the thermostat in energy saving for a residential building in Kerman, Iran. A few technical notes are given about the energy-saving strategies in Iran, especially in hot climate zones that the air-conditioning systems are extensively used and consume a great amount of energy. Most of the studies in the available literature investigated the thermostatic control in European and American climate zones that are completely different from the dominant climate conditions in Iran. The major novelty of the present study is to investigate the effects of employing the thermostatic strategy on the energy-saving in a residential building in one of the hottest climate zones in Iran. In other words, the present study illustrates the effectiveness of the thermostatic approach in improving energy efficiency. To this end, TRNSYS software was utilized to model and evaluate a designed air-conditioning system integrated with a thermostat control. TRNSYS software provides a numerical tool to model a solar heating and cooling system with the dynamics of indoor temperature variation in a residential building. TRNSYS contains a great internal library with numerous technical components that are broadly used in the energy systems. This capability enjoys the major merit of the precise simulation of system dynamics in different operating scenarios with or without auxiliary components. In this study, TRNSYS is employed to model a hot-water fired absorption chiller coupled with evacuated tube collectors (ETCs). Two scenarios are considered to study the impact of the thermostat on energy consumption and saving. In one scenario, the simulation is accomplished without employing the thermostat, while, in the other scenario, an ON/Off thermostat is utilized to keep the indoor air temperature within the desired range by switching the air conditioning system ON or OFF. The results show that employing the thermostat reduces the energy demand by up to 36 %. Therefore, this amount of energy saving can remarkably improve the performance of the system in economic terms and operational terms.

2. THE DESCRIPTION OF PROBLEM

2.1. Building characteristics

Summer cooling is a basic requirement in the thermal comfort basis for the building in the hot climate. Iran is located in hot and sunny climate band with annual average insolation of 4.5-5.5 kWh/m^2/day. In such a context, a sustainable air-conditioning system, such as solar-powered hot-water fired absorption chiller, can provide a viable alternative source for thermal comfort in the buildings. Among the renewable solar-driven air conditioning systems, the hot water-fired absorption chiller is the most promising approach to meeting this requirement. Furthermore, to increase the thermal satisfaction for the occupants by energy-saving approach, thermostats are widely used to create a standard and desired condition in the environment. To illustrate the effectiveness of thermostatic control in the current study, a typical building is considered. The building is 90 m^2 with double-glazed windows. The building is of break and concrete construction, uninsulated. The building characteristics are summarized in Table 1.

The simulation was carried out in August during the middle of hot and dry season. Often, in August, the district experiences the hottest weather conditions. Furthermore, the main scope of the present study is to evaluate the dynamics of the solar-assisted air-conditioning system integrated with thermostat control. It is important to obtain the system behavior in the presence of the installed controller. Therefore, the simulation was carried out in the hottest month of the year in order to clarify the dynamics of the system in complete detail.

Table 1. Building characteristics.

Concept	Type	Total Area (m^2)	Window Area (m^2)
North wall	External	30	10
South wall	Boundary	30	0
East wall	Boundary	27	0
West wall	Boundary	27	0
Ceiling and floor	External	90	0

2.2. Solar-powered cooling system

The research object is a solar-assisted cooling system, including a single effect absorption chiller with ETCs. The ETCs are employed as a heat source to heat water as working fluid. A stratified reservoir tank is employed to reserve the produced hot water, while an auxiliary heater heats up the hot water in the periods that the collector heat gain is not sufficient. The obtained hot water is supplied for the absorption chiller to provide chilled water for cooling coils. Furthermore, the produced hot water can be utilized to meet the occupant's demand.

The total effective ETC area is 10 m^2, and the produced hot water is stored in 500 liters storage tank. The solar-powered cooling system is presented in Figure 1.

2.3. TRNSYS modeling

TRNSYS is a transient system simulation program with a modular structure that was designed to solve complex energy systems problems. The software includes a large library of built-in components that are often validated by experimental data. These components are linked together to form the desired energy systems. The key components of a solar-powered cooling system are described as follows:

1) **Evacuated tube solar collector:** Type 71 models the evacuated solar collector in TRNSYS. ETCs consist of a series of heat pipes inside vacuum-sealed tubes. In an actual installation, numerous tubes are connected to the same manifold that collects the heated working fluid. This class of thermal collectors is particularly useful in areas with cloudy, cold weathers. The thermal efficiency of the collector is given in the user manual of TRNSYS software as follows:

$$\eta = a_0 - a_1 \frac{\Delta T}{I_T} - a_2 \frac{\Delta T^{\,2}}{I_T} \qquad (1)$$

where, η is the thermal efficiency of ETC that is defined by three constant parameters: a_0, a_1 and a_2. Here, a_0 is optical efficiency, a_1 and a_2 are the first-order and the second-coefficients, respectively. These three constant parameters are available for collectors that were tested based on ASHRAE standards or recent European Standards. I_T is the total incident radiation on the collector per unit area, while ΔT depicts the temperature difference.

2) **Stratified tank:** Type 4 models the stratified tank in TRNSYS. The stratified tank operates based on the thermal

stratification process. Stratification is a natural process that occurs when the warm water settles on top of cold fluid water. The process that happens in a stratified tank can be summarized in two simple operations: charging and discharging.

3) **Absorption chiller:** Type 107 models the single-effect hot-water fired absorption chiller in TRNSYS. In this type of absorption chillers, the required heat to desorb the refrigerant in the generator is fed by a stream of hot water, while a cooling tower rejects the energy of the refrigerant absorption process to a cooling air stream. Type 107 uses predefined data to predict the operational performance of the employed absorption chiller.

4) **Auxiliary heater:** Type 6 models the auxiliary heater in TRNSYS. An auxiliary heater is utilized to add heat to the flow stream at a user-designated rate as long as the heater outlet temperature is less than the desired setpoint.

5) **Cooling tower:** The cooling towers are devices that cool down a stream of hot water by rejecting waste heat to the atmosphere. Dry cooling towers operate through convective heat transfer, while a surface separates the hot working fluid from ambient air. They do not use evaporation; hence, the consumption of makeup water is minimal.

6) **3-Stage room thermostat:** Type 8 models the thermostat in TRNSYS. A three-stage room thermostat can be used to manage the working status of the components of an energy system such as solar heat sources and auxiliary heaters by three ON/OFF control functions. This controller is employed to control systems on the basis of temperature levels. The controller sends control signals to switch ON/OFF cooling system at high room temperatures.

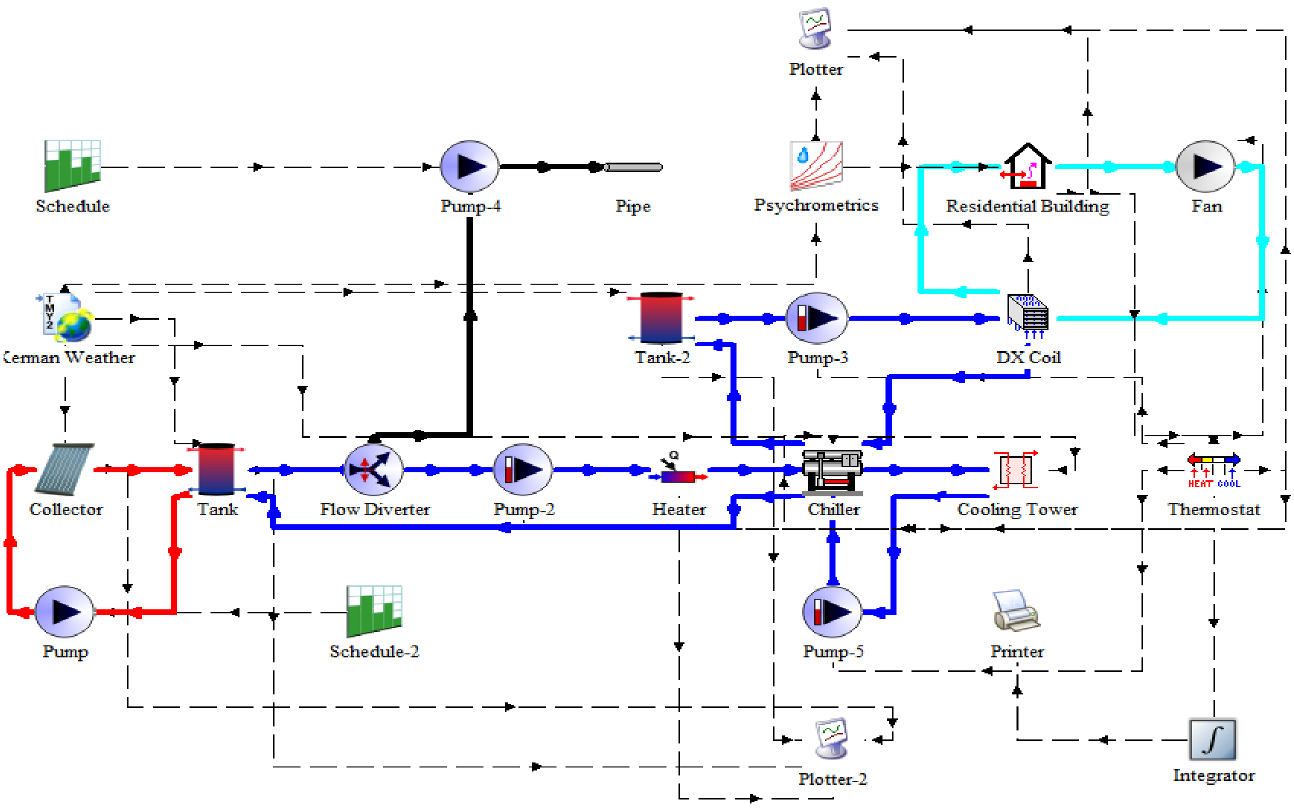

Figure 1. The schematic diagram of simulated cooling system.

2.4. Technical detail of system

The pumps circulate water through the cooling system. The simulation was carried out from August 1st to August 30th. The simulation was performed in one month (August as the hottest month of the year) to clarify the system dynamics in more detail. The solar-powered cooling system includes two main circuits: solar collector (red line) and cooling (blue line). The key features of the solar-assisted air conditioning system are tabulated in Table 2.

Figure 1 indicates the schematic of the simulated solar-powered air conditioning system.

The technical detail of the components of the cooling system under study is presented in Table 3.

2.5. Geological data

The solar insolation and the hourly dry bulb temperature data over a year, which are collected in the Kerman weather station are shown in Figures 2 and 3, respectively. Kerman has the following geometrical coordinates: latitude = 30.2832108 and longitude = 57.0787888. The mean elevation of the city is about 1755m above the sea.

Table 2. Key parameters of the solar-powered air-conditioning. System.

Description	Specification
Cooling set point	25 °C
Operation hours	Continuous
Solar fraction	100 %
Design cooling load	10 kW
Chiller type	Hot water fired absorption chiller
Collector type	ETC
Collector area	10 m^2
Hot water storage tank	500 Liters
Auxiliary heater power	10 kW
Weather data	TMY2, Kerman, Iran

Table 3. Cooling system components.

Description	Technical Specification	
Hot water fired absorption chiller	Single effect	
	Capacity	5 ton
	COP	0.8
	Chilled water inlet/outlet temperature	7/12 °C
	Cooling water inlet/outlet temperature	32/40 °C
	Hot water inlet temperature	85-95 °C
Cooling Tower	Hot side inlet temperature	40 °C
	Cold side inlet temperature	30 °C
	Cold side flow rate	100 kg/hr
	Overall heat transfer coefficient	10 kJ/hr.K
Circulation pump	Power	1 hp
Auxiliary heater	Power	10 kW
	Set point temperature	90 °C
	Efficiency of auxiliary heater	95 %

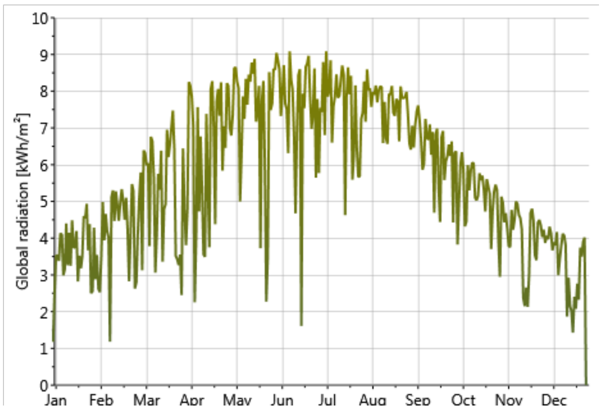

Figure 2. Direct normal radiation of Kerman.

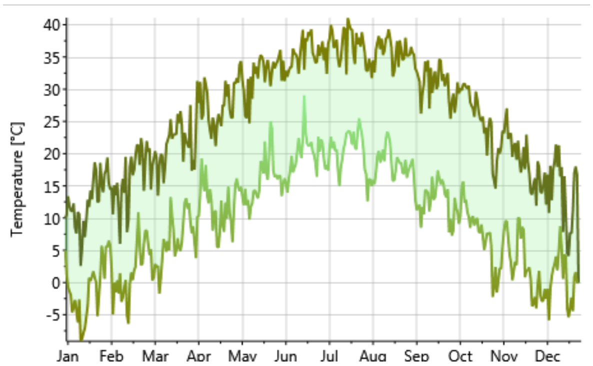

Figure 3. Dry bulb temperature of Kerman.

3. RESULTS AND DISCUSSION

With regard to the simulated model depicted in Figure 1, the case study was developed for Kerman, Iran. According to the schematic of the process, Figure 1, the solar-powered cooling system includes two main circuits: heating-water circuit to produce hot water (red line) and cooling-water circuit to produce chilled water (blue line). In the solar collector circuit, heating fluid (water) is impelled by a circulation pump from a reservoir tank into the ETC and returned to the reservoir tank. In the cooling circuit, the heating fluid is sent to the auxiliary heater to control the supply temperature and flows towards the generator component of the absorption cooling system. Finally, the working fluid is pumped into the tank. The cooling circuit components are controlled by a thermostat that is located inside the residential building. The thermostat is activated to keep the indoor temperature below 25 °C. Furthermore, a flow diverter is employed to meet domestic hot water demand. The indoor temperature is below 25 °C. Furthermore, a flow diverter is employed in response to the need for domestic hot water. It is worth mentioning that the axillary heater adds heat to the flow stream as long as the solar system cannot provide sufficient hot water with desirable temperature to supply the absorption chiller.

Considering that the number of occupants is assumed to be 4, while 150 Lit/day is considered for each of these occupants. The domestic hot water circuit is shown in the black line. The chilled water is kept stored in a tank, and a variable speed pump circulated the chilled water inside the cooling coil. The building returned air passes through the cooling coil by a fan, while its temperature is dropping down. The cooled air enters the building. The maximum total cooling load of the residential building during the simulation period is 3.5 tons. Factors that influence the amount of energy required to cool the air within a building include:

1) Openings with solar radiation,
2) Hours of sunshine,
3) Number of occupants in the building,
4) Electrical and heat-radiating equipment,

The total cooling load includes two main components: the sensible cooling load and the latent cooling load. The sensible cooling load refers to the load, which is required to lower the temperature or maintain the temperature in an acceptable range, while the latent cooling load refers to the load, which is required to remove the moisture from the air or to dehumidify the air.

Figure 4 depicts the outlet temperature from the ETC, hot water reservoir tank, and the auxiliary heater. The auxiliary heater adds heat to the flow stream whenever the external control input is equal to one, and the heater outlet temperature is less than the chiller desirable feeding temperature. As seen in Figure 4, the temperature of water at the outlet of ETC changes in the wide range of 25 °C to 113 °C during a day, while the temperature of the hot water at the installed reservoir tank varies between 85 °C to 100 °C. This finding shows the importance of the auxiliary heater to add the heat to the water when the collector can not provide sufficient hot water to run the chiller. Furthermore, to optimize the heater, the reservoir tank keeps the produced hot water by the collector as long as the thermostat switches off the absorption chiller.

Figure 5 shows the zone and ambient temperatures in accordance with the control signal during the simulation period. The thermostat is set to 25 °C. As long as, the indoor air temperature is equal to or below the setpoint temperature, the thermostat returns the 0-signal control to the solar cooling systems meaning that thermostat switches off the cooling system. However, by exceeding the room temperature above the setpoint temperature, the thermostat returns ON signal to the cooling system. The control system causes the cooling system to turn OFF during the periods that the cooling load is small. One of the components of the evaluated air-conditioning system is the auxiliary heaters that add heat to the produced hot water to reach the hot water temperature to the desired level for entry to the absorption chiller. By switching off the cooling circuit, the total amount of consumed energy in the auxiliary heater will be reduced significantly. Therefore, the thermostat results in saving energy. By integrating the amount of consumed energy by the auxiliary heater, it is concluded that the thermostat results in saving energy by 36 %, approximately.

Figure 6 represents the instantaneous cooling load (presented in kJ/hr) and the thermostat function during the simulation period. As seen in Figure 6, by decreasing the cooling load, the thermostat switches off the system, and to keep the temperature in the desirable range, the thermostat returns ON signal to the system by increasing the cooling load. It is interesting to note that, in some periods (mainly during the nights), the values of the cooling load are negative and show the outward direction of heat transfer while the building loses heat.

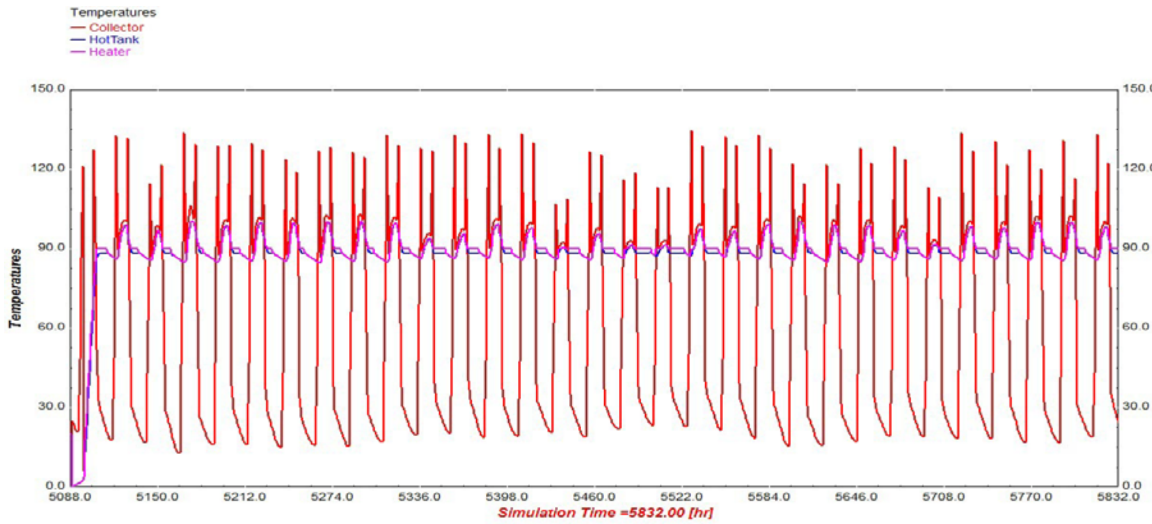

Figure 4. The outlet temperature from the ETC, hot water storage tank and the auxiliary heater.

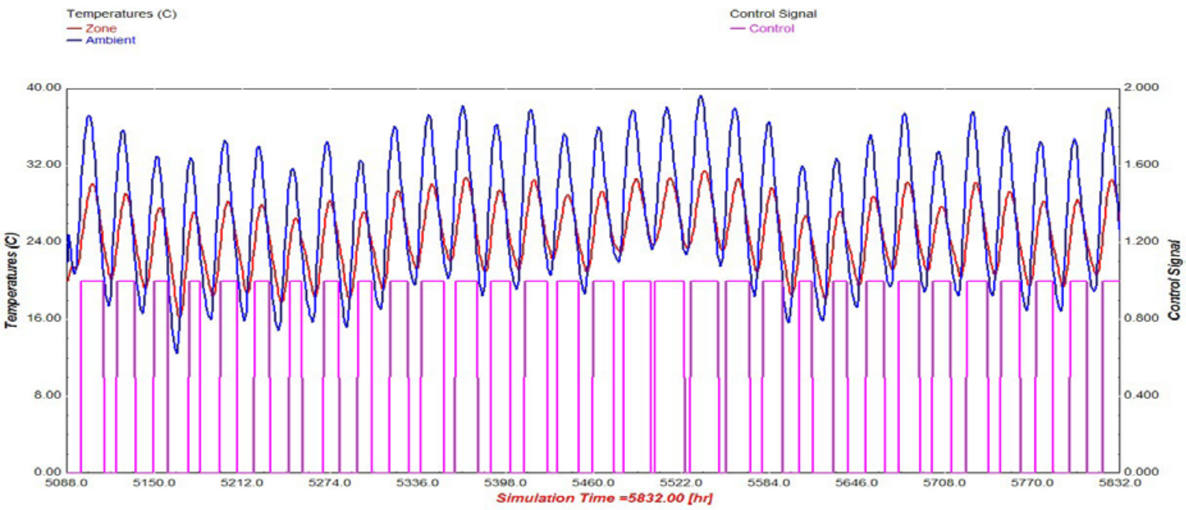

Figure 5. The zone and ambient temperatures in accordance with the control signal during the simulation period.

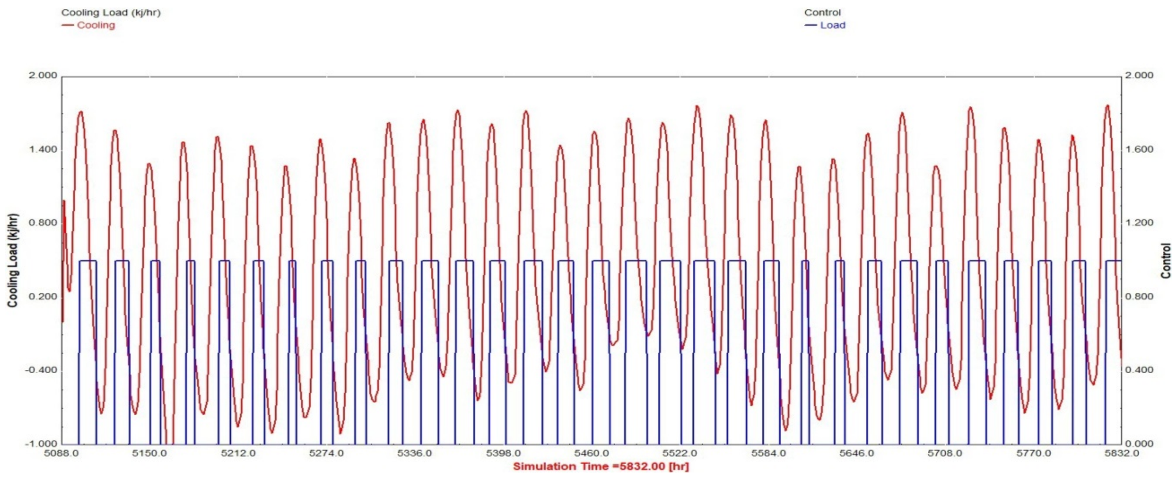

Figure 6: Instantaneous cooling load and the thermostat function during the simulation period.

4. CONCLUSIONS

In this study, a solar-assisted air-conditioning in a residential building is simulated and evaluated by employing TRNSYS 16. The current study represents the potential of employing a solar-assisted cooling system under hot climate conditions. The developed system comprises a hot-water fired absorption chiller, ETCs, and cold and hot water reservoir tanks. A TRNSYS model is simulated using a typical meteorological year. Furthermore, this study investigated the effects of employing the thermostat to control the solar-powered cooling system.

The obtained results show that utilizing the thermostat to adjust the room temperature and control the cooling system can reduce the consumed energy by system components. Reducing the amount of used energy by utilizing the thermostat results in energy saving by up to 36 % in the auxiliary heater unit in the cooling system as shown in Table 4.

Table 4. The amount of required heating.

Assumed scenarios	Auxiliary heating (J)
The 1st scenario without thermostat	2.2×10^6
The 2nd scenario with thermostat	1.7×10^6

5. ACKNOWLEDGEMENT

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