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Application of Solar Thermal Collectors to Improve the Energy Performance of the Fresh Air HVAC Systems

M. Ahmadzadeh Talatapeh

Department of Marine and Mechanical Engineering, Chabahar Maritime University, Chabahar, I.R.Iran
m_ahmadzadeh56@yahoo.com

Abstract: In the preset study, the performance of a solar assisted heating, ventilation and air conditioning (HVAC) system in an operating theater building was studied. The yearly performances of the existing HVAC system and the system with the added solar collectors were simulated in terms of energy consumption and provided air conditions using a transient system simulation software (TRNSYS). In the modified system, the solar collectors feed a liquid-to-air heat exchanger, which was defined to be replaced with the main heater of the HVAC system during the day times throughout the year. Three solar integrated HVAC system configurations consisting of three types of standard liquid flat-plate collectors namely, Configuration A: unglazed, Configuration B: glazed painted, and Configuration C: evacuated tube solar collectors were examined to determine the most proper configuration in terms of energy consumption and provided air conditions. Based on the simulation results, all the configurations examined were capable of providing proper air into the space. However, the energy performance of the configurations indicated that the Configuration A has priority in terms of energy consumption level and was recommended to be implemented in the existing HVAC system.

Keywords: Energy performance, HVAC system, Solar collector, TRNSYS software.

1. Introduction

The world energy consumption is expected to increase by about 56% from 2010 to 2040 from 524 quadrillion British thermal units (Btu) to 820 quadrillion Btu [1]. In addition, buildings consume about 40% of the total energy demands in many countries [2]. In buildings itself, HVAC systems are responsible for approximately 60% of the total energy consumption [3]. This indicates that a great energy efficiency improvement potential exists in the building sector. Therefore, decreasing the energy consumption and consequently environmental effects of the HVAC systems is considered as a primary target for the HVAC designers and producers.

The solar integrated HVAC systems can help designers to reach this objective. By the application of such renewable energy source, the primary energy demand for space air conditioning systems could be considerably decreased. Solar radiation is considered as the world most abundant and clean energy source and solar assisted systems as the environmental friendly systems has interesting advantageous such as: low maintenance cost and silence in operation.

Malaysia as a tropical country lies between 1° and 7° in North latitude and 100° and 120° in East longitude [4]. Malaysia has a relatively high temperature and Relative Humidity (RH). The RH fluctuates between 80% and 90% and the temperature varies from $22^{\circ}C$ to $33^{\circ}C$ with the mean daily temperature of $26.5^{\circ}C$ [5]. Malaysia receives the daily average solar radiation of 4000-5000 Wh/m^2 with the average sunshine of 4-8 hour/day [5]. Therefore, Malaysia has a favorable weather conditions for the establishment of solar energy technologies. Fig. 1 shows the total monthly solar radiation on a tilted surface towards south (surface azimuth angle of zero) in Kuala Lumpur, Malaysia.

A number of research studies and demonstration projects have been conducted on the application of solar energy for HVAC systems [6-14]. For instance Fong et al. [6] examined six hybrid alternatives to solar desiccant cooling systems to further enhance the energy efficiency of the air conditioning systems. The study showed that the six hybrid system alternatives were technically feasible. The study revealed up to 35.2% saving of year-round primary energy consumption against the conventional air-conditioning systems. In another study, the year round effect of a solar hybrid air-conditioning system was investigated for typical office type system [7]. Habib et al. [11] investigated the performance of solar powered combined adsorption refrigeration cycles for tropical areas using evacuated tube solar collectors.

Literature review showed that despite many practical applications of this environmental friendly technology, studies based on a Typical Meteorological Year (TMY) data for solar collectors applied in the tropical climates for yearly operation of 8760 hours were limited. The effect of solar collectors on the performance of HVAC systems in terms of energy consumption encourages the HVAC designers for practical application of the solar collectors in the HVAC systems to enhance the system performance. To this end, this study was conducted and the possibility of enhancing the performance of an existing HVAC system in a tropical building was explored. The HVAC system of an operating theater located in putrajaya hospital, Kuala Lumpur, Malaysia as a high energy demanding system (24 hour running) was considered as a case study for this purpose. In this investigation, a liquid-to-air heat exchanger, which directly fed by an array of solar thermal collectors, was planed to be replaced with the heater of the system during the day hours throughout the year. Three standard types of solar collectors namely, unglazed, glazed and evacuated tube liquid flat-plate collectors were examined in the existing HVAC system to determine the most appropriate design. TRNSYS software was used to study the effect of added solar collectors on the performance of the system in terms of energy consumption level and provided air conditions.

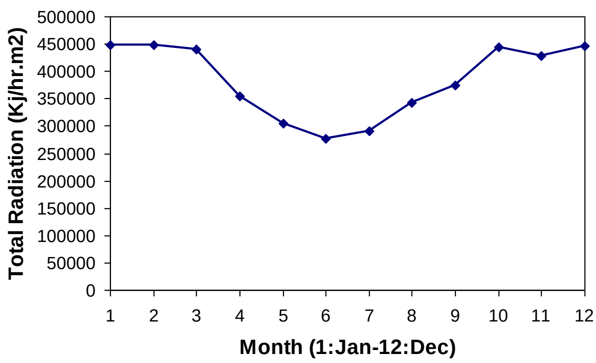


Fig. 1. Monthly solar radiation for a tilted surface towards south in Kuala Lumpur, Malaysia

2. TRNSYS Description

TRNSYS as a transient system simulation software is a certified HVAC system simulation program and was applied in this research [15]. The program uses TMY weather data to simulate the system performance for a whole year of operation in hourly bases. The hourly computation allows for sufficient accuracy in the calculation of the systems performance.

In order to simulate the systems, the components of the systems are assembled in the TRNSYS studio. This can be performed by assembling standard and non-standard components. The standard components are available in the software library; however, the modular nature of the TRNSYS software enables the users to add the non-standard components into the TRNSYS program. For this purpose, the performance characteristics of the equipment are written in FORTRAN source code to present the equipment in the TRNSYS studio as a component.

3. Research methodology

The major aim of the preset research was to investigate the effect of added solar thermal collectors on the yearly energy consumption of the system to determine the possible energy savings. In addition, the effect of the added solar thermal collectors on the provided indoor air conditions was also investigated.

For the energy analysis, first, the performance of the existing HVAC system in terms of yearly energy consumption is presented in section 3.1. For yearly estimations, the existing HVAC system was simulated in TRNSYS studio and the yearly energy consumptions of the system components was determined. Then, the electric heater of the existing HVAC system was replaced with a liquid-to-air heat exchanger, which gets its heat energy from the three different type solar thermal collectors to determine the most suitable type for the system. Sections 3.2 and 3.3 explain the examined array of the solar collectors and HVAC system integrated with the solar collectors, respectively.

The performance of the modified HVAC system (the system with the added solar thermal collectors) was simulated for a whole year of operation and the yearly energy consumption of the components was determined. In addition, the provided indoor and supply air conditions were found out. The yearly energy consumption of the HVAC system was tabulated and compared and the most energy saving capable configuration was recommended. Results and discussions are discussed in Section 4.

3.1. Existing HVAC system study

In order to examine the effect of solar collectors on the performance of the existing HVAC system, the existing HVAC system studied first. For this purpose, the fieldwork measurement was conducted to determine the system performance in terms of energy consumption level and provided air conditions.

There are nine operating theaters under operation in Putrajaya hospital and in this study, operating theatre number three was chosen for the research case study [16, 17]. The HVAC system is a 100% fresh air and exit air is not permitted to return into the space as the requirement for the operating theaters [18]. An energy recovery wheel has already been installed between the fresh outdoor and exhaust air for the energy recovery purpose. Fig. 2 illustrates the schematic diagram of the existing HVAC system. In the conventional HVAC systems, humidity is controlled by cooling the supply air below its dew point temperature by the air handling unit (cooling coils), which is considered as a sub-cooling process. Additional reheat energy (electric heater) is then needed to reheat the air to the required supply air temperature. In these processes, a significant amount of energy is required.

Based on the field measurements, the temperature and RH of the room were 20.4 $^{\circ}C$ and 60.5%, respectively [16]. ASHRAE standards recommend 20-24 $^{\circ}C$ and 30-60% RH for the operating theaters [18]. A comparison between the field measured data and standard recommendations showed that the provided air condition by the existing HVAC system was marginally inside the range.

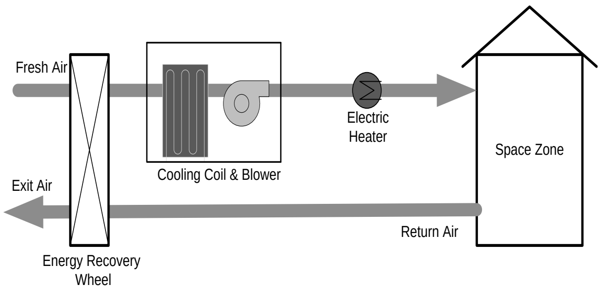


Fig. 2. Schematic diagram for the existing HVAC system

3.1.1. Dynamic simulation for the year-round operation: Existing HVAC system simulation

In order to simulate the existing HVAC system, technical specifications of the equipment, and operational principles of the existing system should be obtained. The standard HVAC components were available in the TRNSYS library and could be assembled. However, the technical specifications of the equipment needed to be defined in the standard components as the parameters and input data to represent the equipment performance accurately in the studio.

In the existing HVAC system, most of the components were represented based on the technical performance and available data. Therefore, these components were described as the non-standard components. The non-standard equipment were defined and added to the simulation studio as described in Section 2.

The building was considered as a single thermal zone and architectural and internal conditions of the building was obtained and defined as Type 56a. Fig. 3 shows the existing HVAC system simulation layout [16,17]. The TRNSYS components and functions are described in Table 1 [16,17].

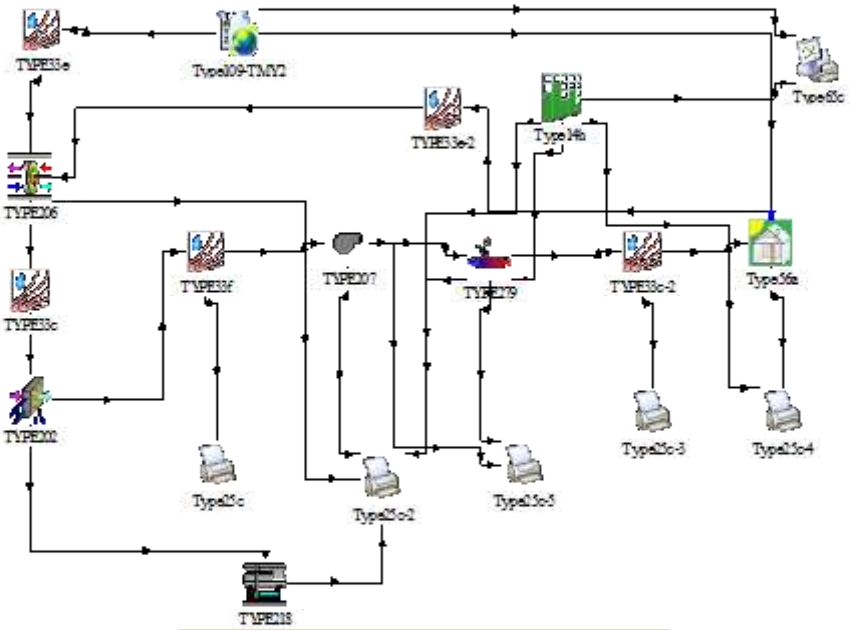
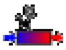
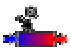
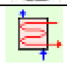
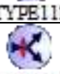


Fig. 3. Existing HVAC system simulation layout

Table 1. The processes and functions in Figs. 3, 6 and 9

Label	Function and Description of the components
 Type109-TMY2	Region Weather Data: This component reads TRNSYS TMY2 format weather file to determine the outdoor condition.
 Type56a	Space: This component takes the inlet DBT, RH and air flow and calculates the space DBT and RH
 TYPE206	Energy recover wheel: This component takes the on coil dry and wet bulb temperature to calculate the off coil air conditions.
 TYPE202	Cooling coil: This component takes the inlet air properties to calculate the cooling coil outlet air properties.
 TYPE207	Blower: This component takes the inlet air DBT and RH to calculate the leaving air DBT and RH.
 TYPE279	Heater: This component takes the entering air properties, air flow, and power input to calculate the leaving air properties and power consumed.
 type285	Auxiliary heater: This component takes the water inlet temperature and calculates the needed water temperature for the liquid-to-air heat exchanger.
 TYPE218	Chiller: This component takes the total load of the air handling unit to calculate the power consumption.
 282	Solar collector: This component reads TMY2 format weather data and inlet water temperature to determine the leaving water temperature.
 type283	Liquid-to-air heat exchanger: This component takes the inlet water temperature and calculates the leaving water temperature and leaving air temperature.
 TYPE11h	Flow mixer: This component takes the two inlet water properties and calculates the leaving water properties.
 TYPE11f	Flow diverter: This component takes the inlet water properties and calculates the two leaving water properties.
 Type14h	Time controller: This component produces a signal, controlling the time based working of the solar collectors, liquid-to-air heat exchanger, and main electric heater.

3.1.2. Existing HVAC simulation outcomes

In order to validate the existing HVAC system simulation, the simulation results were obtained and compared with the field measurements. Fig. 4 illustrates the yearly simulation data for the indoor temperature and RH. Based on the simulation results, the indoor temperature varies between 19.2 $^{\circ}C$ and 20.7 $^{\circ}C$ with the mean value of 19.6 $^{\circ}C$ and RH fluctuates from 57.7% to 60.4% with the mean value of 58.9%. The comparison of the simulated values and filed measurements indicates that there is acceptable agreement between spot measurements and simulation values (see Table 2).

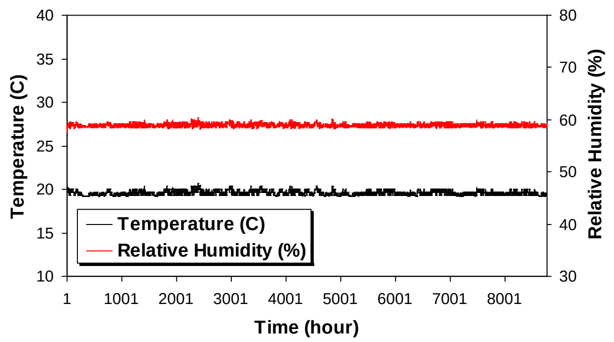


Fig. 4. Simulation results for the existing HVAC system

Table 2. Indoor air conditions for the existing HVAC system [16]

	Indoor Temperature ©	Indoor RH (%)
Field measurements	20.4	60.5
Simulation values	19.6	58.9
Deviation (%)	3.9	2.6

Table 3. Energy consumption of the existing HVAC system [16]

Equipment	Energy Consumption (MWh)	Percentage (%)
Chiller	34.02	47.07
Heater	30.66	42.42
Energy recovery wheel	1.63	2.25
Blower	5.96	8.23
Total	72.26	

The performance of the existing HVAC system in terms of energy consumption were estimated for a whole year and summarized in Table 3. Based on the results, existing HVAC system consumes a total amount of 72.26 MWh in a year, and the chiller and electric heater are responsible for 47% and 42% of the total energy consumption, respectively.

3.2. Examining array of the solar collectors

Before examining the effect of solar thermal collators on the existing HVAC system, an appropriate array of solar collectors for the system was determined. The array of solar collectors recommended by ASHRAE [19] were chosen and examined.

In the solar integrated HVAC system, the heat absorbed by the solar collectors would feed a liquid-to-air heat exchanger and the heat exchanger is expected to be replaced with the system main heater and operates from 8:00 till 17:00. Therefore, the liquid-to-air heat exchanger and solar collectors comes with a time controller which let them to operate during the mentioned hours a day. Fig. 5 and 6 illustrate the schematic diagram for a typical array of solar collectors and simulation lay out as the representative of the configurations examined.

3.2.1. Liquid-to-air heat exchanger component

The liquid-to-air heat exchanger was modeled based on the duct dimensions available. To define the liquid-to-air heat exchanger in the TRNSYS studio, the performance characteristics of the heat exchanger needed to be determined. For this propose, a two rows liquid-to-air heat exchanger was rated based on the S&P coil selection software [20] and the performance curves of the heat exchanger was obtained. Then, the empirical performance equations of the heat exchanger were extracted from the performance characteristic curves (with the highest amount of R^2 value) and used to represent the heat exchanger mathematically in the TRNSYS studio as a component (Type 283). The empirical equations are tabulated in Table 4. The minimum required inlet water temperature for the liquid-to-air heat exchanger was determined based on the water flow rate and the existing HVAC system performance. Therefore, an auxiliary heater (Type 285) was also defined to provide the auxiliary heat in case needed (see Fig. 5).

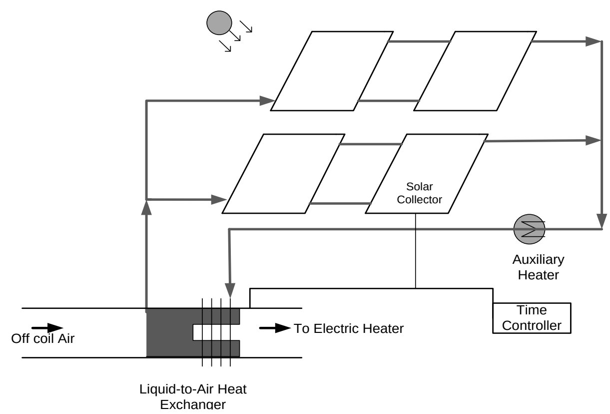


Fig. 5. Schematic diagram for a typical array of solar collectors

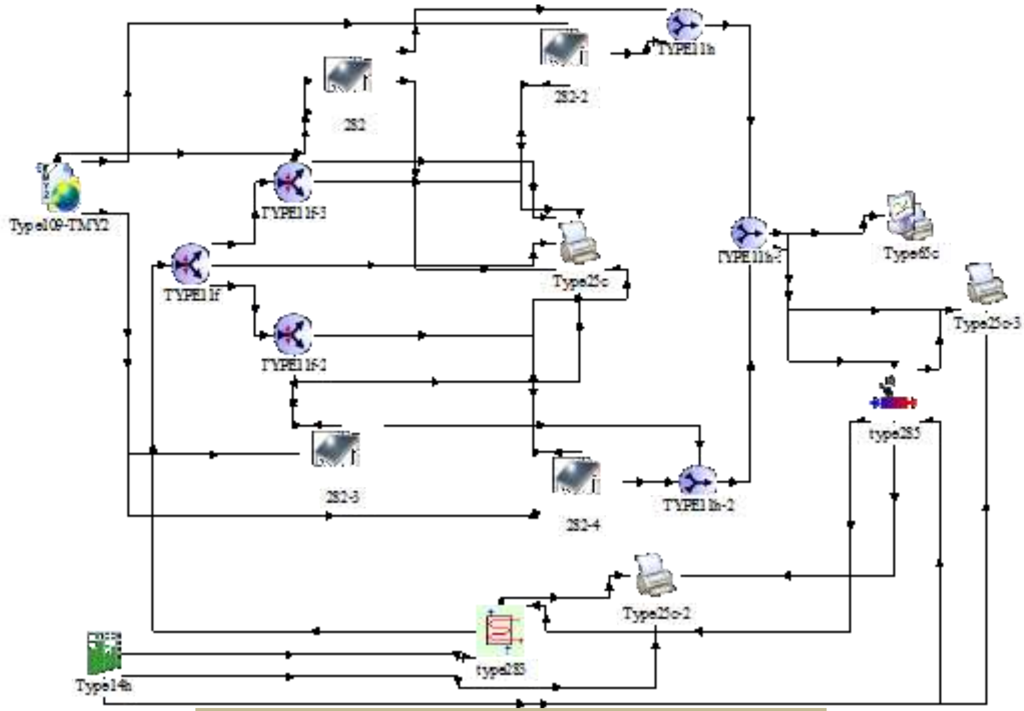


Fig. 6. Simulation layout for a typical array of solar collectors

Table 4. Empirical performance equations of the liquid-to-air heat exchanger

WET range	Empirical performance equation
WET=35 $^{\circ}C$	ALT=0.825*AET+5.766 WLT=0.475*AET+18.633 ALHR=AEHR
35 $^{\circ}C$ <WET<=40 $^{\circ}C$	ALT=0.825*AET+7.133 WLT=0.525*AET+19.133 ALHR=AEHR
40 $^{\circ}C$ <WET<=44 $^{\circ}C$	ALT=0.8*AET+8.5 WLT=0.55*AET+19.5 ALHR=AEHR
44 $^{\circ}C$ <WET<=48 $^{\circ}C$	ALT=0.8*AET+9.7 WLT=0.575*AET+19.833 ALHR=AEHR
48 $^{\circ}C$ <WET<=52 $^{\circ}C$	ALT=0.775*AET+11.167 WLT=0.6*AET+20.1 ALHR=AEHR
52 $^{\circ}C$ <WET<=56 $^{\circ}C$	ALT=0.775*AET+12.33 WLT=0.625*AET+20.267 ALHR=AEHR
56 $^{\circ}C$ <WET<=60 $^{\circ}C$	ALT=0.775*AET+13.533 WLT=0.65*AET+20.4 ALHR=AEHR
WET>60 $^{\circ}C$	ALT=0.775*AET+14.733 WLT=0.675*AET+20.533 ALHR=AEHR

Where WET is water entering temperature, WLT is water leaving temperature, AET is air entering temperature, ALT is air leaving temperature , AEHR is air entering humidity ratio, and ALHR is air leaving humidity ratio.

3.2.2. Array configurations

An array normally consists of individual groups of collectors, called rows, to provide the necessary flow characteristics. Parallel flow as the most frequently used row design [13] with external manifold was considered in this study. In addition, in order to maintain a balanced flow, a direct-return array piping was considered in the simulation studio (see Fig. 5). Five arrays of solar collectors were examined as follows:

A) One row of two collectors, collectors aperture area: 2 m^2.

B) One row of two collectors, collectors aperture area: 4 m^2.

C) Two rows of two collector, collectors aperture area: 2 m^2.

D) Two rows of two collectors, collectors aperture area: 4 m^2.

E) Two rows of four collectors, collectors aperture area: 2 m^2.

In order to obtain the most appropriate configuration in terms of energy performance, a typical unglazed collector liquid flat-plate was considered. A time controller (Type 14h) was defined to let the system (i.e. solar collectors and liquid-to-air heat exchanger) operate from 8:00 till 17:00 in a day.

The array configurations were examined for the month with the lowest radiation and the simulation results for the auxiliary heat are tabulated in Table 5. As it is indicted in Table 5, the arrays D and E need the lowest auxiliary heat and most of the needed energy for the liquid-to-air heat exchanger could be provided by the solar collectors. However, since array D has some kind of compactness and needs less piping arrangements, it was selected for the next step of the simulations. Therefore, array D was added to the existing HVAC system to examine the effect of solar collectors on the performance of the system.

Table 5. Auxiliary heat requirement of the arrays of the collectors, simulation results for June

Array Configuration	Auxiliary heat (kW)
A	906
B	693
C	693
D	395
E	395

3.3. Dynamic simulation for the year-round operation: HVAC system integrated with the solar collectors

As already explained in the paper, the main objective of the present research was to study the possibility of replacing the electric heater with a liquid-to-air heat exchanger fed by the solar collectors during the day times. The standard types of liquid flat-plate solar collectors were examined in the HVAC system to determine the most suitable type of solar collectors for the HVAC system.

3.3.1. Solar liquid flat-plate thermal collectors

The useful heat gained by a solar collector plate under steady sate flow condition equals to the energy absorbed by the heat transfer fluid minus the direct and indirect heat loss from the collector surface to the surroundings area [19]. The thermal performance of the collectors usually comes with an efficiency equation as:

$$\eta = \left[F_R \tau\alpha - F_R U_L \frac{(t_i - t_a)}{I_T} \right] \quad (1)$$

Then, the useful energy delivered by a collector is

$$q_u = I_T . A_C . \left[F_R \tau\alpha - F_R U_L \frac{(t_i - t_a)}{I_T} \right] \quad (2)$$

Efficiency (η) plots against the heat loss parameter ($\frac{(t_i - t_a)}{I_T}$) in Eq. (1), has been given for various standard liquid flat-plate collectors in Fig. 7. In these plots, the intercept of the line with the vertical axis equals $F_R \tau\alpha$ and the slope of the line equals the $-F_R U_L$.

The above mentioned relationship assumes that the sun is normal to the collector plate, which occurs rarely. Therefore, incident angle modifier as in Eq. (3) is used to modify the Eq. (2).

$$K_{\tau\alpha} = \frac{\tau\alpha}{(\tau\alpha)_n} = 1 + b_0 \left[\frac{1}{\cos\theta} - 1 \right] \quad (3)$$

Where q_u is useful energy delivered by collector, A_C is total aperture collector area, I_T is irradiance, total (direct plus diffuse) solar energy incident, τ is transmittance, α is absorptance, U_L is overall heat loss coefficient, t_a is atmospheric temperature, F_R is collector heat removal efficiency factor, t_i is temperature of fluid entering collector, θ is incident angle, $K_{\tau\alpha}$ is incident angle modifier.

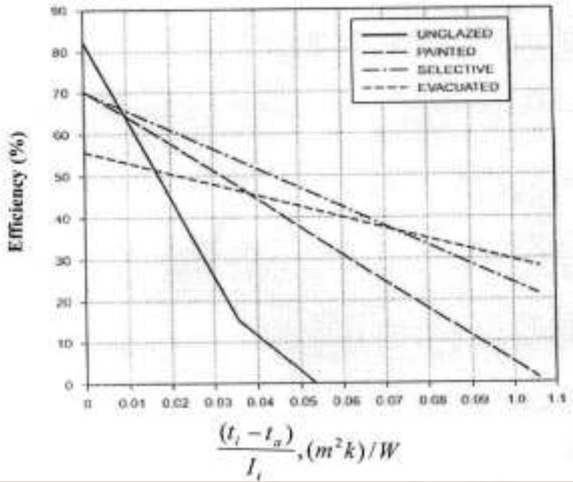


Fig. 7. Solar collector type efficiencies, [19]

The efficiency curves indicate only the instantaneous performance of a collector and could be used as an initial screening device. Therefore, estimating the yearly system performance needs appropriate analysis tools such as TRNSYS, which was used in this research. TRNSYS software provides the hourly weather and sun radiation data for the collectors for the whole year of 8760 hours.

In this research, three standard types of liquid flat-plate collectors namely, unglazed, glazed-painted absorber and evacuated tube were examined. The performance parameters of the collectors are tabulated in Table 6.

Table 6. Average performance, parameters for standard types of liquid flat-plate collectors [19]

Collector Type	Vertical Intercept	Slope, $W/(m^2.K)$
Unglazed	0.807	-18.68
Glazed, painted absorber	0.701	-6.53
Evacuated tube	0.554	-2.52

The performance characteristics of the solar collectors were written in FORTRAN source code to represent the collators in the TRNSYS studio (Type282). The existing HVAC system was redesigned by the added solar collectors, as shown in Fig. 8. In the solar integrated HVAC system, three described liquid flat-plat collectors were examined to determine the effect of collectors on the system performance. The configurations were labeled as:

Configuration A: HVAC system added with the unglazed liquid flat-plate collators.

Configuration B: HVAC system added with the glazed painted absorber liquid flat-plate collectors.

Configuration C: HVAC system added with the evacuated tube liquid flat-plate collectors.

The added solar collectors systems' performance was simulated for the whole year of operation and results were compared to those obtained by the existing HVAC system. Figs. 8 and 9 illustrate the schematic diagram for the system with the added solar collectors and its simulation layout.

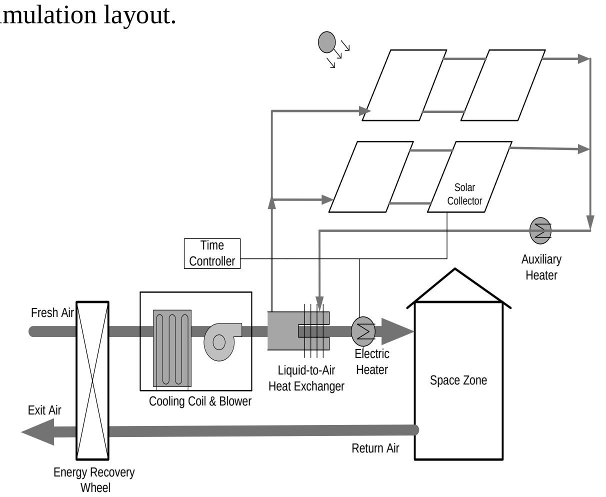


Fig. 8. Schematic diagram for the HVAC system integrated with the solar collectors

3.3.2. Control strategy

In the simulation process of the solar integrated HVAC system, a control strategy was implemented. To this end, a time controller as Type 14h was defined in the simulation studio, which produces an output signal as 1 or 0. The time controller is attached to the main electric heater (Type 279), liquid-to-air heat exchanger (Type 283), and solar collectors (Type 282). During the day hours (i.e. 8:00 till 17:00), the time controller produce signal 1; therefore, output signal make the liquid-to-air heat exchanger to start its operation, while main electric heater stops to operate. In other working hours, the time controller produces signal 0, which turn on the main heater, while making liquid-to-air heat exchanger to stop its operation.

4. Results and discussions

In this section, the simulation results for the provided air conditions and energy consumptions of the solar integrated HVAC systems are presented. The simulation responses for the Configuration A will be described first in subsection 4.1, and the results for the Configurations B and C will be explained later in subsections 4.2 and 4.3, respectively.

4.1. Simulation responses- Configuration A

In Configuration A, the unglazed solar collectors were added to the existing HVAC system to provide the warm water to the liquid-to-air heat exchanger. An auxiliary heater was also provided to operate in case needed. According to the simulation results, the system with this type of solar collectors provides the room temperature and RH at the mean values of 20.4 $^{\circ}C$ and 56.5% (see Table 7). Moreover, the system performance in terms of energy consumption shows that the total energy consumption of the existing HVAC system decreases from 72.26 MWh to 63.19 MWh with this configuration

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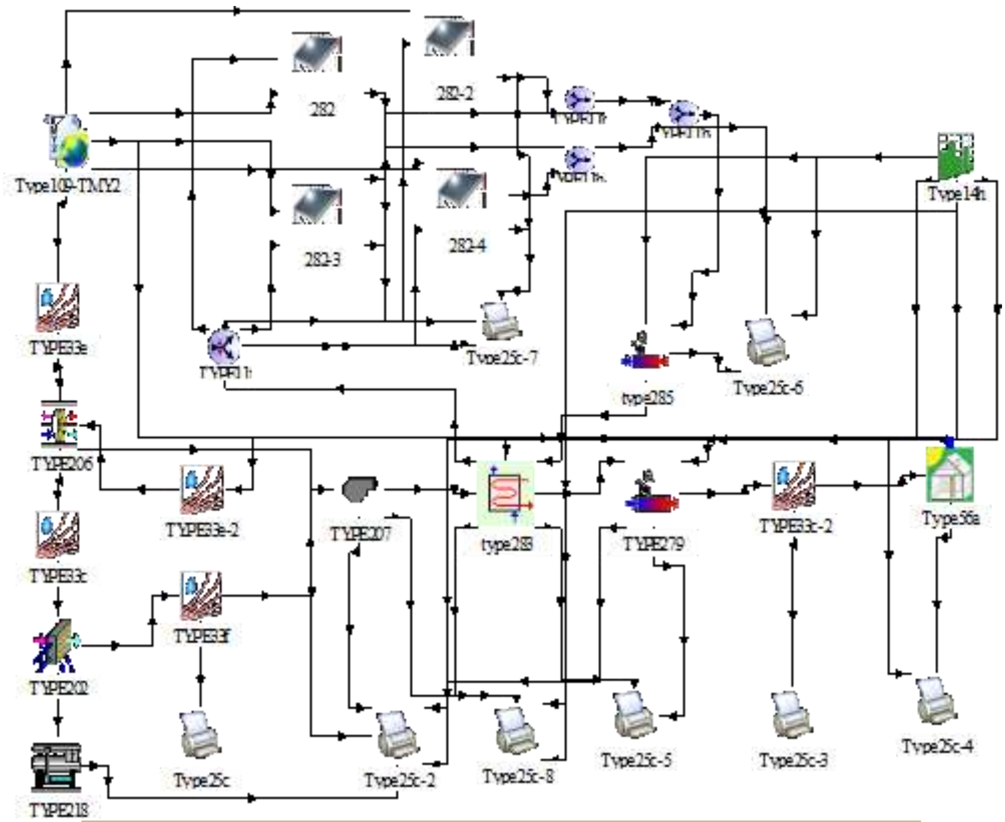

Fig. 9. Simulation layout for the HVAC system integrated with the solar collectors

Table 7. Mean room air conditions for the solar integrated HVAC systems

Configuration	Room Temperature ©	Room RH (%)
Configuration A	20.4	56.5
Configuration B	20.2	57.1
Configuration C	19.9	57.8

As already explained, the solar driven heat exchanger was replaced with the system heater from 8:00 till 17:00 throughout the year. Therefore, the heater energy consumption drops from 30.66 MWh to 17.89 MWh with the added unglazed solar collectors. However, 3.06 MWh of energy was also consumed by the auxiliary heater to provide the minimum water temperature. Therefore, the unglazed added HVAC system has the capability to provide the desired inside air conditions with the potential of saving 9.07 MWh amount of energy in a yearly operation.

4.2. Simulation responses- Configuration B

The HVAC system performance with this solar type configuration was obtained and the simulations indicate that the indoor conditions provided have the mean values of 20.2 $^{\circ}C$ and 57.1%, respectively as tabulated in Table 7. In addition, the energy consumption of the system shows that the system would require a total amount of 3.85 MWh auxiliary heating energy (see Table 8).

Table 8. Yearly energy consumption (MWh) and saved energy (MWh) of the solar integrated HVAC system

	Existing HVAC System	Config. A	Config. B	Config. C
Chiller	34.02	34.65	34.51	34.33
Heater	30.66	17.89	17.89	17.89
Energy Recovery Wheel	1.63	1.63	1.63	1.63
Blower	5.96	5.96	5.96	5.96
Auxiliary Heater	----	3.06	3.85	5
Total	72.26	63.19	63.84	64.81
Saved Energy	-----	9.07	8.42	7.45

4.3. Simulation responses- Configuration C

The evacuated solar collators are some sort of collectors utilizes evacuated tubes. This type of collector consists of simple copper fin tube on a copper sheet or a heat pipe. The evacuated solar collector used in this research is a standard type with the vertical intercept of 0.554 and slope of -2.53, respectively.

The yearly performance of the system with the added evacuated solar collectors shows that the mean indoor air temperature and RH has the mean values of 19.9 $^{\circ}C$ and 57.8%. It is estimated that the Configuration C would improve the system performance by about 7.45 MWh.

The performances of the solar integrated HVAC systems in terms of energy consumption are summarized in Table 8 for more convenient. The systems performance comparison indicate that the Configuration A has the priority in terms of the energy consumption level as it can provide the recommended indoor air conditions to the space. Therefore, considering all the above, Configuration A is recommended to be implemented in the HVAC system of the operating theater under study.

The hourly performance of the liquid-to-air heat exchanger and solar thermal collectors were also determined. For this purpose, the performances of the components in Configuration A as the recommended configuration to the building were studied. Figs. 10 and 11 show the liquid-to-air heat exchanger and solar collectors' temperature profiles during the operating hours for a typical day, respectively. As illustrated in the Fig. 11, the solar thermal collector has the capability to increase the entering water temperature up to 18 $^{\circ}C$ during the operating hours.

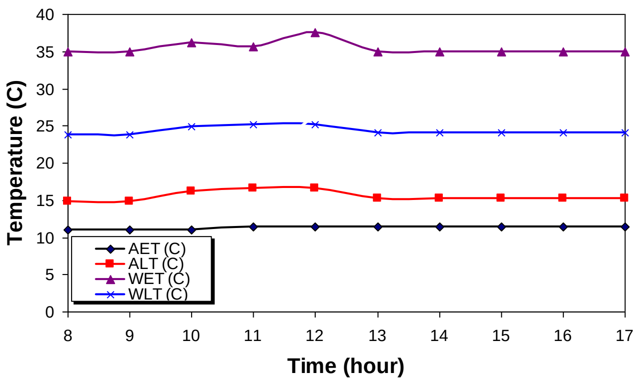

Fig. 10. Hourly performance of the liquid-to-air heat exchanger during the operating hours within a day in January

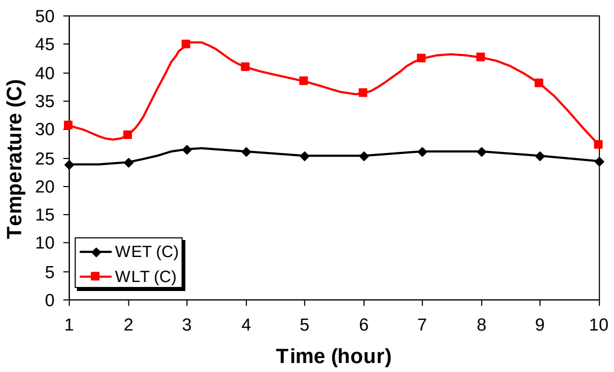

Fig. 11. Hourly performance of a solar thermal collector panel during the operating hours within a day in January

5. Conclusions

In this case study, the effect of solar thermal collectors on the performance of a HVAC system in a tropical building was studied for the whole year of operation using TRNSYS software. To this end, the existing HVAC system performance was monitored and its compliance with the desired indoor air conditions was studied. Then, the existing HVAC system and the system with the added array of solar collectors were simulated. Three standard types of liquid flat-plate solar collectors namely, unglazed, glazed, and evacuated tube solar collectors were integrated with the existing HVAC system as Configurations A, B, and C, respectively. Three configurations were examined to determine the most appropriate configuration in terms of the energy consumption and provided air conditions for the yearly operation. In the mentioned configurations, a liquid-to-air heat exchanger fed by the solar collectors was defined to be replaced with the main heater of the HVAC system during the day hours throughout the year. The energy consumption and provided air conditions of the configurations were estimated and compared with the existing HVAC system. The simulation results showed that the provided air conditions by the configurations were marginally inside the desired conditions; however, the energy consumption level of the systems clearly indicated that the configuration A has a priority in terms of the capability of saving energy. According to the simulation results, Configuration A was capable of saving a total amount of 9.07 MWh per a year. Therefore, the existing HVAC system was recommended to be retrofitted with the configuration A to increase the energy efficiency of the system.

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