DESIGN AND ANALYSIS OF A SOLAR WATER HEATING SYSTEM WITH THERMAL STORAGE FOR RESIDENTIAL APPLICATIONS

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Abstract - This paper represents a design and analysis of a solar domestic hot water and space heating system with thermal storage for single-family house. To meet the energy demand of residential sector like a house, one of the best options is solar water heating system that can be integrated with space heating (SH) and domestic hot water (DHW). This type of systems performance and efficiency relies on proper design method, the actual size of the components, characteristics, and the behaviour of selected heat transfer fluid and the accurate analysis with the appropriate software. In this paper, a complete solar thermal based heating system is introduced that meets the overall energy demand of a house. The designed collector area 18 m^2, storage tank 31 m^3 is chosen with the volume to area ratio 1.72. It is also noticeable that the percentage of solar coverage for space heating and hot water is 32 and 59 respectively with average collector efficiency 51 %. Moreover, the overall hot water and space heating coverage using the designed system are 100 % that makes the good agreement with the literature. Design, simulation results, and detailed analysis of this research are included in this paper.

Keywords: modelling, space heating, domestic hot water, thermal simulation, SHW software.

1. INTRODUCTION

Solar energy use is the blessings of modern technology in order to obtain electricity and heat. Electricity production is an indirect process where a photovoltaic cell is used to generate electricity. On the other hand, heat generation is a direct energy conversion process where different collectors are used to produce heat. Thus, the direct system is better than the indirect system in terms of efficiency, cost, lifetime, and so on. The demand for using this heat energy in terms of space heating and hot water production is increasing to mitigate the mismatch between energy and demand in the world's energy sector. Researchers have focused around the world not only to produce thermal energy but also to find a way to store this energy seasonally referred to as thermal energy storage (TES) due to its use. This energy can be stored through various heat storage technologies such as sensible heat, latent heat, thermochemical heat storage using different mediums like water, sand, air, and so forth. A solar water heating system is the cheapest, easy to maintain, and a non-pollutant way to get hot water that consumes approximately 20% of the total energy consumption of a typical family [1]. According to Natural Resource Canada, in 2015, Natural gas and Electricity are the highest energy provider around 48% as an energy source in Canada's secondary energy use, and the total secondary energy is accounted for 17 % by the end users in Canadian's residential segment. Out of them 62% energy is used for space heating, and 19% energy is used for domestic hot water preparation. Natural gas is Canadian's primary energy source for around 66% space heating and 74% domestic hot water systems and considered the largest contributor for GHG emissions by 29% as the energy source [2] [3]. Also, in Newfoundland and Labrador, Electricity and wood are the highest energy sources approximately 87% as an energy source in Canada's secondary energy use but in residential sector consumption of space heating and water heating energy are accounted for 70.9% and 12% respectively. As an end user, space heating and water heating are responsible for major GHG emissions in this province [4] [5]. Thus, it is perceptible that for both cases, space heating and water heating consumed the highest energy as well as contribute a larger portion of GHG emissions in the environment. Edwards et al. [6] evaluated the performance of single and double tank combi-systems in the residential application. This system consists of radiator for space heating, 48 m^2 flat plate collector and the volume of the diurnal tank up to 2000 L. This research concluded that solar fraction is not achievable more than 50% with this size of the diurnal tank. Edwards added that radiant floor for space heating and used a low temperature hot water as an input and suggested evacuated tube solar collectors may increase the overall required solar fractions. Hugo et al. [7] demonstrated the performance of a solar combi-system based on financial payback with thermal energy storage in Montreal using solar simulation software TRNSYS. This result concluded that there are some factors like high initial capital cost, high payback periods and lower electricity rates, mostly responsible to make the barriers to set up this kind of systems. A solar combi-system project called the Riverdale NetZero was built by the Canada Mortgage and Housing Corporation under the national $EQuilibrium^{TM}$ Sustainable Housing Demonstration Initiative in Edmonton, Alberta. This system consists of vertically mounted 21 m^2 flat plate collector, a 17 m^3 seasonal thermal energy storage tank, a 300 L diurnal thermal energy storage tank with a 7 KW heat pump. According to the Canada Mortgage and Housing corporation, around 83% of domestic hot water and 21% space heating demand was met by this system [8] . An existing 215 m^2 passive house was retrofit in Galway Ireland with the help of 22 m^3 buried water based seasonal thermal energy storage tank and 300 L diurnal thermal energy storage tank. Firstly, this 300 L DTES tank is heated by the 10.8 m^2 evacuated tube solar collector to 65 □ before charging the STES tank. The result showed that domestic hot water and space heating solar fractions is 93% and 56% respectively. It also recommended that this type of combi-systems is more feasible and profitable for energy efficient single-family detached house in Ireland [9]. A single-family residential house was modelled using TRNSYS in Richmond Virginia. A soil based STES system was selected due to its cost effectiveness to other mediums. Six homes were simulated with the range of area from 800 to 2400 ft^2 with an air tightness of 1.0 air changes per hour and the collector size ranging from 39 to 99 m^2. They established around 15 m^3 of STES volume as optimal for the selected case [10] . The first solar house built in MIT (Massachusetts Institute of Technology) in 1939 was considered as the first application of seasonal storage for single family detached house. The solar collector of that house was 136 m^2, cylindrical steel storage tank was 68 m^3, insulated and buried under the house. As the temperature reached 90 □ and thus the performance of the system suffered from condensation which create a barrier to collect solar energy in summer. As a result, in winter the collectors cannot produce more than 55 □ which is not enough for single family house [11] [12]. In Canada, many seasonal storage systems implemented. Hooper mentioned about one such house which built in Toronto in 1976 whose storage tank size was 277 m^3. Though it was expected but the system could not provide enough temperature due to the higher storage losses. The tank was surrounded by the soil and most of the heat from the tank was transferred to soil was the main reason for the losses [13]. According to International energy agency (IEA) SHC-task 13, a house called 'zero-heating energy' was built in Berlin, Germany with 20 m^3 vertical and well insulated storage tank, 54 m^2 high-efficiency solar collector. To adapt the active and passive solar strategies for this kind of house, it is made with higher insulated envelope and airtight to reduce the transmission losses. The result revealed that seasonal water storage in the tank transfers the excess solar energy in summer to heat the house completely in winter months without using conventional energy throughout the year [14] . Based on the simulation result from DEROB-LTH program, Smeds and wall [15] showed that the heating loads of a typical conventional house can be minimized by up to 83% in cold climate zones, and the total energy demand including space heating, DHW and other loads can be decreased up to 92% for a single- family house. A remarkable project called Beddington Zero Energy Development (BedZED) was constructed with 100 eco-homes and workspaces in Hack bridge, London, England. The aim of this project was to feature the houses with high insulation levels, high efficiency windows, active and passive solar design strategies, and combined heat and power plant fuelled by woodchips from waste timber. After one-year simulation, the result indicated that the space heating and DHW demand can be reduced using the above-mentioned features in the house. The reduction of space heating and DHW energy demand was around 88% and 57% compared to conventional houses where the percentage was 90 and 33 respectively [16].

From the literature search, it is found that renewable energy-based systems and projects have ethical aspects in terms of providing thermal energy for space heating and domestic hot water in Canadian's residential sector. It does not only help to reduce the greenhouse gas emissions to make the environment better and liveable but also contribute to pay the less electricity bill. However, before thinking these advantages, the proper method of utilizing solar energy with appropriate control strategy, sizing of the system's components, exact energy demand calculation, cost analysis is the necessary task for this type of system. If this happens, then the proposed solar space heating and DHW system will be viable to supply thermal energy in the houses of Canadians. No such study has been done for Newfoundland, Canada.

In this research, section 2 will present methodology and system design. Section 3 will show the sizing of the collector and storage tank for both space heating and DHW. Various components control, simulation results with discussion will be discussed respectively, and the paper will end with a conclusion.

2. METHODOLOGY AND SYSTEM DESIGN

According to our literature search and the geographical features, one of the suitable options for our selected area in St. John's, NL, Canada with latitude (47.56 °N) and longitude (52.71 °W) [17] is active solar water heating system for producing thermal energy that can meet the annual space and domestic hot water demand in a typical single-family detached house. Figure 1 represents the full system where we sized the essential components like collector and storage tank for both space heating and domestic hot water and gave some vital parameters as an input of the other components. At the beginning of the cycle, the collector is heated by the sun, heat transfer fluid, ethylene glycol, with properties like density 1111.6 Kg/m^3 and thermal capacity 3400 $J/Kg.K$ flows progressively through the collector and gets heated.

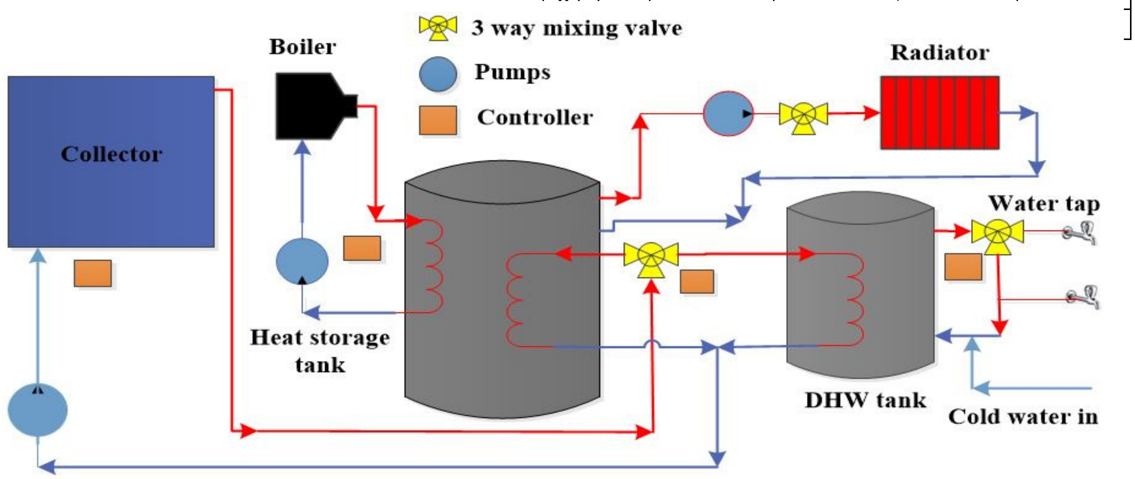

Fig. 1. Space and domestic hot water system for residential application

After that, this heated HTF circulated through the heat exchanger that is connected in DHW tank and heat storage tank with releasing enough heat. System was controlled in a way that 70% heat can be released in the heat storage tank and 30% in DHW tank with the help of control valves. Collector mass flow at DHW and heat storage tank was considered as 0.150 Kg/s. A 3KW e- cartridge or electric heater was placed in DHW tank as the key energy source of reheating domestic hot water. Moreover, a liquid fuel type boiler was connected to the heat storage tank that can supply the additional heat for space heating and helps to maintain the constant temperature of the demand side supply annually. On the other hand, according to the heat demand and the house configuration, we assumed some parameters of the building to find out the total amount of energy needed for space heating. These assumptions are the heating load of the house 3.15 KW, Room temperature 20 □, night setback temperature 20 □, flow temperature in the house radiator 35 □, return temperature 30 □, design temperature or outside average temperature -10 □. The heating temperature starts at 12 □. Also, it has some important parameters that need to be considered for getting the exact heat energy demand for space heating. The house has two floors, contains four rooms with two washrooms on the first floor, and four rooms with a half washroom on the ground floor. Overall dimensions (length: 45 feet and width: 30 feet). It has several windows and the window parameters of the house are shown in the table 1. These values were given as input of the simulation part. Necessary graphs and detailed analysis of this research are included in the result section.

Table 1: Window parameters of the house

Window	window (right)	Window (left)	Window (front)	Window (back)
Gross area (m^2)	7.8	2.8	3.6	2
Inclination (°)	90	90	90	90
Azimuth (°)	0	90	180	270

3. SIZING OF COLLECTOR AND STORAGE TANK FOR DHW

Domestic hot water tank, commonly known as the diurnal tank, is important for every combi-systems. This tank volume mainly relies on the daily consumption of hot water. To determine an appropriate diurnal tank volume, daily hot water consumption through the whole year as well as the peak month demand are important parameters. From the literature, several recommendations were found in order to get the best sizing options for the DHW tank. Evarts and Swan noted a rule-of-thumb value of 60 l/day-person for domestic hot water consumption where four or more people are living and below this number of people, this assumed value might not be perfect [18].In solar applications, Heimrath et al. [19] found that for 200 liters per day consumption of hot water, the diurnal tank should not be smaller than 200 liters. Based on the above literature search, a simple calculation technique is used to find out the geometry of the tank, and these are as follows. Firstly, the amount of energy to heat the daily hot water demand (Q_{DHW}) is calculated using the below formula [20],

$Q_{DHW} = volume\ of\ daily\ DHW * C_w * \Delta T$ (1)

Here, $C_w =$ specific heat capacity of water (1.16 $Wh/Kg.K$)

ΔT= Temperature difference between cold water and desired water temperature (℃)

Using equation (1), the amount of energy for daily hot water demand, Q_{DHW}=240*1.16*(50-5) Wh/day

Q_{DHW}= 12.52 KWh/day

Secondly, the volume of storage tank for domestic solar systems can be found by below equation,

$$V_{cyl} = \frac{2*Vn*P*(T_h - T_c)}{(T_{dhw} - T_c)} \quad (2)$$

Here, V_{cyl}= Minimum volume of tank (L)
$Vn =$ Domestic hot water demand per person/day (60 L)
$P =$ Number of people (4)
$T_h =$ Temperature of hot water at the outlet (45℃)
$T_c =$Temperature of cold water (5℃ in winter time)
$T_{dhw} =$Temperature of stored water (50 ℃)
After putting all values in equation (2), the minimum volume of the tank, $V_{cyl} = \frac{2*60*4*(45-5)}{(50-5)}$
$V_{cyl} = 426$ L
Finally, the collector area to meet the daily hot water demand is calculated using the below equation,

$$Collector\ area, A = \frac{No.of\ days*solar\ fraction*Q_{DHW}}{yearly\ solar\ irradiation*Average\ system\ efficiency} \quad (3)$$

Here, No. of days=1
Soar fraction= 50%
Solar irradiation in St. John's= 3.06 $KWh/m^2.day$
and the average system efficiency= 70%
After putting all values in equation (3), the required collector area, $A = \frac{1*0.5*12.52}{3.06*0.7}$
A =2.92 m^2
For sizing the DHW tank, few equations were assumed, and these are as follows,

Height to diameter ratio, $H/D = 2$ (4)

Here, the selected height, H=1.60 m so, putting this value in equation (4), a diameter of the DHW tank was found around 0.80 m. Now the ratio of height and diameter, H/D =1.60/0.80=2.

4. SIZING OF COLLECTOR AND STORAGE TANK FOR SPACE HEATING

System performance and efficiency of this seasonal space heating system depend on the perfect sizing of the components of the system. In our system, the main components are mainly the solar collector and storage tank. To design the solar collector size correctly, different equations were used from the literature we reviewed that can meet the space heating demand of the house in the heating period. The calculation method for getting the solar collector area is as follows:

$$Collector\ area, a1 = Q_{demand}/Q_{solar1} \quad (5)$$

Here, Q demand=Monthly energy demand of the house from BE opt and Q solar1=Monthly solar radiation of the selected area from RET Screen. The initial collector area, a1 was calculated by using (5) and considering the average collector area, the new Q solar2 was calculated from (6) and determined the excess energy from (7),

$$Q_{solar2} = a1 * Q_{solar1} \quad (6)$$

$$Q_{excess} = Q_{solar2} - Q_{demand} \quad (7)$$

After that, some assumptions have been taken from literature like collector efficiency η=55%, standby loss of insulated storage tank=0.05 kWh/hr., and circulation loss through insulated pipes=8% to get the minimum excess energy with appropriate collector area to meet the space heating demand. Using the below equation (8), Q_{solar3} was found.

$$Q_{solar3} = η * Q_{solar2} - η * Q_{solar2} * 0.05 - 0.08 \quad (8)$$

$$Collector\ area, a2 = Q_{demand}/Q_{solar3} \quad (9)$$

Finally, using (9) we found the new collector area. By following the same procedure, our desired solar collector area, a= 15 m^2, and minimum excess energy amount: 0.150 kWh were found. Based on the efficiency, life expectancy and cost, the selected collector model is the COBRALINO AK 2.2 V, manufacturer: SOLTOP Schuppisser AG, test standard: North America. It is a flat plate solar collector with conversion efficiency 85% and dimensions (length:1.897 m, width: 1.166 m, total aperture area: 1.957 m^2). It also has the angle factor of 0.95 for both longitudinal and transversal [21]. Using this above-mentioned parameter, the total number of solar collectors can be found by below correlation [22],

Collector number, N=A_R/A_S (10)

Here,
$A_R =$ Total required collector area (15 m^2)
$A_S =$ Selected collector's aperture area (1.957 m^2)
Putting all in equation (10), the total number of collectors, N=7.66≅ 8
Apart from the solar collector, storage tank plays a dynamic role in all solar seasonal storage system. It can hold the hot water at the desired temperature for more extended periods. A seasonal storage tank is the most important parameters to supply solar energy to meet the annual energy demand. It is necessary to size this component adequately to reduce the energy loss through the year and obtain the energy with the affordable tank construction and maintenance cost because the tank construction cost per cubic meter normally increases with smaller dimensions. Different researchers have taken various steps to design the storage tank like storage volume to collector area (V/A) ratio, storage volume to collector area with solar fraction, storage volume to collector area with collector area to heat demand ratio, and total collector energy output that can be stored in summer for winter use. In our research, storage volume to collector area with collector area to heat demand ratio option is taken into consideration for selecting the appropriate and perfect size of the seasonal storage tank. According to literature review, a typical storage tank volume to solar collector area ratio 2 m^3/m^2 is found as the suitable option [23]. They also mentioned solar fraction up to 90% can be achievable with V/A and A/heat demand ratio range. These ranges are 1.2- 4.2 m^3/m^2 and 1-2.5 m^2/MWh respectively. An identical but slightly changed value was suggested in Ref.[24], they indicated 2-3 m^3/m^2 as V/A ratio and 1.5 -2.5 m^2/MWh as A/heat demand ratio for getting the solar fraction SF> 0.4. In Ref. [25], A/ (heat demand) ≈ 2.4 m^2/MWh and V/A ≈ 3 m^3/m^2 was put forward for 0.7<SF<0.8. Also, some pilot project has done in Germany, following the above storage tank design

criteria. A size selection review was done based on the tank volume to collector area ratio. They also took five scenarios to obtain the required dimensions of solar collector and storage tank. These scenarios were different from each other. The result showed that the optimal volume to area ratio was 2 m^3/m^2 in order to get the 70% solar fraction. Also, there was storage tank height and funding limitations and made them to choose different V/A ratio [26].

So, after taking all the considerations and design criteria, the total required collector area for domestic hot water and space heating is (2.92+15) =17.92 $m^2 \cong 18\ m^2$. The domestic hot water tank is 0.45 m^3 and the space heating tank is found 2*15=30 m^3 as we took tank volume to collector area ratio, V/A=2.

During the simulation, we gave 3 m height of storage tank as an input, so we need to find out the diameter of the tank. From the literature, we followed several recommendations in order to obtain the best sizing options for storage tank diameter and used some sample equations to obtain the diameter of the tank. These are as follows,

$$\text{Volume, } V = (\pi * D^2 * H)/4 \qquad (11)$$

Here, Height, H=3 m and the volume V=30 m^3. Using equation (11), we got diameter, D= 3.36. So, H/D=3/3.36 =0.89. It showed the good agreement with literature to design the cylindrical storage tank diameter.

5. HEAT SOURCE OF THE PROPOSED SYSTEM

The heat source is one of the crucial components that help to maintain the thermal balance of the full solar seasonal storage system. It is mandatory to keep the temperature of the storage tank constant for the heating periods. So, a good relationship between heat source output temperature and the required heating temperature of the house decides the maximum efficiency of the solar system. In our proposed system, a fixed temperature-based boiler is used as the prime heat source. It is a mechanical device that can produce hot water or steam by burning conventional fuels. This hot water or vaporized fluid can be used in the different process such as water heating, central heating, boiler-based electricity generation, and so on. In our work, a fluid fuel-based boiler is considered. Also, we took some other parameters for the smooth operation of this system. These are, power of the boiler: 4 KW, Boiler outlet temperature: 30 ℃, Mass flow at charge DHW storage: 0.200 Kg/s, Mass flow at charge heating storage: 0.150 Kg/s and mass fraction to DHW storage 30%. But our recommendation is to use an electric boiler in this selected area due to the availability.

6. CONTROL OF THE PROPOSED SYSTEM

Control of this type of solar system is very significant to obtain the highest energy output with minimum loss from the system's components. Without controlling the system, it is impossible to obtain the maximum energy output that is the main requirement of this type of combined system. In this proposed system, a controlling process is used to control the energy supply of different energy source to the collector, DHW storage, and heat storage.

6.1 Collector

The required temperature difference between the collector and the hot water storage tank was 7 ℃ for the beginning of the solar energy supply. Also, 4 ℃ temperature difference was selected between the collector and heat storage tank sensor for exchanging the maximum solar heat energy at the beginning of the solar energy supply. So, the associated sensors for both are located at the collector output section with the maximum collector temperature 100 ℃ is required to run the pump to avoid the stagnation in the collector.

6.2 DHW storage

In terms of DHW storage, the maximum allowable storage temperature by supplying solar energy is 60 ℃ with hysteresis for maximum storage temperature 1 ℃. If this temperature is exceeded while running the collector pump, the pump will be turned off. Also, the maximum allowable storage temperature by supplying heat source boiler and electric energy are 55 ℃ and 54 ℃ respectively, with the hysteresis for maximum storage temperature of 10 ℃ and 4 ℃.

6.3 Heat storage

For controlling the heat storage tank, we considered the maximum allowable storage temperature by supplying solar energy is 60 ℃ at sensor 1 with hysteresis for maximum storage temperature 1 ℃ and the sensor two is placed at the top portion of the tank with the controlling temperature 60 ℃. Also, the temperature difference for loading of domestic hot water is 4 ℃. On the other hand, the maximum allowable storage temperature by supplying heat source boiler and electric energy are 45 ℃ and 50 ℃ respectively, with the equal hysteresis for maximum storage temperature of 5 ℃.

7. PIPING NETWORK OF THE PROPOSED SYSTEM

The necessity of the piping is significance in any solar system to avoid excessive energy loss through the system. In our proposed system, two circulating loops are considered. One is a collector or heat transfer fluid loop, and another one is the energy supply side loop. Both loops are featured with the same specification's PEX pipe based on the North America standard [27]. The pipe materials and specifications are followed by table 2.

Table 2: Pipe materials and specifications of the system

Pipe features	Value	unit
Length	20	m
Diameter	0.0175	m
Wall thickness	0.0018	m

Insulation thickness	0.020	m
Conductivity insulation	0.040	$W/(m.K)$
Density pipe material	940	Kg/m^3
Thermal capacity of pipe material	1900	$J/Kg.K$

8. SIMULATION RESULTS AND ANALYSIS

After sizing and selecting all components of the proposed system, the full system was simulated for one year using freeware SHW- Thermal solar system simulation software, from Austria. Version 1.02 of this simulation software was used to identify various components output as well as the system's overall performance along with various conditions [28]. In addition, to obtain a more accurate and appropriate result, a lot of suitable and convenient parameters of individual components were given as input in this simulation software. Fig. 2 demonstrates the energy requirement for heating and useful energy taken from heating storage. It is indicating that energy demand and energy taken patterns are looking identical. The total amount of energy demand, 7887 kWh, was achieved using BEopt (Building Energy Optimization tool) [29] and the energy production from the simulation for space heating was found 8002 kWh with around 100 % heating covered under this proposed heating system. Among this amount of energy production, the percentage of solar coverage for heating was around 32, and the value was 4381 kWh.

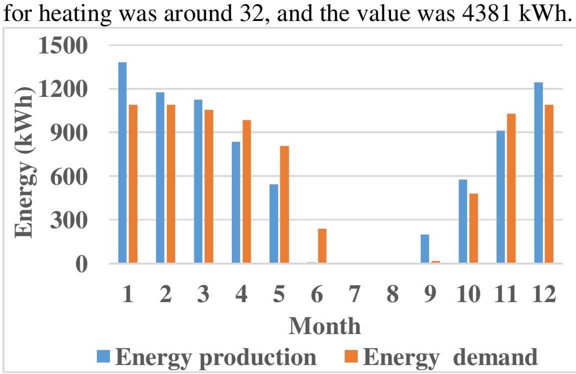

Fig.2. Heating energy demand and energy production for the proposed system

Space heating storage max. temperatures are shown by fig. 3. The result showed that the maximum storage temperature in upper edge of the tank was obtained 60℃. The lowest value was found around 45℃ in the heating periods and became constant throughout the coldest month. It happened because the collector attains the highest daily solar irradiation in the summer and the house have the lowest heating energy requirement.

Fig. 4 offerings the energy requirement for domestic hot water and the useful energy removed from the hot water tank. From the results, it showed that the energy demand and energy production of domestic hot water followed the same profile. The hot water demand was comparatively higher in winter than the summer. The total amount of energy demand and energy production for domestic hot water preparation was 4689 kWh and 4776 kWh respectively. The proposed entire system covered 100% of hot water demand of this house. Among this amount of energy coverage, 60 % of energy was supplied by the solar and the remaining 40% was covered by the electric heater throughout the year.

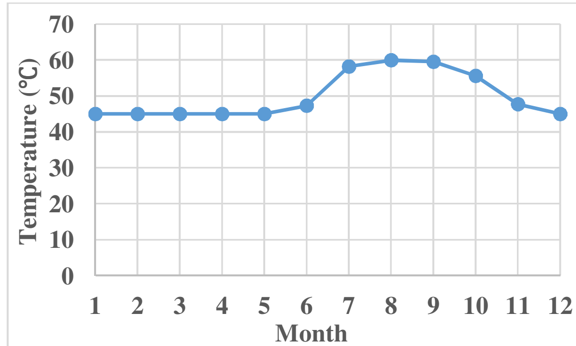

Fig.3. Space heating storage max. temperature

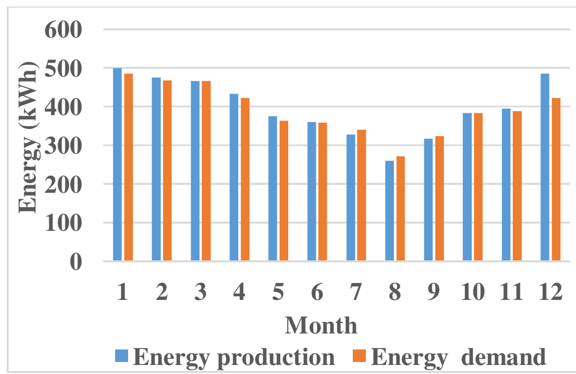

Fig.4. DHW energy demand and energy production for the proposed system

Fig. 5 determines the upper edge temperature of the DHW storage tank. From the results, it is showing that the temperature of summer months was above 60 ℃ but in extreme colder months, the temperature decreased at 55 ℃. As the target temperature was set at 50 ℃ so after subtracting the pipe losses from tank to faucet, this system is able meet the DHW demand all over the year. Also, it provides additional heat energy to heating storage to keep its temperature constant and to avoid the minimum losses.

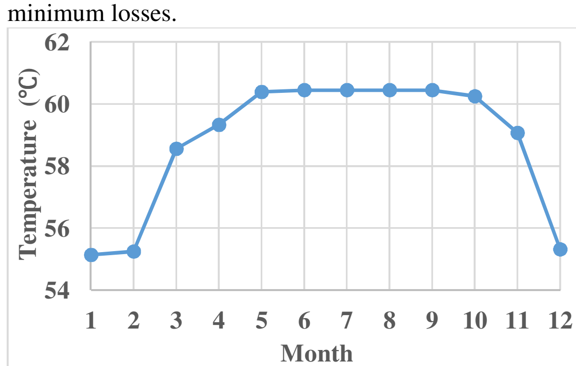

Fig.5. DHW storage maximum temperature of the proposed system

Fig. 6 demonstrates the supplied solar energy for domestic hot water and space heating purposes. From the graph, it is obvious that the amount of solar supply was higher in summer periods compare to winter months because solar collector extracts most of the solar energy in summer. The peak value was found 962 kWh in July. However, the total amount of solar supply energy for both space heating and DHW was 7645 kWh.

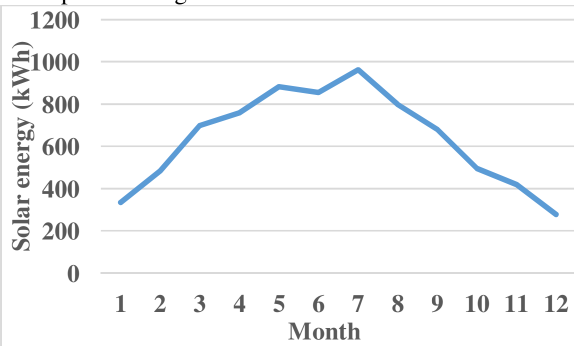

Fig.6. Supplied solar energy for space heating and DHW

Electrical and boiler supply energy for the full system was described by fig. 7. In our anticipated system, the electrical energy source, electric heater, was used directly for supplying energy to the DHW tank not for the heating storage tank. On the other hand, boiler was used to provide additional energy into the system to make the overall energy balance with satisfactory system efficiency. This figure concluded that the supplied electrical energy for DHW preparation was higher in colder months than summer and for space heating, the supplied auxiliary energy was followed the same pattern but in summer the boiler was turned off because there was no space heating demand in summer. Nevertheless, the overall supplied electric energy and boiler energy was 1905 kWh and 5504 kWh respectively. The supplied auxiliary energy was high because of seasonal energy storage.

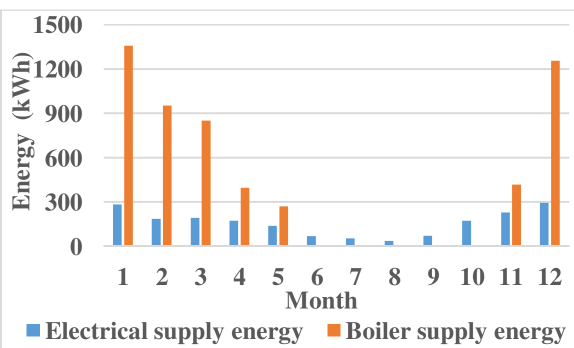

Fig.7. Supplied electrical and boiler energy for the proposed system

Fig. 8 shows the supplied thermal energy from the solar collector and the energy that goes to the storage tank for space heating and DHW. The amount of solar energy from the collector was higher than the solar energy to storage. Here, the total amount of 8331 kWh useful energy from the collector was extracted by the heat transfer fluid and on the contrary, the total amount of supplied solar energy for the hot water and space heating was 7645 kWh. Due to the system design, different losses, and simulation error, both the values were not desirable as it was expected.

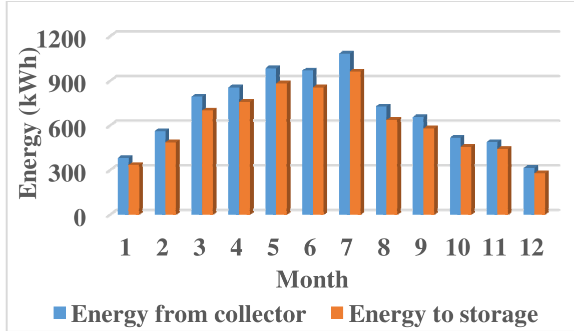

Fig.8. Profile of supplied solar energy from the collector and to the storage tank

Fig. 9 reveals the collector efficiency through the entire system's operation time. It is concluded that the average collector efficiency was about 51 %. It is also noticeable that the collector efficiency was higher in winter months than summer months and that made a good agreement with the literature of this type of system. This solar fraction can be increased if the circulation, collector, and storage tank losses are reduced significantly.

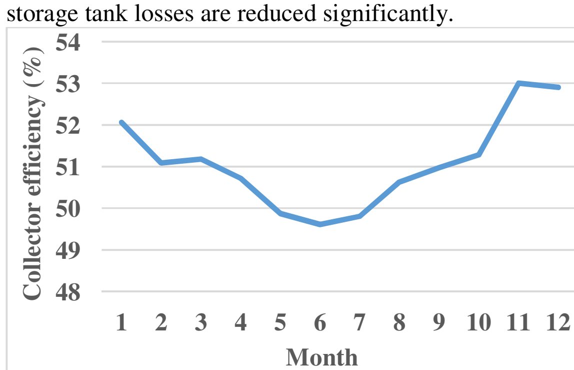

Fig.9. Collector efficiency of the proposed system

9. CONCLUSION

In this study, solar space and domestic hot water-based heating system were designed and simulated with freeware SHW software in order to meet the annual space heating and DHW demand with seasonal energy storage of a single-family house. The selected system consists of 18 m^2 thermal collector, 31 m^3 proper insulated storage tank including 0.45 m^3 DHW tank, 4 KW boiler and so on. The height and diameter for a heat storage tank were 3 m and 3.36 m respectively with 1.60 m height and 0.80 m diameter for DHW tank. The outputs from the simulation result showed that the designed system was able to meet the hot water and space heating demand completely for the selected house. As the energy losses of this type of system has a great effect on overall efficiency, necessary and proper steps should be taken into consideration to minimize the losses in order to implement this kind of system. After that, it can be said that the proposed system will be more practical, profitable and useful in colder countries with greater seasonal differences.

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