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Climatic Design of a Residential Villa and Finding Suitable Solar Heating Technology to Meet Thermal Needs in the Cold Climate of Iran

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Abstract

The aim of the present work is to make maximum use of environmental potentials in order to save energy consumption and increase the quality of comfort in residential space through the design of buildings in accordance with the cold climate in Iran. Also, providing part of the heat needs of the building under study by solar energy is another way to reduce energy consumption. According to studies, and despite the fact that Iran has a high potential to use solar energy, so far no studies have been conducted on the climatic design of residential villas in cold climates with the approach of using solar water heaters (SWHs). Also, the study of six different solar technologies to find the optimal system and also the one-year dynamic analysis of the optimal system are other innovations of the present work. In the present work, initially, with the help of the recommendations provided by Climate Consultant 5.5 software, a residential villa has been designed in accordance with the cold climate of Iran. Then, using TSOL 5.5 software, six systems based on solar heating and boiler have been examined to meet the thermal needs of the villa. After finding the optimal heating system, a one-year dynamic analysis was performed on it. By examining the climatic parameters, the strategies needed to ensure the comfort of the residents were implemented on a psychometric chart. The orientation of the building, the depression in the ground, etc. were among the suggestions to make the design of the villa compatible with the climate. The results of reviewing six solar heating systems showed that the solar system, including a hybrid tank with an internal heat exchanger, with the lowest number of collectors, had the highest heat efficiency and was able to provide 41.5% of the annual heat required by the villa.

Keywords: Climatic design, Domestic hot water, Space heating, SWH, TSOL software.

1. Introduction

Reducing energy consumption in the transportation, manufacturing and agriculture sectors is essential, but not as easy and important in the building sector [1]. Some things that can be done to reduce energy consumption in the building are energy usage reduction in air handling unit [2-7], applying phase change material in building for reduction in energy consumption [8-10] and using solar water heater in building [11].

In Iran, the amount and share of energy consumption in buildings is very high and about 42% of the total energy consumption of the country [12], while 20%-30% of the total energy consumption of buildings is spent on water heating [13]. Therefore, the implementation of projects to reduce energy consumption or supply the required heat by renewable energy such as the solar, is very important [14, 15].

The aim of the present work is climatic design of a building in order to reduce the demand for heating and cooling load and use natural energy sources for create more thermal comfort for residents. Also, one-year dynamic analysis was performed using TSOL

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software and using climatic data of Meteonorm software. Six different solar water heater systems were studied to select the most suitable one. Finally, technical-environmental studies were performed for the selected system. Finally, it should be noted that although the present work is a case study, the present work method can be useful for the climatic design of any building in any other climate.

2. The necessity of present work and comparing with other works

As shown in Figure 1, in 2018, the global solar thermal capacity in operation reached 480 GW_{th} with an energy yield of 396 TWh. It is also mentioned that solar heating, after wind and photovoltaic energy, is in the third place in meeting global needs by new energies [16].

According to the results of Figure 1, given that a large part of the application of renewable energy is their use to produce heat, Iran should seek to expand the use of SWHs at the same time as developed countries, to be able to save on fossil fuel consumption .Therefore, in Table 1, the recent works in Iran and the world regarding the use of SWHs are reviewed.

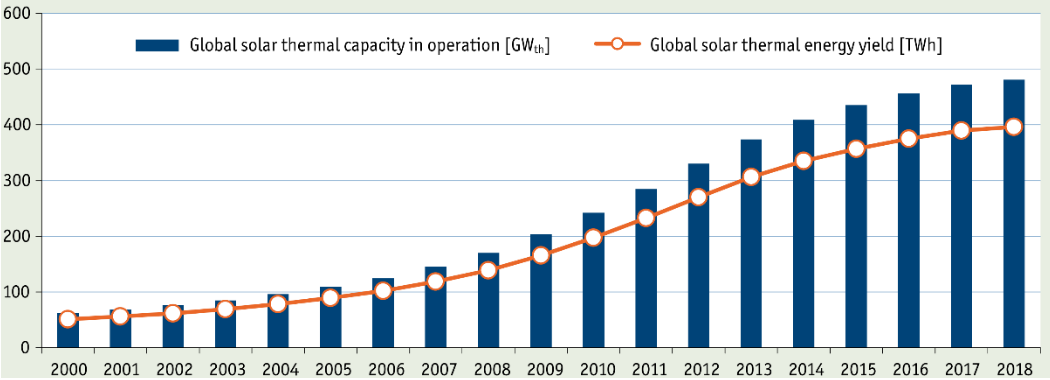


Figure 1. Global solar thermal capacity in operation and energy yield [16]

Table 1. Recent literature review on using SWH in Iran and the world.

Reference	**Location**	**System type**	Method used	Application scale	**Results**
Zahedi et al., 2009 [17]	Malaysia	Thermosiphon SWH with auxiliary electric heater	TRNSYS simulation	House-scale	Vertical storage tank has better performance than horizontal storage tank.
Zaniani et al., 2015 [18]	Pirbalut in Chaharmahal and Bakhtiari, Iran	Flat plate (FP) SWH	RETScreen4 Software	Primary School	If government pay for the 50% of expenditure, the capital return will be obtained 2.4 years sooner.
Hoseinzadeh and Azadi, 2017 [19]	Northern of Iran	Solar-assisted heating and cooling (SHC)	MATLAB software	House-scale	SCHs still appear far from economic profitability.
Khanmohammadi et al., 2019 [20]	Different climate regions of Iran	Thermosiphon SWH	Practical method	Office buildings	Payback time was 2-5 years.
Salehi et al., 2019 [21]	Sarein in Iran	Solar-assisted heat pump, solar heaters and gas boiler	EES software	District heating	Highest values of exergy efficiency and solar heating system were 25% and 220 $/GJ, respectively.
Farzan, 2020 [22]	Kerman in Iran	FP and Evacuated tube (ET) SWH	TSOL software	Domestic-scale	Efficiency of FP SWH and ET SWH were 43% and 50%, respectively.
Mirlohi et al., 2020 [23]	Yazd in Iran	SWH with electric tankless water heater	SketchUp software, Energy plus software	Zero-energy building	Payback period was 5.5 years.

Shalaby et al., 2020 [24]	Egypt	FP SWH with heat storage system	Experimental study	Laboratory scale	Highest daily efficiency was 65% and water temperature was 50-60.4 °C
Alayi et al., 2020 [25]	Saveh in Iran	Photovoltaic and SWH cogeneration	SAM and TSOL software	Residential scale	The proposed system save more than 75% energy
Orouji et al., 2020 [26]	Iran	Identifying regional climate-dependent heat demands	Statistical data analysis	Residential scale	Average heating energy index is less than 1 to more than 41.3.
Present work, 2020	Saman in Iran	Different type of FP SWH	Climate consultant and TSOL software	Residential scale	Finding the best SWH system and one-year techno-enviro analysis

According to the studies in Table 1, so far no study has been done on the climatic design of a villa and then the selection of the optimal SWH for it. Therefore, for the first time, six SWH systems were evaluated by TSOL software in the present work, and after selecting the optimal system, technical-environmental evaluations were performed on it.

3. Location under study

As can be seen in Figure 2, Saman city is one of the most important tourist attractions of Chaharmahal and Bakhtiari province located in Iran, which is located 22 km from the center of the province (Shahrekord) [1].

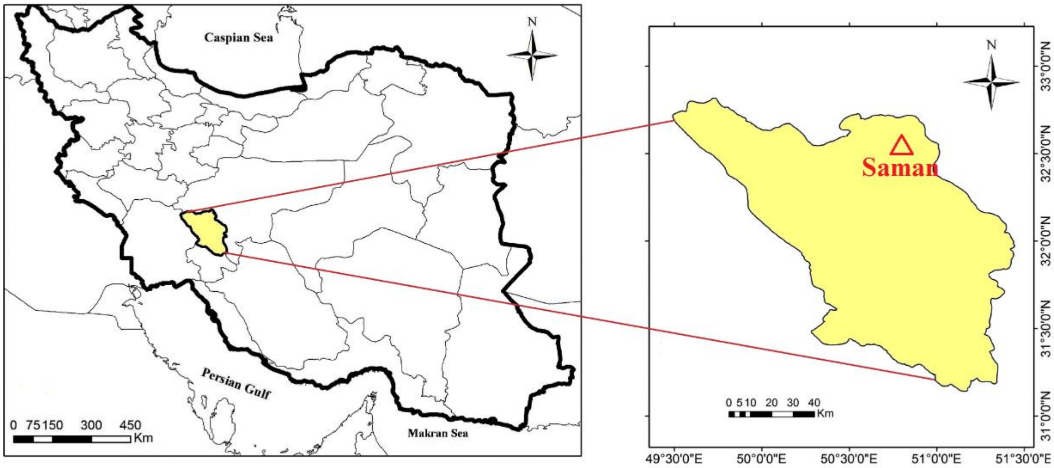


Figure 2. Geographical location of Saman city on the map of Iran

4. Software and data used

4.1. Climate Consultant 5.5 software

Today, energy simulation software has come to the aid of engineers to have a climate-friendly design and implementation [15]. Climate Consultant 5.5 is one of the software that analyzes based on hourly climatic data and suggests the appropriate form of the building [14]. The required data format of the software is .epw (EnergyPlus Weather), which has been prepared for the present work by Meteonorm 7.1 software based on the hourly data of synoptic station.

Climate Consultant software in order to reduce heat loss, reduce the negative impact of wind on heat loss, create proper ventilation indoors, how to use the right outdoor climate, use the positive effect and prevent the negative impact of sunlight and ways to control humidity, Offers suggestions to help the designer achieve the desired climate design.

4.2. TSOL 5.5 software

Investigating the annual performance of a solar water heating system in a one-year period with high accuracy is one of the capabilities of TSOL 5.5 software [27]. There are more than 200 configurations in the software database, each of which is for a specific purpose and application. Having different components such as combined and buffers tanks, having climate information of 8000 points in the world, providing the required space heating and sanitary water consumption separately, as well as providing detailed reports are the other advantages and features of the software [28].

Direct radiation striking to the surface of solar collectors are available in the software database. The following equations are used to find the diffused radiation striking the collector surface. By adding direct radiation and diffused radiation to the collector surface, the total striking radiation to the collector surface is calculated [27, 28].

$0 \leq k_t \leq 0 \cdot 3$:

$$\frac{I_d}{I} = 1 \cdot 02 - 0 \cdot 245\, k_t + 0 \cdot 0123\, sin\alpha \qquad (1)$$

$0 \cdot 3 < k_t \leq 0 \cdot 78$:

$$\frac{I_d}{I} = 1 \cdot 4 - 1 \cdot 749\, k_t + 0 \cdot 177\, sin\alpha \qquad (2)$$

$k_t \geq 0 \cdot 78$:

$$\frac{I_d}{I} = 0 \cdot 486\, k_t - 0 \cdot 182\, sin\alpha \qquad (3)$$

Also, collector losses, total solar fraction, solar space heating fraction and solar hot water consumption are obtained from the following equations [27, 28]. For each kJ of heat produced, the amount of CO_2 emissions in the software is estimated at 5.14355 g [27, 28].

$$\rho = G_{dir} \cdot \eta_0 \cdot f_{IAM} + G_{diff} \cdot \eta_0 \cdot f_{IAM.diff} - k_0\,(T_{km} - T_A) - k_q\,(T_{km} - T_A)^2 \qquad (4)$$

$$Solar\ fraction.total = \frac{Q_{CL.DHW} + Q_{S.HL}}{Q_{CL.DHW} + Q_{S.HL} + Q_{AuxH.DHW} + Q_{AuxH.HL}} \qquad (5)$$

$$Solar\ fraction\ DHW = \frac{Q_{CL.DHW}}{Q_{CL.DHW} + Q_{AuxH.DHW}} \qquad (6)$$

$$Solar\ fraction\ heating = \frac{Q_{S.HL}}{Q_{S.HL} + Q_{AuxH.HL}} \qquad (7)$$

Due to the location of the study site in the northern hemisphere, the azimuth angle was considered zero. Also, the slope of SWHs was considered equal to the latitude of the study area [27, 28].

5. Results

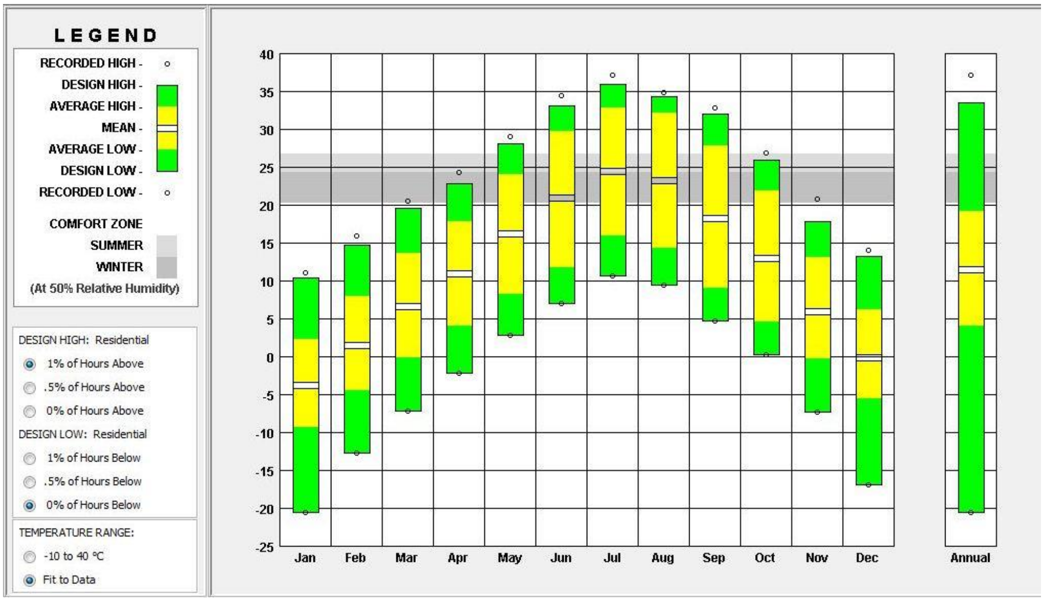
5.1. Examination of the climate using Climate Consultant software

At first, an exact examination of climate of the site was done by Climate Consultant 5.5 whose all calculations were based on ASHRAE standard. In the study done by this software, the hourly statistics of the climatic parameters in the form of .epw are used. Its important output is the psychometric diagram.

5.1.1. Assessment of climatic parameters

As it was shown in figure 3, the comfort temperature for this climate is from 20.5 ºC to 27 ºC, but just three months of the year (June, July and August) are in this range. The most amount of temperature average waste is in December and January and the least in October.

The diagram of wind cycle shown in figure 4 indicates the blowing hours, speed and orientation which are of important climatic issues. During the year, the wind maximum speed is in southwest and is about 10 m/s and the most hours of blowing is in that side.

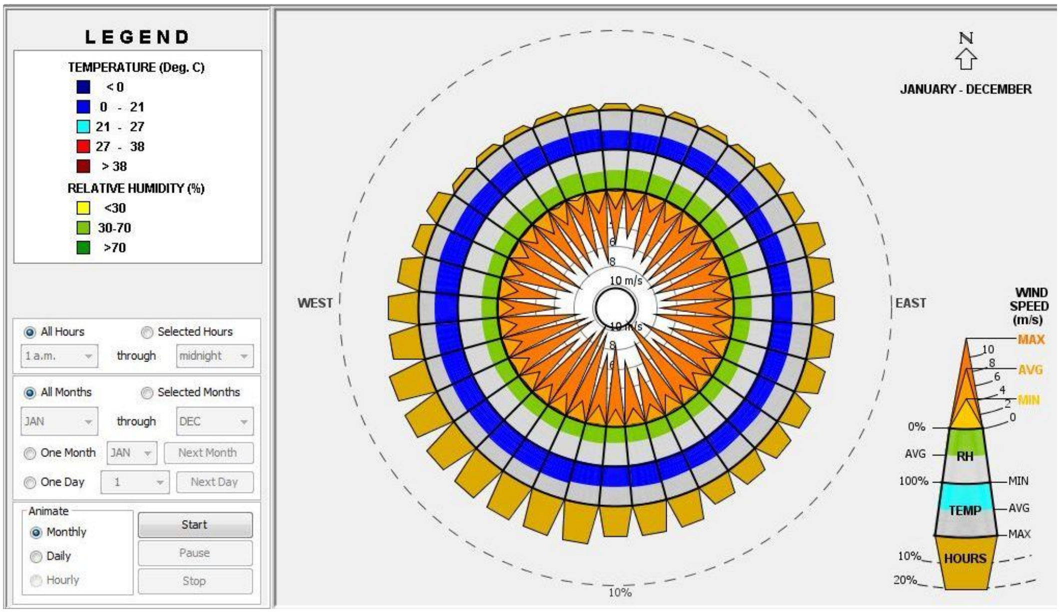


DESIGN HIGH: Residential
● 1% of Hours Above
○ .5% of Hours Above
○ 0% of Hours Above

DESIGN LOW: Residential
○ 1% of Hours Below
○ .5% of Hours Below
● 0% of Hours Below

TEMPERATURE RANGE:
○ -10 to 40 ºC
● Fit to Data

Figure 3. Temperature zone

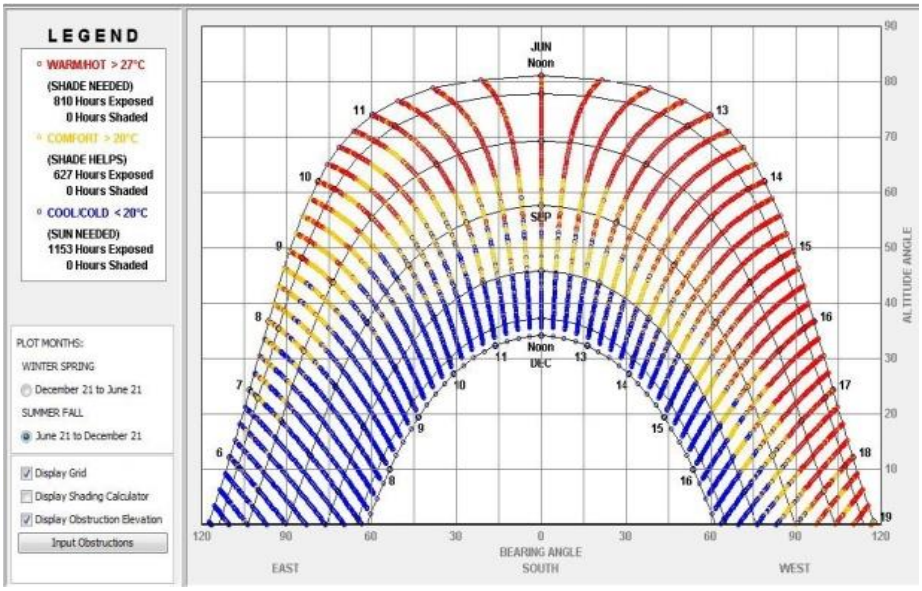


● All Hours ○ Selected Hours
1 a.m. through midnight
● All Months ○ Selected Months
JAN through DEC
○ One Month JAN Next Month
○ One Day 1 Next Day
Animate
● Monthly
○ Daily
○ Hourly
Start
Pause
Stop

Figure 4. Wind cycle

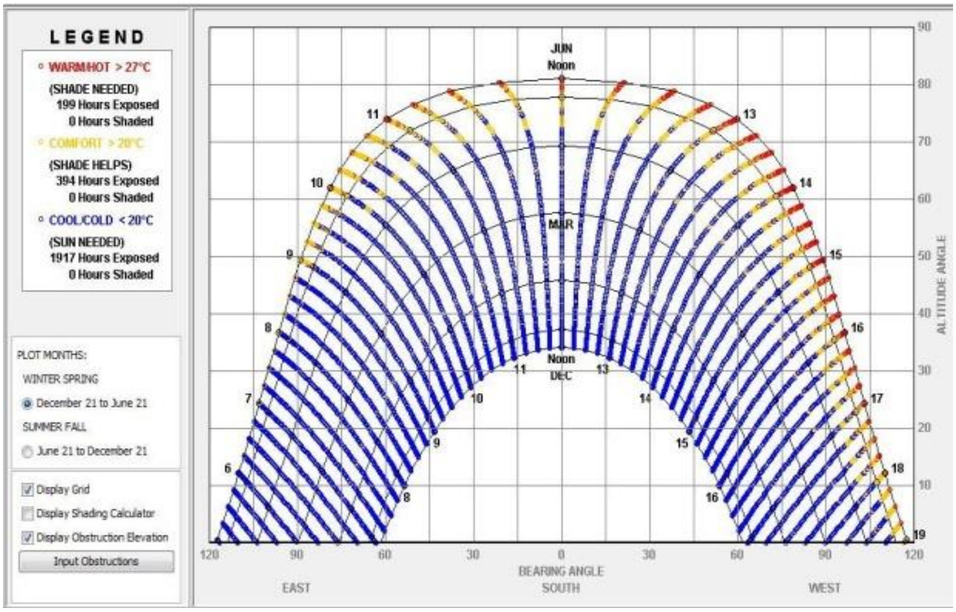
The diagram of sun shade in winter and autumn is shown in figure 5 in which, the red zone indicates the day heat which is about 810 hour during summer. In this zone, the temperature is more than 27 ºC requiring shading. The shading of yellow zone indicates the comfort zone and a remarkable amount of hours (about 627 hour) is in this zone.

The blue zone indicates the temperature below 20 ºC that needing sun. As it is shown in figure 5, the most amounts of hours (about 1153 hour) are in this zone. According to figure 6, during winter and spring, shading, comfort zone and needing sun hours are respectively 199 hour, 394 hour and 1917 hour. According to the results, it is clear that numbers of days having comfort in summer are 1.6 than that of winter. So, appropriate conditions for making comfort in winter are needed.



PLOT MONTHS:
WINTER SPRING
○ December 21 to June 21
SUMMER FALL
● June 21 to December 21
☑ Display Grid
☐ Display Shading Calculator
☑ Display Obstruction Elevation
Input Obstructions

Figure 5. Diagram of sun shade in summer and autumn



LEGEND

○ WARM/HOT > 27°C
(SHADE NEEDED)
199 Hours Exposed
0 Hours Shaded

○ COMFORT > 20°C
(SHADE HELPS)
394 Hours Exposed
0 Hours Shaded

○ COOL/COLD < 20°C
(SUN NEEDED)
1917 Hours Exposed
0 Hours Shaded

PLOT MONTHS:
WINTER SPRING
● December 21 to June 21
SUMMER FALL
○ June 21 to December 21

☑ Display Grid
☐ Display Shading Calculator
☑ Display Obstruction Elevation

Figure 6. Diagram of the sun shade in Winter and Autumn

Diagrams of figure 7 indicate that about 7 months (from December to May), humidity is higher than comfort range, and ventilation and cooling are needed which is more important in first eight hours of the month.

The psychometric diagram in figure 8 can determine that how many hours is Saman in comfort zone in a year and what zones need mechanical devices for heating and cooling. The diagram indicates that Saman is in comfort zone about 13.5% of a year and about 10.1% of a year, shading on windows is needed. There are some conditions in which using materials with high thermal mass in inner spaces and natural ventilation is a good strategy for cooling or all fans of building work to send cool air to inside during night. During days, the building is close thermally. The high spot of this zone is dew point and its low point is thermal comfort. According to the psychometric diagram, about 8.3% of a year needs this strategy.

An approximate estimate of the amount of required heat of a building indicates that this building has thermal inner loads such as lights, humans and equipment. According to the psychometric diagram, about 24.1% of the total hours of a year are in this zone.

If the numbers of south-faced windows are enough, the passive solar heat can increase the room temperature. A special hour is considered as part of this zone if the increase in temperature reaches to the minimum of comfort temperature. On the psychometric diagram, the lower range of this zone is defined by the lowest temperature of outside in which the sunshine makes the least comfort temperature. Here, the glasses can absorb much more heat without any danger. According to psychometric diagram, about 23.2% of the total hours of a year are in this zone.

District heating with humidification represent the number of hours that none of the other selected strategies can provide comfort. As a result, the required heating is generated by a furnace, boiler or heat pump. It should be noted that greater actual number of hours is required to use the above means to generate heat. This is because solar radiation may be actively involved in direct absorption district in several hours. However, adequate radiation is not collected from the previous day. Psychometric graph shows that this strategy prevails in 40.8% of every year. As a result, this strategy prevails most of the times.

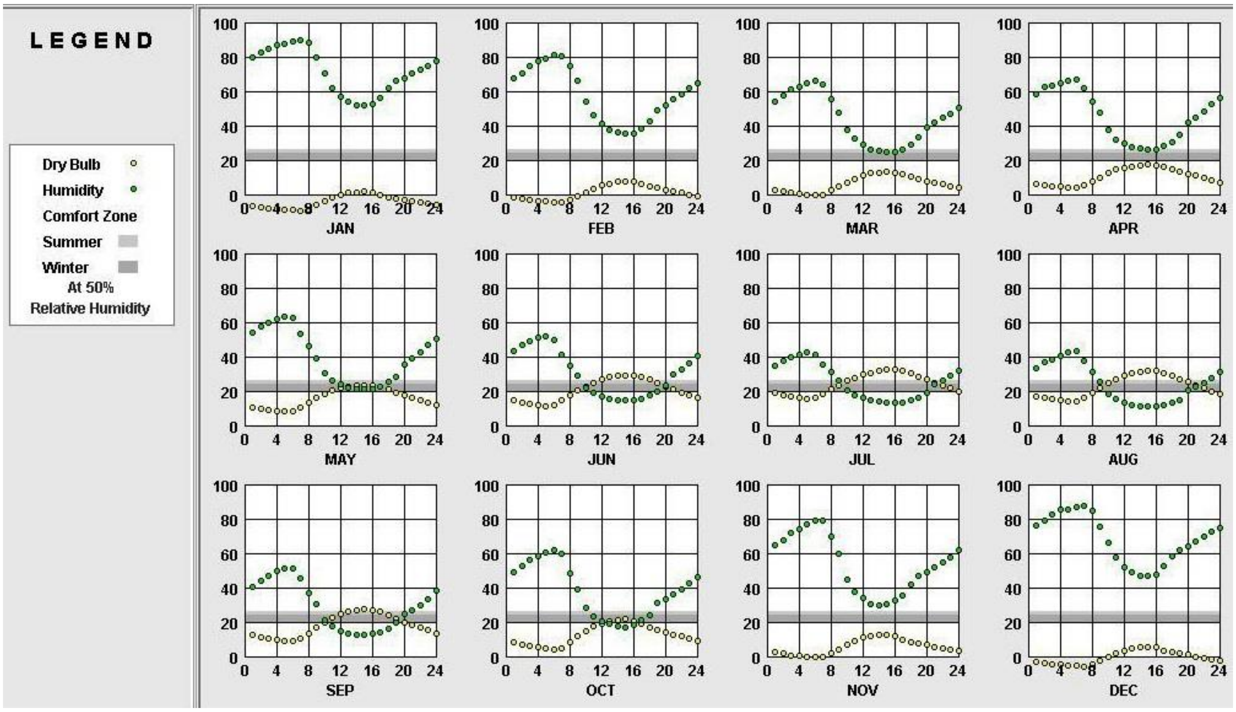
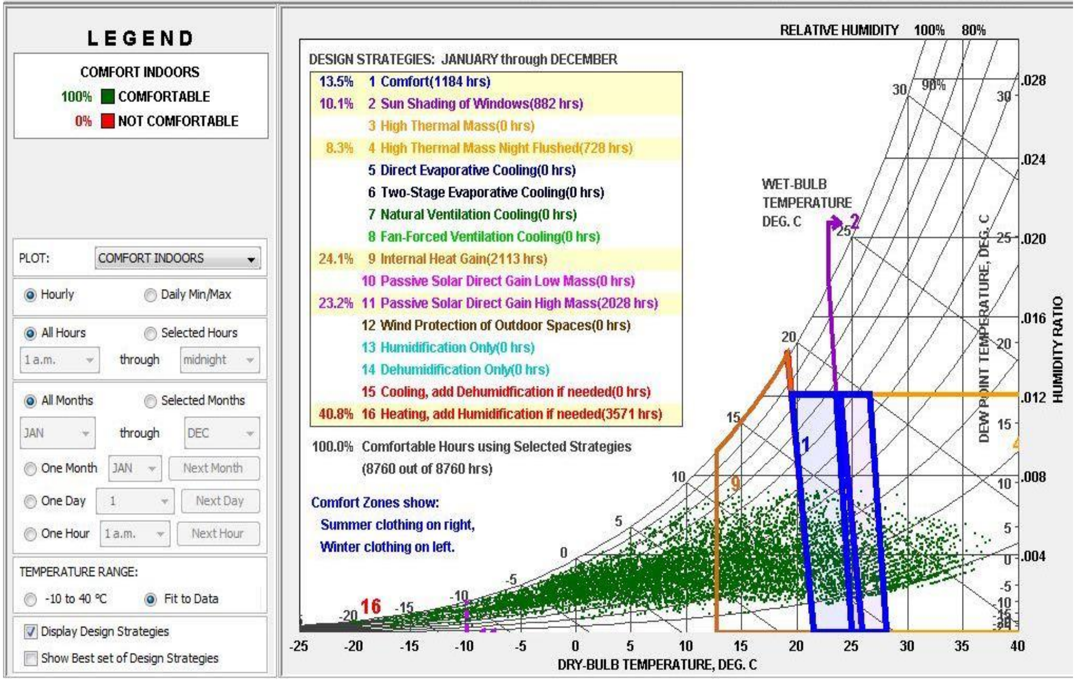


Figure 7. Dry bubble-relative humidity


LEGEND

COMFORT INDOORS

100% 🟩 COMFORTABLE

0% 🟥 NOT COMFORTABLE

PLOT: COMFORT INDOORS

● Hourly ○ Daily Min/Max

● All Hours ○ Selected Hours

1 a.m. through midnight

● All Months ○ Selected Months

JAN through DEC

○ One Month JAN Next Month

○ One Day 1 Next Day

○ One Hour 1 a.m. Next Hour

TEMPERATURE RANGE:

○ -10 to 40 ºC ● Fit to Data

☑ Display Design Strategies

☐ Show Best set of Design Strategies

DESIGN STRATEGIES: JANUARY through DECEMBER

13.5%	1 Comfort(1184 hrs)
10.1%	2 Sun Shading of Windows(882 hrs)
	3 High Thermal Mass(0 hrs)
8.3%	4 High Thermal Mass Night Flushed(728 hrs)
	5 Direct Evaporative Cooling(0 hrs)
	6 Two-Stage Evaporative Cooling(0 hrs)
	7 Natural Ventilation Cooling(0 hrs)
	8 Fan-Forced Ventilation Cooling(0 hrs)
24.1%	9 Internal Heat Gain(2113 hrs)
	10 Passive Solar Direct Gain Low Mass(0 hrs)
23.2%	11 Passive Solar Direct Gain High Mass(2028 hrs)
	12 Wind Protection of Outdoor Spaces(0 hrs)
	13 Humidification Only(0 hrs)
	14 Dehumidification Only(0 hrs)
	15 Cooling, add Dehumidfication if needed(0 hrs)
40.8%	16 Heating, add Humidification if needed(3571 hrs)

100.0% Comfortable Hours using Selected Strategies (8760 out of 8760 hrs)

Comfort Zones show:
Summer clothing on right,
Winter clothing on left.

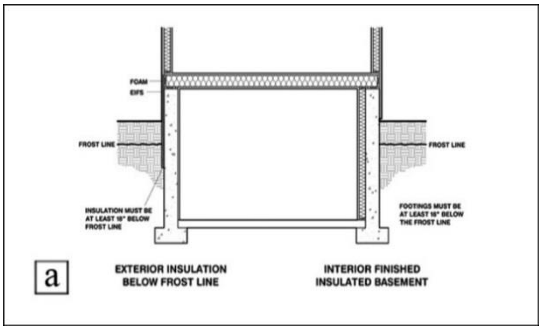
Figure 8. Psychometric chart for Saman

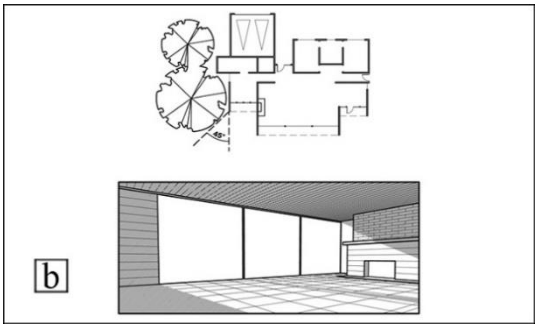
5.1.2. Suggestions for climatic design

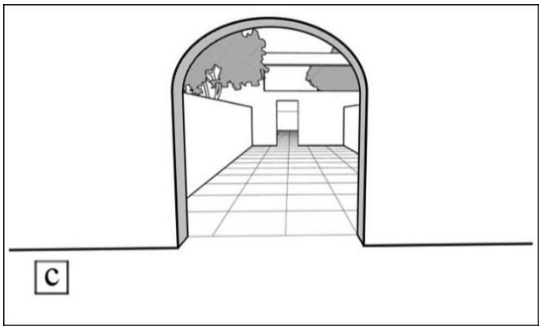
According to thermal analysis and evaluation of diagrams, the software offered some solutions as design strategies that are tailored based on climatic circumstances of Saman.

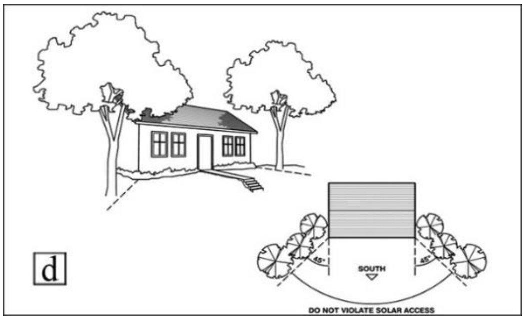
- Basement should be placed 18 inches below the cold-resistant line and be insulated from the outside with foam and from the inside with fiberglass (Figure 9-a).

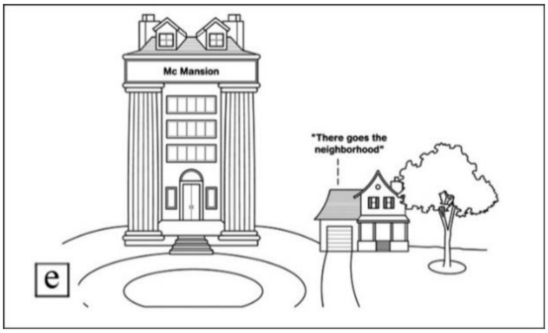
- Floors should absorb maximum solar radiation in winter. There should be no obstacle to absorb heat (Figure 9-b).
- Windshield sunshade in outer spaces can develop living spaces in the cold season such as seasonal sunny rooms, closed Patios, courtyards and balconies (Figure 9-c).
- Trees should not be in front of southern windows (inactive solar system). However, the tress could be located in front of southern windows with an angle greater than 45 degrees from each side (Figure 9-d).
- The house should be built small and compact because large surface area exposed to the outside air leads to loss of cooling and heating energy (Figure 9-e).
- Most glassy spaces should be inclined to the south in order to supply inactive solar heating to absorb more sunlight in the winter but solar radiation should be fully controlled by sunshade in the summer (Figure 9-f).
- Well-insulated small roof windows (less than 3% of the surface area in the clear weather and 5% of the surface area in cloudy weather) can reduce heating and cooling loads in buildings during the day (Figure 9-g).
- Resistant surfaces with high thermal capacity and fireplace should be used. This is because inactive heat is stored in the building in winter. Summer nights are also cool (Figure 9-h).

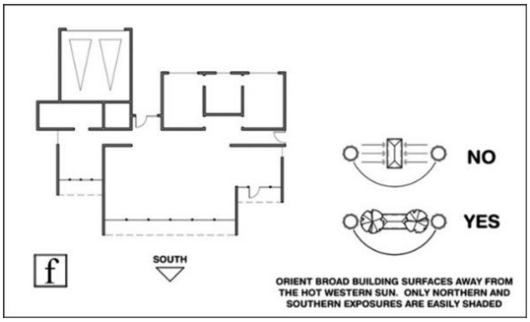












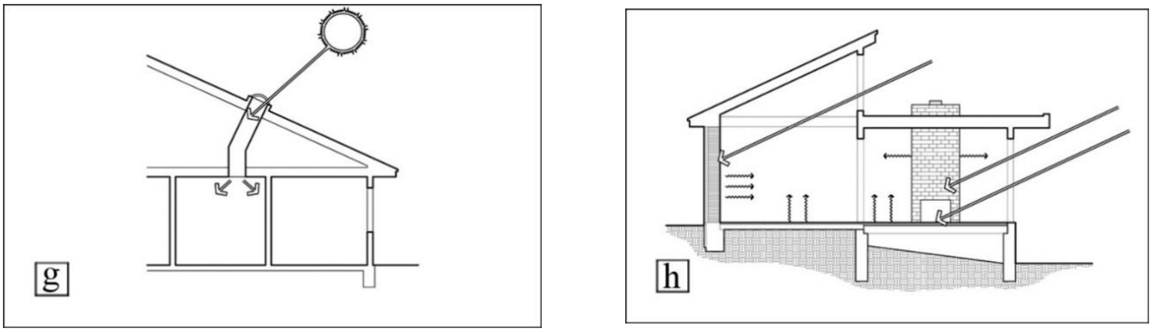
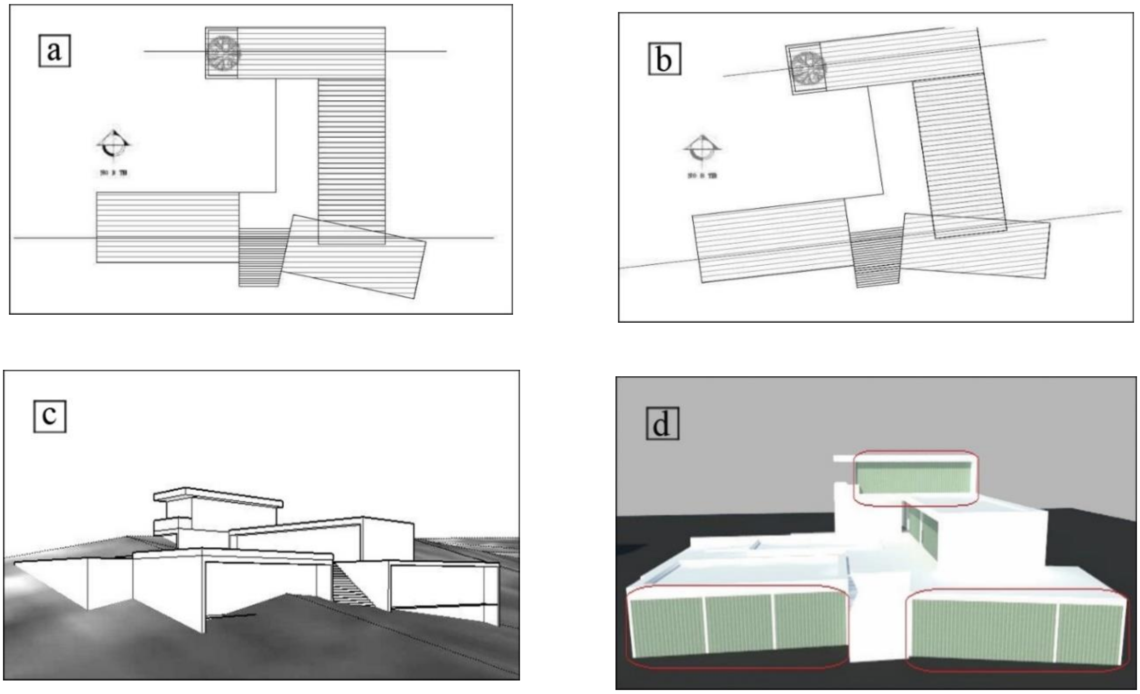


Figure 9. Climatic recommendations of Climate Consultant, a) Basement suggestions b) Floor to absorb solar radiation c) Windshield sunshade d) Trees suggestions e) size of the house f) incline of glassy spaces g) Well-insulated small roof windows h) Resistance surface and fireplace

Preliminary sketches using software recommendation and climactic solutions were developed as follows:

- Extension of the building toward eastern-western direction (Figure 10-a).
- The building is slightly inclined toward southeast direction (Figure 10-b).
- Dipping a part of the building in the ground (Figure 10-c).
- Using large windows in southern part of the building (Figure 10-d).
- Using sunshades in different parts of the building (Figure 10-e).
- Designing solar spaces in southern side of the building (Figure 10-f).
- Designing greenhouse in southern side of the building (Figure 10-g).

Three-dimensional facade and building cut are given according to the above-mentioned issues in Figure 11.



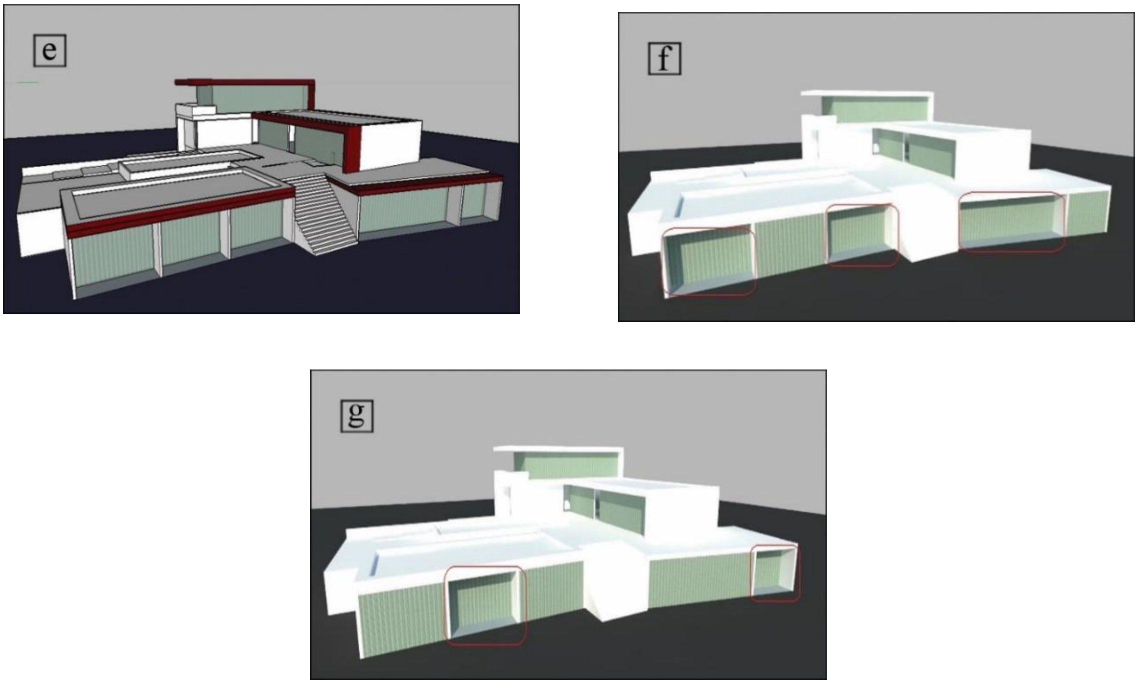


Figure 10. Design procedure, a) Eastern-western direction b)Inclined toward southeast direction c) Dipping in the ground d) Windows in southern part e) Using sunshades f) Solar spaces g) Greenhouse

Figure 11. Building 3D façade, a) Yard view b) Overview

5.2. Application of TSOL Software to supply hot water and space heating

To perform the calculations, TSOL software uses the climatic data of the Meteonorm software, based on which it performs one-year dynamic simulations.

5.2.1. Different SWH systems

In the present work, six different heating systems were used to supply sanitary hot water (SHW) and space heating. Five systems as a radiator and a floor heating system technology were used for space heating operation. Schematic function of every six systems is shown in Figures 12 to 17.

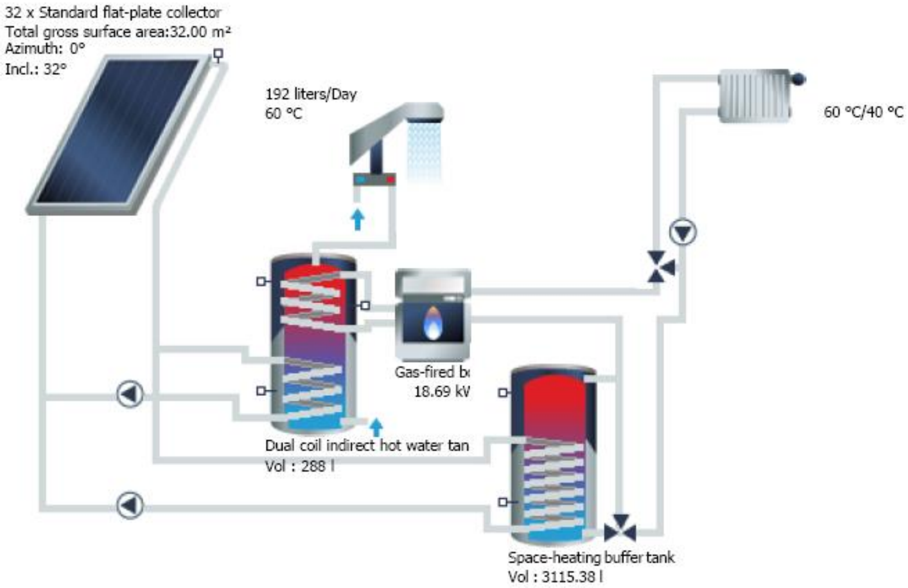


Figure 12. Small system, indirect hot water tank having two coils (Type 1)

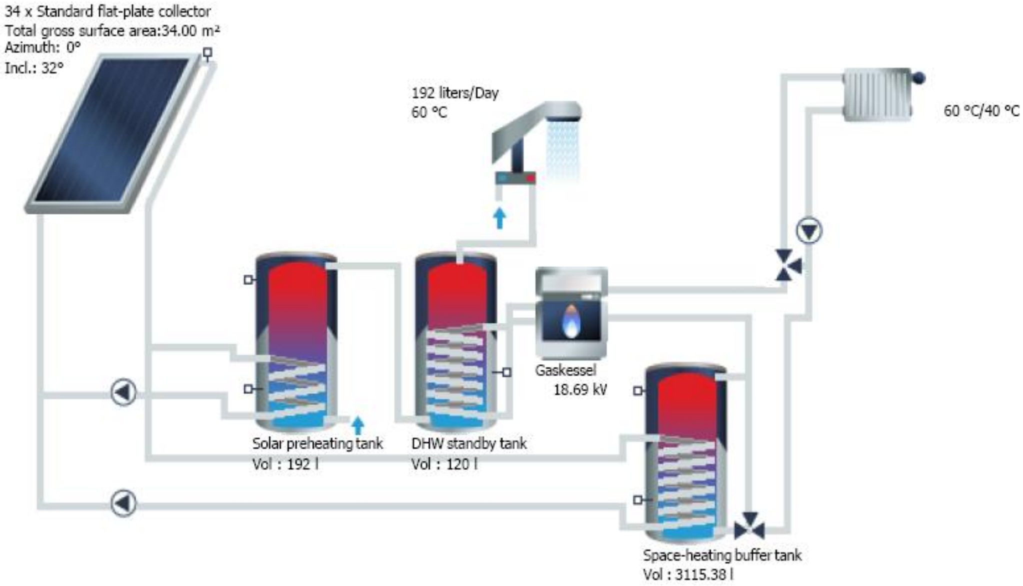


Figure 13. Small system, two tanks (solar preheat and ready-to-work tank) (Type 2)

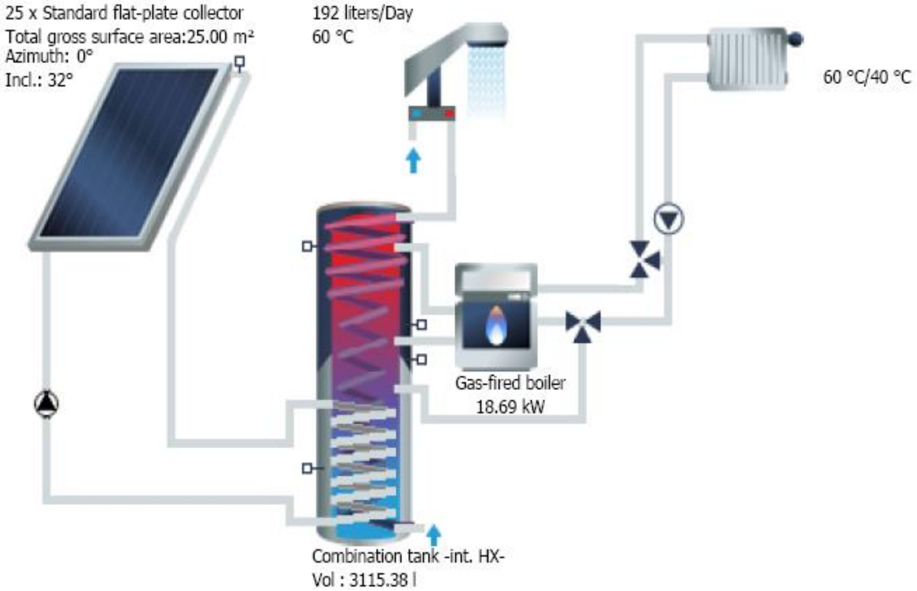


Figure 14. Hybrid system, hybrid tank with internal heat exchanger (Type 3)

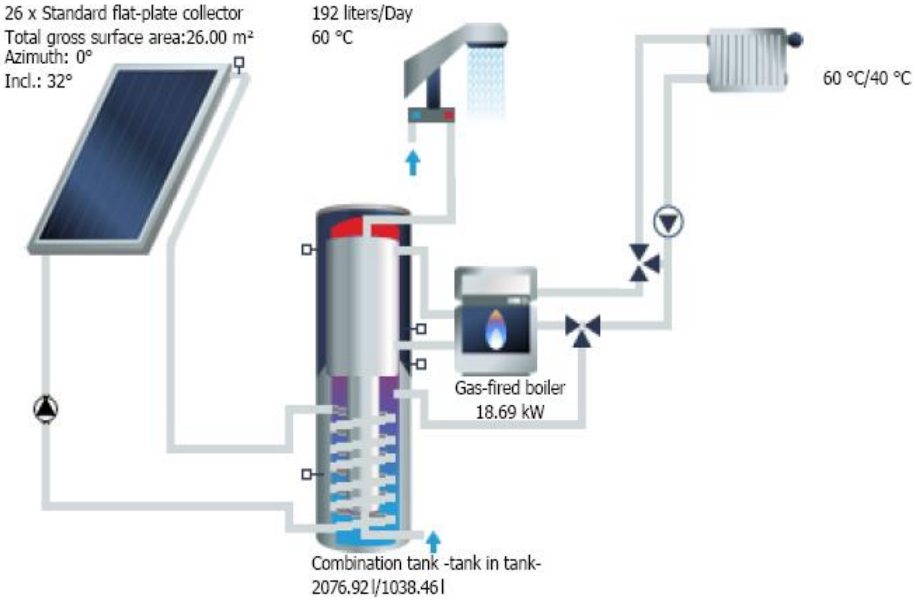


Figure 15. Hybrid system, small consumed hot water tank in the hybrid tank (Type 4)

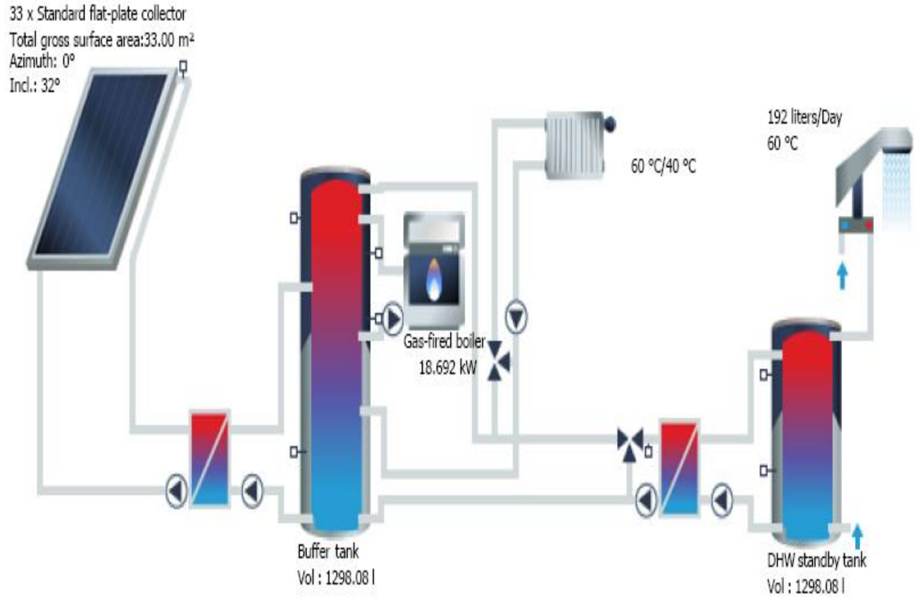


Figure 16. Large systems, buffer tank (Type 5)

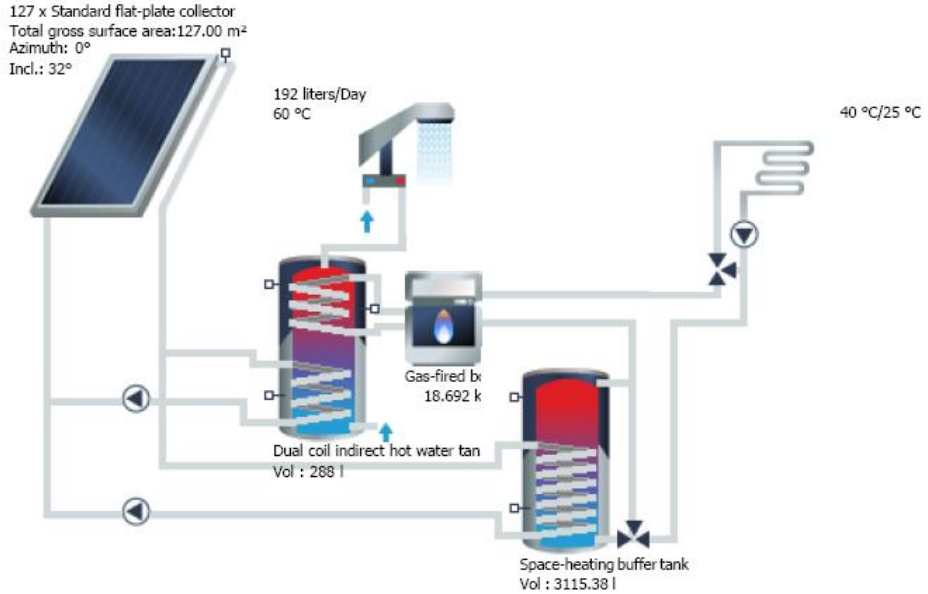


Figure 17. Floor heating system (Type 6)

5.2.2. Results of using different SWH types

Function of the each under study system is summarized in Table 2. The results showed that system type 3 with minimum number of collectors and high efficiency of the system and the largest percent of total solar radiation is a suitable system. The contents of Table 2 show that the system is not responsive and its efficiency is very low despite high number of collectors in floor heating system because of large-length pipe that leads to large thermal losses. In the following, the results of system type 3 as the most efficient system are given.

5.2.3. Results of selected system

Figure 18 shows total energy per kWh required for a week during one year. A fraction of the required energy is provided by solar radiation every month. As observed in Figure 18, the results indicated that total required energy can be supplied by solar energy in a five-month period from June to October, which seems reasonable due to less need for space heating within these five months. Maximum and minimum amount of required energy were respectively as 120 kWh in July and August and 1020 kWh is January. In addition, the highest deficit in solar energy was observed in January and February according to Figure 18.

Carbon dioxide is the main greenhouse gas (GHG) generated by humans. Figure 19 shows prevented emission of this gas due to use of solar energy. As observed in this figure, emission of 2140 kg of carbon dioxide is prevented within a year. As observed in Figure 19, maximum and minimum amount of avoided emission of dioxide carbon were respectively as 230 kg in October and 90 kg in December.

Table 2. Function of solar systems

System type	**1**	**2**	**3**	**4**	**5**	**6**
Number of collectors	32	34	25	26	33	127
Lack of emission of annual CO_2 (kg)	2037.86	2025.84	2139.96	2119.27	2753.18	977.49
Storage Amount of annual natural gas (m^3)	963.7	958	1012	1002.2	1302	462.3
Solar percent of providing SHW	79.5	81	63.6	67.3	-	32.7
Solar percent of space heating	26.9	26.1	29.4	27.4	-	16.6
Total solar percent	41.4	41.4	41.5	41.4	41	20.9
System efficiency	10.8	10.2	15.5	14.7	11.8	1.3

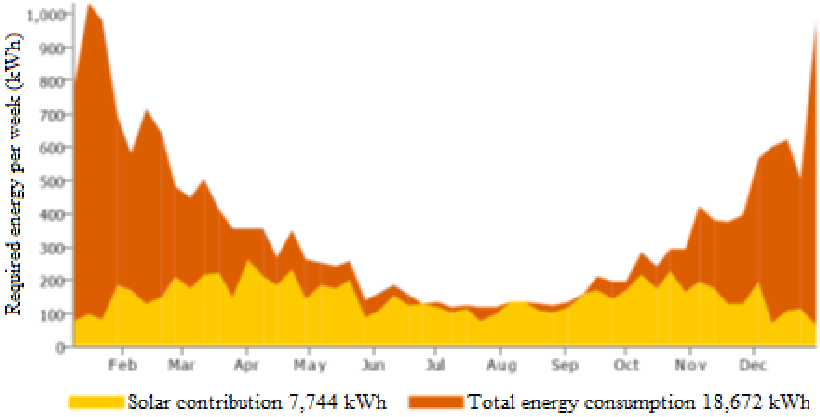


Figure 18. Required energy per kWh for a week in a year, system type 3

Figure 19. Preventing emission of greenhouse gases

According to Figure 20, designed solar energy system supplied required hot water for consumption in 64% of the year and the remaining 36% was supplied by fossil fuels. Maximum and minimum uses of solar energy by the designed system were respectively as 90% in August and 35% in December.

Figure 21 shows the amount of required energy supplied by the boiler. Boiler annually supplied 10928 kWh energy. Maximum and minimum amount of energy supplied by boiler were respectively as 3200 kWh in January and 100 kWh in August.

Figure 22 shows the amount of energy per kWh supplied by solar cells in different months. This energy is used to supply hot water and space heating. In total, 4187 kWh energy is supplied by solar cells in a year. Maximum and minimum amount of solar heat was generated respectively in August (500 kWh) and in December (220 kWh).

Figure 23 shows the amount of stored hydrogen gas during a year. As observed in the figure, 1012 m^3 of hydrogen gas was stored. Maximum and minimum amount of stored gas was respectively as 110 m^3 in October and 45 m^3 in December.

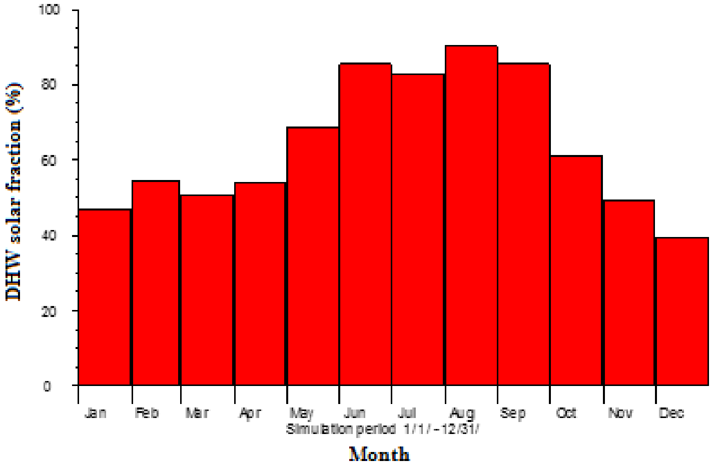


Figure 20. Supply of consumed hot water by solar energy

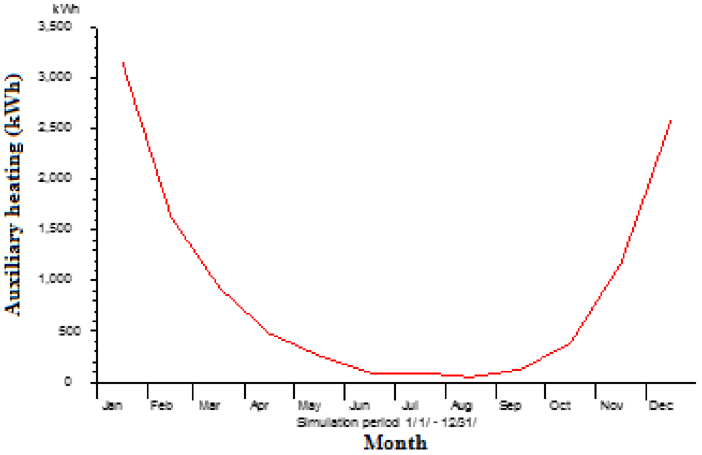


Figure 21. The amount of required energy supplied by the boiler

Figure 22. The amount of energy supplied by solar energy

Figure 23. Stored amount of natural gas

Some amount of energy is wasted during process of heat production in the collector and piping system and storage tank. Designed solar systems are responsible for minimizing loss of energy for each specific scenario. Efficiency of the system is used to evaluate losses as shown in Figure 24. According to the figure 28, average system efficiency was 15.5%. Maximum and minimum system efficiency was respectively as 21% in November and 9% in July.

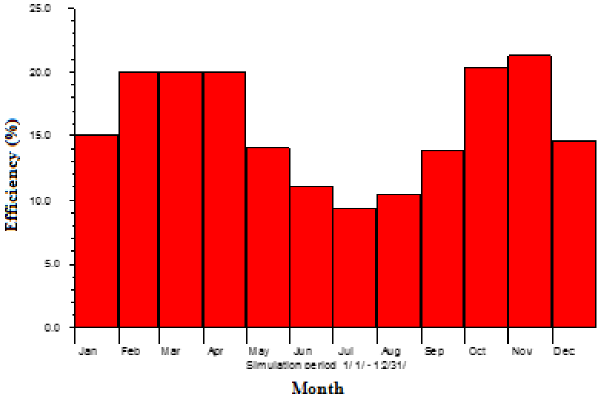


Figure 24. Efficiency of designed solar system

6. Conclusion

One of the most important ways to reduce energy consumption in buildings, in addition to climatic design, is to use new technologies based on renewable energy instead of current technologies based on fossil fuels. One of the technologies based on renewable energy is SWHs, which in addition to reducing greenhouse gas emissions, also reduce the cost of fossil fuels and, due to very low maintenance costs, significantly reduce the overall household costs.

Due to the importance of the above-mentioned issues, in the present work, a residential villa in the Saman city has been designed using the climate suggestions provided by Climate Consultant 5.5 software. After climatic design of the villa, 5 systems based on SWH and radiator and a system based on SWH and underfloor heating were studied using TSOL 5.5 software to select the optimal heating system.

The important results of the present work are:

- Extension of the building is toward eastern-western direction and is slightly inclined toward southeast direction.
- A part of the building is Dipping in the ground.
- SWH system consist of hybrid tank and internal heat exchanger with minimum number of collectors and the largest percent of total solar radiation is the best system.
- The efficiency of floor heating system is very low because of its large thermal losses.
- Emission of 2.14 tons of CO_2 is prevented within a year for the best SWH system.
- The best system efficiency is 15.5 % and equal to supply 7744 kWh by SWHS.
- For the best SWHs system, the amount of required energy supplied by the boiler and supply of consumed hot water by SWH are 10928 kWh and 64%, respectively.

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Nomenclature:

k_t	Hourly clearness index (-)	T_A	Air temperature (K)
I	Total hourly radiation on a horizontal surface (kJ/m^2)	T_{km}	Average temperature of collector (K)
I_d	Hourly diffuse radiation on a horizontal surface (kJ/m^2)	k_q	Heat transfer coefficient (W/m^2. K^2)
G_{dir}	Part of solar radiation striking a tilted surface (kJ/m^2)	$Q_{CL, DHW}$	Collector loop heating for DHW (kW)
η_0	Collector's zero-loss efficiency (-)	$Q_{S, HL}$	Solar heating for heating load (kW)
f_{IAM}	Incidence angle modifier factor (-)	$Q_{AuxH, DHW}$	Auxiliary heating for DHW (kW)
G_{diff}	Diffuse solar radiation striking a tilted surface (kJ/m^2)	$Q_{AuxH, HL}$	Auxiliary heating for heating load (kW)
$f_{IAM,diff}$	Diffuse incidence angle modifier factor (-)	SHW	Sanitary hot water (-)
k_0	Heat transfer coefficient (W/m^2. K)	SWH	Solar water heater (-)
α	Tilt angle (^{o})	GHG	Greenhouse gas (-)
ρ	Collector losses (kJ/m^2)	HL	Heating load (-)
DHW	Domestic hot water (-)	SHC	Solar-assisted heating and cooling (-)
FP	Flat plate (-)	ET	Evacuated tube (-)
EPW	EnergyPlus weather (-)	E Aux	Energy by auxiliary (-)