An Evaluation of a Solar-Powered Heating and Hot Water System for Residential Buildings Using T*Sol

ilhan GARIP *‡, Hameed Hassan Khalaf **, Khaleal Mohsin Hattab ***, Ahmed A. Ali ****, Kadhim A. Jabbar *****, Ausama A. Almulla ******, Kadhum Al-Majdi *******, Ahmed Read Al-Tameemi ********

*+ Department of Electrical and Electronics Engineering, Nisantasi University, Istanbul, Turkey

** Al-Manara College for Medical Sciences/ (Maysan)/Iraq

*** College of Engineering, Al-Esraa University, Baghdad, Iraq

**** College of Petroleum Engineering, Al-Ayen University, Thi-Qar, Iraq

***** National University of Science and Technology, Dhi Qar, Iraq

****** Al-Hadi University College, Baghdad, 10011, Iraq.

******* Department of Biomedical Engineering/ Ashur University College/Baghdad/ Iraq

******** Department of Biomedical Engineering/ AL-Nisour University College/ Baghdad/ Iraq

(ilhangarip24@gmail.com, hameedhassanj125@gmail.com, hattabhmedread895462@gmail.com , ahmedaali@hotmail.com , kadhimajabbar2024@hotmail.com , ausamaaalmullaedu@gmail.com , kadhumalmajdi@hotmail.com, al-tameemi@hotmail.com)

‡ Corresponding Author; ilhan GARIP, Department of Electrical and Electronics Engineering, Nisantasi University, Istanbul, Turkey

Received: 21.11.2023 Accepted: 22.12.2023

Abstract- The outcome of this research was the development of a parameterisation of the thermal inconsistencies associated with the implementation of water heating and underfloor heating systems in domestic settings. The objective of this research is to investigate the use of solar energy to construct a thermal system for heating and domestic hot water for residential buildings based on the use of solar energy as the main energy source. The purpose of this study is not to conduct an experiment but to conduct an exploratory study. This study has several major results, including the fact that it uses data from climate measurements up to the year 2023 as a reference, the simulated information may have variations; T*Sol 2023 software was used for the optimisation and calculation of solar systems. Based on the use of thermal transmission technology and to calculate the performance of domestic hot water heating and heating support equipment. The average seasonal performance of heating systems in buildings can be calculated by using standards and methods. The aim of this research appears to be summarizing the various aspects and methodologies employed in the research related to investigating the utilization of solar energy for constructing a thermal system in residential buildings. It outlines the key components, including the parameterization of thermal inconsistencies, the reliance on solar energy as the primary source, the use of data from climate measurements, the utilization of T*Sol 2023 software for optimization, and the calculation of heating system performance based on thermal transmission technology and established standards. Overall, it aims to explore the feasibility and efficiency of using solar energy for residential heating purposes.

Keywords: Parameterisation, thermal installation, heating, domestic hot water, solar energy

1. Introduction

The study aims to provide an updated bibliography on the use of solar thermal energy through solar collectors, Domestic Hot Water (DHW), and Under Floor Heating (UFH). According to the proposed methodology, the study aims to simulate the variables using computer software to contrast the results. The methodological approach proposed in this study has the potential to be replicated in future research, to obtain a generalised conclusion based on a comparison of the results obtained from the two studies. Based on the use of solar energy in the construction of residential buildings, the general objective is to establish the parameterisation of a UFH and DHW system that uses solar energy to generate heat. This study aimed to describe a solar-based system of heating and DHW for residential buildings based on thermal energy. It is imperative to have access to hot water for domestic purposes in Cuenca due to the low-temperature conditions found in the city. There is currently a need to overcome this deficiency through the use of electricity systems that work through the use of liquefied gas to compensate for the deficiency that has become so evident today. However, these systems cause environmental damage because they emit carbon monoxide during their operation. Solar collectors are another technology that reduces the use of non-renewable raw materials by using the energy provided by the sun to provide DHW. Ecuadorian collectors have been replicated and sent to countries in North America and Europe with different climates and environments [1]. A flat collector is connected to a tank, where the water is circulated without the need for a pressure pump so that no pressure pump is needed to circulate the water. A domestic hot water system is often used in a single-family home, which means the cold water is denser and positioned at the bottom, while the hot water is located at the top. A convection circulation occurs when hot water rises from the collector, and cold waterfalls to its bottom during the day. In the absence of sufficient solar radiation, the water in the panel cools down and becomes denser, removing the driving force. The water stops circulating, and the water remains warm in the tank; it is thermally insulated to prevent heat from leaking out [2]. The use of solar energy is of great importance for obtaining other clean energy sources since it is the most important renewable energy source. The radiation exerted by the sun on the earth can be used directly or converted into electrical or thermal energy for various purposes. As a result, it is important to know that only 40% of the 1.6 million kWh generated annually is used on earth. In Ecuador, which is in the equatorial zone, there is a significant solar resource whose magnitude is determined by its location and ranges from 2.8 kWh/m^2 /day to 6.4 kWh/m^2 /day [3]. According to a comparison of various heating systems, underfloor heating matches the body's temperature closest. A slight temperature difference should be observed between the foot level and the head level based on this profile. The user thus enters a state of thermal comfort as a result of receiving a better sense of warmth [4]. The advantage of underfloor heating over other radiant surfaces, such as ceiling and wall heating, is that it allows individuals to achieve their preferred temperature for comfort. The solar collector, therefore, is an exposed surface that transforms the radiation into thermal energy (heat), which is transported through the water for use in heating and domestic hot water systems. High-temperature collectors are for use at 400 °C, medium-temperature collectors are for use at 400 °C, and low-temperature collectors are for use at 100 °C [5]. It is a heating system that is extremely effective in providing high levels of comfort to users due to its special features and benefits. This is a result of the heat emanating from the floor. In contrast to the conventional system, where the heat comes from elsewhere, this system uses a network of pipes made of polyethylene or polybutylene material, which allows the circulation of hot water in an enclosed space with temperatures between 30-45° C, which is driven from a pump, thus saving energy [6]. A small layer of low-strength self-leveling concrete is cast on top of the network (depending on the structural design) and the desired type of floor finish is applied. Air-conditioning systems are composed of various structures that allow them to achieve efficiency and quality. In addition to reducing the downward temperature loss, it allows the pipe where DHW circulates to be fixed so it transfers its energy to the top layer of the tubular structure. Energy is stored in this layer of the house, and then it is transferred to the flooring, which in turn delivers the energy to the environment [7]. The concept behind underfloor heating is that the source of heat is placed under our feet, thereby providing us with warmth. As a result of the simple procedure for heating, you save 25-30% on your energy costs, because it does not require you to raise the temperature of the ceiling to achieve a suitable temperature, as in the case of ordinary radiators. Additionally, it produces an optimal and uniform level of comfort [8]. The use of non-renewable energies causes greenhouse effects and climate changes that are caused by the production and transformation of pollutants. In a comparison of the various heating systems available on the market, underfloor heating is the most effective in terms of temperature adaptation, which, in the perception of the human being, brings a sense of comfort to the environment. This profile is centered on the fact that the air temperature at the level of the foot is minimally higher than that at the level of the head according to what has been described. This means that the user will receive a better thermal sensation as a result of which they will be able to reach an adequate level of comfort. Since the underfloor heating system is based on the use of low temperatures, the temperature differences are not as large as they may seem, yet they are not strong enough to create strong convection currents. Therefore, the warm air in the room should not stratify, as it is concentrated in the ceiling area and the cold air is located in the lower part.

2. Methods

2.1 Case Study

This study evaluated the efficiency of using thermal energy in residential buildings for the production of heat and cold usable for heating and domestic hot water through the parameterisation of a thermal system for heating and DHW. A swimming pool can be cooled and heated with solar thermal energy. It can also be used to provide domestic hot water, DHW, and air conditioning for recreational areas. A system based on solar thermal energy is designed and implemented for residential buildings to reduce their conventional energy consumption [9]. This is a non-experimental and exploratory study, to establish a parameterisation of a UFH and DHW for residential buildings based on the use of solar energy and simulating heating and DHW processes in computer software to compare the results with the current regulations. Solar thermal and domestic hot water systems can be designed and simulated in a variety of ways. An example is an optimised simulation of the entire system, including primary, secondary, and tertiary circuits. In this study, a suitable design for a thermal, solar, or gas heating and DHW system is examined. A solar energy system is applied to DHW in residential establishments using the design of a solar energy system. The design takes into account the amount of solar energy available, the size of the hot water tank, the efficiency of the solar energy system, and the cost of the entire system.

2.2 Hot Water Consumption

The design of a solar water heating collector depends on the analysis of residential hot water consumption profiles. This is because solar water heating collectors need to be sized to provide enough hot water for the household's needs. The analysis helps to determine the amount of hot water that needs to be collected and stored to meet the needs of a household.

2.3 Sizing and Design Calculation

In calculating the size and design of solar thermal systems, several factors must be considered, including the number of people within the space, the size of the building, the type of collectors, and subsidy conditions. A study aims to parameterize UFH and DHW in residential buildings powered by solar energy. Hot water consumption and other pertinent factors are taken into account when simulating and designing these systems. The use of solar thermal energy in residential buildings is a technological process that converts solar radiation into heat. Solar thermal systems of this type can be used in both domestic and commercial settings. Heat can be generated from solar energy, thereby reducing fossil fuel use and environmental pollution. A thermal system using solar energy for heating and domestic hot water in residential buildings is being studied. The design and implementation of such a system require determining the parameters for solar collection capacity, thermal energy storage and heat distribution.

2.4 Heating System Heat Transmission Coefficient

The material used to make each envelope of the dwelling must be taken into account, such as the floor, external walls, roof, windows, and doors. It's important to consider the material of the envelope because it will affect the insulation, ventilation, and durability of the dwelling. Different materials have different properties, so it's important to choose the one that best meets the needs of the dwelling. There are different building materials can be combined in various ways to meet the specific requirements of a construction project, taking into consideration factors such as cost, durability, aesthetics, and local building codes. Advances in technology continue to introduce new materials and construction methods, influencing the choices made by architects, builders, and homeowners alike. There are different materials used for building materials Concrete, Brick, Wood, Steel, Glass, Masonry, and insulation material like Fiberglass, Foam Board, and Reflective Insulation.

2.5 Transmission Losses Without Supplements (Qto):

Based on the ratio of thermal transmittance coefficients from the previous answer, and considering the areas and envelope materials used throughout the dwelling, this calculation will be accomplished:

$$Q_{to} = \sum[U * A * (T_i - T_e)]\ W \quad \text{----------- (1)}$$

Where,

Q_{to}: Total heat transfer

∑: Denotes a summation, indicating that this equation might be calculating the total heat transfer by summing up individual heat transfer contributions.

U: Overall heat transfer coefficient of the system
A: Surface area through which heat transfer occurs
T_i: Initial temperature of the system
T_e: External temperature (ambient temperature or temperature outside the system)
W: Units, likely indicating that the resulting value is in watts (unit of power)

2.6 Interruption of Service Supplement (ZIS)

An approximate percentage of 5% is taken into consideration.

2.7 Guidance Supplement (ZO)

To find the supplement for orientation, the exterior walls that are exposed to the sun must be considered.

Heat transfer thermal load (Qt):
The formula shall be used: ZZO

$$Q_t = +Q_{to}(1 + ZIS + ZZO)\ W \quad \text{---------- (2)}$$

Where,

Q_t: Possibly the quantity of thermal energy or some other quantity at a given time.

Q_{to}: The initial or base quantity of thermal energy or another quantity.

ZIS and ZO: These could represent coefficients or factors that influence the change in the quantity being measured.

(1 + ZIS + ZO): An expression that combines the influences or factors affecting the change in the initial quantity.

W: Likely a unit or measurement associated with the final quantity Q_t

Ventilation heat load (Qv):

This is obtained from the formula:

$$Q_v = \eta * V_a * p * C_P * (T_i - T_e) W \quad \text{---------- (3)}$$

Q_v: Heat transfer through ventilation
η: Efficiency or effectiveness factor related to ventilation
V_a: Volume of air flow
p: Air density
C_P: Specific heat capacity of air
T_i: Initial (inside) temperature of the air
T_e: External (outside) temperature of the air
W: Units, likely indicating that the resulting value is in watts (unit of power)

2.8 Internal Heat Gain (Qi)

Considering worst-case conditions, it follows that:

Qi = 0(W) Heating heat loads (Q):

The heating load is calculated from the equation:

$$Q = Q_t + Q_V + Q_I W \text{ ---------- (4)}$$

This equation appears to represent the total heat (Q) in a system, which is the sum of three components:

Q_t: This could represent a specific quantity of heat associated with a process, a reaction, or another system component.
Q_V: Likely the heat associated with ventilation or heat transfer through air or airflow within the system.
Q_I: The heat could be related to another specific process or factor within the system.
The equation Q=Qt+QV+QIQ=Qt+QV+QI (where the resulting value is in watts, W) suggests that the total heat in the system is a combination of these three components.

This type of equation is often used in thermodynamics or heat transfer analyses to account for different sources or mechanisms contributing to the overall heat within a system. By understanding and quantifying each component, it becomes possible to assess the total heat and its distribution within the system, which is crucial for various engineering and scientific applications.

Calculation for the implementation of underfloor heating.

The first step is to measure the size of the underfloor heating and the area and volume of the space you wish to heat in your home. Based on the calculated heat transfer load for each space in the house, the heat load for each of the rooms is calculated according to their volume, as follows:

$$Q_v = \eta * V_a * \rho * C_P * (T_i - T_e) W \text{ --------- (5)}$$

Where:
Q_v: Heat transfer through ventilation
η: Efficiency or effectiveness factor related to ventilation
V_a: Volume of airflow
ρ: Air density
C_P: Specific heat capacity of air
T_i: Initial (inside) temperature of the air
T_e: External (outside) temperature of the air
W: Units, likely indicating that the resulting value is in watts (unit of power)

2.9 Domestic Hot Water

Solar thermal DHW systems must be operated correctly by taking into account the number of household members as well as the amount of water consumed each day. An important factor to consider when analyzing DHW is the simultaneity factor, which can be calculated by:

$$k = \sqrt{n - 11} \text{ ----------- (6)}$$

Where:
k: Simultaneity factor.
n: Number of hot water taps.
Amount of water to be used in the whole thermal system. To do this, the amount of water used in the DHW system, the amount used in the heating system and the sum of the two will result in the total amount of water to be consumed.

3. Selection of the Solar Thermal Heater

The type of water heater should be selected based on the amount of water to be used. Using solar water heaters' technical characteristics and climatic data of maximum monthly irradiance, average sunshine hours, and temperature, the efficiency and number of water heaters in the thermal system are calculated. Based on the above characteristics, a simulation in the software will be conducted for the thermal system for heating and domestic hot water, which will reveal similarities and differences between the studies. A demonstration of the proposed parameterisation process will also be provided. The thermal system software for heating and domestic hot water is used to design and calculate a UFH and DHW system. The software allows you to optimize the system's efficiency and ensure proper operation. The software is chosen for its ability to design a domestic hot water and heating system in detail, taking into account factors such as heat distribution, radiator capacity, and hot water demand [10]. Additionally, it allows simulations and analyses to evaluate system performance under various scenarios, such as changing temperature outside or changing heating and domestic hot water demands. Therefore, TSOL 2023 is a dynamic simulation program that can be used to design, optimize, and calculate solar thermal systems, particularly for DHW, swimming pools, and process heat.

4. Case Study

To carry out the comparative analysis between the study and the simulation using the T*Sol 2023 software, the following data should be taken into account to provide an accurate comparison: Table 1 shows the general characteristics of the dwelling. The specific environments or spaces for each area are listed in the following Table 2-8 :

Table 1 General characteristics of the dwelling

Latitude:	-2.90 latitude South
Longitude :	-79.00 Longitude West
Elevation :	2550
Land Area :	102.76 m^2
Area	83.44 m^2
Useful Area :	10 m^2

Table 2 Area and volume of each space in the dwelling to be heated

Spaces	A(m^2)	V(m^3)
Ground Floor		
Kitchen - diner	22.4	66.7
Room	7.87	23.57
Top Floor		
Main Chamber	9.37	28.05
Chamber 1	9.70	29.08
Chamber 2	9.70	29.08

Table 3 Average Maximum Monthly Irradiance

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
kw/m^2	4.96	4.88	4.89	3.96	4.37	4.20	3.68	5.13	4.41	4.66	4.92	5.04

Table 4 Average ambient temperature

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
°C	16.1	16.5	16.2	15.2	15.9	15.0	14.2	14.5	14.4	14.7	14.8	15.5

Table 5 Main results obtained

Service interruption supplement	5%
Guidance supplement	26.9%
Thermal load due to transmission of heat	5070.50 W
Heating thermal load	6428.54 W
Total heat emission	534.23 W/m
Total pipe length	329.90

Table 7 Specific results of the annual simulation

Specification	
Climatic data	Basin
Location	Basin
Annual sum of global radiation	1742[illegible] kWh/m^2
Latitude	-2.90
Longitude	79.2

Table 6 Main results obtained

Features	Result
Average ground surface temperature	27.91 °C
Average water temperature of the pipes	35.48 °C
Supply temperature	36.39 °C
Re-take temperature	26.39 °C
Water flow	0.1465 I/s or 0.527 m'/h
Number of taps	3
ACS per person	50 I/day
Water quantity	150 I/day
Water quantity used in the heating system	66.44 I/day
Total water to be consumed	206.38 L
Solar Thermal Heater	
Storage temperature	50°C
Inlet water temperature	9°C
Heater efficiency	57%
No of heaters	1

4. Results and Discussion

It should be noted, among the results, that one of the principal limitations of the program is that it uses climate data up to 2022 as a reference, so there may be variations in the simulated information regarding heating and domestic hot water. This means that the predictions of the program may not be accurate beyond 2022, as the climate data used is based on current conditions and may not reflect any changes that may occur in the future. Similarly, it has been noted that, when analysing the study that was conducted previously, some values are not taken into account, such as the location of the building concerning the times of light and darkness, and so forth [11]. A similar standard was maintained since the position of windows in the building was not considered. It should be noted that the programme allows a simulation of the operation about the temperature of the same, as well as the conditions of domestic hot water and heating, providing an estimate of its functionality, as well as an economic analysis of the savings that can be achieved from its use. This simulation helps to identify any potential issues that may arise during the operation of the device, as well as any potential savings that can be generated from the device. It also allows for a better understanding of the device's capabilities and potential uses. A complex collection of variables is required for the simulation, but these variables must be considered. It results in significant differences between the simulation results and the ones obtained from using specific formulations when the same factor is absent. The flowchart of the process of entering parameters for the simulation in software is shown in Figure 1.

Table 8 Installation results

Installation	
Manufacturer	Standard
Type	Standard flat plate collector
Number	1.00
Total gross area	1m^2
Total reference area	1m^2
Angle of inclination	45°
Orientation	180°
Azimuth	180°
Heating buffer tank	
Manufacturer	Standard
Type	Heating buffer tank
Volume	0.20m^3
Bivalent ACB tank	
Manufacturer	Standard
Type	Bivalent ACB tank
Auxiliary heating	
Manufacturer	Standard
Type	Gas boiler
Nominal power	31.34kW

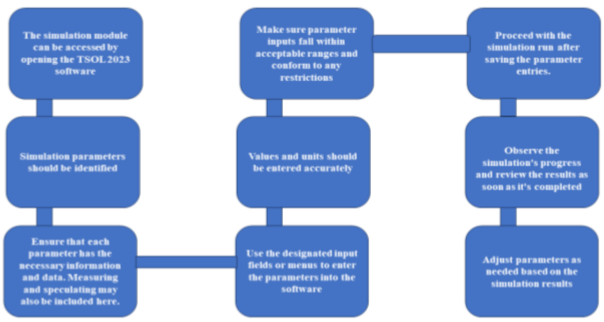

Fig. 1. Flowchart of the process of entering parameters for the simulation in software

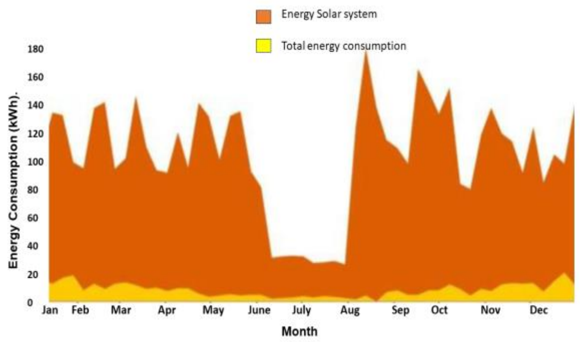

Fig. 2. Share of solar energy in energy consumption

However, several of the final data produced by the simulation were similar to those found in the previous study. This method is therefore considered an appropriate first step in domestic hot water and heating research. Practically, however, the hand-gathered data must be contrasted with the machine-gathered data. The share of solar energy in energy consumption is shown in Figure 2. The installed solar thermal system has a low power (0.455 kW) and a small collector area (1 m^2). This system is located in an area with good solar radiation, as evidenced by the high irradiation at the collector surface (1360.52 kWh/m^2). It is evident that the system is efficient in capturing and transferring solar energy since the collectors supply 735.54 kWh/m^2 and the collector circuits supply 644.61 kWh/m^2. Energy consumption for hot water production (2039.32 kWh) is low compared to energy consumption for heating (3629.97 kWh). Further, the energy provided by the auxiliary heating (5074.8 kWh) is higher than the energy provided by the solar system for domestic hot water (0.00 kWh), indicating that the system is not efficient at generating domestic hot water [12]. According to the data, the installed solar thermal system has a low collector surface and power but is efficient at capturing and transferring solar energy. Despite this, the system relies heavily on auxiliary heating for domestic hot water generation. The maximum daily temperatures in the collector as shown in Figure 3.

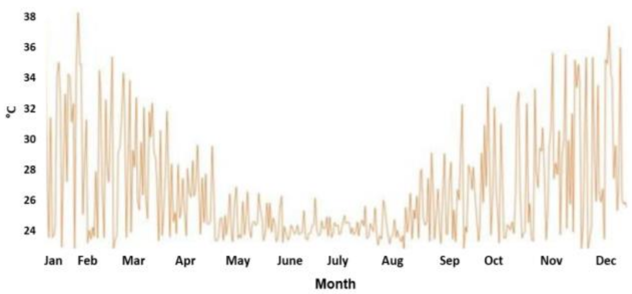

Fig. 3. The maximum daily temperatures in the collector

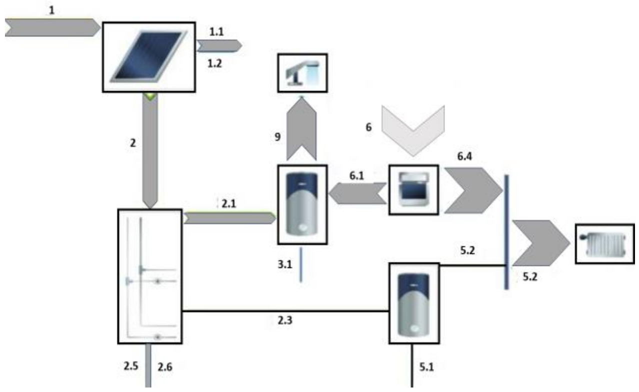

Fig. 4. The scheme of the energy balance

Among the important findings of the present study is the solar fraction, which is a measure that indicates how much solar energy is obtained via the solar technology used, divided by the total energy needed. The solar fraction is calculated as a ratio between solar energy and total energy consumed, as explained by the author. The thermal specification of the solar collector, data logger, and temperature logger are shown in Table 09-11. The purpose of this measure is to assess the efficiency of solar energy systems and the extent to which they can reduce the consumption of conventional energy. There are some situations in which the solar fraction is used to evaluate the efficiency of a solar thermal system. The scheme of the energy balance is shown in Figure 4. It has been shown in a previous study that when it comes to the maximum temperature that is reached at any point during the day inside the solar collector, they refer to the temperature that is reached at the highest point within the collector according to their theory at the peak of the day within the collector. Solar collectors with 50% efficiencies and 23°C ambient temperatures have maximum working temperatures of 60°C. The maximum daily temperature in a collector is determined by its type and the environment in which it is located, according to the aforementioned authors. A solar collector's maximum operating temperature should not exceed 60ºC to prevent burns. The energy balance scheme refers to the amount of energy that enters and leaves a system, in this case, the Earth, concerning the amount of energy that enters and leaves the system. This energy balance is maintained by the atmosphere, which receives solar radiation from the Sun and emits infrared radiation back into space in the form of the same energy it receives from the Sun. Consequently, the energy balance is designed to provide complete and reconciled data on the amount of energy consumed and produced in a system, as well as provide a basis for guiding and making decisions for the design of energy use and production plans.

Table 9: Thermal specifications of solar collector	
Factor	**Typical Range**
Overall Heat Transfer Coefficient	1.5 to 4.0 W/(m²·°C)
Heat Removal Factor	0.80 to 0.95
Collector Efficiency	40% to 80%
Optical Efficiency	50% to 80%

Table 10: Specifications of Model ESDL-30 Data Logger	
Input	**Sensor with SDI-12 signal interface**
Operating temperature range	-30° to 70°C
Humidity	100 %
Power supply	2 x D size 3.6 V/19 Ah Lithium cells, or 2 x D size 1.5 V Alkaline high power cells, or 12V SMF battery chargeable from AC mains or solar panel

Table 11: Specifications of Temperature sensor	
Range	**0°...100°C**
Accuracy	< 0,1°C + NTC-spread over 0°...70°C
Resolution	2 m°C@30°C and 25 m°C@100°C

5. Conclusion

A majority of domestic hot water systems have storage tanks in the basement. A series of pipes is designed specifically to distribute water from these tanks to homes. It is necessary to have a storage tank to supply hot water continuously. This ensures that the water is heated evenly and that potential leaks are prevented. Understanding the concepts of power and efficiency of heating and DHW equipment is important, as is being able to identify different types of equipment from photos. When choosing DHW and heating equipment for your home, it is important to understand the different types of equipment available. It is important to understand the concepts and power and efficiency ratings to choose equipment that is the most energy efficient and saves you money on your utility bills. An energy-efficient solar system is installed on a residential building to provide DHW. The performance of building heating systems and average seasonal heating is calculated using standards and methods. Heat and cold can be generated in buildings by using solar thermal energy.

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