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Long-term Evaluation and Analysis of a Residential Building Integrated with PVT/ water and PVT Al_2O_3/Water Systems in Basra, South of Iraq

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A B S T R A C T

This paper aims to study providing electricity and domestic hot water demand for a single-family house in Basra city, south of Iraq. Three systems have been simulated by TRNSYS 16 software to determine their thermal and electrical performance: traditional house (without PVT), with the PVT/water-based and with the PVT/0.4 % Al_2O_3 systems. The annual energy consumption, collected energy, auxiliary energy, thermal solar fraction and domestic hot water have been analyzed in long-term simulation. The results show that the use of the PVT/water and the PVT/0.4% Al_2O_3 systems combined with the house decreased the annual energy consumption by about 43.54 % and 52. 33 % compared with the traditional house. The results also established that when using the PVT/0.4% Al_2O_3 system, the collected energy increased by 17.12 %, while the auxiliary energy decreased by 31.51 % compared with the PVT/water system. It is also concluded that using both the PVT/ Al_2O_3 and the PVT/water systems with the traditional building covered the domestic hot water demand at about 42 % to 100 %, and 46 % to 100 % in various months, respectively. Finally, the results highlighted that there is an improvement in the thermal solar fraction of about 14.5% in the case of using the PVT/ Al_2O_3 system compared with the PVT/ water) system.

1. Introduction

Solar energy is an essential renewable energy source that sustains life on Earth. Solar energy is considered an available, useful, and cheaper power source[1], [2]. Recently, solar energy has become one of the most significant sources contributing to any society's economic development[3]–[5] It is undeniable that using fossil fuels to produce energy contributes to different environmental hazards such

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as climate change and global warming all over the Earth. Therefore, replacing it with environmentally friendly fuel is irreversible[6]–[8].

Iraq is an essential producer of different types of renewable energy, such as solar and wind energy. Studies have shown that the solar radiation intensity ranges from 416 W/m^2 in January to 833 W/m^2 in June. From 2003 till today, Iraqis have suffered from underserved and continuous power outages, forcing them to use diesel generators to cover household energy requirements, which is causing air pollution and increasing the noise rates[9], [10].

Iraq's electricity is expensive, unreliable, polluting, and limited-resource intensive. Before 1990, at 10,200 megawatts (MW), Iraq's thermal and hydropower plants' combined generation capacity often exceeded demand. Currently, Iraq's demand dramatically outstrips its grid's capacity for supply. During summer heat spells, Iraq's demand often "exceeds peak load by almost 50% when air-conditioning units consume the most power" (IEA 2019)[11]–[13]. Indeed, there is a big gap between peak electricity demand and maximum grid supply, despite the increase in available supply by one-third[13]. In addition, numerous challenges are faced by the electricity sector, such as low oil prices, corruption, electricity subsidies, and technical/nontechnical losses. All these challenges require an array of solutions[14]. For years, the Iraqi government has stated they are interested in the critical development of solar photovoltaic (PV) electricity. Under one unsuccessful 2016 plan, the Iraqi government set out a goal of installing 685 MW of utility-scale solar photovoltaic (UPV) generation by 2020. In any case, the total number of projects implemented is 2% of the plan. While the remainder percentage is regarded as suggested projects[12].

Many researchers studied different types of photovoltaic thermal (PVT) systems combined with building (BPVT) to produce electricity and domestic hot water to cover the demand of the buildings[15]. Moreover, the world today is heading towards zero energy-building to decrease carbon emissions and energy consumption[16]. Many techniques are used to enhance the performance of the PVT system such as cooling media, the type of solar cell and different flow configurations[17].Y. Yu et al. [18] tested two flow configurations of PVT cannel; harp and novel grid channel by experimental and simulating methods in three cities in China. TRANSYS software was used to determine and validate the output data. They concluded that the grid channel type had higher thermal performance than the harp arrangement type while, related to the pressure drop, the harp-one had more effects than the grid. They also found that the annual energy consumption and the production of DHW in Xichang City are more than the others. Shojaeefard et al.[19] investigated experimentally and numerically the effect of using water cooling techniques on the distribution of the PVT temperature under Tehran climate weather. By using ANSYS (22 r1) software the authors found that the using of the PVT water-based system decreased the PV temperature and enhanced the electrical, thermal and exergy of the system. Ying Yu et al.[20] studied two types of PVT systems; unglazed PVT and roll-bond absorber PVT systems experimentally and numerically by TRANSYS software to supply electricity and DHW for rural families. The results show a better thermal performance of the roll-bond system than the unglazed systems. Sourav Diwania1, et al. [21] investigated the performance of the hybrid PVT system cooled by two types of Nanofluid; pure water copper (Cu/water) and aluminium oxide (Al_2O_3). The results mentioned the better performance of the PVT system with (Cu/water) compared with the (Al_2O_3) Nanofluid. Also, using 2% volume concentrations of Cu Nanoparticles improved the electrical and thermal efficiencies by 4.98% and 5.23% respectively. Many factors affect electricity production by PVT system and DHW discussed by Madalina Barbu et al. [22]such as the main temperature of the cooled- water, storage tank and user demand curve. They concluded that the outlet water flow to the user is the highest impact factor on the efficiency at 6.8% followed by the storage tank parameter at 4.7% and the consumer's profile also very important impact. Laetitia et al., [23]analyzed the performance of twenty-eight PVT systems in Western Europe and also, studied the amount and temperature of DHW. The researcher found that the PVT system supplied a good amount of the DHW with a daily temperature reaching above 45 ℃ for about five months. Furthermore, the results demonstrate that the unglazed PVT system is more robust compared with the other types as it has safety for risks of increasing of temperature of solar cells. Muhammad O. et al,[24] improved the performance of the PVT by using (Ag/H_2O) Nanofluid. They simulated the results by ANSYS FLUENT 15 for one year depending on Saudi Arabia's climate conditions to supply electricity and another building's demands. Add to that, they studied the system economically by long-term analysis taking into account the effects of Co_2 emission. and The researchers concluded there is an improvement in the electric power output of the PVT system by 18% by adding (silver/water) Nanofluid. The economic results show that there is a decrease in the energy cost by about 82%. Al-Waeli et al.,[25] investigated experimentally the addition of 3% wt of Sic Nanofluid particles to the water as cooling media in the PVT system comparing it with PV one. The results indicate that this addition increases the electrical efficiency by 24.1% compared with the PV system. Also, the total effectiveness of the PVT system (cooled by sic/water) was higher by about 88.9% compared with the PV alone system. Wei An et al., [26] studied using (Cu_9S_5/water) Nanofluid with PVT collectors experimentally under Shanghai/China weather conditions. They investigated the effect of different concentrations of Nanofluid and the top of the glass cover of the PVT system. The results show that there is an increase of about 17.9 % in overall efficiency. S. Manikandan et al., [27] enhanced the performance of the PVT system experimentally by using sand-propylene glycol-water Nanofluids. The researchers concluded that by using 2% wt of the Nanofluid, the thermal conductivity and solar energy enhanced by 16.3% and 16.5 % respectively while the viscosity decreased by about 47%. M H Shojaeefard et al.,[28] and Emmanuel et al.,[29] reviewed the principles, classifications and applications of the many types of Nanofluid such as TiO_2-water, Al_2O_3- water, ZnO-water, SiC-water, SiO_2-water and Fe_3O_4.Further, they discussed the effects of different flow configurations and types of absorbers on the thermal and electrical efficiencies of the PVT. They concluded that the using of two types of Nanofluid (hybrid Nanofluid) works better than Nanofluid alone. Also, they mentioned that all types of Nanofluid improved the performance of the PVT system in certain proportions. In Iraq, there have been many attempts to solve the electricity cut-off over the years. However, there has been no work until now that includes the use of the (PVT/Nanofluid) system combined with the building in long-term simulation for one year so, the targets of this study are:

- To investigate whether the PVT/ system cooled by Nanofluid is achievable in the south of Iraq.
- To study the effects of using (0.4% Al_2O_3/water) Nanofluid on the annual energy consumption, DHW demand for a single-family house in Basra city, Iraq
- To study the possibilities of using renewable energy by supplying electricity and domestic hot water to residential buildings tailored to a city located in the south of Iraq.
- Finally, to emphasise the dissemination of the culture of depending on renewable energy systems in Iraq to solve the electricity cut-off both in city and off-grid regions.

2. Materials and Methods

To achieve the goals of the ongoing work, three cases have been simulated by TRANSYS 16 software: the traditional building (without PVT), integrated with (PVT/water-based) and again with (PVT/0.4 % Al_2O_3).

2.1. The model geometry

The proposed house simulated in this study contains two floors; the ground floor has two bedrooms, two living rooms and a kitchen; while the first floor has two bedrooms. The total area of the building is 200m^2. The number of occupants is six people. The external and internal walls are made of common brick, while the roof is from concrete. Assuming there is no shading, like a high building or a tree that can cover the roof. The floor plan of the considered building with its 3D max image is shown in Figure 1.

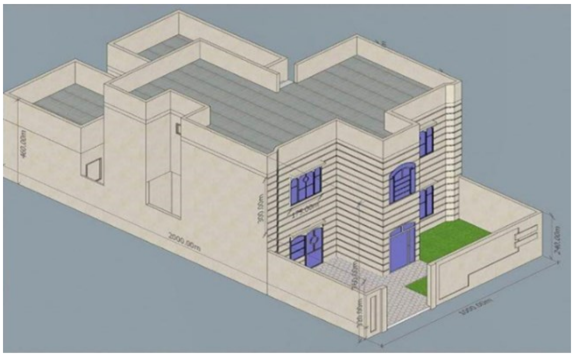


Figure 1. 3DMAX image of the proposed house with dimensions.

2.2. PVT systems

to enhance the performance of the PVT system, the water and (0.4% Al_2O_3/water) have been used as a cooling media [30]. The (PVT/water) system consists of PVT panels, a pump, a storage tank and a controller as shown in Figure 2. The water is pumped to the PVT solar panels through the pipes and absorbed the heat generated by operating the solar cells for long hours, then, the resulting hot water returns to the storage tank to supply the housing demand.

The (PVT/Nanofluid) consists of PVT panels, two pumps, a storage tank, a heat exchanger and a controller. When the PVT system is operating the cooling cycle starts with pumped Nano fluid to the pipes of the PVT system, then Nano fluid will absorb the heat generated from the pipes of the solar panels to the heat exchanger; coincides with the entering of cold water to the heat exchanger as well. The water will absorb the heat and turn into hot water moving through the pipes to the storage tank; finally, the Nanofluid will lose the heat, and be ready to make another cycle, as illustrated in Figure 3.

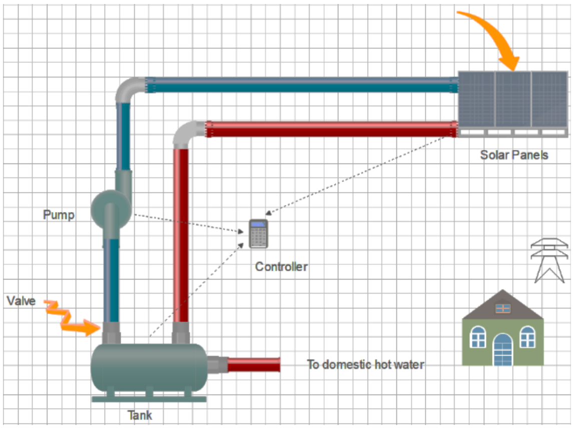


Figure 2. The proposed house with (PVT/water-based) system

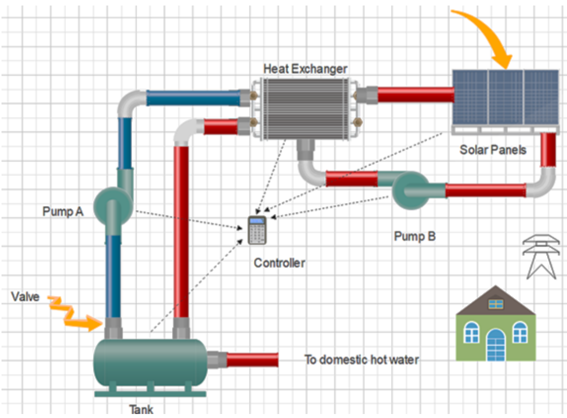


Figure 3. The proposed house with (PVT/Nanofluid) system

The assumed PVT panels consist of 250W monocrystalline PV cells. The technical specifications of the PVT system are listed in Table 1.

Table 1. Properties of the PVT system

Parameter	Value	Unit
Collector Area	1.48	m^2
Thermal efficiency	70	%
Electrical efficiency	15	%
Fluid	water+Al_2O_3	-
The water-specific mass flow rate through the PVT collector	50	$kg/m^2.hr$

2.3. Meteorological conditions

Iraq's weather is dry, cold in winter, and extremely hot in summer, with a few amount of rain falling in the winter season[31]. Iraq from the countries of the solar belt makes it receives a high intensity of radiation (especially in the southern governorates) sufficient to operate solar plants to generate electricity excellently. Basra city located in the south of Iraq between 30.508 N latitude and 47.783 E longitude has been chosen for the simulation of the PVT system. It received a high quantity of solar radiation per month, especially in summer reaching 670 W/m^2 in June. Figure 4 shows the solar radiation during 2019 for Basra City. The coldest month of the year in Basra city is January, when its temperature varies from 5 to 10 ℃, while the hottest month of the year is July, in which its temperature could reach above 45℃. Table 2 presented the average high and low temperature, average relative humidity and wind speed for Basra city obtained from Al-Fau station[32].

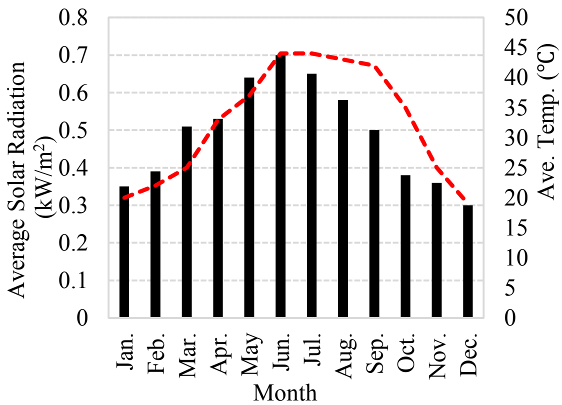


Figure 4. Average solar radiation and outdoor air temperature for Al-Fau metrological station (2019)

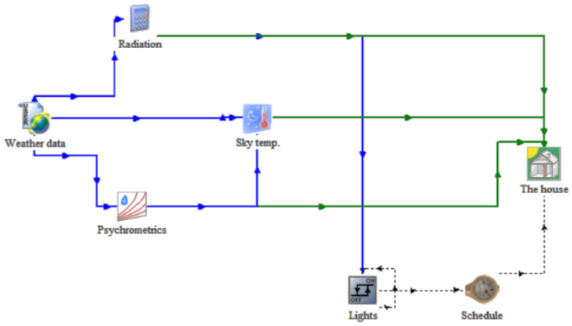
Table 2. Average (high, low) temperature and humidity for Basra city [32]

Parameters/Month	Jan.	Feb.	Mar.	Apr.	May.	Jun.
Average high temp. ℃	18	20	23	28	37	43
Average low temp. ℃	10	11	18	30	31	34
Avg. relative humidity %	64	52	40	30	24	18
Avg. wind speed m/s	3.31	2.9	3.9	2.6	3.3	3
Parameters/Month	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Average high temp. ℃	44	43	42	35	25	20
Average low temp. ℃	36	33	25	23	19	13
Avg. relative humidity %	20	21	22	33	52	61
Avg. wind speed m/s	4.6	3.24	3.2	1.3	2.4	3.43

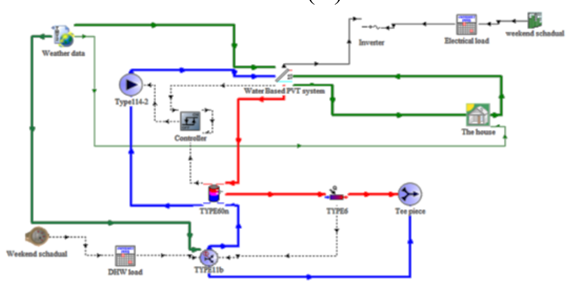
2.4. TRNSYS model

The current study was based on a simulation approach by using TRNSYS 16 software to evaluate the actual condition because there are many difficulties in collecting the actual data such as the electricity cutoff hour by hour and instability in energy generation in Iraq.

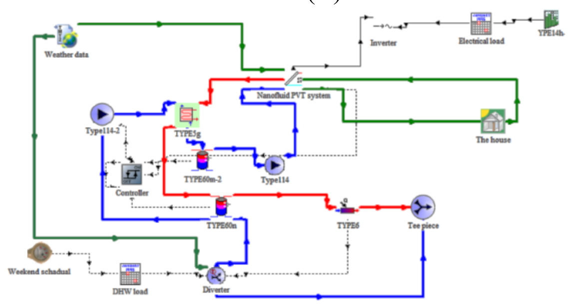
The three models simulated in long-term evaluations by TRANSYS 16 software are presented in Figure 5. The first model (A) explains the traditional building, the second one (B) presents the proposed house which is integrated with the (PVT/water) system and the third (C) shows the proposed house integrated with the (PVT/4% Al_2O_3 +water) system.



Model (A)



Model (B)



Model (C)

Figure 5. The pictorial view of: (A) The proposed building; (B) The proposed building integrated with (PVT/water) system; (C) The proposed building integrated with (PVT/4 % Al_2O_3 +water) system

The TRANSYS 16 software components that were used in the simulation are listed in Table 3.

Table 3. The components used for the simulation

Type	Name
50	PV-thermal module
109	Weather data processor
56	Building model
60	Storage tank model
114	Pump
5	Heat exchanger
6	Auxiliary
11a	Diverter
11h	Tee piece
14	Forcing function
48	Inverter
33	Dry and bulb temperature
69	Sky temperature
14	Schedule

However, the following assumptions are taken into account through the TRANSYS 16 software calculations in this study:

1. The flow has been considered under steady-state conditions as well as one-dimensional
2. The behaviour of daily domestic hot water consumption has been taken to be the same for all days of the year.
3. The effects of the dust and heat losses through all sides of the PVT panels are negligible.
4. There is no shading on the PVT systems.

3. Results and Discussion

By using the metrological data of the Al-Fau station in Basra city and construction data of the proposed house, the three models of the building shown previously in Figure 5 were simulated for one year (2019) using TRNSYS 16 software. Initially, the results of the simulations are given separately for each building model.

3.1. Simulation verification

TRNSYS16 (Transient System Simulation) software is considered one of the most important programs for thermal and electrical energy simulation. It has an extensive library of components such as heat exchangers, pumps, HVAC, solar thermal collectors, and thermal storage. It is an hour-by-hour energy simulation software. After compiling a building description, it produces a detailed simulation of the building, as well as an estimate of how much energy it would use. This software utilizes the full capabilities of designing all cooling and heating systems. Based on many factors such as walls, windows, type of glass and number of occupants, TRANSYS software calculates the monthly energy consumption for the proposed building. It also simulated the multi-zone building calculated the cooling and heating load for each zone and tabulated the building's projected energy for each month.

In this work, as a first step, the TRNSYS16 software results were validated against previous research done by Amar S. et al. [16] in terms of the total annual electricity consumption, where the maximum deviation was about 4.21 % as shown in Table 4.

Table 4. Comparative analysis between the present work and Reference [16] in terms of total annual electricity consumption

Total annual electricity consumption (MWh/year) [present work]	Total annual electricity consumption (MWh/year)[22]	Deviation %
31.57	33.6	4.21

3.2. Simulated annual energy consumption in the proposed building (Model A)

Figure 6 shows the annual energy consumption for the preliminary case. It is noted that the maximum energy consumption takes place in the summer months (January, February, November and December) because of utilize the HVAC system due to the high ambient temperature and solar irradiation while, the minimum energy consumption is obvious in the winter season (January, February, November and December) in Basra city. The TRNSYS16 software results show that the annual energy consumption in this model is about 32.27 MWh in the single-family house.

The consumption of hot water is influenced by many factors such as the number of consumers, consumption schedule and the season. The need for hot water has increased during the winter season. Iraqi families use hot water for cooking, washing and swimming. In the simulation, the daily average hot water consumption is 360 litres at 60 ℃ for a single–family consisting of six occupants (60 L/person) depending on the human need, where the mass flow rate is 123 kg/h as shown in Figure 7.

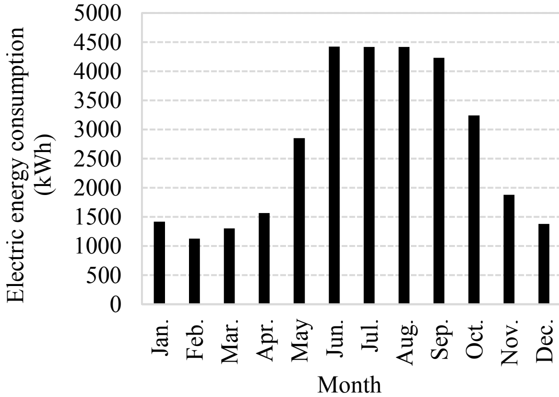


Figure 6. Monthly Total Energy Consumption (Model A)

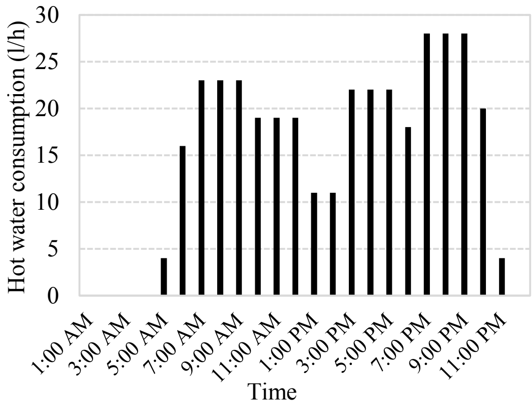


Figure 7. Daily hot water consumption (Model A)

3.3. Impact of using (PVT / Water) with the proposed building (Model B)

The performance of the PVT water-based system is presented in terms of the annual energy consumption, collected energy (Q_{coll}), auxiliary heater energy (Q_{aux}), thermal solar fraction and DHW temperature.

The total energy consumption for each month is shown in Figure 8, where the annual energy consumption is about 18.22 MWh. This means there is an energy saving of about 43.54 % in the annual energy consumption compared with the preliminary case.

Table 5 explains the energy consumption for the (PVT/system), collected energy, auxiliary energy and the total energy saving of energy consumption compared with the preliminary case.

It is clear from Table 5 that the collected energy (Q_{coll}) ranged between 693.4 kWh in January and 1615.5 kWh in July. From the same Table, we can see the monthly variations of auxiliary energy (Q_{aux}). It is established that the (Q_{aux}) varies from 690.6 kWh in

January and 396.5 kWh in September. It is attributed to there is need for additional hours' operation for auxiliary heater operation in winter more than in summer (Q_{aux}) because of low ambient temperature.

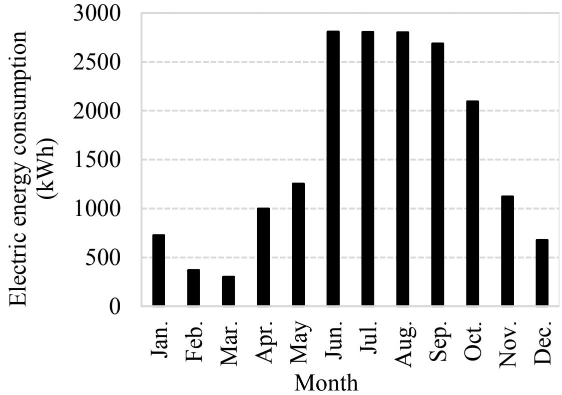


Figure 8. Monthly Total Energy Consumption (Model B)

Table 5. The yearly energy results of the PVT water-based system (Model B)

Month	Monthly total energy consumption (kWh) (Case 1)	Monthly total energy consumption (kWh) (Case 2)	Collected energy (kWh)	Auxiliary energy (kWh)	Energy saving %
Jan.	1421.2	727.8	693.4	690.6	48.79
Feb.	1130.3	370.7	759.6	688.7	67.20
Mar.	1301.6	301.4	1000.2	644.8	76.84
Apr.	1566.4	343.2	1223.2	601.2	78.09
May	2855.3	1254	1601.3	545.9	56.08
Jun.	4422.6	2811.2	1611.4	500.3	36.44
Jul.	4420.4	2805.9	1615.5	456.6	36.52
Aug.	4419.5	2803.8	1614.7	410.7	36.56
Sep.	4234.1	2904.8	1329.3	396.5	31.40
Oct.	3244	2097.2	1146.8	555.6	35.35
Nov.	1878.8	1122.9	755.9	675.4	40.23
Dec.	1377.6	678.5	699.1	688.9	50.75
Total/ average	32271.8	18221.4	14050.4	6855.2	43.54

Figure 9 explains the variations of the monthly thermal solar fraction and average stored water temperature, ℃. The maximum value of the TSF occurred in July (0.84) while the minimum value appeared in December (0.55) because of the decrease in the heat gain. It can be seen that the minimum and maximum average DHW temperatures are 34.5 ℃ and 58.2 ℃ occurred in January and July, respectively.

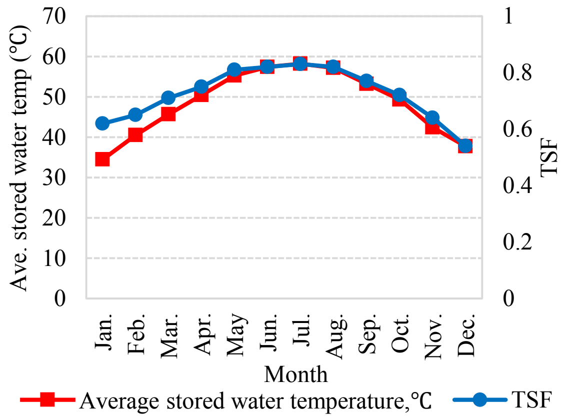


Figure 9. Thermal solar fraction and average stored water temperature for each month through the year

3.4. Impact of using PVT with (Al_2O_3/Water) in the proposed building (Model C)

Using (4% Al_2O_3 /water) in PVT system simulation has been discussed in this section. It is clear from Figure 10 and Table 6 that the annual energy consumption of the examined building is equal to 15.36 MWh.

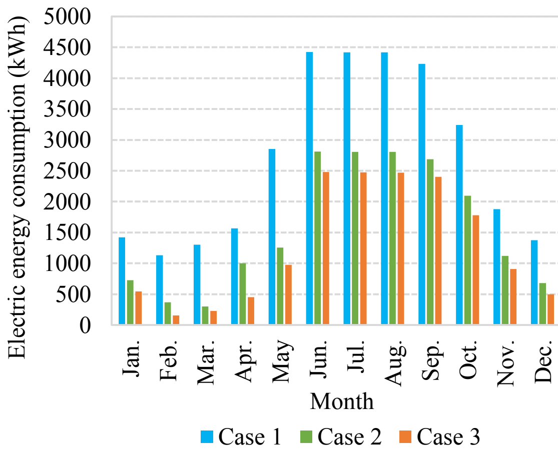


Figure 10. Impact of using PVT with water and (Al_2O_3) Nanofluid on the annual energy consumption with the proposed building

Figure 10 also established that using (Al_2O_3) in the PVT system, the annual energy consumption decreased by about 52. 33 % and 15.69 % compared with the base case and PVT /water-based system, respectively.

Table 6. The yearly energy results of the PVT water-based system (Model C)

Month	Monthly total energy consumption (kWh) (Case 1)	Monthly total energy consumption (kWh) (Case 3)	Collected energy (kWh)	Auxiliary energy (kWh)	Energy saving %
Jan.	1421.2	544.3	876.9	510.6	61.70
Feb.	1130.3	156.4	973.9	508.7	86.16
Mar.	1301.6	230.4	1123.3	464.8	75.71
Apr.	1566.4	453.7	1223.2	421.2	71.04
May	2855.3	976.7	1878.6	3°C.9	65.79
Jun.	4422.6	2477.3	1945.3	320.3	43.99
Jul.	4420.4	2473.1	1948.3	276.6	44.05
Aug.	4419.5	2471.3	1947.2	230.7	44.08
Sep.	4234.1	2400.4	1586.9	216.5	37.48
Oct.	3244	1777.5	1466.5	375.6	45.21
Nov.	1878.8	907.6	971.2	495.4	51.69
Dec.	1377.6	499.1	878.5	508.9	63.77
Total/ average	32271.8	15367.8	16819.8	4695.2	52.33

Figure 11 indicates the collected energy (Q_{coll}) and the auxiliary energy (Q_{aux}) for each case. It can be seen that the (Q_{coll}) increase in the summer month more than winter month because of high solar radiation thereby increasing of electricity production of PVT system. The minimum and maximum values of (Q_{coll}) ranged between 876.9 kWh in January and 1948.3 in July. It was also seen that using (0.4% Al_2O_3), Q_{coll} increased by about 17.12% compared to the case using water as mentioned in Table 6.

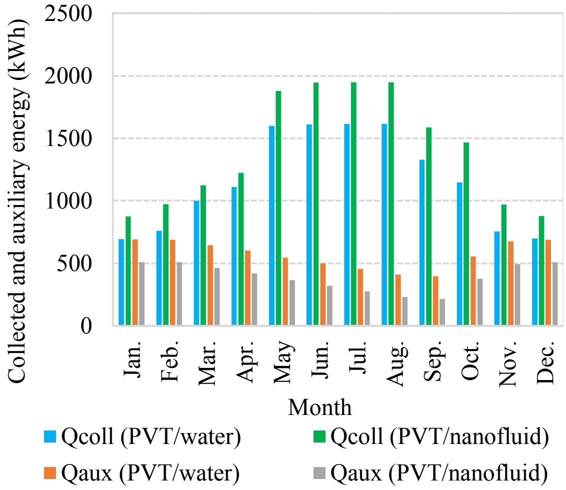


Figure 11. Collected and auxiliary energy for (PVT/water) and (PVT/Nanofluid) system

In addition, Figure 11 explains the monthly variation of the auxiliary energy (Q_{aux}). It can be concluded that the Q_{aux} increased in the winter month with a maximum value equal to 690.6 kWh in January and decreased in the summer month with a minimum value reached to 396.5 kWh in September. Furthermore, using Al_2O_3 at 0.4 v%, Q_{aux} decreases by about 31.51 % points compared to using (PVT /water) system.

The monthly variation of the thermal solar fraction and average stored water temperature are illustrated in Figure 12. It is shown that TSF ranged between 0.77 and 0.896 in December and July respectively which means, the use of 4% Al_2O_3 increases the solar fraction by 14.5 % compared with the (PVT/water) system. In addition, Figure 12 established that there is an improvement in the average stored water temperature of about 10.18 % compared with (PVT/ water). It can be noted that the T_s reached 68.4 °C in July and 39.2 °C in January.

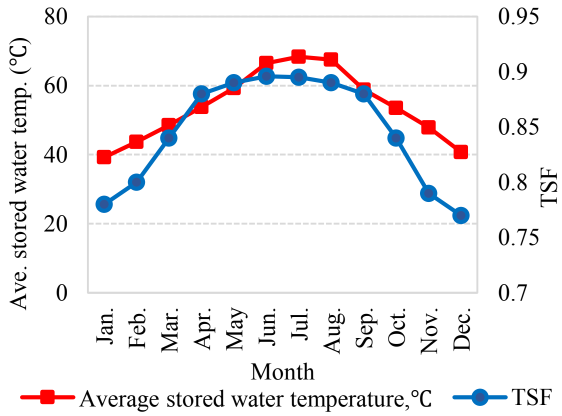


Figure 12. Thermal solar fraction and average stored water temperature for each month through the year (Model C)

4. Conclusions

Long-term thermal performance and comparison of the traditional building (without PVT system), combined with (PVT/water) and (PVT/Nanofluid) have been presented numerically by TRANSYS 16 software in this work. TRNSYS16 (Transient System Simulation) ware was used to simulate the annual energy consumption, collected energy (Q_{coll}), auxiliary energy (Q_{aux}), thermal solar fraction TSF and DHW temperature for the three models to supply electricity and hot water demand for a single-family house located in Basra city, south of Iraq, the following points have been concluded in the going work:

1. The results show that the using of the (PVT/water) and (PVT/0.4 % Al_2O_3) covered the energy

demand of about 43.54 % and 52.33 % respectively.

2. Using (4% Al_2O_3) in the PVT system, the collected energy (Q_{coll}) increased by 17.12 % compared with using water.
3. The auxiliary energy has been decreased by 31.51 % in the case of using Al_2O_3 Nano fluid compared with the water case.
4. There are holistic effects on the thermal solar fraction of about 14.5 % in the case of using (PVT/Al_2O_3) compared with (PVT/water).
5. Using (PVT/ Al_2O_3) and (PVT/water) with the traditional building covered the domestic hot water demand at about (42 % to 100 %), and (46 % to 100 %) in various seasons respectively for single-family houses with six occupants.
6. There is an improvement in average stored water temperature T_s with the PVT/ Al_2O_3 system reaching 10.18 % compared with the PVT/water system. It can be concluded that the T_s reached 68.4 ℃ in July and 39.2 ℃ in January, while it ranged between 34.5 ℃ and 58.2 ℃ in January and July respectively with (PVT/water) system.

Nomenclature

T_s	Average Stored water temperature (℃)
Ta	Ambient temperature (℃)
Q_{coll}	Collected energy (W)
Q_{aux}	Auxiliary heater energy (W)
DHW	Domestic hot water
TSF	Thermal solar fraction
M	Flow rate (kg/s)
BIPV/T	proposed building integrated photovoltaic/thermal
G	Global irradiance (W/m^2)
T_{amb}	Ambient temperature (℃)
HVAC	Heating, ventilation and Air conditioning

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