# Validated TRNSYS Model for Solar Assisted Space Heating System

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**ABSTRACT**

The present study involved a validated TRNSYS model for solar assisted space heating system as applied to a residential building in Jordan using new detailed radiation models of the TRNSYS 17.1 and geometric building model Trnsys3d for the Google SketchUp™ 3D drawing program. The annual heating load for a building (Solar House) which is located at Royal Scientific Society (RSS) in Jordan is estimated under climatologically conditions of Amman. This Paper is to compare of measured thermal performance of the Solar House and with that was modelled using TRNSYS. The results showed that the annual measured space heating load for the building was 6,188 kWh while the heating load for the modelled building was 6,391 kWh. Moreover, the measured solar fraction for the solar system was 50% while the modelled solar fraction was 55%. A comparison of modelled and measured data resulted in percentage mean absolute errors for solar energy for space heating, auxiliary heating and solar fraction of 13%, 7% and 10%, respectively. The validated model will be useful for long-term performance simulation under different weather and operating conditions.

**KEYWORDS: TRNSYS, space heating, flat plate collector, solar house**

## 1. INTRODUCTION

It is now universally conceded that fossil fuel resources are finite and it is only a matter of time before reserves will essentially be depleted.

Using of solar thermal energy and applying of energy conservation marks a route for extending available energy resources. Solar water heating systems can be used for domestic hot water and for space heating applications. Thermal insulation and double glazing windows occupy a distinguished place in energy conservation systems and is considered one of the important tools for rising the efficiency of thermal systems.

Up until now, Jordan depends almost exclusively on imported fuel which totalled to 6.14 million tons oil equivalent (TOE) in 2011 [1], and the concern over the future viability of fuels has caused an increased awareness of the need to conserve energy used for heating and cooling in residential building.

Typical solar assisted space heating (Solar House) was built at Royal Scientific Society in Amman, the capital of Jordan. The Solar House was a pilot project which was well-insulated and oriented such that it permits most of the solar energy to be entered through the windows in winter days. In summer days, most of the solar radiation will be rejected through vertical and horizontal overhangs.

A validated TRNSYS model for forced circulation solar water heating systems used in temperate climates was presented by (Ayompe et al., 2011) where the systems consist of two flat plate collectors (FPC) and a heat pipe evacuated tube collector (ETC) as well as identical auxiliary components present. A comparison of modelled and measured data resulted in percentage mean absolute errors for collector outlet temperature, heat collected by the collectors and heat delivered to the load of 16.9%, 14.1% and 6.9% for the FPC system and 18.4%, 16.8% and 7.6% for the ETC system respectively [2].

The aim of this study is to validate the measured thermal performance parameters of the Solar House using TRNSYS software tool.

## 2. BUILDING DESCRIPTION AND METHOD

The house under consideration has the following parameters:

- The study was performed on a house with floor area of 65 m2 and ceiling height of 3 m. It consists of bedroom, living room, kitchen and bathroom.
- Average number of occupants is 5.4 persons [3].
- Heating thermostat setting is adjusted at 21°C for heating in winter.
- It is assumed that all walls have aluminium-framed windows with double glazing.
- Heating system is under floor heating type, which consists of flat plate solar collectors, well- insulated storage tank with capacity of 2500 litre which is connected with solar collector in open loop, circulating pumps, temperature difference (delta T) controller, auxiliary hot water boiler and pipe network.
- Walls and roof are insulated with rigid panel's rock wool of 5 cm.
- Overhangs were built at all windows to reduce the penetration of solar radiation in summer days but admit most of solar energy to pass through the windows as a direct gain.

Table 1 shows the thermal properties of the material used in the building construction.

Table 1: Thermal conductivity and thickness of materials used in construction of the house [4, 5].

| NAME OF THE MATERIAL | DENSITY ($kg/m^3$) | $\lambda$ ($W/m^2$ C°) | THICKNESS (m) | R ($m^2$C°/W) | SPECIFIC HEAT (kJ/kg.C°) |
|---|---|---|---|---|---|
| Stone | 2580 | 2.27 | 0.07 | 0.03 | 0.24 |
| Normal aggregate concrete | 2400 | 1.5 | 0.2 | 0.1143 | 0.84 |
| polystyrene | 30 | 0.039 | 0.05 | 1.29 | 1.25 |
| Gravel | 1420 | 0.37 | 0.15 | 0.41 | 0.23 |
| Cement plaster | 2000 | 1.2 | 0.02 | 0.02 | 0.28 |
| Terrazzo tiles | 2145 | 1.35 | 0.03 | 0.022 | 0.267 |
| Reinforced concrete | 2300 | 1.75 | 0.25 | 0.14 | 0.28 |
| Hollow concrete (Rips) | 1400 | 0.95 | 0.18 | 0.189 | 0.28 |
| Tile mortar | 2200 | 1.2 | 0.1 | 0.083 | 0.23 |

The existing building of the solar house and a layout drawing were shown in Figure (1 and 2).

Figure 1: Photo of the Solar house where the back façade is faced to the south.

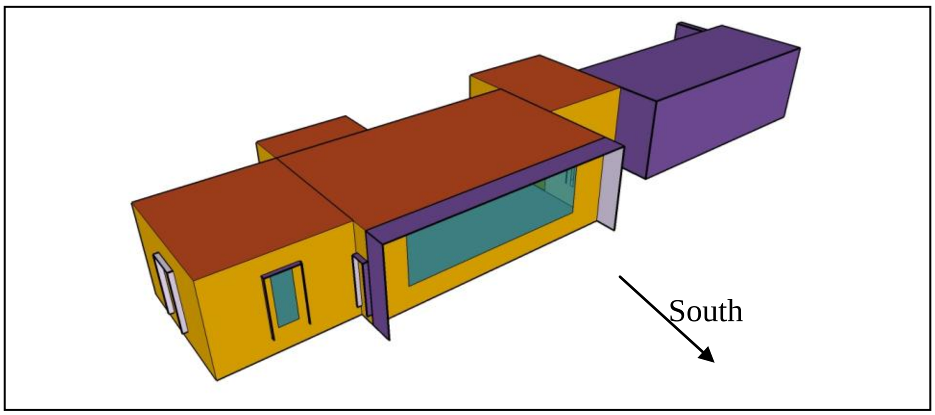


Figure 2: The Solar House which was drawn using 3D Google sketchUp

Many different approaches have been used to calculate heating load in buildings and several energy analysis tools have been developed to aid building designers. Recently, detailed powerful energy estimating computer program such as DOE-2, DEROB and TRNSYS have been used to estimate the thermal energy requirement of buildings.

Of hourly simulation program available, TRNSYS version 17.1 [6] is one of the most desirable package since it is based on hourly simulation calculation methods. The hourly data was provided from the Meteonorm 6.0 [7] software. Three dimensional data for the building geometry was created from scratch through by adding zones and draw heat transfer surfaces, draw windows and draw shading surfaces by Trnsys3d for TRNSYS which is a plug-in for Google SketchUpTM, as shown in Figure (2).

## 3. SYSTEM DESCRIPTION

Typical solar water heating systems used in temperate climates consist of four rows of locally manufactured flat plate collectors, FPC, a hot water storage tank, control unit and circulating pumps. The solar system is located in Amman at latitude of 31.95° N and longitude of 35.93° E. The collectors used in this study were installed on a tilt roof so that the tilt angle of the collectors are 42 ° and faced to south (azimuth angle = 0). The hot water cylinders were installed nearby in the building's plant room. The solar circuits consisted of 25 mm diameter carbon steel pipes insulated with 30 mm thick rock wool. All pipe fittings were also insulated to reduce heat losses. The solar circuit pipe lengths for the flat plate collector for each of supply and return were 20 m. The FPC system consisted of 36 flat plate collectors each with a gross area of 1.32 $m^2$ connected in parallel-series array and reverse – return bank piping loop. Each collector had maximum operating and stagnation temperatures of 120° C with a maximum operating pressure of 6 bars. The system was equipped with a 2500 L steel hot water cylinder tank and insulated with glass wool insulation with thickness of 220 mm. In space heating, under floor heating techniques was used for all space zones for total area of 65 m2. The solar loop is directly connected with the cylinder without coil exchanger in the cylinder such that the bottom end and the top end were connected with the solar heating circuit, while the auxiliary heating systems , diesel boilers, is connected with the hot water line. Analogue thermostats placed at the top of the hot water cylinders were set to turn-on the boiler when the temperature of water at the top of the tank doesn't reach 50° C.

## 4. HEATING LOAD ESTIMATION USING DEGREE DAY (DD) METHOD

In this method, good results can be obtained with less information and efforts. The DD method of estimating loads is based on the principle that the energy loss from a building is proportional to the difference in temperature between indoors and outdoors. It is assumed that a building does not need to be heated when the outside temperature is more than the base temperature of 18.5°C.

A month's heating load can be obtained over the month and (UA)h and Tb are assumed to be constant, then the monthly heating load is given by:

$$L = \Sigma\ (AU) \times DD \times 24$$

Where L is Annual Heating Energy Demand (kW.h), DD is the number of degree days, and (UA) is the summation of the heat losses for all parts of the building through which heat can be lost times the area of the walls, ceiling, floor, door and windows.

The heat loss coefficient for different house configurations was estimated and was 257.77 Watt/ °k.

The monthly degree days, ambient temperature and heating load for Amman was estimated and summarized in Table 2.

Table 2: Monthly and annual heating load based on DD method for Amman.

| Month | Avergae $T_a$ (° C) | Heating Degree Days | Load (kWh) |
|---|---|---|---|
| Jan | 7.7 | 321.1 | 1986.6 |
| Feb | 9.0 | 253.9 | 1570.8 |
| Mar | 11.6 | 204.3 | 1263.8 |
| Apr | 15.8 | 88.0 | 544.6 |
| May | 20.0 | 0.0 | 0.0 |
| Jun | 23.6 | 0.0 | 0.0 |
| Jul | 25.1 | 0.0 | 0.0 |
| Aug | 25.2 | 0.0 | 0.0 |
| Sep | 23.4 | 0.0 | 0.0 |
| Oct | 19.9 | 0.0 | 0.0 |
| Nov | 14.3 | 124.2 | 768.6 |
| Dec | 9.4 | 269.6 | 1667.8 |
| | | Total Load | **7802.3** |

Table 2 above shows that the annual heating load for the building is around 7800 kWh based on DD method. The above mentioned value is higher than the calculated using TRNSYS model and higher than measured values, as will be mentioned below.

**5. TRNSYS MODEL**

The solar water heating system model was developed using transient systems simulation (TRNSYS) software, which is a quasi-steady state simulation program. In order to facilitate the selection of the system components, a flow diagram for the models was developed, as was shown in Figure 3.

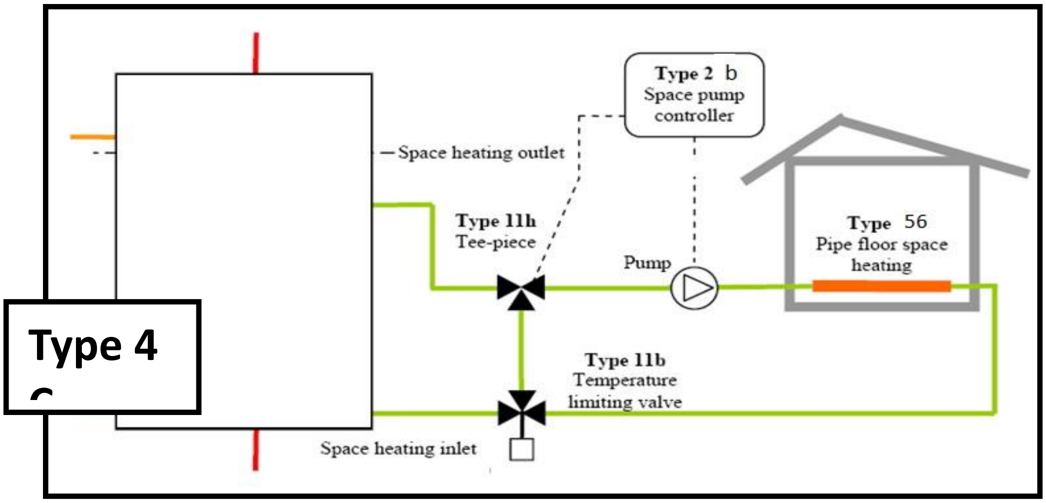


Figure 3: TRSNYS components for space heating loop for the Solar House

The main component of the model is the building (type 56). Additional components to the model include:

Solar energy flat plate collector (Type 1b), Type 31 pipe duct, Type 4a hot water cylinder, Type 2b differential temperature controller, Type 3d circulating pump, type 518 Monthly Schedule, type 1502 simple thermostat for space heating zones, type 11 tempering valve and mixing valve, type 647 divergence pipe and type 649 mixing pipe used in the TRNSYS model. Table 3 shows values of parameters for the solar collector.

Table 3: Solar collector parameters

| Parameters | Unit | Value |
|---|---|---|
| Collector area | $m^2$ | 1.32 |
| Fluid specific heat | kJ/(kg * K) | 4.186 |
| Intercept efficiency | - | 0.65 |
| First order efficiency coefficient | kJ/(hr*m2*K) | 19 |
| Collector slope | Degree | 42 |

## 6. RESULTS AND DISCUSSIONS

Annual heating load was measured for the solar house by measuring the mass flow rate of the hot water , temperature of the hot water supply to the under floor space heating and the water return temperature during winter months (November, December, January, February, March and April). Global horizontal solar radiation as well as ambient temperature were measured hour-by hour and logged for the whole winter days. When the produced energy by the solar system is not sufficient to cover the heating the load, an auxiliary diesel boiler will run to cover the partial or the complete load. Annual heating load for the solar house building was estimated from the measured parameters and found to be 6,188 kWh. During the measurement, the house is not occupied by people. Therefore, the internal heat by human, lighting and electrical equipment was ignored. Since the building was created using 3D drawing program and Trnsys3d, 3D external shading of external windows was taking into account and the detailed mode for beam radiation distribution shading and insolation matrices have to be generated to get more accurate calculation of the heating load. In the beginning, the building was simulated by TRNSYS such the heating load was cover using hypothetical heating power within the TRNBuild in type 56 to keep indoor air temperature around 22° C. The results show that the annual heating load for the winter days was 6,350 kWh. The results show that the TRNSYS model performed slightly differences as compared with the measured value. The different between the two values was not exceeded 3% from the measured value.

Solar heating system was then introduced and coupled with the building which representative by type 56. Figure 4 shows the TRNSYS modelling of the solar system and the building,

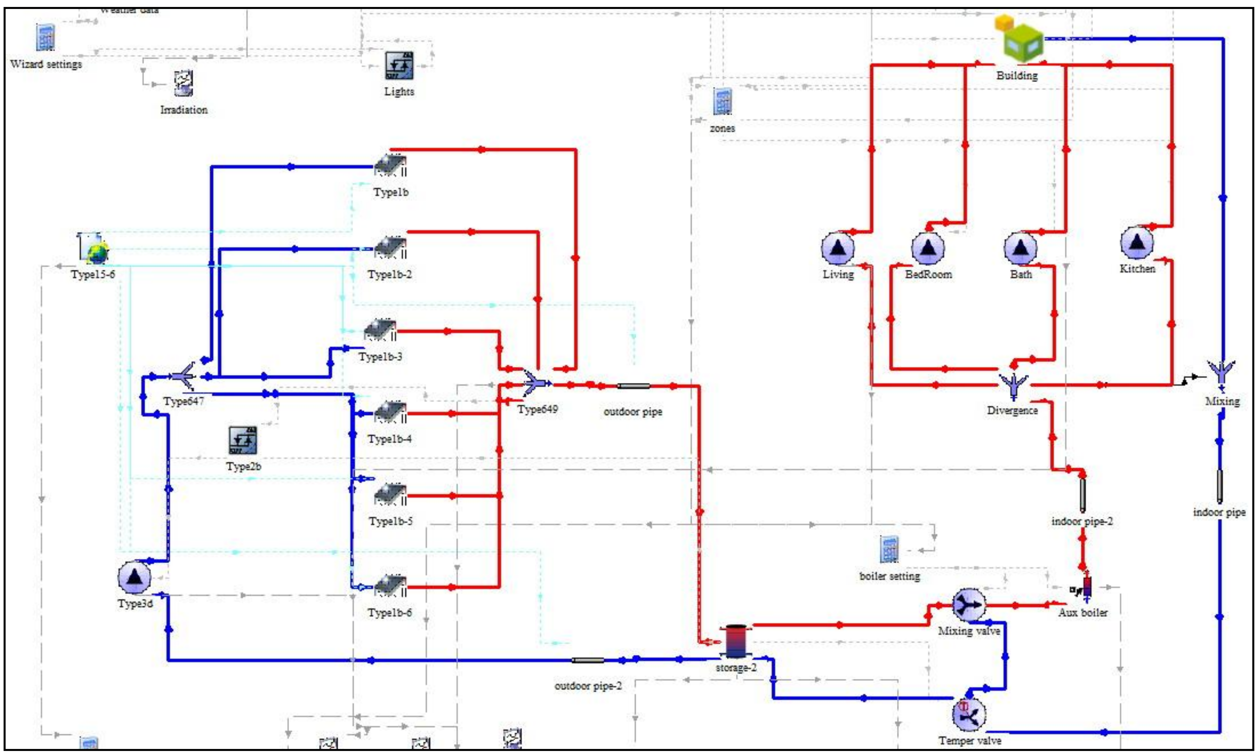


Figure 4: TRSNYS modelling of the solar system and the building

The solar water heater were in the TRNSYS were connected with type 56 (the solar house) to heat the space through under floor heating system. The results shows that the average monthly measured solar radiation was around 5.4 kWh and it was quite matched the solar radiation of type 15 represent Amman weather data.

The delivered solar energy by solar system was measured to be 3091 kWh for the whole heating days, while the simulation shows that the solar heating system produce about 3499 kWh during the same heating period. The difference between the simulation and the measured was around 13%.

Moreover, the measured auxiliary energy produce by diesel boiler to cover the residual heating was 3097 kWh while the simulation by TRNSYS shows 2892 kWh, then the difference percentage between the measured and simulation values was around 7%.

In addition, it was found that the measured total space heating (for both solar energy and auxiliary energy) was 6188 kWh, while the simulated value was 6391 kWh and the percentage difference between these values was only 3%.

The solar fraction is the fraction of the load that was covered by solar system to the total energy load. In this study the solar fraction was estimated for both cases. The results shows that the measured solar fraction was 50%, while the simulated solar fraction was 55%. The percentage difference was 10%.

The above results were summarized in Table 4.

Table 4: Space heating comparison between measured and simulated values for the solar house

| Mothly irradiation_tilted | | Solar energy for space heating | | Auxiliary Heating | | Total Space_Heating | | Solar Fraction | |
|---|---|---|---|---|---|---|---|---|---|
| kWh/day (Average) | | kWh | | kWh | | kWh | | % | |
| TRNSYS | Measured | TRNSYS | Measured | TRNSYS | Measured | TRNSYS | Measured | TRNSYS | Measured |
| 5.4 | 5.4 | 3499.4 | 3091.1 | 2892.0 | 3097.4 | 6391.4 | 6188.5 | 55% | 50% |
| Differences % | | | | | | | | | |
| 0% | | 13% | | 7% | | 3% | | 10% | |

The results show that the model performed slightly different from the measured values. The main reasons for the differences in the results shown above in table (3) can be summarized as follows:

1. Much of the discrepancies between the simulated and experimental results can be attributed to experimental errors which are a function of the accuracy of the measurement devices used.
2. Also, the existing TRNSYS proformas for solar collectors might not be fully representative of collector absorber.
3. Moreover, in the actual case, the boiler controller was operated such that the ambient temperature can be fed back to control system in order to start or stop boiler several hours before the internal thermostat response to room temperature. The controller that are using feedback temperature from the outside are temperature is important in case of thermal storage in the under floor heating system.

The indoor air temperature was quit comfort during the simulation of TRNSYS. Figure 5 shows the room temperature of the living room.

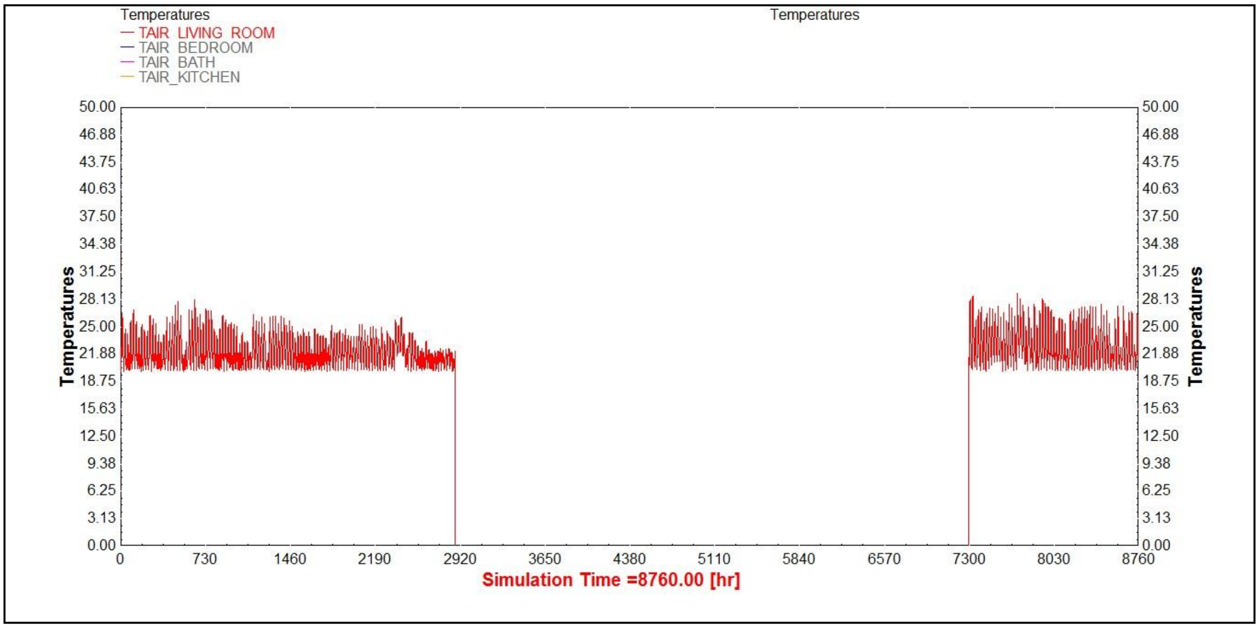


Figure 5: Living room temperature during the winter days.

Figure 5 shows that the room temperature was fluctuated between 20°C and 25° C during the winter days. The other zones, bed room, kitchen and bath were also within comfortable range.

## 7. CONCLUSION

A TRNSYS model was developed for a building located in Amman and connected with circulation solar water heating systems with flat plate collectors. Results obtained showed that the model differs from the measured with about 13% and 7% for space heating covered by solar system, auxiliary system and total space heating differences was 3%.

The validated TRNSYS model can be used to:

Predict long-term performance of the solar water heating systems in different locations.

Simulate system performances under different weather and operating conditions.

Optimize solar water heating system sizes to match different load profiles.

## REFERENCES

[1] Energy 2012 Facts & Figures, Ministry of Energy and Minerals Resources, Amman, Jordan.

[2] Validated TRNSYS model for forced circulation solar water heating systems with flat plate and heat pipe evacuated tube collectors

[3] Jordan in Figures, Department of Statistics, Jordan, 2011.

[4] Thermo acoustic Insulation, Jordan Rock Wool Industries Co. Ltd., (1996).

[5] Thermal Properties of Building Material, RSS, 1987

[6] TRNSYS: a transient simulation program version 17.1, solar energy laboratory: Madison, University of Wisconsin, USA
[7] METEONORM software version 7, 2012.