Design and Modeling of Space Heating System Using Solar Energy for Weather Conditions of Pakistan

By
Fareeha Ahmed
Reg # 117551
Session 2015-17

Supervised by
Dr. Muhammad Bilal Sajid

A Thesis Submitted to the US Pakistan Centre for Advanced Studies in Energy in partial fulfillment of the requirements for the degree of

MASTERS of SCIENCE
in
THERMAL ENERGY ENGINEERING

US-Pakistan Centre for Advanced Studies in Energy (USPCAS-E)
National University of Sciences and Technology (NUST) H-12,
Islamabad 44000, Pakistan

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Signature: ____________________________

Name of Supervisor Dr. Muhammad Bilal Sajid

Date: ____________________________

Signature (HoD): ____________________________

Date: ____________________________

Signature (Dean/Principal): ____________________________

Date: ____________________________

Certificate

This is to certify that work in this thesis has been carried out by **Ms. Fareeha Ahmed** and completed under my supervision in, US-Pakistan Center for Advanced Studies in Energy (USPCAS-E), National University of Sciences and Technology, H-12, Islamabad, Pakistan.

Supervisor:

____

Dr. Muhammad Bilal Sajid
USPCAS-E
NUST, Islamabad

GEC member # 1:

____

Dr. Adeel Javed
USPCAS-E
NUST, Islamabad

GEC member # 2:

____

Dr. Nadia Shahzad
USPCAS-E
NUST, Islamabad

GEC member # 3:

____

Dr. Amin Faheem
SNS
NUST, Islamabad

HoD-Thermal Energy Engineering:

____

Dr. Adeel Javed
USPCAS-E
NUST, Islamabad

Principal/ Dean

____

Dr. Zuhair S. Khan
USPCAS-E
NUST, Islamabad

Dedication

I humbly dedicate this work to my parents and siblings whose endless prayers, continuous motivation and infinite sacrifices equipped me with everything it takes to be an accomplished human being.

Acknowledgment

I would like to thank my Creator Allah Almighty, the Gracious, and the beneficent, whose benediction bestowed upon me, provided me the ample opportunity and guided me throughout this work at every step.

I am grateful to my beloved parents and siblings Fatimah Ahmad and Mubashir-ul-Islam who nurtured me and continued to support me throughout in every step of my life.

I would like to express special gratitude to my supervisors Dr. Muhammad Aamir and Dr. Muhammad Bilal Sajid for their priceless help and tremendous support. I would also like to thank Dr. Adeel Javed, Dr. Nadia Shahzad and Dr. Faheem Amin for all their guidance.

I am especially grateful to my dearest friends Hina Pervaiz, Naseer Ahmed Khan, Ali Abdullah, Ujala Sarwar and Muhammas Asad without them this work would not have been possible. And I am thankful to Abdul Sammad Farooq for his continuous support and cooperation.

Finally, I am thankful to all the individuals who have rendered valuable assistance to my study.

List of Publications

- **Fareeha Ahmed**, Muhammad Aamir, Sufyan Naeem, Noor ul Ain Binte Wasif Ali "High Temperature Solar Heated Space Heating with Seasonal Storage System for Commercial Heating" International Conference on Solid State Physics 2017 to be held on December 10th-14th, 2017 at Center of Excellence in Solid State Physics, PU, Lahore.

- Noor Ul Ain Binte Wasif Ali, Dr. Muhammad Aamir, Dr Zafeer Saqib and **Fareeha Ahmed** "Anatomization of Solar Radiational Data & Analysis of Land Surface Temperature Variability in Islamabad, Pakistan, Using Remote Sensing." Spring Scientific Colloquium 2017 Organized by HEC at Post graduate college Jehlum.

Abstract

Due to increased energy demand, development of renewable energy sources is motivated because of shortage of fossil fuels and concerns over environmental impact. A room space heating can utilize solar energy to optimize the efficiency of heating system. Thus decreasing fossil fuel usage. A room space heating which is solar based system, is modeled and simulated in TRNSYS software which attain the load of standard room (8m x 5m x 3.12m). This whole system consists of solar collector, storage tank, auxiliary boiler and radiator. The heated water from the solar collector passes through the storage tank where heat is stored which is then used to heat water which gives heat to the room through radiator which is placed inside the room. Where auxiliary boiler is only used for heating purpose on cloudy days. Weather data file obtained from Meteonorm software for Islamabad (33.71^{o}N, 73.06^{o}E) is used in present work.

Simulation is run for whole winter season in TRNSYS by using two different collectors, which are flat plate collector and photovoltaic thermal collector. By varying the collector area, collector slope and storage tank size, analysis are carried out to estimate the optimum system performance in terms of heat stored and compactness of system. Simulation results of whole system shows that proposed system gives significant primary energy savings with payback 7.6 years.

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Chapter no. 1

Introduction and Motivation

1.1 Motivation

To protect the humankind from the extremes of climate can be considered the primary role of buildings. Moreover, to find the satisfactory building designs to which human is best adjusted is the constant effort of the human race which is evident by the entire history of engineering. Old-style buildings were built with consideration to climate conditions to keep inside building cool in summer and warm in winter, whereas, in modern architecture, these features have been forgotten, which implicates a large amount of energy expenditure for mechanical methods of heating and cooling [1].

With the increase in resources, the use of energy is increasing. Energy demand increases as countries came out of poverty and grow in economics. This world is blessed with energy. Even in some developed countries energy supply become less protected due to a drastic increase in price. Therefore quest for low-cost energy becomes significant. Previously, coal was one of the cheapest and efficient sources of energy but now it’s too risky for the climate because of its harmful emissions. Now developed countries are finding the natural gas as the best alternative. According to the increase in energy demand, it is quite difficult to keep up with domestic supplies. For this multifaceted approaches are required. One way to facilitate is to increase resources efficiency. Innovation in finding other energy resources should also expand. [2]

Due to increasing energy demand, development of renewable energy sources is motivated because of decrease in fossil fuels and effect on environment. One of the main renewable energy source is solar energy [3], which have irregular nature and is dependent on efficient energy storage systems for effective utilization. The major part of energy demand will be met by the back-up or auxiliary energy if no energy storage is used in solar energy systems and thus the annual solar load fraction will be very low. Thermal energy can be stored when energy is abundantly available and then can be used whenever required. Efficient, economical and reliable solar thermal energy storage devices and methods will have to be developed if solar thermal energy is to become an important energy source. [4]

Renewable energy resources are also increasing to cope up with the energy demand. The most efficient renewable energies are hydro, solar and wind. Fossil fuels are a still dominating source of energy production.

Figure 1: Increase in Renewable energy resources

1.2 Research Questions

Some questions regarding research work that needs to be focused:

1. What are the other ways of room space heating?
2. How can we store heat for night time use?
3. Which type of collector is more efficient?
4. How can we build the heating system which is more cost efficient?

1.3 Goals and Objectives

The purpose of this research is to study the thermal behavior and develop the small-scale solar space heating system. Its other purpose is to design such a system which is cost effective and can be used not for a day but also for night time. The goals and objective achieved are:

- Model a complete room space heating system.
- Comparison between two models using two different collectors, flat plate collector and photovoltaic thermal collector, in TRNSYS.
- Study the different effect on the system operation by changing the size of collector and thermal storage tank.
- Comparing the collector efficiency of both, flat plate collector and photovoltaic thermal collector.
- Economic analysis in RETScreen software.

1.4 Importance of Solar Energy

In Pakistan, almost 54% of energy is used in commercial and domestic sectors. Solar energy can be used to contribute to producing energy for these sectors. In this way rural area need for energy can also be met, new employment and local equipment manufacturing opportunities produce. Pakistan is present in a region where solar energy potential is maximum and it is the most important type of renewable energy. In Pakistan, every region has more than 300 sunny days in a year.

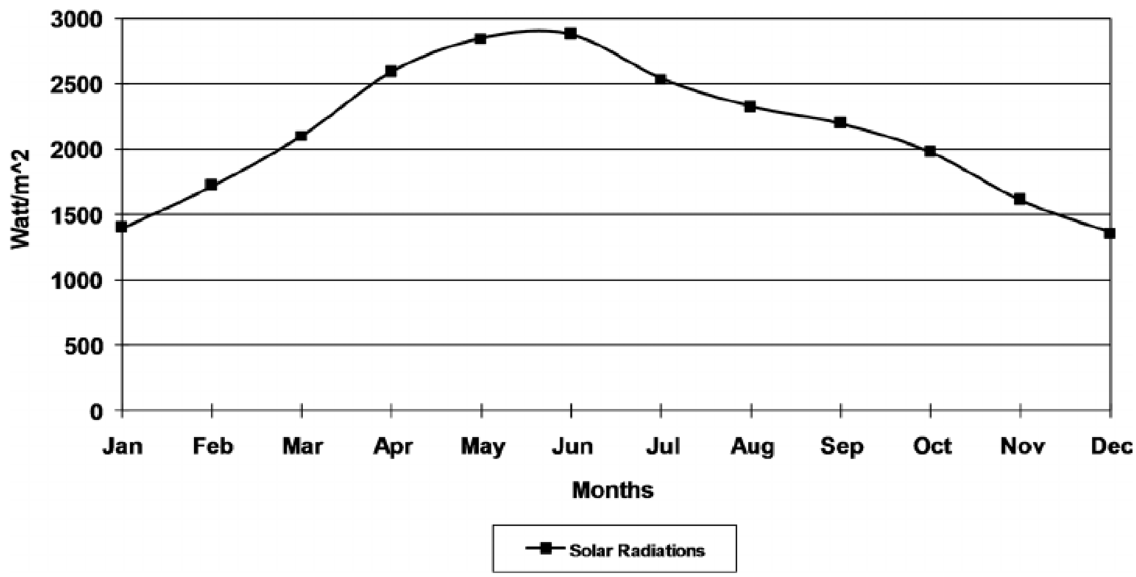

Figure 2: Pakistan's solar radiation throughout the year [8]

1.5 Geographical Overview of Pakistan

Pakistan is situated in South Asia bordered by the Arabian Sea. It has China in north, Arabian Sea in the south, India in the east and Iran and Afghanistan in the west. Location of Pakistan, latitude in between 23.8º and 36.78ºN and longitude in between 61.1º and 75.88ºE, and the total area of the country is 803,940 km^2. In Pakistan, climate conditions and environment effects differ from region to region. Pakistan shares about 1050 km of maritime via the Arabian Sea. The population of Pakistan is about 207 million, which is increasing at an unprecedented rate of 2.4% per annum. With respect to population, Pakistan is the 6^{th} biggest country in the world. Pakistan is divided into four provinces Punjab, Sindh, Baluchistan and Khyber Pakhtunkhwa. [10]

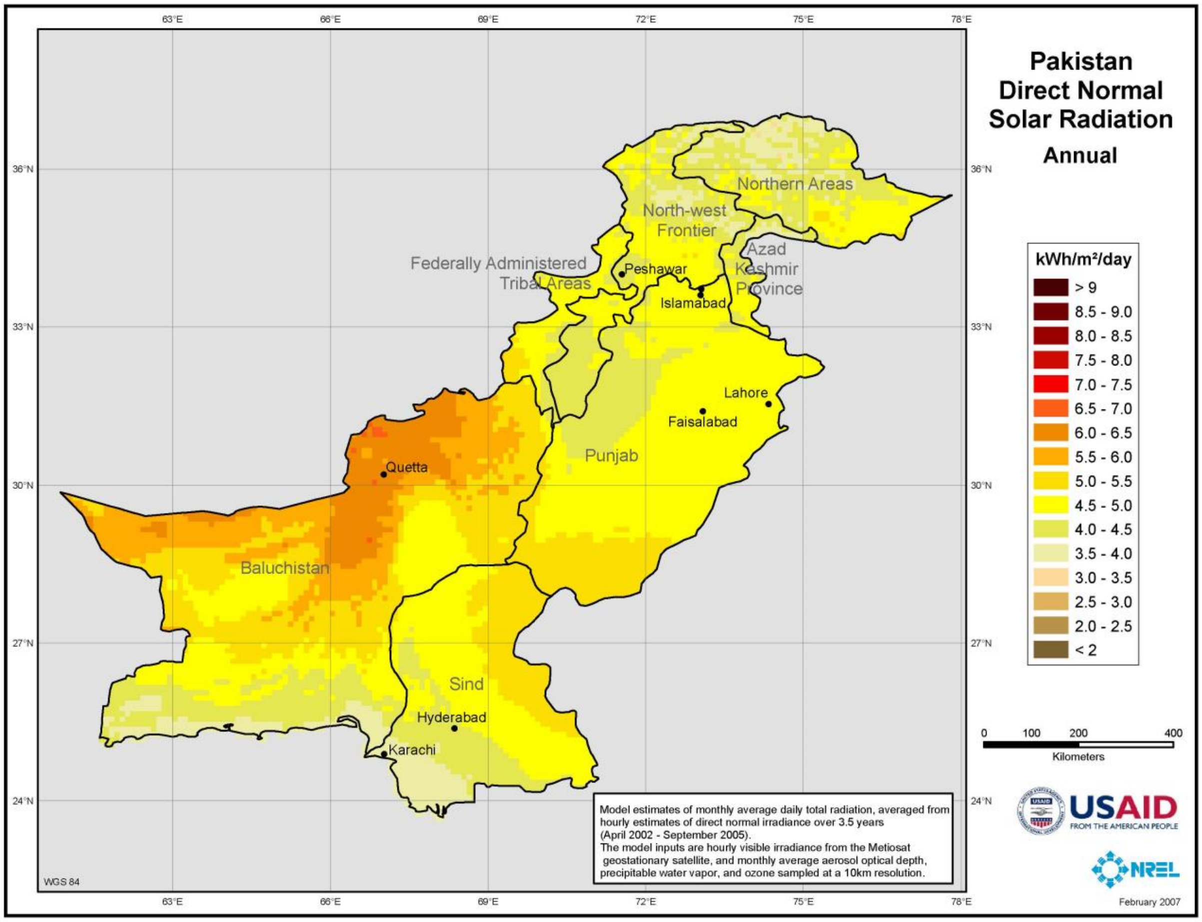

Figure 3: Climatic zones for Pakistan and contours of annual-mean daily solar irradiation. [11]

1.6 Climate of Islamabad

In Pakistan, the climate weather conditions of Islamabad are that where the solar energy utilization potential is high as compare to other locations.Islamabad’s climate is warm and the temperature is higher. Winters have high solar radiations which can utilize to produce safe energy. The average annual temperature is 21.3^{o}C. [12]

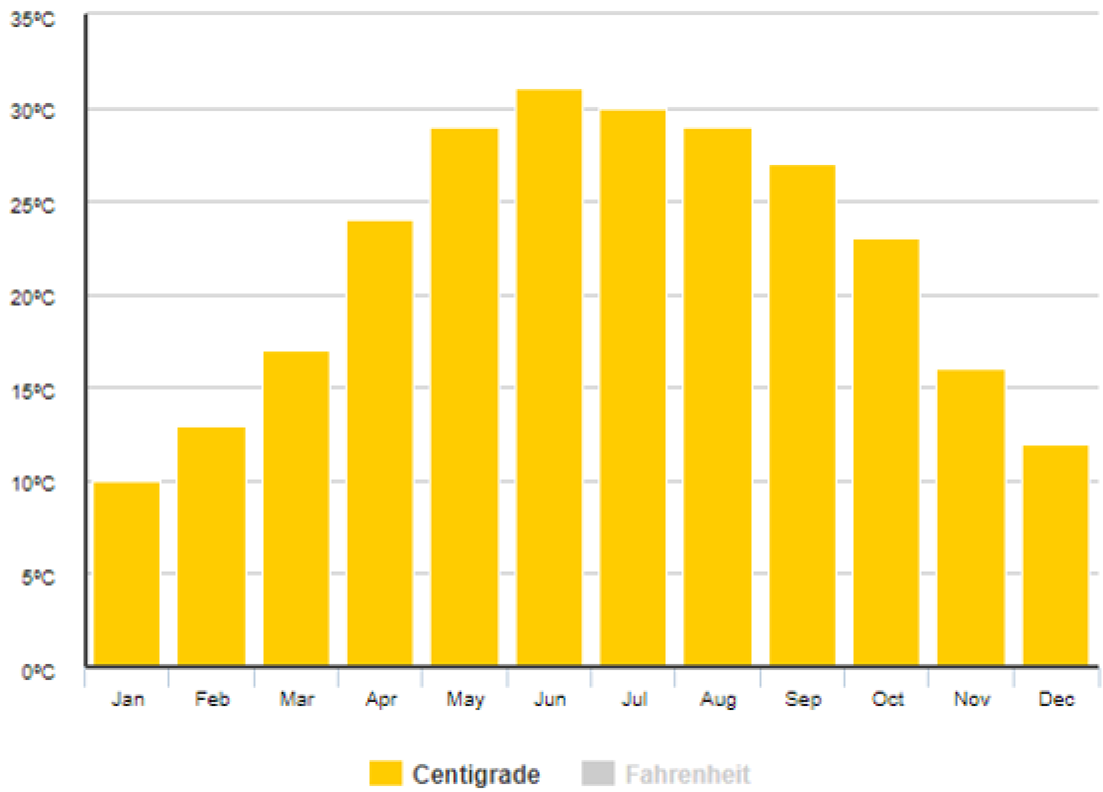

Figure 4: Monthly average temperature values

Potential of global, beam and diffused radiation in winters in Islamabad region are shown in the figure below. Beam radiation are those solar radiations that received on earth without been scattered by the atmosphere. Beam radiations are also called direct radiation from the sun. Diffuse radiations are that solar radiation which received on earth, by changing the direction from scattering by the atmosphere. Diffused radiations are also called radiations or solar sky radiations. Global radiations are also called total radiation on the horizontal surface. The sum of the beam and diffuse radiations are called global radiation.

Data of these radiations are taken from the *Metronome*.

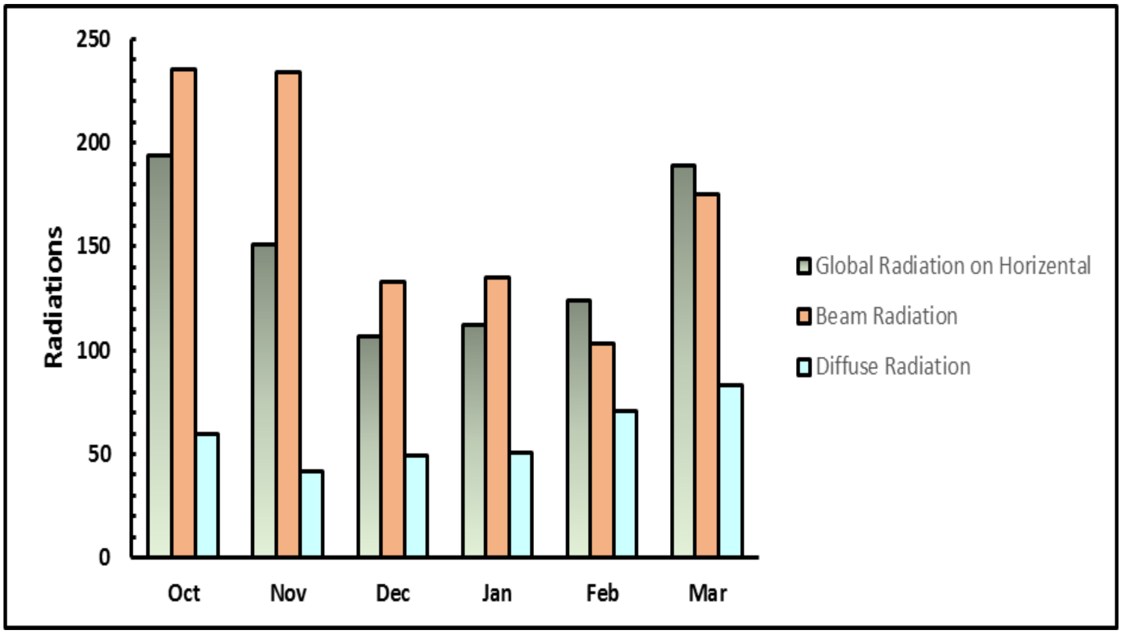

Figure 5: Solar Radiations in winters in Islamabad

Chapter no. 2

Literature Review

2.1. Background

Due to the continuous increase in greenhouse gas emissions and increasing prices of fossil fuels, it has become important to find the alternative ways to develop energies. The alternative energies must be cheap, clean and sustainable. Solar energy is one of them that satisfies these conditions [14]. Solar energy has a great opportunity for building heating and cooling, heating water for domestic and industrial purposes, warming greenhouses for agricultural crops etc. but the main problem is solar energy is available only during daytime. Thus it requires thermal energy storage so that heat collected during the daytime may be stored for later use during night time.

The development of alternative energies is nowadays a more important issue, due to the continuous increase in greenhouse gas emissions levels and fossil fuels climbing prices [13]. Solar energy has a great prospect for buildings heating and cooling, warming greenhouses for agricultural crops, etc. [15, 16].

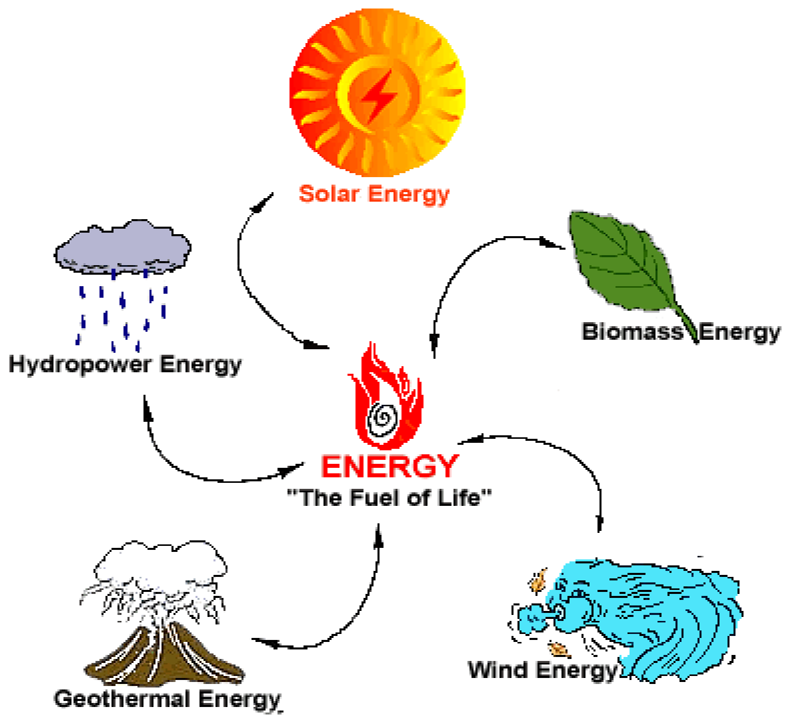

Figure 6: Different sources of Renewable Energies

2.2. Energy Scenario of Pakistan

After analyzing the scenario of Pakistan we come to a conclusion that Pakistan is going through energy deficiency [17]. This is because of its increasing population. It has limited conventional energy resources like gas, coal, and oil. These resources are not enough to take account of growing energy demand. It has only 0.5% share of the world's total energy consumption, even though its energy consumption has increased by 3 times over the past 20 years. Today Pakistan is facing energy crises because of the increase in energy demand [18]. In energy production of Pakistan, fossil fuels contribute about 64% in total sources of energy production. Second main source of energy is hydroelectric which is currently providing 30% of total demand. Remaining 6% of energy demand is fulfilled by nuclear resources. Life without energy is nearly impossible as energy is needed in every sector. Source and consumption of energy for different sectors of Pakistan has been defined in fig [7]

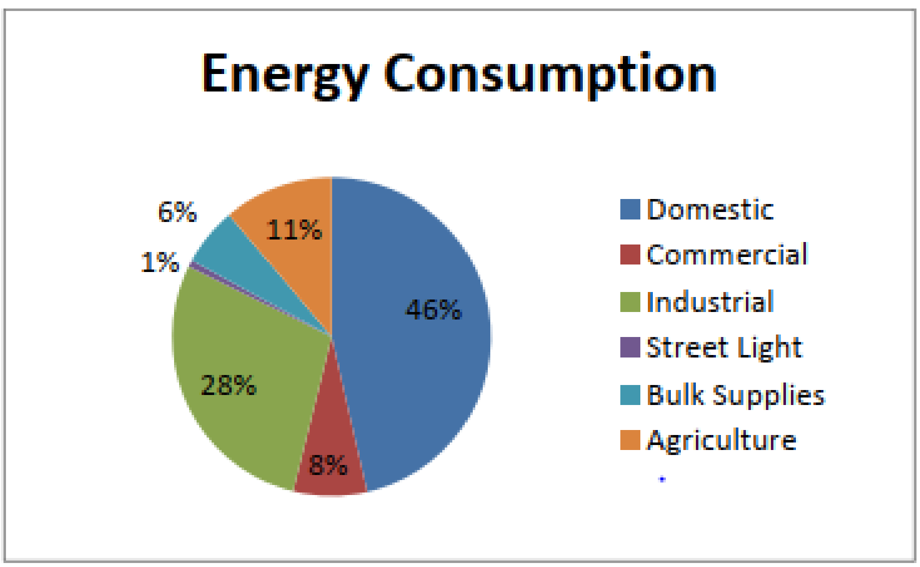

Figure 7: Pakistan's energy consumption by sector

About 74% of energy is mainly consumed by the industrial and household sectors. Similarly, almost 18% is consumed by transport, street lights and agriculture etc. in Pakistan natural gas and oil gives almost 80% of the primary energy. Where Pakistan has a vast source of natural gas, so it fulfills substantial percentage of the requirement at the domestic level. But there is no other renewable energy source contributing a significant role in Pakistan's energy except hydropower. Because of the increase in rapid energy demand, a decrease in conventional resources is threateningly imminent and that's why the role of renewable energy sources is very important and cannot be ignored.

2.3. Thermal Storage Systems

Thermal energy storage can be stored as a change in internal energy of a material as sensible heat, latent heat and thermochemical. In sensible heat thermal energy, energy is stored by raising the temperature of a solid or liquid. In latent heat storage heat is absorbed or released when a storage material undergoes a phase change from solid to liquid or vice versa. Whereas in thermochemical system energy absorbed and released in breaking and reforming of molecular bonds in a completely reversible chemical reaction [19].

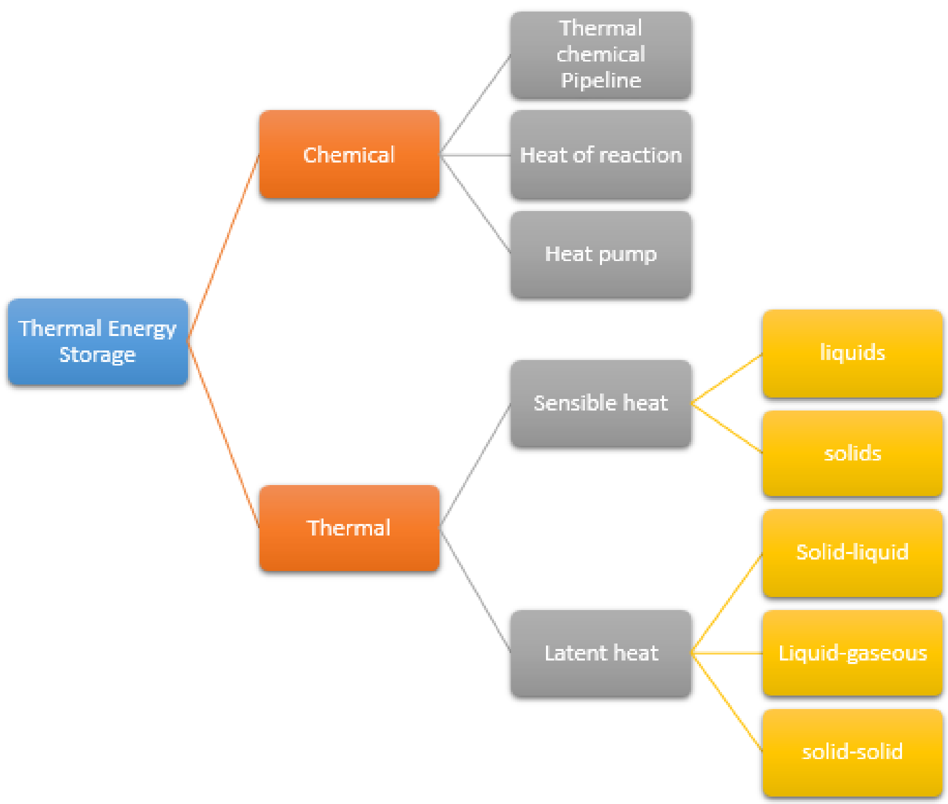

Figure 8: Types of Thermal Energy Storages

Miqdam T. Chaichan et al. [20] investigated improving thermal energy storage extracted from the solar heater and using for the domestic purpose. Two materials were used to improve heat storage inside the tank. Pebbles were used as a sensible store medium. The second material was paraffin wax which stores heat as latent heat. The two materials were stuffed in ten copper pipes (1” in dia.). The stored energy of each material was compared to an ordinary conventional solar heater. These tests were conducted in Baghdad-Iraq wintertime (December 2012, January and February-2013). The two materials improved the storage efficiency of the system and increased the duration of storage, but the phase change materials (PCMs), as latent heat storage is more efficient than sensible heat storage. Paraffin wax provides many advantages, as it has high storage density and the isothermal nature of the storage process. It increases the time of storage and preserves water temperatures in case of no water drawl.

2.4. Solar Energy Systems

Solar power is clean and sustainable energy but the intensity of solar irradiation is unstable due to change of season, weather, day and night. So it is necessary to store the utilized energy. The collectors transform but not store the solar energy. The storage is accomplished in the storage tank. The heat storage system can be used as a buffer to mitigate the fluctuation of solar incidence.

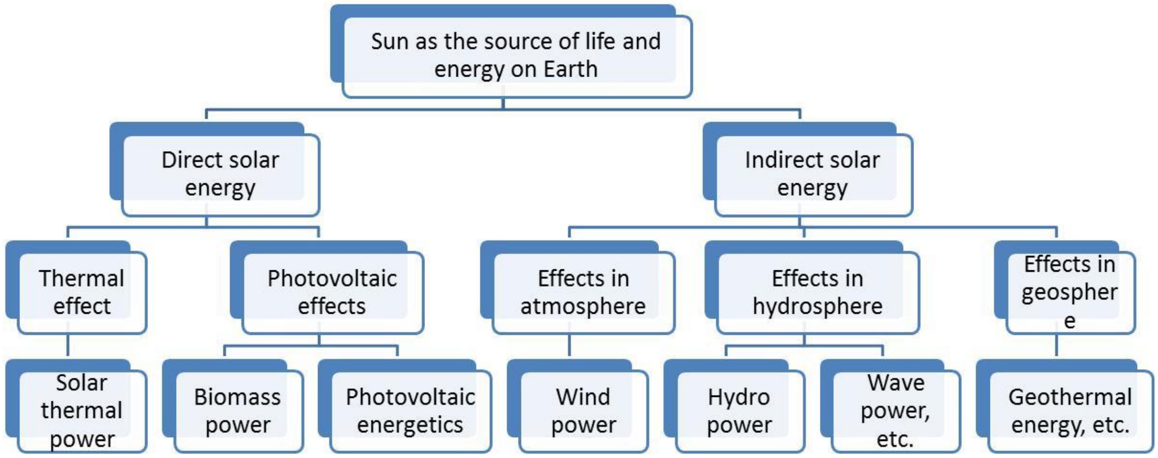

Figure 9: Different source of renewable energies from sun

Morrison, Abdul Khalik [21] and Jurinak in their different studies [22] calculated the performance of solar systems using phase change storage unit. Enibe [23] designed, developed and carried out a performance evaluation of a natural convection solar air heater with PCM energy storage. The system is suitable for use as a solar cabinet crop dryer for aromatic herbs, medicinal plants, and other crops.

2.5. Historical Perspective

A. Arteconi et al. [24] studied the heat pumps in the aspect of load management for the environment. They used heat pumps in combination with radiators and other heating system technologies. The objective of the study was to analyze the behavior of the heat pump. The results showed that the Demand Side Management (DSM) can be efficiently catered with heat pumps.

Ashly Maria Tomy et al. [25] with the help of Artificial Neural Network (ANN) simulated flat plate collector in which silver/water nanofluid was used as a heat transfer fluid. The objective of the study was to examine the results of radiation heat flux, inlet temperature, and mass flow rate on heat transfer coefficient and thermal efficiency. They also studied the comparison between experimental and simulation results. The results show that the comparison between ANN and experimental results came to an agreement with a deviation of less than ±2%

Gurjot S. Gill and Alan S. Fung et al. [26] studied the different effects of components of the hybrid model on GHG emissions and electricity consumption per year. The objective of this paper was to develop the solar based domestic hot water system. Results show the 80% decrease in GHG emission and electricity cost when using gray water heat recovery unit, as compared to the conventional systems without the gray water heat recovery unit. The advantage of the system was that the payback was lowest as compared to other systems.

R. J. Rabehl, W. A. Beckman and J. W. Mitchell et al. [27] studied the technique to develop the heat and mass Transfer Components for use in TRNSYS. Using the Catalog Data, the performances of the components were set by characterizing the parameters. The objective of the paper was to model the three heat and mass transfer devices: sensible heat exchangers, chilled water cooling coils and a direct expansion cooling coil. The performance of the equipment can be accurately valued using the technique offered in the paper.

Malleboyena Mastanaiah et al. [28] studied the flat plate collector which uses the water and air as heat transfer fluid to collect solar energy. By comparing the flat plate collector with other collectors we came to know that it is easiest and more economical to design, set up and maintain. By carefully using the collectors with specific coating surfaces, a reflector to increase and absorb the incident radiation and heat-resistant material, temperature up to 70^{o}C can easily be attained. The performance of the collector is affected by the properties of the working fluids flowing through it. The objective of the paper was to investigate the performance of the solar flat plate collector by using a different surface coating and a different mixture of heat transfer fluids. The results show that maximum outlet temperature is obtained by using black chrome coating and also it increases by decreasing the flow rate of water.

Paul McKenna and Donal P.Finn et al. [29] worked on TRNSYS to build the simulation model of a building integrated ground source heat pump with a phase change material Thermal energy storage tank. The objective of the paper was to construct the individual model to simulate the various components of the building like PCM tank, fan coil unit, heat pump etc.

Vineet Veer Tyagi and D. Buddhi et al. [30] review were of different heating and cooling methods in buildings. The objective of the paper was to study the thermal performance of the different systems like PCM building blocks, PCM shutters, PCM wallboards etc. this paper concluded that this kind of systems which used PCMs have good heating and cooling potential and also reduce the energy demand of the buildings.

Özgül GÖK et al. [31] studied the different types of thermal storage systems which are latent and sensible heat storage. Inorganic salts hydrates have more advantages when used as a latent heat storage medium. But when these salt hydrates used as Phase change material problems occur. The problems like Sub-cooling occurred because of weak nucleation properties. In this paper, they worked on the stabilization of Glauber's salt to prevent incongruent melting. And adding of the nucleated agent to prevent supercoiling.

A. Felix Regin et al. [32] in this paper studied the performance of the Capsules which used PCM, mostly paraffin wax, for heat transfer. Where the temperature of the heat transfer, which collects heat from the PCM, ranging from 70^{o} to 82^{o} C when the radius of the capsule was 4 mm. In this paper, a model was developed which used the enthalpy method and finite difference formulation. Not only that, this model also used to find the effect of the radius of the capsule and the effect on thermal performance due to Stefan number. Results show that at small radii and higher Stefan number it takes less time for PCM to melt and higher time-averaged heat flux in capsules.

A. Felix Regin et al. [33] studied the behavior of the thermal energy storage system which is a packed bed with latent heat. This bed was built of capsules filled with PCM mostly paraffin wax combined with the solar water heating system. In this paper they worked on the numerical modeling of the system, using the enthalpy method. The objective was to study the effect of the inlet heat transfer fluid temperature, mass flow rate, and phase change temperature. The results show that we should take in account and should accurately know the phase change temperature range of PCM for proper modeling of the performance of the system.

Ka Mil Kaygusuz et al. [34] studied the importance of the thermal energy storage systems as the demand for renewable energy sources has been increasing. In a thermal storage system a good thermal energy storage is the main component and also it allows minimum energy losses. In this paper, they discussed the thermal conservation bot theoretical and experimental.

Ben Xu, Peiwen Li and Cholik Can et al. [35] studied the technologies of thermal energy storages with phase change material in it. The objective of the paper was to discuss the five issues that came up after the survey to the state-of-the-art developments and understandings. The first issue was the use of different phase change materials in thermal storage systems. The second was to study the status of the research and application of those thermal storage systems. The third issue was the mathematical and numerical calculation. The fourth issue was the integration of that system in power generation systems. The last issue was the discussion about the cost and comparison between sensible and latent heat. This work will be very helpful for the students and people who are connected to the solar thermal industry.

Kinga Pielichowska and Krzysztof Pielichowski et al. [36] studied the phase change material used for thermal energy storage systems. PCM stored energy as latent and sensible heat. The latent storage heat gave much more density of energy storage with a smaller temperature difference between storing and releasing heat than sensible heat storage method. In this paper, they have discussed different types of phase Change materials like inorganic like salts and salt hydrates and inorganics like paraffin and polymeric materials.

Samar Jaber and Salman Ajib et al. [37] studied the high energy storage density during phase change in this paper. Moreover, cooling unit was designed, simulate and modeled using PCM, it was named Indirect Evaporation and Storage Unit. This Unit has been technically and economically optimized according to the Mediterranean Climate.

Taha K. Aldoss and Muhammad M. Rahman et al. [38] studied the different PCM designs to improve latent thermal energy storage system performance. For the design capsules of PCM were used who melting temperature variation has matched to heat transfer fluid, so as to increase the maximum heat transfer rate between heat transfer fluid and PCMs. In this paper, the authors worked on the latent thermal energy storage system with spherical capsules. In this paper, single and double PCM designs of two and three stages were investigated. The results show that by increasing the number of stages the performance of multi-PCM thermal energy storage increased.

M. Iten and S. Liu et al. [39] offered a procedure to design the thermal energy storage system in which PCM was used. The procedure had two main aspects which were, selection of material and heat exchanger development. Both play the main role, there is a range of PCMs available according to different research going on for years. However, every PCM had its own disadvantages. The other main aspect was the formation of the heat exchanger. For this purpose, the appropriate container must be chosen for PCMs and for heat transfer enhancement. In this paper preparation of design and model through the experimental and numerical study was done.

N.H.S. Tay, M. Belusko and F. Bruno et al. [40] worked on the latent energy that was stored in the tube-in-tube phase change thermal energy storage system. The characterizing and optimizing of the system had been done. For this system, the actual useful energy which was stored in the phase change material was determined. To determine the useful energy effective-NTU model was used, it indicates how much PCM was useful. The results gave the storage effectiveness of 68% and 75%. And also found out that tube-in-tank systems can store 18 times more useful energy than sensible storage systems.

S.M. Vakilaltojjar and W. Saman et al. [41] studied the different materials with different melting temperature for phase change energy storage medium, for air conditioning applications. In this paper, a semi-analytical model was developed and calculations were done for the models. The results from three different models are compared. The system was developed for energy storage in solar heating and energy efficient space heating and cooling applications.

Chapter no. 3

Methodology

3. Methodology

There two types of thermal energy system discussed, both have different Thermal energy Collectors: Flat Plate Collector and Photo-voltaic Thermal Collector.

3.1 Thermal Energy System's Discussion and Configuration

The thermal energy systems consist of three loops, as shown in the figure. These loops are described below.

1. **First loop** consists of a collector storage tank in which pump circulates hot water from solar collector to a hot water storage tank. The pump on/off conditions are controlled with the help of controller, as shown in the figure. Controller conditions are defined as, if the collector out is greater than the inlet temperature, the pump will be switched on. Another condition of the pump is it works only from 9 AM to 5 PM.

2. **Second loop** consists of Radiator which is attached to the storage tank. Pump collects the hot water from the collector storage tank at 50^{o}C and circulates in tubes of the radiator. In this loop, the pump works from 5 PM to 11 PM. The pump on/off conditions are also controlled with the help of a controller, as described. Controller conditions depend on the Reference Temperature of the room which is 26^{o}C.

3. **Third loop** consists of Boiler, which maintains the air temperature up to 26^{o}C on cloudy days when there is no sun. The boiler is attached to the room and radiator, it also attached to the thermostat which turns the boiler on and off according to the requirement. The loop also consists of Radiator which is attached to storage tank and boiler. The boiler is attached to the Thermostat. $T_{air\ in}$ strikes with the walls of the radiator and $T_{air\ out}$ come back with hot air.

Here the thermal system configuration schematics is shown below:

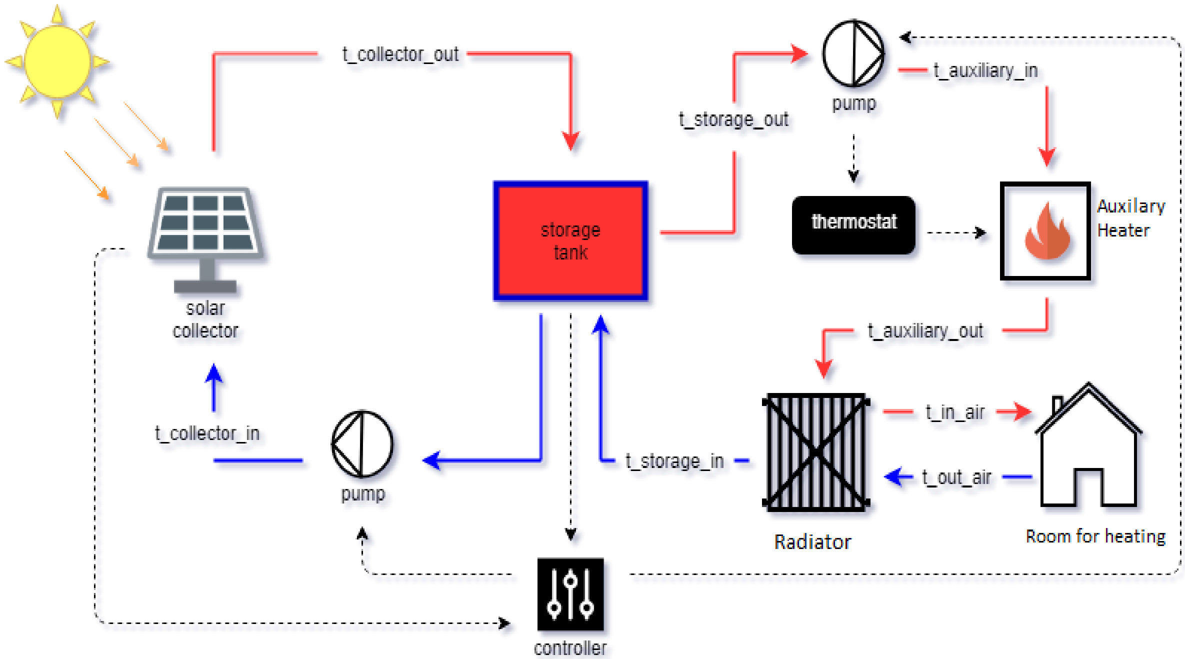

Figure10: Schematic Diagram of Configuration

3.2 Modeling in TRNSYS

The modeling is done by using TRNSYS 17.0. It is a dynamic tool for simulation and whole system performance can be simulated for complete one year. It is a FORTRAN based tool of simulation used to study the transient response of different energy systems. Every component of TRNSYS has its own predefined characteristics equations.

The pictorial view of the TRNSYS model is given below:

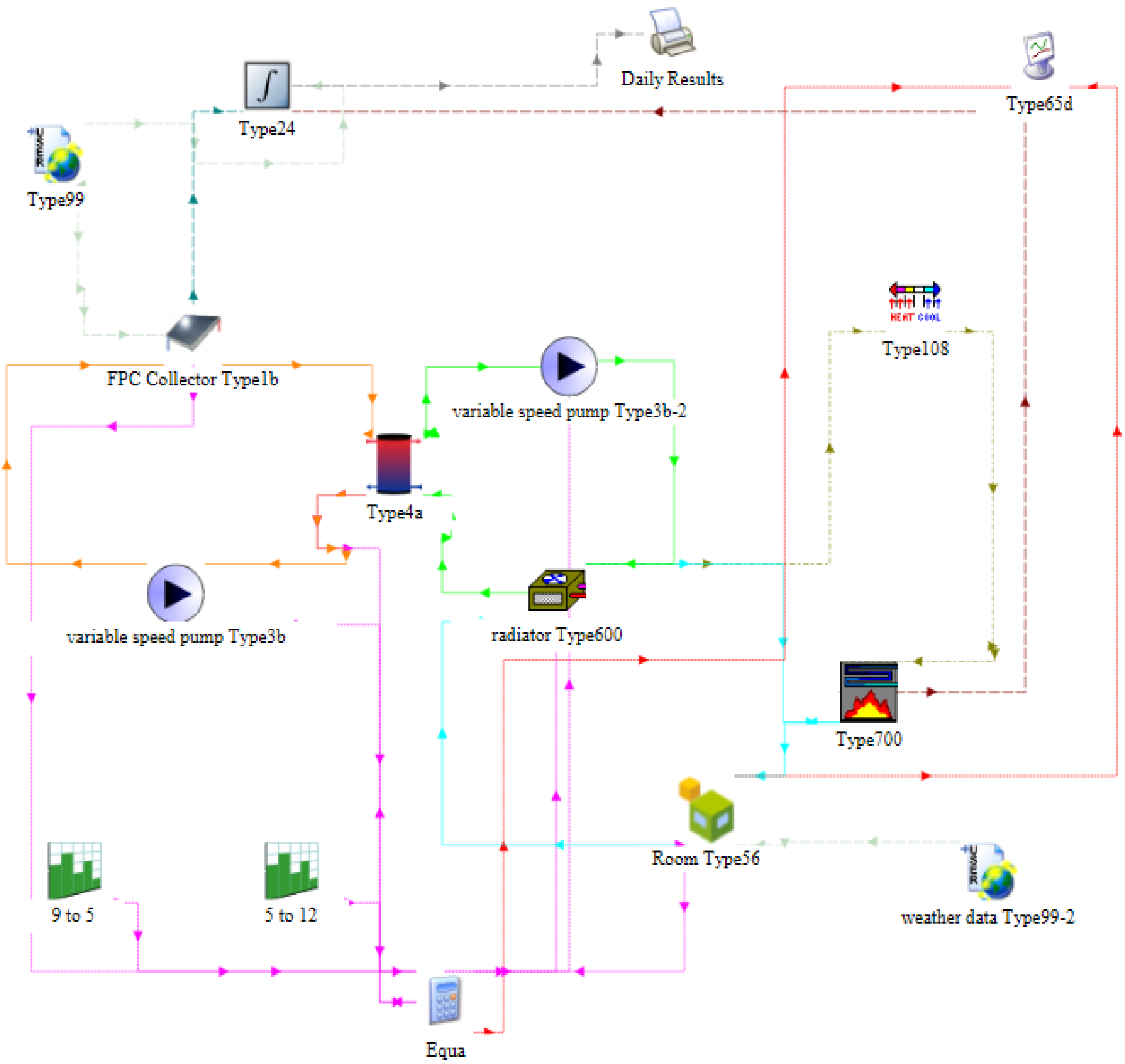

Figure 11: Pictorial view of TRNSYS with FPC in simulation studio

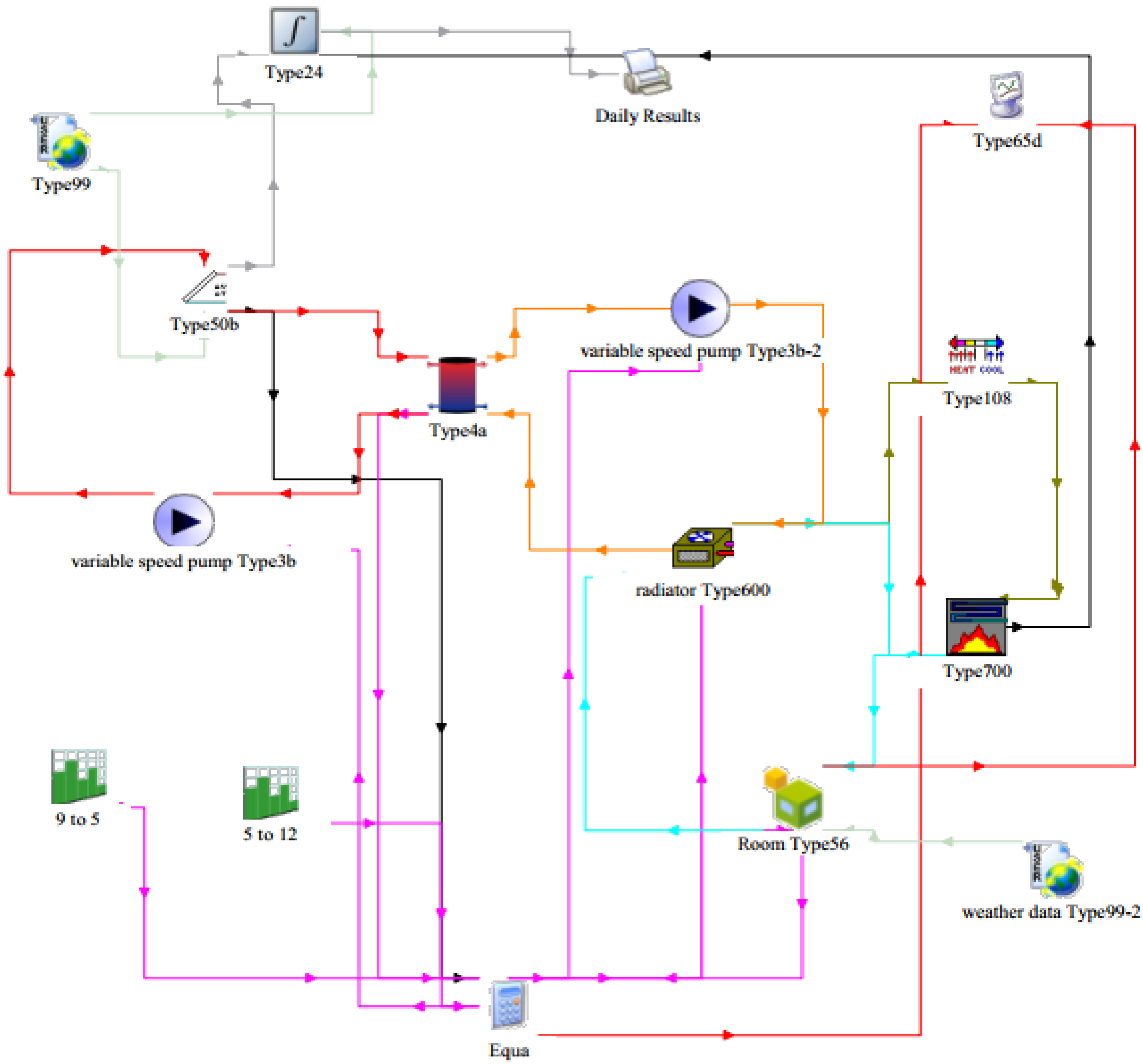

Figure 9: Pictorial view of TRNSYS with PVT Collector in simulation studio

3.3 System Components

The Components used in the TRNSYS model of thermal energy system are given below:

3.3.1 Solar Photovoltaic/thermal Collector (Type 50b)

In this type standard, PV module is added in a standard flat plate collector. The working principle of type 50 PV/T collector is based on the combined collector which use the working principle of Florschuetz. Type 50 has four different modes in TRNSYS.

Mode 1 to 4 is used for the simulations of the flat plate collectors and 5 to 8 are used for the simulations of the concentrating collectors.

In this case, we are using mode 4 which is the combination of mode 2 and 3. U_L for this mode is calculated from the following equation.

$$U_{L,j} = \frac{3.6}{\frac{N_G}{\frac{C}{T_{P,j}}\left(\frac{T_{avg} - T_a}{N_G + f}\right)^{0.33}} + \frac{1}{h_w}} + \frac{3.6\sigma(T_{avg,j}^{2} + T_a^2)(T_{avg,J} + T_a)}{\frac{1}{\varepsilon_p + \frac{1}{0.05N_{G_{1-\varepsilon_p}}} + \frac{2N_{G+f-1}}{\varepsilon_g} - N_G}} + U_{be}$$

The parameters of the collector that are used given below:

Table 1: PV-T parameters

Parameters	Value	Unit
Mode	2	-
Collector Area	1	m^2
Number of glass covers	1	-
Collector plate emittance	0.09	-

Collector Slope	45	Degrees
Temperature of cell reference efficiency	25	1/K
Packing factor	o.8	-
Cell efficiency	0.5	-

3.3.2 Flat Plate Collector (Type 1b)

TRNSYS component 1b is used to model the thermal performance of the solar flat plate collector. Total collector array depends upon the number of the modules in series and characteristics of each module. For the collector, user has provided results from standard tests of efficiency versus a ratio of fluid temperature minus ambient temperature to radiation.

Solar collector thermal efficiency is defined as

$$\eta = a_o - a_1 \frac{(T_{in} - T_{amb})}{l_T} - a_2 \frac{(T_{in} - T_{amb})^2}{l_T}$$

Where a_0 is the optical efficiency, a_1 and a_2 are the negative of first and second order energy loss coefficients, T_{in} is the temperature of water at the inlet of the solar collector and T_{amb} is the ambient temperature. The parameters of the collector used in the model are given below:

Table 2: FPC parameters

Parameter	Value	Unit
Collector area	1	m^2
Fluid specific heat	4.190	kJ/kg.K

Tested flow rate	40	Kg/hr.m^2
Efficiency slope	2.7	W/m^2.K
Efficiency mode	1	-

3.3.3 Storage Tank (Type 4a)

TRNSYS component Type 4a is used to model a hot water storage tank which is thermally stratified. For this purpose, the multi-node approach is used in the component in which the tank is divided into N sections or nodes and energy balances for each node are written. Consequently, N differential equations are obtained that can be solved for the temperatures of N nodes as functions of time. [11,30]. The flow towards collectors always leaves from the bottom node and flow towards load always leaves from top node. In this simulations, the tank is divided into ten number of nodes and constant heat loss coefficient 3 KJ/hr-m^{2}K is used in all simulation.

An energy balance of ith tank segment can be described as [30]

$$m_i C_{pf} \frac{dT_i}{d_t} = \alpha_i m_h C_{pf}(T_h - T_i) + \beta_i m_L C_{pf}(T_L - T_i) + UA_i(T_{env} - T_i) +$$

$$\begin{cases} \gamma_i (T_{i-1} - T_i) C_{pf} & if\ g_i > 0 \\ \gamma_i (T_i - T_{i+1}) C_{pf} & if\ g_i < 0 \end{cases}$$

3.3.4 Auxiliary Boiler (Type 700)

After the air absorbs the heat from the water to air heat exchanger goes into the auxiliary boiler. In our model Type 700 is used from the TRNSYS library for fulfilling the energy demand from the auxiliary source. The controller is attached which check the temperature of the incoming air and if this temperature is blown 50^{o}C then the controller turns the signal on which turned on the boiler to reach the stream on the desired temperature. Fluid specific heat can be changed depending upon the working fluids running through the boiler.

The energy consumed in type 700 depends upon the efficiency of the combustion and boiler that are defined. When the boiler is turned on, the heat energy required for the temperature to the desired level is calculated from the following equation:

$$Q_{boiler} = m_f C_{pf}(T_o - T_i)$$

m_f is the mass flow rate with the C_p is the specific heat respectively.

The parameters of the auxiliary boiler used in the model are given below.

Table 3: Auxiliary Boiler Parameters used.

Name	Value	Unit
Rated Capacity	1000	kJ/hr
Fluid Specific heat	4.190	kJ/kg.K
Minimum turn-down Ratio	0.2	-

3.3.5 Radiator (Type 600)

In the TRNSYS library, type 600 is used as an air heat exchanger. As this heat exchanger is a two pipe fan coil system thus it mixes the two streams of air then pass them through the fan, then this stream of air passes across the coils that have either hot or cold water. As it has a free-floating coil system so that means there is no internal control of outlet air and water temperature.

To control the on/off signal of the fan inside the heat exchanger, there is a control function. But for our model, we have used a controller which control the signals from 5 PM to 12 AM. In the parameters of type 600, there is an option of specific heat of fluid, in which depend upon the fluid used. We can also change the humidity mode from 1 or 2. Mode 1 is selected if the humidity ratio is considered and mode 2 is selected if percentage relative humidity is considered.

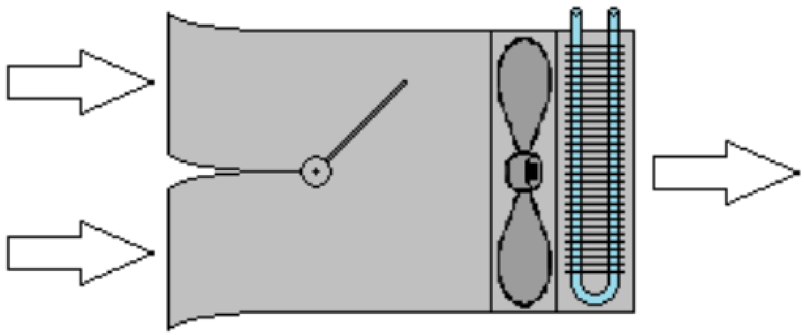

Figure 13: Two pipe fan coil Schematic diagram

3.3.6 Time-dependent forcing function

In the TRNSYS library, type 14h is used as a time-dependent forcing function. It is used to control the signal to turn the device on/off according to our requirement. In our model, we have used two of these components for 2 loops. First one is to control the pump one from 9 AM to 5 PM.

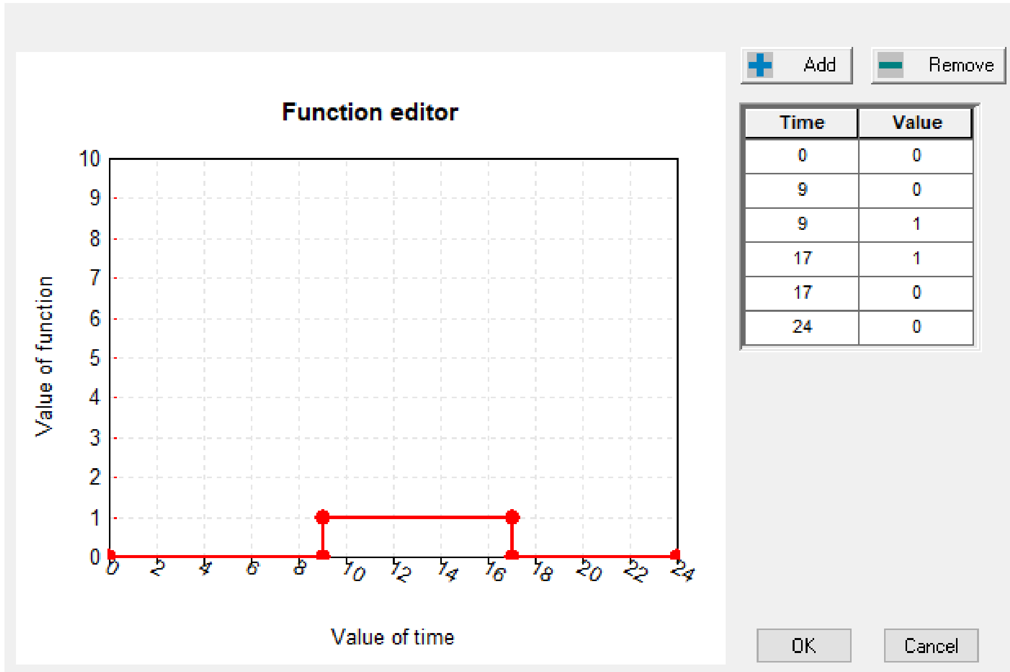

Figure 10: Time dependent forcing function from 9am-5pm

Where the other one is attached to the second pump which turns the pump on from 5 PM to 12 AM.

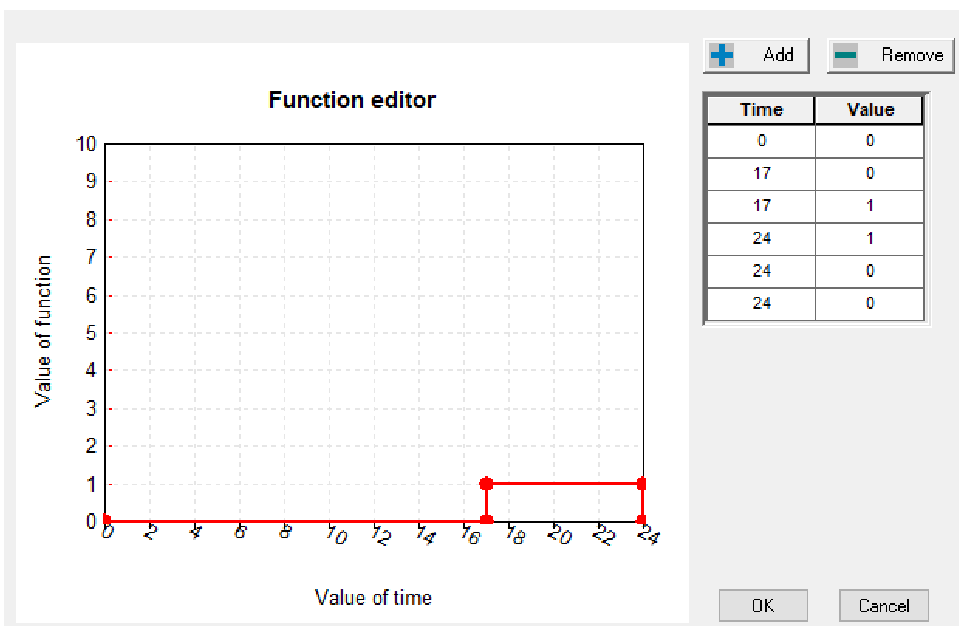

Figure 11: Time dependent forcing function from 5pm-12am

3.3.7 Thermostat (Type 108)

In the TRNSYS library, type 108 is used as a thermostat. This component is used to control the temperature of the room and some specific devices. It can be used to control heating or cooling depending on the requirement. In our case, it is used to control heating. It monitors the temperature of the water to air heat exchanger, when the temperature of the air is 50^{o}C it didn't generate the on signals but when the temperature decrease from 50^{o}C it turn on the auxiliary heater. There are five different stages of set point temperature. First three are for heating mode while the last two are for the cooling mode. In our case, we set the first stage point temperature 50^{o}C. While the exit air stream from water to air heat exchanger is attached with the monitoring temperature. The figure given below shows the setpoint definition.

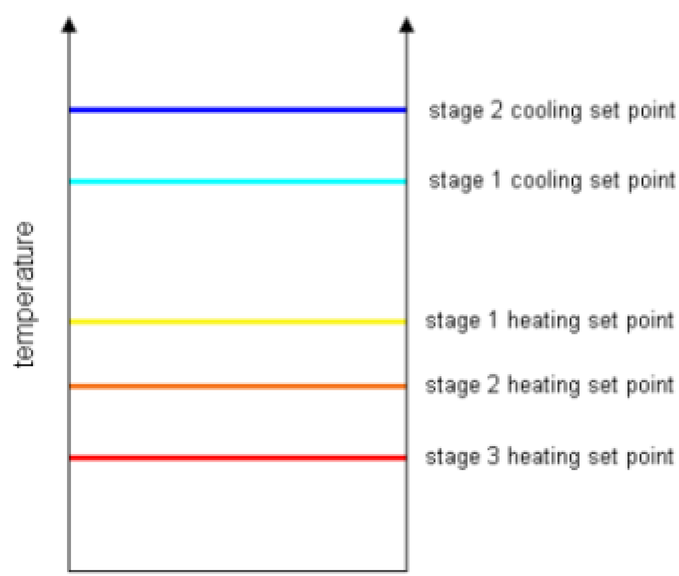

Figure 12: Set point definition

Here some furnaces are designed with lower and high burner settings. If the monitored temperature falls from the specific point then the low burner set point turn on. If the temperature continues to fell then burner with the highest power turns on.

3.3.8 Variable Pump (Type 3b)

In TRNSYS Library, type 3 is used as a variable pump. There are two variable pumps used in the model. One pump is attached to solar collectors, while the other one is attached to the thermal storage tank. The flow rate of the variable pump can be easily changed depending on our requirement. The parameters for the variable pumps are given below:

Table 4: Variable pump parameters used

Name	Value	Parameters
Maximum flow rate	30 (can vary)	Kg/hr
Fluid specific heat	4.190	kJ/kg.K
Maximum power	746	W
Conversion coefficient	0.05	-
Power coefficient	0.5	-

The outlet temperature of the pump can be calculated by the following equation:

$$T_{out} = T_{in} + (f * Power)(m * C_p)$$

3.3.9 Building Room (Type 56)

TRNSBuild is plugin software for TRNSYS, simulating any closed or open air zone. Here, a room of a building is being examined, which was designed in TRNSBuild software which was the part of the TRNSYS 17. All the exterior walls were directed to four different directions and there was only one window on the wall, facing south.

The figure of the room is given below:

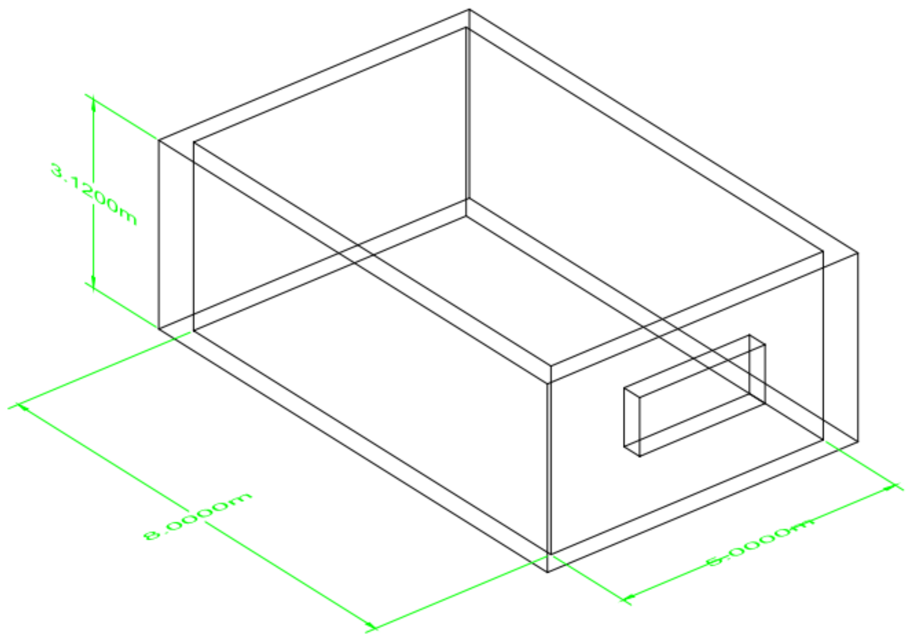

Figure 13: Room 3-D model

Table 5: Dimensions of Room

Wall	**Length (m)**	**Width (m)**	**Height (m)**	**Area (m^2)**	**Window (m^2)**
West	8.0	0	3.12	24.9	0
South	5.0	0	3.12	15.6	1
North	5.0	0	3.12	15.6	0
East	8.0	0	3.12	24.9	0

Roof	8.0	5.0	0	40	0
Floor	8.0	5.0	0	40	0

An insulation was used in the examined room and because of that it has low heating demand.

The thickness of the outer walls is 21.2 cm each consisting of following layers with 2.166 W/m^2 K U-value.

1. 1.2 cm plaster
2. 20 cm Composite bricks

The thickness of the roof is 25.2 cm with the following composition with 0.717 W/m^2 K U-value.

1. 10 cm Concrete
2. 10 cm Composite Bricks
3. 5.2 cm mineral wool

The thickness of the floor is 20 cm with the following composition with 2.816 W/m^2 K U-value.

1. 10 cm Concrete
2. 10 cm Composite brick

Where the window was made up of insulating glass have U-value of 2.83 W/m^2 K and g (glazing) value 0.755%.

Table 6: Characteristics of Room

Feature	Values
The volume of the Room	125 m^3
Capacitance	150 KJ/K

Capacitance is defined as the total thermal capacitance of the zone air for a volume of space. The designed room in TRNSBuild attached with TMY file for Islamabad for calculation of total heating load in the building.

Energy rate control method is being used for load calculation through TRNSBuild. In this method, heating and cooling type must be activated in TRNSBuild, setpoint temperature must be specified and Q_{sens} must be noted from the output generated by type 56. The peak values of Q_{sens} are peak heating and cooling loads for each zone and the integrated value of Q_{sens} is the annual heating and cooling load. The Q_{sens} output from TRNSBuild is not the total demand but it is just sensible energy demand. There would be a latent load in addition to the sensible load only if humidity set point in the zone is imposed.

3.3.10 Weather Data (Type 99)

In the TRNSYS library, type 99 is used for reading weather data. Weather data file is downloaded from the metronome software and then linked in type 99 for the external file where it is placed. The downloaded file contains Islamabad's data having the latitude of 33.71^{o}N and longitude of 73.06^{o}E. It is used to convert the data, obtained on the surface of the tilted collector, in the desired format for solar radiation.

Variation of hourly global and diffuse solar radiation on a horizontal plane is shown in fig given below.

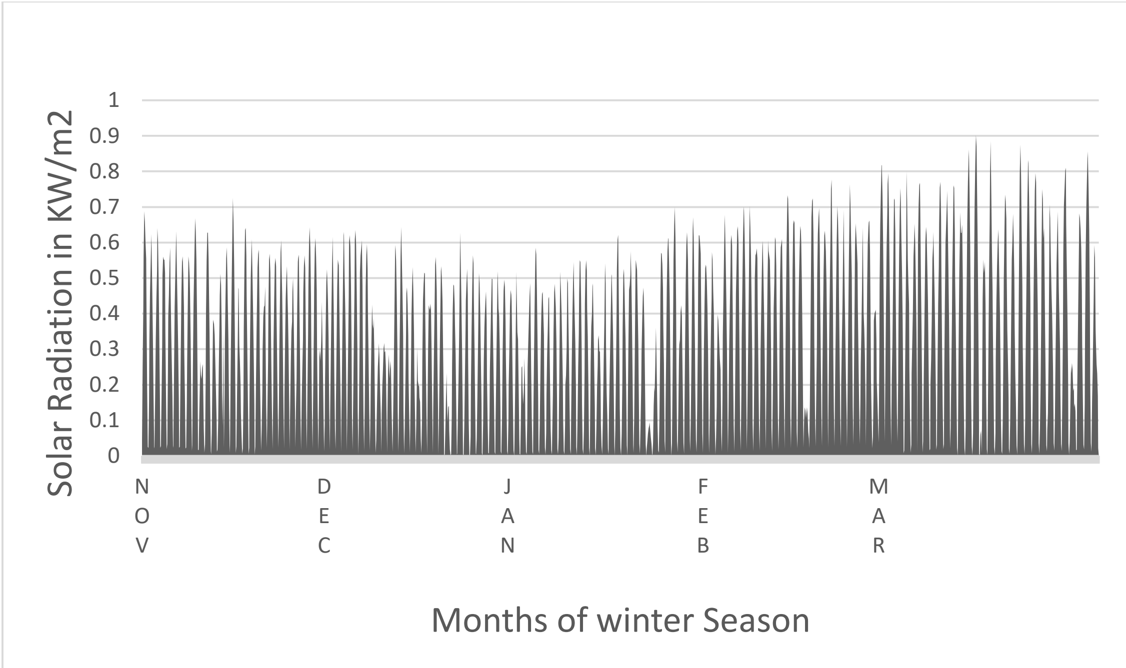

Figure 14: Hourly global and diffuse solar radiations

3.3.11 Integrator, printer, and other components

Type 24 is called the integrator and integrate the value of defined time. Type 25 is a printer which print all of the values and type 65d is an online printer. These components are the output devices and used for showing results.

Chapter no. 4

Results

4. Results

Simulations performed in TRNSYS 17 for whole winter season starts from November to March. The simulation starts at 7296 hours and ends at 2160 hours i.e from November to March for space heating.

4.1 Space Heating Load Profile

It shows the load profile generated by TRNSBuild according to the specifications of designed room. The load profile generated by the sensible and latent load. According to the generated profile, the designed building has required almost 6 KW heating system for fulfillment of the heating need. Generated load profile shows the daily requirement of heating load in the room, which tells the heating requirement is maximum in December and January.

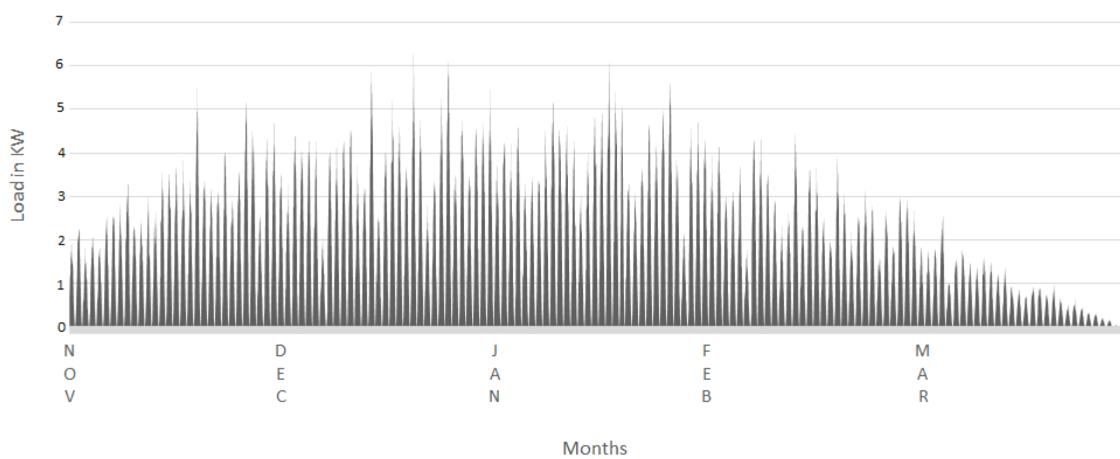

Figure 19: Heating load profile by TRNSBuild

4.2 Solar Fraction

Solar fraction is the important parameter during consideration of solar technology. The solar fraction tells us that how much energy is provided by the solar collector and how much by the auxiliary source. It is described as following:

$$SF = \frac{\int Q_u}{\int Q_u + \int Q_{aux}}$$

Where Q_u is the useful energy gain by the solar collector and Q_{aux} is the heat energy added from the auxiliary boiler. Solar fraction's value is 0 when the entire system is running on the auxiliary heater or it's 1 when all the required energy is provided by the solar collector.

4.2.1 Collector Area vs Solar Fraction

The figure given below shows the seasonal variation in a solar fraction of Flat Plate Collector and Photovoltaic Thermal Collector for a simulated system with respect to area. As we increase the area of the solar collector the amount of solar radiation collected by collector also increase. The greater amount of solar radiation capture means a greater amount of solar energy is being absorbed. According to the figures FPC has a higher value of solar fraction as compared to PVT collector.

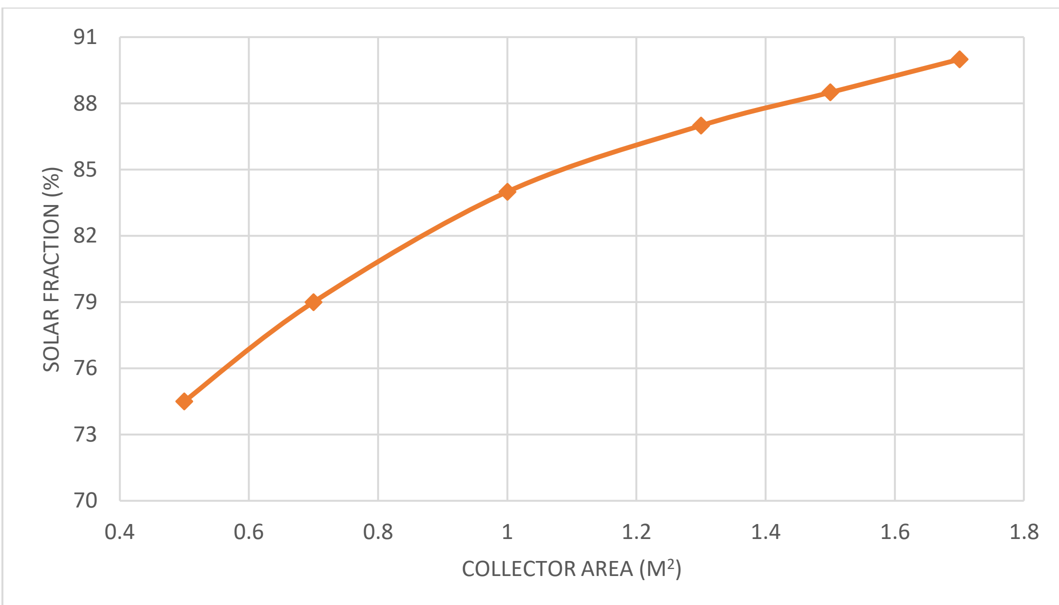

Figure 15: Collector Area VS Solar Fraction of FPC

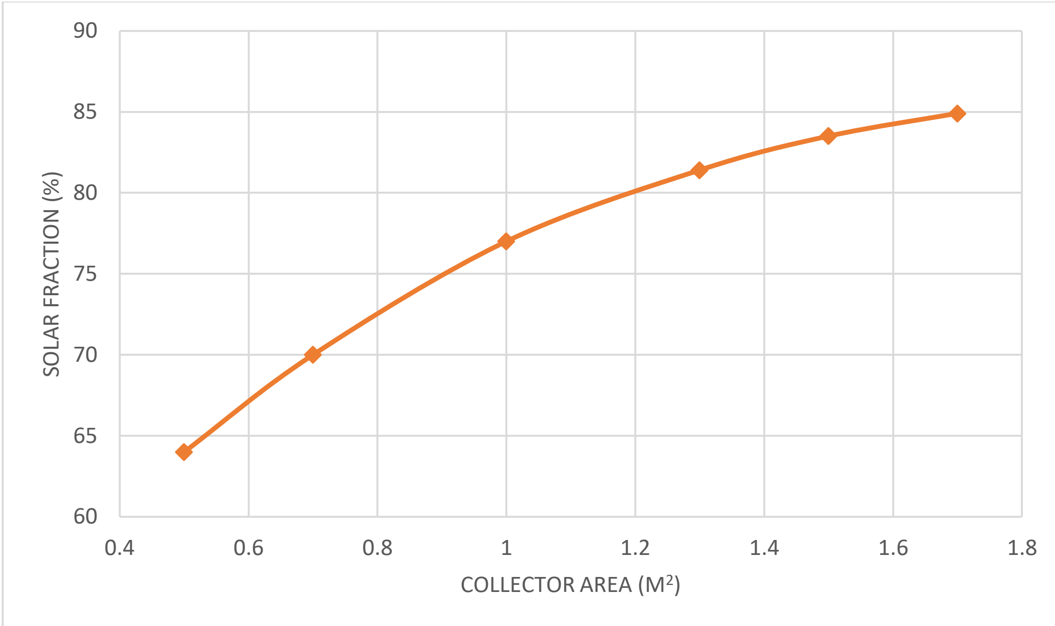

Figure 16: Collector Area VS Solar Fraction of PVT Collector

4.2.2 Collector Slope VS Solar Fraction

The figure given below shows the effect of collector tilt on solar fraction. The maximum solar fraction of flat plate collector and Photovoltaic Thermal Collector is in the range of 45-55^o for winters in Islamabad region. For calculation of solar fraction mass flow rate, the area of collector and volume of storage is kept constant.

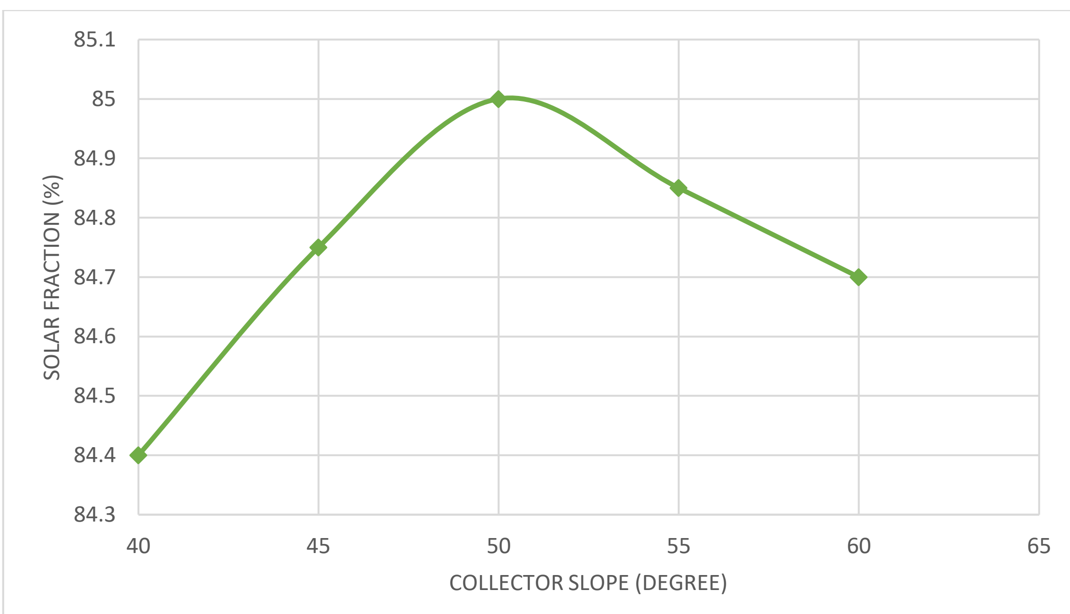

Figure 17: Collector Slope VS Solar Fraction of FPC

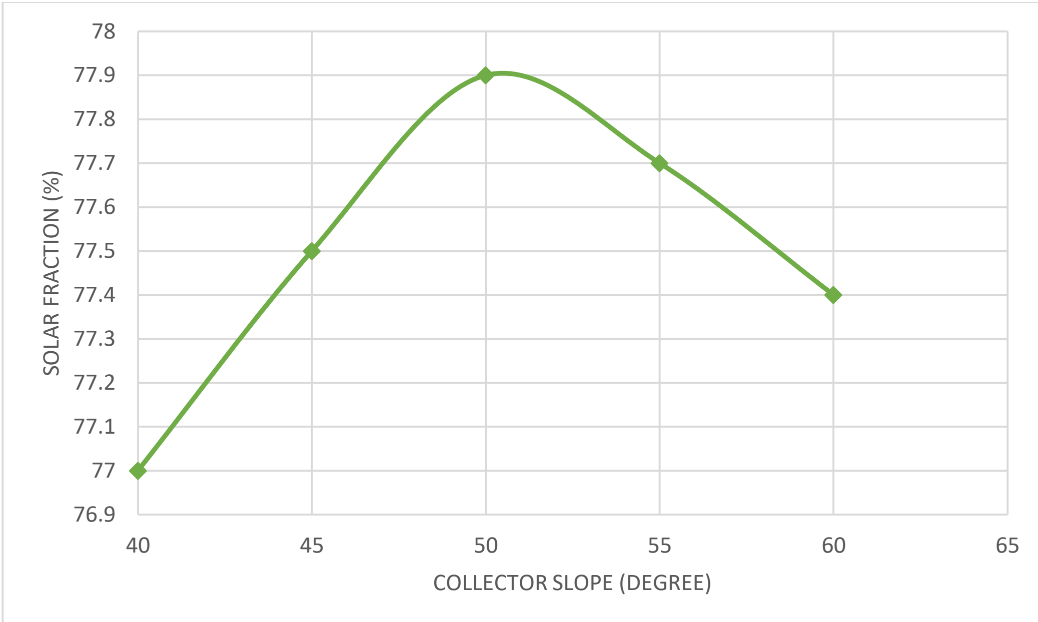

Figure 18: Collector Slope VS Solar Fraction PVT Collector

4.2.3 Storage tank vs Solar Fraction

The figure given below shows the effect of changing storage tank size on the solar fraction in which area of flat plate collector and Photovoltaic Thermal collector is 1m^2, for the designed model. The trend shows that solar fraction is increasing with respect to increasing in the tank size at certain limit after that it decreases with increase in the size of the storage tank. It is because when storage size increases solar energy, from the collector, will not be enough to heat the storage water for driving the system.

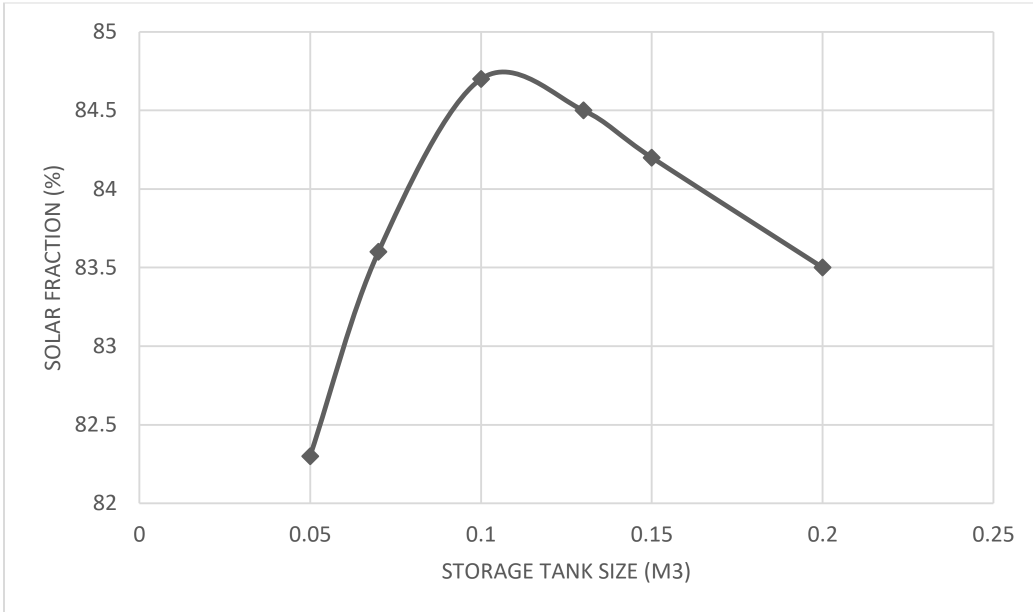

Figure 19: Thermal Storage Tank VS Solar Fraction of FPC

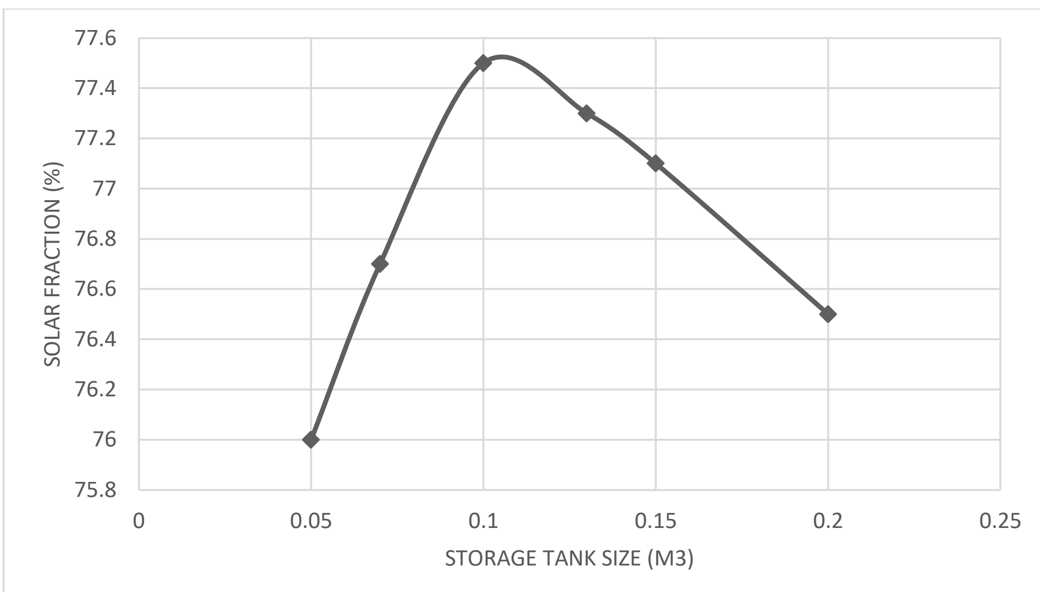

Figure 20: Thermal Storage Tank VS Solar Fraction PVT Collector

4.2.4 Solar Fraction on monthly basis Results

The figure given below shows the monthly solar fraction at a constant collector area, tank size and pump flow rates. The trend of the solar fraction is higher in November and March is due to lower heating demand when compared to January and December in which there is a maximum heat load.

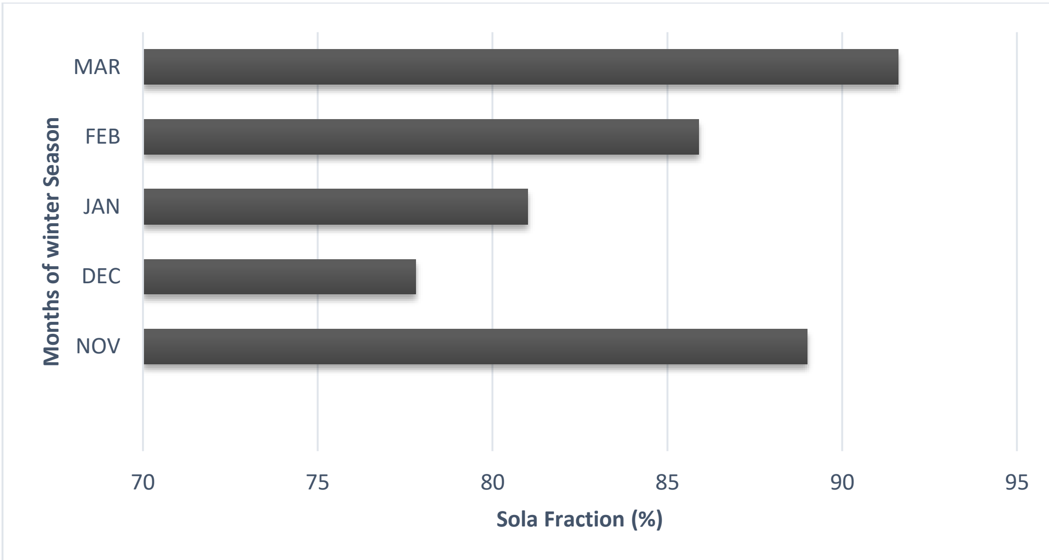

Figure 21: Comparison of months VS Solar Fraction of FPC

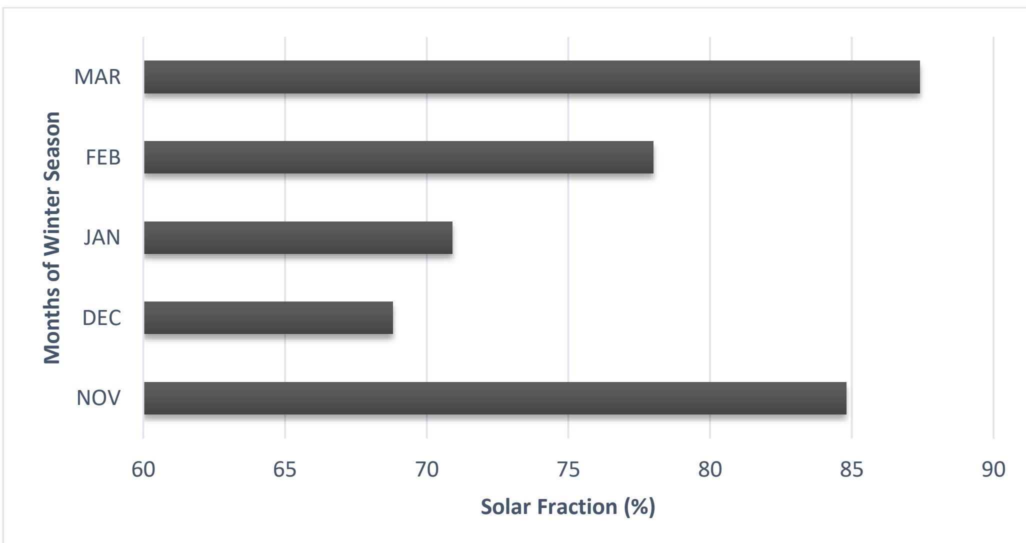

Figure 22: Comparison of months VS Solar Fraction of PVT Collector

4.3 Collector Efficiency

Solar Collectors long-term performance can be accessed by estimating its efficiency which is defined by the following equation:

$$\eta = \frac{\int Q_u dt}{A\int G dt}$$

Where G is the global solar radiation on a horizontal plane and A is the area of the collector.

4.3.1 Collector's efficiency on Monthly Basis Results

Collector efficiency of flat plate collector and Photovoltaic Thermal collector on monthly basis is shown in the figure. Flat plate collector efficiency lies in the range of 40-43.6% with the average seasonal efficiency of 41.8%.

Whereas Photovoltaic Thermal collector efficiency lies in the range of 25.6-28.7% with average seasonal efficiency of 27.15%

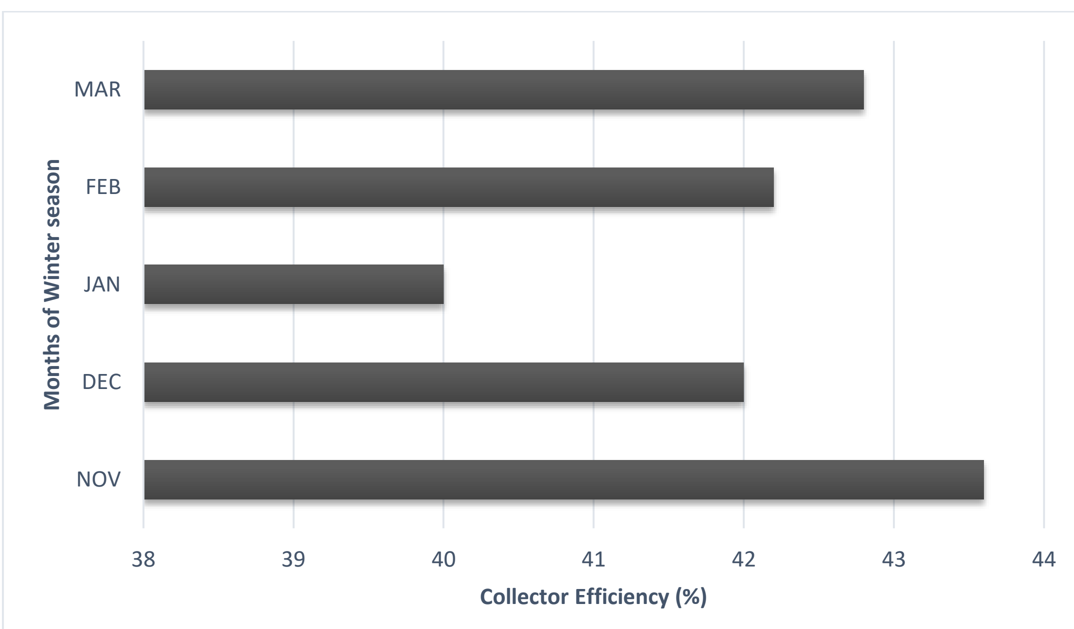

Figure 23: Comparison of months VS Collector Efficiency of FPC

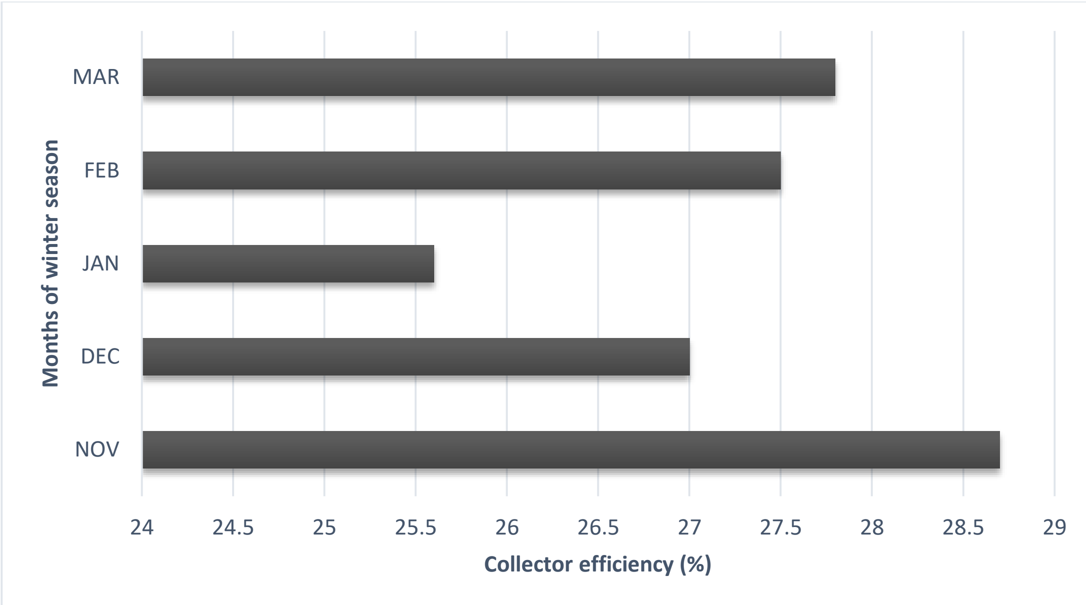

Figure 29: Comparison of months VS Collector Efficiency of PVT Collector

4.4 PV-T Collector Area vs Solar Fraction

The figure shows the variation of electrical and thermal solar faction of the Photovoltaic-thermal collector with respect of area. As the area of solar collector increase the number of solar radiations collected by the collector also increase. As the solar radiation increase, the energy of utilization also increased.

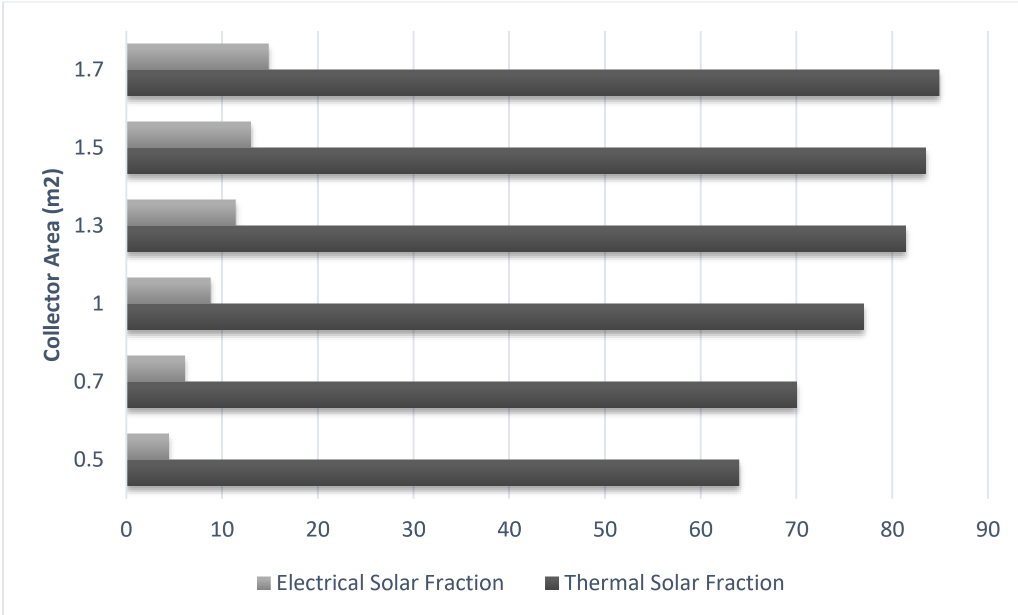

Figure 24: Comparison of Area VS Solar Fraction

4.5 PV-T Solar Fraction on monthly basis Results

The graph shows the Thermal and electrical solar fractions vary from month to month. While the maximum solar fraction is obtained during the month of March.

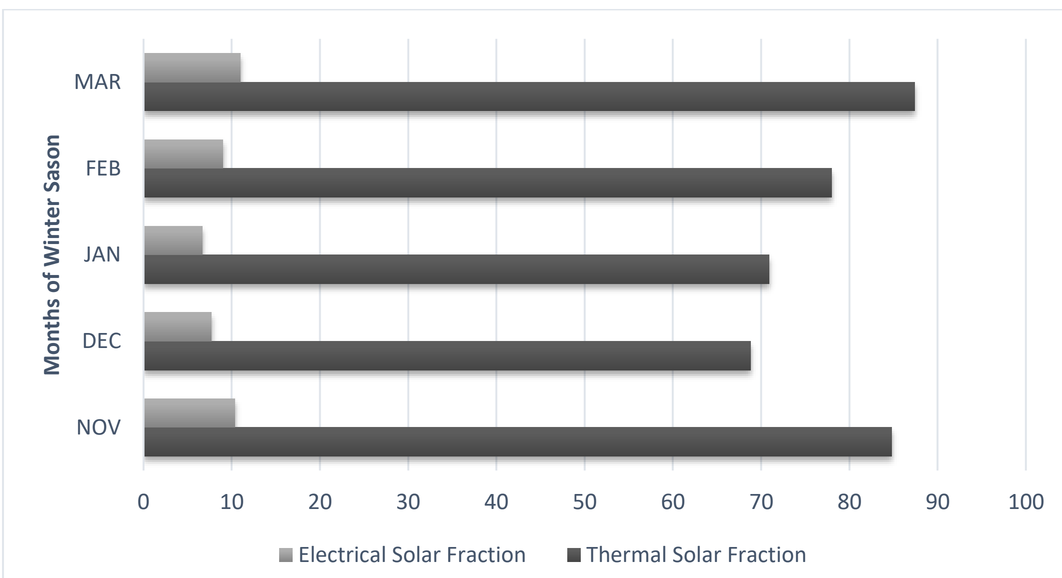

Figure 25: Months VS Solar Fraction for Collector area = $1m^2$

4.6 Room Temperature

The figure shows the variation in room temperature which is being heated from the solar system. The temperature variation shows the room temperature is almost equal to 25^{o}C in weekdays. This temperature is enough for the comfort of occupants. Temperature is equal to ambient at weekends because the system is considered not working on weekends. The system is being started every morning at 9 AM and shut off at 12 AM of weekdays with the help of a controller. In the controller as the room temperature exceed the 25^{o}C the hot water connect will be cut off which means no heat will be going inside the radiator. Whereas when the room temperature decrease because of the cloudy days, the boiler in the model starts to heat the water going inside the radiator, which then maintain the temperature.

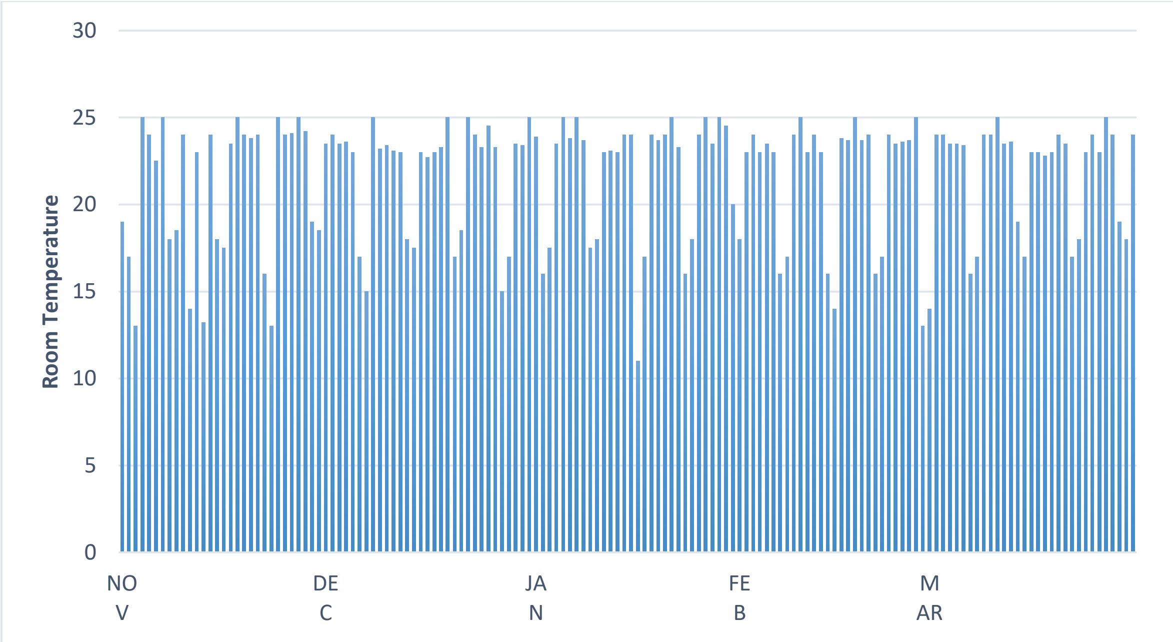

Figure 26: Variation in Room Temperature on monthly Basis

Chapter no. 5

Economic Analysis

5. Economic Analysis

RETSCREEN is used to carry out the Economic Analysis of the system. Following Parameters are considered for analysis of solar heater.

Table 7: Parameters for Room Heater Analysis

Facility Type	**Commercial**	
	Base Case	**Proposed Case**
Indoor Temperature℃	25	25
Operating day per week	5	5
Operating hour per day	8	8
Slope of Collector	45	45

Table 8: Monthly usage of heater

Monthly usage of Solar heating system	
January	100%
February	80%
March	50%
April	0%
May	0%
June	0%
July	0%
August	0%
September	0%
October	0%
November	70%
December	100%

Flat plate collector with Area of $1m^2$ has been considered of manufactures Matrix Energy with price of 15,000 PKR. Electricity rate of 12 PKR considered in this case.

Natural gas is considered as base case for heating system while biomass suggested.

Engineering cost, feasibility study cost, operation and maintenance cost and other heating components cost are considered 70,000 PKR.

According to RET Screen emission analysis GHG emission in case of Natural gas is 0.7, while in case of solar biomass proposed system is 0.2, which shows that proposed system is environmental friendly.

Inflation rate is taken as 4.2% while the project life is considered to be 25 years. As shown is graph the payback period is almost 7.6 years.

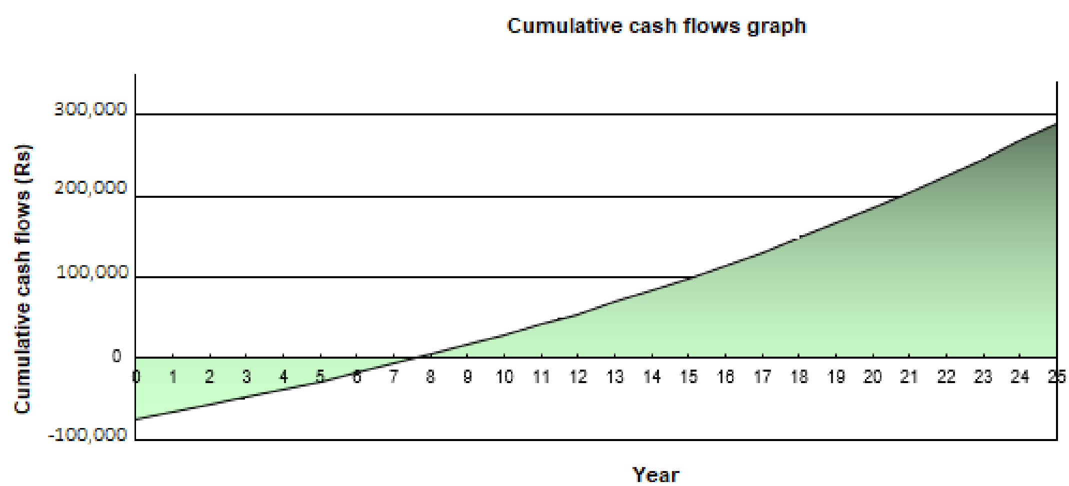

Figure 27: Pay back of solar space heating system

Chapter no 6

Conclusion and Future Work

Conclusion

In this study, configuration based TRNSYS model was developed and simulate to evaluate the thermal performance of solar thermal space heating system for a peak load of 6 KW. The available components in TRNSYS library were used in the modeling of the system. Weather data file for Islamabad location (33.7^{o}N, 73.06^{o}E) is used to simulate the system for entire winter season. Collector slope based on solar fraction was estimated 45^o-55^o for both FPC and PVT collector. Simulation results of entire winter months show average Solar Fraction 84% and average collector efficiency 42% are obtained in case of flat plate collector with area of 1m^2 and storage tank size of 0.1m^3. On the other hand Solar Fraction 80% and collector efficiency 27% are obtained in case of PVT collector with area of 1m^2 and storage tank size 0.1m^3. Whereas for the PVT collector configuration, thermal solar fraction 78% while electrical solar fraction is 9%. So, simulation results show FCP is preferred over PVT due to less heating demand. Economic analysis show the proposed system is environmental friendly. The proposed system has no carbon emission which harms the human and environment. No experimental data was available for model validation of simulation results, but overall trends of results were determined using already published data.

Future Work

In this study simulation results shows that there is a good potential for solar based air conditioning system in Pakistan.

However, the following ideas should be addressed in future work:

1. The proposed system can be suggested for off grid areas by using thermo-syphon collector and simulation of space heating.
2. Components used in TRNSYS can be designed in ANSYS/Comsol.
3. Experimental setup can be installed to validate the simulation based results.
4. The proposed system can be simulated for different locations of Pakistan.

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