Design of a Combined Solar Thermal Water and Space Heating System for a Commercial Building in Climatic Conditions of Islamabad, Pakistan.

By

Hafiza Mahreen Fatima

Reg# 119895

Session 2015-17

Supervised by

Dr. Muhammad Bilal Sajid

A Thesis Submitted to the Centre for Energy Systems in partial fulfillment of the requirements for the degree of

MASTERS of SCIENCE in

THERMAL ENERGY ENGINEERING

US Center for Advance Studies in Energy (USPCAS-E)

National University of Sciences and Technology (NUST)

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THESIS ACCEPTANCE CERTIFICATE

Certified that final copy of MS thesis written by Ms Hafiza Mahreen Fatima, (Registration No. 119895), of US Center for Advance Studies in Energy has been vetted by undersigned, found complete in all respects as per NUST Statues/Regulations, is free of plagiarism, errors, and mistakes and is accepted as partial fulfillment for award of MS degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in the said thesis.

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Certificate

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List of Publications

- **Hafiza Mahreen Fatima,** Muhammad Bilal Sajid "Integrated Solar Thermal System for Space and water Heating Applications", International workshop on Sustainable Energy Solutions for Community Development in Pakistan, University of Agriculture, Faisalabad on 8th-9th November 2016. (Abstract)
- **Hafiza Mahreen Fatima,** Muhammad Bilal Sajid, Abdul Waheed Badar "Integrated Solar Thermal System for Space Heating Applications in a commercial building for Building", Student Research Paper Conference (SRPS 2017), Institute of Space Technology (IST), Islamabad on 18th -19th May, 2017.
- **Hafiza Mahreen Fatima**, Muhammad Bilal Sajid, Abdul Samad Farooq "Modeling and Simulation of Solar Water for Islamabad Region, Pakistan", 7th International Conference on Environmental Sustainable Development, Comsats Institute of Information Technology (CIIT) campus Abbottabad on 26th-28th August 2017.
- Muhammad Mohsin Tanveer, Muhammad Bilal Sajid, **Hafiza Mahreen Fatima** "Effect of Micro Channel Aspect Ratio on Pressure Drop and Heat Transfer", 7th International Conference on Environmental Sustainable Development, Comsats Institute of Information Technology (CIIT) campus Abbottabad on 26th-28th August 2017.
- Abdul Samad Farooq, Muhammad Bilal Sajid, **Hafiza Mahreen Fatima,** Abdul Waheed Badar, "Simulation of Solar Energy Driven desiccant and vapor compression based Air-Conditioning System for Pakistan", 7th International Conference on Environmental Sustainable Development, Comsats Institute of Information Technology (CIIT) campus Abbottabad on 26th-28th August 2017.

Abstract

In this work, a solar combi-system is modelled and simulated in TRNSYS to meet the space heating load of a standard office room (8 m × 5 m × 3.12 m) and to fulfill the water heating demand of ten persons present in the office. The solar based system primarily consists of a solar collector, storage tank and an auxiliary boiler which feeds hot water to the room radiator unit for space heating and to the domestic hot water tank for heating purpose at cloudy weather. Weather data file obtained from Metronorm software for Islamabad (33.71° N, 73.06° E) is used in present work.

TRNSYS simulation are run for the whole winter season by using flat plate and evacuated tube collectors. Performance analysis are carried out by varying the collector area, collector slope and storage volume to estimate the system performance. Our whole system simulation result shows that proposed system gives the significant savings in primary energy with payback five to seven years.

Keywords: *Renewable Energy, Space heating, Water Heating, TRNSYS, TRNSBuild, Solar Fraction, Primary Energy Savings*

Contents

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Nomenclature

$T_{col,i}$	Temperature of fluid at the inlet of solar collector (K)
$T_{col,o}$	Temperature of fluid at the outlet of solar collector (K)
$T_{,aux,i}$	Temperature of fluid at the inlet of auxiliary boiler (K)
$T_{,aux,o}$	Temperature of fluid at the outlet of auxiliary boiler (K)
T_{sh}	Temperature of fluid at the inlet of radiator (K)
$T_{in,air}$	Temperature of inlet room air (K)
$T_{st,i}$	Temperature of fluid at the inlet of storage Tank (K)
$T_{st,o}$	Temperature of fluid at the outlet of storage Tank (K)
$T_{hw,in}$	Hot water inlet temperature (K)
$T_{hw,set}$	Hot water set-point temperature (K)

Greek

H_c	Thermal efficiency of solar collector (–)
η_{boiler}	Efficiency of boiler (–)
E_{fossil}	Primary Energy of fossil fuel (–)
ΔT	Temperature difference between fluid and ambient temperature (K)

Abbreviations:

ETC	Evacuated tube collector
FPC	Flat plate collector

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Chapter 1

Pakistan's Energy Scenario

1 Introduction

The demand of clean energy in future can be meet up by introducing the percentage of alternative oils and renewable resources such as biomass, solar and wind are playing an essential role in the development of new energy economy in the world. The existing energy networks will be insufficient even with incremental improvements to meet the clean energy demand. Deteriorating reserves and ever-growing energy concerns have the impact of carbon fuels burning and global climate change. Due to increase in population fossil fuel sources are not enough to fulfill the energy demand as in the past. The intimidating challenge of the global society for 21^{st} century is finding appropriate supplies of hygienic and sustainable energy. Unfortunately, use of fossil fuel as the source of energy has a serious and negative environmental effect such as air pollution, carbon emissions, deforestation, greenhouse gas emission and overall global environmental degradation. A mix of clean energy sources will contribute to our health and prosperity in future. A mix of clean energy technologies which is environmental friendly must be used to meet our future energy uses. So, for sustainable future, a renewable energy revolution is our hope. Most of the population in the world lives in rural areas without access of electricity and most of these people lives without access to safe and clean water. Solar energy has a potential to provide clean and sustainable energy for these people with minimum changes in infrastructure. Solar energy provides that endures life on earth for all living organisms. It delivers a convincing explanation for all communities to meet their needs for clean, and sustainable source of energy in the future. Basically, Solar energy is the nuclear interactions at the center of the sun where the energy comes from the conversion of hydrogen into helium. Sunlight is a safe source of energy which is free from the geopolitical tensions; our atmosphere and our global climate system do not pose a threat to pollution production. Solar energy reached on the earth through the electromagnetic waves. Electromagnetic waves are itself present in the form of particles. The earth is a source of energy collection, collected from the sun, many solar energies in various forms, such as hot air groups that cause winds, direct sunlight for plants, photo synthesis and ocean evaporation, forming rain water, rivers and providing hydropower. Solar energy can be used directly to overcome the energy crisis. By far the largest carbon free energy source on the planet is sunlight. The energy of the sunlight (4.3 * 1020 J) in one hour exceeds the energy used on all the earth in the year (4.1 * 1020 J). [1] Renewable energy is given priority by leaders, although Earth's annual energy from daily life is about 10 times the amount of oil, coal, natural gas and uranium combined reserves.[1]. Because of the perfect energy storm in the twenty-first century, we are witnessing a shift from global paradigm to clean energy. With the rise in conventional energy prices, new alternatives will begin to emerge and be more economically competitive. Future energy solutions depend on local, national and world policies. The solution also depends on our personal choice and policy as a social implementation. This does not mean that we must live in the Stone Age to deny our energy inputs, but we must overcome the twenty-first century of energy crisis by isolating our homes, driving energy-efficient vehicles, installing solar heating and cooling systems.

1.1 Geographical information for Pakistan

Pakistan is the country situated in South Asia bordered by Arabian Sea. It has China in the north, Arabian Sea in the south, India in the east, Iran and Afghanistan in the west. While Pakistan is located latitude in between 23.8 and 36.78N and longitude in between 61.1 and 75.88E, and total area of the country is 803,940 km^2. In Pakistan climatic conditions, socio economic and environmental effects differ considerably from region to region. Pakistan shares 1050 km maritime border with Oman. Population of Pakistan is about 180 million, which is increasing with the flow that is expected to cross 210 million by year 2025. With respect to population, it is at eighth big country in the world. There are four provinces in Pakistan named Punjab, Khyber Pakhtunkhwa (KPK), Sindh and Balochistan and has two territories: The Federally Administered Tribal Areas (FATA) and the northern regions are administered under Federal administration. Additionally, Azad Jammu and Kashmir (AJK) is also under the administration of the Government of Pakistan. Pakistan has Nominal GDP US $ 1650 per capita, while the three main sectors: industry, agriculture and services make up a share of GDP of 26.6, 25.2 and 48.2%, respectively.[2]

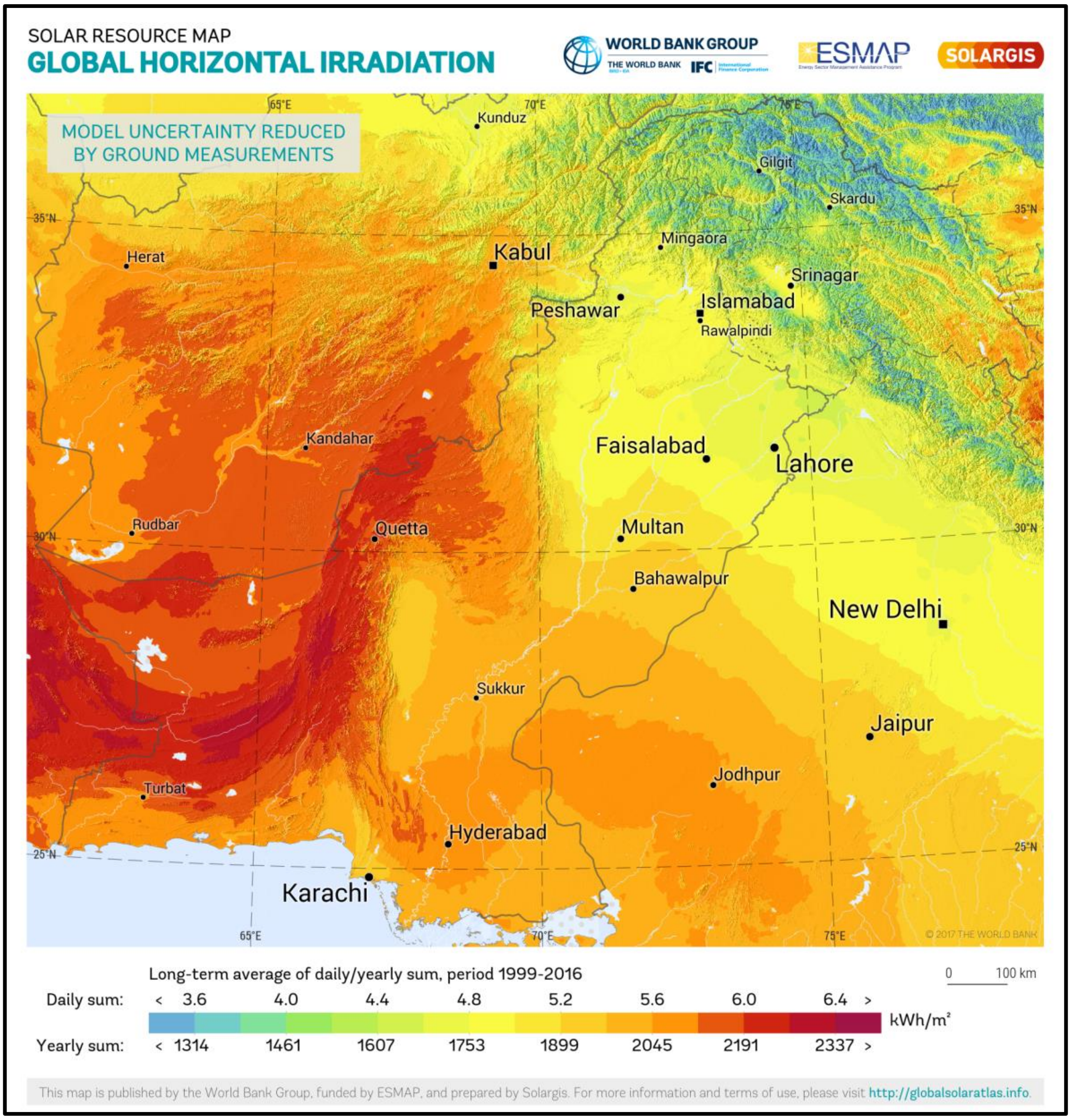

Figure 1 shows the solar potential in Pakistan. [3]

1.2 Pakistan's Energy Needs and Renewables Potential

Pakistan is facing serious energy scarcity due to fast increasing population. It has limited Conventional energy resources like gas, coal and oil, and resources available are not enough to take account of growing energy demand. Pakistan still has for only 0.5% of the world's total energy consumption, even though its energy consumption is increased by 3 times over the past 20 years. Although electricity production is increased, still less than 50% of households have electrical supply, Pakistan has per capita electricity supply is only 443 kWh/year while in comparison developed countries like United States and Japan have 12,500 kWh and 7500 kWh respectively [4]. Fossil fuels are prime sources of energy production in Pakistan which provides 63% of the total energy demand. Second main source of energy is hydroelectric which is currently providing 36% of total demand. Remaining 1% of energy demand is fulfilled by nuclear resources. Pakistan’s total primary energy supply was 47.1 million measured in tons of oil equivalent (TOE) in year 2002-2003.

God blessed Pakistan with many of the natural resources due to this it has enormous potential for the development of renewable energy. Pakistan's three provinces, (KPK, Sindh and Balochistan) have vast unexploited resources for hydroelectric power, wind and solar power. Climatic conditions and geographical location of these provinces of Pakistan forced engineers and scientists to get best out of these resources to cope up the energy demand. By the grace of God, ideally Pakistan is situated in the region where the sunny belt is available to get the benefits from technologies of solar energy. Large potential of solar energy resources is available extensively with no cost. The province of Baluchistan is predominantly rich in solar energy and average annual sun duration is considerably longer there. Global warming and greenhouse gas emission are mainly caused by energy production from fossil fuels. Renewable energy resources cause very less global warming. Environment and humans are healthy the areas where energy is obtained from these resources as compared to fossil fuels production areas. Using all its resources to maintain economic growth and to support the global and regional economic initiatives of the future, energy security should be strengthening in Pakistan.

Life without energy is nearly impossible as energy is needed in every sector. Energy requirement in each sector in Pakistan as shown in figure.

About 64% of the total energy mix (especially natural gas and electricity) is mainly consumed by industrial and household sectors. Similarly transport sector consumes 32% of the total National energy mix; about 98% of transport fuel is provided using oil products. Oil and natural gas give about 80% of primary energy usage. As Pakistan is having vast resources of Natural gas so domestic production easily meet with all this its requirements, but indigenous production of oil which is 64,000 bbl/day against a consumption of 3,51,400 bbl / day, [8] due to which a large proportion of the import invoice is limited solely by oil. There is no other renewable energy source contributing a significant role in Pakistan’s energy mix except hydropower. As the energy demand is increasing rapidly and there is threat of conventional resources decrease, role of renewable energy sources is very important and cannot be ignored.

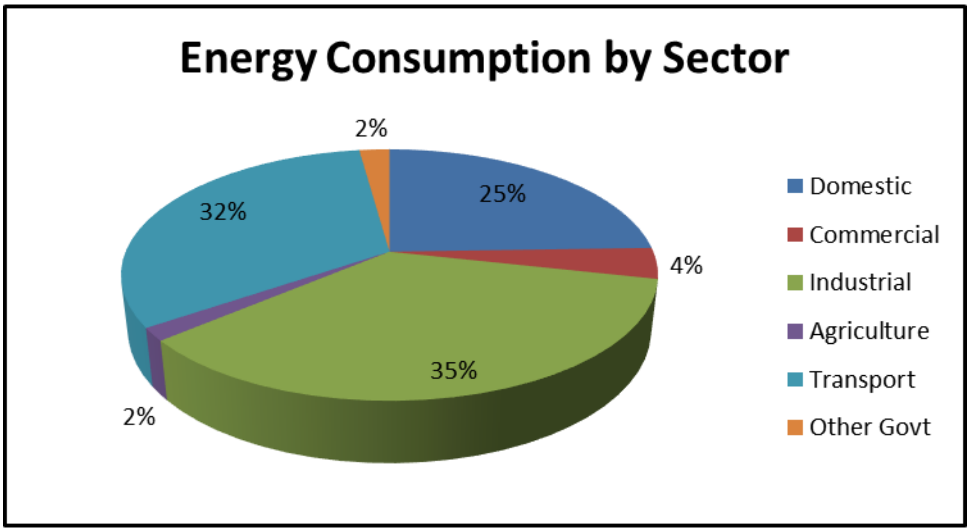

Figure 2 Pakistan's energy consumption by sector (GW h) [7]

A fact that provides the high importance of tumbling the energy ingestion in buildings is that use of energy in building sector is about one third of total worldwide energy consumption. [5][6] Space heating, water heating and air conditioning are main uses of energy in buildings. Figure shows the increase in energy consumption of building during each year.

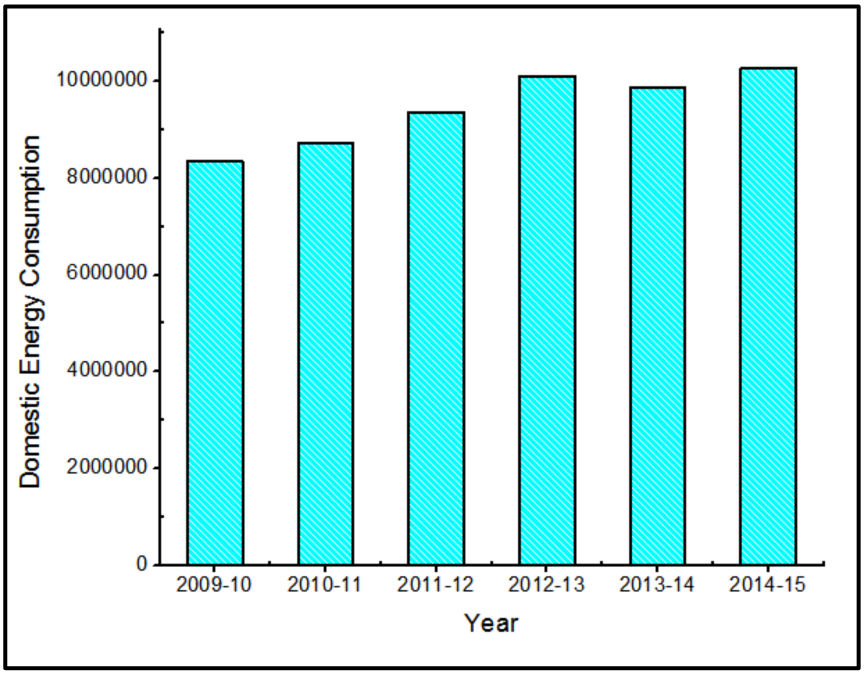

Figure 3 Domestic Energy Consumption [7]

1.3 Outlooks of Solar Energy for Pakistan

Pakistan has a huge potential of renewable energy resources i.e hydroelectric power, solar, wind and biomass. The proper utilization of these energy resources can improve energy supply market, long term energy sustainable, reduce reliance on import. In this way, rural area need for energy can also be met, new employment and local equipment manufacturing opportunities produce. Pakistan is present in that region where solar energy potential is maximum and it is most important type of renewable energy. In Pakistan, every region has more than 300 sunny days in a year. Figure 4 shows data of solar irradiations for six major locations in Pakistan. These data were estimated from measurements of long-term sun duration records using validated models. [9]

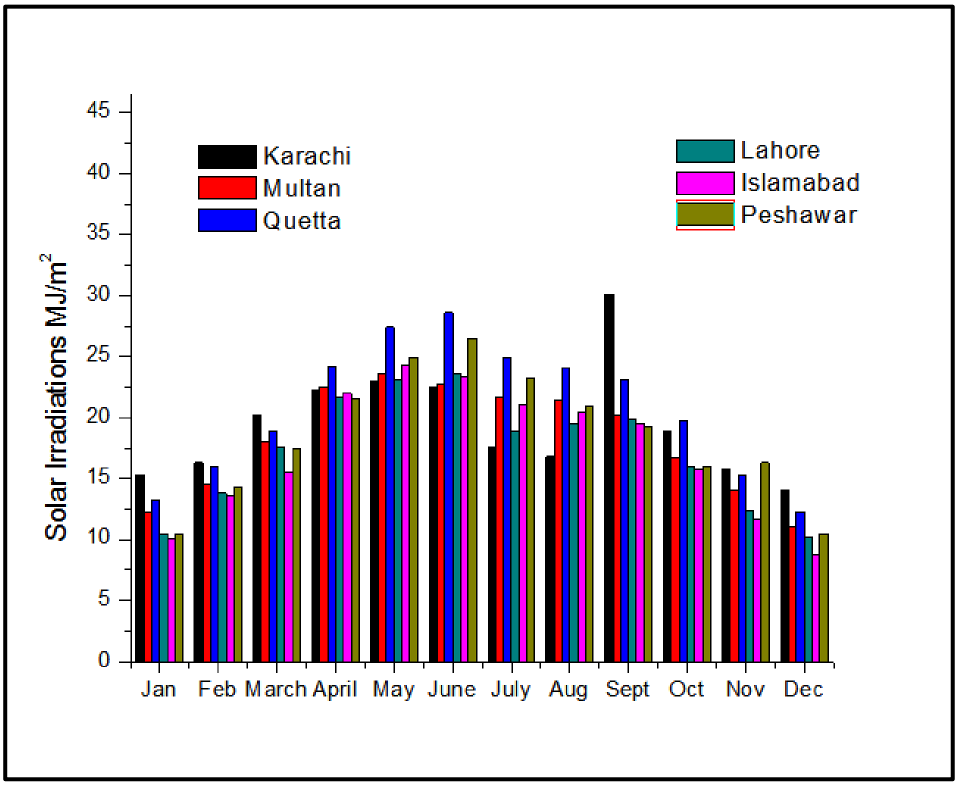

Figure 4 Monthly average daily irradiation values MJ m^{-2} d^{-1}

1.4 Climate of Islamabad

In Pakistan, weather conditions of Islamabad are that where the solar energy utilization potential is high as compare to other locations. In Islamabad climate is warm and temperate. Winters have high solar radiations which can utilize to produce safe energy. The average annual temperature is 21.3˚C. Precipitation here average 941 mm. [10] Below figure shows the temperature of Islamabad in whole year.

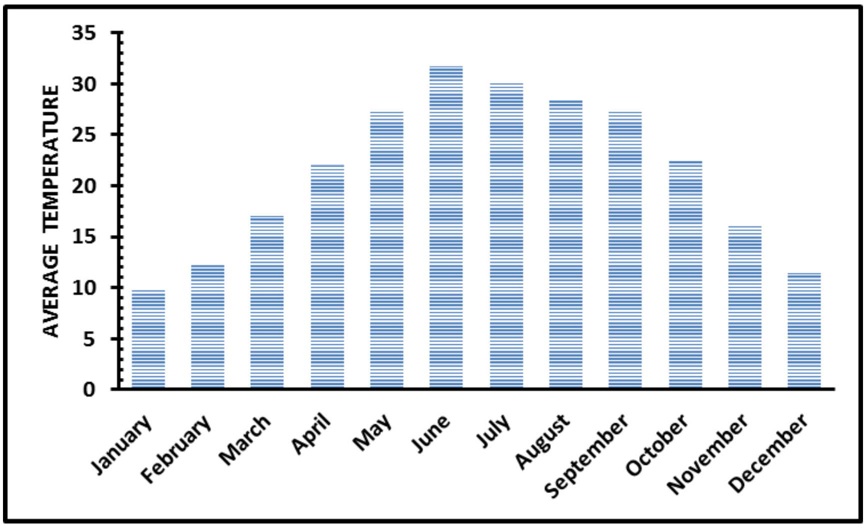

Figure 5 Monthly average temperature values ˚C

Potential of global, beam and diffuse radiations in winters in Islamabad region are shown in below figure. Beam radiation are those solar radiations that received on earth without been scattered by atmosphere. Beam radiations are also called direct radiation from sun.

Diffuse radiations are those solar radiation which received on earth, by changing the direction from scattering by atmosphere. Diffuse radiations are also called sky radiations or solar sky radiations.

Global radiations are also called total radiation on horizontal surface. The sum of beam and diffuse radiations are called global radiation. Data of these radiations are taken from weather data file.

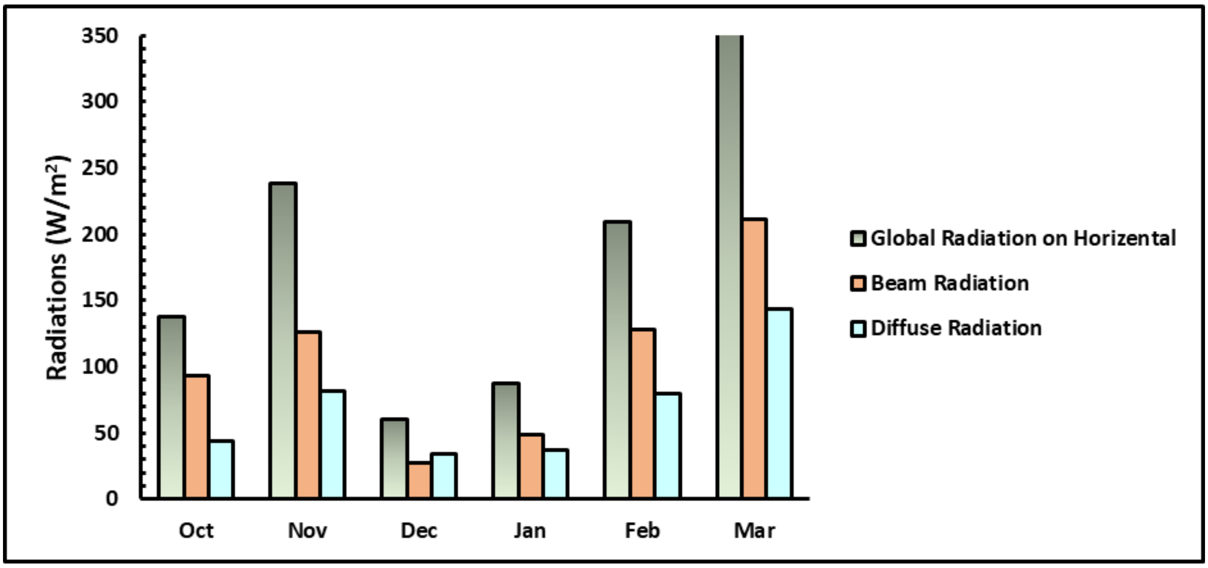

Figure 6 Solar Radiations in Winters in Islamabad

Chapter 2

Literature Review

2 Literature Review

Researches tried to resolve the issues by performing wide range of experiments. It was hard to assume the experimental approach because of technical restrictions faces during experiments. By putting long term experiments under consideration, modeling and simulation found to be fruitful and significantly mitigate the repetitive experiments. Simulation can be considered mathematical experiment similar to practical experiments [11]. The understanding which could not be gained through physical experiments due to different factors i.e. non-occurrence of ideal environment and financial related issue, can be achieved via simulation. Usually, practical experiments are expensive and time taking while simulation is cheaper and fast. Simulation's result is mostly dependent on correctness of applied mathematical approach. Simulations allow us to execute variety of technical approach by removing numerous uncertain conditions related to weather, human errors and bias. [11]

Nowadays, simulation and modeling are chiefly a vital way to resolve complex issues, it started almost 300 years ago, which was introduced by a French naturalist, Comte de Buffon (1707 – 1788). He got fame by his needle tossing problem which considered as first simulation. Later, this technique was adopted by two mathematicians named Jon von Neumann and Stanislaw Ulam in 1946 during World War II while designing of hydrogen bomb. Hit and trial method was very expensive way to solve neutron puzzling issue. Roulette wheel method was applied to resolve the problem iteratively and notable success achieved. [12] The first electronic computer was made in 1946 which was called as ENIAC. Ulam introduce computer based simulation while facing neutron puzzle during working on hydrogen bomb. The 'Monte Carlo' was considered as great achievement which was introduced during design of thermonuclear weapons by Teller-Ulma.[13] Simulation became famous in industrial and business applications right after World War II. Outstanding progress in modeling and simulation was started in mid of 1920s. Mechanical differential analyzer was also used in some common differential equations but it was limited to research only. The main development was done in 1950s when electronic replaced bulky machine. Simulation was promoted by vast development and industrialization. In 1960s, analog computer was replaced by digital which advances the computing tools, which later advanced modeling and simulations as well. simulation became user friendly in 1990s after the introduction of computer graphics.[14]

2.1 Historical Perspective

It has proved by literature research that Greek also used solar energy for heating. Teachings of Greek Philosopher Socrates (470-399 B.C) for residences orientation were recorded by classic Greek Xenophon as a proof. [15]

For houses which faces south, the sun's rays in winter enters the porticoes whereas in summer it is exactly above the shades on the top. so, we should have made the south side loftier in winters to get solar heat and north side lower to keep away the cold air.

According to Hottel (1989), in 1938, beginning of research in solar heating is marked by Godfrey L. Cabot using a donation to the Massachusetts Institute of Technology for solar energy studies. As per Hottel (1989), Godfrey L. Cabot started research on solar heating in 1938, which was funded by Massachusetts Institute of Technology for solar energy studies. He built first solar heated house, in MIT with named MIT Solar House I, in United States in 1939. House was a 16 x 31-foot one-story combination office and solar laboratory. A house was built, over an insulated storage tank with volume of 62 m^3 of water, contained a solar system 34 m^2 of triple-glazed collector on its roof facing towards south. Study tells that collector in Solar House IV was shifted 60° southward to gain the maximum result in cold season and water flowing through collector with rate of around 40 kg/h per square meter of collector, whereas storage ration with respect to collector was approximately 95 $1/m^2$. Collector had efficiency of 45% normally and energy gain was enough to provide 48% of entire house load including space heating service hot water supply. [16]

As per szokolay 1975, In Europe the first house was built in France in 1972, with the Chauvency-le-Chateau house and the Odeillo houses which selected rather passive solar heating system. Another house, Milton Keynes house, built in Britain in 1974 that was working on solar heating system which has flat plate solar collector and water storage system to fulfil space heating and hot water as per requirements. The storage to collector ratio of that house was 116 l/m^2 and simulated performance of system was 30% on average efficiency of collector and an annual solar fraction of 59% [17]

Duffle and Beckman (1980) explained that a working solar heating system can consists of five elementary modes of processing which is related to number of circumstances related to the scenario that is going on that time. These are:

a) The collected energy is stored in the storage system, if solar energy is available but not needed in the building.
b) The collected energy is directly transferred to the load, if solar energy is available and heating needed in the building.
c) Heat is required in the building while no solar energy is available and thermal energy is stored in storage unit, in such scenario heating load requirements are met by heat from storage system.

d) Heat is required in the building while no solar energy is available even storage unit is also empty, in such circumstances heating load requirements are met by using auxiliary energy.

e) Heat is not required in the building while solar energy is available and storage unit is full, in this scenario, the collected energy is discarded.[11]

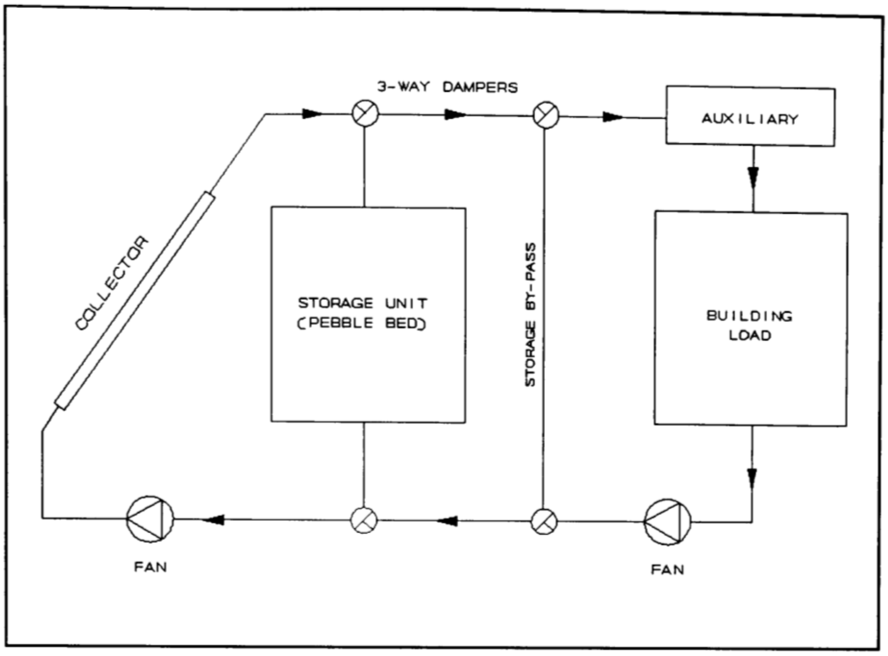

Figure 7 Schematic of basic air-type solar heating system

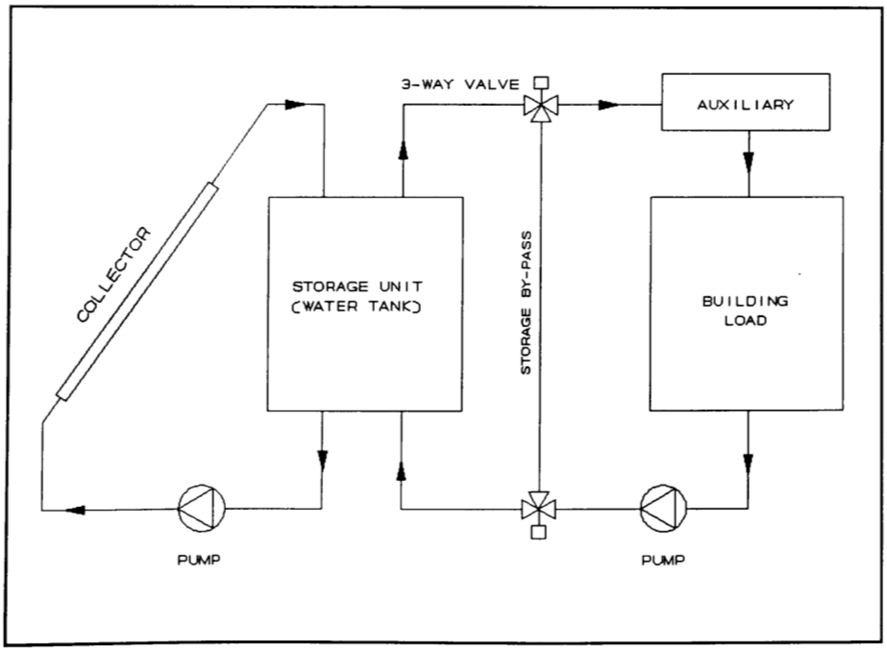

Figure 8 Schematic of basic liquid solar heating system

TRNSYS was used by Ammar et al in 1989 to examine the performance of space and domestic heating system in Alexandria, Egypt. They simulated the ideal conditions for water based heating system with respect to weather and socioeconomic conditions of Alexandria. They recommended at in ideal conditions that working collector orientation must be equal to Latitude. Storage to collector area must be of the order of 300 kg m^{-2} and flow rate of water via collector must be 50 kg h^{-1} m^{-2} [18]

TRASYS was user by Freeman et at in 1979 to study the working of combined solar heat pump systems for residential space and domestic hot water heating. They discovered that the amalgamation of a heat pump and a solar energy system reduce the disadvantages each system has when operating separately.

a) Temperatures are low in winter season so energy collected from the solar system is too low to use for direct solar heating.
b) Due to low ambient air temperatures in winter season the coefficient of performance of a heat pump is also low.[19]

Brademuchl and Beckman in 1979 produced a a process to calculate the economic analysis and feasibility of solar heating system in terms of life cycle over a predictable heating system. They used two parameters to explore life cycle savings which narrate all life cycles. The two parameters are cost for fuel of first year and cost of initial investment. They created a way for estimating the design of solar heating system, which maximize the life cycle savings, with the help of general life cycle saving equation.[20]

In 2002, Weiss et al 2003 introduce twenty-one combi, in market which was identified and categorized according to specifications. Nine of them were investigated deeply in simulation system. Buffer storage for space heating is used by most of them. This storage can be used for space heating or as supplementary heater. [21]

In Canada, Leckner and Zmeureany (2011) life cycle cost for net zero energy building is fortified with solar combi systems.[22]

For space heating, Amer Al-damook studied thermal performance of unglazed solar air collector. The highest outlet air temperature is 34 ˚C, which indicates that for space heating this collector can be used in Ramadi in cold season. [23]

D.M. Whaley et researched about modeling, building and preliminary experimental testing of performance of a integrated solar thermal system prototype for provision of space and domestic heating of water. This goal behind this system designing is to change the existing domestic water heaters and to make it more efficient in humid and hot weather conditions by using liquid fuel. Those results, of experiments, are compared with TRNSYS simulation. [24]

A report from the calculation for German Energy utilization in 2013, done by David Fischer et, indicates that 83% energy in residential sector is used for creation of domestic hot water (13%) and space heating (70%). Thermal profile demand is important to properly control the working and sizing of technology. The stochastic bottom up method for electric load has increased to domestic hot water and space heating demand. Authentication with respect to measured data for German single family houses represents an association of the normal daily load profile for DHW utilization of 0.92 and a mean relative error of 3% and for space heating 0.89 and 9%, accordingly. [25]

Fossil fuels based conventional energy resources are used to accomplish the need of required heating, during the winter, flat plate along with evacuated tube collectors are generally used to fulfil heat requirement. At present, studies are according to the weather conditions of Taxila, Pakistan. MATLAB based simulation system has designed for five locations different of Pakistan, Peshawar, Taxila, Multan, Karachi and Lahore based on potential assessment. Calculation depending upon an experimental setup, designed for Taxila, indicates that the highest temperature difference with fixed heliostat was 3 ˚ C, Q_{abs} was 27 W and highest efficiency was 30%. [26]

2.2 Research Objective

As cleared from literature review, very few installations were related to combine water and space heating system are available all over the world and no study related to climatic conditions of Pakistan. This means that this technology needs more development. The design parameters of this system are not yet standardized and properly documented. Moreover, for this analysis there is still a need to further investigate the dynamic parameters for such system under conditions, system configuration and control scheme. In present study various design parameters are optimized for solar based heating system. Dynamic simulations for whole winter season are carried out using TRNSYS for an office building which is designed in TRNSBuild located in Islamabad (33.71˚ N, 73.06 ˚ E). The performance parameters are solar fraction, solar collector thermal efficiency (η), fractional primary energy saving, f_{pes} and optimized size of hot water storage tank.

Chapter 3

System Configuration and Modeling in TRNSYS

3 Description of Thermal System's Configuration

In the designing of the system it has been divided into four loops.

First loop consists of collector storage tank loop in which pump circulate hot water from solar collector to hot water storage tank. Pump on/off conditions are controlled with the help of controller (shown in figure). Controller conditions are defined as if the collector out is greater than inlet temperature pump will be switched on.

Second loop consists of auxiliary heater and flow divider. Pump receives hot water from collector storage loop at 60˚C for space and water heating which is illustrated in the figure. If the temperature of the hot water at the exit of storage tank below the defined value auxiliary boiler will be switched on and will raise the water temperature at desired 60˚C ($T_{aux,\ i}$ in figure). Thermostat is used to monitor the temperature of the hot water at outlet of storage tank continuously. When ($T_{aux,o}$ = 60˚C) hot water moves towards flow divider. Flow divider divides the water into two portions space heating and water heating.

Third loop consists of radiator and building for space heating. Hot water leaves the flow divider for space heating and circulates in the tubes of radiator. $T_{air\ in}$ Room air strikes with the walls of radiator and $T_{out,air}$ come back with hot air for occupants.

Forth loop consists of hot water tank and load. Occupants obtain hot water $T_{hw,in}$ according to the requirement. For Refilling of tank pumps are installed according to the water usage of occupants in different time. Controller is attached with the pump for on/off

When the high temperature fluid returning from the radiator and mix the relatively cold fluid present in the tank. This fluid decreases the overall temperature of the working fluid inside the tank and auxiliary boiler must make up for this energy loss. This situation could also happen during cloudy day to fulfill the heating demand of occupants.

Configuration schematics is shown in below figure.

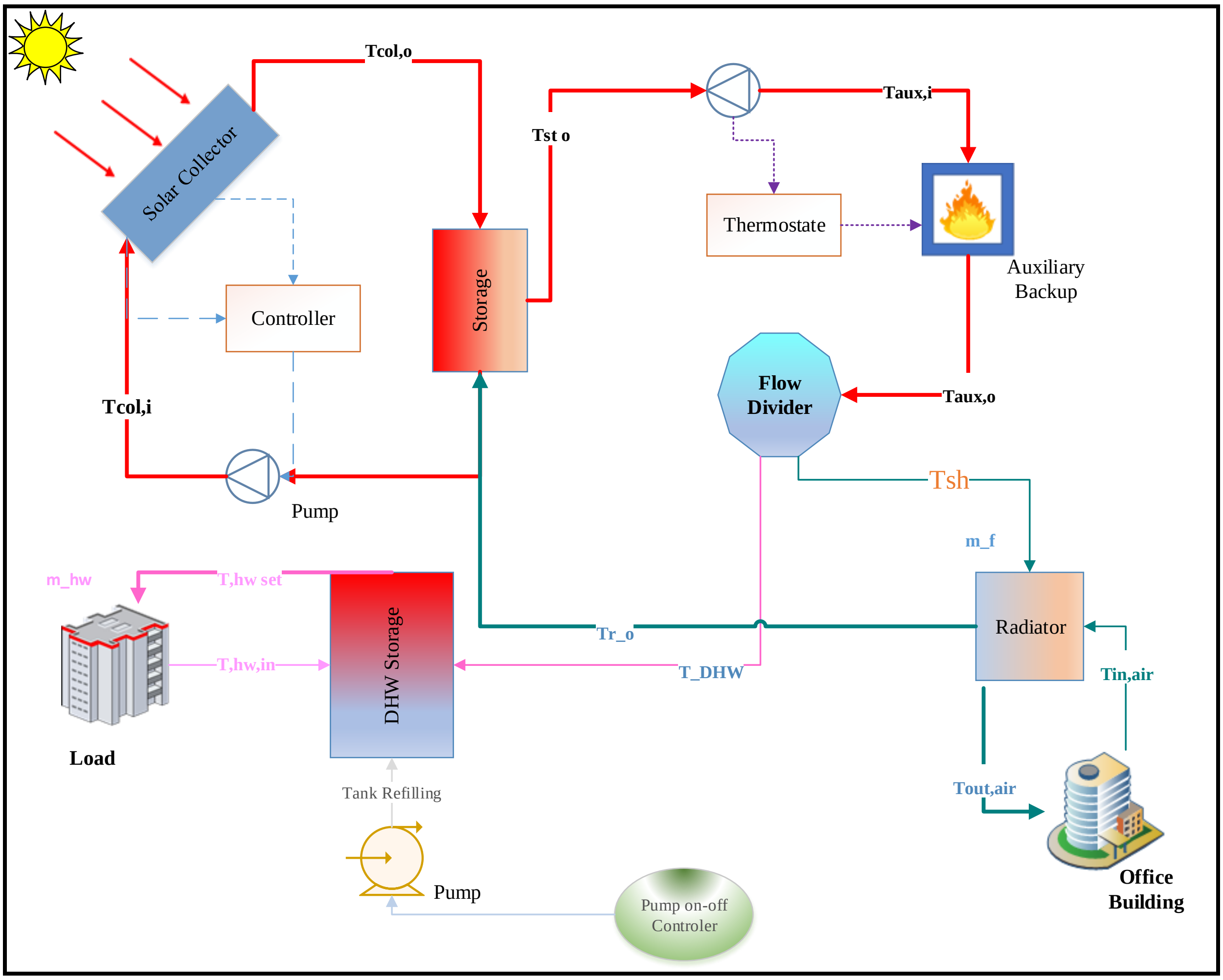

Figure 9 Schematic Diagram of Configuration

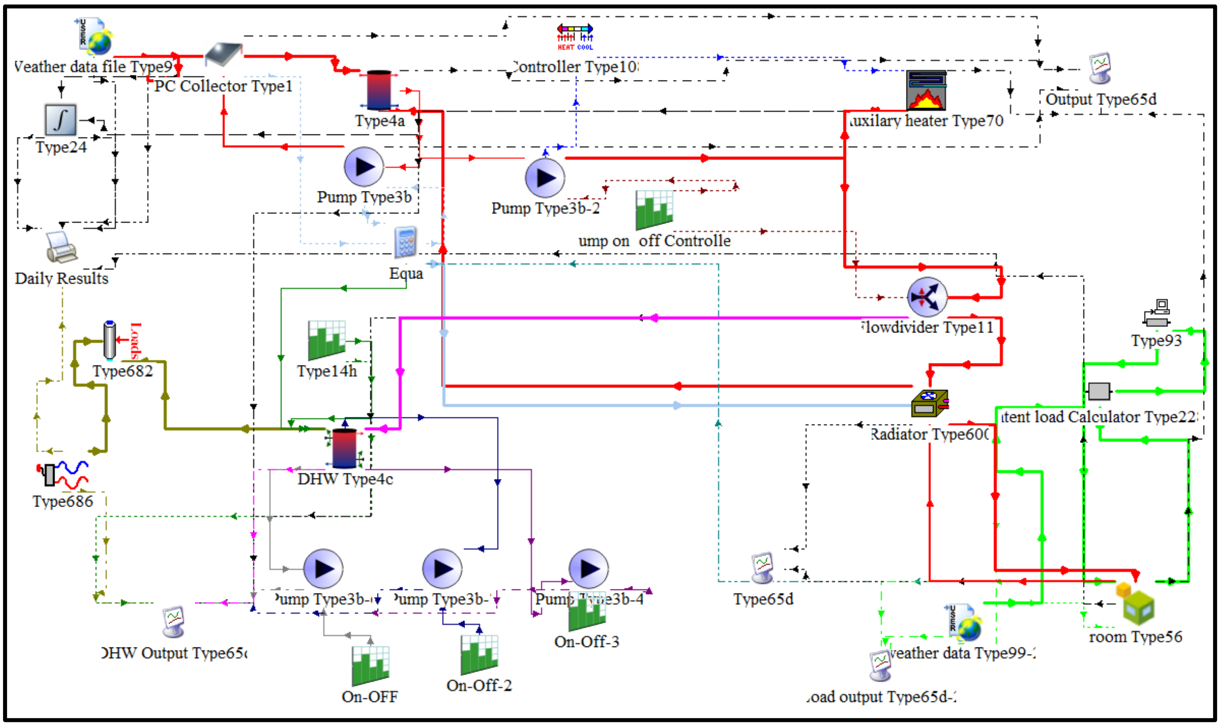

Figure 10 Pictorial view of TRNSYS with FPC in simulation studio

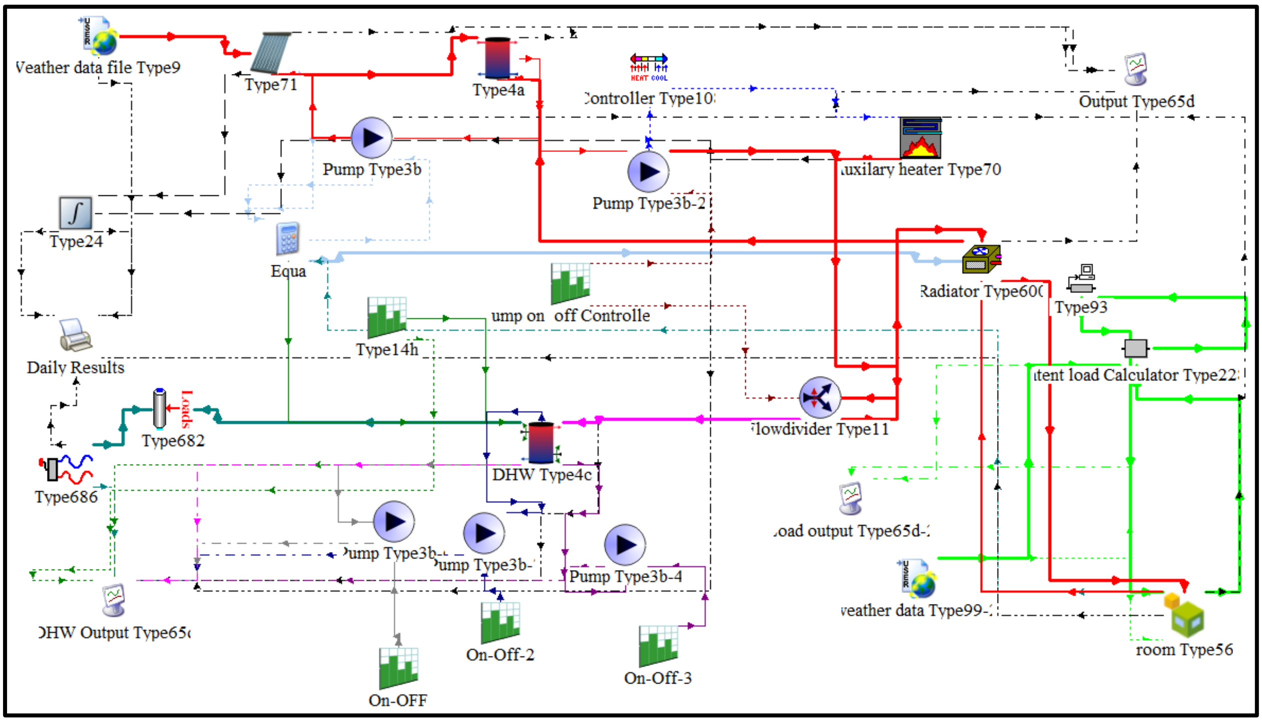

Figure 11 Pictorial view of TRNSYS with ETC in simulation studio

3.1 Modeling in TRNSYS

The described system configuration scheme of the solar based combine space and water heating system is modeled in TRNSYS and TRNSBuild to meet the heating demand of 3.5 Kw for location of Islamabad (33.71 ˚N, 73.06˚ E). The TRNSYS program (version 17) is used to model and simulate the system for weather file of typical metrological year (TMY) file for Islamabad.

As the purpose of this study is to primary analyze the effect of overall thermal performance of the configuration, following assumptions are made in TRNSYS modeling and simulation:

- Thermal properties of the material used remains constant and do not change with respect to temperature.
- Heat transfer coefficient remains constant throughout the simulation.
- Mass flow rate is uniform throughout the simulation.
- Energy losses in the connected pipes and/or valves are ignored

Figure 10,11 shows the pictorial view of combine water and space heating model on TRNSYS simulation studio.

3.1.1 Solar Thermal Collectors (Type 1b and Type 71)

For model the thermal performance of solar flat plate collector, TRNSYS component 1b is used. Total collector array depends upon the number of modules in series and characteristics of each module. Similarly, type 71 is used to model the thermal performance of evacuated tube collector. For both these collectors, 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,[11]

$$\eta = a_0 - a_1 \frac{(T_{in} - T_{amb})}{I_T} - a_2 \frac{(T_{in} - T_{amb})^2}{I_T} \qquad (3.1)$$

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 inlet of solar collector and T_{amb} is the air temperature. Typical values for these parameters for FPC [27] and ETC [28] at their specified flow rates are in table 1

Table 1. Efficiency parameters for FPC and ETC

Collector Type	Area m^2	a_0	a_1 $(W/m^2.K)$	a_2 $(W/m^2.K^2)$	m Kg/hr m^2
FPC	7	0.749	2.77	0.023	40
ETC	6	0.84	1.47	0.01	42

Collector tests is performed only at the incidence angle modifier (IAM) value at optical mode two. For flat plate collectors, $(\tau\alpha)_b /(\tau\alpha)_n$ can be approximated from ASHRAE test results (ASHRAE, 2003) as [29]

$$\frac{(\tau\alpha)_b}{(\tau\alpha)_n} = 1 - b_0\left(\frac{1}{\cos\theta} - 1\right) - b_1\left(\frac{1}{\cos\theta} - 1\right)^2 \qquad (3.2)$$

Incidence angle typically 50˚, here $(t\alpha)_b$ for beam radiation depend upon incidence angle and $(t\alpha)_n$ at normal incidence, b_1=0 and calculated b_0 = 0.2 from above equation.

3.1.2 Storage Tank (Type 4a)

TRNSYS component Type 4a is used to model hot water storage tank which is thermally stratified. For this purpose, multi-node approach is used in this 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 function of time.[11][30] The flow toward collectors always leaves from bottom node and flow towards load always leaves from top node. In this simulation 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]

$$\dot{m}_i C_{pf}\frac{dT_i}{d_t} = \alpha_i \dot{m}_h C_{pf}(T_h - T_i) + \beta_i \dot{m}_L C_{pf}(T_L - T_i) + UA_i(T_{env} - T_i) + \begin{cases} \gamma_i(T_{i-1} - T_i)C_{pf} & \text{if } g_i > 0 \\ \gamma_i(T_i - T_{i+1})C_{pf} & \text{if } g_i < 0 \end{cases} \qquad (3.3)$$

Here C_{pf}, m_i, m_h, m_L are specific heat of the tank fluid, mass in the ith section, fluid mass flow rate to tank from heat source, fluid mass flow rate to the load and/or of the makeup fluid, β_i defined control function.

3.1.3 Auxiliary Boiler (Type 700)

Type 700 is a steam boiler which is employed in our model to serve as an auxiliary backup to raise the temperature of working fluid to the required driving temperature for space and water heating system. It predicts the energy consumed based on defined combustion and boiler efficiency. Whenever the boiler is switched on, the heat energy ($\dot{Q}_{boiler}$) required to increase the temperature of the working fluid from inlet temperature (T_i) to the desired outlet temperature (T_o) is calculated as:

$$\dot{Q}_{boiler} = \dot{m}_f C_{Pf} \, (T_O - T_i) \qquad (3.4)$$

where $\dot{m}f$ and Cpf are the mass flow rate and specific heat of the fluid flowing between storage tank and flow divider, respectively. In our case auxiliary heater is a natural gas gasifier which will run with help of natural gas which produced with the help of domestic garbage or bagasse.

3.1.4 Radiator (Type 600)

Type 600 model is an air handling device that mix two streams of air, passes a mix stream across the fan and then across the coils that contains either hot/cold water. This component relies on the bypass approach to modeling the energy exchange between the air stream and the hot water coil. This component has a free-floating coil in that model contains no internal controls on either the water or the outlet air temperature. The outlet condition results only depend upon the inlet conditions.If the temperature of the liquid entering the coil is higher than the temperature of the air leaving the fan coil is determined to be in heating mode. An iterative approach is used to determine the equilibrium between the coil and the air.

Energy transfer from the air stream to the liquid steam is computed as;

$$\dot{q_{liq}} = m_{air,\dot{c}oil}(1 - f_{bypass})(h_{air,coil} - h_{air,fan}) \qquad (3.5)$$

3.1.5 Office Building (Type 56)

TRNSBuild is plugin software for TRNSYS for simulating any closed or open-air zone. Our examined building is an office building, which has been has been designed in TRNSBUILD software which is a part of TRNSYS 17. Main dimensions of examined building are as follow (8 m × 5 m × 3.12 m). All exterior four walls are directed to four directions and windows are positioned in east, west and south facing.

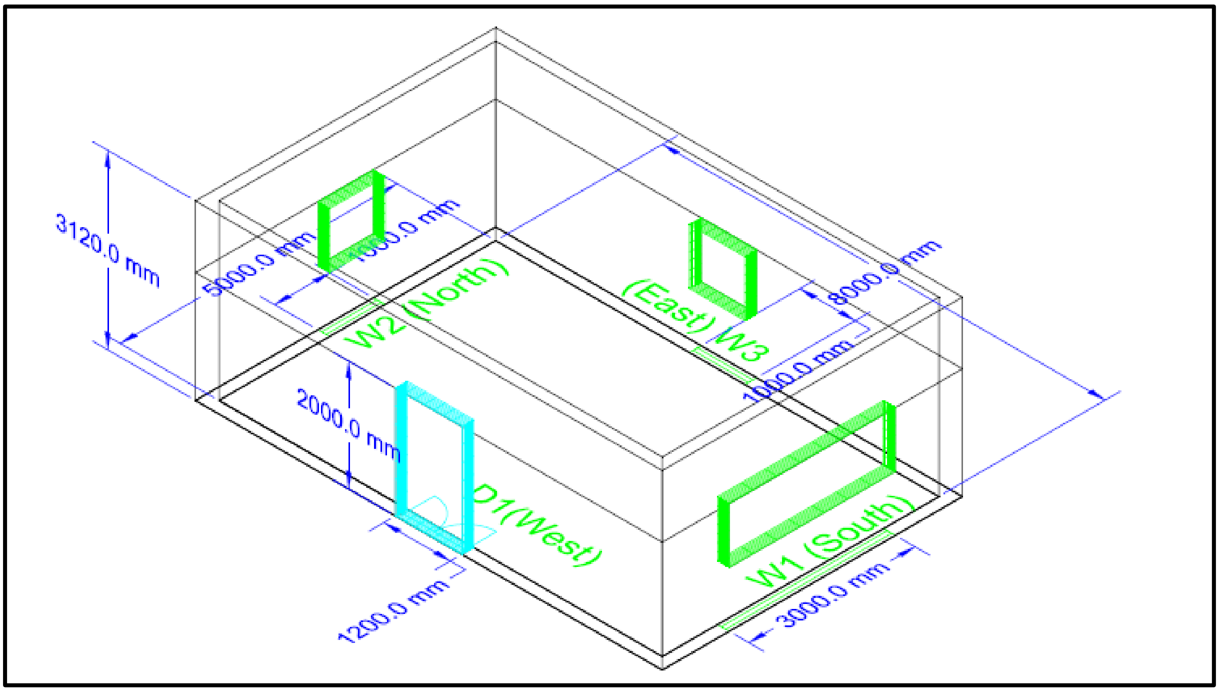

Figure 12 Room 3-D model

Table 2 Dimensions of Office Building

Wall	**Length (m)**	**Width (m)**	**Height (m)**	**Net Area (m^2)**	**Window (m^2)**
West	8.0	0	3.12	24.9	0
South	5.0	0	3.12	15.0	3
North	5.0	0	3.12	15.0	1
East	8.0	0	3.12	24.0	1
Roof	8.0	5.0	0	40	0
Floor	8.0	5.0	0	40	0

The examined building has an insulation which is good enough and due to this fact, it has relative low heating demand. The thickness of outer walls is 21.2 cm each consisting on following layers: 1.2 cm plaster, 20 cm combrick (composite bricks), with 2.166 W/m^2 K U-value. Thickness of roof is 25.2 cm with following composition: 10 cm concrete, 10 cm combrick (composite bricks) and 5.2 cm mineral wool insulation with 0.717 W/m^2K U-value. There are various layers of the floor from concrete and tile, with a total thickness of 20 cm with following composition 10 cm concrete and 10 cm combrick (composite bricks) with thermal transmittance (U-value) equal to 2.816 W/m^2 K. All three windows are made up of insulating glass have U value equal to 2.83 W/m^2K and g (glazing) value 0.755%.

Materials which are being used in building designing have following thermal properties.

Table 3 Thermal Properties of Materials [22]

Thermal properties of structural materials			
Material	C_p (J/kg K)	ρ (Kg/m^3)	k (W/m K)
Brick	1000	1800	0.85
Plaster	1000	2000	1.4
Insulation	800	40	0.04
Concrete	800	2400	2

We are considering 5% of internal heat gain values in building. Furthermore, in examined building computers of occupants which has main load around 2.3 kW, the load for lighting is 1 kW and 10 seated persons have been taken in this analysis.

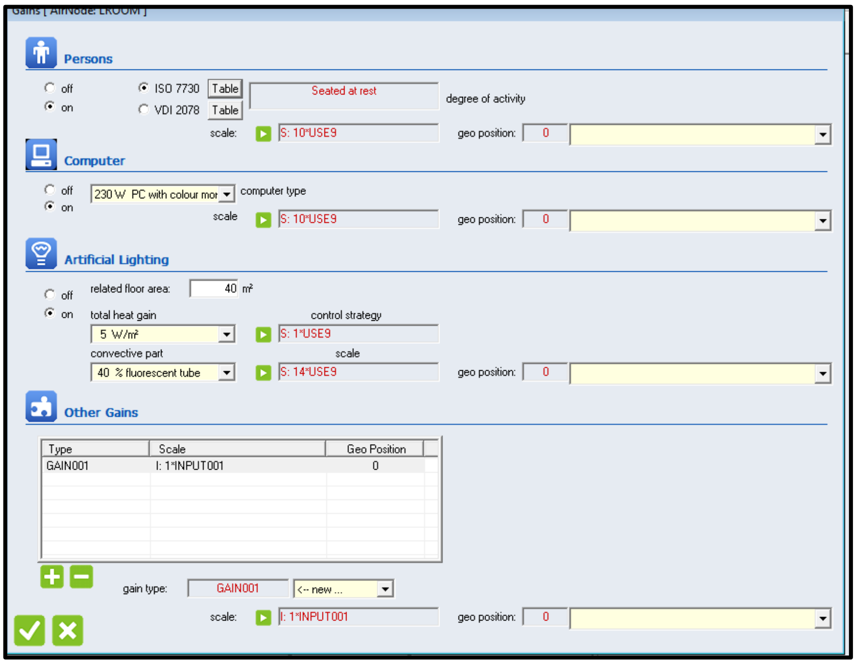

Figure 13 Gains in room

The structure is an office building which works from 9:00 to 17:00 on daily basis. For purpose of ventilation in building we have considered three air changes every hour. This is called air change rate. This analysis has been conducted for months from November to March.

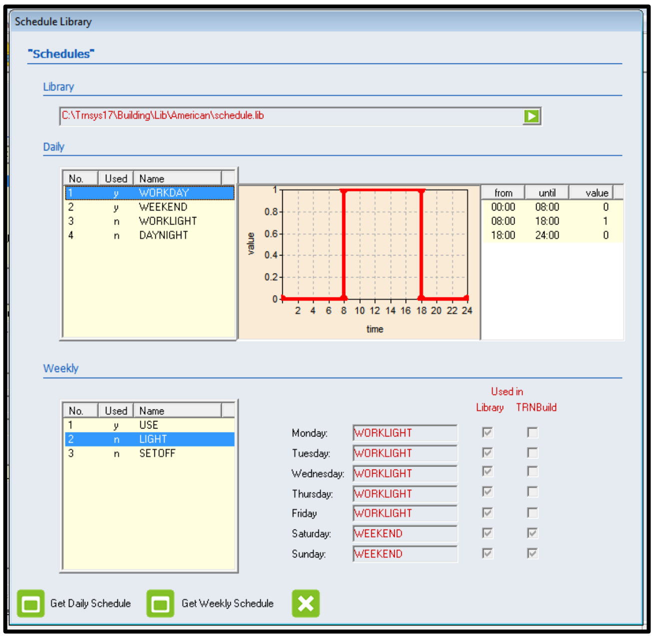

Figure 14 Working days Schedule

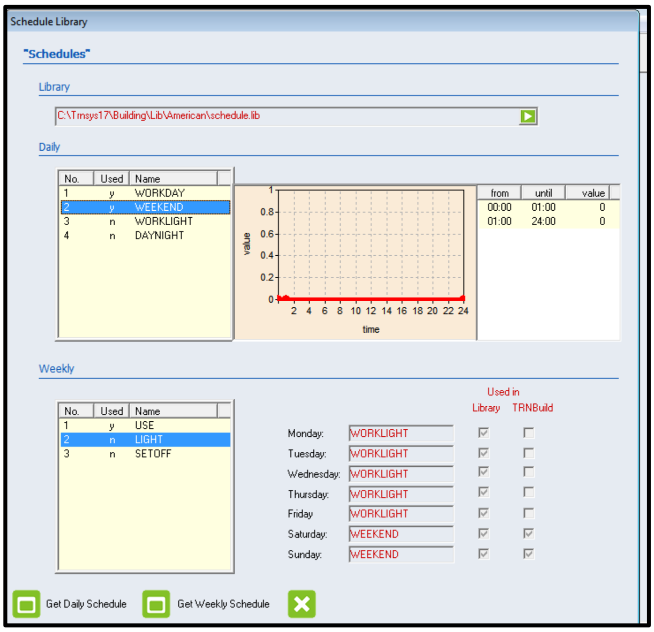

Figure 15 Weekend Schedule

Table 4 Characteristics of Office Room

Feature	Value's
Volume of lecture room	125 m^3
Capacitance	150 KJ/K
Air change rate	3 per hour
Heat gain from people	100 watt per person at rest

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

For load calculation through TRNSBuild energy rate control method is being used. In energy rate control method activate a heating and cooling type in TRNSBuild, specify a set point temperature (5 ℃) against heating and see the Qsens output that Type56 generates. The peak values of Qsens are peak heating and cooling loads for each zone and the integrated value of Qsens is the annual heating and cooling load. The Qsens output from TRNSBuild is just the sensible energy demand, not the total demand. There would be a latent load in addition to the sensible load, if we impose a humidity setpoint in the zone.

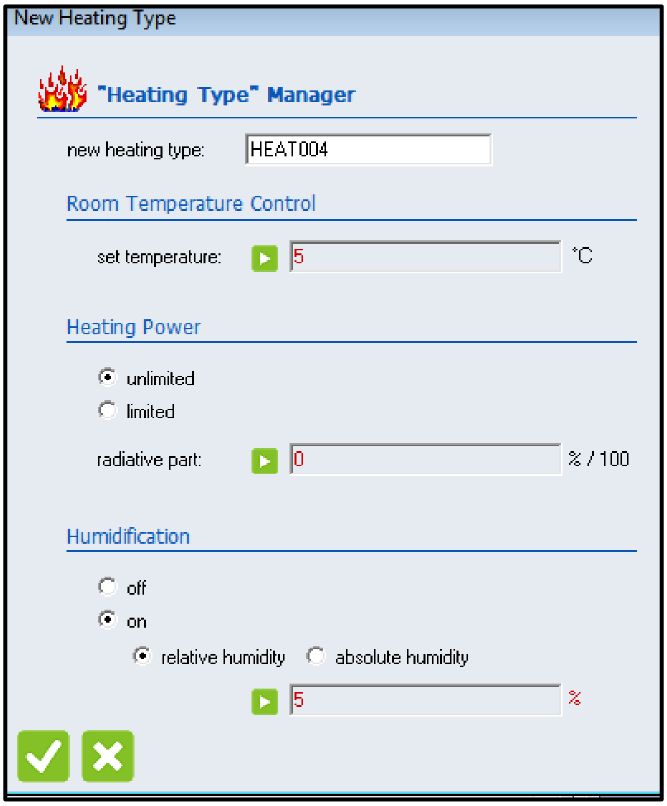

Figure 16 Heating load Manager

There is a "latent load calculator" component in the TESS loads and structures library. This computes the latent cooling/heating that typically happens because of sensible cooling/heating and can be used to get the total cooling/heating. Type2280 is normally used is to connect the sensible cooling load, air temperature and air RH outputs from a building model (such as Type56) to Type2280's inputs. Type2280 computes two things; the moisture removal rate and the latent energy. Type 93 (input value recall) is used to recall the latent load value from type 56. For use of type 93 with latent load calculator we need to add new input to Type56. Type56's input list is defined in TRNBuild. Open TRNBuild and go to a zone that is being cooled/heated. Open the gain manager for that zone and add a moisture (latent) gain.

The latent energy removal can then be combined with the sensible cooling/heating load to come up with an estimate of the total heating/cooling that occurs.

3.1.6 DHW Storage Tank (Type 4c)

Type 4c is fixed inlet and variable outlet tank, due to variable outputs it can easily use for providing hot water in building. Thermal performance of a fluid filled sensible energy storage tank, subject to thermal stratification, can be modeled by assuming that tank consists of nodes which are fully mixed equal volume segment. The value of N tells degree of stratification. If N is 1, the storage tank is modeled as a fully-mixed tank and no stratification effects are possible. Options of fixed or variable inlets, coefficients of incremental loss, dead temperature band on heater thermostats, unequal node sizes and losses to gas flue of auxiliary heater are all available.

Energy balance on ith segment can be defined as,

$$m_i C_{Pf} \frac{dT_i}{dt} = \begin{cases} (\dot{m_1} - \dot{m}_3) C_{pf} (T_{i-1} - T_i) & \dot{m}_1 \dot{\geq} \dot{m}_3 \\ (\dot{m_3} - \dot{m}_1) C_{pf} (T_{i+1} - T_i) & \dot{m}_1 \geq \dot{m}_3 \end{cases} \quad (3.6)$$

3.1.7 Heating and cooling Load (Type 682)

Usually in simulation of an HVAC system, the heating and cooling loads of the building have already been calculated, either by manual calculations or using another simulation studio. In TRNSYS studio simulation task is to simulate the effect of these loads upon the system. This component makes an interaction between pre-calculated loads and the HVAC system by imposing the load upon a liquid flowing through a device. This component simply carried out a user-specified load (cooling = positive load, heating = negative load) on a flow stream and calculates the resultant outlet fluid conditions. While simulating the system boiling and freezing points are ignored. This component can represent any devices such as water-heating building loads, chillers, heat pumps load, radiators load, etc. where the removal of the correct amount of energy from a flow stream is important.

In type 682 it is considered that it makes interaction between building and liquid working fluid in HVAC system. From mathematical point of view, this model is quite simple, user must provide the specific heat of liquid, flow rate, and temperature of liquid at a specific point in the loop. The building loads are added or subtracted from working fluid, in this method it gives an outlet temperature just past the interaction point.

$$T_{out} = T_{in} + \frac{\dot{Q}}{\dot{m} C_P} \quad (3.7)$$

According to the signs, positive load shows T_{out} is higher than T_{in} and vice versa. A negative load shows T_{out} lower than T_{in}.

3.1.8 Synthetic Building Load Generator (Type 686)

This component generates hourly cooling and heating loads for a synthetic building based on defined peak cooling and heating loads. This component is modifying sine-wave functions are used to account for daily variations, seasonal variations and weekday/weekend differences. The user may experience some random noise generated by system on daily and hourly basis to more realistically model the real building loads. This component is an excellent choice for commercial, industrial, and residential buildings requiring heating and cooling loads. This component represents a quick method to provide realistic loads without the time-intensive modeling required of a real building.

This component allows the value of cooling and heating loads to change according to the cooling and heating season by using a modifying SIN wave function. In this components user must define the start and end of cooling and heating season. The user must define the offset and multiplier parameters of SIN function according to requirement. The calculation of SIN function depends upon wheatear the season crosses the first day of the year or season is completed within one year. If the season crosses the annual boundary, two functions are required; one for the time of the year in which consider from the start of the year to the end of the season and one for the time of the year which is considered from the start of the season to the end of the year. There are no cooling loads during the non-cooling season and no heating loads during the non-heating season. The hourly based cooling and heating loads of a building are defined in this method:

$$\textbf{Load} = \textbf{Design Load} * X_{day} * X_{hour} * X_{noise,\,hour} * X_{noise\ day} \qquad (3.8)$$

3.1.9 Flow Divider, Thermostat and other Components

Type 11f (see Figure 12 & 13) are used as flow divider. Their function is normally controlled by an external control function, e.g. temperature and/or humidity. [30] In our model, type 11f (flow divider) is controlled by defining the value of temperature in such way so that whenever the temperature at the outlet of the storage tank ($T_{st,o}$) is more or less than 60˚C (i.e. the driving temperature for heating), it diverts all the flow towards the storage tank or towards the auxiliary boiler, respectively.

Type108 is a thermostat which works as a controller and control the operation of the boiler which depends upon the set point temperature. Type 3b is called variable speed pump which use to transfer the heat from one source to other and type 14h is called forcing function which controls the pumps operation with in specified hours (i.e 0900-1700 hours) in working days. System operates in defined hours and shut off after specific time and day.

Type 24, type 25c and type 65d are output devices and used for showing results. Type 24 is called integrator and it gives integrated value of defined time. Type 25 is printer which gives print of all values and type 65d is online plotter.

3.1.10 Weather Data (Type 99)

Weather data processed by type 99 containing user defined notepad file of Islamabad's data having latitude and longitude of 33.71° N and 73.06° E, respectively. Figure shows the variation of hourly global and diffuse solar radiation on horizontal plane.

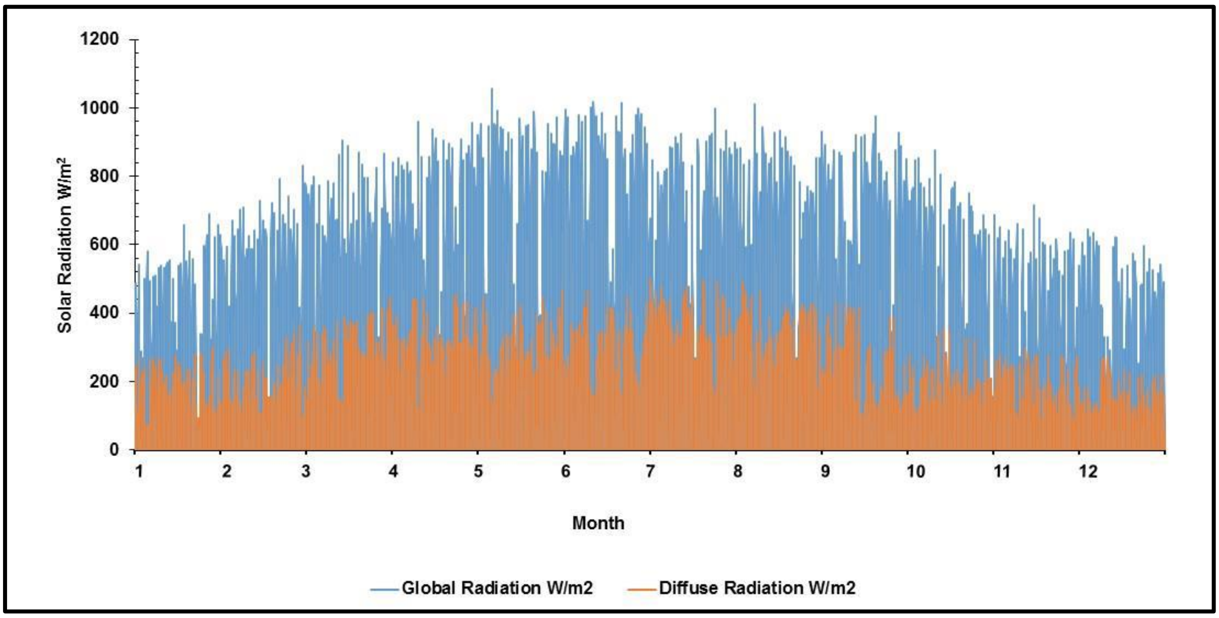

Figure 17 hourly global and diffuse solar radiations

3.2 System Performance Indicator

Following performance indicators based on integrated energy values over the whole winter season, are used to optimize the system:

3.2.1 Solar Fraction

Solar Fraction (SF) is the amount of energy contributed by solar collector divided by total energy required to meet the required heating demand. [32]

$$SF = \frac{\int Q_u}{\int Q_u + \int Q_{aux}} \quad (3.9)$$

where Q_u is the useful energy gain by the solar collector and Q_{aux} is the heat energy added from auxiliary boiler. S.F value is zero when system is entirely running on auxiliary heater/ cloudy days and 1 when all the required energy is provided by the solar system. High value of solar fraction is always desired to impose less load on auxiliary device.

3.2.2 Collector's Efficiency

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

$$\eta = \frac{\int Q_u dt}{A\int G dt} \qquad (3.10)$$

where *G* is the global solar radiation on a horizontal plane and A is the collector's area.

3.2.3 Primary Energy Savings

Equation for fractional primary energy savings (f_{PES}) is defined as [33]

$$f_{\text{PES}} = 1 - \left[\frac{\frac{Q_{bioler}}{\epsilon_{fossil}\, \eta_{boiler}}}{\frac{Q_{boiler,ref}}{\epsilon_{fossil}\, \eta_{boiler,ref}}} \right] \qquad (3.11)$$

where Q_{boiler} is the auxiliary heat supplied by the boiler for combine water and space heating system, $Q_{boiler,ref}$ is the sum of energy demand for space heating and energy demand for water heating, ϵ_{fossil} is the conversion factor for fossil fuel. $\eta_{boiler,ref}$ mean annual efficiency of the reference boiler, η_{boiler} mean annual efficiency of the auxiliary boiler.

ϵ_{fossil}= 0.9 (kWh final energy per kWh primary energy of fossil fuel)

η_{boiler}= 0.95 mean annual efficiency of the auxiliary boiler.

Chapter 4

Results and Discussions

4 Results

Simulations performed in TRNSYS 17 for whole winter season (i.e. from October to March). Simulation starts from 7296 hour and end at 2160 hour (i.e. November to march) for space heating and starts from 6552 hours and ends at 2160 hours (October to march) as for water heating, simulation time step of 0.125 hour.

4.1 Space Heating Load Profile from TRNSBuild

Figure 18 shows the load profile generated by TRNSBuild according to the specifications of designed building. The load profile generated from the building sensible and latent load. According to generated profile, designed building has required almost 1-ton heating system for fulfillment the heating need of occupants. Generated load profile shows the daily requirement of heating load of occupants in building which tells the heating requirement is maximum in December and January.

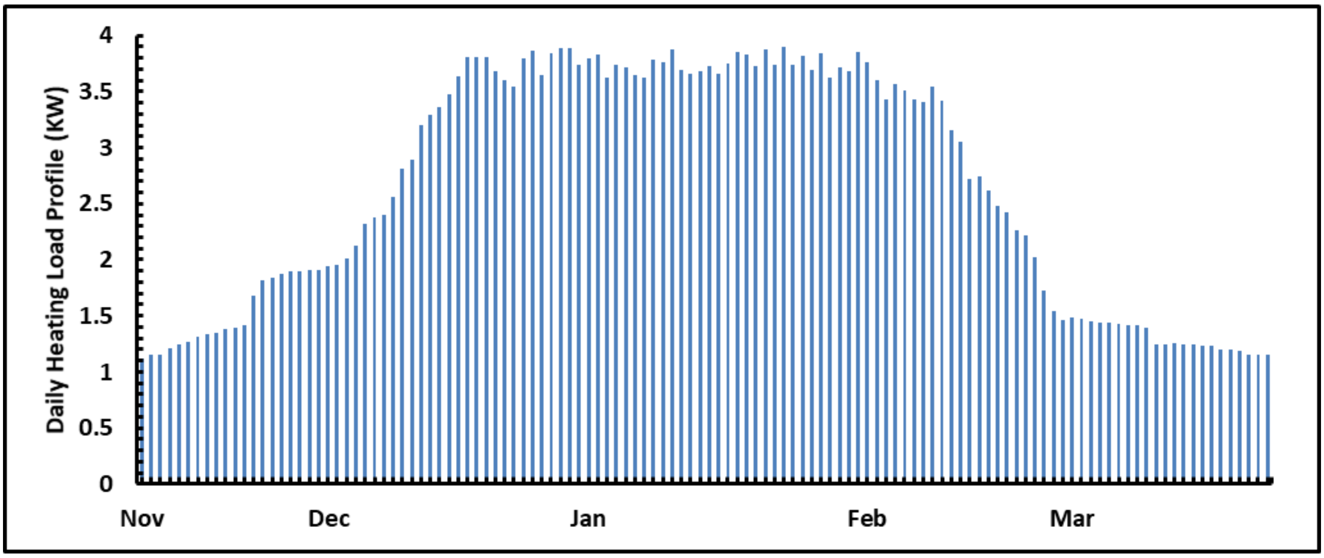

Figure 18 Heating Load Profile by TRNSBuild

4.2 DHW Load Profile

Figure 19 shows the load profile of hot water for entire winter months October to March with the help of synthetic building load generator based on defined 1 tonn peak heating load, variation of load by considering day time and seasonal variation on hourly basis. It provides realistic load instead of time consuming manual load calculations. This heating load profile shows utilization of hot water in winters month. The profile shows that water heating demand in October is less because this month is beginning of winter season as the winters going heating requirement increases. Figure shows December and January has maximum heating requirement.

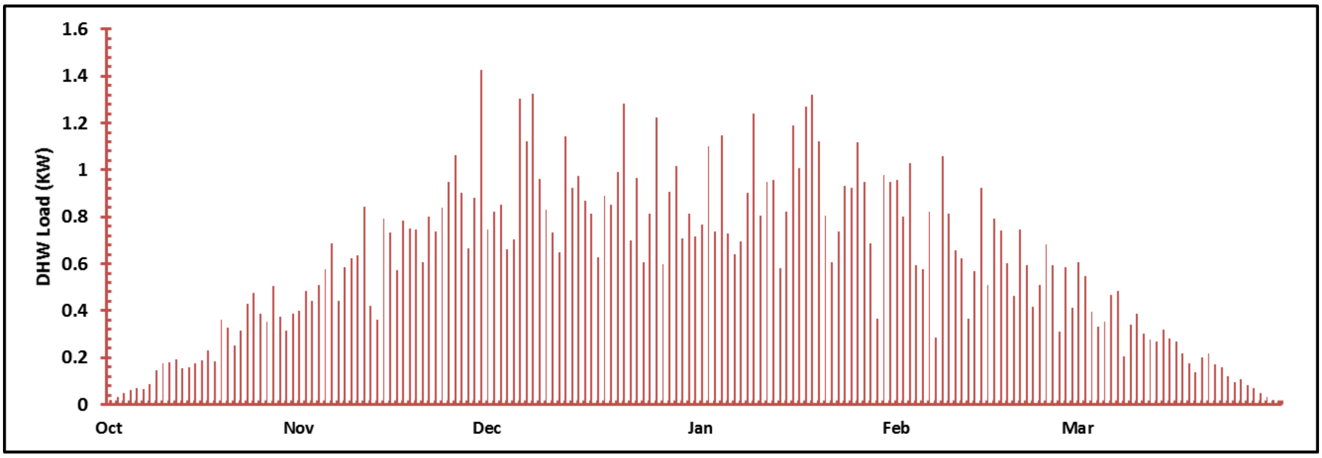

Figure 19 Domestic Heated Water load profile on Monthly Basis

4.3 Collector Slope VS Solar Fraction

Figure 20 shows the effect of collector tilt on solar fraction. Maximum solar fraction of flat plate collector is in the range of 30-40˚, while for Evacuated tube collector is in the range of 35-40˚ for winters in Islamabad region. For calculation of S.F pumps mass flow rate, area of collector and volume of storage remains constant. Similar trend for summers , with collector tilt and SF are observed by [34]

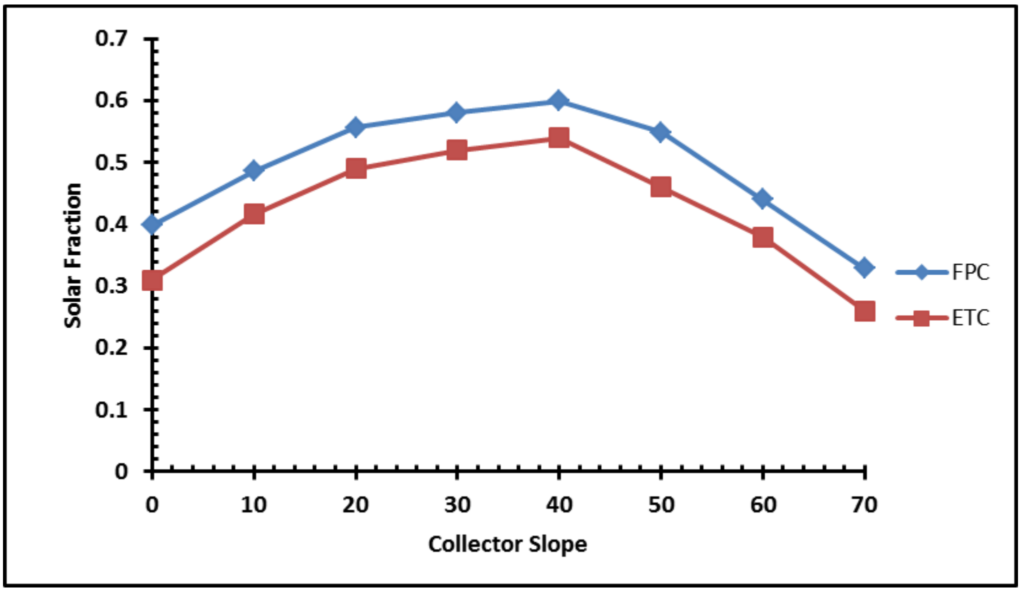

Figure 20 Solar Fraction Variation with Collector tilt for FPC (7 m^2) and ETC (6 m^2)

4.4 Collector Area VS Solar Fraction

Figure 21 shows the seasonal variation in solar fraction of flat plate and evacuated tube collector for simulated system. It shows as collector area increases solar fraction is also increasing because with the increase of collector size amount of solar radiation increases. Large amount of solar radiation forms more energy for utilization in system. It shows that ETC has higher value of solar fraction as compare to FPC. ETC has number of tubes due to which heat of solar radiations absorbs in tubes and less losses occurred and performance of system increase. The difference between FPC & ETC decreases with increases collector area. SF similar trend has been observed by [34]

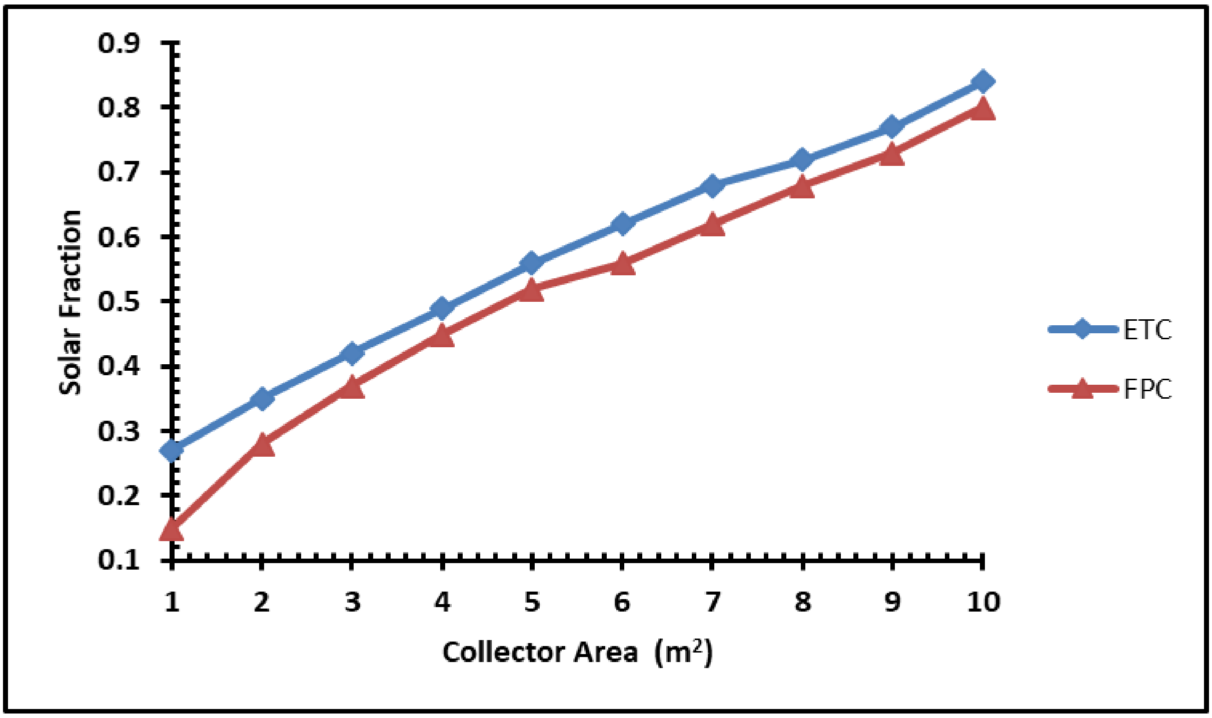

Figure 21 Seasonal Variation of Solar Fraction with FPC & ETC

4.5 Collector Area VS Primary Energy Savings

Figure 22 shows the seasoanl variation of primary energy savings with respect to flat plate and Evacuated tube to meet the heating demand of occupants.

Evacuated tube collectors yields for both configurations are always higher primary energy savings as compare to flat plate collector with the increase in collector area. This means that solar system is significant in primary energy saving of fuel/electricity.

Collector area is selected where 50% primary energy savings of fuel/electricity is obtained, which is 7 m^2 for FPC & 6 m^2 for ETC.

The difference between both values are decreases with the increase of collector area. It is because when working fluid come back from the radiator at high temperature it mix with the low temperature fluid in the storage tank . It reduce the temperature of the remaining fluid present in the storage tank due to this auxilary boiler remains on for longer period.

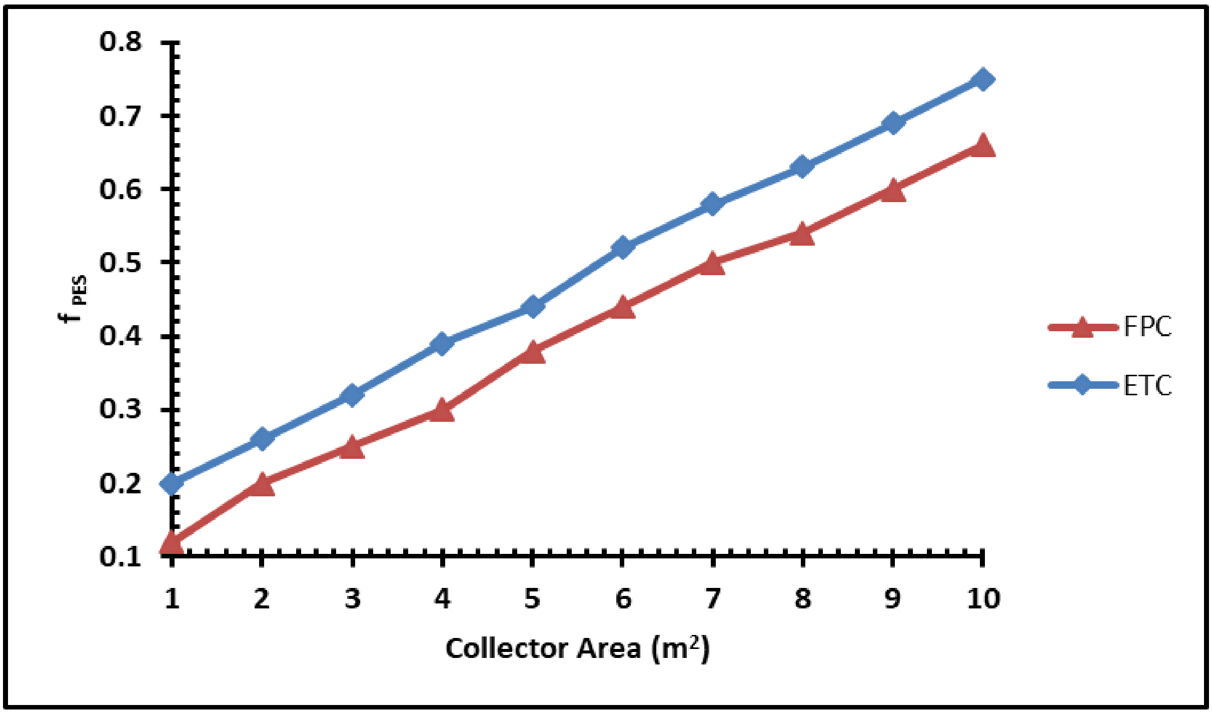

Figure 22 Seasonal Variation of Primary energy savings with FPC & ETC

4.6 Monthly Basis Results

Areas for both collectors have been decided according to the primary energy savings and pumps flow rates are constants for both configurations then simulations are performed on the monthly basis for winter seasons (i.e November to March).

4.6.1 Primary Energy Savings

Figure 23 shows the monthly primary energy savings for constant FPC & ETC areas for configuration and at constant pump flow rates. The graph shows that maximum primary energy savings obtained in month November because according to TRNSBuild load profile November, march and February have minimum required heating demand for both space and water heating. December and January have maximum required heating value so that both these months have minimum primary energy savings. In Islamabad region December and January are the coldest months so in these months maximum heating required to the occupants for comfort level. Primary energy savings from ETC has higher value at less area as compare to FPC.

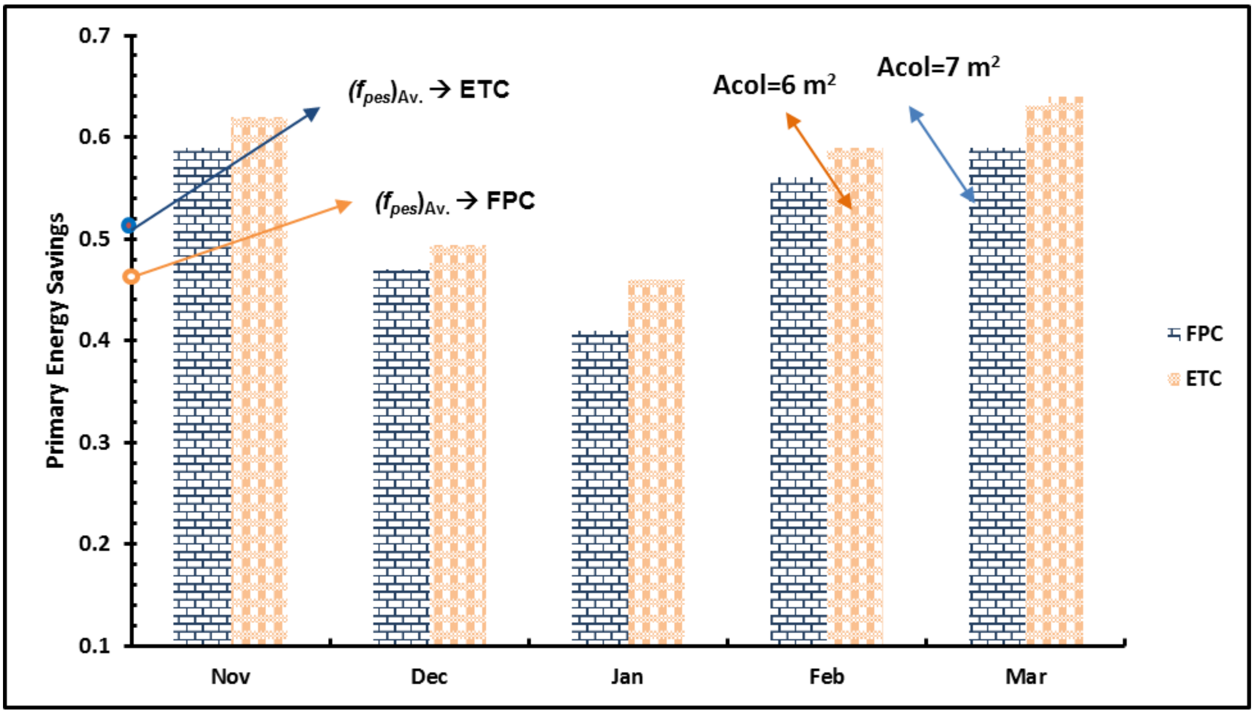

Figure 23 Monthly Variation in Primary energy savings of FPC & ETC

4.6.2 Collector's Efficiency

Collector efficiencies of FPC and ETC on monthly basis are shown in figure. The collector efficiencies presented here are also for the collector where primary energy savings are obtained at least 0.50. FPC's efficiency lies in the range of 0.29-0.5 with average seasonal efficiency 0.38. On the other hand, ETC seasonal efficiency is larger lies between the range of 0.33-0.58 with average 0.44. The difference between efficiencies of FPC and ETC is due to driving temperature of system.

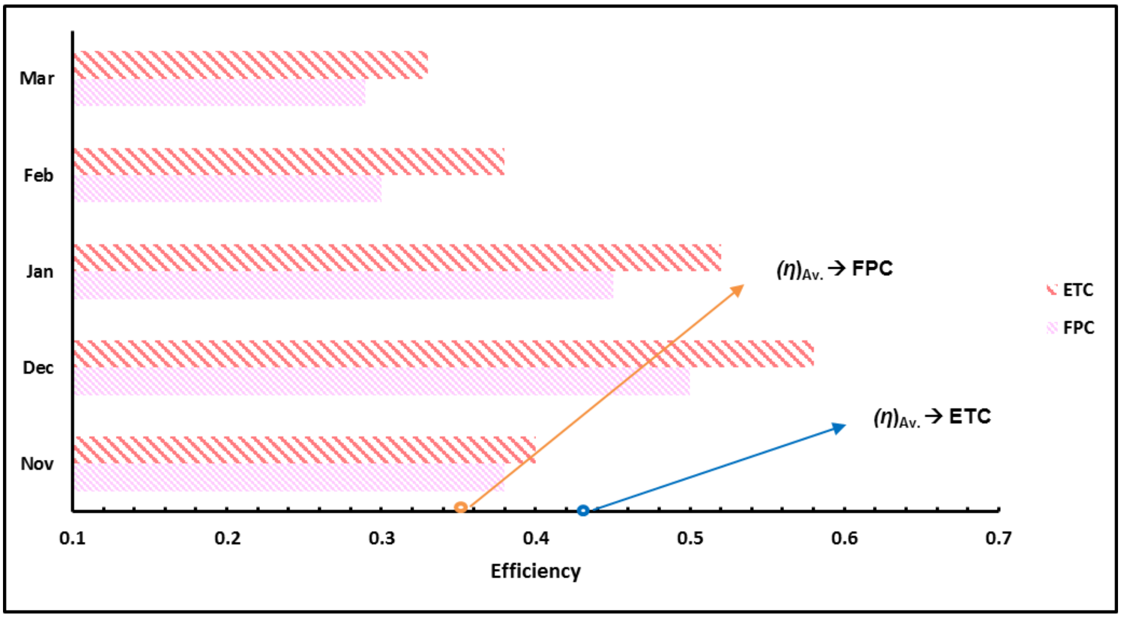

Figure 24 Monthly Variations in Collector's Efficiency for FPC & ETC

4.6.3 Solar Fraction

Figure 25 shows the monthly solar fraction at constant collector areas and pumps flow rates. The trend of solar fraction is higher in November and march is due to lower heating demand when compared to January and December in which maximum heating load. As for the case of collector efficiencies the influence of system configuration on SF is also marginal (about 1%). It is since in the expression of solar fraction and collector efficiency the amount of energy from solar collector (Q_u) is accounted for those periods also when this energy is not being utilized for heating.

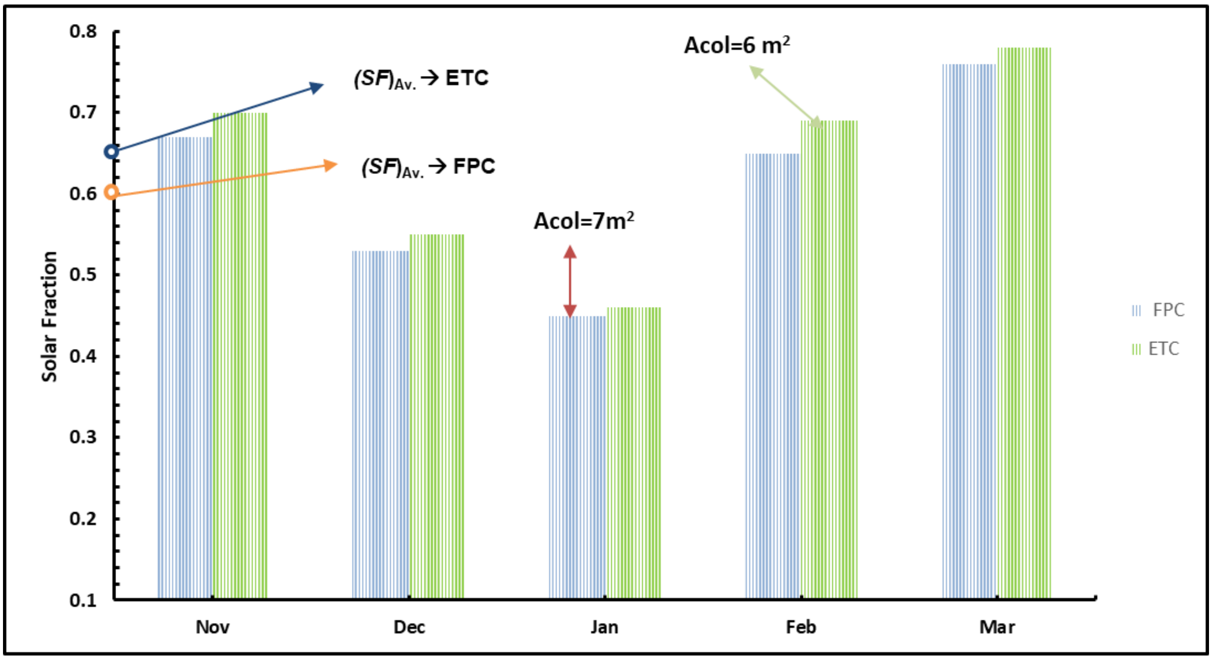

Figure 25 Monthly Variations in Solar Fractions of FPC & ETC

4.7 Storage Tank Size Optimization

For optimization of storage tank size solar fraction and primary energy saving factors are considered on different storage sizes. This simulation runs for whole winter seasons (November to March).

4.7.1 Solar Fraction

Figure 26 shows effect of changing storage tank size on seasonal primary energy savings and solar fraction in which area of FPC ($7m^2$) and ETC ($6\ m^2$) for designed model. Trend shows that solar fraction is increasing with respect to increase in the tank size at certain limit after that it decreases with the increase of storage size. It is because as the storage size increases solar energy (Q_u) will not enough to heat the storage water for driving the system.

For storage optimization similar way has been used by [34]

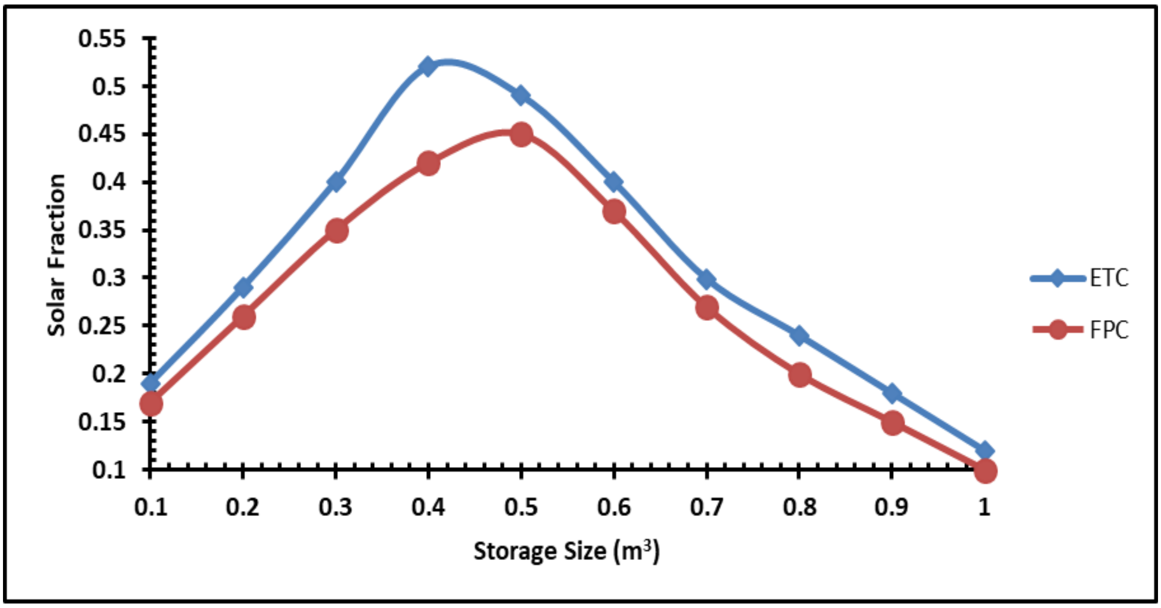

Figure 26 Seasonal Variation of Solar Fraction by varying storage size with FPC (7 m^2) & ETC (6 m^2)

4.7.2 Primary Energy Savings

Figure 27 shows the trend of primary energy savings against storage tank size for both configurations with FPC & ETC. Primary energy savings increases with the increase of storage size but it decreases after certain limit. It is because when working fluid comes back from the radiator at high temperature it mix with the fluid in the storage tank . It reduce the overall temperature of the remaining fluid due this auxilary boiler remains on for longer period to fulfill the heating requiremnet.

Figure shows that optimum storage for ETC is less due to high thermal efficiency. For ETC required solar collector and thermal storage volume are less to achieve maximum primary energy savings.

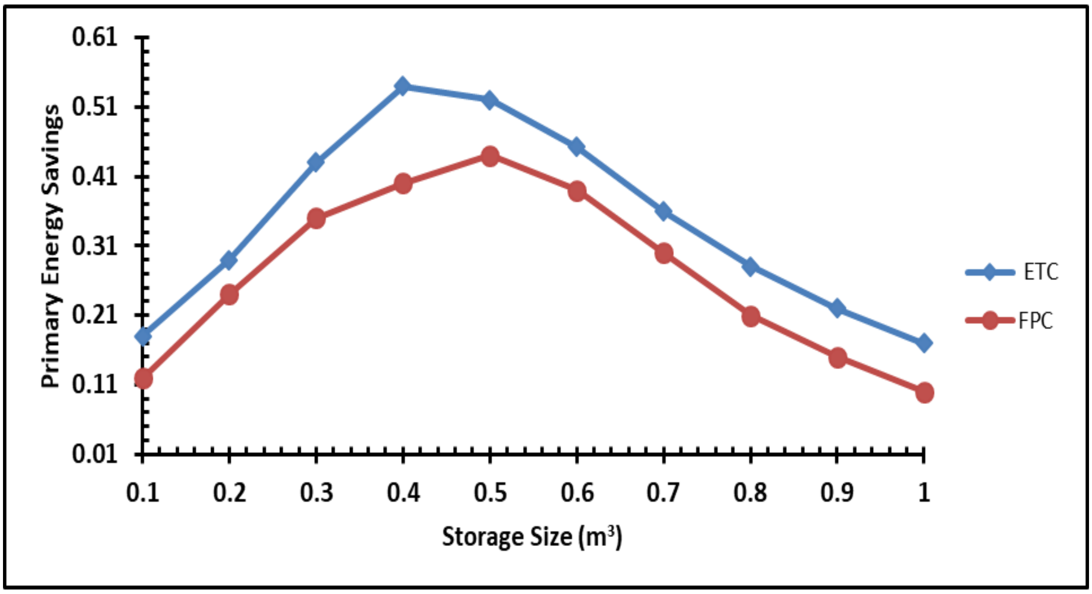

Figure 27 Seasonal Variation of Primary Energy savings by varying storage size for FPC & ETC

It is concluded that primary energy savings should be used as the deciding factor to evaluate and compare the performance of whole system, which would lead to selection of optimum system configuration to be employed in practice. We have seen solar fraction and collector efficiency is also important parameters but these parameters may not give a conclusive result about the comparison of system's performance based on different schemes. Area required to achieve the minimum 50% primary energy savings are higher in case of flat plate collector than evacuated tube collector.

4.8 Primary Energy Savings against Pump Flow Rate

Figure 28 shows the primary energy saving trend against storage auxiliary loop's pump flow rate. If the pump is flowing heat from storage to auxiliary at minimum flow rate than less heat will move from storage to auxiliary, and large amount of Qaux will require for heating purpose in this way primary energy savings will minimum. As flow rate increases primary energy savings increase after a certain increase pump will supply heat from storage to auxiliary very fast so less amount heat will stay in auxiliary for heating purpose. In this manner, more Qaux will require for heating in this way primary energy savings decrease.

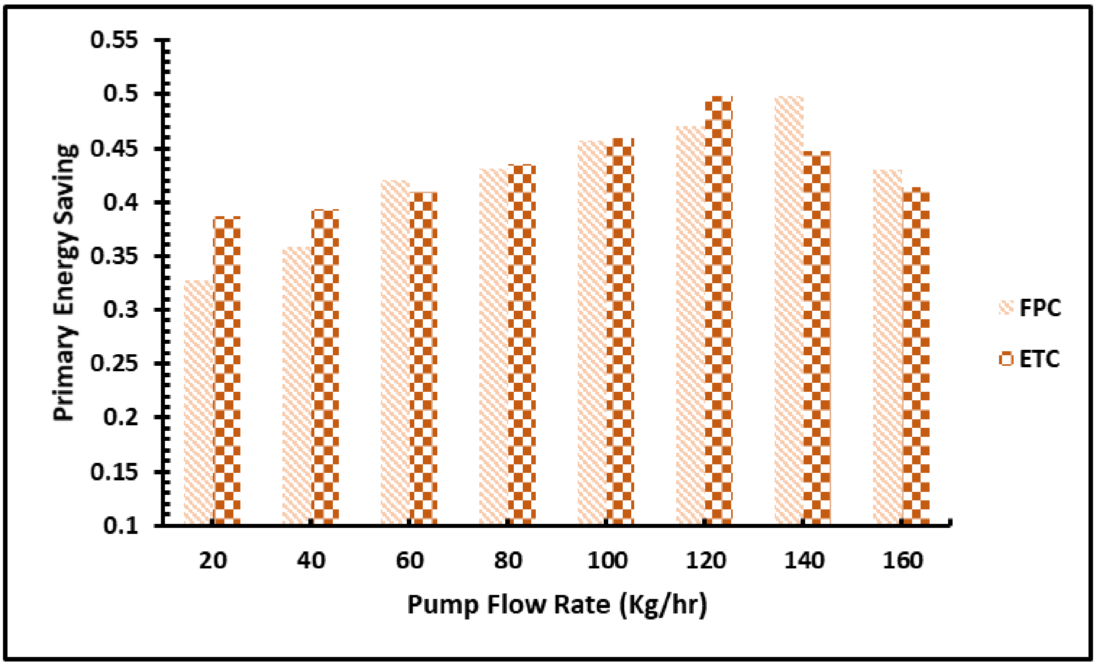

Figure 28 Seasonal Variation of Primary Energy savings by varying pump flow rate for FPC & ETC

4.9 Room Temperature

Figure 29 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 24˚C in week days. This temperature is enough for the comfort of occupant's present in the office building and temperature is equal to ambient at weekends because the system is considered not in working condition at weekends. System is being shut off after 1700 hours of week days with the help of controllers and being started at every morning on 0900 hours. Room temperature achieved in both collectors is almost show same profile because radiator fan is controlled with the help of controller. In this controller as room temperature exceeds fan will not allow hot water to pass heat into the room. So, in all configurations room temperature profile will be same.

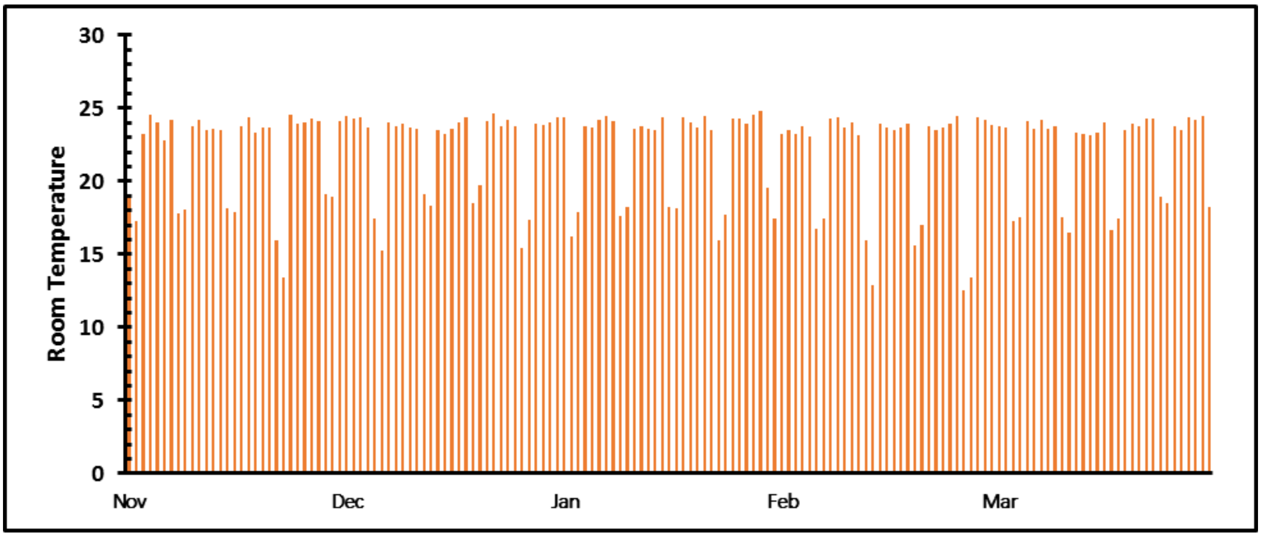

Figure 29 Variations in Room Temperature on Monthly Basis

4.10 Hot Water Temperature

Figure 30 shows the hot water temperature achieved from the DHW tank for utilization in winter days. The achieved temperature is in range of 53-58 ˚ C in working days while in 20-40˚C at weekend. Water is enough heated for fulfilment of heating requirement of occupants.

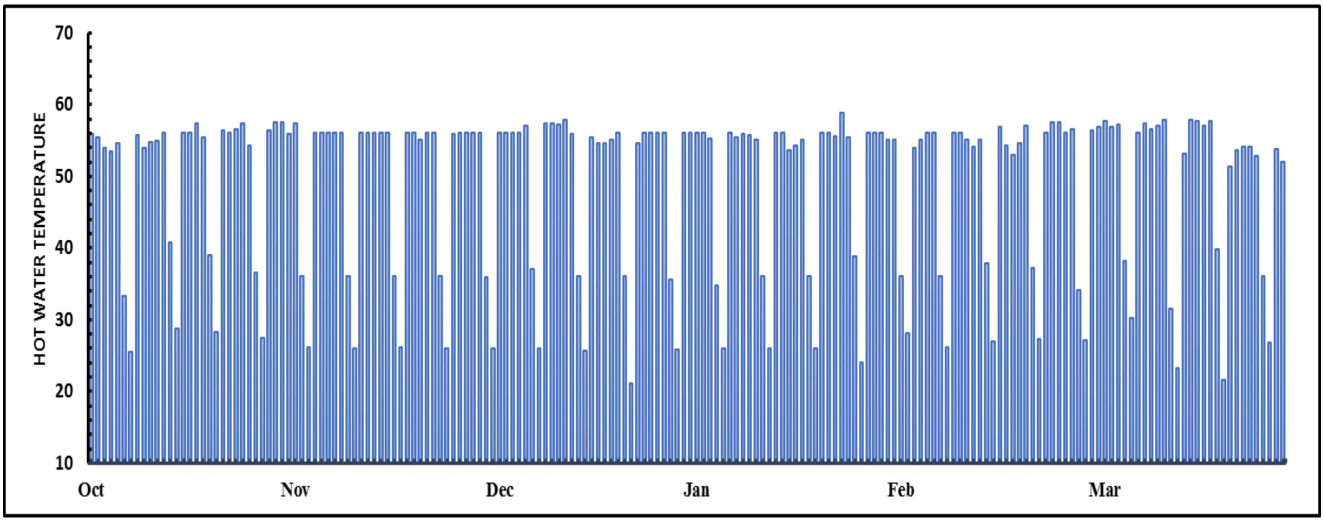

Figure 30 Variations in hot water Temperature on Monthly Basis

4.11 One Day Profile

For clear picture of solar radiation, T_{col} , T_{amb}, room temperature, hot water temperature, space heating and water heating load profiles, and storage out temperature one day profile has been drawn of FPC and ETC .

4.11.1 FPC Profile

Figure 31, shows one-day (20th December) temperature and load profile of the whole system of FPC. This profile has been generated on constant collector area, (7 m^2) storage tank (0.5 m^3) and flow rates. The profile shows that as the sun rising, collector gaining heat from sun and whole system has started working. Figure shows that in the presence of sun, system performance is according to the comfort of occupants in regard of space and water heating. Figure 21 shows temperature of the collector is enough to attain the heating demand and storage temperature is not equal to desire temperature (60 ° C). So, to achieve desire temperature auxiliary heater switched on.

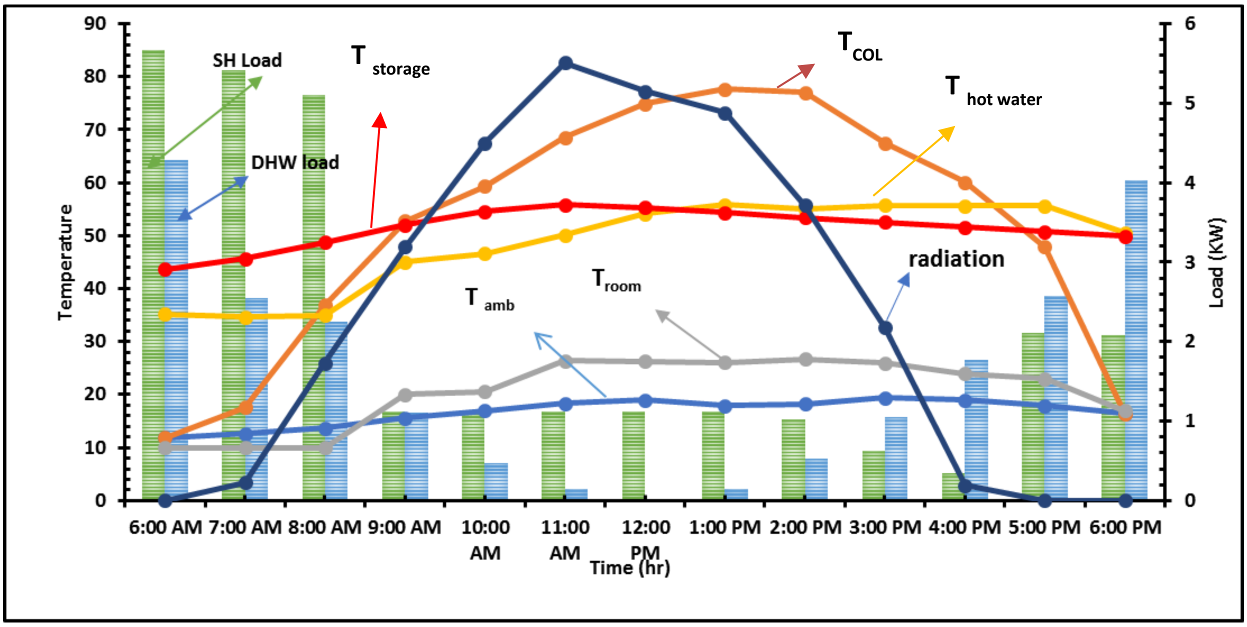

Figure 31 One-day (20th December) Profile for FPC

4.11.2 ETC Profile

Figure 32 shows one-day (20th December) temperature and load profile of the whole system of ETC. This profile has been generated on constant collector area, (6 m^2) storage tank (0.4 m^3) and flow rates. The profile shows that as the sun rising, collector gaining heat from sun and whole system started working. From 0900-1700 hours, system performance is according to the comfort of occupants in regard of space and water heating. Figure 23 shows the collector and storage out temperature for ETC in which auxiliary on/off depends upon storage out temperature. In this process, more auxiliary is required to cope up the heating demand of system.

Results obtained from ETC are good as compare to FPC, in ETC room and hot water temperature during the whole day is more than enough for the comfort of occupants while in FPC to achieve the comfort temperature it may take time. Results obtained from ETC shows that minimum auxiliary heating required to achieve a comfort temperature. The minimum area required for flat plate collector to achieve 0.5 primary energy savings is more than evacuated tube collector.

Overall it is concluded that ETC is the optimum choice for the current system and location.

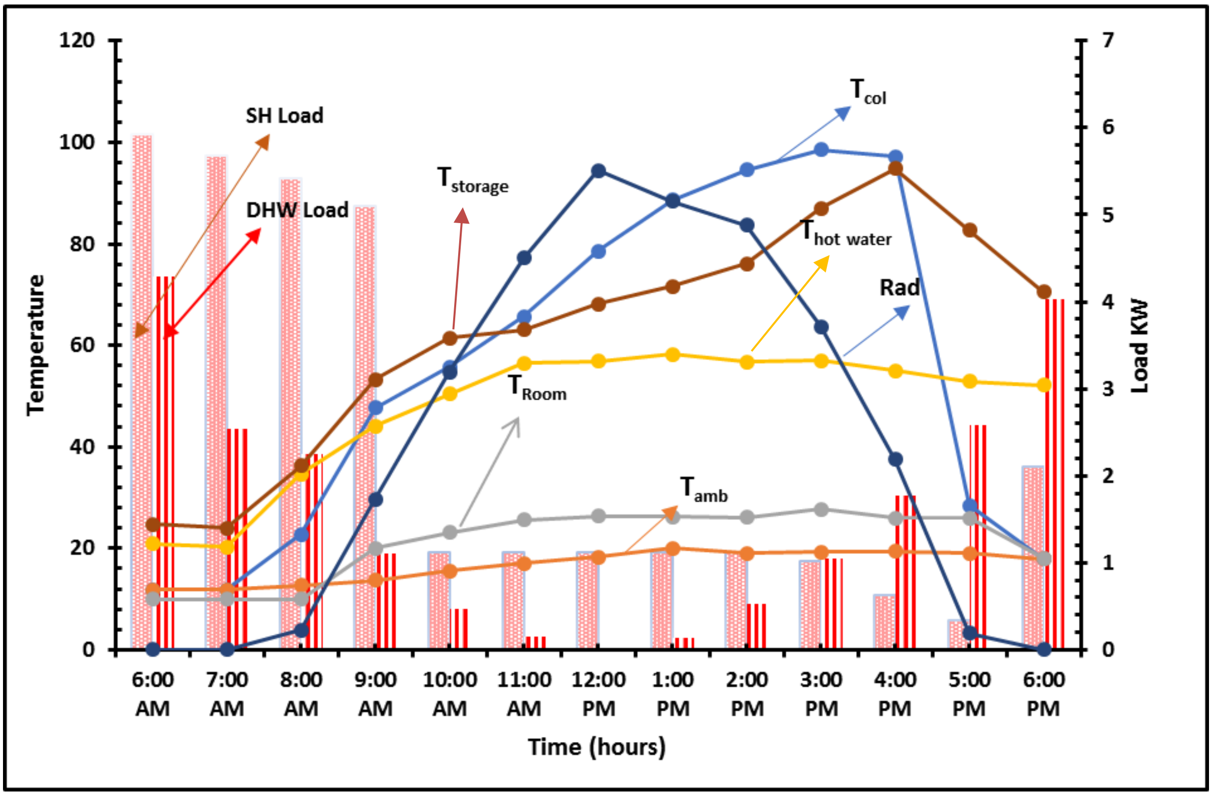

Figure 32 One-day Profile (20th December) for ETC

Chapter 5

Economics Analysis

5 Economic Analysis

Economic Analysis of both systems are carried out on RETSCREEN by consider 50% heating delivered to each system by storage. Economic Analysis of both systems are performed individually.

5.1 Solar Air Heater

For solar air heater, base case of natural gas analysis with proposed case of natural and solar system. Following Parameters are considered for analysis of air heater

Table 5 Parameters for Air Heater analysis

Facility Type	Commercial	
	Base Case	Proposed Case
Indoor Temperature ℃	25	25
Air temperature ℃	40	40
Design Air flow rate m^3/hr	655	655
Operating day per week	5	5
Operating hour per day	8	8
Slope of Collector	45	45

Table 6 Monthly usage of air heater

Monthly usage of air heating system	
January	100%
February	80%
March	50%
April	0%
May	0%
June	0%
July	0%
August	0%
September	0%
October	0%
November	60%
December	100%

Flat plate collector with area of $3m^2$ has been considered of manufacturer solar-max heating with price of 20000 PKR. Pump power 140 W/m^2 with electricity rate of 13.00 PKR considered in this case. Natural gas is considered as a base case for heating system while natural and solar suggested. Engineering cost, feasibility study cost, operation and maintenance cost other heating components cost are considered 61000 PKR. According to RET Screen emission analysis, GHG emission in case of Natural gas is 0.7, while in case of solar natural gas proposed system is 0.4. This shows the proposed system is environmental friendly. According to RET Screen analysis proposed system fuel mix ratio is from natural gas 45.7%, solar 35.2% and electricity 18.8% .

In financial analysis following parameters are considered

Table 7 Financial Analysis Parameter

Financial Parameters	
Fuel Cost Escalation rate	10%
Inflation Rate	5%
Discount Rate	5%
Project Life	30 year

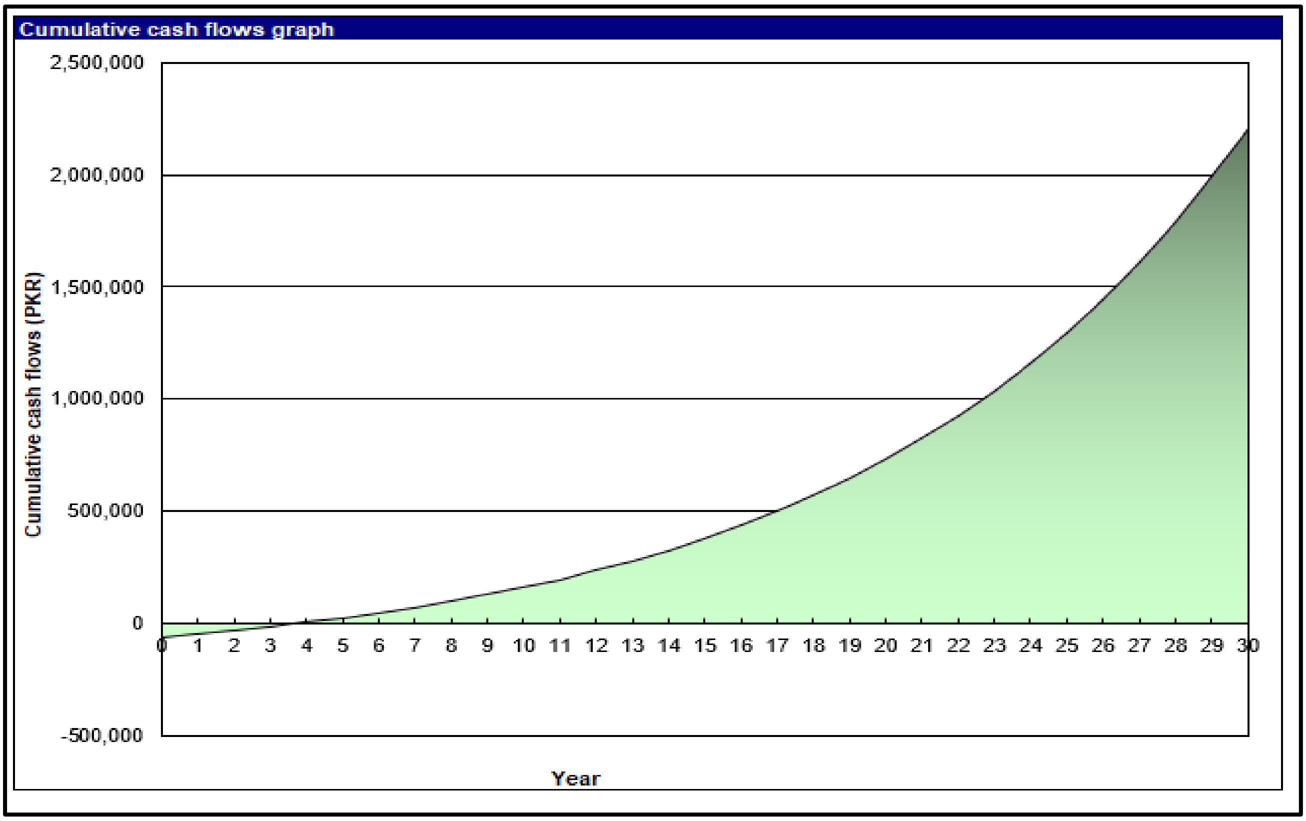

Figure 33 pay back of solar air heated system

Figure 33 shows the payback period of solar air heater is almost 3.8 years.

Table 8 Saving from solar air heater

Net Present Value	776,569 PKR
Annual Life Cycle savings	50,518 PKR
Benefit to cost ratio	13.9
GHG Reduction cost	270,815

5.2 Solar Water Heater

For solar water heater, base case of natural gas analysis with proposed case of natural gas and solar system. Following Parameters are considered for analysis of water heater.

Table 9 Parameters for water heater

Load Type	Office		
	Unit	Base Case	Proposed Case
Number of Units	Person	10	10
Occupancy Rate	%	100	100
Daily hot water use	L/D	40	40
Temperature	℃	45	45
Operating day per week	D	5	5

Flat plate collector with area of 3 m^2 has been considered of manufacturer solar-max heating with price of 20000 PKR. Pump power 240 W/m^2 with electricity rate of 13.00 PKR considered in this case. Natural gas is considered as a base case for heating system while biomass suggested. Engineering cost, feasibility study cost, operation and maintenance cost other heating components cost are considered 60000 PKR. According to RET Screen emission analysis, GHG emission in case of Natural gas is 0.7, while in case of solar natural proposed system is 0.1. This shows the proposed system is environmental friendly. According to RET Screen analysis proposed system fuel mix ratio is from natural gas 6%, solar 58% and electricity 36.4%. In financial analysis following parameters are considered

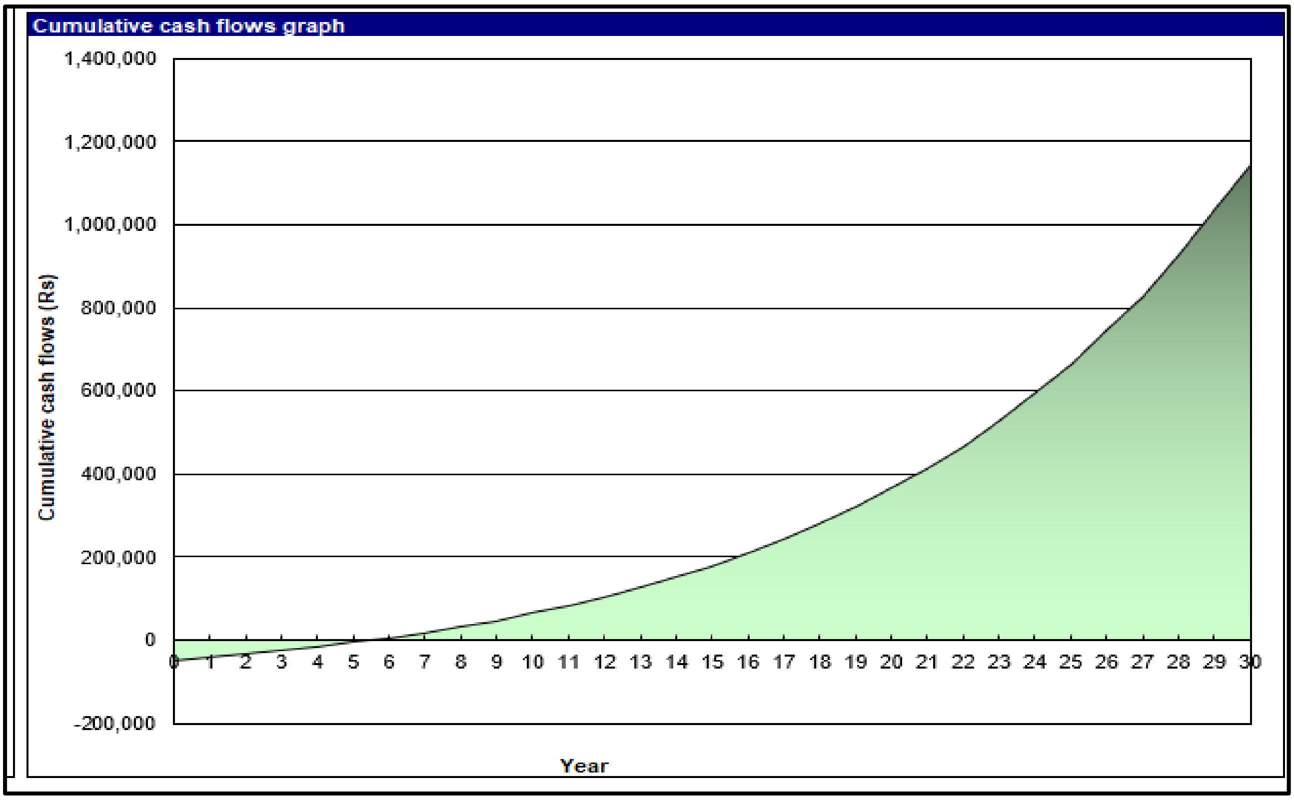

Figure 34 pay back of solar water heated system

Figure 34 shows the payback period of 5.4 years for solar water heater

Table 10 Saving from solar water heater

Net Present Value	390116PKR
Annual Life Cycle savings	25378PKR
Benefit to cost ratio	8.8
GHG Reduction cost	174,319

Chapter 6

Conclusion and Future Work

6 Conclusion

In this study, configuration based TRNSYS model was developed and simulated to evaluate the thermal performance of solar based combined space and water heating system having a peak heating load of 3.5 KW. The available components in TRNSYS library are used in the modeling of this system. To simulate system for entire winter seasons, weather data file for Islamabad (33.71°N, 73.06°E) is being used. Collector slope based SF was estimated 40°- 45° for ETC and FPC.

Simulation results marked up to 25% between collector efficiencies of ETC and FPC. Simulation results of entire winter months show average S.F 0.51, primary energy savings 0.47 and average collector efficiency 0.21 are obtained in case of flat plate collector with area and storage tank size, 07 m^2 and 0.5 m^3 respectively. On the other hand, SF 0.61, monthly primary energy savings 0.51 and collector efficiency 0.28 are obtained in case of ETC with collector area and storage size, 6 m^2 and 0.4 m^3 respectively. So, simulation results show as the heating demand is high Flat Plate Collector is not preferable. Overall results show that evacuated tube collector is the optimum choice for the current system and location.

Economic analysis shows the proposed system is environmental friendly with 0.2 GHG emissions. The proposed system has no carbon emission which harms the human and environment. Simulation results were determined according to already published data.

6.1 Future Work

In this study simulation results shows that there is a good potential for solar based heating system in Pakistan. Till date there is no experimental combined heating system is installed in Pakistan. So, this model can be taken as a reference model for designing and installing a combined water and space heating system.

However, following ideas should be addressed in future work:

1. The proposed system can be simulated for different locations of Pakistan i.e Lahore, Karachi, Abbottabad.
2. By addition of PV panels in proposed system, the electric load of pumps can be shifted on PV panels. In this way, it will be less dependent on electricity from grid hence results in more energy savings.
3. By addition of some components, the proposed model can be used to carry out for simulation of space cooling.
4. The proposed system can be suggested for off grid areas by using thermosyphon collector and simulations can also be performed in TRNSYS.
5. Components used in TRNSYS can be designed in ANSYS/ Comsol

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