Solar Absorption Cooling System Assisted with Geothermal Heat Exchange Technology for Energy Efficient Buildings

By

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Supervised by

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Certificate

This is to certify that work in this thesis has been carried out by **Mr. Sufyan Naeem** and completed under my supervision in solar thermal laboratory, Centre for Energy Systems, National University of Sciences and Technology, H-12, Islamabad, Pakistan.

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Dedication

To Almighty Allah, who is the most merciful and beneficent . To my parents, siblings and friends for their love and care, and always providing me support in my education. Especially to my mother for always believing in me and giving me courage. Finally I dedicate my research work to my thesis supervisor, Dr. Muhammad Bilal Khan and all the GEC members for providing me with enormous guidance.

Abstract

This paper presents a study on 3 TON capacity solar absorption cooling system designed and simulated on TRNSYS software. The case study is a lecture room in USPCAS-E, at NUST University Islamabad, Pakistan that is simulated on TRNBuild which is a plugin to TRNSYS. The real parameter of the lecture room are modified with an inclusion of an insulation material to the original specs of buildings envelop in order to reduce the cooling load lecture room. The cooling technology based on renewable that is used to reduce the room heat is absorption chiller which involves both hot water cycle and cold water cycle in order to generate chilled water cycle. In the second system solar water heater are used for generating hot water cycle and cooling tower is used for generating cold water cycle. In the third system solar water heaters are used for generating hot water cycle but geothermal heat exchange system is used for cold water cycle of the chiller. The lecture room is also simulated for cooling using conventional 3 TON AC system. The results of all the different models were collected for parameters such as energy consumed, carbon footprint generated, payback period etc.

The result show that cooling load of modified lecture room, when envelop is modified with insulation, decreased to 3 TON from 3.5 TON. The results also indicate that an optimum working Solar Absorption Cooling system for a 3 TON system could be designed using 8m^2 of collector area of solar water heater, having 0.4m^3 of storage tank volume. The geothermal heat exchange system uses HDPE (high density polyethylene) pipe with a diameter of 2 inches and length 100 meters having horizontal assembly underground. This is enough to exchange heat with the soil in order to maintain thermal comfort temperature zone in lecture room.

The results show that using conventional AC system uses 8,735 MJ of energy in order to operate far a whole summer season. The CO_2 emission is up to 1.62 ton/yr. The results show that SAC system with cooling tower uses 4,728 MJ of energy to operate for lecture room cooling with CO_2 emissions being 0.86 ton/yr, Payback period 12.7yrs. The SAC system using GHX system uses 1,929 MJ of energy to operate. The payback period decreases to 9.7 years with reduction in CO_2 emissions to 0.35 ton/yr only. The COP of the system was calculated to be 0.71 in summers and solar fraction of 0.96.

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1. **—**”Solar Absorption Cooling System Assisted with Geothermal Heat Exchange Technology for Energy Efficient Buildings in Pakistan”, International Journal of Sustainable energy, Tylor and Francis.*

* Annexure I

List of abbreviation

SACs	Solar absorption cooling systems
HVAC	Heating ventilation and air-conditioning
COP	Coefficient of performance
VCS	Vapor-compression system
CFC	Chloro-fluorocarbon
TRNSYS	Transient energy system simulation tool
FPC	Flat plate collector
NPV	Net present value
HTG	High temperature generator
LTG	Low temperature generator
TESS	Thermal energy system specialists
SHG	Solar heat gain
AHG	Auxiliary heat gain
CBR	Cost-Benefit Ratio
NPV	Net Present Value
PBP	Pay Back Period
Ton	Ton

Chapter 1

INTRODUCTION

1.1 Background

Today science agree that world energy consumption is increasing drastically. The last two decades of 20h century portray a fact that the global demands for energy have increased by 49% [1]. Understood fact also remains that the trend would continue [2]. Three sectors have been stood responsible for waste consumption of energy domestic, commercial and industrial [1]. The average growth rate for energy consumption for domestic building for developed countries have been found to be 1.1% while for underdeveloped countries it is found to be 3.2% [3].

Due to the increase in population the energy demand for buildings is also increasing to meet loads such as lighting, HVAC, heating and comfort [3].

Energy consumption for different types of buildings has been shown in fig.1.1. Around 30-50% of energy, utilized in commercial building, is required for the HVAC systems [1, 4]. While the energy consumption for lighting and other low load is pretty less. So, it becomes very crucial to control the huge amount energy required for HVAC systems in the buildings.

1.1.1 Pakistan energy scenario

By analyzing the scenario of Pakistan we conclude clearly that it has energy deficiency [5]. Pakistan's infrastructure for energy also remains under developed despite being only not managed well [6]. Pakistan today faces energy crises, because of increase in energy demand [6], while Fossil fuels contribute to be 60% in total sources of energy production [5]. Source and consumption of energy for different sectors has been defined in fig 1.2 [6].

Figure 1.1 is very well at illustrating that energy consumption by domestic and commercial sector is almost half of the total consumption [2]. And even in these two sectors we find more than 60% of energy being utilized for HVAC. Thus it becomes crucial to introduce new methods for the working of HVAC in order to reduce its waste consumption.

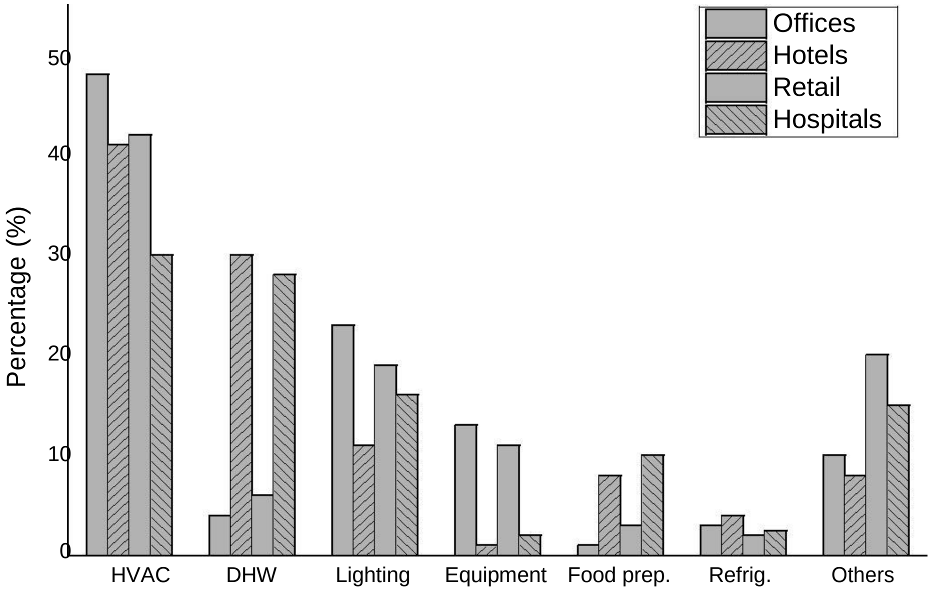

Figure 1.1: Energy Consumption in different types of buildings [1]

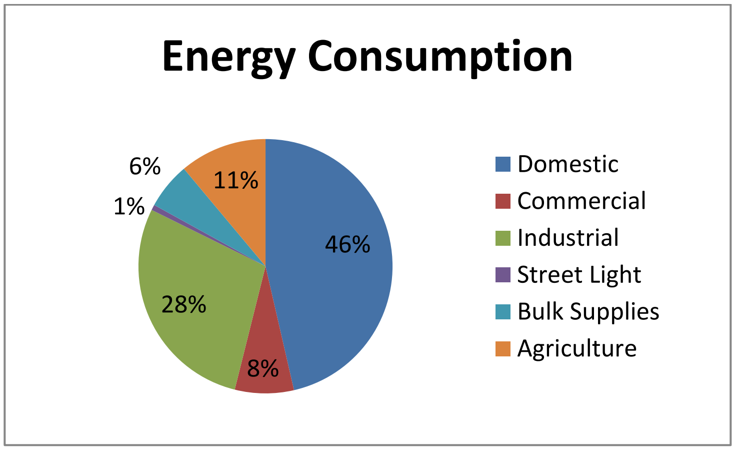

Figure 1.2: Energy consumption in different sectors in Pakistan [6]

1.2 Conventional system for HVAC

With the passage of time the demand in energy to meet requirements is also rising. Vapor compression systems are very commonly used around the world in order to meet the cooling demands [7]. Due to smaller size and lesser weight and their high coefficients of performance (COP), these systems are very common worldwide as compare to other cooling systems [7]. The idea being to use vapors of coolant such as of hydro-chlorofluorocarbon (HCFC) chloro-fluorocarbon (CFC) and hydro-fluorocarbons (HFC) for the purpose of cooling by these systems [7]. However these gases to be used as refrigerant, has caused a serious damaging problem to the ozone layer from the last six decades [4]. This has now become a serious and most researchable issue round the globe by the experts [8]. Major drawback of these systems is that they are highly energy intensive [9]. They have now become a serious burden on the national grid.

1.3 Using renewables to meet energy demand

Due to conventional VCS systems being very energy intensive experts have found number of solutions to meet cooling demand including solar absorption cooling systems [10, 11]. These technologies of solar absorption (SAC) utilize solar thermal in order to meet the cooling demand and reduce the energy consumption load on electricity [8]. Therefore the system depending solar could become very handy in reducing the energy demand on grid, for the purpose of cooling [12, 14]. Using ammonia, water and methanol as refrigerant causes no harm to environment and ozone layer also as they mostly use solar energy therefore they also come in handy to reduce greenhouse gases emissions. [7][12]. These systems are maintenance free as these systems do not poses any rotating element also due to friendly compounds being used for refrigeration, they cause no corrosion to the machinery too[8].

Pakistan stands as a country which faces a lot of energy deficiency especially during summers [15]. Thus this technology could be very handy in reducing our demand of electricity from the grid and meeting our cooling demands too [16].

Pakistan is high on solar sunshine which makes this technology to be used in country very viable solution [17]. The price of electricity being high also provides a very high favor for these technologies to be used in the country.

1.3.1 Benefits of solar cooling systems

The benefits of solar cooling systems can be summarized as follows.

- Reduction in the dependency on imported fuel.
- Diversification of energy demand and supply.
- Natural resources could be saved.
- Reduction CO_2 emission.
- reduction in air pollution
- Electricity bills could be greatly reduced.

They also could be responsible for new business and job opportunity thus improving economy [19].

1.4 Solar cooling

Solar passive cooling had been used from ancient times thus making it renowned by the world from quite a lot of time [20]. Solar passive cooling technology is regarded as very efficient technology as it uses no power to function [21]. The main principal of passive cooling depends on not letting the heat enter into the building or eradicating it, and building architecture design plays a vital role in establishing tis principal [21]. The three main principals for altering the air conditions inside the room are [22]:

1) The transmission of radiation from outer space through walls into the building. Heat transfer through building mass plays a vital role in this regard
2) Radiation also travels into the room via open space or transparent medium such as opening and glass of windows. Using curtains greatly reduces this transmission.
3) Other infiltrations such as through openings and cracks or the being the window and doors are kept open also plays a significant role in this regard. All leaks and cracks must be filled up nicely

The heat gain inside building can greatly reduce the transmission of radiation into the building, but still is enough to maintain thermal comfort temperature zone especially when it comes to humidity. Thus, an active solar cooling technology also becomes vital to be used. Solar absorption cooling (SAC) systems are active solar cooling technologies and are attractive options to provide active cooling in the buildings [13].

1.5 Research objectives

The objective of research to be done on this issue includes, designing such a solar absorption cooling (SAC) system which would eradicate the heat from the room, thus maintaining thermal comfort temperature zone. The case study being, a lecture room of United States Pakistan Centre for Advance Studies in Energy (USPCASE), at NUST University, Islamabad, Pakistan.

Research study would focus on objectives defined below:

i. Conventional 3-TON AC model would be designed on TRNSYS to perform thermal analysis of the lecture room.
ii. SAC system would be designed on energy software such as (TRNSYS, TRNBuild).
iii. SAC system designed will focus on the thermal performance study of room.
iv. SAC system would be designed and optimized for different parameters, for the region of Islamabad.
v. Economic analysis of the system would also be performed on software RET-Screen
vi. CO_2 emission analysis by using SAC systems.
vii. Payback, Net Present Value and Cost-Benefit Ratio would also be calculated

1.6 Scope of the work

A solar absorption cooling system (SAC) system would be designed using advance energy software such as TRNSYS. The model of case study being a lecture room of USPCASE at NUST University, is designed on advance Energy software TRNBuild. Total cooling load of the lecture room is selected via taking into account different parameters such as material of building envelop, number people present in it, other electronic loads present. Passive cooling to the lecture room is provided in the software by introduction of insulation to its envelop.

For active cooling single effect LiBr-H_2O refrigerant based SAC system is used to accomplish the cooling requirements of lecture room. Thermal performance of SAC system is performed for lecture room on TRNSYS-17, which is complete and sophisticated simulation software for renewable energy projects [23]. SAC system work using two different temperature water streams. One being of hot water 70-110^{o}C. The other is of cold water from 22-30^{o}C. The cold water stream production is done using two different systems first based on cooling tower and second based on Geothermal Heat Exchange (GHX) system separately. Therefore two different SAC systems are designed.

SAC system modeling is done using suitable components which are placed on the deck window. Then, the optimization of the SAC systems components parameters is done. Feasibility and economic analysis of the SAC systems is also performed in comparison with conventional vapor compression refrigeration (VCR) system.

Therefore we have three models designed for the same lecture room one being based on conventional 3-TON AC system, the VCR based, the second being SAC system with cooling tower and the third being SAC system with GHX system.

Payback period, Net Present Value (NPV) and CO_2 emissions are also calculated for all three models.

1.7 Study Limitations

This research is done on the model of lecture room strictly, because of the advantage of having information regarding its operational timings, number of occupants etc. any other building and parameters would change thus changing the cooling demand of the lecture room.

The design of chiller focuses on only single effect hot water fire absorption chiller using refrigerant LiBr-H_2O. This study is not valid for double effect absorption chiller.

Design of different components of the research project are not taken into account during the research

Due to the large capital cost required the research study was limited to simulation setup only and not practical demonstrations.

Summary

We observe that the demand for energy increasing day by day in the world. The sectors most responsible at the consumption of energy are domestic and commercial. Around 50-60% of the energy utilized is used solely for the purpose of HVAC. The most widely used technology for the cooling of buildings is vapor compression based cooling systems, which are not only energy intensive but also are responsible for the emissions of GHG gases, thus in the depletion of ozone layer. On the other hand we see that solar energy based cooling systems are far energy efficient, as they depend on abundantly available natural resources. Hence these technologies become a very attractive solution to meet cooling demand problems in our country. Pakistan faces a lot of energy deficit and electricity rates are also very high. Pakistan is a country having 300 days of sunshine with a radiation value of 1900-2200 KWh/m^2; therefore it is quite evident that this technology can very efficiently be used to meet the cooling demands.

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Chapter 2

LITERATURE REVIEW

2.1. Refrigeration

It is the process by which, temperatures are lowered by doing work. They have been used in AC systems in buildings and refrigerators to keep food safe from getting rotten. [1].

2.2. Solar cooling systems

Solar cooling technologies have been divided into two major categories. First is one being driven by electric force and the second one being one driven by thermal energy [2].

1. Electric energy driven cooling system
    - Stirling refrigeration system
    - Vapor Compression dependent cooling system
2. Systems driven by thermal energy
    - Refrigeration using Absorption cooling system
    - Refrigeration using Adsorption cooling system
    - Chemical reaction refrigeration using chemical reaction system
    - Cooling system using desiccant technology
    - Geothermal heat exchange system

2.3. Electrical energy driven cooling system

2.3.1. Stirling refrigerator

Stirling cooling system is one that uses the process based on carnot cooling cycle, integrated with solar panels to drive the rotary motion. This system has a lower COP than one with vapor dependent cooling system [6]. A small Stirling refrigeration system with cooling capacity of 100 W was presented by Ewert [7].

The COP of the system designed by Ewart; ranged from 1.2 to 1.6. The range of COP actually depends on the temperature of hot and cold reservoir where the working fluid moves [8]. The main drawbacks faced by this system are that it has lower power density and loss of temperature within the working fluids [9]. In larger systems these problem overwhelm the possible solution system and therefore only small scale systems are said to be convenient to be used [3].

2.3.2. Vapor compression refrigeration system

These are mostly used cooling refrigeration systems in the world. They work on the principal of vapor compression, its expansion and cooling. They use a lot of electricity to work therefore are energy intensive. Due to being energy intensive in terms of the usage of electricity, they can be used to from the electricity generated from solar panels. The material of the cells plays a very important role in maintaining its efficiency and therefore cost [3]. Solar panels have a efficiency of about 14% in the market, and the one integrated with building loads tend to have almost 10% efficiency [4]. Figure 2.1 represents a simple solar driven compressor for vapor compression process to run.

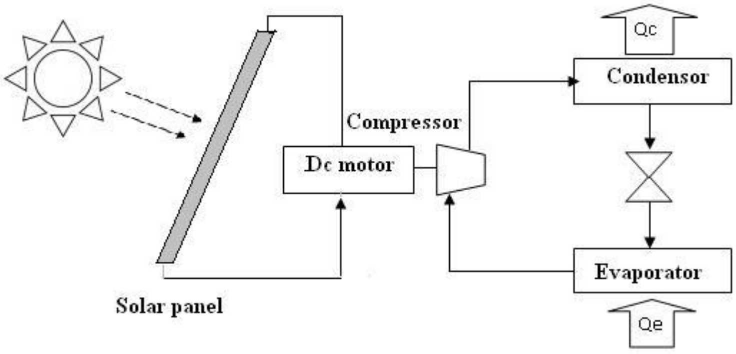

Figure 2.1: Systematic diagram of solar driven vapor compression system [3].

The overall efficiency for the refrigeration cooling system is given by Eq. (2.2).

$$\eta_{cool} = \frac{Q_e}{W} \tag{2.2}$$

While the efficiency of solar driven refrigeration system, depends on the solar panel's efficiency and refrigeration system's Efficiency and is calculated using Eq. (2.3)

$$\eta_{solar-cool} = \eta_{solar} * \eta_{cool} = \frac{Q_e}{Q_s} \tag{2.3}$$

2.4. Solar thermal refrigeration

The driving energy in these systems for the purpose of refrigeration comes mainly from solar thermal. Solar thermal energy can be collected using solar heat collectors. We basically have two types of collectors. The first being the non-concentrating ones and the second being concentrating ones. The non-concentrating collectors are ones which are cheaper than concentrating collectors, but provide lower thermal power which can be used to drive low energy demanding systems such as absorption chiller systems [10, 11]. The two commonly types of available non-concentrating collectors are;

1. Evacuated tube collectors
2. Flat plate collector

Evacuated tube collectors (ETC) are ones in which vacuumed tubes are used in which the fluid runs and contain metallic absorber inside. Flat plate collector are another commonly type of solar collector used worldwide [12]. They contain flat metallic absorber plate to absorb solar radiations and transfer heat to the fluid running beneath. Figure 2.2 [3] provides a brief information about the inner schematic of the two collectors.

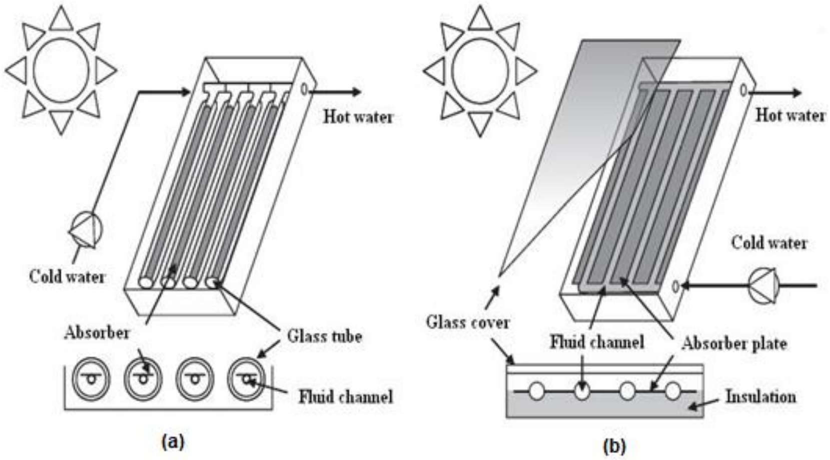

Figure 2.2: Systematic diagram for (a) Evacuated tube collector (b) Flat plat collector.

These collectors provide a deal of thermal energy for the thermally driven refrigeration systems to work. These collectors follow a principal for their efficiency that when the working temperature of fluid increases the efficiency decreases.

On the other hand, the efficiency of the system improves if the temperature of the fluid lowers [14].

2.4.1. Absorption refrigeration system

Absorption cooling system in which the refrigerant is absorbed by the absorber, this system is thermally driven and used for cooling [15]. It requires very less amount of electricity to work. These systems do not require electricity to operate like VCS, but thermal energy to operate. As they do not require a compression for the compression of coolant, therefore their maintenance is very easy [15]. For absorption cooling system three main streams of fluid are required, namely;

1. Cold reservoir where the heat from the cooling space would be dumped,
2. Hot reservoir from where the thermal energy is derived for it to operate
3. Space in which the process of cooling can be performed.

The COP of the absorption chillers have been low typically ranging from 0.4 – 0.7, as they require large amount of energy to regenerate their refrigerant [15].

2.4.2. Refrigerant –absorbent pairs

Absorption cooling system utilizes different kinds of refrigerant-absorbent pairs. Most common pairs used for solar cooling, that also stand as environmentally friendly are given below [17].

1. Water (H_2O) – Lithium bromide (Li-Br) Pair

    Due to its temperature range of (90–120 ^{0}C), it is widely used as it stands convenient [16].

2. Water (H_2O) – Ammonia (NH_3) Pair

    Due to the higher temperature range of (125–170 ^{0}C) it does not stands very convenient to be used for solar cooling purposes [17].

2.4.3. Working principal of solar based absorption cooling system

Figure 2.3 defines the working of solar based absorption cooling system

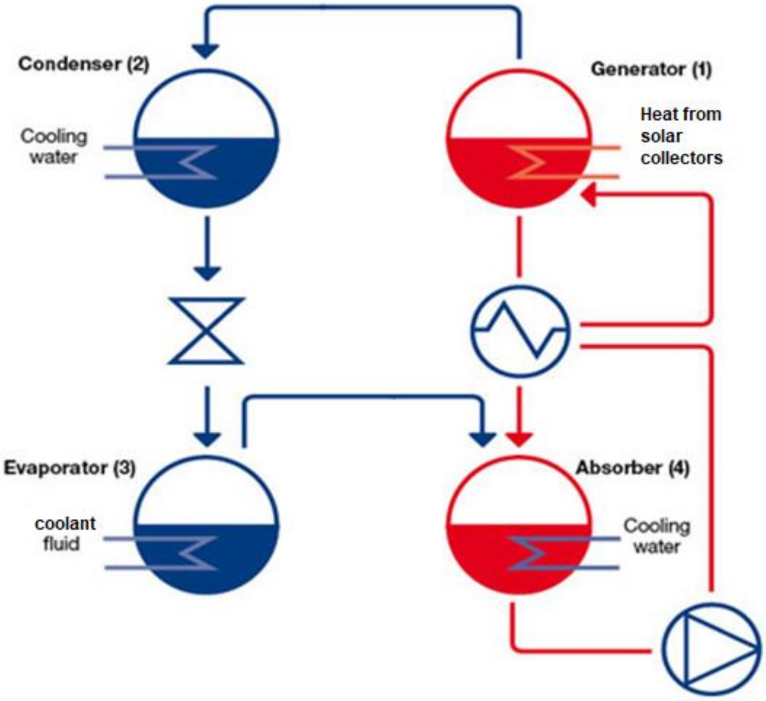

Figure 2.3: Working principle of solar based absorption cooling system.

For the working of solar based absorption cooling system, we require hot water. This hot water is obtained for the solar thermal collectors. The heated water from the collectors is passed on the generator side of the chiller. The heat from this hot water is utilized to separate hot water vapors absorber on the surface of absorber LiBr. The size of LiBr molecule is bigger than that of water therefore the water molecule absorbs inside. When this solution is heated the water molecule escapes at the generator chamber of chiller. This produces not only heated water vapors but also pressurized water vapors.

This stream of pressurized hot water vapors is passed to condenser side of the chiller where the cooling water is used to cool down the stream of vapors while it still remains pressurized.

In the meantime the strong solution of LiBr-H_2O returns from generator side to absorber side, thus again getting ready to absorb H_2O.

The cooled water vapors at condenser sides, still at high pressure pass through the expansion chamber, thus reducing it temperature even more. This water now the chilled water is used to extract the heat from the room and eradicate it into the environment.
An external loop of cold water runs in the chiller at condenser side to cool down the pressurized water vapors and at absorber side to eradicate the thermal energy brought by the chilled water from the room, to the environment. At absorber side this loop of cold water is also required in order to cool down the LiBr concentrated solution back from generator chamber. This is because water absorbs well into LiBr at lower temperatures.

2.4.4. Description of cooling process

The steps involved for the coolant in the process of absorption chiller are illustrated in the Figure 2.4.

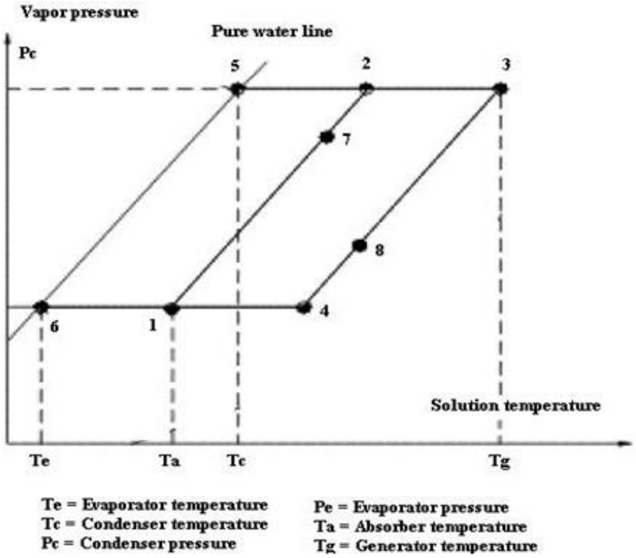

Figure 2.4: Process diagram of single effect absorption air-conditioning system [18]

- Starting from process 1-7 line indicates that solution of LiBr and water absorbed in it, moving into the generator chamber.
- Line 7-2 indicates that the solution of LiBr and water being heated up prior to entering the generator chamber. This solution of LiBr and water is heated by the concentrated solution of LiBr only, coming back from generator chamber to absorber chamber, thus cooling itself down too before entering the absorber chamber

- Line 3-8 indicates the movement of LiBr solution from generator chamber to absorber side. In doing so it is also preheating the solution of LiBr and water from absorber chamber going into generator chamber
- Thus the cooled solution of LiBr only, enters now the absorber chamber to absorb water coming from the evaporator side thus following 8-4-1 line.
- On the other hand line 2-3 indicates the heating of preheated solution of LiBr and water to even high temperatures. This heat is provided from solar water heaters. At this stage due to high heat, the water vapor also starts to desorb and then they would transfer to condenser chamber of the chiller.
- Line 3-5 indicates the cooling down of pressurized water vapors from high to lower temperature using a external cooling water loop.
- Line 5-6 indicates the water temperature and pressure dropping. This is because the pressurized water vapors cooled at condenser chamber earlier, are passed down the expansion valve, thus reducing the pressure and temperature both.
- This water now known as chilled water is used to extract heat from space for cooling purpose. This water enters into the absorber chamber indicated by line 6-1, thus The heat brought back by this water from room further extracted by external cold water loop and thus is eradicated into the environment.

Much of the research has been conducted by various researchers in the field of solar absorption cooling systems. One of the research, conducted by Tsoutsos. On the TRNSYS software concluded that with the investment cost of 173,992 € the payback period is 11.5 years [19]. The system conducted research by setsu optimized a SAC system and concluded that by the close optimization of the system the solar fraction could be increased from 50%-90% [20]. Gomri studied a Sac system for a building in Algeria; it was observed that COP of 0.82 was achieved by changing the temperature of condenser and generator [21].

Mateus and Oliveria studied a SAC system which changed the cost of energy sources and a found a reduction in CO_2 production [22]. Assilzadeh analyzed an Evacuated tube collector (ETC) based SAC system and found that, a hot water tank of 0.8 m^3, a collector area of $35m^2$ sloped at 20^o is necessary for maintaining an uninterrupted system [23]. M.Mozloumi A lithium bromide based absorption chiller cooling system was modeled for Ahwaz region (Iran). The modeled system fulfilled the cooling demand requirement of 17.5 KW. Parabolic trough collector was used to feed hot water to the absorption chiller with area of $56m^2$. The model clearly stated that flow rate has a significant effect on the efficient running of the system [24]. T.He et al A solar absorption cooling system was modeled for a building in Beijing using TRNSYS. The area of collector was $358m^2$ with tilt angle of 10^o facing south. The capacity of the absorption chiller was 175.8 KW with a COP of 0.7 using biomass boiler as auxiliary heater. The size of thermal storage tank found optimum to be used is $15m^3$ and $8m^3$. The efficiency of solar collector calculated is 37.6% with solar fraction for summer and winter being 0.76 and 0.38 [25]. An absorption cooling system was modeled for region Nicosia, Cyprus on TRNSYS software. The solar collector used was parabolic trough collector using slope angle 30^o and storage capacity of 0.6 m^2. Optimization of the system was done for the parameters such as area of collector, volume of storage tank and thermostat setting of the auxiliary boiler [26].

2.5. Adsorption refrigeration system

It has been classified further into two sub-adsorption techniques:

(a) Physical adsorption

(b) Chemical adsorption

2.5.1. Physical adsorption

In this technology, silica gel, zeolite, alumina and activated carbon are used to adsorb refrigerant unto their surfaces as their surface-volume ratio is very high, therefore they are very porous [3]. They hold a refrigerant molecule to them and when heated, release the refrigerant molecule [3]. In a single vessel containing both, the refrigerant and adsorbent, they tend to decrease the volume by adsorbing the refrigerant molecule with their own surface hence decreasing the pressure. Therefore for a smooth running adsorbent based cooling system several chambers of adsorbent-refrigerant are required [27]. This technology is so well utilized that 4-7 Kg of Ice can easily be provided using one square meter area of solar thermal collectors [28]. For the purpose of space cooling, Silica gel-water paired adsorbent-refrigerant systems have been used [29-31]. On the other hand these systems tend to have lower cooling capacities against absorption chillers, also they have working machinery which requires large space area and is bulky [32].

2.5.2. Chemical adsorption

In chemical adsorbent technology, unlike physical adsorption technology, chemical bonds are formed between adsorbent and refrigerant [27]. Very commonly used adsorbent is calcium chloride ($CaCl_2$) and refrigerants being ammonia (NH_3) and water. Ammonia (NH_3) and water (H_2O) adsorbs Calcium chloride ($CaCl_2$) to produce $CaCl_2.6H_2O$ and $CaCl_2.8NH_3$ respectively [27]. It can also be used in combination with physical adsorbents like silicates to enhance the process [33, 34].

2.6. Desiccant cooling

Desiccant cooling is a technique in which humidity in the air is trapped using sorbents such as: activated alumina, silica gel, LiBr and LiCl [3]. A liquid desiccant circulates between the sorbent and refrigerant. This system differentiates itself from absorption as such that in liquid desiccant, the smooth running of system depends heavily on the partial pressure of water vapors in the air, while for absorption cooling system it depends upon pressure of water vapors.

2.7. Electrochemical refrigeration

This technology works on the principal that certain chemical reactions occur where heat is absorbed and released at a large rate, but when voltage is applied to their cell [35]. However this technology is at a very early stage of development and not used for space cooling purposes.

2.8. Geothermal Heat Exchange

In the past times this technology has really emerged out for hot climatic condition environments. In this technology the underground earth acts as a thermal storage mass. During the year in summer season the underground earth temperature is cooler than surface, while in winters it turns out to be at higher temperature than the surface.

The fluid can be run down underneath the surface of the earth during summers and hence cooled down. The fluid can be water or air. While in winters it can again be run down underneath and hence heated.

A cooling system of fluid was modeled using underground earth tubes. The underground earth tubes not only provide relative low temperature air during summers but also relative high temperature air during winter. The efficient working of the system depends on number of parameters being optimized including average temperature of the ground, length and diameter of the tubes used, extreme range of temperature during winter and summer, handling of the condensate and the intake being located at slope or drywell [36]. A geothermal heat pump system was modeled assisted with solar thermal collector. Heating and cooling, models were developed where during cooling, the heat energy is injected into ground while during winter, and this stored heat energy could be used for heating purposes. The model clearly suggested for the efficient working of the system all the parameter such as borehole separation distances, thermal properties of material used, relative difference of the ground thermal load play a vital role and are case-dependent [37].

Summery

Refrigeration is a process in which cooling is provided using energy intensive process to eradicate heat. Energy used to run these cooling systems can be in the form of electricity or thermal energy from solar. Therefore for electricity, solar PV and for thermal energy, solar thermal collectors can be used. Therefore solar driven cooling technologies can be divided into two types. First types are ones that work using electricity like, Stirling refrigeration, Vapor compression refrigeration and thermo-electric refrigeration system. However there are others too that are driven by solar thermal energy like adsorption based refrigeration system, absorption based refrigeration system, chemical reaction based refrigeration system, desiccant cooling system and geothermal heat exchange systems.

Absorption chiller seems to be a good choice for Pakistan, as they require plenty of thermal energy available from solar. Also the geothermal heat exchange systems seems to be very promising for providing cool water required for absorption chillers to work Therefore, absorption refrigeration system assisted with geothermal heat exchange system is used in this study to provide space cooling in educational building which is a lecture room of USPCASE department building at NUST university Islamabad.

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Chapter 3

RESEARCH METHODOLOGY

An outline of a procedure and methodology adopted to study the effects of Solar Absorption System for space cooling is defined.

3.1. Approach towards Research

The steps followed for modeling and simulation of the system is shown in Figure 3.1 and discussed below.

1. First of all the research study is based on the simulation methodology and not practically. This due to a very sum of finances involved. Therefore the softwares used are TRNSYS, TRNBuild and Ret-Screen.

2. The basic data we require in order to carry out the study is of climate of the location of study. Our location of research is Islamabad; therefore we require the climatic and other weather data of Islamabad. Weather parameters include ambient temperature, humidity, diffuse radiation, direct radiation and underground thermal gradient profile. TMY data for Islamabad is required to be used in the TRNSYS software.

3. The next most important thing to be designed in the software is the case study. Our case study being the lecture room of a USPCASE department building at NUST University is to be designed in TRNBuild software. By designing the building with correct parameters we would be able to know the real cooling demand of the lecture room for the whole summer season.

4. Each and every parameters of lecture room are taken care of e.g., the width height and length of room. Also the thickness of walls roof windows and its material are put in the software correctly. Other cooling load effecting parameters such as number of occupants, heat gain of each individual, the timing schedule

for which they would be present in the room and heat load from the electrical equipments are also put into software correctly. Once the cooling load is calculated with real parameters of buildings envelop.

5. In the next section we bring certain changes in the envelop of the building such as the inclusion of a 2-inch thick insulation into its envelop i.e., walls and roof. Also we introduce double glazed window and a good insulated door in its design. In the finances section we also include the finances spent on the filling of any cracks and other air infiltration spaces. The cooling load of lecture room with this new envelop design is again calculated.
6. With the new cooling load calculated, we design and analyze the performance of three different types of cooling systems, for the cooling of this lecture room.
   - First being the use of conventional 3-TON Ac system, along with its optimization and finance calculations.
   - The second system being the Hot water fired single effect LiBr-H_2O pair, solar absorption cooling (SAC) system assisted with cooling tower. All components such as pumps, storage tanks, thermal collectors, auxiliary heaters and fan coil systems are included in the design. This system is also optimized and its finances calculated
   - The third system is the Hot water fired single effect LiBr-H_2O pair solar absorption cooling (SAC) system assisted with GHX system. All components such as pumps, storage tanks, thermal collectors, auxiliary heaters and fan coil systems are included in the design. This system is also optimized and its finances included.

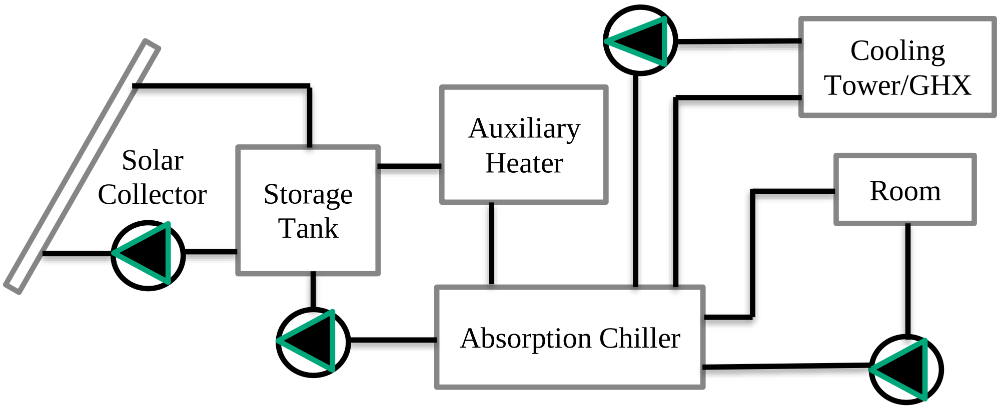


Figure 3.1: Layout of SAC system

All these systems when optimized to meet the cooling load of lecture room were then used to calculate and analyze the performance depending on certain parameters such as amount of energy used to perform function, the total energy eradicated from the room to maintain cooling and the temperature range they were able to maintain in the room.

7. These systems design, optimized and simulated for best results to meet the cooling demand of the lecture room in summer season. SAC systems have always been known for their high costs and low COP [1]. The financial parameters such as total investment, payback, NPV, CO_2 emissions and cost benefit ratios are calculated using Ret-Screen software. The CO_2 emissions are calculated based on the fact that $1m^3$ of gas burned produces 1.8564 kg of CO_2 [2].

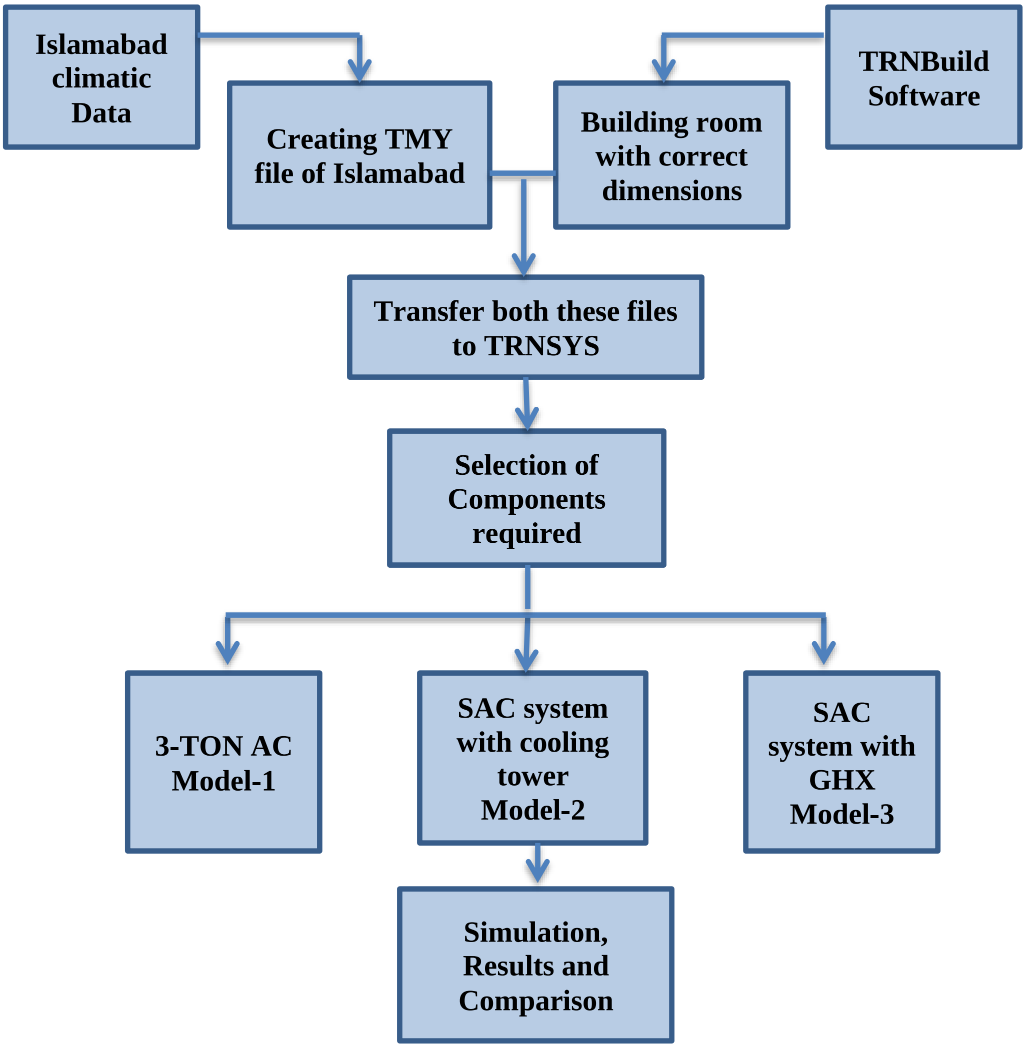


Figure 3.2: The overall methodology chart of the research

3.2. Mathematical description of collectors

The efficiency of solar thermal collectors depends mainly on the temperature difference between the inlet and outlet water. The overall efficiency of the collector is given in the Eq. (3.1) [3].

$$\eta = a_o - a_1 \frac{(\Delta T)}{I_T} - a_2 \frac{(\Delta T)^2}{I_T} \tag{3.1}$$

Where —$\Delta T = (T_i - T_a)$ which is the difference between water inlet temperature and ambient temperature, —I_T: incident radiations.

Table 3.1 presents details about other parameters of solar thermal collectors. Various important parameters, on which the efficiency of solar collectors depends, include a_0, a_1, and a_2. Their values used in the research have been given in table 3.1. Other parameters influencing the efficiency of collectors include temperature of water at inlet and outlet and also the ambient air temperature around the collectors.

Table 3.1: Parameters of Flat Plate collector [3]

Parameter	Description	Value
Collector type	Flat plate	
Cp	Specific heat capacity (kJ/kg K)	4.19
ή	Efficiency mode	1 (Ti - Ta)
m_{Test}	Flow rate at tested condition	40
a_o	Intercept efficiency	0.79
a_1	Efficiency slope	13
a_2	Efficiency curvature	0.05
Optical mode		Incidence modifiers

3.3. Mathematical description of absorption chiller

The performance of any cooling system is analyzed by studying its COP, coefficient of performance. The COP of absorption chiller to be calculated is given in Eq. (3.2).

$$COP = \frac{Q_{chw}}{Q_{hw}} \tag{3.2}$$

The COP is defined as ratio of energy removed by chillers using chilled water stream —Q_{chw} to the energy removed by chiller from hot water stream —Q_{hw}. For any defined SAC system using solar collectors, the overall performance of the system can be calculated as a product of COP into the efficiency of solar thermal collectors' —η_c, given in Eq. (3.3).

$$\eta_{system} = \eta_c . COP \tag{3.3}$$

While the energy extracted from the stream of chilled water —Q_{chw}, which it collected from the space for cooling, is defined by —$Q_{removed}$, to make the room temperature reach the range of defined set point temperature and is given in Eq. (3.4)

$$Q_{remove} = m_{chw} Cp_{chw} (T_{chw,in} - T_{chw,set}) \tag{3.4}$$

$$Q_{hw} = \frac{Capacity_{rated}}{COP} f_{design\ energy\ input} \tag{3.5}$$

$$T_{hw,out} = T_{hw,in} - \frac{Q_{hw}}{m_{hw} CP_{hw}} \tag{3.6}$$

—m_{chw}: Mass flow rate of chilled water stream

—Cp_{chw}: Chilled water capacity

—$T_{chw,in}$: Temperature of fluid entering the chilled water stream

—$T_{chw,set}$: Chilled water stream set point temperature

—Q_{hw}: Energy removed from hot water stream

—$Capacity_{rated}$: Rated cooling capacity of the device

—$f_{design\ energy\ input}$: Fraction of design energy input currently required by the system

—$T_{hw,out}$: Temperature of fluid exiting the hot water stream

—$T_{hw,in}$: Temperature of fluid entering the hot water stream

—$T_{hw,in}$: Mass flow rate of the hot water stream fluid

—C_{ph}: Specific heat of the hot water stream fluid

$$Q_{cw} = Q_{chw} + Q_{hw} \tag{3.7}$$

Where —Qcw is energy removed by cold water stream usually kept in the range of 22-30°C before entering the absorption chiller.

3.4. Mathematical Description of Economic Parameters

There are number of financial parameters that are needed to be collected to analyze the performance of the cooling system. This includes many parameters like payback period, NPV, efficiency of the system, CO_2 emissions and solar fraction of the system.

i. Payback period is determined by

$$P.B=log[(C/E)*(i/100)+1]/log[1+(i/100)] \tag{3.8}$$

Where;

‘C’: is the capital cost of the system

‘i’: Energy inflation rate

‘E’: Energy saving per year (PKR/yr)

ii. Net Present Value of the system can be calculated using equation

$$NPV = \mathrm{Y}\frac{1}{\mathrm{r-i}}[1-\frac{1+i}{1+r}]^{l}\text{-C} \tag{3.9}$$

Where;

‘Y’: yearly benefit in PKR/yr

‘r’: Discount rate from market

‘l’: life time of the system

‘C’: Cost of the installation of the system

‘i’: Energy inflation rate

iii. CO^2 emissions produced from Ret screen software

iv. Efficiency of flat plate collector used, is calculated using equation

$$\eta = a_o - a_1\,[\frac{\Delta T}{IT}] - a_2\,[\frac{\Delta T^2}{IT}] \tag{3.10}$$

v. Solar Fraction is calculated

$$S.F_{thermal} = \frac{\int Q_{solar}}{\int Q_{solar}+\int Q_{heater}} \tag{3.11}$$

As a complete financial analysis is required therefore the capital cost also plays an important role. Hence the prices of different components to be used are also collected and are given in Table 3.3.

Table 3.2: Financial data for SAC system [1, 4, 5]

Equipment	Cost
Absorption chiller	53,592 PKR/kW
Solar collector (FPC)	35,000 PKR/m^2
Auxiliary heater	6,699 PKR/kW
Cooling tower	6,699 PKR/kW
Storage tank	80,388 PKR/m^3
Insulation	538 PKR/m^2
Pump 50W	6,500 PKR
Ground Digging	20,000 PKR
GHX HDPE Pipe	1,090 PKR/m
Double Glazed Window	12,000 PKR/m^2
Cost of energy	
Natural gas PKR/MMBTU	637 PKR/MMBTU
Electricity	18PKR/KW

3.5. Description of the Lecture room

TRNBuild is plug-in software of TRNSYS. It is used to model a 3-D case study, in order for it to be studied under different thermal performances on software. A 3-D model case study created in TRNBuild is then transferred to TRNSYS and is available in TYPE-56 file format. The case study of this research being a class room of USPCASE department is fully modeled on TRNBuild. The dimensions of this classroom are mentioned in Table 3.3.

Table 3.3: Dimensions of the lecture room

Wall	Length (m)	Width (m)	Height (m)	Window (m^2)	Door (m^2)	Net Area (m^2)
SW	**8.356**	**0**	**3.66**	**0**	**0**	**30.6**
SE	**8.15**	**0**	**3.66**	**11.12**	**0**	**18.7**
NE	**8.356**	**0**	**3.66**	**0**	**0**	**30.6**
NW	**8.15**	**0**	**3.66**	**0**	**8.8**	**21.1**
Roof	**8.356**	**8.15**	**0**	**0**	**0**	**68.1**
Floor	**8.356**	**8.15**	**0**	**0**	**0**	**68.1**

Properties of these walls and roof are given in Table 3.4. This model is of original lecture room. No insulation or double glazed window is used.

Table 3.4: Properties of unmodified lecture room

All walls				
Outer plaster layer (m)	**Brick wall (m)**	**Window**	**z**	**Inner plaster layer (m)**
0.0125	**0.2**	**Single Glazed window**	**0**	**0.0125**
Roof				
Lower plaster (m)	**Concrete layer (m)**	**-**	**Insulation (m)**	**Tiling (m)**
0.0125	**0.1**	**-**	**0**	**0**
Floor				
Lower plaster (m)	**Concrete layer (m)**	**-**	**Insulation (m)**	**Tiling (m)**
0.025	**0.1**	**-**	**0**	**0.025**

Next we create another model of the lecture room in which the insulation of 2-inch thick polystyrene in included into the walls and roof of the lecture room. Also, double glazed windows are introduced on the walls instead on single glaze. The properties of lecture room which are modified is given in Table 3.5.

Table 3.5: Properties of modified lecture room

All walls				
Outer plaster layer (m)	**Brick wall (m)**	**Window**	**Insulation (m)**	**Inner plaster layer (m)**
0.0125	**0.2**	**Double Glaze**	**0.05**	**0.0125**
Roof				
Lower plaster (m)	**Concrete layer (m)**	**-**	**Insulation (m)**	**Tiling (m)**
0.0125	**0.1**	**-**	**0.05**	**0**
Floor				
Lower plaster (m)	**Concrete layer (m)**	**-**	**Insulation (m)**	**Tiling (m)**
0.025	**0.1**	**-**	**0**	**0.025**

Along with dimensions and properties of buildings envelop, there are certain other factor which play important role in deciding the cooling load of the space. These factors include information like number of people present in the space. Time for which they are present and working, also the time of the day and year they are present along with other heat dissipating loads present. Moreover the volume of room thus the air present, the capacitance of room and air change rate required to maintain the low temperature is also required. This information for our case study model of lecture room has been provided in the Table 3.6.

Table 3.6: Time schedule, capacitance, air change rate etc. for the lecture room

Feature	Value's
Volume of lecture room (m3)	266
Capacitance KJ/K	299
Air change rate	0.5
Heat gain from people (W)	100 (per person at rest)
No. of occupants	40
Occupancy time	9am-5pm (Mon-Fri)

3.6. System Description

The simple working schematic of the 3-TON AC cooling systems is given in figure 3.3. It shows that a lecture room is affected by the radiation of the ambient conditions such as radiation and temperature. The cooling system chosen is a conventionally used 3-TON AC system, the cooling systems performance is affected by the ambient conditions when eradicating lecture rooms heat to the environment.

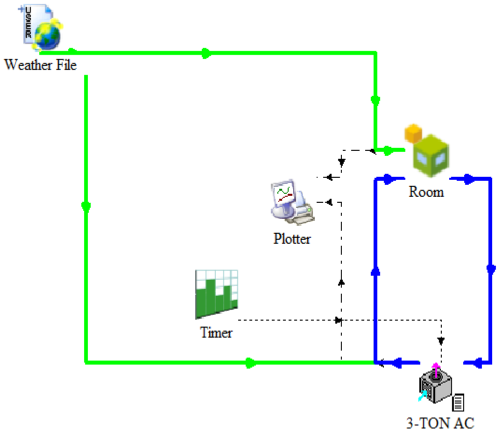


Figure 3.3: Schematic diagram of 3-TON AC system on TRNSYS.

Weather conditions in the software are introduced by the weather file. The function of timing file is to limit the working of cooling system from 9:00am morning to 5:00pm evening, Monday to Friday from 15th of May to 15th of October.

Figure 3.4 shows the schematic Layout of SAC cooling system assisted with cooling tower. In this condition not only the room air temperature and conditions are affected by ambient conditions, but SAC system itself is affected too. Mainly the energy gain in this condition is from solar thus solar radiation play vital role in deciding the performance of the system. When eradicating the room heat, cooling tower is also affected by the ambient conditions. The hot water from solar collectors is heated due to solar energy and is stored in storage tank. If further high temperature is required this hot water then flows through auxiliary heater thus raising its temperature even more. The absorption chiller on having hot water and cold water produces chilled water. The chilled water produced flows through 2-fan coil system, located inside the room. This chilled water then is used for eradicating the heat from the room.

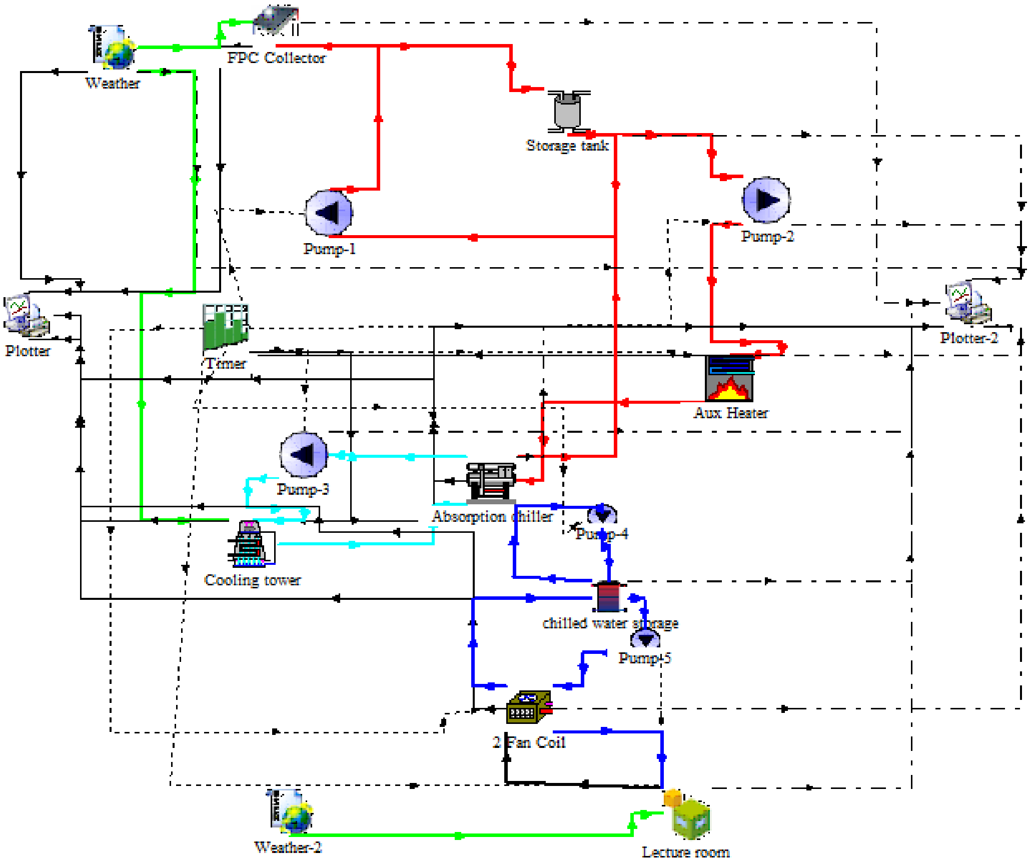


Figure 3.4: Schematic diagram of SAC system with cooling tower on TRNSYS.

Any component used in the schematic layout of SAC system assisted with cooling tower is given in Table 3.7.

Table 3.7: Components chosen from the TRNSYS library to complete the layout

TRNSYS Component Types	
Component	**Type**
User defined file	Type 56
Weather data file	Type 99
Flat Plate Collector	Type 1b
Storage Tank	Type 38
Auxiliary Heater	Type 751
Absorption Chiller	Type 107
Pumps	Type 3b
Cooling Tower	Type 510
2-Fan coil System	Type 600

Figure 3.5 shows the layout of SAC system which is assisted by GHX system for cold water loop system. The hot water cycle remains same as for SAC system with cooling tower. The only difference comes in the layout of cold water cycle where GHX system is used to eradicate the space heat into the earth. Where eradication of room heat to the environment was affected by the ambient conditions in GHX system it is affected by the underground thermal gradient profile.

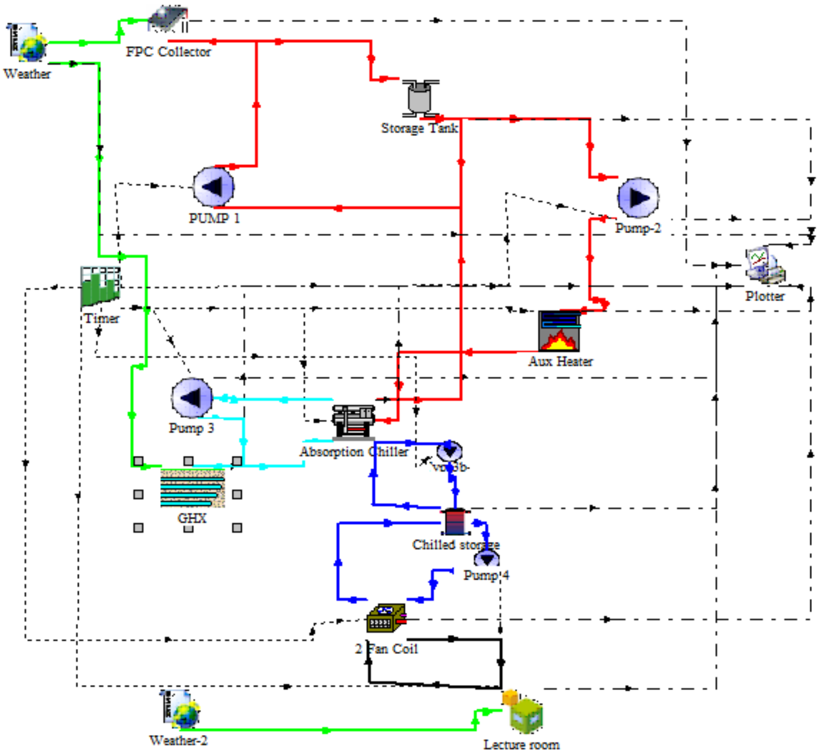


Figure 3.5: layout schematic of SAC system assisted with GHX system.

Details of Other components used in the SAC system with GHX system are given in Table 3.8. The GHX system is made up of High Density Poly-Ethylene (HDPE) pipes which are laid underground in horizontal, vertical or helical assembly. The hot water would flow through the pipe underground. As the ground is at lesser temperature than that at surface, and remains like that for all year around, therefore the heat from water is exchanged to the earth around. And hence the water is cooled down.

Table 3.8: SAC system with GHX system

TRNSYS Component Types	
Component	**Type**
User defined file	Type 56
Weather data file	Type 99
Flat Plate Collector	Type 1b
Storage Tank	Type 38
Auxiliary Heater	Type 751
Absorption Chiller	Type 107
Pumps	Type 3b
GHX	Type 997
2-Fan coil System	Type 600

The main objective of the study is to observe the best possible renewable driven energy efficient cooling system. For a given cooling load which is the lecture room building of USPCASE department at NUST University, three cooling systems are designed. First being the 3 –TON conventional AC system. The second one being the Solar absorption cooling system assisted with cooling tower i.e., SAC system with cooling tower. In this system it si the responsibility of the cooling tower to collect the heat of the lecture room and heat dissipated by the functioning of the absorption chiller into the environment. Our third system to be tested is SACX system assisted with GHX system. In this system GHX is responsible to dissipate the heat from lecture room and absorption chiller to underground cooler part of earth as mass storage. All the systems are run and simulated for the months of summer season in Islamabad i.e. 15th of May to 15th October. The daily schedule followed is if 40 students in the lecture hall present from Monday to Friday, from 9:00 am to 5:00 pm. All the systems will be tested and analyzed for some parameters such as capital cost, payback period, NPV, CO_2 emissions and the total energy utilized for the working of the system.

3.7. TRNSYS software

TRNSYS software is used by many researchers and engineers in the world for extensive research on thermal and PV based projects. It’s a FORTRAN based tool of simulation used to study transient response of different energy systems [6]. TRNSYS software is very good at search on thermal based energy system, and includes number of very important components in its library. These components follow certain algebraic equations and lay their output response based on those equations. TRNSYS has been very good to study projects including;

- Solar thermal systems
- Solar PV systems
- Heat exchange cooling and heating systems
- Turbine power generation with steam
- Solar tower power generation system

3.8. TRNBuild Software

TRNBuild software is a plug-in to TRNSYS software. Any 3-D design of the building is laid down in TRNBuild with all dimensions, properties such as their thickness, material of walls, roof, floor, windows and doors, and their height from floor, and characteristics such as timing of schedule, infiltrations and other heating loads present. The final cooling or heating loads are calculated and hence the file is available in TRNSYS file with the component of TYPE-56 [7].

Any weather parameter can act on it using TYPE-99 weather file. The components connected to it for different types of cooling systems or heating systems can then be built on TRNSYS, connected to TYPE-56 file run and simulated. Hence the overall resultant response can be analyzed.

Summery

A brief methodology of research has been analyses in this chapter. FORTRAN based TRNSYS software is chosen for energy analysis of the research. It has been recognized as the most viable tool to study energy response of any renewable and thermal based energy system, used by many researchers and engineers all over the world. TRNBuild software is chosen for the 3-D modeling of the lecture room. TRNBuild defines all the properties and characteristics of room with all its dimensions.

There are three models developed for cooling of the lecture room. First being the 3-TON AC system, second being the SAC system with cooling tower, and third being the SAC system with GHX system. All three models build and simulated separately and their energy response would be analyzed on TRNSYS.

Finally all these three models compared on the basis of different parameters such as energy used, efficiency, cost, payback period, NPV and CO_2 emissions produced by each system. The cost economic analysis would be done using Ret-Screen software.

References

[1]. Tsoutsos, T., et al., Design of a solar absorption cooling system in a Greek hospital. Energy and Buildings, 2010. 42(2): p. 265-272.

[2]. Gomri, R., Simulation study on the performance of solar/natural gas absorption cooling chillers. Energy Conversion and Management, 2013. 65: p. 675-681.

[3]. TRNSYS 17 Mathemat ical Reference. The University of Wisconsin-Madison Solar Energy Lab, Madison, 2007. 4.

[4]. Tsoutsos, T., et al., Solar cooling technologies in Greece. An economic viability analysis. Applied Thermal Engineering, 2003. 23(11): p. 1427-1439.

[5]. Oil and Gas Regulatory Authority Pakistan. 2013.

[6]. TRNSYS. The University of Wisconsin-Madison Solar Energy Lab, Madison, 2007.

[7]. TRNSYS 17 Multizone Building modeling with TYPE 56 and TRNBuild. The University of Wisconsin-Madison Solar Energy Lab, Madison 2007, 5.

Chapter 4

RESULTS AND DISCUSSIONS

In this chapter, the obtained results for all different parameters of experimentation and simulation, is presented in the form of figures, charts and tables. The climatic data of Islamabad is also presented which is used in simulation model.

4.1. Climatic data for Islamabad

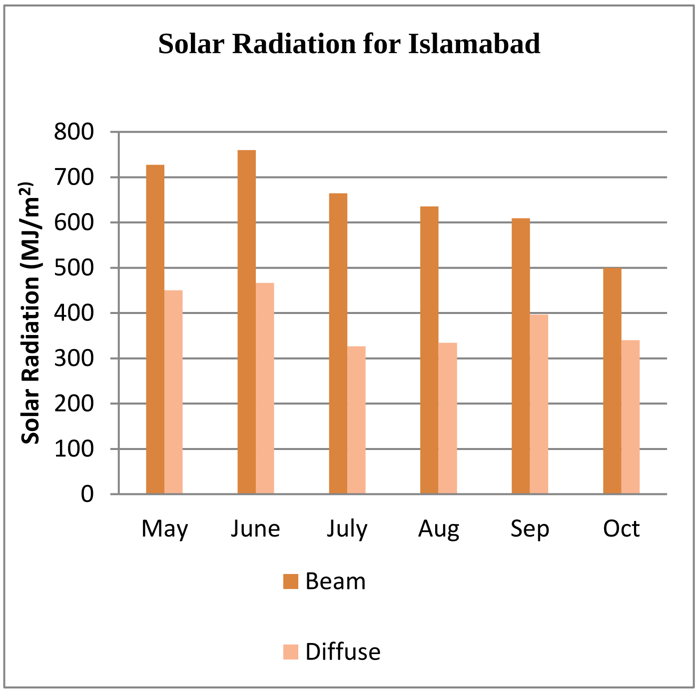


Figure 4.1: Direct and diffuse radiations for month of summers for Islamabad.

Figure 4.1 represents the radiations data for the region of Islamabad including both direct and diffuse radiations. It is observed that solar radiation is high for the months of May and June having values up to 754 MJ/m^2 and 760 MJ/m^2 respectively. Where the direct radiation is 465.4 MJ/m^2 and 466.7 MJ/m^2 and diffuses radiation is 288.7 MJ/m^2 and 293.2 MJ/m^2 respectively. No cooling is required for the months from November to April, as the ambient for these months is less because of less radiation.

Figure 4.2 and Figure 4.3 represent the monthly average ambient temperature and relative humidity for Islamabad. It is clearly observed that the highest average ambient temperature is achieved in June whereas, relative humidity is lowest. Cooling is only required for the months from April to October as the Ambient temperature remains high for the months. These figures (Figure 4.1 and Figure 4.2 and Figure 4.3) show clearly that more cooling is required when high radiations are available on the other hand, by using SAC system these radiations can be used to provide space cooling.

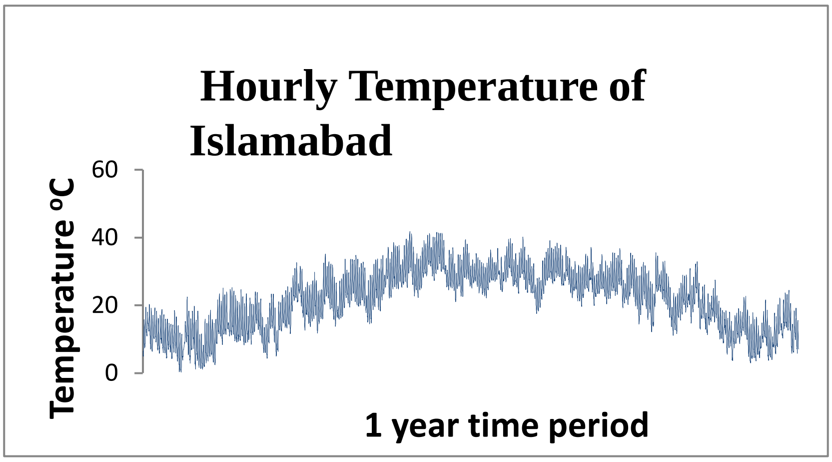


Figure 4.2: 1 year average ambient temperature for Islamabad.

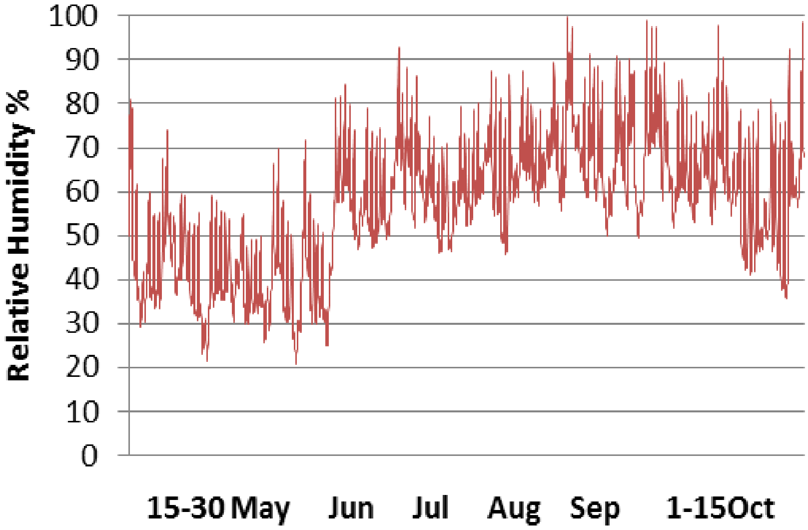


Figure 4.3: Monthly average percentage relative humidity for Islamabad.

Figure 4.4 shows the variation in ambient temperature of the air of lecture room on monthly basis for the months of summer, calculated using TRNSYS. It is observed that temperature of the air of lecture room reaches up to 43^{O}C during the month of June and at the same time cooling load is also high.

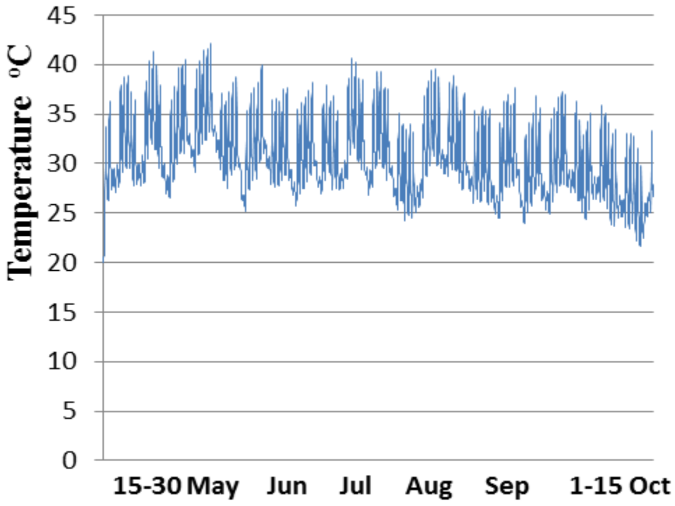


Figure 4.4: Monthly ambient temperature of the air in the lecture room.

4.2. Cooling Load for the Real and Modified Building

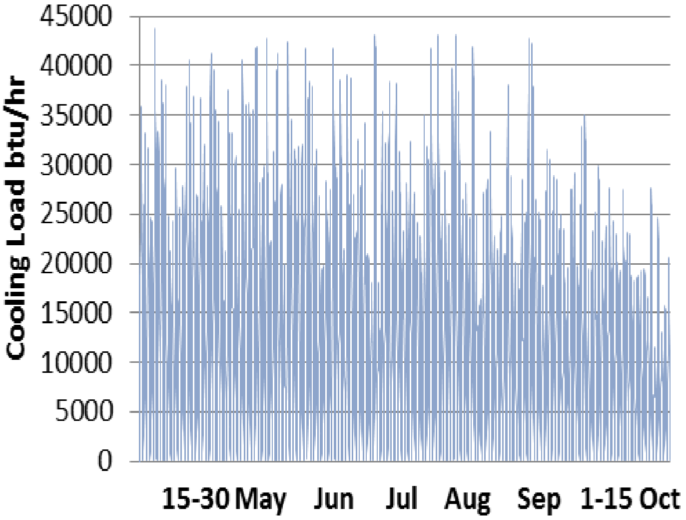


Figure 4.5: Hourly cooling load for the real building during summer season.

Hourly cooling load for the real building (without insulation and external shading) is presented in Figure 4.5. It observed that the cooling load of the lecture room without any insulation in the envelop, for the months of summer is very high. It reaches maximum value of 42,000 Btu/hr which is 3.5 TON. The radiation is transferred from walls, roof, windows, doors and other leakages.

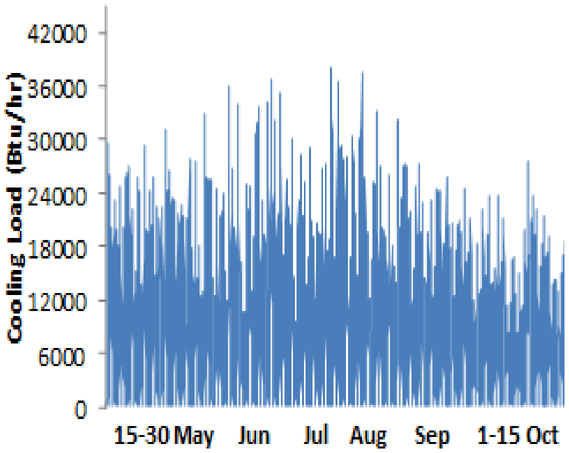


Figure 4.6: Hourly cooling load for modified building during summer season.

The real building when modified as including a an insulation in the envelop of 2 inch polystyrene, also using double glazed window instead of single glaze as in original design, the cooling load then did decreased. Also the insulation was included in the roof and the leakages were modified. Figure 4.6 shows the new cooling load which has been reduced from 42,000 KJ/hr to 36,000 KJ/hr, the transmittance of radiation greatly reduced using double glazed window.

Maximum cooling load calculation is necessary for knowing the size of SAC system [1]. Cooling load of the lecture room is calculated by performing simulation at the set point temperature of 26 ^{o}C.

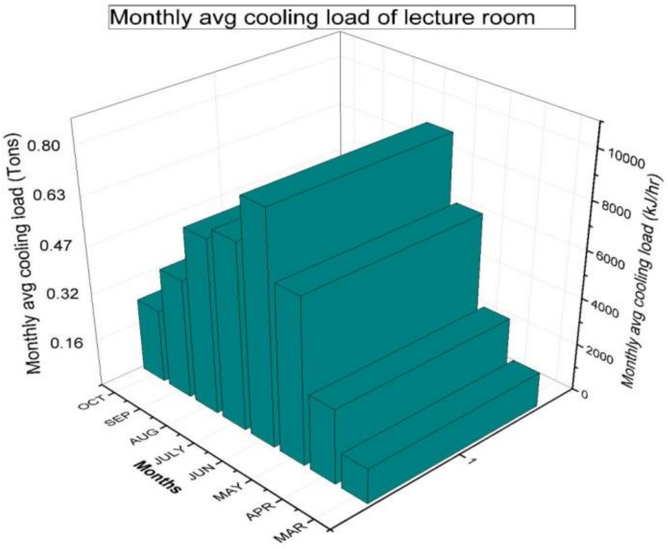


Figure 4.7: Monthly average cooling load of the real building for different months.

In Figure 4.7 average monthly cooling load for the summer season is illustrated. It is clear that the cooling load is low for the month of April, having cooling load of 3,170kJ/hr only. Afterwards, the cooling load starts to increases reaching maximum of 9,670 KJ/hr for the month of June. In May, July and August cooling load is approximately same.

4.3. Thermal performance of FPC for SAC system

Figure 4.6 represents the effect of variation in slope of the collector on solar heat gain (SHG) by the collector for the months of summer.

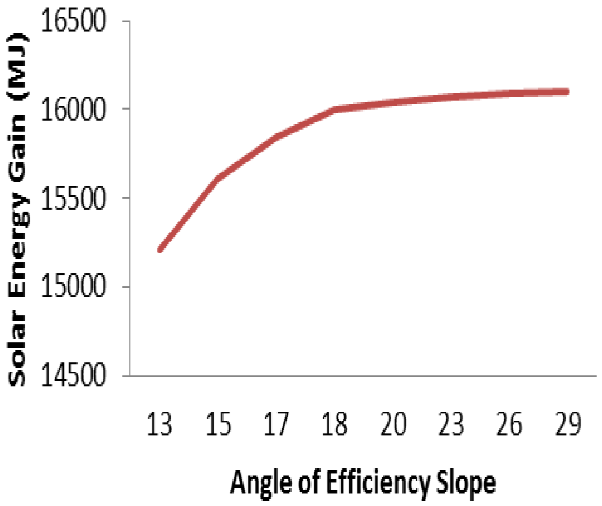


Figure 4.8: Effect of slope of the collector on solar heat gain.

It is observed that by changing the slope of the collector, solar heat gain (SHG) also varies. The solar heat gain is maximum for angles between 18° and 20° having value of 16,100 MJ for FPC. If we further increase the slope angle then, SHG decreases because of the reduction in beam radiations fall on the surface.

In Figure 4.9 the effect of changing the volume of hot water tank on SHG for FPC is illustrated. It can be seen that with the increase in volume of the tank, the SHG also increases. Solar heat gain seems to be less at volume of 2 m^3 because, the water stays for very short time in the tank and moves back in to the collector again and will absorb less heat because it will be already at high temperature. From the efficiency equation (Eq. 3.1) the efficiency of collector decreases with the increase in inlet water temperature.

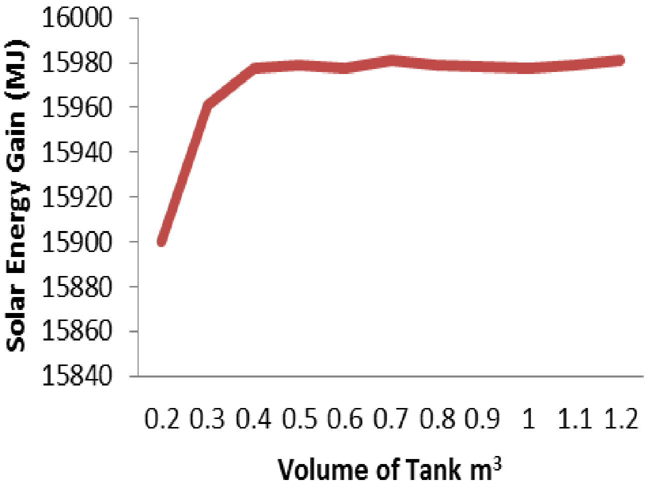


Figure 4.9: Effect of volume of hot water tank on solar heat gain.

As the storage tank volume increases, so does SHG, as Water will stay for more time in the storage tank and heat would be used more effectively in the chiller to provide cooling. There is no significant increase in SHG after the volume of 0.4 m^3 and 0.6 m^3. If we further increase the volume of hot water tank the system size will increase and losses will also increase.

Figure 4.10 shows the variation of auxiliary heat gain (AHG) with the volume of hot water storage tank. With the increase in volume of hot water tank, AHG decreases and its value is found to be lowest at 0.4 m^3. This is due to the fact that water gains more heat from collectors than auxiliary heater.

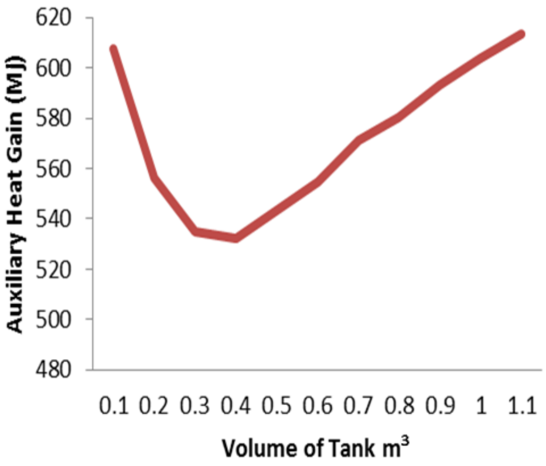


Figure 4.10: Effect of volume of hot water tank on auxiliary heat gain

After 0.4 m^3 he again from auxiliary heater starts to increase because, with further increase in volume, losses will also increase and more heat will be required form the auxiliary heater to bring the water temperature to the set point temperature.

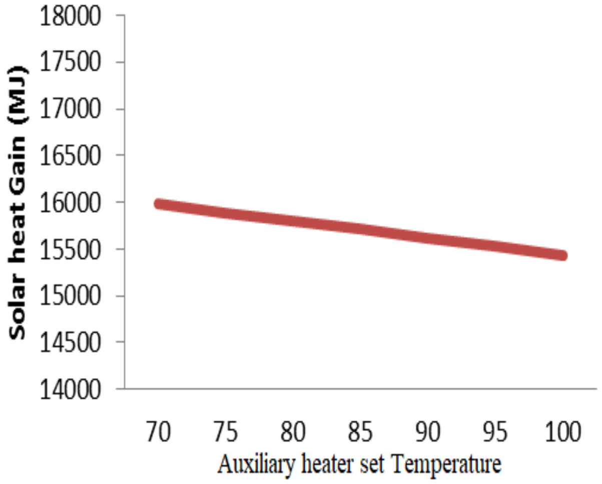


Figure 4.11: Effect of set point temperature on solar heat gain.

By changing the set point temperature of auxiliary heater the SHG also changes as shown in Figure 4.11, with the increase in set point temperature the SHG decrease. At higher set point temperature the water goes back at high temperature in the hot water storage tank. From efficiency equation of collector (Eq 3.1) the efficiency of collector decreases with the increase in water inlet temperature therefore, SHG reduces with the increase in set point temperature.

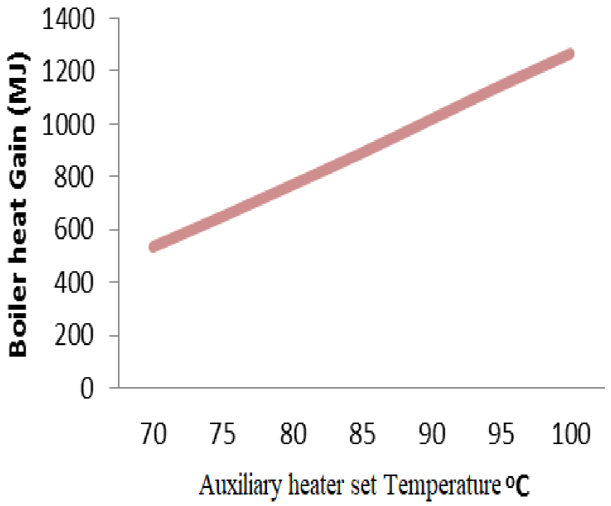


Figure 4.12: Effect of set point temperature on auxiliary heat gain.

In figure 4.12 it is illustrated clearly that the maximum efficiency of the system is obtained at the set point temperature of 70°C, because at these set point temperatures system takes minimum heat from auxiliary heater and provides more cooling. If set point temperature is further increased then boiler heat gain also increases because the COP almost remains constant. Therefore, the optimized values of the set point temperature is 70°C using FPC, as overall efficiency of the system turns to be highest at the specified temperature for specific collector type [2].

Figure 4.13 shows the variation of solar heat gain with collector area. As the collector area increases SHG also increases up to 10 m^2 using FPC. When collector area is increased above 10 m^2 the rise in SHG is comparatively small. Because by further increase in area of collector it generates extra heat than the heat required for absorption cooling.

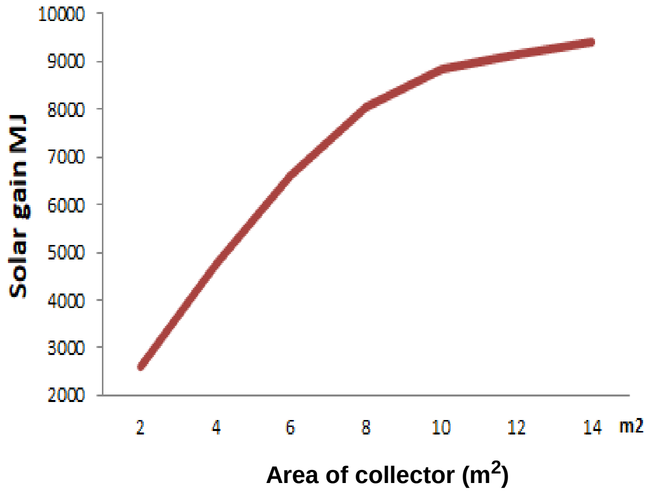


Figure 4.13: Effect of the area of collector on solar heat gain using FPC.

In figure 4.14 underground thermal temperature gradient profile for the region of Islamabad is illustrated. We observe that during summer season, the surface is about 35°C for day times, But as the underground depth increases the temperature of underground decreases. At the depth of 3 meters beneath the surface, the temperature reaches up to 21°C - 23 °C. Even at the depths is increased further, there is no significant variation in the temperature range. Thus the temperature reaches a constant variation of 21°C-23°C at the depth of 3 meters.

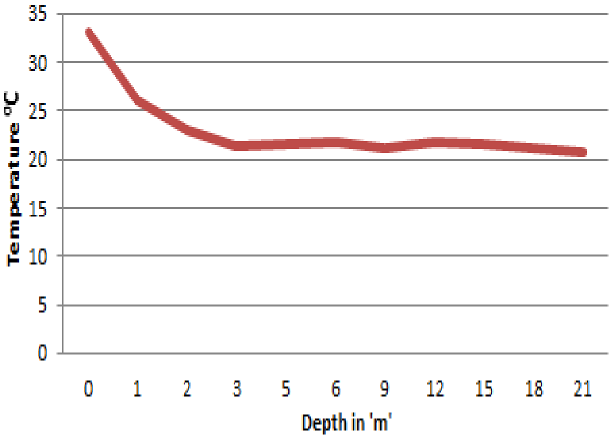


Figure 4.14: Underground thermal gradient profile for Islamabad.

In figure 4.15 it is illustrated that the pump-1 flow rate highly alters the solar gain of the system. It is clearly evident from the figure that before the flow rate of 50kg/hr, the system is not stable enough to run. At 50kg/hr of flow rate the runs in quite stable manner. Increasing flow rate decreases the solar gain further. Thus flow rate of 50kg/hr is selected for pump-1.

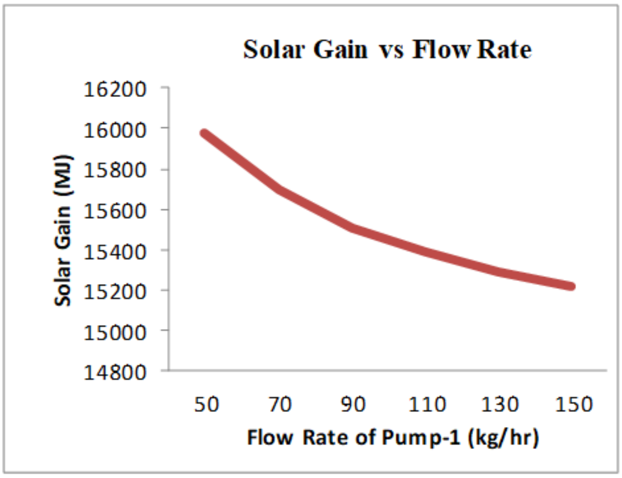


Figure 4.15: Pump-1 flow rate vs solar gain.

In figure 4.16 it is clearly shown that altering the flow rate of pump-1 also greatly alters the heat gain from auxiliary heater. Thus we choose the optimum value for the working of the system. We see that before the flow rate of 50kg/hr the system is not stable enough. Again at 50kg/hr the system starts to function in stable manner. As we increase the flow rate auxiliary heat gains increase. This is not suitable for the system, as we need more energy from solar. Thus the optimum operating value of 50kg/hr flow rate is selected.

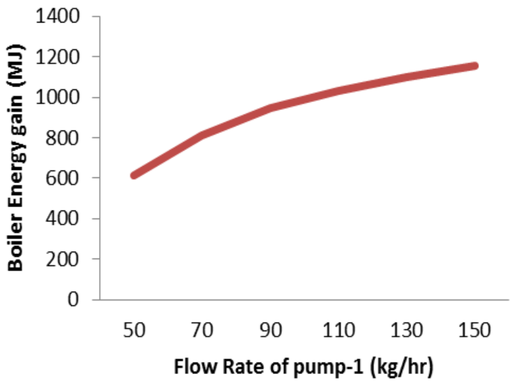


Figure 4.16: Pump-1 flow rate vs Auxiliary Gain.

In figure 4.17 it is illustrates the total amount of energy that is removed from the room in summer season in order to reduce its temperature. The first case being removing the amount of heat from room sing conventional 3-TON Air-conditioning system. The second on as removing heat from the room using SAC system assisted with cooling tower. The third one being the case where room heat was removed using SAC system assisted with geothermal heat exchange system.

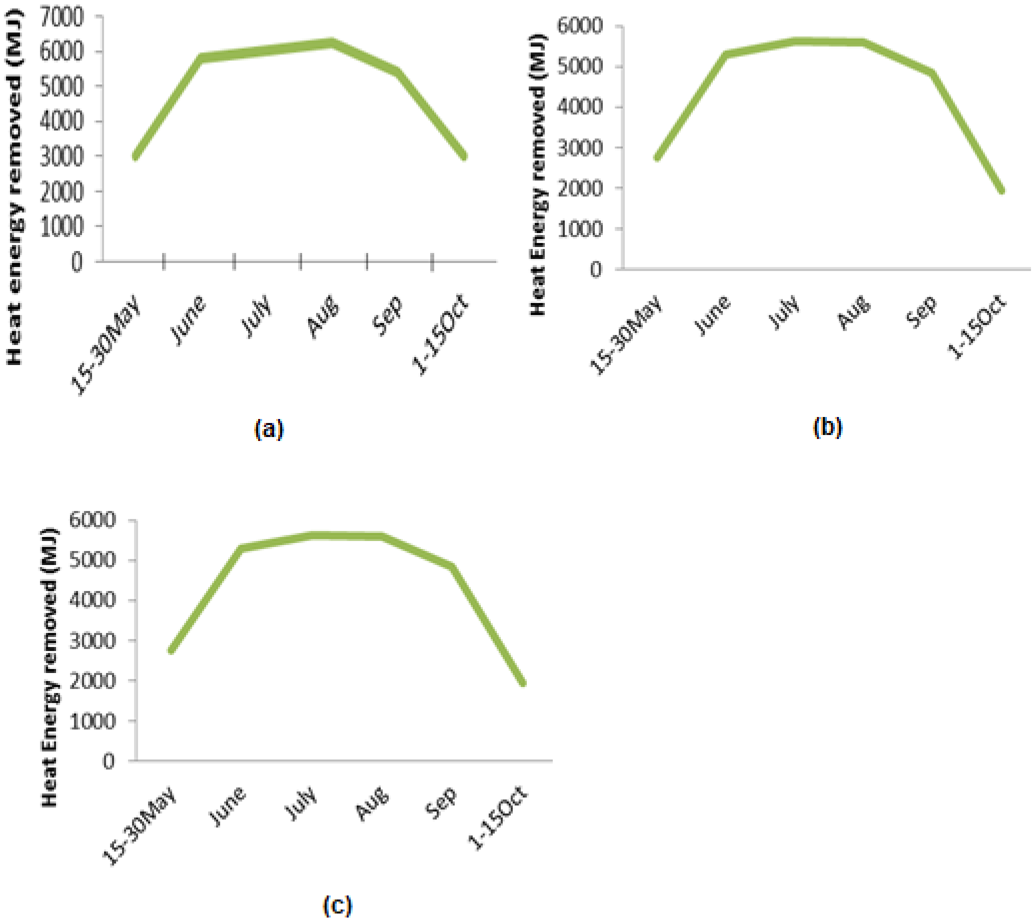


Figure 4.17: Energy use by (a) 3-TON AC (b) SAC system with cooling tower (c) SAC system with GHX system.

The total amount of heat energy removed using conventional 3-TON AC system is 29,470 MJ. Secondly the amount of energy removed using SAC system with cooling tower is 27,032 MJ, while the amount of energy removed from room using SAC system with GHX is 26,040 MJ.

Figure 4.18. is evident to show that the heat energy rejected by the sinks of the system is almost equivalent to the heat energy removed from the lecture room. The heat energy rejected by the cooling tower system to the environment is 27,840 MJ and the amount of energy rejected by the GHX system to the ground is 27,835 MJ.

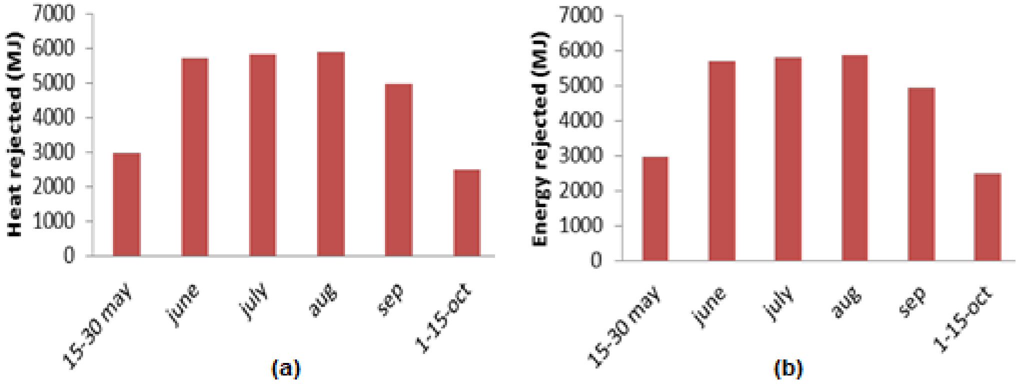


Figure 4.18: (a). Heat rejection by cooling tower (b) Heat rejection by GHX

Therefore both the systems are good at eradicating the heat energy from the room thus maintaining it at lower temperatures during summer season.

Figure 4.19 illustrates the inlet and outlet temperatures of the cold water cycle at both the heat sinks of the systems. Cold water carries the heat of the room and system machine and eradicates it into the environment. The first case being the cooling tower as a heat sink while the second one being GHX as the heat sinking system.

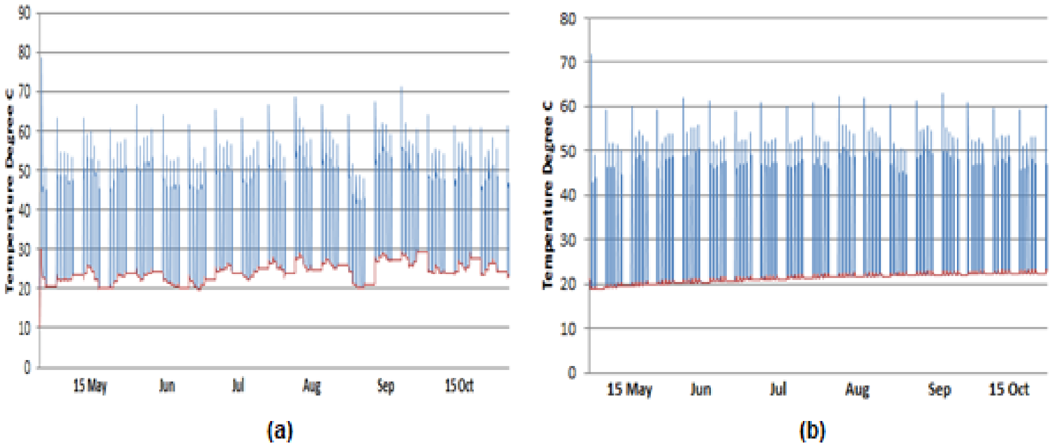
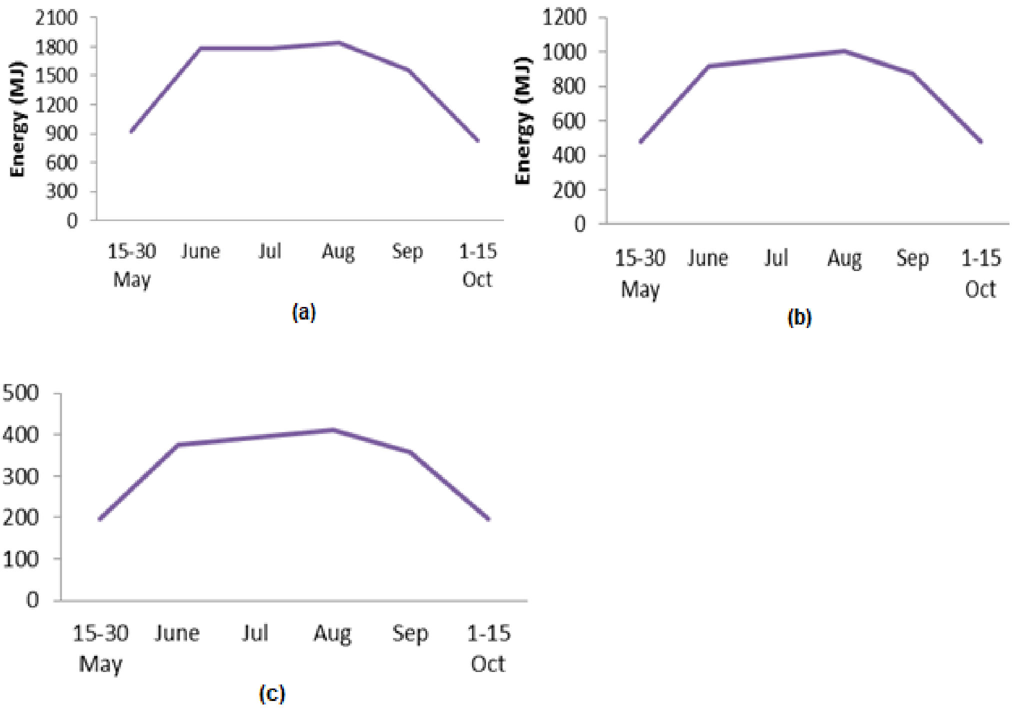


Figure 4.19: (a). Cooling water at cooling tower (b) Cooling water at GHX

The inlet water temperature at cooling tower was found to be between 45°C and 60°C, while the temperature of water at outlet was found to be in the range from 20°C-25°C. We see very interesting response at GHX heat sink side. The water temperature at outlet follows a very steady range between 18°C - 24°C, while temperature at inlet comes out to be in a range of 45°C-60°C. Also the outlet water temperature follows a steady pattern of temperature increment over the time period of summer season. This is because the earth not only performs as a heat sink but also as a energy storage. Thus the temperature over a time period under the surface of the earth increases. While at the cooling tower the sink depends on number of parameter such as ambient temperature, wind, humidity etc., thus the inlet water temperature never remains under any range of temperature.

In figure 4.20 illustrates the total amount of energy utilized by each system in order to work and perform cooling function. Each of the system requires energy to perform its function. The system in which 3-TON AC performs cooling function requires total electrical energy. The other two systems however along with electricity, utilize solar also to perform their functionality.



(a)

(b)

(c)

Figure 4.20: Monthly average energy consumption of: (a) 3-TON AC system (b). SAC system with Cooling tower (c). SAC system with GHX system

The total amount of electrical energy utilized by 3_TON AC system to operate for the whole summer season is 8,735 MJ. The SAC cooling system which utilizes cooling tower utilizes 4,728 MJ of electrical energy to operate for the whole summer season. This is the amount of energy utilized to collect heat from the lecture room and eradicate it into the environment. The total amount of energy required by the SAC cooling system with GHX to operate is 1,929 MJ for the whole summer season.

All of them maintain a temperature which comes comfortably in the human comfort thermal zone range. 3-TON AC and SAC with cooling tower use a lot of energy to operate while SAC with GHX produces same cooling and utilizes very less energy to operate.

As three different technologies were used to produce cooling for lecture room, result obtained clearly show that they produce cooling and utilize different amount of energy to operate. Figure 4.21 shows the temperature produced by cooling of these technologies.

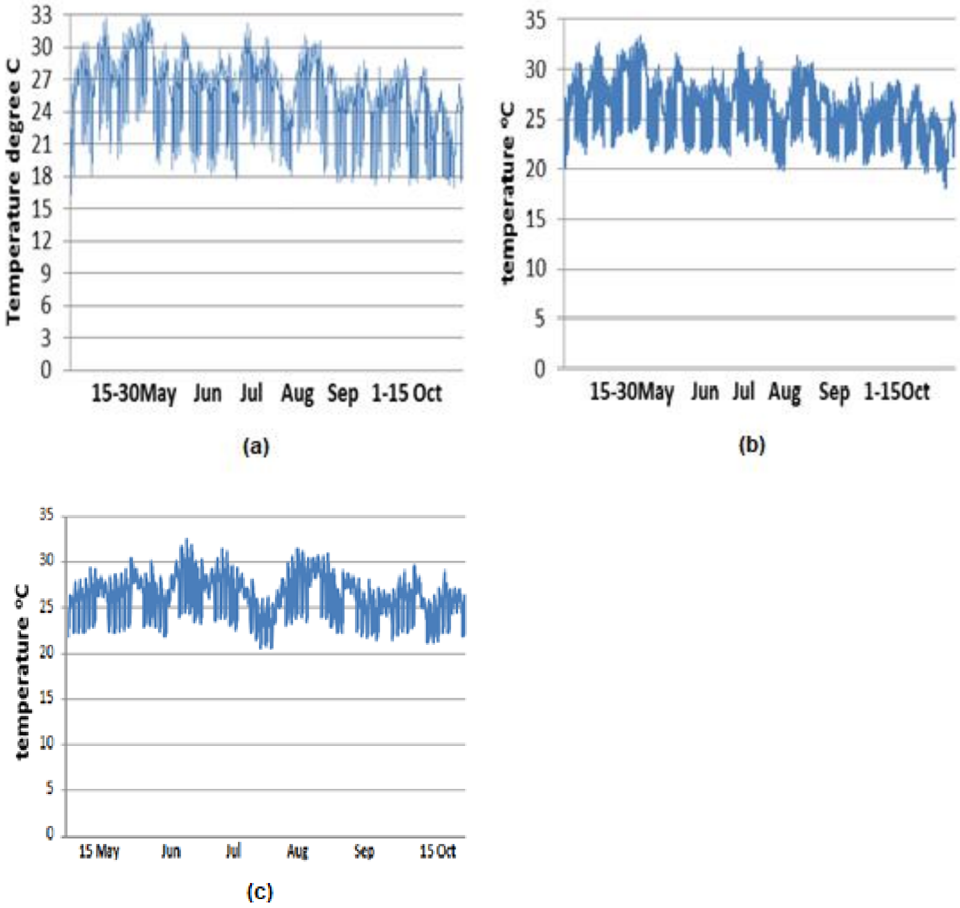


Figure 4.21: Daily average temperature of room by: (a) 3-TON AC system (b). SAC system with Cooling tower (c). SAC system with GHX system

The temperature maintained by 3-TON AC system in lecture room ranges in between 18 °C - 21°C. The temperature maintained by SAC system with cooling tower in lecture room ranges in 20 °C -23 °C. However on the other hand, the temperature maintained by SAC system with GHX, in lecture room ranges in 22 °C -24 °C. all these temperature ranges lie well within the constraints of human comfort temperature zone.

Another very important aspect is the share of solar energy in the working process of SAC systems. Figure 4.22 illustrates the Solar fraction of the system clearly stating the share of renewable technology solar energy in working of SAC systems.

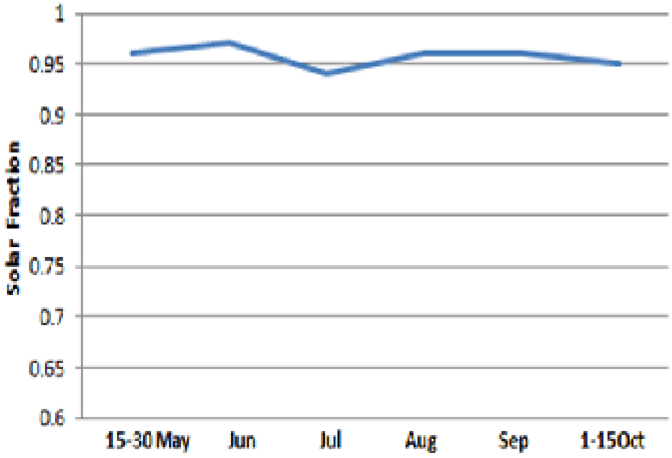


Figure 4.22: Monthly average solar fraction of system during summers.

We see that the solar fraction remains within the range 0.93-0.97 for the whole summer season. This means on average our system gains 95% of its energy from solar for the process of cooling.

4.4. Optimized size of the system

Table 4.1 presents the optimized size of the SAC system. It is therefore the final values of each parameter selected in order for the system to work in the most optimized fashion. The value of total cooling capacity selected for cooling to occur in the lecture room with certain conditions is also calculated and given. The cooling load of lecture room is affected by the conditions such as its envelop design, number of people present in it, radiation from roof, walls, door, windows and leakages etc. All the values of different parameters and components are given below.

Table 4.1: Optimized size and values of collectors, Heater, chillers and pumps, cooling tower, 2-Fan coil and GHX systems

TRNSYS Component Types		
Component	**Type**	**Capacity**
Flat Plate Collector	Type 1b	8 m^2
Slope of collector		18^o
Storage Tank	Type 38	0.4 m^3
Chilled Water Storage Tank	Type 4a	0.4 m^3
Auxiliary Heater		
Auxiliary Heater	Type 751	0.5 KW
Auxiliary set temperature	Type 751	70^0C
Absorption Chiller		
Absorption Chiller	Type 107	36000 Btu/hr
C.O.P of Chiller		0.7
Pump-1 (flow rate)	Type 3b	50 Kg/hr
Pump-2 (flow rate)	Type 3b	12 Kg/hr
Pump-3 (flow rate)	Type 3b	300 Kg/hr
Pump-4 (flow rate)	Type 3b	140 Kg/hr
Pump-5 (flow rate)	Type 3b	600 Kg/hr
Cooling Tower		
Cooling Tower	Type 510	36000 Btu/hr
Cooling Tower	Type 510	600 W
2-Fan coil System		
2-Fan coil System	Type 600	150 W
2-Fan coil System (Air Flow)	Type 600	7000 Kg/hr
GHX System (HDPE)		
Pipe length	Type 997	60 m
Pipe inside diameter	Type 997	0.053 m
Pipe outside diameter	Type 997	0.0602 m
Thermal conductivity of pipe	Type 997	0.5 kJ/hr m K
Horizontal pipe separation	Type 997	1 m
Depth of pipe layer	Type 997	3 m

4.5. Economic and Cost analysis of the system

The system is simulated and then analyzed for cost and economic analysis on the Ret-screen software. For the very reason original prices of all the components were sought out in the market and then put in the software. And the cost analysis of all the three systems was demonstrated. The cost of components used is given in table 4.2.

Table 4.2: Shows the cost of components

Equipment	**Cost**
Absorption chiller	53,592 PKR/kW
Solar collector (FPC)	35,000 PKR/m^2
Auxiliary heater	6,699 PKR/kW
Cooling tower	6,699 PKR/kW
Storage tank	80,388 PKR/m^3
Insulation	538 PKR/m^2
Pump 50W	6,500 PKR
Ground Digging	20,000 PKR
GHX HDPE Pipe	1,090 PKR/m
Double Glazed Window	12,000 PKR/m^2
Cost of energy	
Natural gas PKR/MMBTU	637 PKR/MMBTU
Electricity	18PKR/KW

Likewise the economic analysis was also carried out on the Ret-screen software. The project life selected being 30 years. The economic analysis was governed by certain parameters such as escalation cost, GHGF credit, inflation rate, fuel escalation etc. all these parameters were selected on from the values given by state bank and given in Table 4.3.

Table 4.3: shows all the parameters selected for performing economic analysis.

Parameter	Value
Fuel Escalation (%)	**10**
GHG credit (PKR/tons CO_2)	**25,722**
Inflation rate (%)	**8**
Discount rate (%)	**10**
Installation cost (%/equipment cost)	**12**
O & M cost (% of capital cost)	**1**
Transportation cost (% of capital cost)	**5**
Training and commissioning cost (% of capital cost)	**2**
Salvage value (% of capital cost)	**10**
Project life (year)	**30**

Figure 4.23 demonstrates the payback period of the system 3-TON conventional AC system. As this system does not work any on any kind of renewables therefore the positive payback is not expected. Thus we observe from the payback period graph that over the course of analysis of 30 years, the utility electricity would only cost harshly to the system. The graph is therefore negative. Total capital investment of the system is 0.15 million PKR.

As this system utilizes a lot of electricity therefore the CO_2 production in contrast to the production of utility electricity by burning fossil fuel is also very high. Therefore the amount of CO_2 production accounts up to 1.62 tons per year.

This is a huge amount of pollution added to the environment just whilst using conventional cooling techniques.

Parameters	**Value**
Total initial investment	PKR 0.15 Million
Payback period	-
CO_2 Production	1.62 ton
Cost-Benefit Ration	-1.83

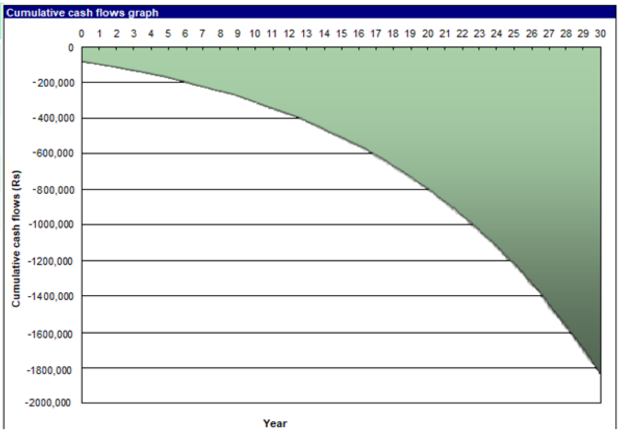
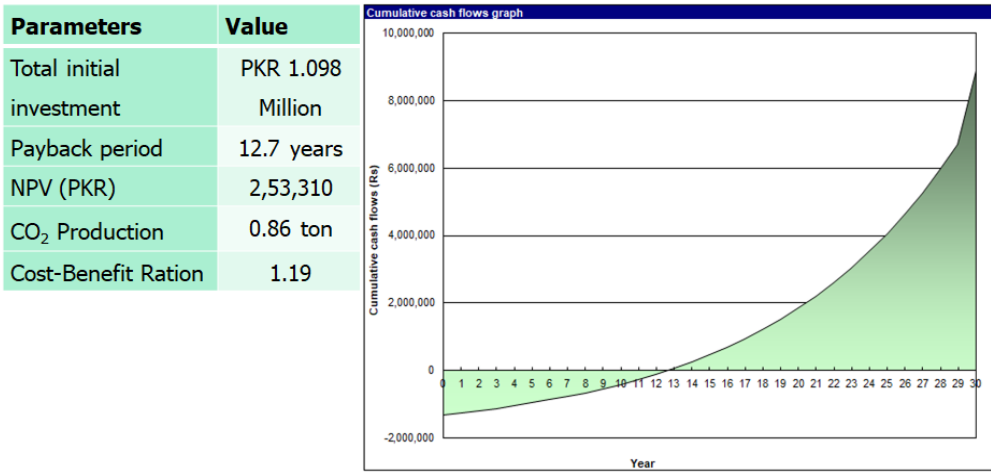


Figure 4.23: PBP, CO_2 production and CBR with conventional 3-TON AC System

As this project from capital investment accounts for only spending money on payment of utility bills only, therefore the CBR of the system is negative. This indicates that the system would yield no benefit for as long as it functions. The CBR of the system is -1.83.

Figure 4.24 shows the payback period of second system which is SAC system assisted with cooling tower. This system as utilizes renewable energy also to function therefore we observe the payback period to be positive. The payback period of this system is calculated to be 12.7 over the period of 30 years. This is due to high capital initial investment. The energy from utility is greatly reduced using renewables. Total initial investment of the system is 1.098 million PKR.



Parameters	**Value**
Total initial investment	PKR 1.098 Million
Payback period	12.7 years
NPV (PKR)	2,53,310
CO_2 Production	0.86 ton
Cost-Benefit Ration	1.19

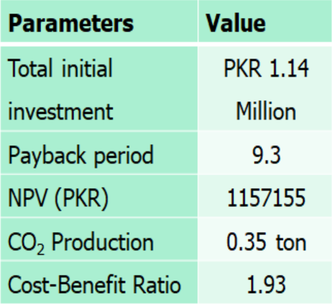
Figure 4.24: PBP, CO_2 production, NPV and CBR of cooling tower SAC system

This because utilizes renewable energy therefore, uses very less electricity and therefore CO_2 production is less. The amount of CO_2 production for this system is 0.86 ton. This due to the utilization of utility electricity being gone down to half compare to the system, with 3-TON AC system.

The CBR of this system is positive indicating that the total investment would return. Due to the utilization of renewables the CBR produced is positive indicating independence from utility power sources. The CBR of the system is 1.19. The net present value calculated is 2,53,310 PKR.

Figure 4.25 indicates the payback period of the SAC system with GHX. This system though utilizes solar thermal energy but for cold water production utilizes geothermal heat exchange system.

The cold loop being closed therefore the system utilizes even less electricity from the utility. While the capital cost being somewhat equal to that of Sac system with cooling tower, therefore the payback reduces even more. The payback period of the system with GHX is 9.3 years only. The total capital investment of the system is 1.14 million PKR.



Parameters	Value
Total initial investment	PKR 1.14 Million
Payback period	9.3
NPV (PKR)	1157155
CO_2 Production	0.35 ton
Cost-Benefit Ratio	1.93

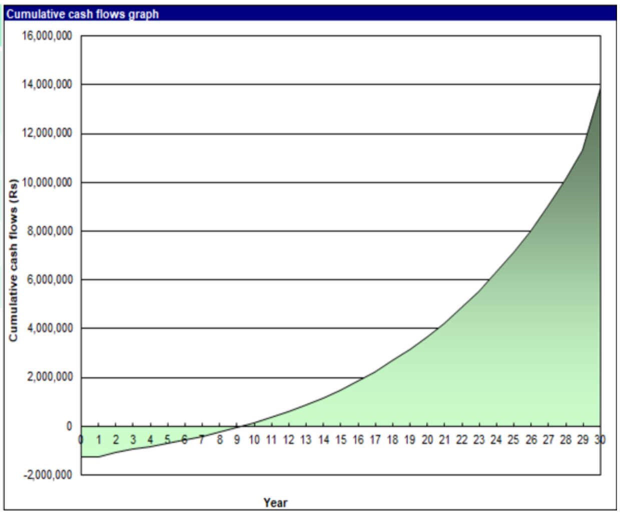


Figure 4.25: PBP, CO_2 production, NPV and CBR of SAC system with GHX

As the system utilizes even less electricity therefore the CO_2 production due to the utilization of utility electricity would also be very less. The amount of CO_2 production for the system with GHX is 0.35 tons per year. this decrease in CO_2 production is 4.5 times less than that of conventional 3-ton AC system.

The system also has a positive CBR, indicating that the total investment would return. Due to the utilization of renewables the CBR produced is positive indicating independence from utility power sources. The CBR of the system is 1.93, indicating that its highly appreciable. The net present value calculated is 11,57,155 PKR.

4.6. Comparison of all Cooling Systems

Three different technologies were used to maintain a cooling temperature in the lecture room. The first being the conventional 3-Ton AC system, while second being Solar Absorption cooling (SAC) system assisted with cooling tower. The third one simulated and used is solar absorption cooling system (SAC) assisted with Geothermal Heat Exchange (GHX) system.

All systems simulated were then analyzed for their performance on different parameters such as energy consumption, CO_2 production, cooling maintained, payback period etc.

The summary of the three systems with all the parameters to be analyzed is given below in table 4.4

Table 4.4: shows the comparison of all three cooling systems

Parameters	**System-1 (3-TON AC)**	**System-2 SAC (cooling tower)**	**System-3 SAC (GHX)**
Analysis period (year)	**30**	**30**	**30**
Capital cost (Millions PKR)	**0.15**	**1.098**	**1.14**
Room energy Removed (MJ)	**29,470**	**27,032**	**26,040**
Room Temp. Maintained (°C)	**18 - 21**	**20 - 23**	**22 - 24**
Electrical Energy Consumed for working (MJ)	**8,735**	**4,728**	**1,929**
Electrical Units Consumed	**2426**	**1313**	**536**
CO_2 Production (ton)	**1.62**	**0.86**	**0.35**
Cost-Benefit Ratio	**-1.83**	**1.19**	**1.93**
Payback period	**-**	**12.7**	**9.3**

We observe very clearly that the present widely used cooling technology of vapor compression cooling system is not only very expensive but also very energy intensive. It utilizes 8,735MJ of energy to function and maintain cooling in the lecture room. It is responsible for wide range of production of CO_2 gas to the environment. The amount of CO_2 produced by system 1 is 1.62 tons/yr. system works purely on utility electricity source and uses no renewable source. That’s why the cost benefit ration of this system is negative. The room heat removed by this system is 29,470MJ. The temperature maintained by this system in the room is 18-21°C.

On the other hand system 2 with SAC system assisted with cooling tower and dependent on renewable source such as solar for its function, despite being expensive is energy efficient against system 1 utilizing 4,728MJ of energy to function and also produces less CO_2 comprising for only about 0.86 tons/yr. Being dependent on renewable gives you a benefit for having a payback period for your project. For system 2 we have a payback of 12.7 years. The cost benefit ratio is positive. The total amount of heat energy removed from the room by system 2 to maintain a cooling temperature in the lecture room is 27,032MJ. The range of room temperature maintained by this system is 22-23^{o}C, which is well in the thermal comfort temperature zone of the ASHRAE standards.

However with system 3 which is SAC system assisted with GHX system and is also dependent on renewable source such as solar for its function, despite being more expensive than system 2, is energy less intensive using 1,929MJ of energy to function and produces even less CO_2 being only about 0.35 tons/yr. the payback period for system 3 is of 9.3 years. The cost benefit ratio is positive. The range of room temperature maintained by this system is 22-24^{o}C which well in the thermal comfort temperature zone of the ASHRAE standards. The amount of heat energy removed from room using this system is 26,040MJ.

Summery

In this chapter the overall function and optimization parameters of SAC systems have been discussed extensively. The climatic data for the region of Islamabad, the temperature and humidity conditions of air inside the lecture room have also been covered. The cooling load, the introduction of energy saving techniques such as insulation in building envelop is also studied, its design and simulation on TRNBuild software has also been covered. System was then designed to meet the cooling demand using SAC system on TRNSYS. The effects of both SAC systems i.e. SAC system with cooling tower and SAC system with GHX, is covered. The cooling system that uses 3-ton AC system is also studied and simulated in TRNSYS. Both the SAC systems were then compared with 3-ton AC system. The systems were compared in terms of different parameters such as payback period, NPV, CO_2 emissions and energy consumption.

References

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Chapter 5

CONCLUSIONS & FUTURE RECOMMENDATIONS

- Using energy saving techniques for the building envelop such as introduction of insulation in its envelop design, using double glass window, filling all air leakages and infiltration gaps and use of curtains was very helpful in reducing the cooling load of the building.
- Using conventional AC system the energy utilized for its functionality is up to 8,735MJ while the total energy it eradicates from room is 29,470MJ.
- There is no payback of the system as it involves no renewable technology as an energy source and CO_2 emissions up to 1.62 tons/year.
- SAC system assisted with cooling tower though costs more but is energy efficient which utilizes only 4,728MJ of energy to operate while the total amount of energy eradicated by the system is 27,032MJ from the room, thus maintaining thermal comfort temperature in the room.
- Payback of the system is about 12.7 years while the CO_2 emissions reduced to 0.86 tons/year.
- SAC system assisted with GHX system has even more capital cost but utilizes even lesser energy than SAC with cooling tower, only about 1,929MJ.
- The total amount of energy eradicated from the room by this system is 26,040MJ to maintain comfortable temperature in the room.
- Payback period of the system reduces about 9.7 years while the CO_2 emissions reduced to 0.35 tons/years.
- Simulations using parabolic trough would also be vital for future research.
- Solar PV system would reduce even more the dependency of this system to work on utility electricity.

Annexure I

Solar Absorption Cooling System Assisted with Geothermal Heat Exchange Technology for Energy Efficient Buildings in Pakistan

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Abstract **- This paper presents a research on a 3 TON capacity solar absorption cooling (SAC) system assisted with geothermal heat exchange (GHX) system simulated on TRNSYS software. The case study is an arbitrary room with given dimensions located in Islamabad city of Pakistan. The GHX technology hybridized with SAC system is used as a heat sink to dispose the room heat, while heat required by absorption chiller is provided using solar water heaters. The results were also analyzed for economic and environmental analysis on Ret Screen software. The results indicate that an optimum working SAC system could be designed using 8m^2 area of flat-plat collectors and 0.4m^3 volume of storage tank. The GHX system uses HDPE pipes having 2 inch diameter and length 100 meters, having horizontal assembly. The COP of the system calculated is 0.71 in summers,**

solar fraction 0.96 and payback period 9.7 years and carbon production 0.8 TON.

Keywords—solar energy; solar water heater; absorption cooling; geothermal cooling system; TRNSYS; TRNBuild

ABBREVIATION

Q_{chw}	Chilled water energy
Q_{hw}	Hot water energy
P.B	Payback period
NPV	Net present value
a_o	Optical efficiency
a_1	Efficiency slope
a_2	Efficiency curvature
IT	Incident solar radiation
I	Energy inflation rate
C	Capital cost of system
E	Energy saving compare to VCR
Q_{solar}	Solar energy gain
Q_{heater}	Energy gain from heater
η	Collector efficiency
$S.F_{thermal}$	Solar Fraction
MJ	Mega joules
kg	Kilo gram
r	Discount rate from market
hr	Hour
VCR	Vapor compression refrigeration
SAC	Solar absorption cooling system
GHX	Geothermal Heat Exchange
yrs	Years
Y	Yearly benefit
hr	Hour
ΔT	Difference of water temperature at inlet and ambient

I. Introduction

The depleting fossil fuel resources increase in energy consumption is the core issue to be addressed for better future of Pakistan. It is estimated that by 2020 Pakistan would require 100000 GWh of electricity to fulfill its energy needs [1]. A Sector wise energy consumption analysis of Pakistan shows that almost 41 % of the energy is consumed by the residential sector [2]. Out of the total energy consumed by the residential sector 55% is used for space heating and cooling purpose [3]. Building energy uses is responsible for 30% of the CO_2 emission [4]. The operating cost of HVAC for building in both commercial and residential building is very high [5]. Thus the most viable option for temperature maintenance in building is to use absorption chiller. They work with low consumption of electricity depending mostly on solar energy collected using solar thermal collectors. There working is based on the absorption of refrigerant vapor onto the surface of the liquid thus allowing the pressure of the vapor to be increased economically on receiving heat energy, using simple pump than rather by a vapor compressor that requires much more mechanical and electrical energy input. Other cooling techniques include using GHX system using underground cooling tubes. GHX is very viable as it is not only used for cooling during the summer season but also heating during the winter season. This technology in use these days is concerned with underground heat storage. The temperature of soil beneath the ground remains below 25^{o}C throughout the year. Figure 1 shows ground temperature of a borehole dug in Nicosia, Cyprus [6]. The temperature remains to be constant at a depth of 5 meters. This property of the soil can be used for the purpose of cooling during the summer season

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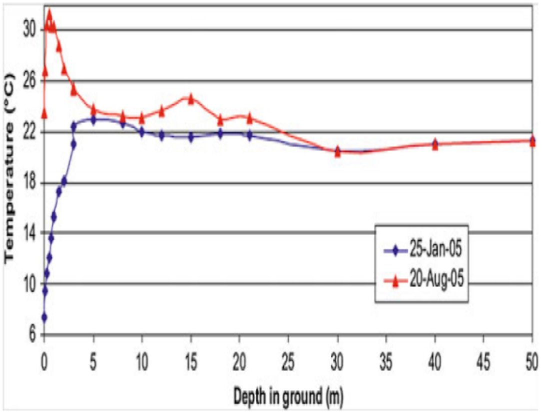

Figure 0.1: Underground thermal gradient profile for Nicosia, Cyprus [6]

The use of these techniques can be efficiently simulated on software using TRNSYS which is FORTRAN based software. TRNSYS software follows set of equations in order to produce output of different parameters. It is user friendly software which predicts output for a desired period of time. TRNSYS is being used by many researchers for modeling and simulating the solar based cooling systems.

II. Literature review

There are actually three main characteristics that affect the thermal control directly. The solar radiation is absorbed by the mass of the building i.e., the outer wall and through conduction transfers heat into the building thus increasing inside temperature. This can be reduced by using insulation into the walls. The solar radiation reaches inside of the building through transparent surface such as glass. This greatly increases the inside temperature of the room. Use of curtains greatly decreases these transmissions of radiations. The outside hot air reaches directly into the room due to infiltrations through opening or cracks in wall. Closing all lose opening, filling of cracks and using window control ventilation [7].

An ETC connected absorption chiller system was modeled for a tropical region Malaysia. The model was simulated on TRNSYS software with collector slope 20° and area 35m^2. A storage tank with capacity of 0.8m^3 was found to be essential for the smooth working of system. The modeled system fulfilled the cooling capacity requirement of 3.5KW [8]. A cooling and heating system was modeled for a hospital in Crete using TRNSYS software. Solar fraction was selected as a main criterion for the optimization of the system. Other parameters such as area of collector slope of collector, storage tank capacity, cooling tower and chiller capacities were also optimized [9]. An absorption cooling system was modeled for region Nicosia, Cyprus on TRNSYS software. The solar collector used was parabolic trough collector using slope angle 30^o and storage capacity of 0.6 m^2. Optimization of the system was done for the parameters such as area of collector, volume of storage tank and thermostat setting of the auxiliary boiler [10]. A lithium bromide based absorption chiller cooling system was modeled for Ahwaz region (Iran). The modeled system fulfilled the cooling demand requirement of 17.5 KW. Parabolic trough collector was used to feed hot water to the absorption chiller with area of 56m^2. The model clearly stated that flow rate has a significant effect on the efficient running of the system [11]. A solar absorption cooling system was modeled for a building in Beijing using TRNSYS. The area of collector was 358m^2 with tilt angle of 10^o facing south. The capacity of the absorption chiller was 175.8 KW with a COP of

0.7 using biomass boiler as auxiliary heater. The size of thermal storage tank found optimum to be used is 15m^3 and 8m^3. The efficiency of solar collector calculated is 37.6% with solar fraction for summer and winter being 0.76 and 0.38 [12].

A geothermal heat pump system was modeled assisted with solar thermal collector. Heating and cooling, both models were developed where during cooling, the heat energy is injected into ground while during winter, this stored heat energy could be used for heating purposes.

The model clearly suggested for the efficient working of the system all the parameter such as borehole separation distances, thermal properties of material used, relative difference of the ground thermal load play a vital role and are case-dependent [13]. A cooling system of fluid was modeled using underground earth tubes. The underground earth tubes not only provide relative low temperature air during summers but also relative high temperature air during winter. The efficient working of the system depends on number of parameters being optimized including average temperature of the ground, length and diameter of the tubes used, extreme range of temperature during winter and summer, handling of the condensate and the intake being located at slope or drywell [14].

III. Methodology

The model of absorption cooling system assisted with solar water collectors for heating and GHX for cooling is fabricated on TRNSYS and studied.

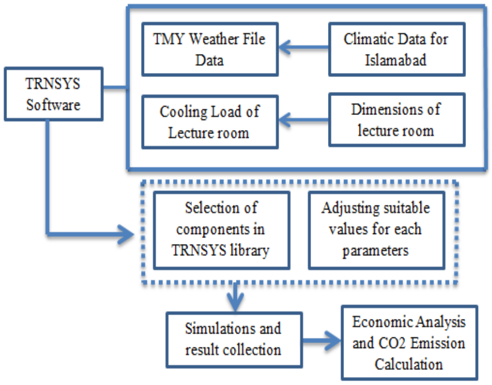

Figure 0.1: Flow chart for the research methodology

Basic methodology layout is represented in figure 2, working through which the system components are arranged and simulated for data collection. The parameters to be studied in order to evaluate each case are as follows;

i. The COP (coefficient of performance) of absorption cooling system is given by

$$COP=\frac{Qchw}{Qhw} \qquad (1)$$

ii. Payback period is determined by using

$$P.B=\log[(C/E)*(i/100)+1]/\log[1+(i/100)] \qquad (2)$$

iii. Net Present Value of the system can be calculated using

$$NPV = \mathrm{Y}\frac{1}{\mathrm{r}-\mathrm{i}}\left[1-\frac{1+i}{1+r}\right]^{1}\text{-C} \qquad (3)$$

iv. Total energy consumption and CO^2 emissions produced from Ret screen software.

v. Efficiency of flat plate collector used, is calculated using equation from [15].

$$\eta=a_o-a_1[\frac{\Delta T}{IT}]-a_2[\frac{\Delta T^2}{IT}] \quad (4)$$

Table 1: Properties of solar thermal collector used

Collector Type	a_o	a_1	a_2
FPC	0.8	13	0.05

vi. Solar fraction can be calculated using [16].

$$S.F_{thermal}=\frac{\int Q_{solar}}{\int Q_{solar}+\int Q_{heater}} \quad (5)$$

As the economic analysis involves the cost of the system therefore the prices of different components to be used are also collected.

Table 2: Price list Data of different components in Pakistan [17] [9] [18]

Equipment	**Cost**
Absorption chiller	53,592 PKR/kW
Solar collector (FPC)	35,000 PKR/m^2
Auxiliary heater	6,699 PKR/kW
Storage tank	80,388 PKR/m^3
Inner wall Insulation	538 PKR/m^2
Pump 50W	6500 PKR
Cost of energy	
Natural gas 637 PKR/MMBTU	637 PKR/MMBTU
Electricity	18PKR/KW
Life period of system	30 yrs
Energy inflation rate	8%
Installation cost	12% of equipment cost
Maintenance cost of VCR	4% of investment cost
Maintenance cost of SACs	1% of investment cost

IV. Modeling

The case study is the lecture room at USPCAS-E, at NUST University, Islamabad. The simulation is performed for the cooling of lecture room using SAC system on TRNSYS. Dimensions of lecture room of USPCAS-E building are simulated in TRNBuild software and cooling load is calculated so as to calculate the capacity of SAC system required to keep the thermal comfort temperature maintained in the lecture room.

A. Modeling of the lecture room

TRNBuild is plugin software for TRNSYS for simulating any closed or open air zone. After building the zone it is provided with desired climatic conditions in simulation studio in TRNSYS and is simulated. It is represented in TRNSYS using TYPY-56 component. Our model includes two lecture room models. The first being the base case with present calculated dimensions, while the second being the proposed model will also be made on TRNBuild. The dimensions of the lecture room are given in Table 3.

Table 3: Dimensions of lecture room

Wall	**Length (m)**	**Width (m)**	**Height (m)**	**Window (m^2)**	**Door (m^2)**	**Net Area (m^2)**
SW	8.356	0	3.66	0	0	30.6
SE	8.15	0	3.66	11.12	0	18.7
NE	8.356	0	3.66	0	0	30.6

NW	8.15	0	3.66	0	8.8	21.1
Roof	8.356	8.15	0	0	0	68.1
Floor	8.356	8.15	0	0	0	68.1

Each wall is made of 0.203m inch brick with 0.012m inch plaster on both sides. This also includes a 0.0508m of insulation between the bricks. The roof is 0.101m inch concrete followed by 0.0508m of insulation and then 0.012m inch of plaster layer. The floor is also 0.101m concrete followed by 0.050m inch plaster and tiling.

The usage of the lecture room is that it will be occupied by 40 people 5 days a week from Monday to Friday, from 9:00 am to 5:00 pm. Other features are given in Table 3.

Table 4: Characteristics of the lecture room

Feature	**Value's**
Volume of lecture room	249.25
Capacitance	299.1
Air change rate	0.5
Heat gain from people	100 watt per person at rest
Relative humidity	50%

Capacitance is defined as the total thermal capacitance of the zone air of the particular volume of space, while the Natural air change rate is defined as the air flow into the zone from outside the zone and its value is 0.5 per hour.

The lecture room is simulated in the TRNBuild software with given dimensions and was linked with TMY file for Islamabad so as to calculate the total cooling load for the lecture room.

B. Working of the system

1. Average value of temperature, humidity, solar radiation both beam and diffuse for each month for Islamabad is collected using MHP station and a TMY (Typical Meteorological File) file is generated using Type-99 component in the TRNSYS. All the weather parameter including solar radiation; both beam and diffuse with their incidence angle, solar zenith angle, solar azimuth angle, ambient temperature, relative humidity is taken into account and a TMY file for the whole 1 year for Islamabad is generated.
2. Components are chosen and SAC system is constructed on TRNSYS using components for single effect hot water fired Lithium Bromide (LiBr) absorption chiller. The input of different parameters of the TMY-99 weather file is linked to TYPE-73, Flat Plat Solar collector and the water is heated. This water flows into a storage tank and using variable flow rate pump the water in storage tank. It is again circulated through the collector in order to gain maximum solar energy and hence a loop is created. The storage tank used is a plug flow tank. The other two terminals of the tank complete another loop through which the solar heated water is fed to an auxiliary heater hence further increasing the temperature of water. This hot water is then fed to absorption chiller. After exchanging its heat with the fluids in absorption chiller the water flows back again to storage tank in order to collect further energy from solar heated water. Multiple simulations are run in order to set values of different parameters for each component in order to produce most energy efficient SAC system.

Absorption chiller also needs a cooling water cycle in order to operate therefore either cooling tower is used or GHX (geothermal heat exchanger) system is used. Both the components are included in the design in order to generate cooling water and tested for different results in order to have their optimum efficiency. The temperature of water decreases after passing through them and the cooling water cycle completes. Properties of cooling tower and GHX system is given in Table 5.

3. Another cycle that runs is of chilled water that is used for cooling of the lecture room. The chilled water from the absorption chiller moved towards heat exchange tank with storage volume of 0.35m^3. The temperature of water in tank remains low. The fluid from 2-fan coil system (evaporator), carrying heat energy from the room, flows through the heat exchanger tank and cools down. This cooled fluid again passes through the evaporator in order to bring more heat energy back from lecture room to cool it down further.

Table 5: Properties of GHX system

Parameter	**Values**
GHX System	
Pipe	
Pipe length	60 meter
Pipe inside diameter	0.053m
Pipe outside diameter	0.0602m
Thermal conductivity of pipe	0.5 kJ/hr.m.K
Horizontal pipe separation	1m
Depth of pipe layer	3m
Soil	
Thermal conductivity of soil layer	8.722 kJ/hr.m.K
Specific heat of soil layer	0.84kJ/Kg.K
Density of soil layer	3200kg/m^3
Amplitude of surface temperature (Δ°C)	11°C
Emissivity of soil surface	0.9 (fraction)
Absorptance of soil surface	0.3 (fraction)
Fluid Used (Water)	
Fluid specific heat	4.190kJ/Kg.K
Fluid density	1000 Kg/m^3
Fluid thermal conductivity	2.14 kJ/hr.m.K
Fluid viscosity m^2	3.21 kg/m.hr

The complete layout of each component's connection for the whole SAC system is given in figure 3.

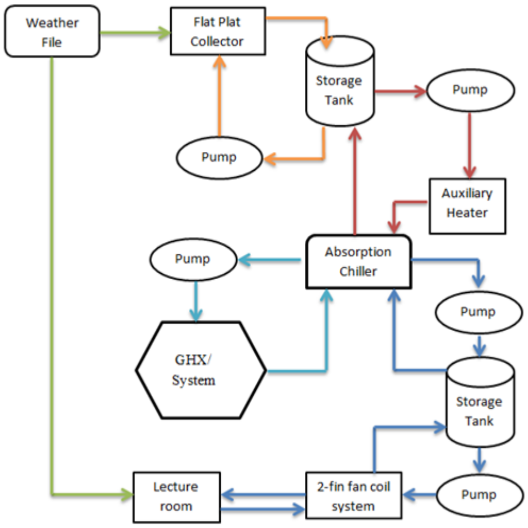

Figure 0.1: Layout of the SAC system for the cooling of lecture room

C. *Layout of components in TRNSYS software*

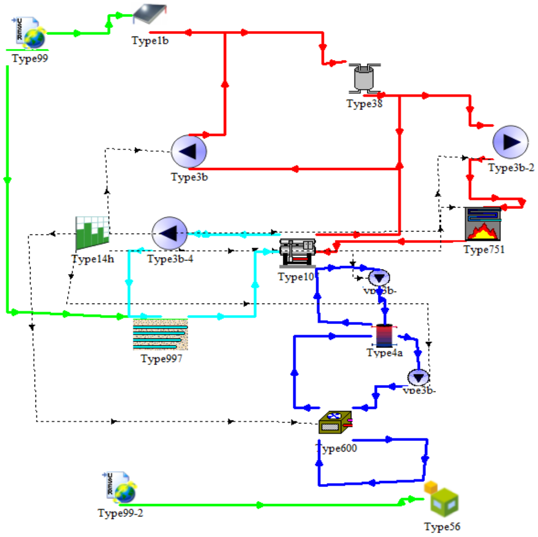

Figure 0.2: Layout of SAC system with GHX on TRNSYS software

The layout of the SAC system with GHX (geothermal heat exchange) system is shown in Fig 4. All the components are connected for the proper functioning of the cooling system.

V. Results and discussion

A. Solar radiation data for Islamabad

The monthly average temperature for Islamabad illustrated in fig 5 shows that during the months from January to April the temperature remains up till 25°C due to which no cooling is required. But from mid-May to mid-October the temperature rises to maximum daily average value of 33°C too. Along with that, due to high humidity of air being more than 90% and above it becomes vital to use cooling technique during these months. Otherwise it is in-appropriate for humans to live in these conditions.

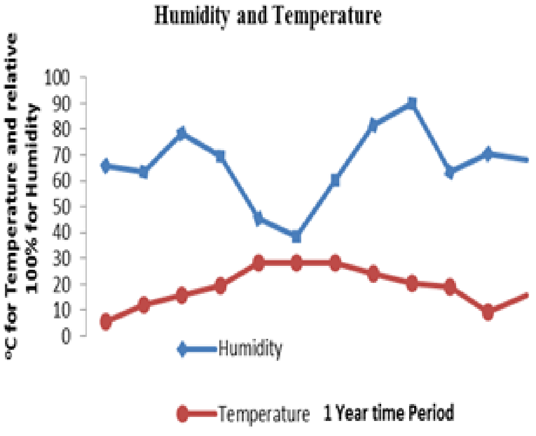

Figure A.1: Monthly average value Temperature and Humidity for Islamabad

The hourly temperature data for Islamabad illustrated in fig. 6 shows that the ambient temperature values reach above 38°C from mid of May to mid of October. This temperature range is out of the comfort temperature zone for human beings therefore it is necessary to a cooling operation.

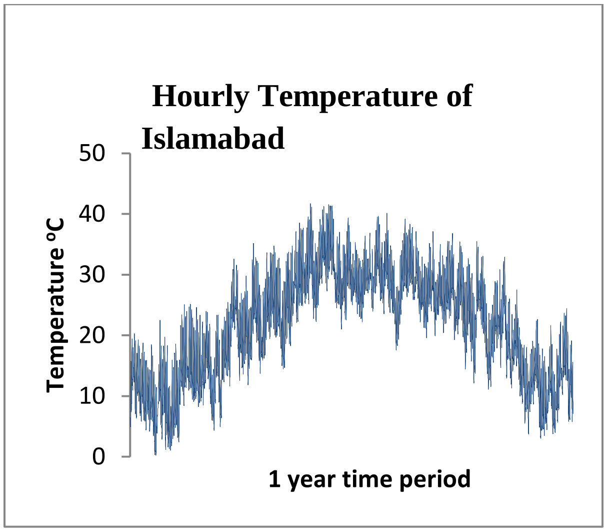

Figure A.2: Hourly temperature recorded for Islamabad

The solar radiation data available in fig.7 shows that there is plenty of solar energy available which can be harnessed as a renewable energy source. The maximum solar radiation available is in the month of May and June, which is 727 (MJ/m^2) and 760 (MJ/m^2) respectively.

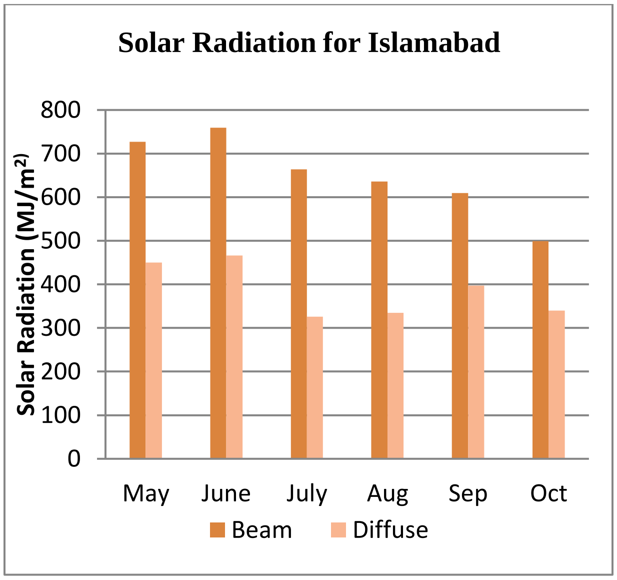

Figure A.3: Beam and diffuse solar radiation for Islamabad

B. Cooling Load and air conditions of lecture room

The cooling load for the lecture room is shown in fig. 8, for a time period from 15th of May to 15th of October for the lecture room, it reaches a maximum limit of 36,000 Btu/hr (3ton).

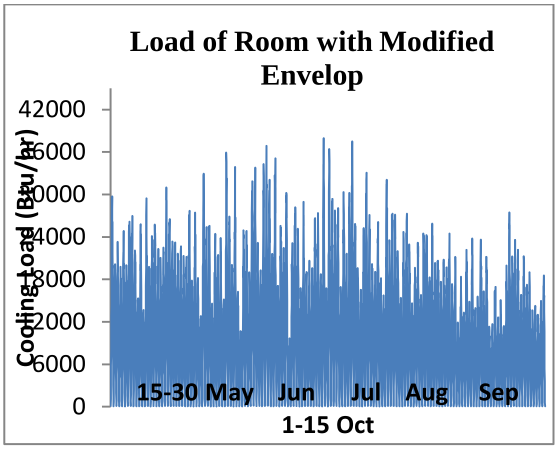

Figure B.1: Cooling load of lecture having modified lecture room envelope

The dimensions of the lecture room's envelop is illustrated in Table 7 for which the cooling load is calculated to be 36,000 Btu/hr (3 TON).

Table B.2: Dimensions of the envelop of modified lecture room

All walls				
Outer plaster layer (m)	**Brick wall (m)**	**Window**	**Insulation (m)**	**Inner plaster layer (m)**
0.0125	0.2	Double Glaze	0.05	0.0125
Roof				
Lower plaster (m)	**Concrete layer (m)**	**-**	**Insulation (m)**	**Tiling (m)**
0.0125	0.1	-	0.05	0
Floor				
Lower plaster (m)	**Concrete layer (m)**	**-**	**Insulation (m)**	**Tiling (m)**
0.025	0.1	-	0	0.025

As the ambient climatic conditions act on the lecture room, we see it has high temperature inside if no cooling is implied, during the summer season. Highest temperature values are indicated for the months of early June to end July as it has high solar radiation values. In fig. 9 it is indicates that on average, the temperature value maintained in room without using any cooling method is on average 33°C. This implies the importance of using a cooling method to bring it in comfort temperature zone for humans.

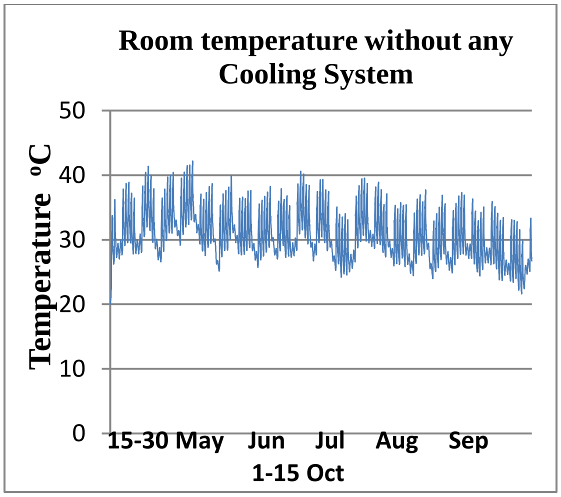

Figure B.3: Temperature of lecture room without any cooling system

Humidity of the environment inside the lecture room was recorded for time between 9am to 5pm without using any cooling method and illustrated in fig 10. We see that the humidity levels cross well beyond relative humidity 50% limit. Especially for the month range from early July to mid-October when humidity value reached way beyond 80% limit. This limit is strictly out of the comfort zone of any human being according to ASHRAE standards.

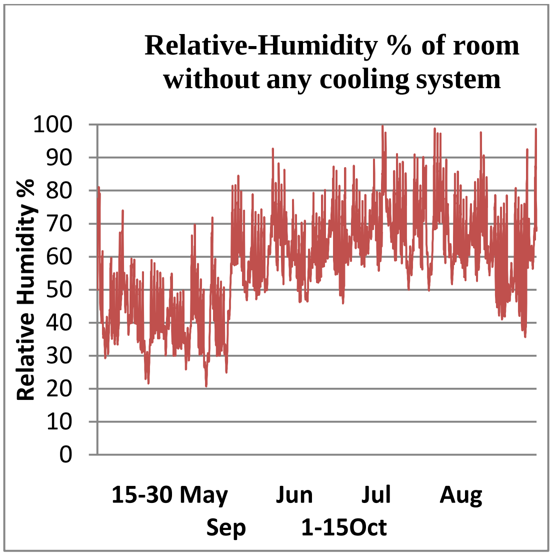

Figure B.4: Humidity in air of the lecture room without any cooling system

As illustrated in fig. 11, temperature of the room is maintained well between 22° C and 25° C daily from 9am to 5pm, Monday to Friday using SAC. The temperature achieved is well in the range of thermal comfort temperature zone for a human being. This establishes that solar absorption cooling is a viable and very dependable option to be used for meeting cooling load demands.

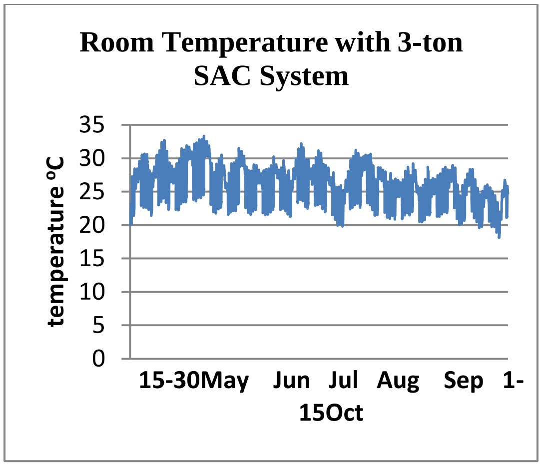

Figure B.5: Temperature of room air using 3-TON SAC system

C. Solar and auxiliary heater heat gain

As indicated in fig. 12, as the slope efficiency angle increased, there was increase in the solar gain of the collector till 18^0 but then there was no noticeable change and the solar gain remained almost constant. So for further simulations 18^0 was chosen as efficiency slope value.

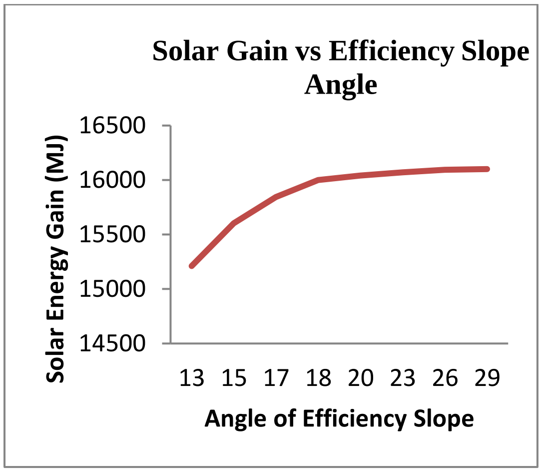

Figure C.1: Solar gain against the efficiency slope angle

The results in fig. 13. illustrate that for a given area of collector, if we increase the volume of storage tank there is a noticeable change in solar gain and it increases till 0.4 m^3 volume but afterwards there is no noticeable gain in solar energy. Thus this indicates it is best to use a storage tank of volume 0.4m^3. The increase in solar gain is due to the fact that more hot water remains in storage tank for longer time period thus more solar energy is stored in tank.

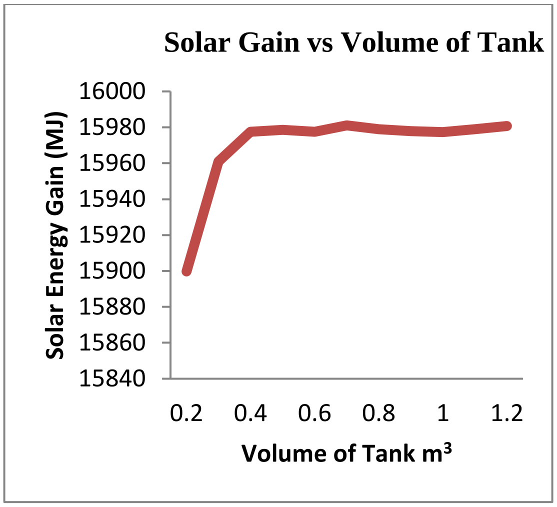

Figure C.2: Impact on solar gain by FPC in comparison to the volume of storage tank used

The impact of boiler energy required for different volume of storage tank is indicated in fig. 14. It is very obvious from the figure that increasing the storage tank volume decreases the energy required from boiler till 0.4 m^3 but then again starts to increase. Therefore 0.4m^3 volume is chosen as the energy from auxiliary heater required is least at this volume.

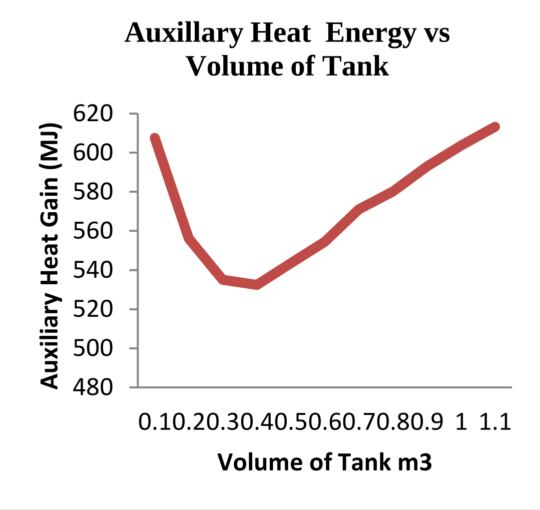

Figure C.3: Impact on energy required from boiler in comparison to storage tank volume

For the effect on solar gain with respect to different set-point temperature as illustrated in fig 15, we see that as we increase the set point temperature of boiler, the gain in solar energy decreases. This is because more of the energy is gained from boiler itself in order to complete the heat energy demand of absorption chiller. Thus the temperature of water moving back to storage tank from the chiller is still at higher temperature and thus the solar gain to this water from FPC will not maximize.

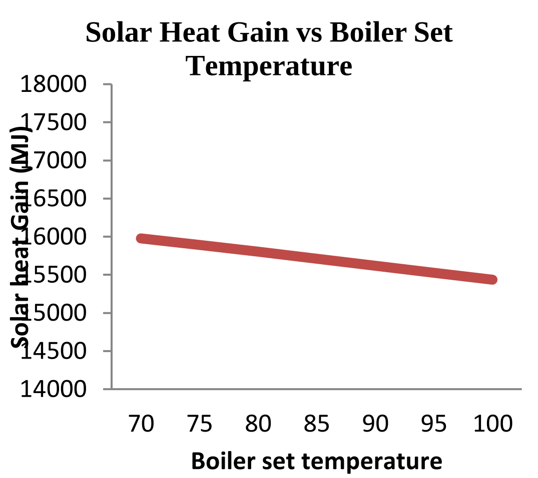

Figure C.4: Effect on solar gain in comparison to different set point temperature of boiler

The result indicated in fig. 16, reveal that as the set point temperature of the auxiliary heater increases, the energy gain from it also increases. Thus it is best to use the set point temperature of 70°C at which our solar gain is maximum, while our heat gain from boiler is minimum. At this temperature our cooling demand is also met.

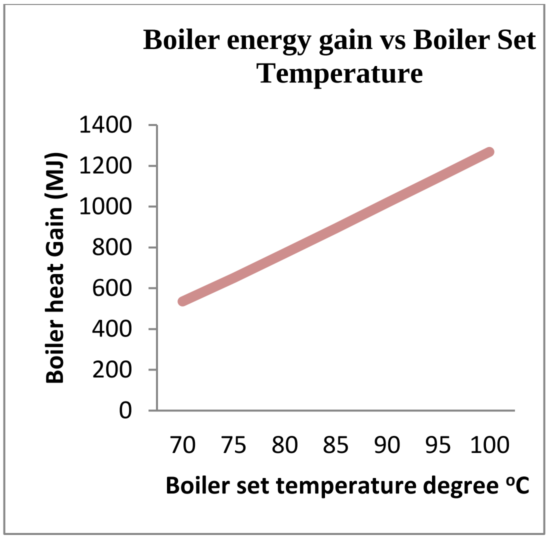

Figure C.5: Impact on auxiliary heater energy gained in comparison to the set-point temperature

The result for pump flow rate in comparison to solar gain illustrated in fig. 17, indicates that as flow rate increases the solar gain from FPC decreases. This is because the water flowing through the collector gets very less time to be heated up, thus the overall solar gain decreases.

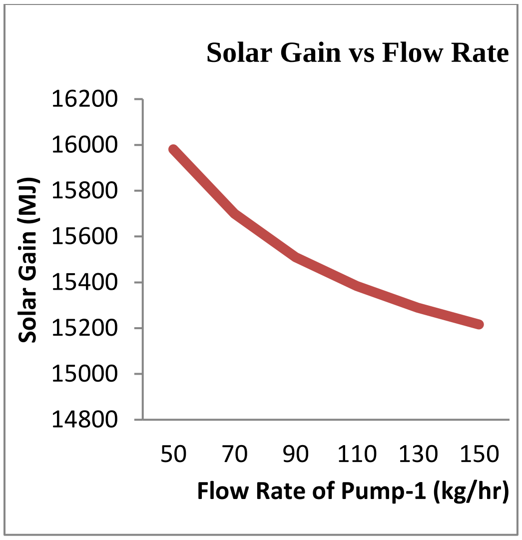

Figure C.6: Solar gain in comparison to flow rate of pump-1

The results illustrated in fig 18, indicate that increase in the flow rate of pump increases the energy gain from auxiliary heater. This is because water is not able to collect maximum solar energy thus it fulfills the energy requirement from boiler heat. The results clearly indicate running pump on least flow rate gains maximum energy from solar and least energy from boiler.

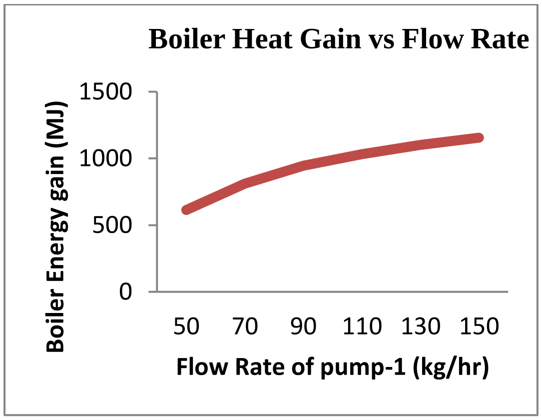

Figure C.7: Gain from boiler in comparison to flow rate of pump-1

D. Rejection of heat energy from room

The result in fig. 19, indicates the monthly average values of amount of heat energy removed from the lecture room using SAC system. The total amount of heat energy removed is 26,040 (MJ). This is a bit less than the amount of energy removed by conventional AC system. But as the SAC system maintains the comfort temperature of the room therefore it is viable to be used.

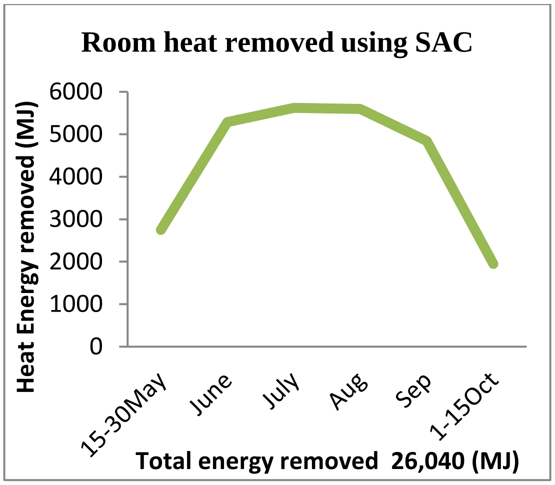

Figure D.1: Heat energy removed from lecture room using 3-TON SAC system

E. Heat rejection by cooling tower and GHX

The result in fig 20, illustrate that the heat rejected from cooling water cycle of absorption chiller using GHX (geothermal heat exchange) system. The temperature range of water coming out of absorption chiller is 50-55°C. This water then flows through GHX system and the heat is rejected to the earth underground through piping. The water temperature achieved using GHX is 24-27°C. The total amount of heat rejected using GHX is 27,810 (MJ). This result further implies the fact that GHX can be used as an alternate to cooling tower for cooling water cycle.

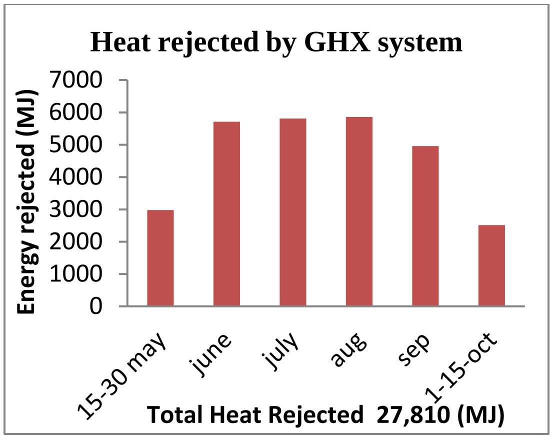

Figure E.1: Heat energy rejected from cooling water cycle using GHX

F. Energy Consumption Analysis

The result in fig 21, illustrates the amount of energy consumed by SAC system assisted with GHX system for its operational working. This includes the working of pumps in order to circulate different fluids and also the working of fans for 2-fan coil system. These results are the monthly average values again for the summer season which includes both, the amount of electrical energy and boiler energy consumed. The total amount of energy consumed using SAC with GHX system for summer season is 1,929 (MJ).

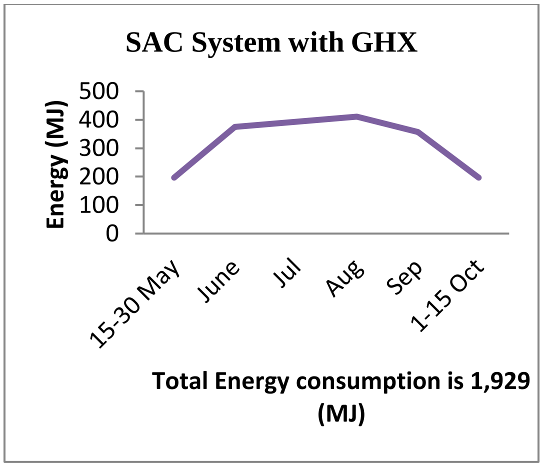

Figure F.1: Energy consumption by SAC system assisted by GHX

Fig. 22, illustrates the monthly average values of the amount of energy consumed by GHX system alone. The total amount of energy consumed by GHX for cooling water is 124 (MJ).

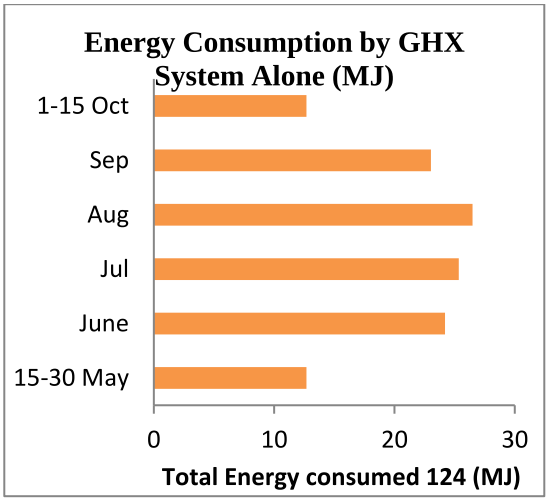

Figure F.2: Energy consumed by GHX system only

G. Economic Analysis

The economic analysis is done for the parameters of carbon emission, payback period, net present value and solar fraction. Higher solar fraction helps reduce the cost for running auxiliary heater as more of the energy consumed from solar source. All the results for the desired parameters are given in table 8.

Table G.1: Different economic parameters of the cooling system

SAC system with GHX	
Net present Value	14,36,553 PKR
CO_2 Emission	0.8 ton
Pay Back Period	8.8 years
Solar Fraction	0.91

The SAC system with GHX for cooling water cycle produces only 0.8 tons of carbon emission, while the payback period comes out to be 8.8 years. The solar fraction of the system calculated is found to 0.91.

Conclusion

Envelop of the lecture room is modeled on TRNBuild software. The cooling load of the lecture room with given parameter is 3 TON. This lecture room is then simulated on TRNSYS software with a SAC system in order to study the cooling of the lecture room through solar energy. The cooling capacity of the simulated SAC system is 3 TON. The system is simulated and run multiple times to be optimized and results are collected for each parameter such as energy consumption, solar energy gain, and auxiliary heater energy consumption. The flow rates of fluid for each part of the system are altered in order to achieve maximum solar gain and minimum energy gain from auxiliary heater. The SAC system is simulated for the modified lecture room assisted with GHX system for generating cooling water.

.The results for the simulations reveal that a horizontal GHX system using HDPE pipes with a diameter of 2 inches and a flow rate set to 300KG/hr, buried 3 meters underneath the surface of the earth gives a very good result for heat exchange rate with soil.

The SAC system using GHX system for cooling water cycle uses 1,928.5 MJ of energy to operate with payback period being 8.8 yrs and CO^2 emissions being 0.8 TON/yr only.

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