Effectiveness of Passive Adaptation Measures Against Climate Change for Building Thermal Performance

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Declaration

I certify that this research work titled “Effectiveness of passive adaptation measures against climate change for building thermal performance” is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

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Copyright Statement

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Abstract

Due to the climate changes over the past few years, the outdoor atmosphere has drastically changed. In accordance to that, already existing as well as the new buildings being built need some adaptation in order to provide comfortable living for the tenants.

Climate change widely impacts the atmospheric parameters hence the energy efficiency of the building envelope. South Asian countries have been impacted a lot by rise of temperature and heat waves in accordance with the climate change over the period.

Passive climate change adaptation measures (PCAMs) are useful coping with the discussed issue. They are useful in providing healthy indoor environment, with a minimum or preferably no increase in energy consumption and also to reduce the Green House gas emissions.

In this study, six passive climate change adaptation measures (PCAMs) have been used and their results have been analyzed regarding the energy efficiency on two types of building envelope (i) single flat (ii) Full floor flat design containing four flats on the floor.

Increase in thermal resistance, green Wall and solar shading were found to be the most efficient (PCMs) to reduce the building energy in accordance with the weather conditions of Pakistan. By implementation of these PCAMs, cooling demand can be decreased by 12% for the apartment building.

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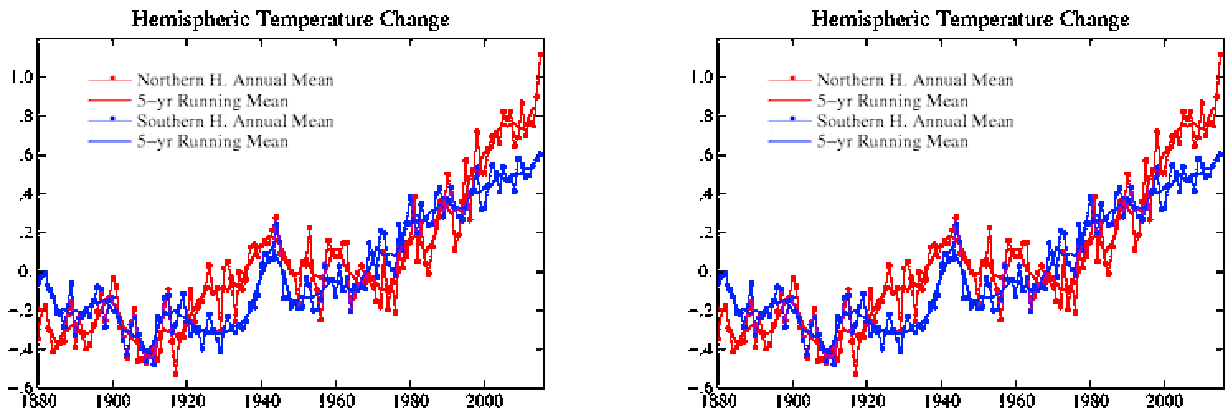
1 INTRODUCTION

1.1 Background

The planet's climate and atmosphere has constantly been changing over the period of geological time. The world has experienced some drastic effects of the climate change from droughts happened in Africa to the tropical storms in Southeast Asia. Millions of people have suffered from these catastrophic experiences. During the summer in 2018 people from the Greece, USA, Japan and Pakistan experienced Heatwaves due to the climate change conditions. Heatwave is generally considered as the duration or period of high temperatures as compared to the previous average zonal temperatures. Heatwaves are more common to occur in the oceanic areas and for Pakistan it has clearly shown its effects in the cities adjacent to the sea. Climate change and Global warming not only causes the rise in temperatures and Heatwaves, but it also causes increase in sea water levels [1,2], catastrophic weather conditions and events and also in the shifting of natural wildlife habitats. One of the biggest reasons for the climate change is the burning of fossil fuels oil, gases and coal which produce the Greenhouse gases. To facilitate our modern lives, we are doing this through burning fossil fuels, minimizing the agricultural land to facilitate the overpopulation needs and many other factors. This causes the high amount of energy coming from the sun to be trapped in the system and not radiated to the outer space.

1.2 Climate Change and Global Warming

Global warming is defined as the increase in global temperatures due to the burning of fossil fuels which produce CO2 and Methane gases while the Climate change comprises of both, the global warming and the changes in weather patterns caused by the Global warming. Earth's natural atmosphere has always acted like a greenhouse to ensure the sustainability of conditions required for life at earth. Without this natural atmospheric greenhouse, the earth might have frozen. This layer of greenhouse ensures the entrapment of energy coming from the sun to make it a sustainable place for the life at earth. The stability of earth's atmosphere and greenhouse has been severely disrupted due to the burning of fossil fuels, deforestation, heavy industrialization, minimizing the agricultural land and many more. The emission of greenhouse gases has broken the record of previous 800,000 years in this century. Following is the overview of global warming presented by NASA.



(a) (b)

Figure 1(a): Global Land-Ocean temperature index(b): Hemisphere temperature change graph

1.2.1 Effect of global warming & climate change in Pakistan

In the recent studies accessed by the Intergovernmental Panel on Climate Change (IPCC) it is stated that there will be a rise in the global surface temperature of 1-3.5 degrees by the end of 21st century. Also, there will be a rise of 15-95 cm of sea levels by the end of 21st century. The devastating effects of this climate change can occur in the form of storms, droughts, tornados, hurricanes and floods, all of which have been subsequently increasing in the intensity with the passage of time. According to the survey, almost the world faces 300-400 disasters of these kinds every year.

Although Pakistan contributes very less in the emission of Green House Gases but overall, it has also been affected by the shocks of climate change globally. According to a research, Pakistan's total Green House Gases emission in 2016 was 310 million tons which was very low as compared to the international standards [3]. It comprised of the following gases mentioned in figure 2.

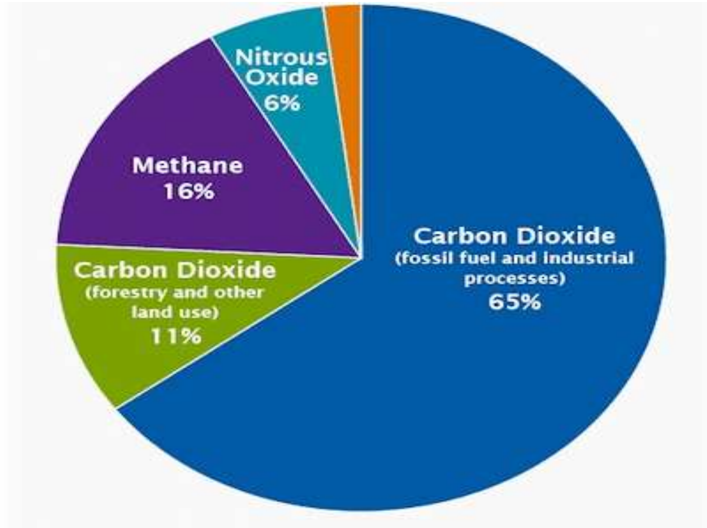


Figure 2: Breakdown of GHG emissions

Pakistan has also been subjected to many Heatwaves over the previous decade. there was a record rise in temperatures up to almost 49 degrees in the province of Sindh. Pakistan had been under the threat of this devastating climate change since 1952[4]. The Heatwave attack in 2015 around the coastal areas of Pakistan recorded 2000 deaths [5]. Pakistan also expects to see a rise of 70 cm in ocean water by the end of 21^{st} century [6]. Pakistan is among the top ten countries worst hit by the effects of climate change [7]. The adverse use of energy and Green House Gas emissions will lead Pakistan towards the catastrophic results. In 2019, there was a 29 % increase in the manufacturing of air conditioning and refrigeration units in Pakistan [8]. United Nations (UN) has also emphasized on the worsening climate conditions in Pakistan.

1.3 Overview of Pakistan Energy Generations

There has always been and unresolving issue between the energy produced and the energy demand in Pakistan. Energy is produced, transmitted, distributed and retail supplied by the two public companies (WAPDA) and (K- Electric). K-Electric is responsible for the energy supply in Karachi and its surrounding area while the WAPDA is responsible for the rest of the country. Both of these companies come under the National Transmission and Dispatch Company Limited (NTDCL) [9]. In 2020 total power generation capacity of Pakistan is 37,402 MW while there is still a deficit of 3000 MW which results in blackouts across the country. Although Pakistan has worked a lot in the power generation sector, yet there is so much work to be done to overcome the increasing power demands. In the past 4-5 years Pakistan has installed many electric power generation plants with the help of CPEC project in the essence of early harvest CPEC projects which has lowered the power shortages. The main sources of energy production in Pakistan includes hydel, thermal, nuclear, renewables and other independent power producers (IPPs). Pakistan currently produces very low amount of energy from renewable sources [9]. Pakistan aims to increase its renewable energy production up to 6 % by the end of 2030 which is currently at 4.2 %. Pakistan has always been dependent on producing its electric energy from the fossil fuels, but due to the increase in fossil fuels pricing, it made a dent in Pakistan's foreign exchange reserve. In the year 2014-15 Pakistan government allocated a budget of 340 million to allocate on its energy portfolio [10,11] which increased the renewable energy generation capacity from 1136MW to 1691 MW [9]. Table 1 provides the details and Energy generation breakdown in Pakistan.

Source of Generation	Hydel	Thermal	Nuclear	IPPs	Renewables	Total
Capacity (MW)	10132	12 427	1482	15,581	1691	37,402

Table 1: Breakdown of energy generation in Pakistan

Figure 3: Breakdown of Pakistan Energy Generation

1.4 Over view of Pakistani Buildings

The buildings in Pakistan are mainly classified into three main categories i.e., concrete structures, wooden, and brick with mortar(masonry) construction. Masonry structures can further be categorized into 11 classes depending on the materials used in the construction or based on construction units used [12]. Masonry structures with brickwork construction are widely practiced across the country while wood constructions are preferred in northern mountainous regions of the country. Over time, the trend of usage of concrete structures is also growing in many cities.

Pakistan has very diverse nature in every aspect of life from weather, living life style, culture and traditions. Most of the buildings in Pakistan consist of residential building. There are also industrial constructions, apartment buildings and sky scrapers as well but that consists of a small amount as compared to residential housings. In the rural areas of Pakistan, there is a common practice of mud bricks construction with the layers of mud on both sides. Residential constructions are much simpler in the rural areas of Pakistan. For the urban areas and big cities, the common practice used is the construction with red bricks with cement on both sides of the wall which provides better thermal resistance and thermal mass. Pakistan Building Codes (PBC) provides the building codes for the construction of buildings in Pakistan according to the weather climate conditions and the common practices of Pakistan. U-values for the roof and walls are defines in Pakistan Building Codes. Similarly, a common practice in Pakistan is the construction of 9-inch-wide external wall and the construction of 4-inch-wide internal partitions wall which has been incorporated in this research. There is ample amount of wood available in the northern areas of Pakistan due to the forests and green mountain ranges. That’s why the common practice of building construction in those areas is the use of wood. Wood can be beneficial in reducing the cooling loads of the building as it possesses lesser thermal mass but Northern areas of Pakistan remain cold almost throughout the year. Over the past few years, the use of hollow concrete blocks has also increased in Pakistan. Concrete blocks used as an alternative for the bricks with cement of both sides can provide better thermal resistance but also increases the thermal mass of the building. The effect of using concrete blocks on the cooling loads has also been studied in this research.

2 SCOPE OF WORK

Global warming and climate change have become and evident truth of today's world. Due to the increase in temperatures and heatwaves the climate of the earth is constantly changing. Due to the changing outdoor climate, is has become essential to facilitate new as well as already existing buildings to facilitate with healthy indoor environment. Rise in outdoor average surface temperatures will cause more energy demand to cope with the indoor environment of the building. In this current study, an apartment building has been analyzed to check the energy demands of the building. Cooling demands of the building have been analyzed keeping the building up to Pakistan building standards. Passive cooling measures have been incorporated to check their efficiency on the apartment building and the reduction in cooling loads. Simulations are run on the base case building and the passive measures installed on the building using Design Builder which is based on Energy Plus having a user-friendly interface. For this sole purpose, an apartment building (cant view apartments) from the city of Karachi has been selected. Two types of apartment buildings are considered

- Single apartment building with 100% outside openings
- Full floor plan with 50% openings in the corridor which is a typical standard design for big apartment buildings.

2.1 Koppen Classification of Karachi

Pakistan has the most unique characteristics when it comes to change in altitudes. Pakistani altitudes range from the sea level to the second highest mountain in the world. Karachi is the city located at the coast of Arabian sea. Karachi almost experiences no rain over the course of whole year. The climate at Karachi is classified as BWh by Köppen-Geiger system. The average annual temperature for Karachi is 26.9 °C.

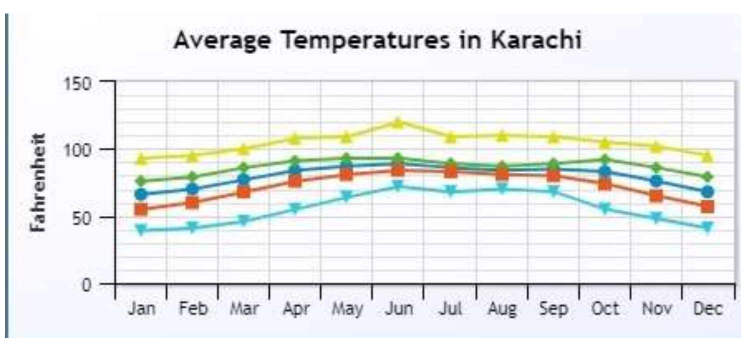


Figure 4: Annual Average temperature in Karachi

The warmest month of the year is June with the average temperature 31.7 degrees centigrade. The coolest month of the year is recorded to be January. The lowest temperature recorded for Karachi is 3.5 °C. the average annual amount of precipitation in Karachi is 8.6" (218.4 mm). The BWh in the Koppen classification index represents (Arid, Desert, Hot) weather conditions in Karachi as of mentioned in figure 5.

1st	2nd	3rd
A (Tropical)	f (Rainforest) m (Monsoon) w (Savanna, Wet) s (Savanna, Dry)	
B (Arid)	W (Desert) S (Steppe)	h (Hot) k (Cold)
C (Temperate)	s (Dry summer) w (Dry winter) f (Without dry season)	a (Hot summer) b (Warm summer) c (Cold summer)
D (Cold (continental))	s (Dry summer) w (Dry winter) f (Without dry season)	a (Hot summer) b (Warm summer) c (Cold summer) d (Very cold winter)

Figure 5: Koppen classification details

3 LITERATURE REVIEW

3.1 Effects of climate change

The term Global warming indicates the increase in green House effect. Shear impact of human negligence i.e. excessive burning of fossil fuels, depletion of forestry, excessive smoke and waste from industries and shrinking of agriculture land are responsible for the climate change. Global warming due to the greenhouse gas effect is the basis of the gradual increase of 1.53°C (1.38-1.68°C) in the mean land surface air temperature and 0.87°C (0.75-0.99°C) increase in global mean surface temperature in the period from 1850-2015. Under these circumstances the world is bound to witness more heatwaves in future [1].

Global warming and climate change are responsible for the increase in temperatures across the globe. China has witnessed an increase of 0.5°C in mean surface temperatures in 2000 and it is studied that it will increase further up to 2.2 °C by the end of 2050 [13]. Future projections for the 21st century in East Mediterranean & Middle East with PRECIS regional climate model predict 1~3°C, 3~5°C and 3.5~7°C rise of mean temperature in near-future (2010-2039), mid-century (2040-2069) and by the end of century (2070-2099) respectively [14]. A rise of 0.84°C is analyzed over the period of past 100 years in different cities of India [15] while a rise of 2~5°C was seen in Japan in the past 100 years [16].

Pakistan was no exception when it came to the effects of climate change. Although Pakistan's GHG emissions are very low as compared to international standards, yet it has been struck badly by the effects of climate change in the form of disasters. According to Asian Development bank Pakistan has seen a rise of 0.5 degree centigrade in annual mean temperature over the past five. decades [6]. There have been many heatwave activities in the first two decades of the century. Glaciers in the north are also melting due to the rise in temperature. Clean drinking water has also shrunk to a dangerous limit. Due to the increase in sea water level, there has been cyclone activities as well endangering the people living around the coastal areas of Pakistan especially Karachi [17]. ADB profile report forecasts a 3°C to 5°C increase in the annual mean temperature for a central global emission scenario by the end of the next 70 years. A rise of 60 cm is also expected in the sea level for the next five decades [6].

United Nations has also shown its concerns towards the climate change conditions of Pakistan and its worsening effects on the people of Pakistan. The Government of Pakistan is trying to cope with the changing effects of these climate changes by implementing special measures. Recently the govt has taken initiative to plant more trees across the whole country and also to reduce the use of fossil fuels and implanting the renewable energy sources into consideration. Still there is a lot of work to be done regarding this scenario.

IIPC has reported increase in mean surface temperatures in the future which will lead to extreme weather conditions i.e. extreme summer and winter condition. Due to these extreme weather conditions cooling and heating demands of the buildings are going to increase to facilitate the residents with friendly environment inside the building [18]. As a result, the demand of active cooling system is going to increase across the globe [19,20]. The excessive use of mechanical cooling equipment is further going to increase the burning of fossil fuels and GHG emissions.

3.2 Energy consumption of buildings

With the increase in thermal temperatures across the globe, buildings are bound to use more energy to provide healthy atmosphere for the residents. Heat gains through the building envelope are responsible for the increase in inner temperatures. Use of mechanical techniques can further increase the energy and climate problems. An alternative way of reducing the building energy loads is through the use of passive climate adaptation measures (PCAM's). These (PCM's) comprise of natural ways of controlling the internal gains and energy demands of the buildings.

Building sector constitutes a major portion of net energy consumption all over the world. S. Dhaka accounted for 33% of total energy consumption for buildings in India [21]. Research by [22,23] concluded that worldwide energy usage by the residential sector is between 16-50%.

Table 2 shows the access of electricity in Pakistan.

Population without electricity	National electrification rate	Urban electrification rate	Rural electrification rate	Population relying on traditional use of biomass	Percentage of population relying on traditional use of biomass
51 million	73%	90%	61%	105 million	56%

Table 2: Access of energy in Pakistan

According to statistics report, around 75% are domestic users in Pakistan at the end of the 2017-18 fiscal year. In power market forecast survey, domestic electricity sale has increased from 47% to 61% in the periods 2003-04 to 2013-14 respectively which can further increase to 65% in 2023-24

3.3 **Passive Climate adaptation Measures**

To cope the modern energy demands and energy conditions of Pakistan, passive climate adaptation measures are a better approach to deal with the increase in thermal demands of the buildings. These measures do not use any energy or mechanical equipment to deal the thermal issues of building, rather they use natural ways to resolve the heating and cooling demands without using any excessive energy. Huang [24] conducted building simulations for a typical residential building in Taiwan and predicted 31%, 59%, and 82% increase in cooling demand in the 2020s, 2050s, and 2080s respectively, however, combination of adaptation measures can effectively counteract this rise. Another study [25] represents the 32.4% reduction in the energy usage in Jeddah Saudi Arabia by using the passive climate adaptation measures. Similarly, in IIT, Roorkee, India, building simulation modeling of an unconditioned academic block considering passive strategies resulted in overall 40.4% minimization of total energy consumption accompanied by improvement of occupants' thermal comfort [26]. Evaluation of three types of PCAMs including variable air volume systems; replacement of high coefficient of performance (COP) chillers with low COP chillers; and upgrading lighting systems and glazing of windows for an institutional building in Queensland, Australia is carried out by Rahman [27] which provided energy save of 41.87% without risking internal thermal environment. Retrofitting of an educational facility in Kuwait saved 52% of total energy consumption [28]. Effects of climate change in three cities of Brazil were analyzed by Invidiata [29] whose study showed an increase in annual energy demand from 24.6 - 147.0 kWh/m_2 in the 2020s rising to 48.7 – 217.1 kWh/m_2 in 2080s, however, Brazilian houses with right passive design techniques can reduce up to 50% of cooling and heating consumption. An office building in Semnan, Iran with three proposed conservation measures is simulated which reduced energy consumption up to 13-18% [30]. In similar researches by [31,32], it is evident that the energy consumption of a residential or commercial premise can be mitigated by imposing passive climate adaptation means.

These mentioned Passive climate Adaptation measures are elaborated briefly below. In this research study seven of these PCM's are used and discussed to view their effect on the apartment building located in Karachi building designed according to the building standards of Pakistan.

3.3.1 Green Roof and Green Wall

Roof covers the e top of the building and provides a shield against rain, snow, wind, storm and other weather conditions. Roofs are designed in various forms i.e. flat, pitched, domed or in the combination of these depending upon the construction needs and building needs. As the roof is directly exposed to outer atmosphere, it is most responsible for the heat gains. A specially designed insulated roof can help reduce the internal gains and energy consumption of the building. An additional layer to the existing roof in the form of green roof (vegetation) can help reduce the heat flux through roof, hence resulting in lower cooling loads. A green roof reduces energy due to the following scenarios (1) change in short-wave reflectivity (2) addition of insulation layers (3) change in thermal mass (4) increase of convective heat transfer (5) evapotranspiration. A green roof also provides the following benefits (1) a green roof lasts longer than the conventional building (2) it helps in reducing the cooling loads and cooling costs (3) absorbing the storm water (4) improving air quality. There are two types of Green Roofs, intensive and extensive, for the research purpose extensive roof design is used in the study to analyze its effects on the apartment building in Karachi. To increase internal thermal comfort and reduction in cooling loads green walls are also very effective.

The experiments by Djedjig et al resulted in the increase of thermal comfort and the reduction of internal temperature by 5 °C. the results showed a decrease of 33% in the cooling demands of building annually under the studied environment and building construction [33]. Similarly, another study on school building found 2.4°C reduction in internal temperature and 40% decrease in annual cooling loads [34]. Similar researches on green roof and green wall are carried out by [35,36,37] which also resulted in the decrease of annual cooling loads.

3.3.2 Albedo (short wave reflectivity)

Albedo is the measure of reflection of light through a body or surface. It indicates the amount of light reflected from a surface without being absorbed. External walls and roof are mainly responsible for the absorption of light and increasing the internal gains of the building resulting in lower Albedo and thermal discomfort. It has been analyzed from studies that light color material reflects more of the incident light resulting in higher albedo while the dark color materials absorb most of the incident light hence resulting in lower albedo. Figure7 demonstrate the difference between both of these cases.

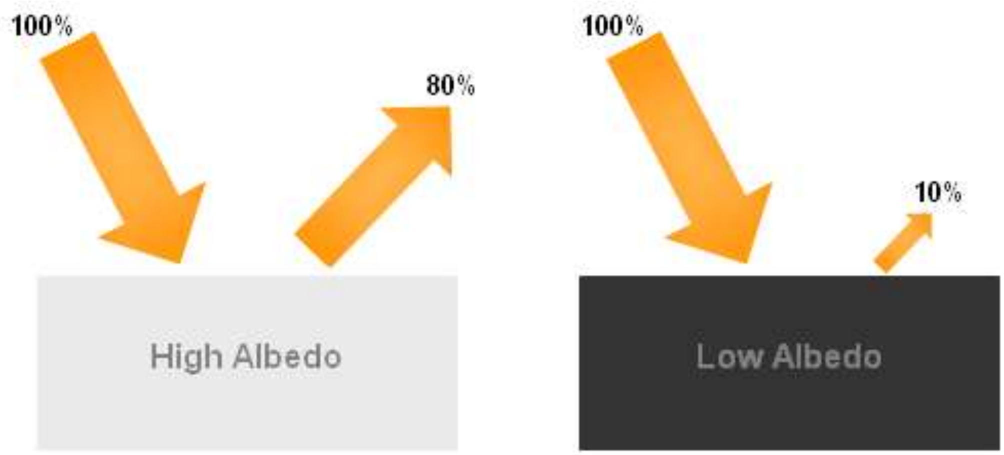


Figure 6: Difference of high and low albedo

By lowering the albedo and higher reflectivity value it enables to decrease the cooling demand by about 10% while heating demand is slightly increased [18]. Similarly, Akbari et al [38] also observed the impacts of high albedo and found 80% energy savings for a house while 35% energy savings for a school building.

3.3.3 Window Glazing

Windows and doors are the primary reasons for the internal heat gains in summer through their opaque and transparent surfaces. A door or window can gain or loss heat through the following ways (1) conduction of sunlight through window or door (2) radiation of the light through these facades (3) air leakage though these objects. Solar transmittance factor (U) defines the amount of heat flowing through the window and doors which is expressed in Btu/hr-ft2-oF. Glazing of glass helps to reduce the solar infiltration and Solar Heat Gains (SHG) through windows. Double glazed glass consists of two layers of glass and an inert gas in between them. Double glazed glass helps in many ways i.e. (1) it acts as an insulator to reduce the amount of radiations entering through window hence lowering the cooling demands (2) it acts as a sounding insulation material as well (3) it plays an important role in the safety as well as it is tougher to break.

A decrease of 7.3% is calculated by using double glazed glass instead of single glazed glass [27]. The effect of using double glazed glass instead of single glazed was also studied by [39] and the results were 1-70% decrease in cooling loads for dry climate and 1-40 for humid climate. In another study conducted by [40] different types or glazing were applied and the results were 1.5-1.5% decrease in cooling loads.

3.3.4 <u>Natural Ventilation</u>

Natural ventilation is the use of fresh air by allowing openings of the buildings to operate at regular intervals. Natural ventilation has also proved to be a very effective and cost-efficient method to control the building energy demands. It allows to control the thermal buoyancy without the use of any mechanical system. There are several factors which effect the Natural Ventilation i.e. (1) geographical location (2) wind speed (3) orientation of building (4) humidity (5) window sizing .it has been observed by studies that favorable atmosphere and right orientation of the building can cause from 10-30 % cooling load decrease in building. Natural ventilation requires pressure difference to cause the air to flow which is created by difference of temperatures and buoyancy. During the wind blow the fresh air naturally enters and exits through the window to reduce the cooling loads without any use of outer energy or force.

Natural ventilation depends upon the nature and habits of occupants to open and close the windows. D.T.H. Chyee [41] surveyed the use of natural ventilation for typical residential areas of Malaysia and observed the trend of more daytime ventilation than night ventilation. Their field experiment resulted in a 2.5°C reduction in indoor air temperature during night. In another research by M.Z.Yusoff [42], it is seen that the use of natural ventilation for the underground buildings was also effective to control the cooling loads of the building and to provide a better environment.

3.3.5 <u>Thermal Mass</u>

Thermal mass is defined as the property of a material to absorb and release energy. Concrete, bricks and tiles tend to have higher thermal mass while timber has lower thermal mass. Thermal mass is also very useful in controlling the indoor atmosphere of the building by controlling the heat inertia of the building. Thermal mass can be beneficial in storing the heat gains from solar reflectivity and internal gains as well during the hot durations and to release it when the conditions are cooler. This way it can be beneficial in summer and winter both.

A material with high density would be preferably ideal than the lighter and low-density material if it can store a significant amount of energy. Studies have shown that the thermal mass property of a material mainly depends upon the environment conditions of the building area. It depends upon the material behavior under that specific weather condition [43,44]. Dodoo, studied the effects of changing thermal mass of building and implementing wood and concrete as thermal mass materials and their effect on energy loads [45]. Al-Sanea studied the effects of masonry materials and thermal mass effects in a building with insulated walls and studied their effects on energy demands of the building [43].

3.3.6 **Thermal Resistance**

Thermal resistance is known as the resistance in the heat flow between the outer surface of the wall and its surround. Heat transfers when there is a difference in the temperatures. Heat transfer takes place under all modes of heat transfer i.e. conduction, convection and radiation. The transfer of heat due to the temperature difference on both sides goes through following processes (1) transfer of heat to the wall from hot side (2) transfer through wall (3) transfer of heat to the colder side (4) diffusion or flow of air through the wall in each direction. Increasing or decreasing the thermal resistance of the wall has great impact on the internal gains and energy demands of the building.

M. S. Van Dusen studied the effects of thermal resistance on 17 different layouts and types of walls [44]. He studied the effects of different thermal resistances on the wall temperatures for 17 wall types. Every component of the building has its own thermal resistance as they all behave differently towards the outside atmosphere. Dubai Green Building Regulation limits maximum U-values for roof and wall to 0.3 and 0.57 W/m_2K respectively [45]. Friess [45] also gives a summary of the energy reduction of 0.9% to 26.8% by implementing thermal resistance in studies by various other authors. Building codes of Pakistan prescribes R_c-value of 1.75 m_2K /W for walls and 2.27 m_2K /W for roofs.

3.3.7 **Solar shading**

As mentioned in section 3.3.3 windows are the main source of heat gains in summer are windows. Although window add to the beauty features of the building but they are also exposed to the direct solar radiations which causes internal gains and increase in energy loads. This problem can be solved by using solar shadings in the building. Solar shading is of two types (1) internal shading (2) external shading. Internal shading comprises of drapes, curtains and blinds while external shading consists of overhangs, louvers and side fins. The strategy of blocking sun and shading windows have been used in many energy efficient buildings. Window shading is an excellent way of preventing the solar radiation to enter the building in summer. External shading devices can be used alone or in combination with the window glazing to reduce the internal heat gains and to provide a comfortable environment for the tenants. Direction of sun and the azimuth angle are two main factors for the solar shading. Nearly all types of buildings in warm and sunny climate can benefit from solar shading. There are many types of solar shadings available in the market these days from roll down shutters, solar cells, concrete overhangs, vertical louvers to shutters.

In Pakistan, the use of curtains and drapes is very common. Curtains and drapes come under the category of internal shading and provide better resistance towards the solar radiations. Curtains and drapes can help reduce the internal gains and to provide better thermal comfort inside the building. They are also very useful providing the privacy for the tenants. The most common practice is the use of silk, cotton or velvet curtain on the inside surface of the windows. Curtains and drapes have many benefits but they are not as efficient in providing the inside thermal comfort.

Whereas window overhang and window overhang have significant amount of effect on the building when it comes to reducing the cooling loads of the building and to provide a better thermal comfort inside the building envelope. Window overhang and window louvers provide the solar shading from outside the window envelope and are directly incidental towards the solar radiation.

Window overhangs are also practiced in Pakistan which are made of concrete. The trend of using window louvers is also increasing specially in the office and school buildings. The use of side fins is very rare in Pakistan and not generally practiced in buildings. Solar shading can be applied individually or in combinations of internal and external shading to check their effect on the passive cooling adaptation measures. Pakistan has very hot and humid climate which requires the implementation of best solar shading available to provide thermal comfort inside the building envelope.

In a literature review study by Prieto to improve cooling strategies in warm climates, dynamic exterior shading having application of high reflectivity slats on facades resulted in cooling energy savings of 4% to 93% for the warm dry climate and 5% to 56% for warm humid climate [39].

4 METHODOLOGY

4.1 Research approach

In this research, an attempt is made to reduce the building's cooling demands and to provide a healthy environment inside the building envelope. The building studied is located in BWh Koppen classification which refers to (B= arid, W= desert, h= hot). the building is located in the coastal area of Pakistan i.e. Karachi. It is an apartment building consisting of four apartments on the floor design. Individual apartment as well as the whole floor plan is studied to analyze the results of both on energy demands. PCAM's are applied later to analyze their effect on both type of apartment building i.e. single and full floor plan. Simulations are run using Design Builder which integrated with Energy Plus having a friendly user interface, weather data and modeling the design facility. Table 3 represents overview of the methodological study.

Steps	Analysis Framework	Remarks
1	Defining the Objectives	Reduction of cooling demands in apartment building using PCAM's
2	Select location and its appropriate weather file	Typical Meteorological year weather file
3	Select PCAM's	Listed in table 10
4	Specify other model assumptions	Operation and occupancy schedule
5	Choose software	Design Builder
6	Design and Modeling of building	Figures 7-11
7	Implementation of PCAM's	Section 4.8
8	Simulations	Section 5
9	Evaluation of simulation results to see if they meet the objective	
10	Formulate the result and find best solutions	Section 5 & 6

Table 3: overview of study framework

4.2 Overview of the site Location

Pakistan is located in the South East Asian region. Pakistan is blessed with 4 seasons, beautiful landscapes from sea to the second highest mountain the world situated in the Northern areas of Pakistan. Pakistan stands 5th in the ranking of most populous country which is 212 million. It consists of four provinces comprising of Balochistan, Punjab, Sindh, and N.W.F.P and includes Islamabad Capital Territory (ICT), territories of Azad Jammu & Kashmir (AJK) and Gilgit-Baltistan.

Karachi is the capital city of the province of Sindh with a population count of around 28 million people. Karachi is the Pakistan's biggest city and world's 7th biggest city [48]. It is situated on the coast of Arabian sea and has two main ports controlling the harbors. Total area of Karachi is 3780 square kilometers. Karachi is divided into 5 districts which are further sub divided into 18 towns. Karachi is the financial and commercial hub of Pakistan [49]. Karachi has a BWh Koppen classification in terms of the weather climate conditions which makes it an arid, desert and hot land. The building under study is located in Karachi.

4.3 Building Description

The building under study represents a modern type apartment design which is followed in the urban areas of the Pakistan. Two cases are being studied one being the single flat while the other being the full floor design containing four flats of same design. This way the effects of PCAM's can be seen on the single flat having no constraints and opening issues as well as on the full floor design having some opening constraints.

In case 1 of single apartment 4 residents are considered to be living in the apartment which is a 3-bed room apartment. Apartment has an area of 93.64-meter square with the occupancy density of 0.04271. Five split air conditioners have been assumed for the apartment, 3 in the bedrooms, one for the lounge and one for the drawing room. No external shading from any dimension is considered in the base case as to mimic the neighboring buildings. The building is openly analyzed without the intervention of any outside constraint.

Similarly, for the full floor plan, four apartments of the same design are considered to mimic the standard apartment floor plan practiced in Pakistan. Corridor separates the flat and all the main doors to the apartments open in the corridor. Corridor has a main entrance door on one side while on the other hand it has a stair case to approach the roof. Flat roof design has been integrated in both the case as per Pakistan Building codes. The total area or full floor plan is 401.34-meter square. Total 19 residents have been considered in the full floor (4,6,4,5) and the building has occupancy density of 0.0473. split air conditioners are also considered for the full floor plan to meet the cooling demands of the building. For cooling, electricity from the grid while for heating natural gas is considered for the study. The roof, walls, windows, doors and all the other design perimeters are selected according to the Building codes of Pakistan and the practices in the region of Karachi. Simple building designs are made and cooling loads are analyzed. PCAM's are later included to check the effect on loads.

Case 1			
Floor Area	93.64 m^2	Residents	4
Occupancy Density	4/93.64= 0.04271	Location	Karachi

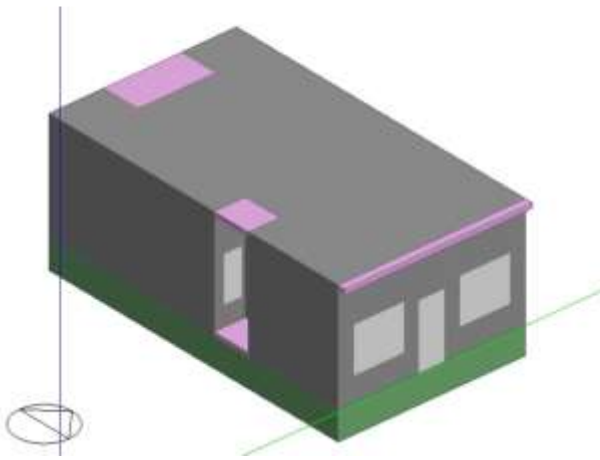
Table 3: Building description for case1

Case 2			
Floor Area	401.34m^2	Residents	19
Occupancy Density	19/401.34= 0.0473	Location	Karachi

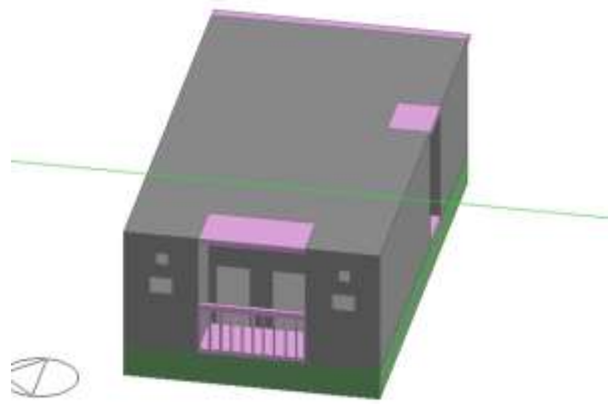
Table 4: Building description for case 2

The layout of the apartment is shown in figure below.

Figure 7: floor design for the apartment



(a)



(b)

Figure 8(a): front view (case 1), (b)back view(case1)

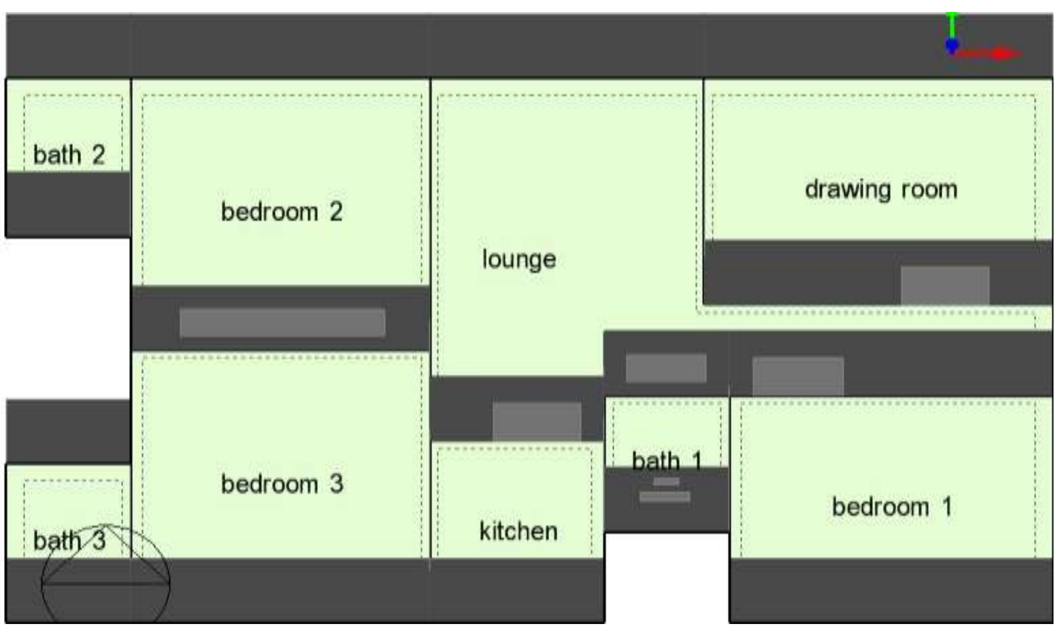
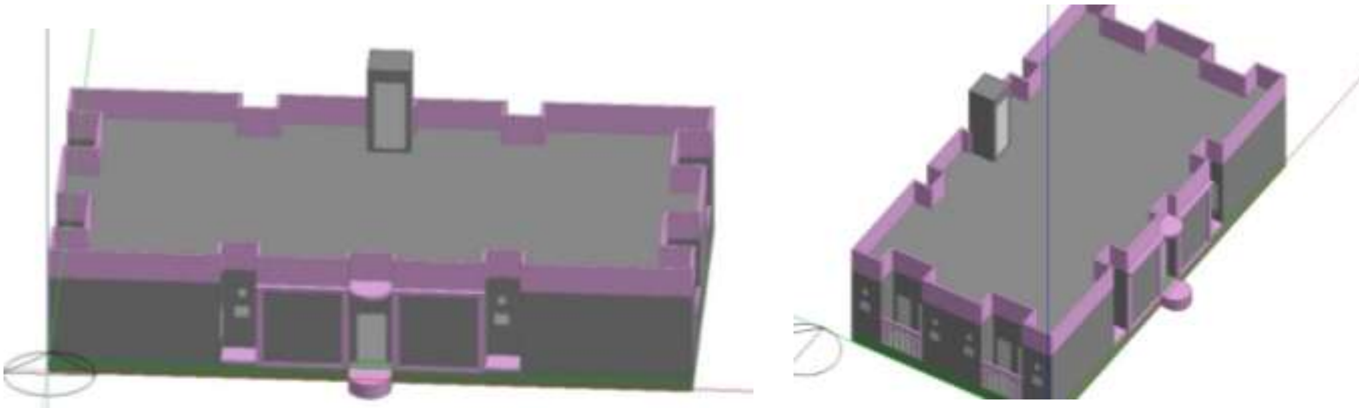


Figure 9: design builder layout (case 1)



(a) (b)

Figure 10(a): front view (case 2), (b) back view (case 2)

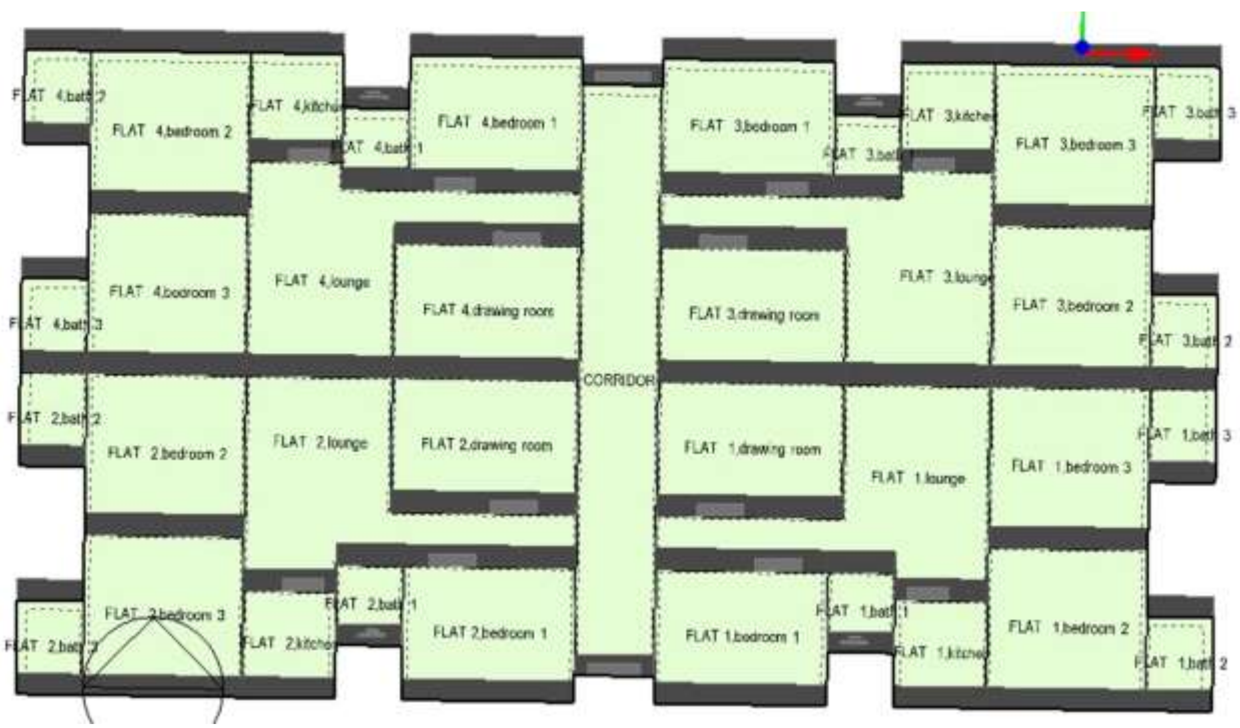


Figure 11: design builder layout (case 2)

4.4 Building Energy Simulations

The results have been calculated using Design Builder software. This software is integrated with the Energy Plus which has a very friendly user interface. Energy Plus is widely used for the thermal calculations of the Buildings. There are two types of input files required for the Energy plus to run simulation i.e. Input Data File (IDP) and the weather data file. IDP is provided in the form of design builder file which a 3d model of the building design with all the required building descriptions. Design Builder file include all the basic information of the building, criteria of construction, openings, lightings and HVAC. This software is widely used for calculating energy consumption, evaluating façade options for overheating and visual appearance, thermal simulations of naturally ventilated buildings, modeling of lighting control systems for effective energy savings, rendering of building model and visualizing solar shading on the building at the site, computing heating and cooling values. Energy Plus works in (ERL) Energy Plus runtime language and has the following solution algorithms (1) Conduction Transfer Function (CTF) and (2) Finite Difference (FD). The weather data file is a (TMY) file which is acquired applying the Freinkestein Schafer statistical methods on the actual weather file for the period of past 30 years.

4.5 Software Validation

Energy Plus software is widely used for the thermal simulations of the building design. Energy Plus was design in the 90's and later it was updated in 2014 into the c++ language module. Energy Plus is an open source coding software which is easily available online for the developers to make further improvements in the software design. It is very user friendly for the user as well as for the developers. That's why it is often called as the black box software.

Here, for the sake of calibration, a validation study is presented. The graph in the Figure 12 shows the comparison of the results using a reference the energy consumption data reported by [50]; the model is based on survey data performed by KACST [51]. The results show a reasonable agreement. Both models were equipped with constant volume DX Air/Conditioning system having COP of 2.17 with thermostat setting of 72 °F for heating and 76 °F for cooling. It was reported by Ahmad [50] that his building having total floor area of 525.0 m_2 consumed total annual energy of 138,293 kWh while our validated model having total floor area of 520.21 m_2 used net site energy of 131,411.13 kWh. Ahmad [50] presented this energy model for a detached villa of single-family having masonry materials construction and he simulated for climate of Dhahran, KSA. Same model was opted by Alaidroos et al [52] as well for optimization of energy performance in Riyadh, KSA. The same base case model of villa used by Ahmad [50] for climate of Dhahran was modelled in the Design Builder software having Energy Plus simulation engine and simulation was performed to validate the results. Evidently from Figure 12 a reasonable agreement between measured values of research paper and validated model was achieved.

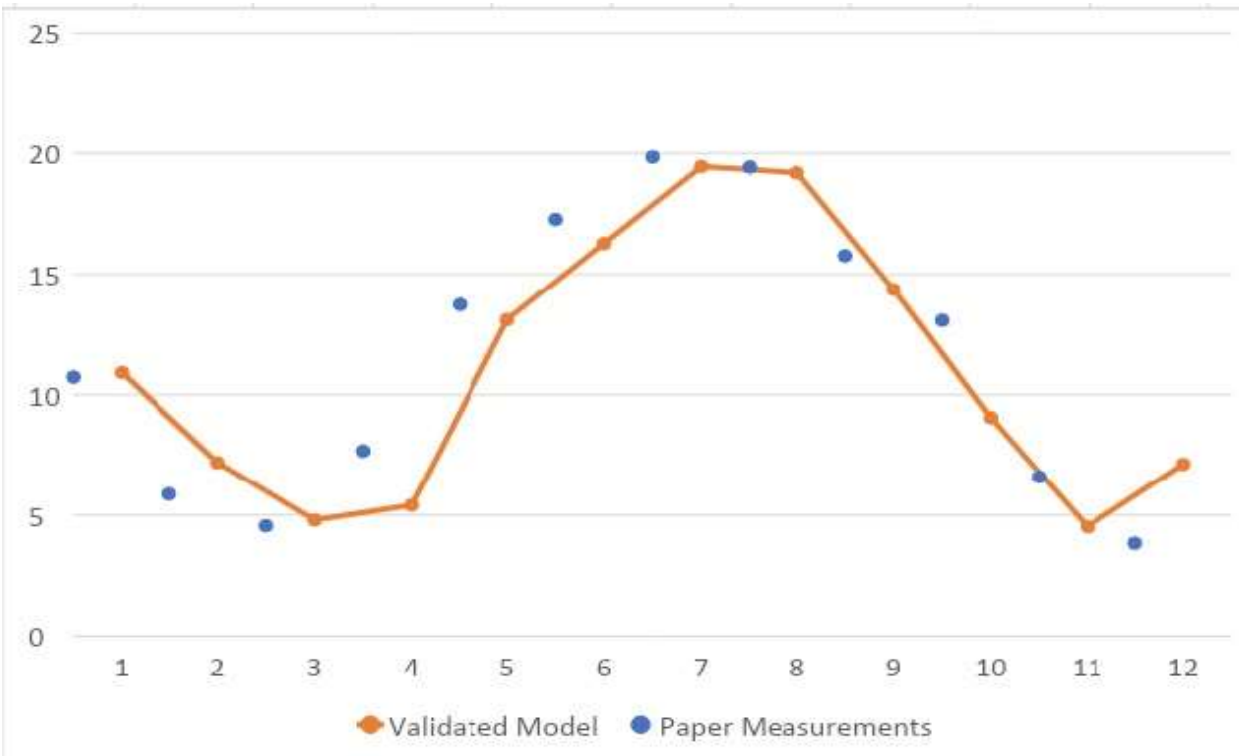


Figure 12: software validation graph

4.6 Weather Data

Energy Plus requires an input data file (IDP) and a weather data file to run the simulations. The weather data file used in the study is based on a Typical Meteorological Year (TYM). A TYM file is bases on the actual weather data file for a specific location having the meteoritical data for at least a minimum of 10 years duration. The actual weather data is collected for the previous years to calibrate with the statical methods for the construction of a TMY file. Friekenstein Schafer statistical method is used to make a TMY file. The weather data for 32 years (1985-2017) has been recorded for the formulation of a TMY to generate the EPW weather file for Islamabad [53]. These files contain hourly readings of outdoor air temperature, solar radiation, wind velocity, sky conditions, and relative humidity, etc. These hourly values are averaged down into monthly values as tabulated in Table 6.

	Dry Bulb Temp [C^0]	**Wet Bulb Temp [C^0]**	**Atmospheric Pressure (kPa)**	**Relative Humidity %**	**Dew Point Temp [C^0]**	**Wind Speed (m/s)**
JAN	19.08	12.27	101.16	46.53	5.35	2.00
FEB	22.19	15.28	101.02	50.84	9.64	2.97
MAR	25.95	17.79	100.95	48.61	12.34	3.35
APR	28.88	20.49	100.87	50.47	14.70	3.40
MAY	30.78	24.91	100.75	63.81	22.68	5.29
JUN	31.79	26.55	100.21	67.58	24.80	4.71
JUL	30.44	25.42	100.47	67.58	23.64	5.32
AUG	29.20	24.66	100.63	69.79	23.00	5.38
SEP	29.47	24.39	100.92	67.44	22.48	4.99
OCT	29.01	22.67	100.79	61.57	19.79	2.59
NOV	25.15	18.27	100.98	55.18	13.82	2.11
DEC	20.79	13.34	101.03	45.20	6.80	2.55

Table 5: weather data information for Karachi

4.7 Construction Details and Building Properties

The 3-D model of the building under study is designed in Design Builder software. The Building Codes of Pakistan for building construction and operation are considered while designing the model [54]. The normal practice of wall according to the Building Codes is the construction of 9-inch external wall with the use of bricks, with cement on both sides of the wall. Similarly, the internal walls are of 4 ich brick walls with cement on both the sides. The external wall has U-value of 0.57(W/m2K) while the internal wall has U-value of 0.54 (W/m2K). No natural ventilation, solar shading or the wall paint is considered in the base case of the building as they are incorporated later as the Passive Cooling Adaptation measure. In case 1, 4 occupants have been considered in the apartment while for the full floor plan 19 (4,6,5,4) occupants have considered. Overview of construction details and building details is as follows.

Element	Material Layers (Outer to inner)	U-value (W/m^{2}K)
External Wall	Cement plaster, brick, cement plaster	0.57
Internal Wall	Cement plaster, brick, cement plaster	0.54
Ground Floor	Brick, cast concrete, mortar, marble	0.76
Internal Floor	Cement plaster, cast concrete, mortar, marble	1.19
Roof	Brick, cement plaster, polyethylene/soil, concrete, cement plaster	0.44

Table 6: construction details for the studied building according to PBC

For the cooling, electricity from the grid is considered while for heating the use of Natural Gas is considered in the study. May, June and July are the hottest months in Karachi with and average temperature of 31.7 ^{0}C. Global warming and the climate change has increased the global surface temperatures and it has caused many heatwaves over the period. This study enlightens the objective of reducing energy consumption when the installation of an active cooling system is applied. The cooling and heating setpoint and setback temperatures are listed in Table.

Zone	Cooling		Heating	
Bed	25	28	18	12
Drawing Room	25	28	18	12

Table 7: cooling and heating set point details

The use of active cooling measures for the simulation is scheduled as shown in the table 9

Table 8: Schedule of PCAM's

TIME (until)	Operating Schedule			
	Bedroom		Drawing Room	
	Weekdays	Weekends	Weekdays	Weekends
0400 HRS	1	1	0	0
0800 HRS	0	1	0	0
1230HRS	0	0	0	0
1300HRS	0	1	0	0
1530 HRS	1	1	0	0
1600 HRS	0	1	0	0
1700 HRS	0	0	0	1
2000 HRS	0	0	1	1
0000 HRS	1	0	0	0

4.8 Setting of PCAM's

During the designing of building in 3-D model, Pakistan Building Codes have been considered for each parameter. PCAM's have been implemented according to the codes as well to check their effectiveness on the cooling loads. A brief description has been laid in the table 10.

Measure	Description	Nomenclature
Green Roof and Green Wall	In reference to (PBC) base case has 6 layers in roof design while an additional vegetated roof is added to the design for insulation with Leaf Index Area of 5. Similarly, outside wall is added with a green layer to check the effect on building.	GR, GW
Albedo- Short wave Reflectivity	Base case is equipped with cemented grey solar exposed surfaces while for PCAM effect of white paint is implemented.	SWR
Window Glazing	The window is equipped with double glazing glass instead of single glazing glass	DGG

Natural Ventilation	Natural ventilation is turned on to check the effect of fresh air on cooling loads when the outdoor temp is lower than indoor temp	NV
Thermal Mass	Base case has brick construction for walls while for PCAM the effect of hollow concrete blocks on cooling loads is analyzed	TM
Thermal Resistance	The effect of 2 thermal resistance values i.e. 1.25m^2K/W and 3.5 m^2K/W on cooling loads is analyzed	TR
Solar Shading	The trend of cooling loads is analyzed by implementing the solar shading in the form of overhangs and louvers	WOH, WL

Table 10:brief description of passive cooling adaptation measures

Green Roof and Green Wall:

In this study two types of vegetation have been considered on both the cases. The effect of implementing and extra vegetated layer on the roof and the effect of implanting vegetated layer on the outside wall surface have been analyzed. For the vegetated Green Roof and extra layer of 0.15m and leaf area index of 5 is considered on top of the already existing 6 layers roof design in base case. For the external green wall an extra green layer is implemented on the wall surface to check its effects on the building energy loads. The height of plants is considered 0.1m long while the leaf reflectivity is 0.220. an extra vegetated roof acts as an insulation and also adds to the beauty of the roof, not to mention the environmental effects and benefits. Similarly, the green wall acts as an insulation and increases the thermal resistance of the wall as well. It also adds to the beauty of the wall and the building.

Figure 13(a) depicts the external Green wall while Figure 13(b) depicts the Green roof design.

(a) (b)

Figure 13(a): design builder layout of green wall (b) layout of green roof

The set properties for the Green Roof design are shown in Figure 14.

Figure 14: green roof properties

<u>Short Wave Reflectivity</u>:

In the base case, the solar absorptance value for the facades and roofs are maintained at 0.6 as per Pakistan Building Codes. This set of values represents the cemented grey structure of the building. While in the PCAM case the solar Absorptance value is changed to 0.3 and the emissivity to 0.9 for the walls which depicts the implementation of white paint on the walls. The roof values have been kept same as those of base case as per Pakistani Building Conventions.

<u>Window Glazing:</u>

As per Pakistan Building Codes, the best window glass practice in Pakistan is the use of Single Glazed Glass. The base case is considered with the single glazing glass in the windows while for the PCAM the use of double-Glazing Glass is considered in both the cases to measure the effectiveness on the cooling loads. Double glazed glass more resistance towards the solar radiations. Double glazed with two layers of 3mm grey glass and a layer of 6mm air cavity is considered as a passive measure. The Solar Heat Gain coefficient (SHGC) of the discussed glass is 0.615 and the U-value is 3.159 W/m2K. The Design Builder description of double-glazed glass is shown in Fig 15. The windows are equipped with internal shading of drapes in the base case with the single glazed glass on the windows. While for the passive cooling adaptation measure the double-glazed glass on the windows and the internal shading of drapes in considered for study.

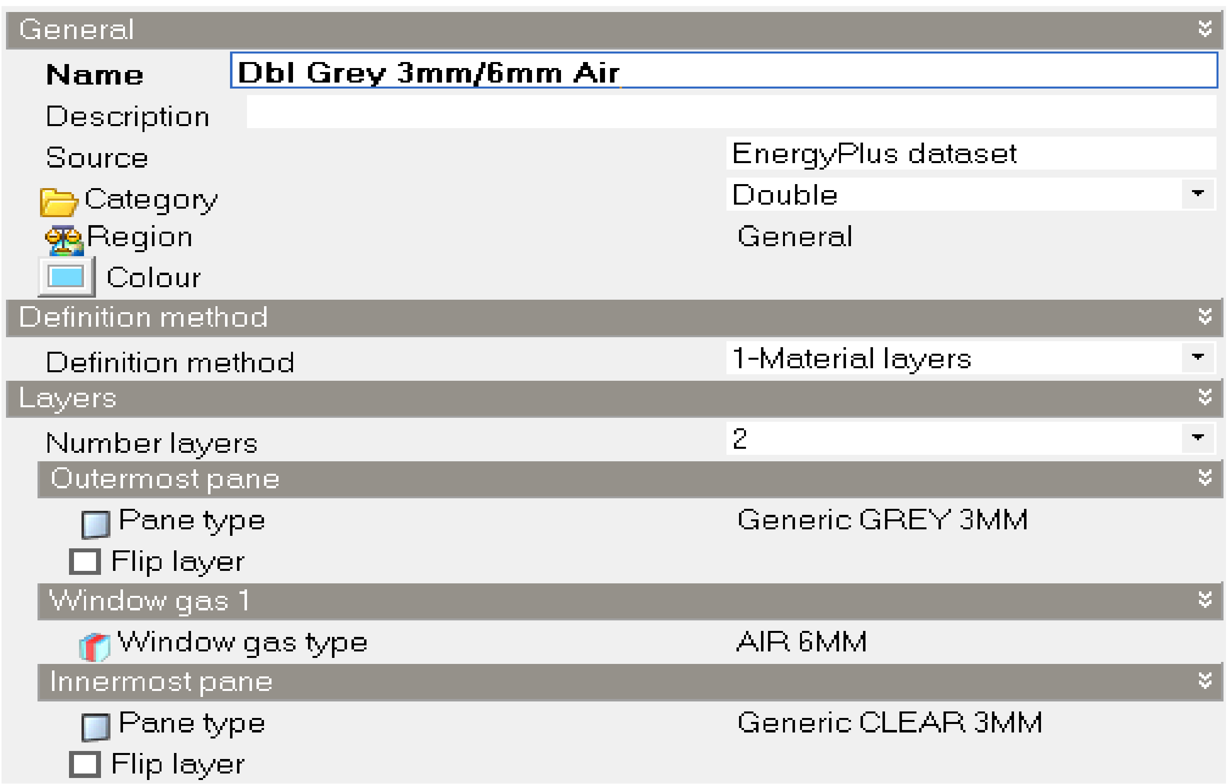


Figure 15: double glazing glass properties

<u>Natural Ventilation:</u>

Natural Ventilation allows the fresh air flow through windows and doors. It completely depends upon the nature of the occupants, wind speed, outside air temperature and window size. In the base case design for both the cases natural ventilation is not considered. Natural ventilation is later implemented on both the cases as a passive cooling adaption measure to check the effect on cooling loads. The properties of the natural ventilation implemented are shown in fig 16

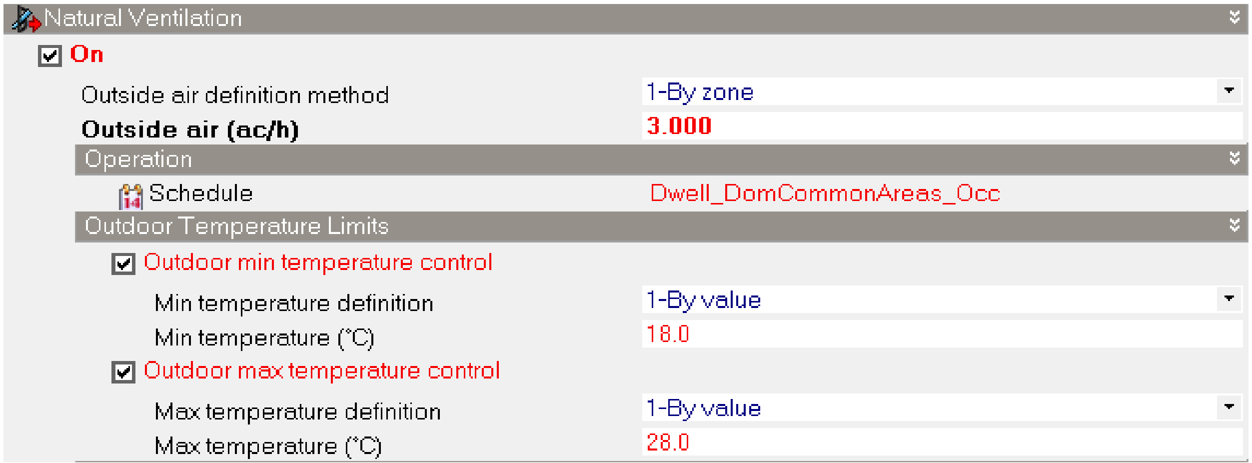
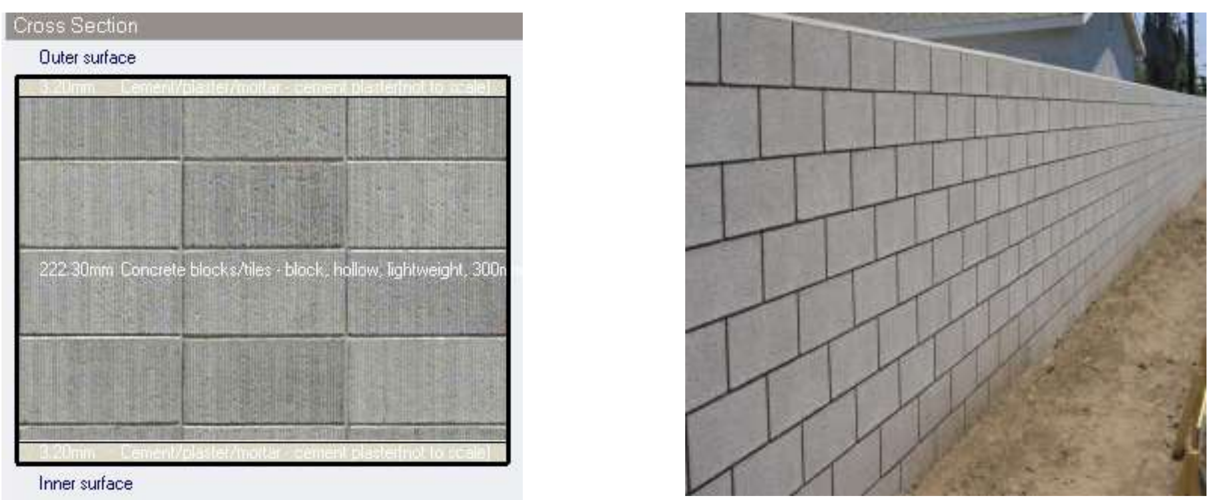


Figure 16: natural ventilation properties

<u>Thermal Mass:</u>

According to the Pakistan Building Codes (PBC) red bricks are used for building construction which have a very high thermal mass. But with the on-going trend, the use of concrete blocks is also increasing which is an alternative for the bricks. Concrete has a tendency of high thermal heat capacity and density which results in higher thermal mass than bricks. The effect of concrete blocks is analyzed as a passive adaptation measure for both the cases. The external wall is of 9 inches with concrete construction while the inner partitions have 4-inch concrete walls. The thermal resistance values are selected as per the building codes. The complete overview of the wall made with concrete blocks is shown in fig 17.



(a) (b)

Figure 17 (a): design builder layout concrete wall(b): concrete wall construction

Thermal Resistance:

In the building design, prescribed U-values and R-values by the Pakistan Building Codes for the wall and roof have been used. In the base case R_c-value of 1.75 m^2K /W has been used while in the case of passive measure, two alternative values of 1.25 m^2K /W and 1.75 m^2K /W have been analyzed to check their effects on the cooling loads.

Solar Shading:

Windows are a main source of the internal gains in summer. According to general practice in Pakistan internal drapes are considered in base case as well as in the passive measure. For the solar shading two alternative cases have been studied i.e. window overhand and window louvers.in the first case an overhang of thickness 0.002m and projection of 0.457 is analyzed while in the other case louver of 0.076 m width and 0.127 m vertical spacing has been analyzed. Parameters of window overhang have been explained in fig 18 while parameters of window louvers are explained in fig 19.

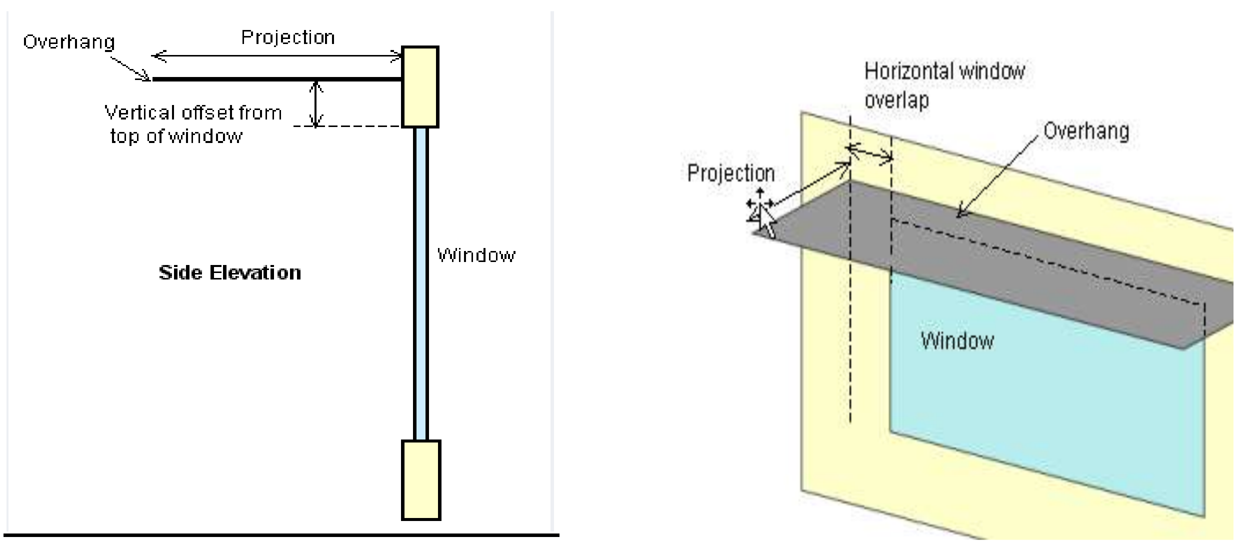


Figure 18: Window Louvre Parameters

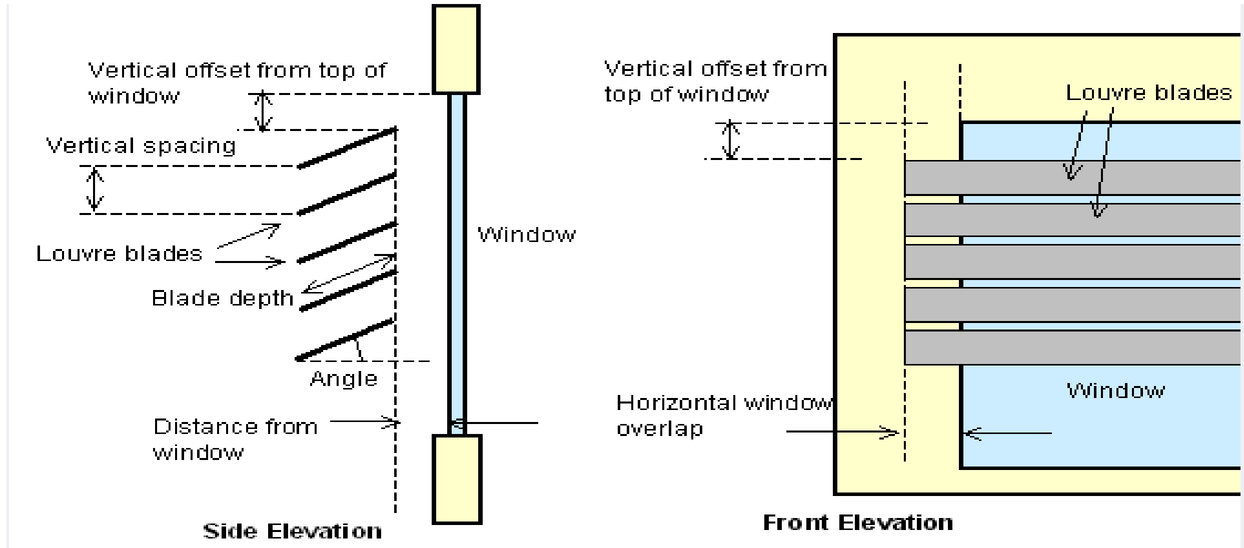


Figure 19: Windows Louvre Parameters

In the case of window overhangs, projection plays an important role. The projection of the window overhang has been explained in the figure 18. While in the case of window louvers, vertical spacing between the louvers is very important. Vertical spacing decides the space between two consecutive louvers and the open area for the solar radiations to enter. Less vertical means less area for the solar radiations to penetrate the window.

In this research the effect of outside solar shading is considering in essence with the internal drapes. The effect of window overhangs and window louvers in combination with the inside drapes is analyzed in this research to check their effect on the cooling load demands of the building for both the cases.

Base cases for both the considered apartment buildings have been designed using the Design Builder software for 3-D modeling and the simulations are run using the Energy Plus software to find the annual cooling loads of the building in both cases. Passive cooling adaptation measures are implemented individually later to check their effectiveness on the cooling loads. Results are analyzed to find the best PCAM's available for the apartment buildings.

The complete overview for the base case for apartment building and the PCAM's implemented is shown in table 11.

	Green Roof	Albedo	Window Glazing	Natural ventilation	Thermal mass	Thermal resistance	Green wall	Overhang	Louvers
Base	No GR	Cemented grey	Single glass glazing	No NV	Brick construction	1.75 m^2K/W	NO GW	NO Overhang	NO louvers
GR	Vegetated roof (LAI=5)								
SWR		White paint							
DGG			Double glass glazing						
NV				On 24 hours					
TM					Concrete block construction				
TR 1.25						1.25 m^2K/W			
TR 3.5						3.5 m^2K/W			
GW							Vegetated wall		
WOH								Overhang with internal drapes	
WL									Louvers with internal drapes

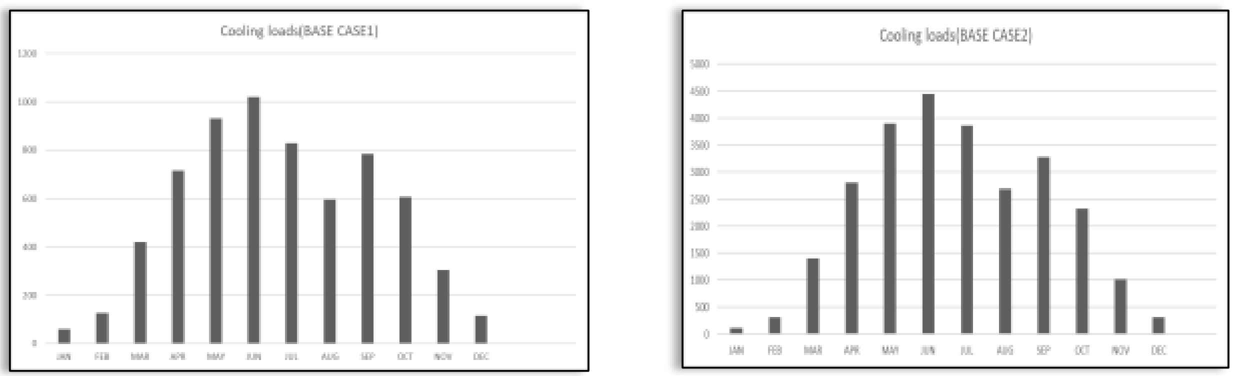
Table 11: setting of simulated PCAM's

5 RESULTS

There has been a clear difference in the cooling loads of the building envelope after implementing the passive adaptation cooling measures. The results are as follows:

5.1 Base Case

The 3-D model of the building design was made using Design Builder software. After implementing the (TMY) weather file for Karachi and running the simulation, following results have been found for both cases



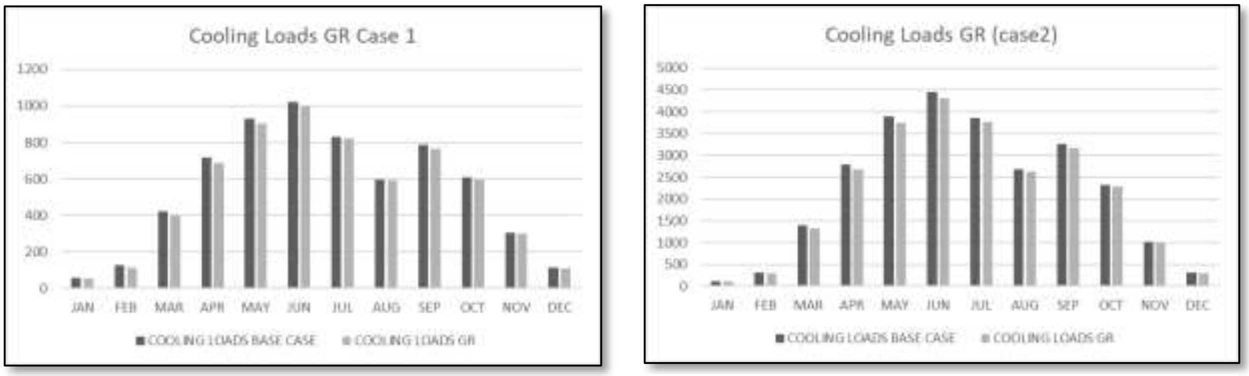
(a) (b)

Figure 20(a):annual cooling loads base case 1(b):annual cooling loads base case 2

The maximum cooling loads have been seen in the months of MAY, JUNE and JULY which are the hottest months as per the location's climate and weather file. JUNE has the highest number of cooling demands in both the cases.

5.2 Green Roof

In Base case study, 6-layers of the roof had been considered while an additional layer of vegetation is considered as a passive adaptation cooling measure and the effects on the cooling loads have been analyzed. In case 1, there is a decrease of 2.55% in the annual cooling loads while for the case 2, there is a decrease of 3.11% annual cooling loads. The extra vegetated layer provides better insulation and resistance towards the solar radiations. Case 2 has greater roof area than the case 1, that's why there is a greater decrease of cooling loads in the results. An extra vegetated roof does not cost much but can have a greater effect in the decrease of cooling loads for a longer run. The graphical description of the cooling loads after the implementation of vegetated roof is shown in the fig 21.

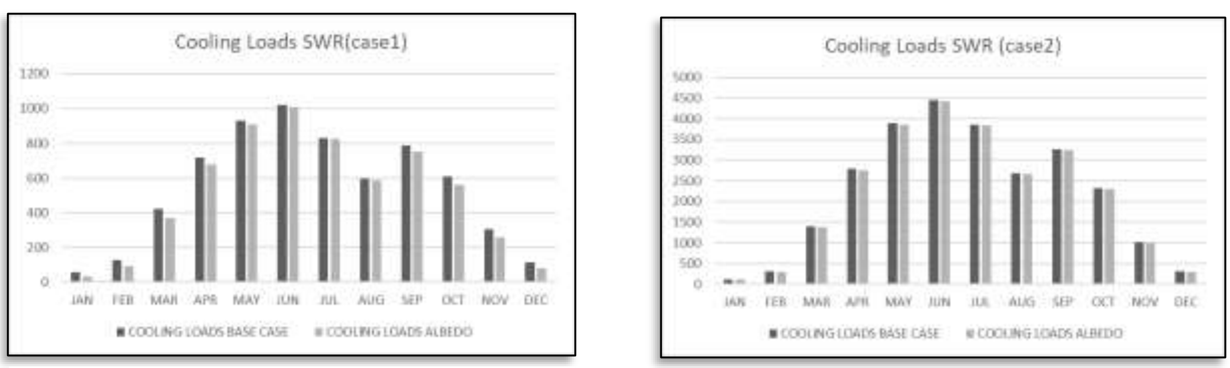


(a) (b)

Figure 21 (a):annual cooling loads GR case 1(b) annual cooling loads GR case 2

5.3 Albedo (Short wave reflectivity)

Cemented grey exposed outer surfaces were considered in the base case while the effect of white paint was considered on the outside walls as a passive cooling adaptation measure. In case 1, there is a decrease of 5.5% annual cooling loads while for the case 2, there is a decreasing trend of 4.78 %. The case 1 has open facades from all the sides while in case 2 the front side of each apartment opens in the corridor which is inside the building. Due to the explained aspect of the building design in the case 2 there has been a decrease in the value related to the case 1. The graphical representation of the results is shown in fig 22.

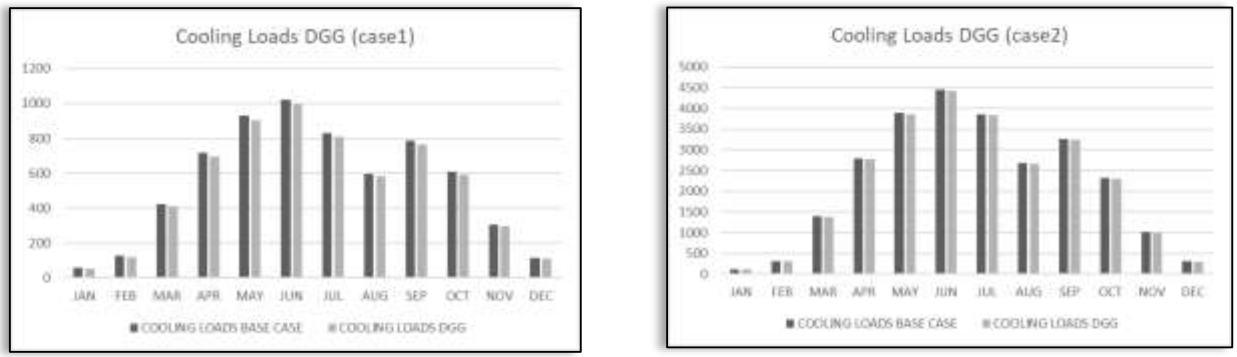


(a) (b)

Figure 22(a):annual cooling loads SWR case1(b):annual cooling loads SWR case2

5.4 Window Glazing

Single glazing is being used in the base case structure of the building for both the cases while the effect of double-glazing glass is analyzed in the passive cooling measure. In case 1, there was a reduction of 2.74 % annual cooling loads of the building. In case 2, there was a reduction of 1.23 %. In case 2, eight windows open in the corridor, the bedroom 1 of each apartment and the drawing room windows. These eight windows open inside the envelope of the building that's why the results are low as compared to case 1. The graphical representation of the building is given in the figure 23.

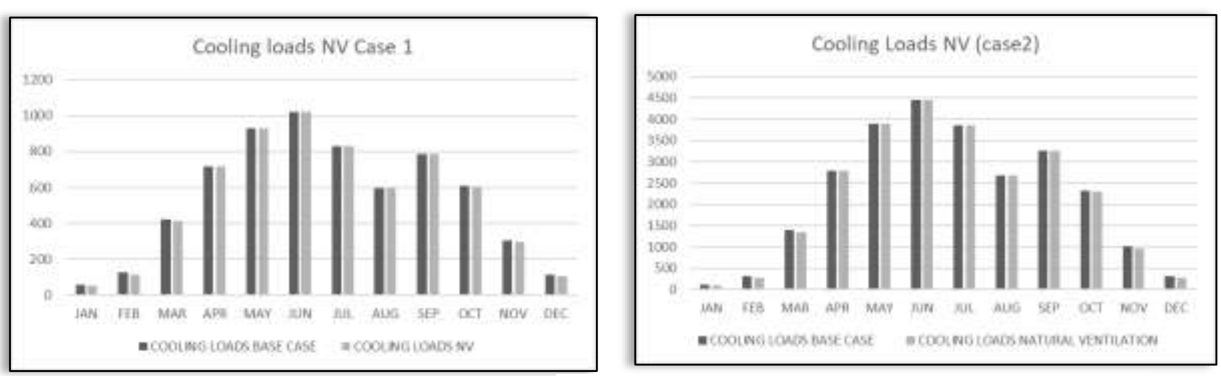


(a) (b)

Figure 23(a):annual cooling loads DGG case 1(b):annual cooling loads DGG case2

5.5 Natural Ventilation

Natural ventilation was not considered in the base case construction while for the PCAM the effect of natural ventilation is considered to check its effectiveness on the cooling loads of the building. There has been a decrease of 0.65% annual energy demands for the case 1, while for the case 2, there is a reduction of 0.9 % annual cooling loads. The fig 24 represents the graphical representation of the cooling load variations across the whole year.

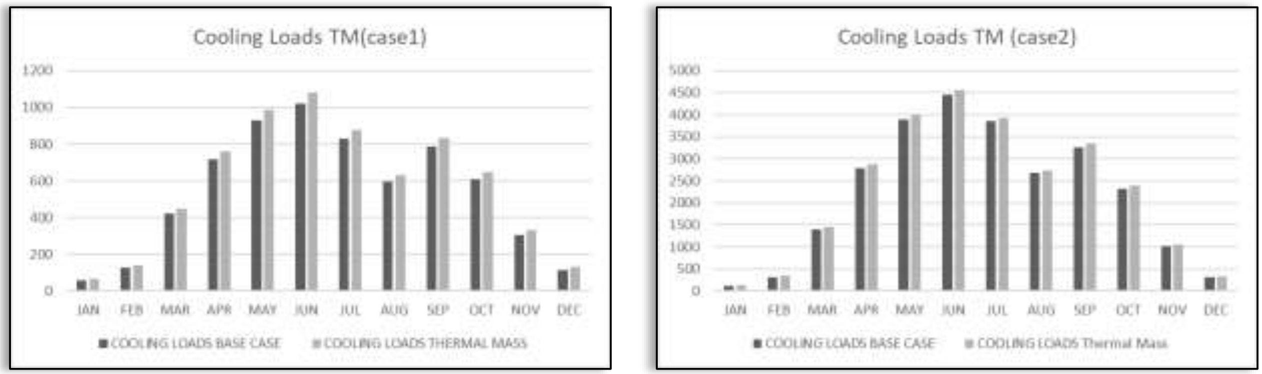


(a) (b)

Figure 24(a):annual cooling loads NV case 124(b):annual cooling loads NV case 2

5.6 Thermal Mass

The use of concrete blocks has been considered as a passive cooling adaptation measure for the cases. The effect on the building cooling loads have been analyzed and graphical representation of the results has been shown in fig 25. There has been an increase of 6.46% annual energy loads in case 1 while there has been an increase of 2.87% in case 2.

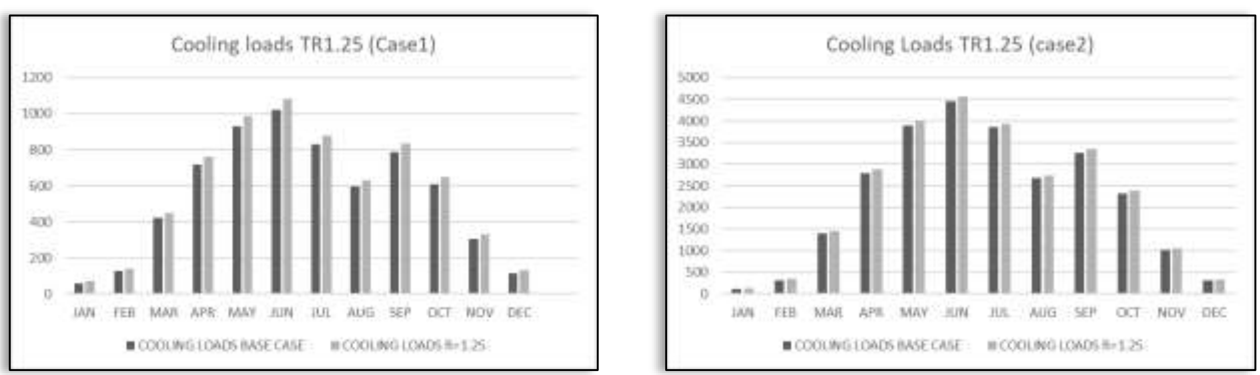


(a) (b)

Figure 25(a):annual cooling loads TM case 1(b):annual cooling loads TM case 2

5.7 Thermal Resistance

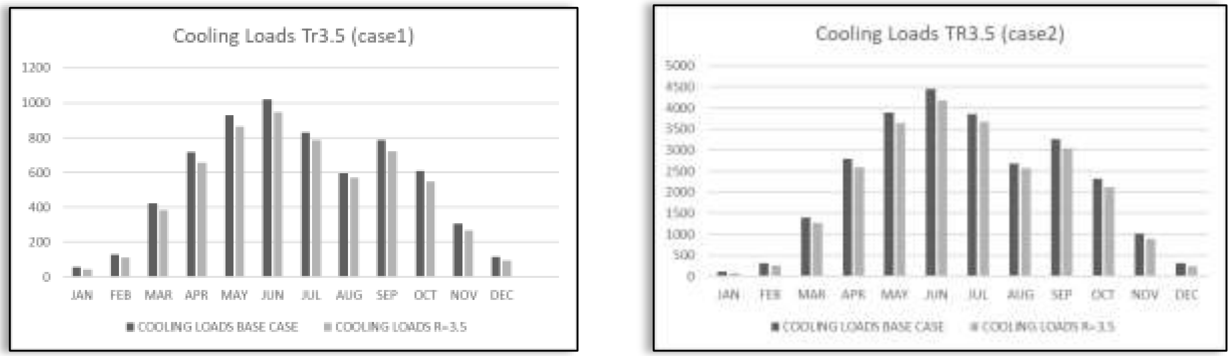
Two different values of the thermal resistance were analyzed for both the cases in this work. Base case had a thermal resistance value of 1.75. when the thermal resistance of the outer wall was decreased to 1.25, there was an increase of 6.15% annual cooling loads while for case 2, there was an increase of 2.85% annual cooling loads. Fig 26 depicts the results



(a) (b)

Figure 26(a):annual cooling loads TR1.25 case 1(b):annual cooling loads TM case 2

When the thermal resistance is increased to 3.50, there is a decrease of 7.96% annual cooling demands of the building in case 1 and 7.07% reduction in the cooling demands for case 2. The graphical representation of the results for (TR=1.25 & TR=3.5) is shown in fig 26 and fig 27.

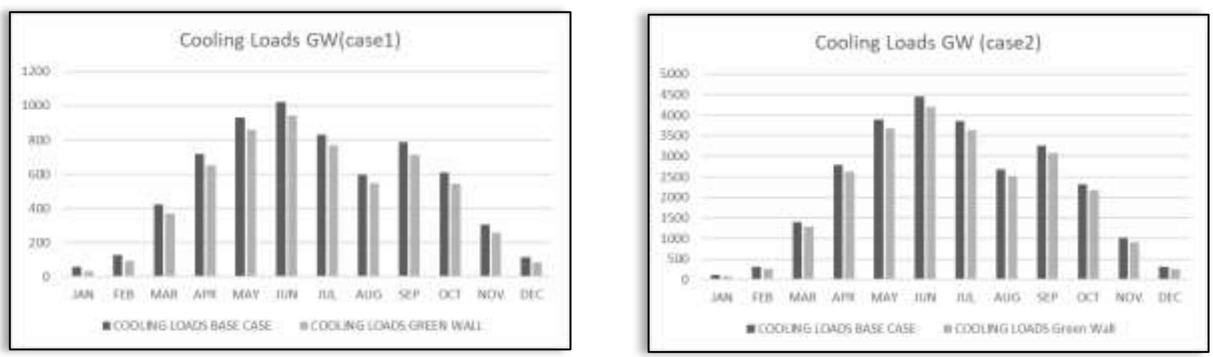


(a) (b)

Figure 27(a):annual cooling loads TR3.5 case 1(b):annual cooling loads TR3.5 case 2

5.8 <u>Green Wall</u>

After the implementation of Green outside wall as a passive cooling adaptation measure, there is a decrease of 9.83% in annual cooling loads for the case 1 and a decrease of 6.50% annual cooling loads for the case 2. The graphical representation is shown in fig 28.

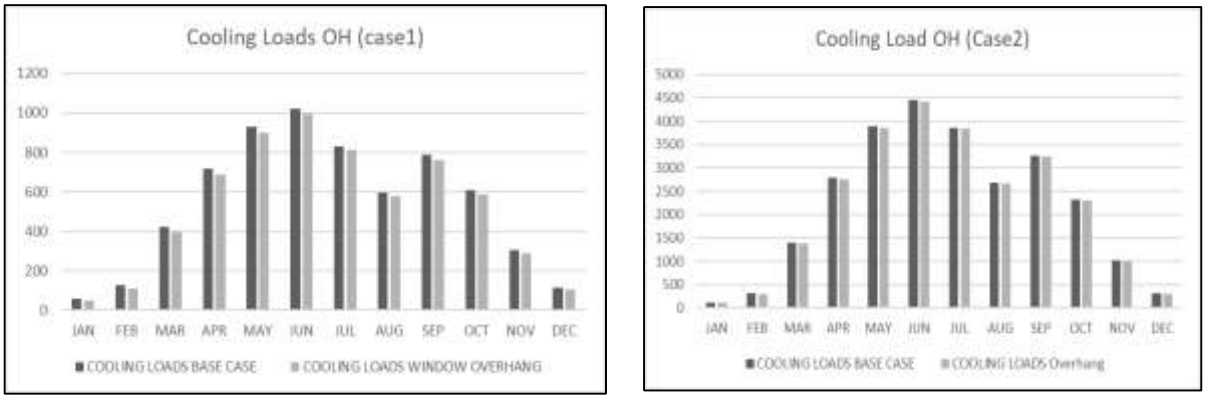


(a) (b)

Figure 28(a):annual cooling loads GW case 1(b):annual cooling loads GW case 2

5.9 <u>Window Overhang and Louvers</u>

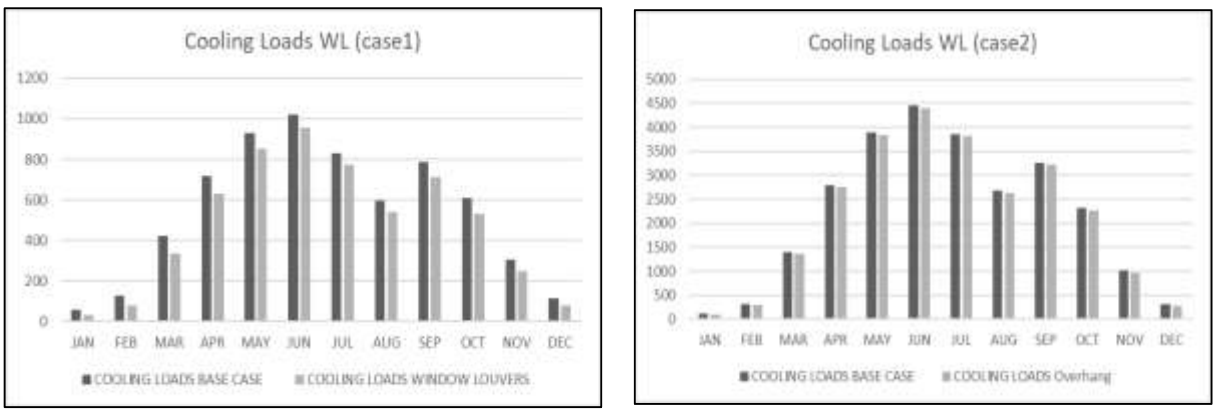
After the implementation of Overhangs over the outside window envelopes, there has been a decrease of 3.81% in the annual cooling demands for case 1, while for case 2, there is a decrease of 1.72% annual cooling demands. The graphical representation is shown in fig 29.



(a) (b)

Figure 29(a):annual cooling loads OH case 1(b):annual cooling loads OH case 2

For louvers there is a decreasing trend of 11.36% in case 1 and 4.95% in case 2. Fig 30 illustrates the results for window louvers on cooling loads.



(a) (b)

Figure 30(a):annual cooling loads WL case 1(b):annual cooling loads WL case 2

5.10 Energy Efficiency

5.10.1 Case 1:

The overall annual cooling load trends for case 1 single apartment building are as follows;

GR=2.55%, NV=0.65%, R1.25= -6.15%, R3.5=7.96%, DGG=2.74%, WHO=3.81%, WL=11.36%, GW=9.83%, SWR=5.5%, TM=-6.46% Decrease in Loads

Graphical representations for case 1 are shown in fig 31 and fig 32.

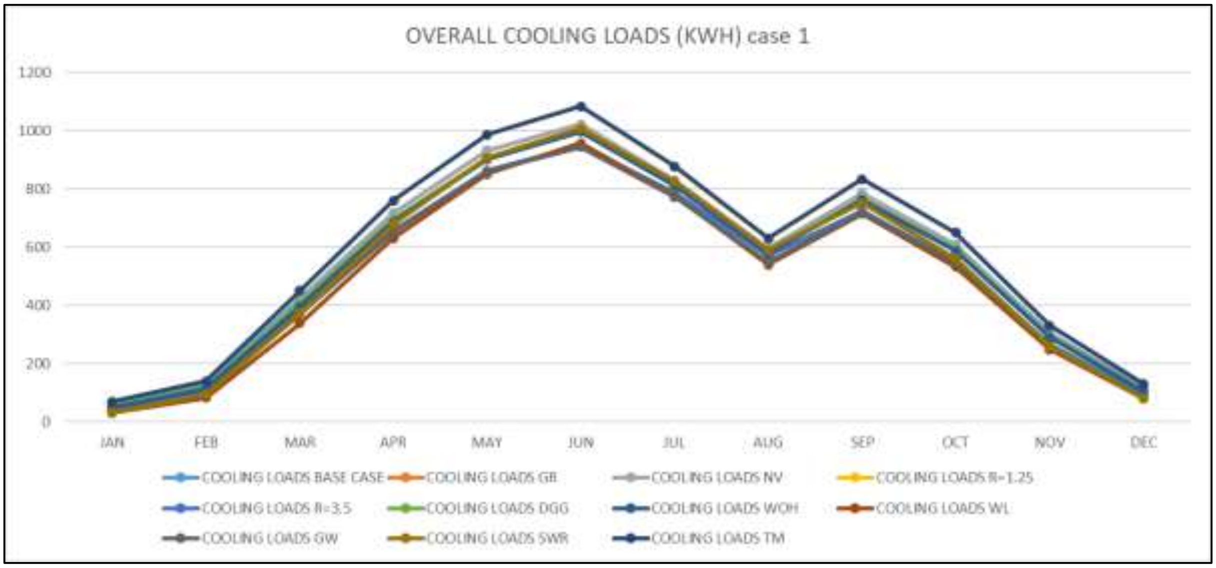


Figure 31:overall annual cooling loads (KWH) (case1)

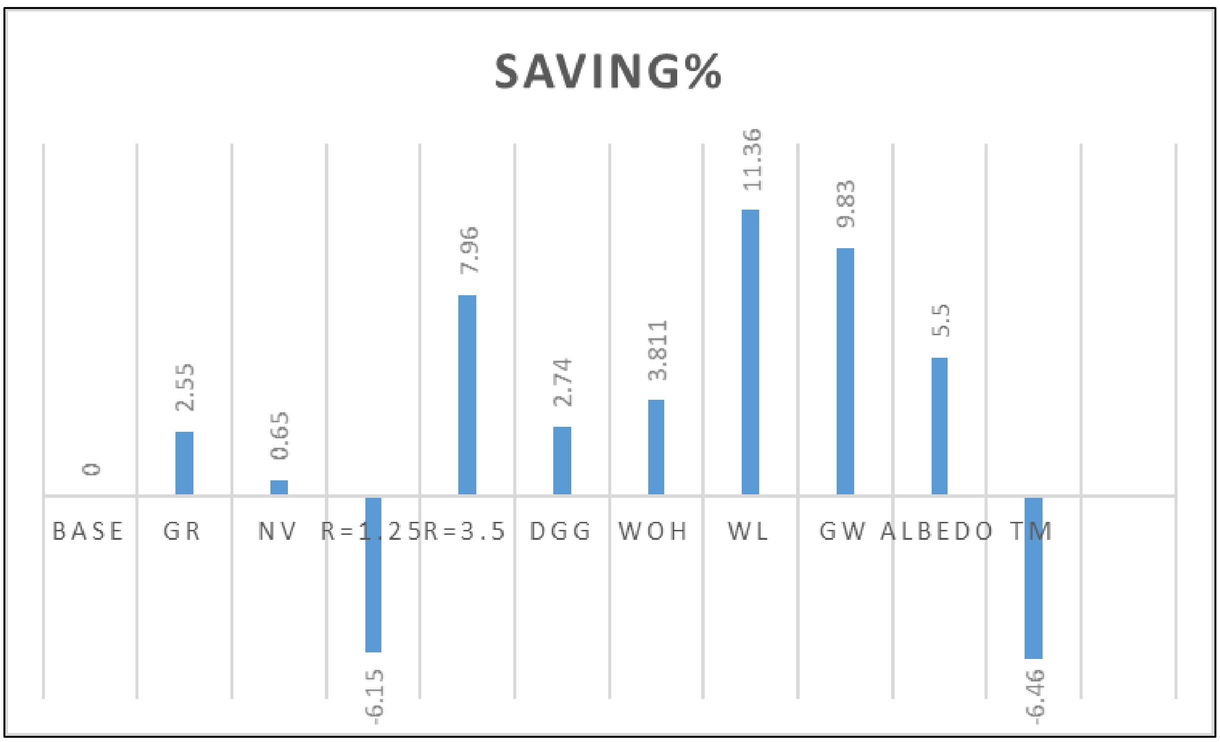


Figure 32:annual cooling loads saving (case 1)

5.10.2 Case 2:

The annual cooling demands trend for the case 2 is as follows:

GR=3.101%, NV=0.9%, R1.25= -2.86%, R3.5=7.07%, DGG=1.23%, WHO=%, WL=4.96%, GW=6.5%, SWR=54.78%, TM=-2.87% Decrease in Loads

The graphical representation of the results is shown in fig 33 and fig 34.

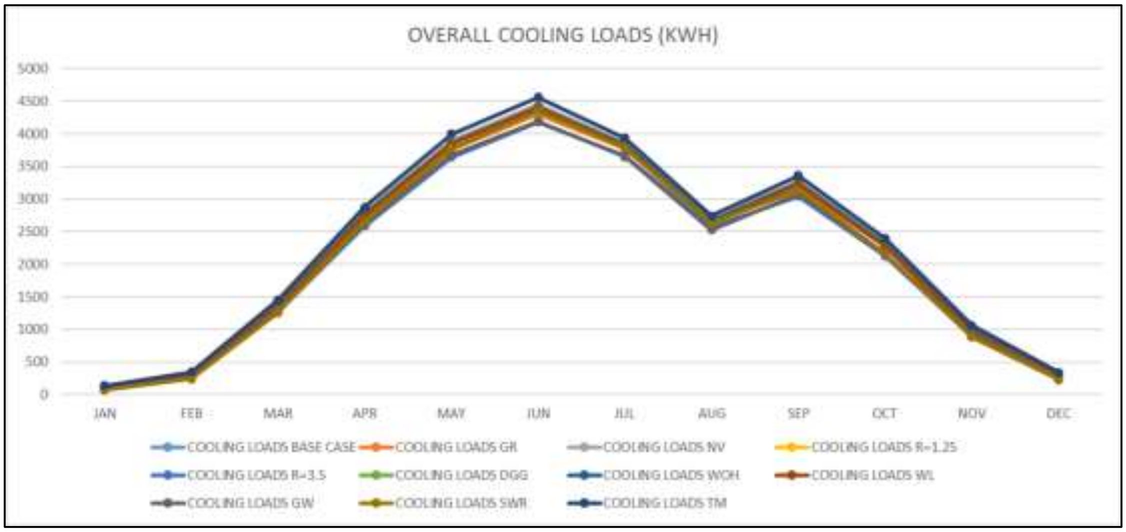


Figure 33:annual cooling loads KWH (case 2)

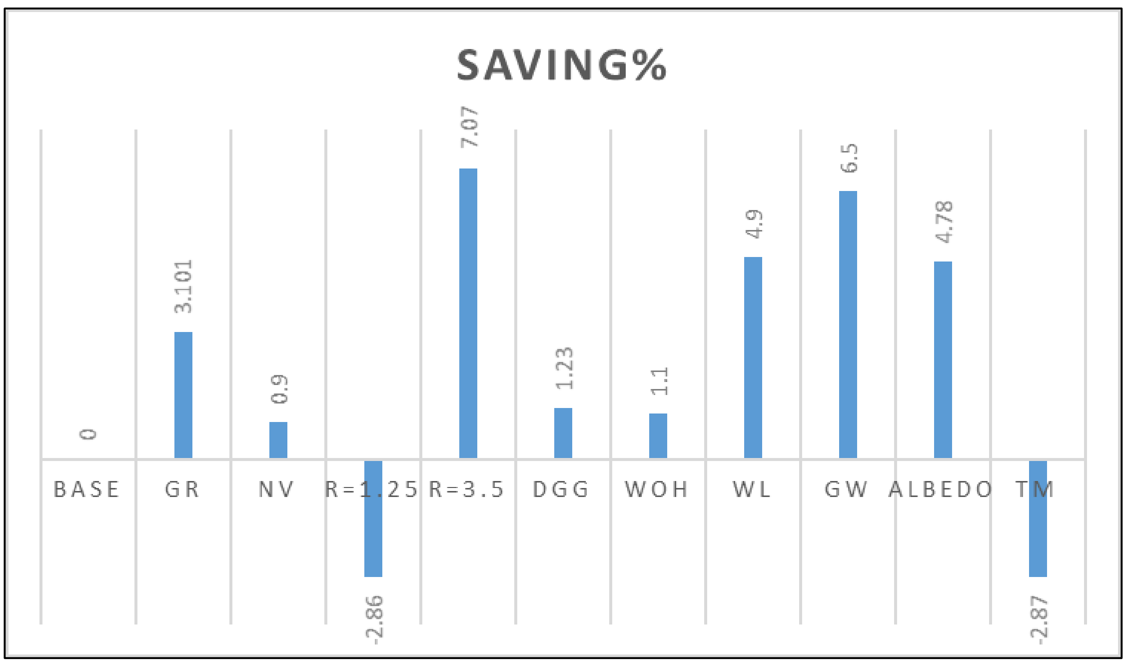


Figure 34:annual cooling loads saving (case 2)

6 Discussions and conclusions

6.1 Discussions

Pakistan is located at the coast of Arabian sea and shares its borders with India, Iran, China and Afghanistan. Pakistan has a subtropical climate with hot summers and cold winters. Northern area comprises of cold weather and snowy mountain ranges while centrally located areas have moderated climate. Southern areas of Pakistan have relatively hotter and more humid climate. The area under study belonged to BWh Koppen Classification (B= Arid, W= Dessert, h= hot). The building under consideration is an apartment building with 3-bedrooms (attached washrooms), a drawing room, kitchen, lounge and balcony on the back façade of the building. Pakistan has been facing serious issues regarding the power generation for a very long time. The power generation still does not meet the power demand of the country which results in blackouts over the year. Keeping these circumstances in the country, a study has been done to calculate the energy consumption of the apartment building annually and to analyze the effect of Passive Cooling Adaptation Measures on the energy demands of the building envelope. Design Builder software is used to make 3-D model of the building design and Energy Plus software to run the simulations. Pakistan is blessed with ample amount of Natural Gas reserves which is used for heating purposes domestically. Natural Gas is cheap and does not cost much domestically. That's why the annual heating energy demands are not considered in this study. Moreover, due to the hot climate around the country, the cooling loads are thrice as compared to the heating loads. Pakistan is already suffering to meet ends with the energy supply and demand gap. That's why annual cooling load calculations are considered for the study and the effect of PCAM's on the cooling loads.

3-D model of the original apartment building (Cantt View Flats) is designed using Design Builder and PCAM's are applied later one by one to check their effectiveness on the cooling loads annually. May, June and July are the hottest months according to the TMY weather file data and the effects of this climate condition can be seen on the cooling load results of the building. The most cooling load demand is in the months of May, June and July both in the base case as well as in the PCAM's. Green Roof, Natural ventilation and Double-Glazing Glass has the minimal amount of effect on the cooling loads annually. These three PCAM's reduced the cooling loads slightly when implemented individually. Lowering the thermal resistance has a negative impact on the cooling loads of the building. Decreasing the thermal resistance of the outside wall increased the annual cooling load demands of the building. Similarly, increasing the thermal mass of the building by using the concrete block design instead of bricks also increased the annual cooling demands of the building. Increasing the thermal resistance of the outside wall decreased the annual cooling load demands by a great margin. Window overhangs, window louvers and external green wall also reduced the annual cooling demands by a great number. The greatest effect on reducing the cooling demands of building was seen by implementing window louvers and green wall as PCAM's.

6.2 Conclusions

Following conclusions are drawn after the Energy Plus simulations of the designed apartment building and implementing all the passive cooling adaptation measures individually:

- Natural ventilation played a very minimal role in decreasing the cooling loads of the apartment building mainly due to the weather climate conditions in Karachi. Natural ventilation can help reduce the cooling loads in the less hot months but plays a very minor role during the peak summer months. In case 1, Natural ventilation decreased the annual cooling loads by 0.65 % and in the second case by 0.9 %.
- Using the double-glazing glass instead of single glazing glass also had a very minor effect on the cooling loads according to the results. In case 2, 50 % of the main windows are located in the corridor for each apartment, so glazing could not be much beneficial in decreasing the cooling loads. In case 1, there was a decrease of 2.74% annual cooling loads while for second case it was 1.23 %.
- Green roof is a very important measure to reduce the cooling demands of any building is it also improves the environment and provides a better look for the building. Greater the green roof area, greater reduction in the annual cooling loads is witnessed. In case 1, there was a decrease of 2.55% and for the second case 3.101 % reduction in the cooling loads is seen.
- Window overhangs can help in providing better thermal indoor environment for the tenants. The results of window overhangs with inside drapes were quite moderate

for both the cases. In case 1, there was a decrease of 3.81 % annual cooling loads while for case 2, there was a decrease of 1.1 % annual cooling loads. The reduction in the results for case 2 is mainly due to the lesser openings outside the building as compared to case 1.

- Green wall in essence of the green roof plays very vital role in reducing the cooling demands of the building and can reduce the energy loads by a huge margin. In the following research the results after the implementation of green outside wall were quite satisfactory. There was a reduction of 9.83% annual cooling loads for case 1 and 6.5 % reduction of loads for case 2.
- Implementing the white paint on the outer surfaces of the building envelope reduced the cooling loads by 5.5 % in case 1 and 4.78 % reduction in cooling loads for the case 2.
- Increasing the thermal resistance for the outside wall also played good role in increasing the indoor thermal comfort in summer. In case 1, 7.96% annual cooling loads reduction is seen and for case 2, 7.07 % reduction in annual cooling demands of the building.
- Window louvers reduced the cooling loads the most and proved to be the best PCAM for apartment buildings. In case 1, there was a reduction of 11.36 % in annual cooling demands of the building while for case 2 there was a reduction of 5 % in the annual cooling demands of the building.
- Reducing the thermal resistance of the outer surfaces increased the cooling demands in both the cases from 2-7 % annually.
- Also increasing the thermal mass of the building with the use of concrete blocks increased the cooling demands of the building by 2-7 % annually.

6.3 Future work

The current study is carried out under several constraints which can lead to many options for future work

- Future work can include a range of combinations of passive measures to investigate their effect on cooling loads. PCAM’s are analyzed individually in this research to calculate their effect on the cooling loads for apartment building. In future multiple combinations of these PCAM's can be analyzed to find the best combination for reducing the building energy demands

- It can Include the effect of net zero energy building by implementing solar panels on the roof. For this research the electricity from the grid has been considered for meeting the energy demands of the building. Future work can include the consideration of solar panels on the roof to meet the energy requirements of the building
- it can include the study of carbon dioxide emission studies
- Only flat roof type is studied in this work while other types can be further studied in future work
- Other sources of renewable energy can also be utilized in order to analyze their effects of energy generation and consumption
- Limited number of PCAM's are analyzed in this research. Further PCAM's can also be included in the research for future work.

6.4 Symbols Used

°C	Centigrade
CO2	Carbon dioxide
U-value	Thermal Transmittance
Rc-value	Thermal Resistance

6.5 Abbreviations

ADB	Asian Development Bank	OH	Overheating Hours
PCAM	Energy-Efficient Measure	RC1.25	Thermal Resistance of 1.25
NTDCL	National Transmission and Dispatch Company Limited	RC3.5	Thermal Resistance of 3.5
TM	Thermal Mass	NV	Natural Ventilation
COP	Co-efficient of Performance		
EU	European Union		

SWR	Short-wave Reflectivity (Albedo)
VR	Vegetated/Green Roof
BCP	Building codes of Pakistan
GHG	Greenhouse Gases
EPW	Energy Plus Weather
TMY	Typical Meteorological Year
FW	Front Green Wall
WO	Window Overhang
WL	Window Louvres
DGG	Double Glazing Glass

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