Impact of Climate Change on the Future Energy Demand and Energy Efficiency of Buildings in Pakistan

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Abstract

Global climate is changing due to an increase in greenhouse gases. Climate change has increased the annual average temperature. Temperature is the most important weather component that determines the cooling and heating needs of a building. For a better understanding of future energy needs, it is important to estimate the climate of that region. With this knowledge, it will be easier to plan for that future or even design the buildings according to that climate. This study is performed to calculate the estimated change in annual energy demand for buildings in three cities of Pakistan. These cities were selected based on their different current climate. A global climate model HadCM3 was selected which is designed to represent future atmospheric changes. Morphing method was applied to the hourly data that was recorded over several years. Future hourly weather files were generated for 3 future time periods namely 2020, 2050 and 2080 and two building models were created. Building energy simulations were then performed on these two buildings for the base case and future scenarios. Simulation was repeated for all three cities with all 4 weather files (1 current and 3 Future). Results were compared for all the time periods. A decrease in the requirement for heating energy was observed. Cooling energy needs were predicted to have a significant increase. For some cases cooling is required for months that currently do not require cooling. Lighting and equipment loads are not a significant change from the present. Overall annual energy needs will increase because for Pakistan decrease in heating energy is not enough to balance the increase in cooling energy.

Key Words: *Building Energy Simulation, Future Climate, Morphing Method, Heating and Cooling Energy*

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CHAPTER 1: INTRODUCTION

This chapter contains the motivation behind this study and the objectives that were set for it. A brief account of how the changes in our environment have impacted our lives. A wide range of effects that are being studied by different researchers in response to climate change around the world is explained. Some of those studies involve a particular area whereas some deal with global impacts of climate change. The purpose of this chapter is to give an introduction to this study.

1.1 Background, Scope and Motivation

Climate change is a growing concern among the scientific community around the world. Extreme weather phenomena are occurring on regular bases. Heat waves, forest fires, floods and storms are ravaging the earth more frequently than ever before. Studies have found that heat waves at the end of the 21st century will be severe and will last for longer periods of time [1]. These phenomena are in part due to climate change. Wildfires in Australia and America destroy a lot of flora and fauna.

A recent increase in emission is anthropogenic. Advancements in technology have increased the number of factories and industries. Exhausts from these factories produce a variety of greenhouse gases. Another large contributor to greenhouse gases is the growing number of meat farms. Carbon dioxide and methane are among the largest emissions causing the greenhouse effect. These greenhouse gases get trapped in the atmosphere and absorb heat from the earth's surface. This heat is then reverted into the atmosphere. Due to this phenomenon, the temperature of the earth keeps increasing. Cold climates are warming up whereas hot climates are getting hotter with every passing year. The global annual average temperature is rising more rapidly every year than it is observed ever before in history.

The impact of climate change on our everyday life is being studied by many researchers. With the growing amount of greenhouse gases, it is imperative to understand their impacts on humans and other living beings. Studies have been conducted on how climate change will impact people's health, food availability, changes to environment and changes to energy requirements. Climate change has a direct influence on our agricultural system. Changing climate will affect the production of crops due to changes in rains, changes in temperature and changes to soil composition. With the change in people's dietary habits, livestock production is increasing which is a fifth of total greenhouse gas emissions. Climate is a big aspect of the availability of water for masses and agricultural needs.

Heat waves in recent years have taken the lives of thousands in recent years. Heat waves in Pakistan were studied to have an increasing trend of 0.71 days/decade [2]. An increase in heat waves is related to the daily maximum and minimum temperature.

Among all other effects that climate change will have on our lives in the future, one of the major will be an increase in energy demands. In our daily life, energy is required for different purpose. Fossil fuels are directly used as gasoline or diesel in automobiles or indirectly as electricity from thermal power plants. The energy requirement is attributed to many aspects of life. Buildings are one of the major consumers of energy globally. All types of buildings require some degree of energy for their proper working. In Pakistan, domestic buildings utilize 45.9 % of the total annual energy [3]. Half of the energy consumed by the domestic sector is used for an HVAC system, lighting and appliances. Pakistan is an energy deficient country which causes load shedding during summer months. Thermal power plants are the major source of electricity production in Pakistan. Thermal plants are also responsible for Global Climate Change. Since a large percentage of energy is utilized by building it is important to understand how much change will occur in the coming years.

Researchers have estimated many aspects of the climate that will be affected by climate change. Many types of research have been conducted for different areas of Pakistan that utilize a few of the variables that represent climate as a whole. Farooqi at el estimated changing trends of temperature and precipitation by using previously recorded data [4]. Temperature, precipitation, wind speed, etc. individually doesn’t represent the clear picture of climate. There are a large number of other aspects of weather which are also as important to present a whole situation. Among those include wind speed, wind direction, solar irradiation, direct normal irradiance, diffused horizontal irradiance, cloud cover, sea level pressure and others are also as important. There isn't a study that includes all of these variables to estimate future climate for Pakistan. On the other hand energy for building in the future hasn't even been explored. Therefore this study is done to introduce both those aspects.

1.2 Aim and Objective

This research aims to estimate possible future building energy demands in different cities of Pakistan and to estimate the change in the current and future energy demands. To achieve those goal two objectives were set for this research. One was to predict future climate on an hourly manner taking into account a wide range of weather variables. The other was to estimate the change in energy used in a building. Since the main use of building energy is for the HVAC system its breakdown was also calculated. As part of the second objective, the change in heating and cooling energy that will be required in the future and its change with respect to the present is estimated.

1.3 Thesis structure

Chapter 2 involves a literature review from previous studies. In chapter 2 several studies have been reviewed that are related to future climate prediction and method used for building energy calculations. Studies have been reviewed that have been used to estimate the total energy used by the buildings. Chapter 3 consists of the process involved in generating future weather files and a brief explanation of the Morphing Method that is used for future weather data. The terms and procedures involved in this are explained in detail. Chapter 4 entails the 3D modeling of the geometry of selected model types. Building construction and material parameters are presented as they are used in the models to replicate real-world buildings. Chapter 5 includes results that are acquired after multiple runs of simulations. Chapter 6 represents the conclusion of this research. Other future works that can be derived from this work are also suggested in this chapter.

CHAPTER 2: LITERATURE REVIEW

In the past, several researchers have used many different methods to estimate the future climate using mathematical models and computer simulations. Some studies were carried out just to estimate climate variables that are related to predicting weather disasters. Different researches have been carried out using similar techniques for many cities around the globe. Different parts of a country have different climates. Wide research has been carried out to predict building energy requirements. Some of those studies are reviewed below. After the review, a path was devised for this study which is briefly explained in this chapter.

2.1 Past Work

Analysis of energy consumption of two buildings in America was performed by Shen [5]. An apartment and an office building located in four different cities were selected. Each city with a different climate was selected so that the impact of climate change can be observed for different climates. The morphing method for generating future weather files for 2040 to 2069 time period was utilized. Simulation results showed an increase in cooling energy and a decrease in heating energy for both building types. Annual Cooling energy under very realistic emission scenario A2 had an increase of 6.6% to 12.4% for an office building and 17.4% to 27% for residential building. Annual heating energy had a decrease of 9.1% to 18.1% for an office building and 14.7% to 35.4% for residential building. The total annual energy consumption had a change from −1.64% to 14.07% in residential building and from −3.27% to −0.12% for an office building with A2 scenario. This implies that for office building total energy for the selected time period would decrease.

The building energy consumption for four cities in Turkey under three different climate scenarios was analyzed by Dino et al. [6]. A typical Turkish residential building was selected in their experiment. Cities were selected based on their climate characteristics to represent future changes in different climates. The changes between a baseline time period and 2060 were analyzed. Change in annual mean temperature was observed from 3°C to 5°C. Heating degree days were estimated to decrease by 491 to 961 °C-days, while Cooling Degree Days are expected to increase by 154 to 415 °C-days.

Linear regression on mean, maximum and minimum temperature for Karachi was performed by Sajjad et al. [7]. Analysis of the data from 1947 to 2005 concluded that Karachi has a lot of temperature variation throughout the year. But a consistent trend of increasing average temperature from 1975 to 2005 was found. During 1976–2005, the mean maximum temp, mean minimum temp and mean average temp increased 2.7°C, 1.2°C and 1.95°C respectively.

A method called morphing that produced a weather data file which could be utilized to simulate building energy needs was developed by Belcher et al. [8]. Sequenced average weather conditions that showed realistic future weather conditions were produced. Downscaling of the global climate model was performed to get finer results for building energy. To verify the method calculations of heating degree days was compared with the GCM and the results of morphing which were agreeably similar in both. This method was applied to the baseline test reference year for London, Manchester, and Edinburgh. A regional model for the UK called UKCIP02 was used for comparison to their results. It was discovered that for 2080 in London monthly mean temperature for the month of august raised to 5.9 °C. The Heating degree days for medium-high emissions dropped by 20-30 degree days per year for both London and Edinburgh. This coincided with projections from UKCIP02 with which it was concluded that morphing is a robust method for calculating HDD and CDD for building Simulations.

The electric and fuel energy consumption for 2 models that are provided with EnergyPlus was performed Fumo et al. [9]. Predefined parameters that are in the model were used and no alteration was made. These parameters were obtained by software developers after running the simulation multiple times. The hypothetical buildings were placed in Atlanta and Meridian. A benchmark building from EnergyPlus library was selected and compared with a real building. After studying the benchmark buildings' results a few coefficients to find the utility bills were selected by them. A comparison of their findings with the utility bills of a similar building was made. It was observed that differences between simulated results and bills were within 10%. The results indicated that the use of predefined EnergyPlus library values is a viable and time-saving tool for building energy consumption.

An analysis of change in building heating and cooling needs for 4 different time slices was performed by Frank [10]. The buildings were placed in Switzerland's Zurich–Kloten area. Firstly the change in monthly mean temperature for the recorded data was observed. The change in temperature for 3 past scenarios and 1 possible future time period of 2050-2100 was observed. For the last scenario, an increase of 4.4°C in mean annual air temperature was detected by him. For this study, a simulation method called HELIOS was utilized. This method takes hourly data and implements a heat balance equation. These equations take into account parameters like air density, ventilation, the mass of internal air, air temperature. The results showed an increase in the cooling period by 49 -72 days a year with an increase in cooling energy by 365–1050%. Heating days reduced between 30-60 days per year with a decrease in heating energy by 36-58% for different office buildings.

Different tools that have been developed based upon morphing method were studied by Luke et al. [11]. First is CCWorldWeatherGen and the second is WeatherShift. Weather generator is MS Excel based tool that uses HadCM3 as GCM and A2 emission scenario. It is used to project weather for 3 future time slices in 2020, 2050 and 2080. WeatherShift is a web-based tool that uses 14 GCMs that are integrated into the programming. It follows 2 of the recent emission scenarios RCP 4.5 and 8.5. The differences in building energy with morphed files from both these tools were studied by them. 3 buildings that were already designed and simulated according to ASHRAE standards were used by them. No alterations to any parameter of the building design were made. Simulations showed a similar pattern of increase in site and source energy. Since RCP scenarios come with different percentile differences in all GCMs breakdown of the total energy some similarities and some differences were observed. It was hinted that the use these tools to be time saving and good enough for weather projection. Concluded was made that these differences represent the need for understanding these weather variables in much more detail.

The cooling energy needs for residential buildings in Taiwan were simulated by Huang et al.[12]. The changes in energy demand that are to be seen in the future under climate change were calculated. Since Taiwan lies in a moderately hot region only cooling energy was calculated. An increasing trend in energy was observed by them. For 2080 prediction of an increase of 82% in cooling energy from present energy was estimated. Another aspect of the study dealt with passive measures that can be employed to reduce the use of an active energy source. Solar heating, natural ventilation, evaporative cooling among others were praised by them. a combination of these strategies was concluded by them to help reduce active energy from electric grid or gas stations.

2.2 Observations from review

A number of observations were made from the above-mentioned studies that are given below.

- It is possible to estimate future weather to a realistic degree.
- The morphing method is a reliable and computationally easy way of estimating future weather.
- Climate change is changing the energy used by buildings.
- Simulating building energy changes in the future is a good way to help prepare for future energy demands.

2.3 Hypothesis

Many of the studies conclude that the total energy required for a building will vary in the future. Most of the researches that have been done for different cities concludes an increase in energy required for cooling in the buildings. Heating is predicted to decrease as well. Based on those results it can be summarized that similar changes will also occur in Pakistan. To what extent these changes will be in Pakistan is the focus of this study.

2.4 Software

- EnergyPlus for energy simulation.
- SketchUp (with Open Studio plugin) for 3D modeling of buildings
- MS Excel for weather file generation and result calculation.
- MS Word for documentation of the study

2.4.1 Energy Plus

Energy Plus is building energy simulation software that is designed to be used by design engineers and architects. Its purpose was to help engineers with HVAC system configuration. Ever since its development, it has evolved into a widely approved tool for building energy simulation across the world. Many researchers have used it in their research since. It now has a multitude of features other than HVAC to calculate other energy loads. It provides the options to include lighting, water, equipment and other plug and play loads. It has multiple features to create a model for the building which needs optimization or you can model a building that is to be built.

It has a large library for materials and construction parameters. Materials that are common building material are included in the library. It gives you the ability to change a certain parameter to your needs. It even gives you the option to customize your building material by adding its dimensions, conductivity, density, etc. Similarly, it has a large library for HVAC systems that you can choose from. Depending on your model you can choose a system with a large cooling tower or you can choose a split indoor and outdoor unit. For a building that is still to be constructed, you can run the simulation using multiple HVAC systems and then calculate the optimum system for your building. Lighting, equipment load can also be calculated to find energy consumption for the model.

Its integration with other software helps in understanding the simulation better. Results can be obtained on an HDML interface or as an Excel file. Building models can be viewed on a CAD tool.

2.4.2 SketchUp

It is a 3D modeling software that is developed for architectural, interior and engineering models. It provides the user with multiple drawing tools. Users can drag and drop the tools to create their desired geometry. For use in energy plus it requires an OpenStudio plugin that provides a drawing tool corresponding to the EnergyPlus. After the geometry is created model is converted into an Input Data File (IDF) that is used as EnergyPlus Input.

2.5 Thesis methodology (Summary)

After the review of a number of studies, the morphing method was concluded to be a reliable method for future prediction of climates. This research consists of two main sections. Firstly it is necessary to generate a projected future climate that shows us climate conditions of the future. This is done through the extrapolation method known as the morphing method. Projections of possible future are done for 3 time periods of 30 years apart. Secondly model of a building needs to be created which is done with a 3D modeling software SketchUp. Afterward both these weather file and model is added to EnergyPlus as inputs. EnergyPlus based on those projections and models calculates energy needs for different buildings.

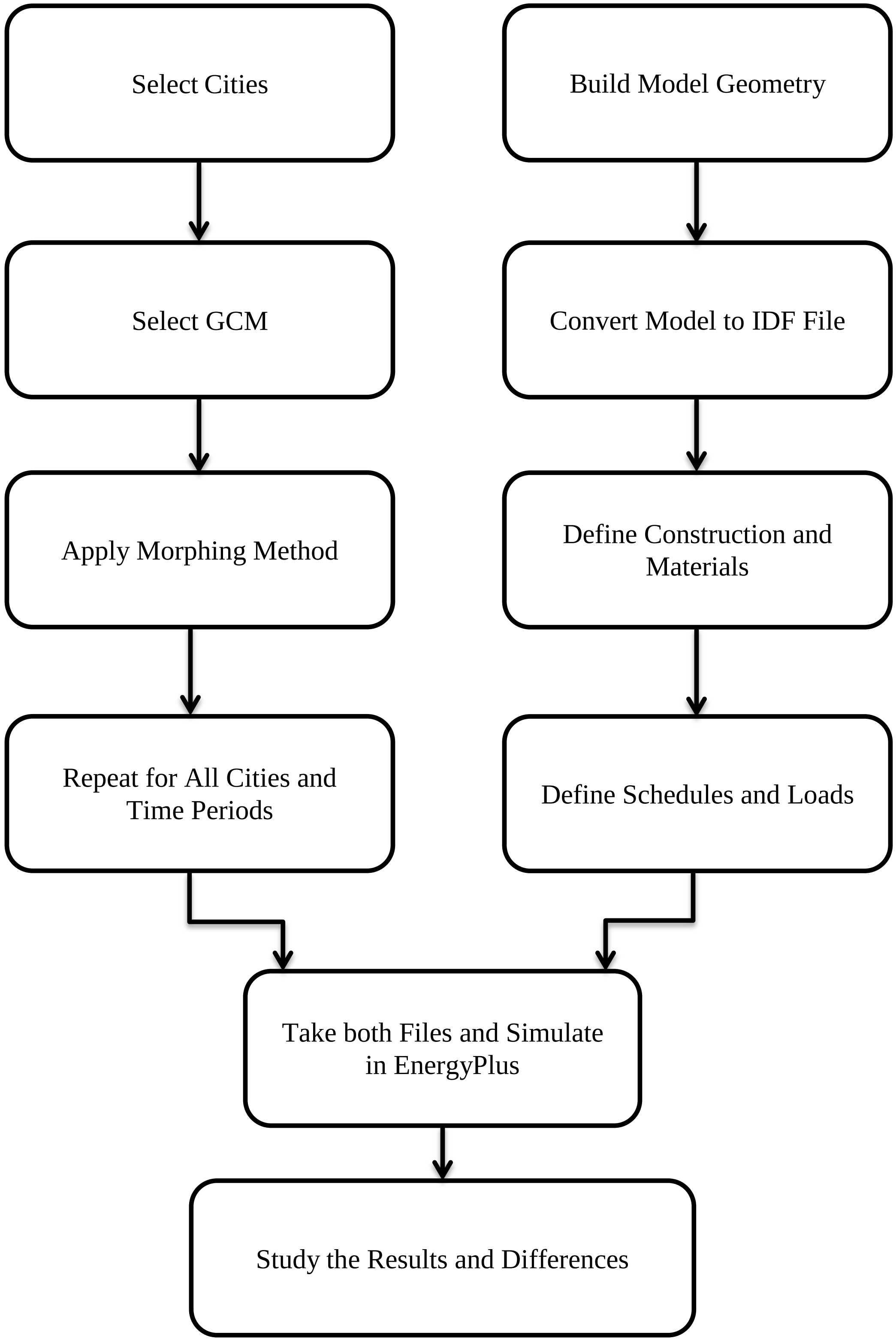

Figure 1: Flowchart Representing Research Path

CHAPTER 3: GENERATION OF FUTURE WEATHER FILES

To generate a future weather file for any place a number of decisions are to be made. Here the generation of future of weather files is explained in detail. Starting from the selection of cities until applying the morphing method is included in this chapter.

3.1 Selection of Cities

Pakistan is a diverse country based on its climate. The climate of Pakistan moving from north to south changes from cold winter to mild winters and severe long summers. Up in the north, mountains are covered in snow all year long. In the south, lies the Arabian Sea providing a coastal climate. Köppen-Geiger Climate Classification is a global climate classification based on precipitation and temperatures averaged annually and monthly [13]. According to Köppen-Geiger Climate Classification, Pakistan has areas with cold summer climates as well as arid hot desert climates [14]. To better understand the effects of climate change it is necessary to select cities with different climates. Karachi and Lahore are the most populated cities in Pakistan. They both are in different climate zones according to the Köppen-Geiger Climate Classification. Islamabad is the capital city and it has some similarities with Lahore. According to the above-mentioned classification, it lies in a different zone. So these three cities are selected for this study. Following is a brief description of these cities' climate.

3.1.1 Karachi (Arid) (BWh)

Karachi is located in the Sindh province of Pakistan. Sindh is mostly covered with desserts. This closeness to desert makes Karachi's climate similar to that of a desert. Köppen-Geiger Climate Classification classifies Karachi as BWh which represents a hot desert climate. In this climate, the evaporation rate is higher than precipitation. Karachi has longer summer seasons. Summers are humid and hot but cool sea breezes make the nights during summer pleasant. Annual average Precipitation is low in Karachi. Winter season is brief and last 3 months between December and February. Usually, winter months are dry.

3.1.2 Lahore (Semi-arid) (BSh)

Lahore is located on Indus plain. It is represented with BSh in climate classification, which is used for hot semi-arid climates that have hot summers and warm to cool winters. They tend to have a minimal amount of precipitation. June is usually the hottest month of the year and January the coldest in Lahore.

3.1.3 Islamabad (Temperate) (Cwa)

Islamabad is located near the mountain ranges. Its climate is represented by Cwa that shows hot semi-arid climates that are influenced by the monsoon season. Islamabad faces cold winters and hot summers. The temperature of Islamabad changes between 13 °C in January and 38 °C in June.

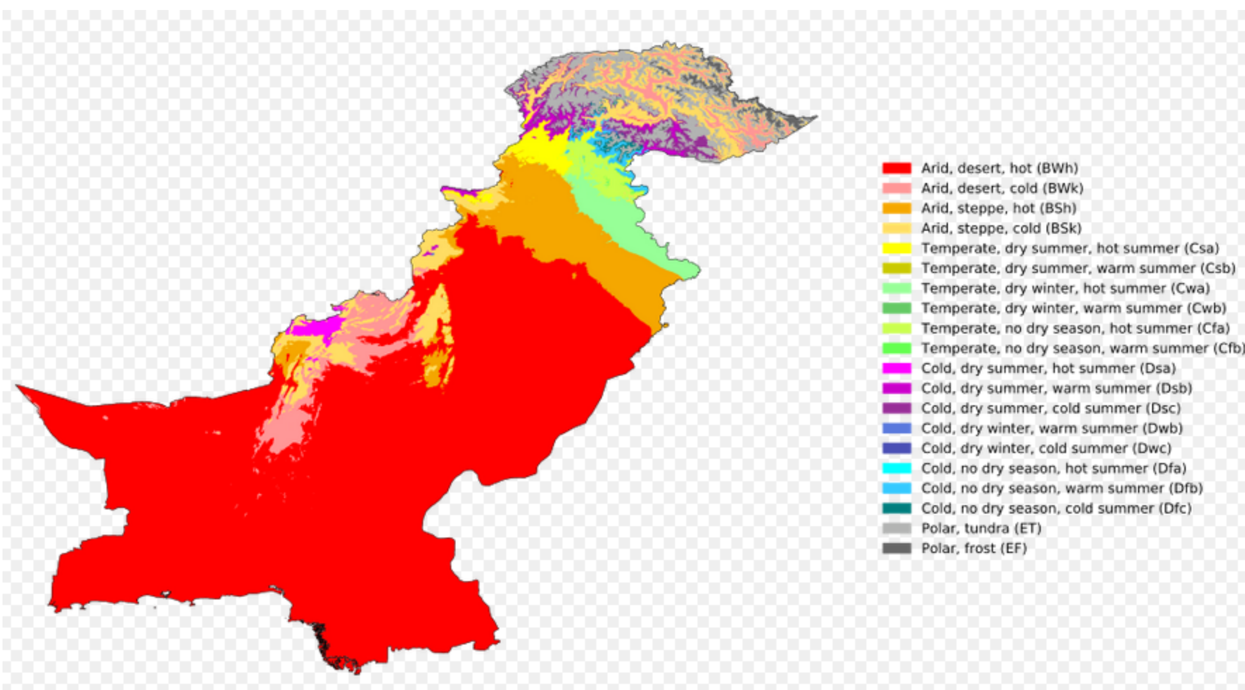

Figure 2: Köppen-Geiger Climate Classification map of Pakistan

3.2 Selection of GCM

After the selection of the cities, a global climate model (GCM) needs to be selected. Development of Future weather requires selecting a GCM. GCMs are mathematical models of planetary atmospheric and oceanic circulation. They employ Navier–Stokes equations for a rotating sphere [5]. Global climate models are developed for the earth as a whole so they have a large grid size. A number of GCMs have been developed by different studies according to climate data. HadCM3 model is GCM introduced by Hadley center for future weather prediction [15]. HadCM3 model was used as the main GCM during International panel on Climate Change's (IPCC) Third Assessment meeting [16]. The most important aspect of the Hadley model is its temperature sensitivity. The HadCM3 model gives projections for all the required climate variables to directly 'morph' current weather data. Building energy simulation will produce better results with a temperature sensitive GCM. It has 144 divisions of the globe along the latitude and 96 along the longitude.

Along with a GCM, some emission scenarios are also required for the morphing method. International panel on Climate Change (IPCC) has presented them in their Third Assessment Report and Fifth Assessment Report. These scenarios represent the global greenhouse gas emissions at different rates. During the Third Assessment Report, they presented four scenarios from extreme to least drastic future projections. They categorized them into 4 different categories.

Different Emission scenarios are developed by IPCC according to the rate of emission of greenhouse gases. IPCC holds different seminars for climate change awareness every year. They also have summits where they present details about emissions and their impacts. They present best to worst scenarios for emissions. These four scenarios are described below.

- A1 Scenario

This scenario represents a rapid economic growth. The world population is expected to increase by 9 billion by the year 2050 and the rapid integration of technology worldwide. A1 is further divided into sub scenarios among which includes the A1F1 scenario. A1F1 is a fossil fuel intensive scenario.

- A2 Scenario

A2 scenario represents growth of the economy at a regional level. The population is estimated to increase but not as fast as A1. Relatively low levels of emissions are assumed.

- B1 Scenario

It is a more eco-friendly scenario in which technologies for environmental stability are introduced at a global level

- B2 Scenario

This scenario represents a divided world where every nation has its policies regarding climate. This scenario is also an ecofriendly one where very small emissions are predicted.

Based on the above different types of scenarios A2 scenario was assumed to best reflect the future climate of Pakistan. A1F1 scenario is a fossil fuel reliant emission scenario with rapid technological advancements. Pakistan relies heavily on fossil fuels but for electricity production, hydro power plants also play a big role. With the construction of new dams, fossil fuel for electricity will reduce. For this study selection of A2 was assumed to be best.

3.3 Typical Meteorological Year (TMY)

A typical meteorological year is a set of data that represents a whole year. It consists of hourly readings of a number of variables that are associated with weather. Typically it has the following variables along with some others.

- Dry bulb temperature (deg. C)
- Relative Humidity (%)
- Global horizontal irradiance (W/m2)
- Direct (beam) normal Irradiance (W/m2)
- Diffuse horizontal irradiance (W/m2)
- Infrared radiation downwards (W/m2)
- Wind speed (m/s)
- Wind direction (deg.)
- Air pressure (Pa)

This TMY will act as the baseline weather conditions that represent present-day weather conditions.

3.4 Selection of Baseline

Morphing method requires weather data to produce a future climate scenario. Baseline weather is needed to be set. A baseline is a weather sequence data that is averaged over multiple years. According to The World Meteorological Organization data of 30 years is not sufficient to represent full weather conditions but is a recommendation for creating a baseline [17]. They have divided the 30 year gap starting from 1901-1930; 1931-1960 and 1961-1990 and so on it will be 1991-2020. But since that period isn't over ideally 1961-1990 period is to be used.

$$(x_0)_m = \frac{1}{24 \times d_m \times N} \sum_N \sum_m x_0 \tag{1}$$

Here x_0 is the variable that is to be averaged (Wind speed, solar irradiation, etc.). m Represents the month for which that variable is to be calculated. N is the total number of years that data is to be analyzed, d_m is the number of days in that month and 24 represents hours of a day.

It depends on the availability of data. For our study hourly data of 30 years is not available for the selected cities. So here it depends on how much data is available. Pakistan Meteorological Department provided data that had some missing variables necessary for the morphing later on. So it was decided to use another method. ASHRAE developed weather files for 227 different cities around the world based on the data available to them. They called it International Weather Files for Energy Calculation (IWEC). They applied another method for deriving a baseline climate. They used weather data for 1982-1999 and instead of averaging the data another technique was used. They selected a complete month from 19 year period that best represented the average conditions of that month. So January was selected from one year and February from either the same year or from another year. First IWEC findings included weather file of Karachi and an area near Lahore. Second IWEC was developed using the same technique for 3012 locations using data from roughly 1983-2008. IWEC 2 included Islamabad as one of the locations. Degelman [18] tested IWEC data and WMO data with recorded data for 50 cities. He concluded that the average error for average monthly temperature is an average error of about 0.13°C. Solar radiation and Degree days only yielded aggregated values 0.3% to 0.7% difference as compared to the IWEC data. The main conclusion of his study proved that the results produced by IWEC were in fair proximity to the Statistical records. So the use of IWECs in this study is justifiable.

3.5 Morphing

It is a method introduced by Belcher et al to produce a weather sequence that holds the pattern of current weather variables and predicts changes that may occur in the future.

3.5.1 Morphing Algorithms

The morphing Method uses different algorithms for different weather variables. It has 3 Algorithms that it uses,

- Shift
- Stretch
- Combination of stretch and shift

3.5.2 Shift

Shift applies a monthly change into the current value

$$x = x_0 + \Delta x_m \qquad (2)$$

For a variable x, its value is morphed by adding future monthly change (Δx_m) to the current value of that variablex_0. Here m represents the month for which variable is calculated. A shift is applied for all those values that are given as absolute change. Atmospheric pressure has an absolute change, so shifting is applied to calculate its future value.

3.5.3 Stretch

Variables that have fractional change undergo linear stretching. A scalar factor is multiplied to the variables current value

$$x = a_m x_0 \qquad (3)$$

The fractional change in monthly mean value is represented by a_m. Variables that have fractional change stretch algorithms are applied.

3.5.4 Shift and Stretch

The weather variables that need to be adjusted to monthly mean, as well as their monthly amplitude, needs correction requires both shift and stretch algorithms to be performed.

$$x = x_0 + \Delta x_m + a_m[x_0 - (x_0)_m] \qquad (4)$$

For temperature daily mean as well as variance is needed so shift and stretch are applied in combination.

These algorithms will produce a weather data set that has a pattern similar to that of local recorded as well as coincide with the Global Climate Model that is used.

CHAPTER 4: BUILDING MODELS DESCRIPTION

This chapter entails which types of buildings are selected to be simulated. The generation of geometries of both buildings using SketchUp software is explained. After the creation of geometry models are enriched with parameters to represent real world conditions. Both models are incorporated with materials and constructions matching that of the real world. Schedules of loads are explained later in the chapter as well.

4.1 Selection of buildings

Another vital decision for simulation is to select a building type. All the buildings require some form of energy. Some buildings work on 24 hour bases throughout the year and then there are buildings that work for a specific period during the day. Residential buildings require energy at all times. Office buildings and markets mostly work during day time. On the bases of their structure and space, their energy requirement will differ as well. It is not possible to cover every single building in this study. It is ideal to select buildings with different structures and working hours to estimate the change in energy demand. Depending on the schedule the HVAC, lighting and appliances that consume energy will be different for different days.

In this study, two buildings with different sets of characteristics were selected. The first building is of a residential type that has a varying number of occupants throughout the day. This type of building has to maintain a certain comfort level throughout the day. The second building type was selected as a building that is occupied for certain hours during the day. A university building block was chosen for this purpose. Blueprints for the School of Mechanical and Manufacturing Engineering (SMME) were obtained from university officials.

4.1.1 Residential Building

Residential buildings vary from a single-story building with a small area to multistory apartment buildings. For this study residential building is taken as a 10 Marla house. The house was selected at random with double story building that included 5 bedrooms with washrooms, 2 TV launches, 2 kitchens, 2 store rooms and 1 drawing room. The total number of rooms that were fitted with an HVAC system was 8. Bathrooms and kitchens were only added for lighting and equipment load. The model was based on the drawings given in the figures below.

Figure 3: Floor plan of a residential building, ground floor (left) and 1st floor (right)

Model is a detached building meaning it is exposed to sun and wind from all sides. Features that do not affect the energy load were omitted for energy modeling such as terrace, lawn, side ally on the left side, etc.

4.1.2 University

For this model School of Mechanical and Manufacturing Engineering (SMME) block located in National University of Science and Technology (NUST), Islamabad main campus was selected. Blueprints of the buildings were acquired. Efforts were made to create an exact model of the original building.

Figure 4: Front view of SMME building

The building is a 4 story structure with rooms that are used for a variety of purpose. The building is designed in three sections that are joined together. The central structure is joined by two wings called east wing and West wing. Both wings are identical and mirrored at a 90° angle with the central wing. Many rooms are used as classrooms that require HVAC and lighting. Since there are rooms that function as laboratories also have an equipment load assigned to them. Some rooms that are also important for our research are faculty rooms, conference rooms, the library, etc. All these rooms are considered in this study. Corridors are added only for lighting load.

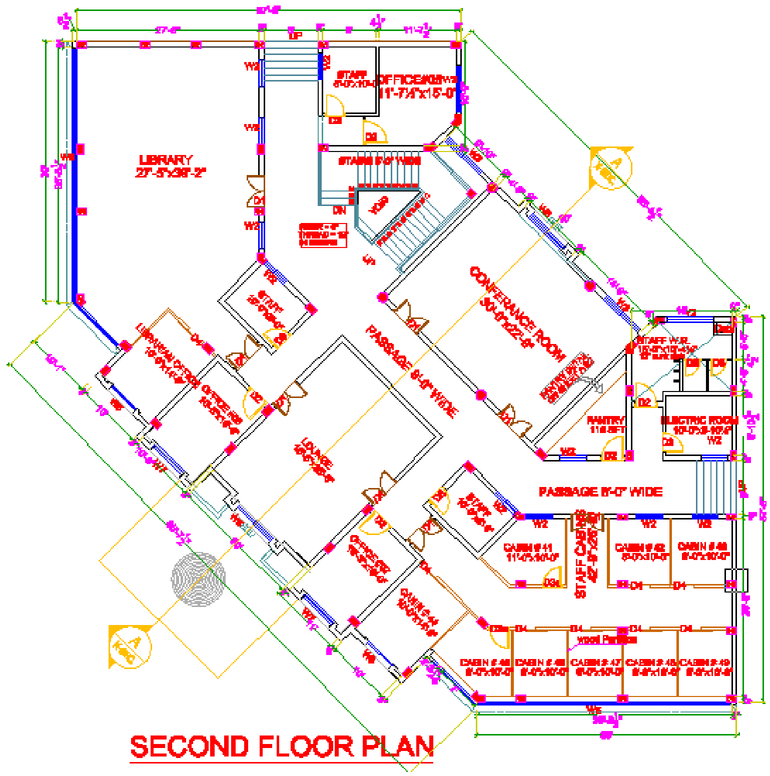

Figure 5: Floor Plan of the central wing

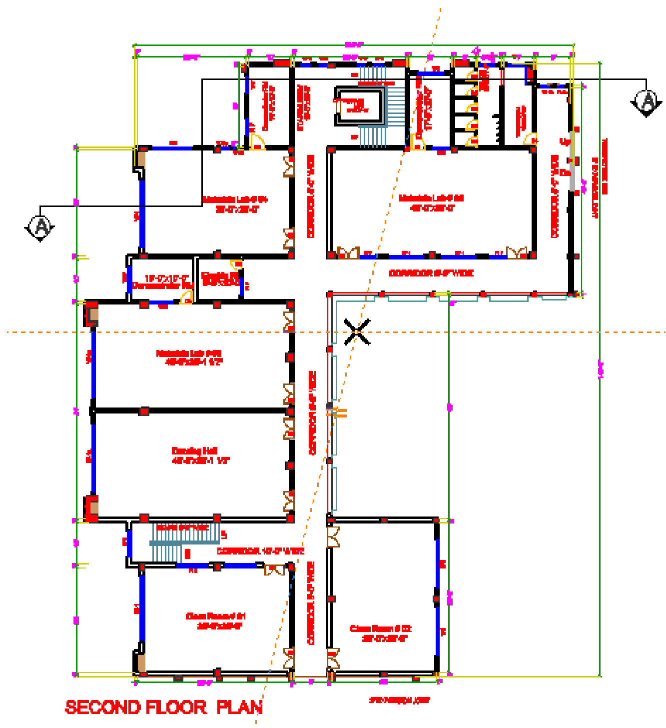

Figure 6: Floor plan of the east wing

4.2 Modeling

Energy plus have model designing feature but it is a value and co-ordinates based so have to do extensive computational work for a complex model. Floor plans for both residential and university buildings were created using SketchUp and simulations performed using EnergyPlus.

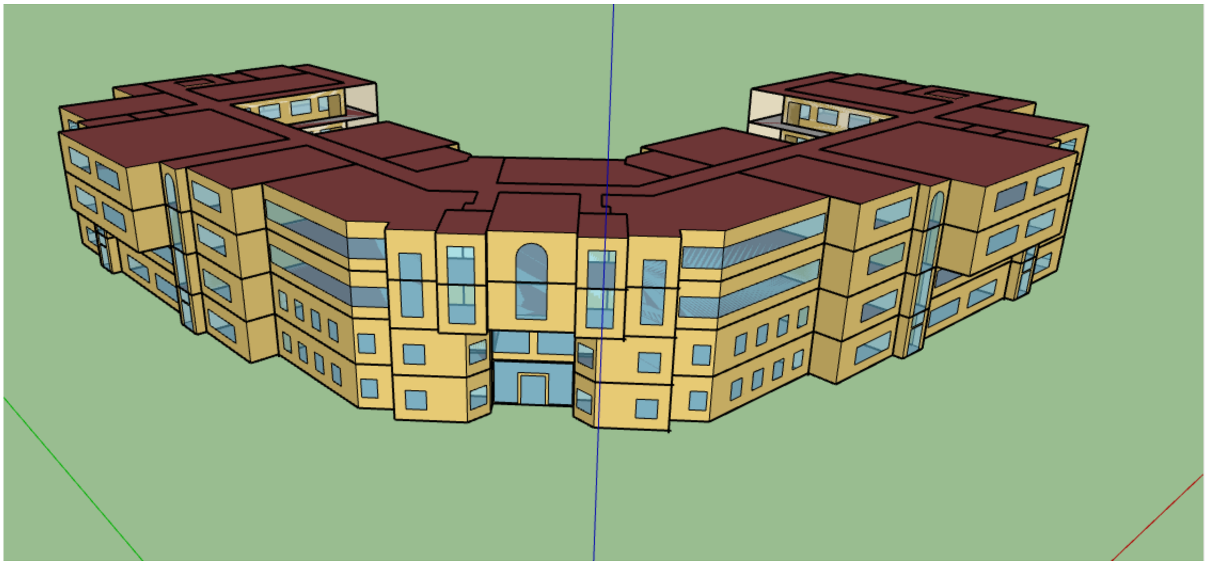

Figure 7: Front view of SMME building model from SketchUp

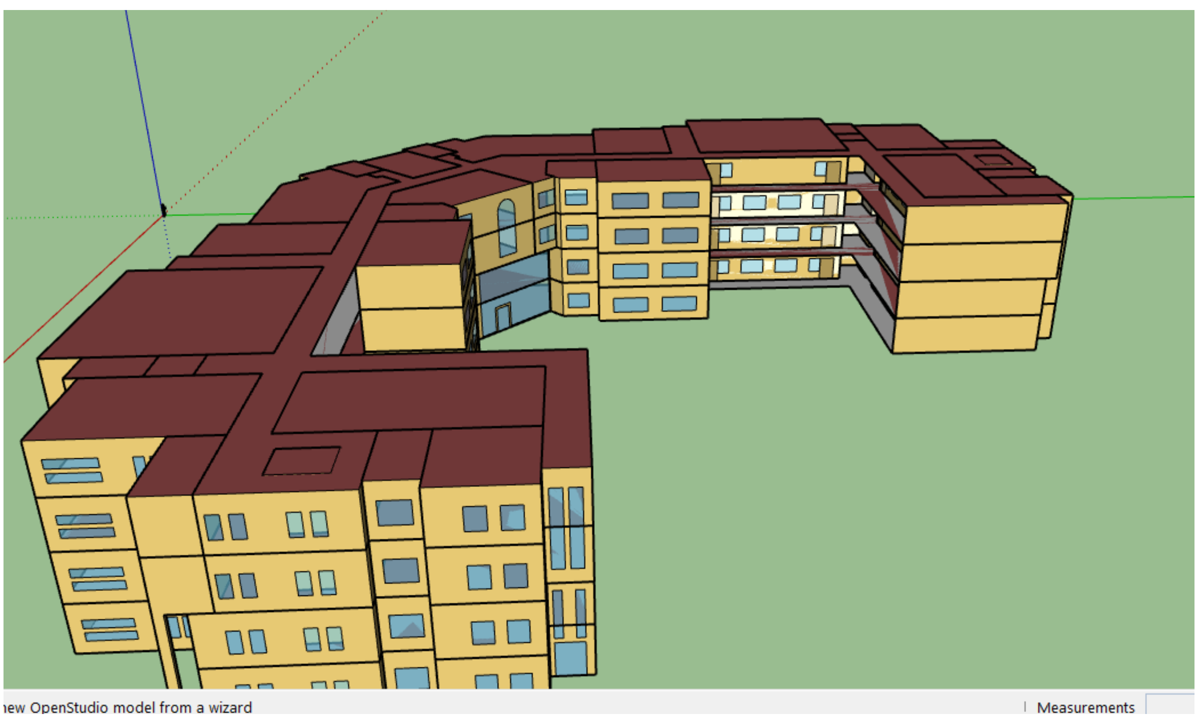

Figure 8: SMME building model side view

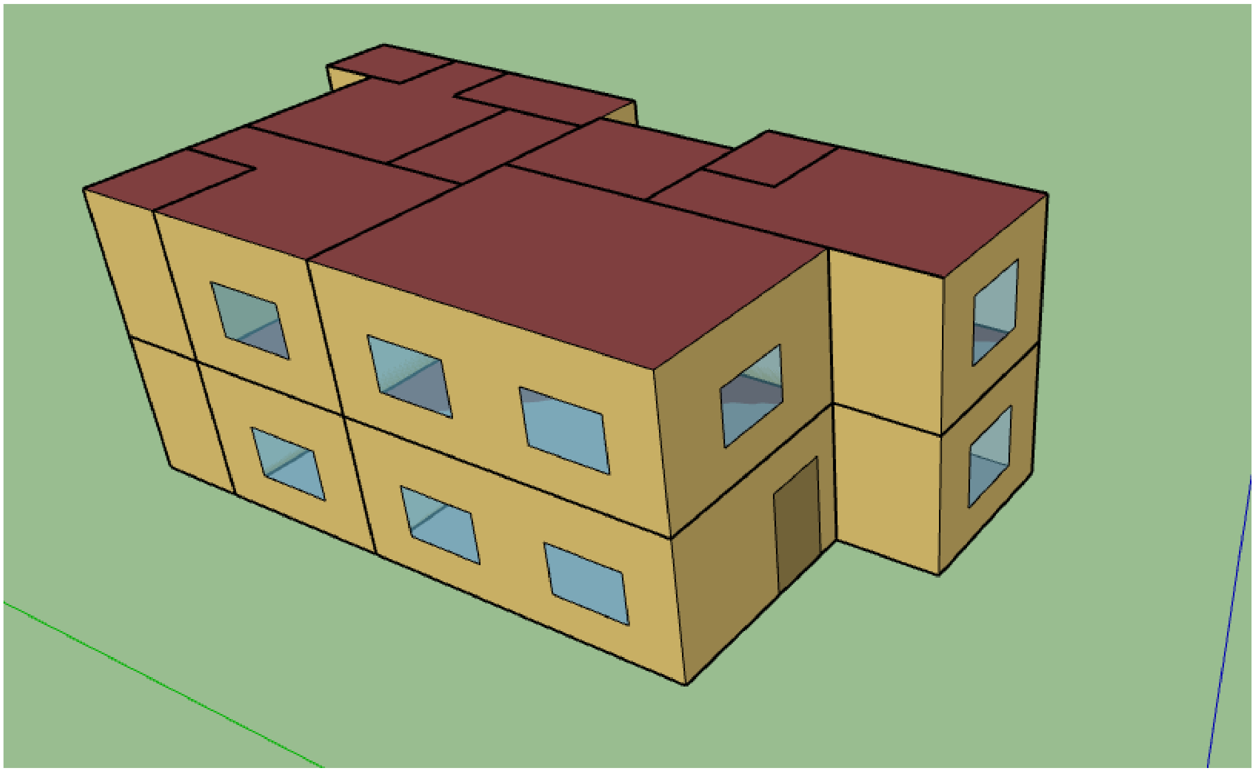

Figure 9: Model of residential building

4.3 Construction

Construction of the models is defined in EnergyPlus IDF Editor. Construction is all of the different features a model has. They include doors, windows, walls, etc. This is done through the addition of different layers with the features. For example, a single glass layer is used to describe a window. Ceiling/Floor features here represent the ceiling of the first story which is also the floor of the second story.

4.3.1 Residential building

It is taken to be ordinary houses in Pakistan that have no insulation on roofs and walls. Construction layers are represented as they start from outside moving inwards.

Table 1: Construction Feature Layers of Residential models

Feature	Layer 1	Layer 2	Layer 3
Windows	CLEAR 3MM		
Door	Wood		
Walls	Cement Mortar	9" Brick	Cement Mortar
Ground Floor	2" P.C.C (1:2:4)	Tiles / Flooring	
Ceiling/Floor	Cement Mortar	Concrete Slab	Tiles / Flooring
Roof	Concrete Slab		

4.3.2 University

University building features were made as given on the floor planes of the building. EnergyPlus library contains most of the layer material. Those that are not in the library are manually added.

Table 2: Construction Feature Layers of University Model

Features	Layer 1	Layer 2	Layer 3	Layer 4
Ceiling	Cement Mortar			
Door	Mild Steel Sheet			
Floor	Concrete Slab	2" P.C.C (1:2:4)	Tiles / Flooring	
Ground Floor	3" Sand	3" P.C.C (1:4:8)	2" P.C.C (1:2:4)	Tiles / Flooring
Roof	Concrete Slab	Hot Bismuth	3"Polyurethane Sheet	3" RCC
Windows 1	CLEAR 5MM			
Windows 2	CLEAR 8MM			
Walls	Cement Mortar	9" Brick	Cement Mortar	

4.4 Materials

Building materials vary with countries they are used in. The main material difference in Pakistan is the use of clay brick rather than ceramic bricks. Wall structures of both buildings are made with clay brick. Bricks are a mixture of clay and water that are made from 9"x4.5" molds. They are sundried and fired in coal furnaces. Construction materials for both building types are given in the tables below.

Table 3: Materials Used in Residential building

Materials	Roughness	Thickness (m)	Conductivity (W/mK)	Density (kg/m³)	Specific Heat (J/kgK)
Wood	Medium Smooth	0.0254	0.15	608	1630
9" Brick	Medium Rough	0.222	0.78	1760	790
Concrete Slab	Medium Rough	0.1524	1.95	2400	900
Cement Mortar	Smooth	0.0032	0.69	2160	837
2" P.C.C (1:2:4)	Medium Rough	0.0508	1.95	2240	900
Tiles / Flooring	Smooth	0.0381	1.59	1920	1260

Table 4: Materials Used in University Building

Materials	Roughness	Thickness (m)	Conductivity (W/mK)	Density (kg/m³)	Specific Heat (J/kgK)
2" P.C.C (1:2:4)	Medium Rough	0.0508	1.95	2240	900
3" P.C.C (1:4:8)	Medium Rough	0.0762	0.29	512	880
3" RCC	Medium Rough	0.0762	1.95	2400	900
3" Sand	Medium Rough	0.1524	2.05	1600	800
3"Polyurethane Sheet	Smooth	0.003	0.033	30	1500
9" Brick	Medium Rough	0.222	0.78	1760	790
Cement Mortar	Smooth	0.0032	0.69	2160	837
Concrete Slab	Medium Rough	0.1524	1.95	2400	900
Hot Bismuth	Smooth	0.001	7.97	100.5	151
Mild Steel Sheet	Medium Smooth	0.002032	45	7861	511
Tiles / Flooring	Smooth	0.0381	1.59	1920	1260

Most of the material characteristics are already in the library. But some that are not given were estimated and some are taken from other research works. Brick that are conventional construction material in Pakistan were used in the model [19].

4.5 Air Conditioning

The HVAC system is the primary consumer of energy for our chosen buildings. Our model buildings are relatively small in size so boilers and chillers are not considerable options. VRF System is introduced in the model because they are relatively more energy efficient on the basis that it can have multiple indoor units with a single outdoor unit. SMME building uses a VRF system for air conditioning. Based on its efficiency instead of split system residential model is also incorporated with a variable refrigerant flow system. Estimated energy savings for different cities with a VRF system to be up to 55% as compared to the unitary system.[20]

4.6 Schedule

4.6.1 HVAC Schedule

Residential building has a schedule of 24 hour cooling and heating. The system is at ON position all year round. When the temperature drops below the set limit heating function come into effect or if temperature rises above a set limit cooling starts.

For university building, HVAC works on a schedule of 9:00 am till 9:00 pm for weekdays and remain turned off during weekends. It is observed that all the rooms are not occupied all the time during the day. A schedule was generated for HVAC systems based on timetable of spring 2019 semester. An average daily occupation of rooms was calculated and introduced into the model.

4.6.2 Occupancy Schedule

Occupancy was used as a ratio throughout the day. For the residential model, a total number of 8 peoples were used. Based on observation it is estimated that all the people are present during the night and most of the people are away during the day.

For university buildings, an average of 35 students as a class was assumed. Average of 35 is assumed because different classes have different numbers of students and absent students. During the day when a class is to be held in a certain class, a ratio of 1 is used to show the presence of all students. And in-between classes a small ratio shows some students remaining in the class.

4.6.3 Lighting Schedule

Lighting is another load that also increases the total energy requirement. Since all the rooms do not require lighting throughout the day a schedule for lighting is also important.
For the residential building, lighting is assumed as 10.66 W/m^2. A fraction of total lighting is ON during the day. From 17:00 till 22:00 a fraction of .95 lights are ON and after that, till 05:00 it is 0.05. This schedule is followed throughout the year.

University building lighting is averaged as 7 W/m^2. A relatively small value is used for this schedule to compensate for large areas that do not require lighting as much. The fractional value of 0.3 is used during the day until 17:00 and 0.9 from 17:00 till 21:00. Weekends are compensated as 0.05 throughout both days.

4.7 Simulation

Chapter 3 entailed weather file generation for different cities in different time periods. This chapter detailed the production of models for selected building types. Both of these files are used as inputs needed in EnergyPlus to simulate building energy requirements. Multiple simulations were run changing weather files and models to account for all the cities and all the time periods. The simulation was run a total of 24 times.

CHAPTER 5: RESULTS

In this section, all the results from morphing and simulation are placed. A number of different ways results are compiled. Annual cooling and heating load are shown in graphical form. Total energy breakdown and energy per meter square is calculated.

5.1 Morphing Results

Morphing produced weather variables in an hourly manner. It was repeated for three times to get results for different time periods. Tables below represent the average annual values of different variables that are used for energy calculation for the later part of the research. It can be observed that the temperature for all the cities has a rising trend. Relative humidity another big aspect related to the climate has varying average annual values.

Table 5: Morphing Result of Lahore

Weather Variables	Present	2020	2050	2080
Dry Bulb Temperature (◦C)	27.43	28.62	29.84	31.81
Dew Point Temperature (◦C)	15.93	17.22	18.56	19.90
Relative Humidity (%)	54.51	56.33	57.25	57.46
Atmospheric Station Pressure (Pa)	100357.60	100364.89	100315.41	100242.35
Horizontal Infrared Radiation Intensity	407.50	416.02	425.85	439.36
Global Horizontal Irradiance (W/m2)	205.80	201.09	197.97	195.80
Direct Normal Irradiance (W/m2)	200.44	170.26	164.05	161.22
Diffuse Horizontal Irradiance (W/m2)	78.21	91.43	92.40	92.33
Wind Speed (m/s)	1.75	1.71	1.70	1.67
Total Sky Cover (%)	3.32	3.38	3.46	3.58

Table 6: Morphing Result of Islamabad

Weather Variables	**Present**	**2020**	**2050**	**2080**
Dry Bulb Temperature (◦C)	21.74	23.04	24.39	26.53
Dew Point Temperature (◦C)	13.44	14.56	15.60	16.78
Relative Humidity (%)	63.48	63.31	62.77	61.04
Atmospheric Station Pressure (Pa)	95410.58	95391.08	95330.77	95231.26
Horizontal Infrared Radiation Intensity	378.11	400.02	408.62	421.45
Global Horizontal Irradiance (W/m2)	220.49	216.80	214.39	214.15
Direct Normal Irradiance (W/m2)	215.50	201.10	193.98	193.44
Diffuse Horizontal Irradiance (W/m2)	80.19	83.85	85.84	85.91
Wind Speed (m/s)	2.38	2.34	2.33	2.29
Total Sky Cover (%)	5.19	5.19	5.27	5.20

Table 7: Morphing Result of Karachi

Weather Variables	**Present**	**2020**	**2050**	**2080**
Dry Bulb Temperature (◦C)	26.23	27.11	28.04	29.53
Dew Point Temperature (◦C)	16.53	17.73	18.76	20.31
Relative Humidity (%)	59.68	60.85	61.36	62.09
Atmospheric Station Pressure (Pa)	100559.05	100547.84	100507.08	100453.01
Horizontal Infrared Radiation Intensity	391.99	410.66	418.25	430.61
Global Horizontal Irradiance (W/m2)	208.47	201.37	196.98	194.59
Direct Normal Irradiance (W/m2)	150.79	136.40	128.72	124.81
Diffuse Horizontal Irradiance (W/m2)	104.25	107.21	108.36	108.67
Wind Speed (m/s)	3.27	3.25	3.27	3.34
Total Sky Cover (%)	3.24	3.27	3.36	3.53

5.2 HDD and CDD

A heating degree day is a quantitative measure of heat energy that is required for heating a building at a certain set point and cooling degree day is the amount required to cool at a set point. HDD is calculated by averaging days high and low temperature and then subtracting this average from a heating set point. If the average is above the set point it means heating isn't required. This will count as 0 °C-day for the day. But if it is below the heating set point it will be the resultant value of the above subtraction. HDD for a month is calculated by the summation of daily °C-days of that month.

- HDD Base Temperature 18°C
- CDD Base Temperature 26°C

$$Temp_{avg} = \frac{Temp_{high} + Temp_{low}}{2} \tag{5}$$

$$HDD = Temp_{base} - Temp_{avg} \tag{6}$$

$$CDD = Temp_{avg} - Temp_{base} \tag{7}$$

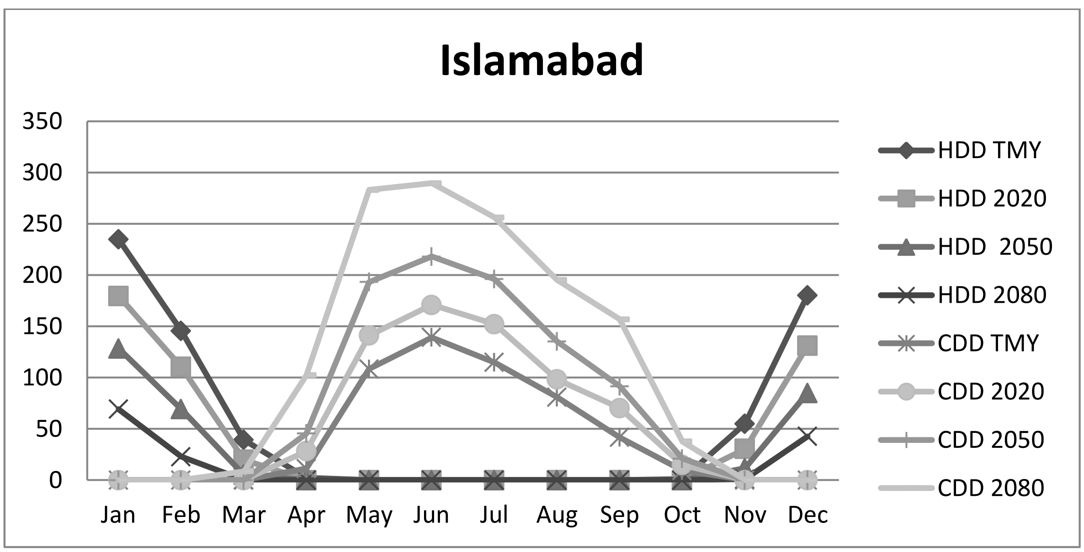

Figure 10: CDD and HDD of Islamabad for current and future times

It can be observed from the graph that CDD for TMY year starts from April and require cooling until October whereas for 2080 cooling needs to start in March until October. The largest increase is in May which is 174.48°C-days from TMY. HDD has a pattern of decrease from

TNY to 2080. The largest difference can be seen in January. Current heating is required from October until April whereas 2080 has a very small amount for November and a small amount for March. In general, current heating is required for 7 months whereas 2080 requires it for 5 months.

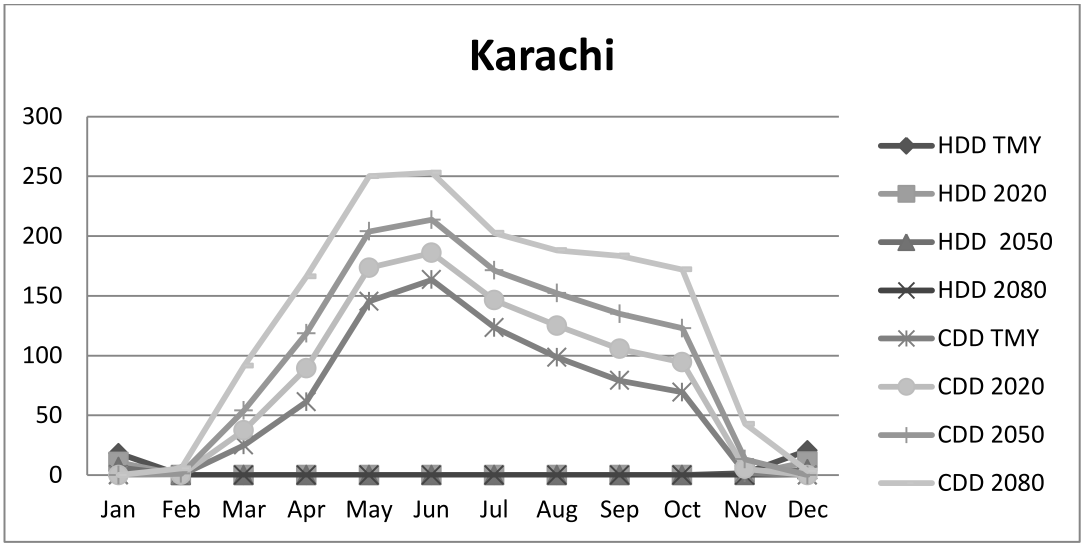

Figure 11: CDD and HDD of Karachi for current and future climates

Karachi shows a similar pattern as Islamabad. HDD has a pattern of decrease in the future. At present in Karachi buildings require a small amount of heating for November, December and January but 2080 line shows that heating will be required only in January. CDD for Karachi shows an increase in cooling energy but its difference from current TMY is smaller than CDD of Islamabad. Cooling will be required the whole year round except for January.

5.3 Heating and Cooling Loads

University Building

Lahore

It can be observed from the graphs that Lahore model does not require heating at the current TMY the same trend continues for all three future time periods. It is to be noted that there is no heating requirement at all. The reason for that could be that this building is only functioning during days and around 8 off days every month.

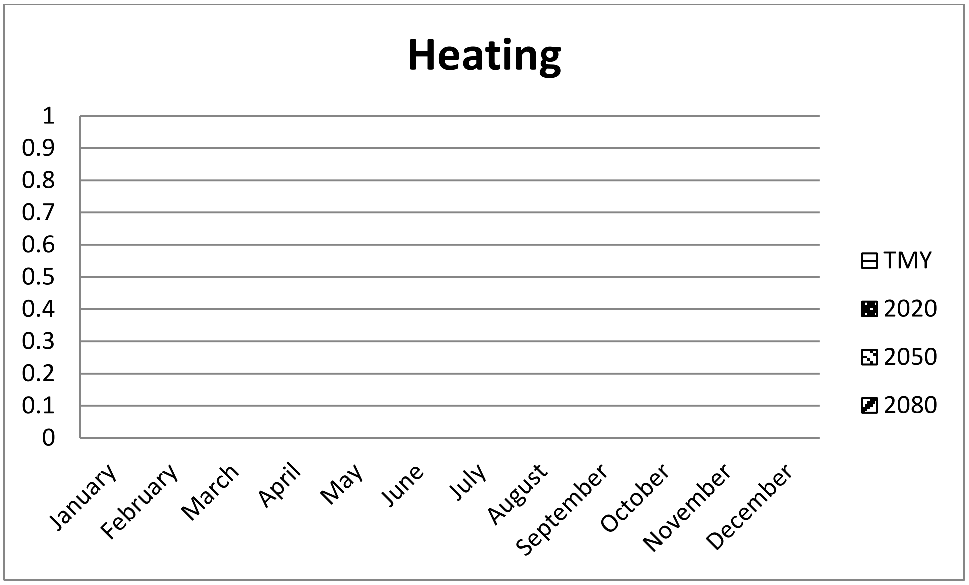

Figure 12: Heating load for Lahore University Model

The cooling load has an increasing trend for most months but for April and May, it shows a different trend. It shows an increase for 2020 but then starts to decrease for 2050 and 2080. It is to be noted that it shows cooling energy for January and December. During day temperature may rise inside the building above the set point so simulation calculated it as a cooling load.

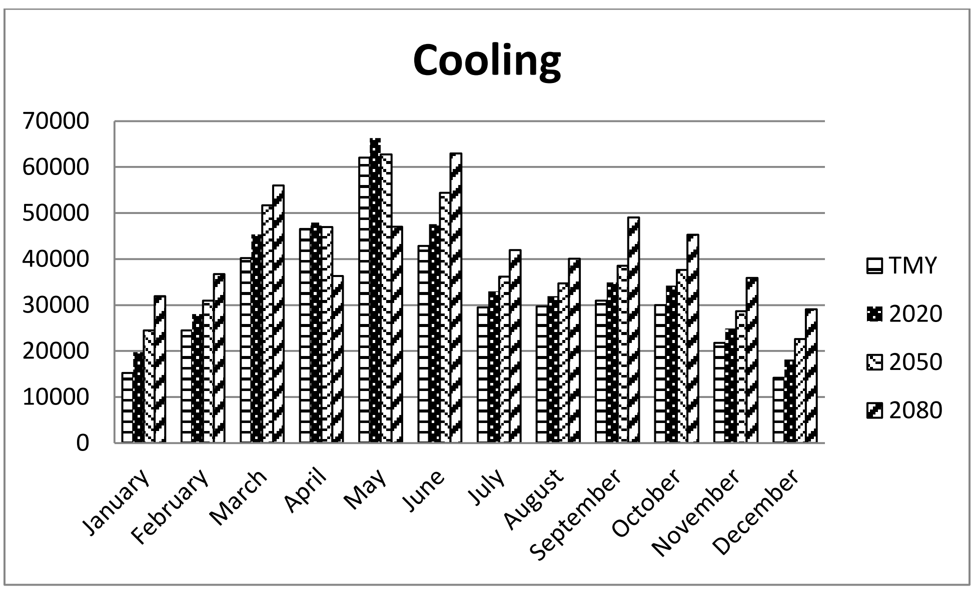

Figure 13: Cooling load for Lahore University Model

Islamabad

For our model, it is observed that for input time period heating is required from October through April. Whereas 2080 only shows a small amount of possible heating energy for

December, January and February. It has a maximum decrease of 7189.67 for January between current TMY and 2080.

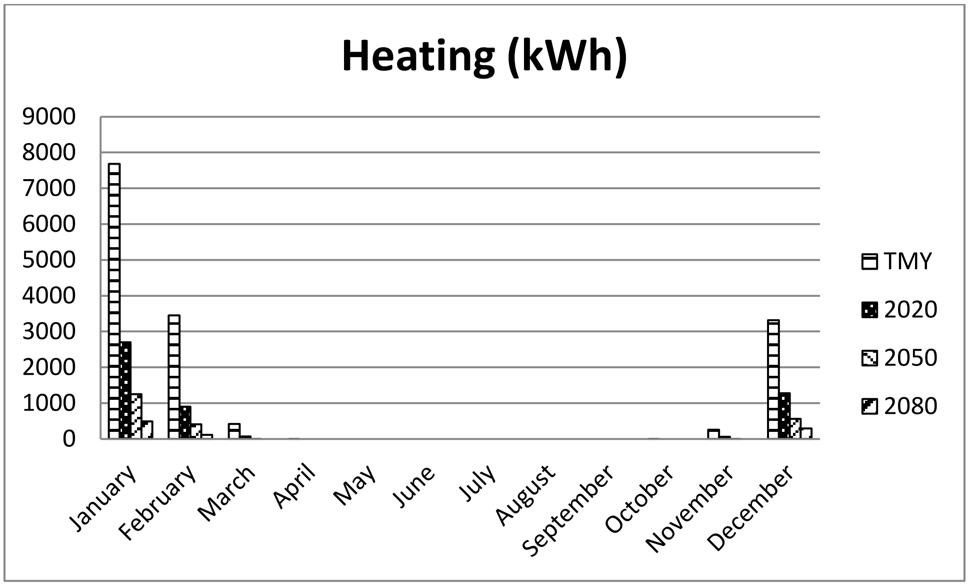

Figure 14: Heating load for Islamabad University Model

Cooling Energy has an increasing trend for SMME building. One of the significant differences can be seen for the month of July. It is observed that after the 2020 time period July will become the hottest month and will require the most cooling. A similar exponential increasing trend can be observed for August and September as well. December and January have insignificant changes.

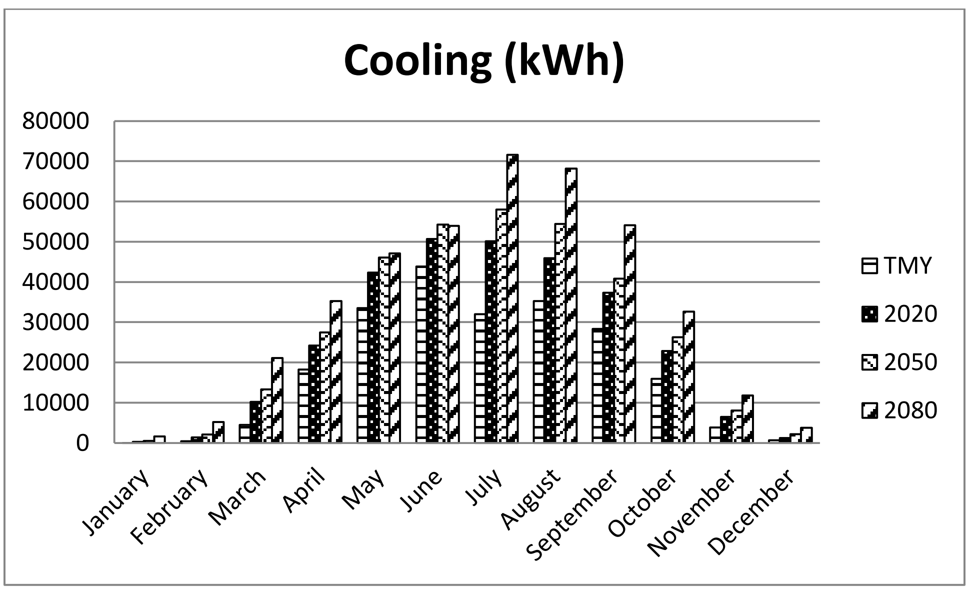

Figure 15: Cooling load for Islamabad University Model

Karachi

Figure represents the heating energy requirement at present to be 172.12 kWh for January and 85.07 kWh for December. But for 2080 there is only a small amount of 2.38 kWh of electricity during January is predicted annually.

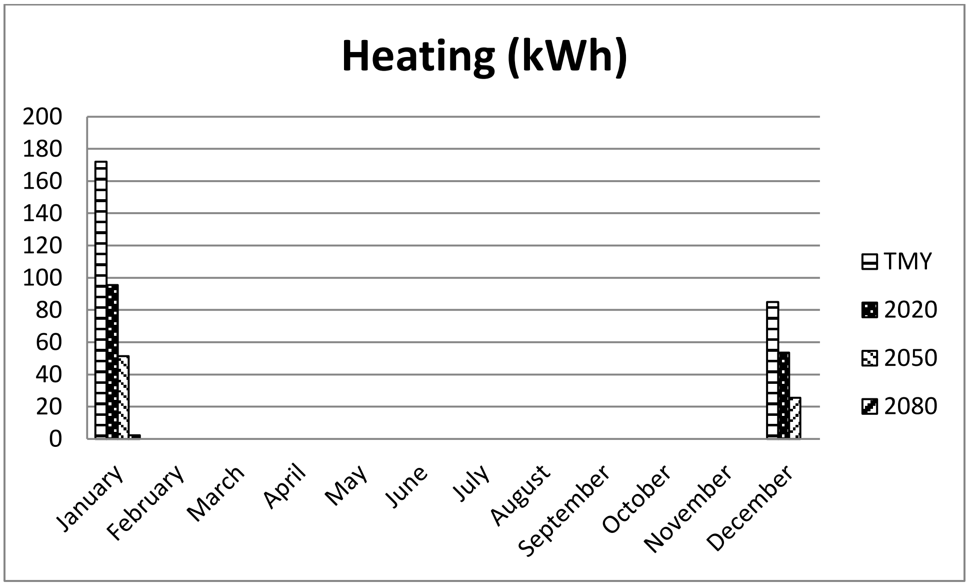

Figure 16: Heating load for Karachi University Model

Cooling like before again has an increasing trend. It can be seen that for July monthly cooling energy will increase from 53 MWh to 80 MWh. Months that are relatively less hot will also require more cooling.

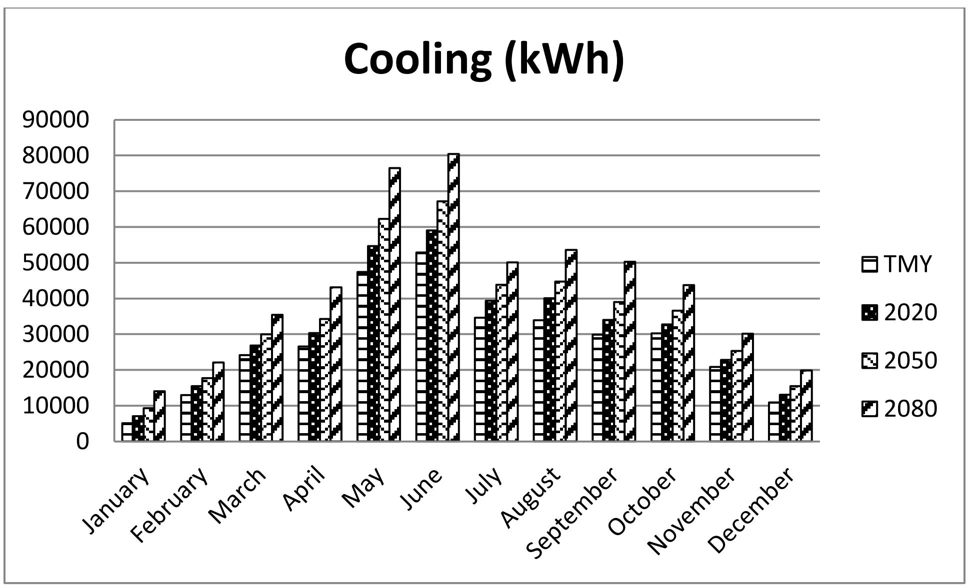

Figure 17: Cooling load for Karachi University Model

Residential

Lahore

Residential building in Lahore shows heating needs in November through February for the present weather. Heating energy decreases with passing time. With every 30 years, months that require heating decreases by one 2020 require heating for 3 months, 2050 for 2 months and 2080 only in December a mere 0.39 kWh. University building does not show any heating could be based on timing since university buildings operated only on weekdays and during day hours.

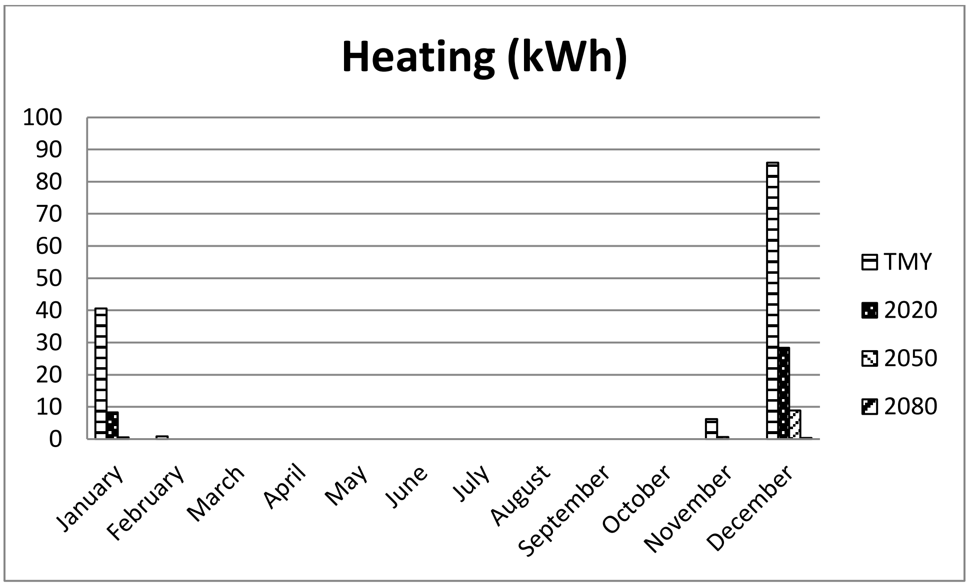

Figure 18: Heating load for Lahore Residential Model

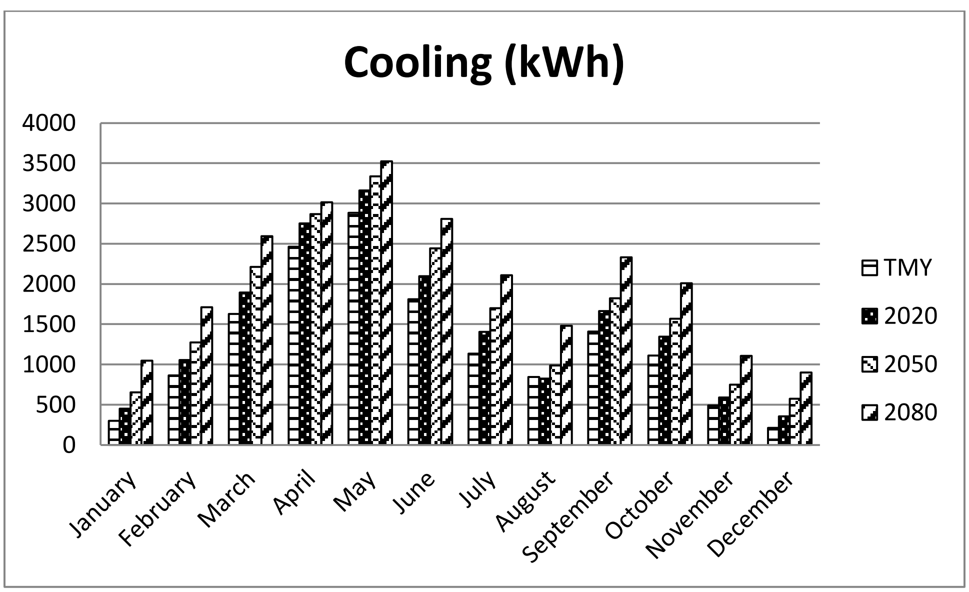

Figure 19: Cooling load for Lahore Residential Model

Based on cooling set point cooling is required throughout the year. Some months can be seen to have a small variation in cooling requirement and some have a large variation.

Islamabad

Heating requirements of Islamabad residential building is also observed to be decreasing like others. Current heating requirements are seen to be at varying levels for 10 months. Bear in mind May, June and September are relatively hotter months but simulation is based on the set points. If the temperature falls below the heating set point HVAC system will turn on automatically even though in manual systems people might not turn on the air conditioning.

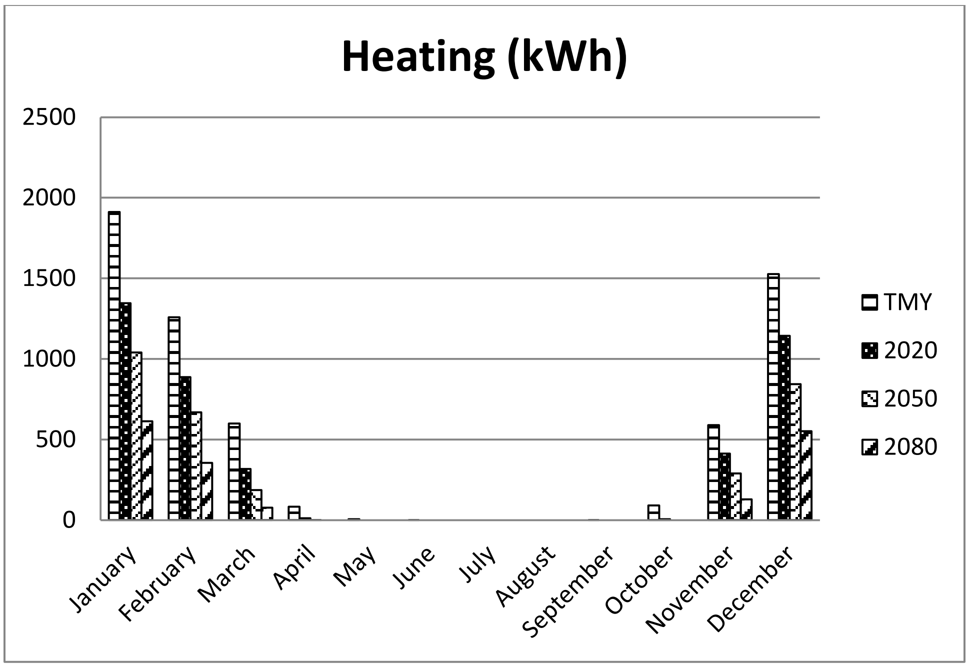

Figure 20: Heating load for Islamabad Residential Model

The cooling trend is seen to be increasing and requiring cooling in months that do not require cooling at present. At present June and July have a difference of over 1 MWh that changes to 12 kWh for the 2080 time period.

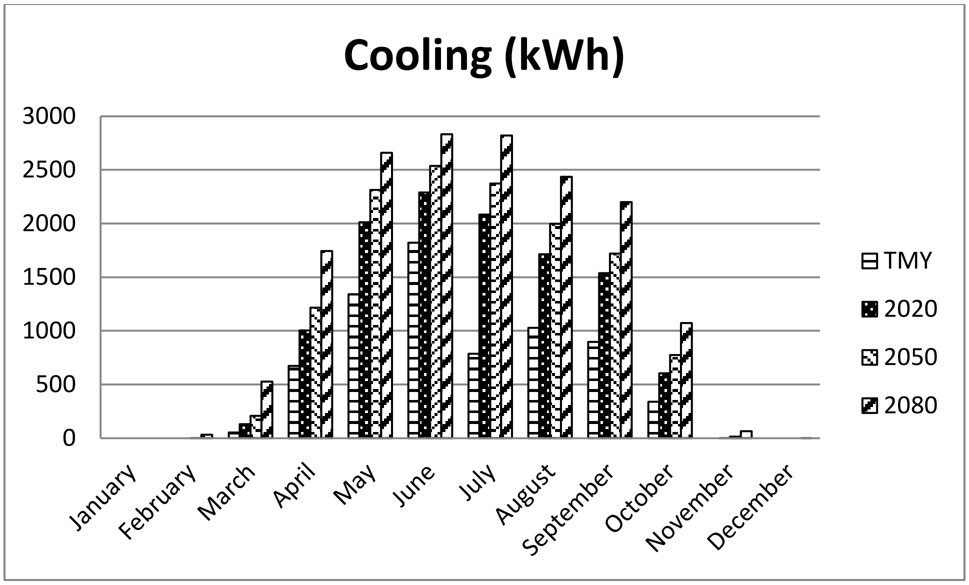

Figure 21: Cooling load for Islamabad Residential Model

Karachi

Similar to others it has a decreasing trend of heating energy load. Karachi's heating needs change from 434 kWh in January to 92 kWh. Karachi being coastal area has colder nights even on warmer days. This heating can be assumed to be the requirement at nights during winter months.

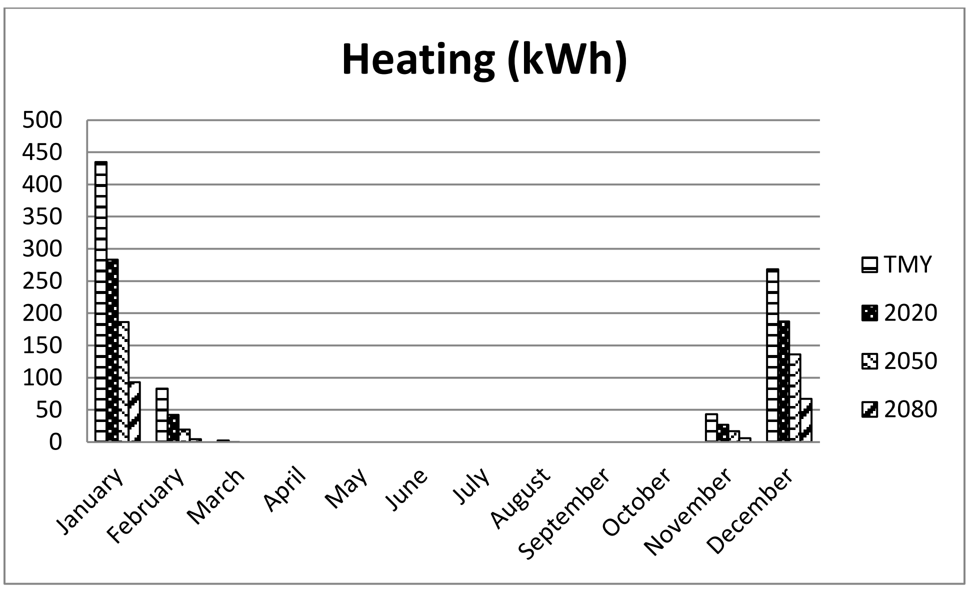

Figure 22: Heating load for Karachi Residential Model

May is the hottest month in Karachi which can be observed from the figure below. It remains the hottest month for all time periods. Again more cooling energy will be required to maintain the set point temperature. Unlike other results, Karachi's residential buildings have an almost similar ratio of increase throughout the year.

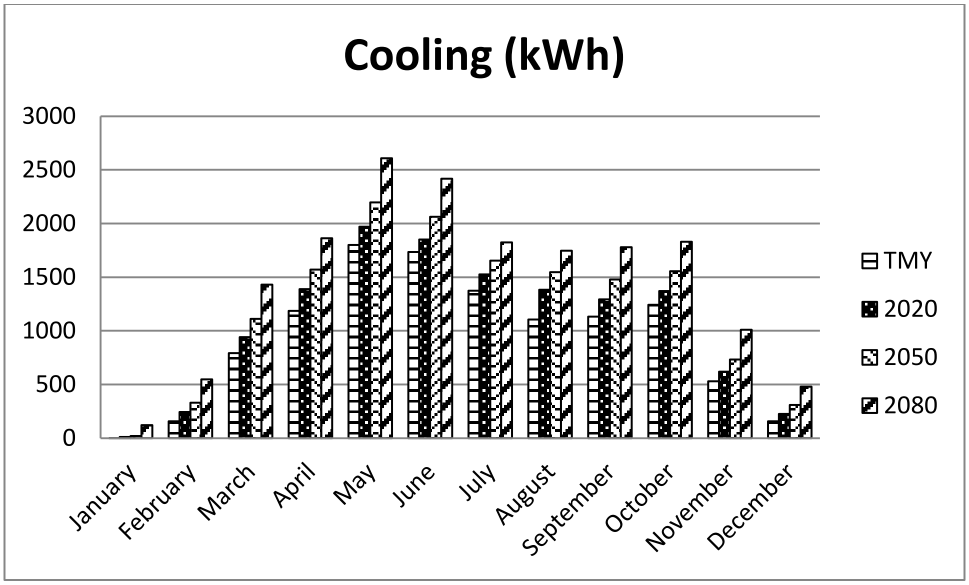

Figure 23: Cooling load for Karachi Residential Model

5.4 Breakdown of annual load

Figures below give us a total breakdown of utilities that are used in the model. All these figures represent the total energy used by all the features as 100%. The total energy that these different features use is presented in percentage for all 4 periods.

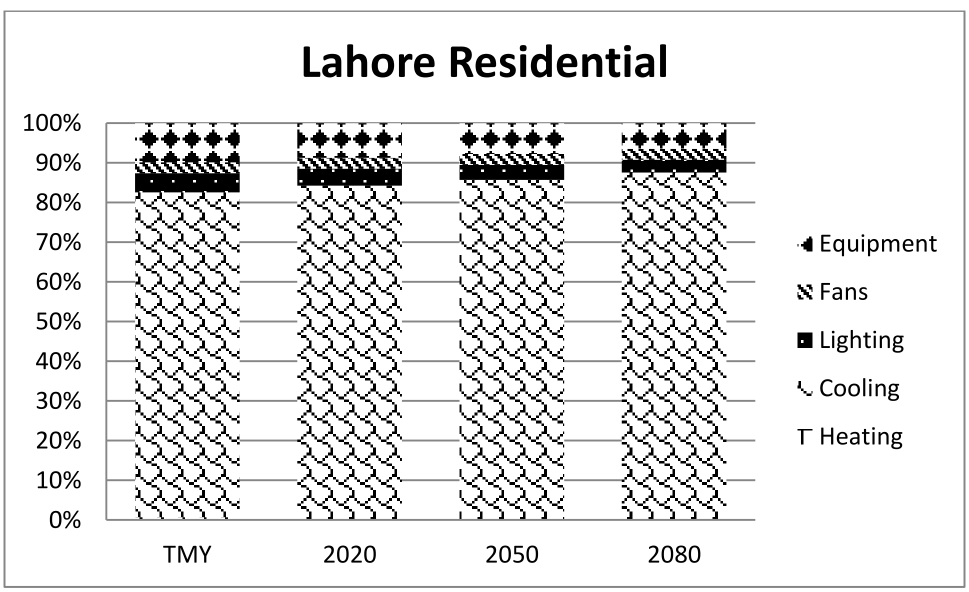

Figure 24: Energy Breakdown for Lahore Residential Model

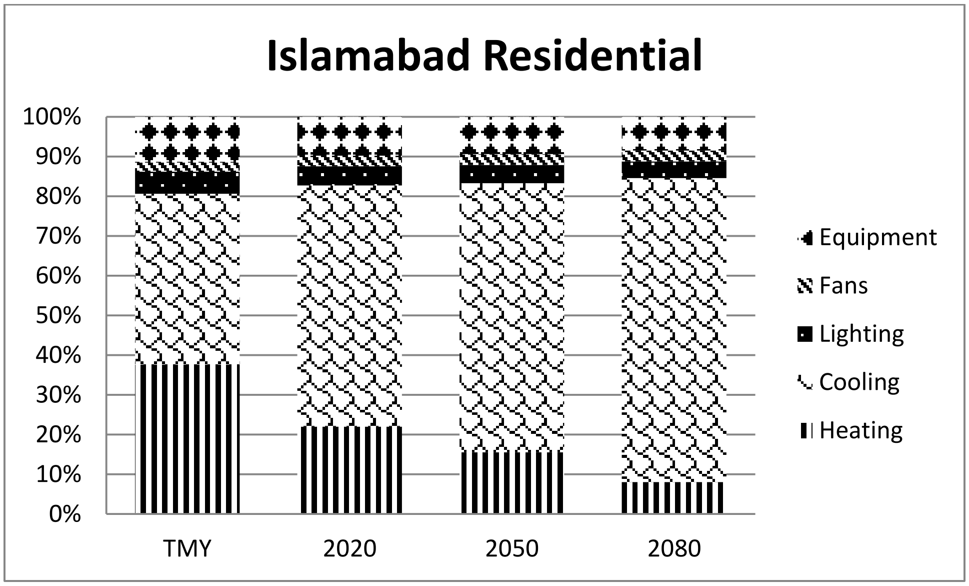

Figure 25: Energy Breakdown for Islamabad Residential Model

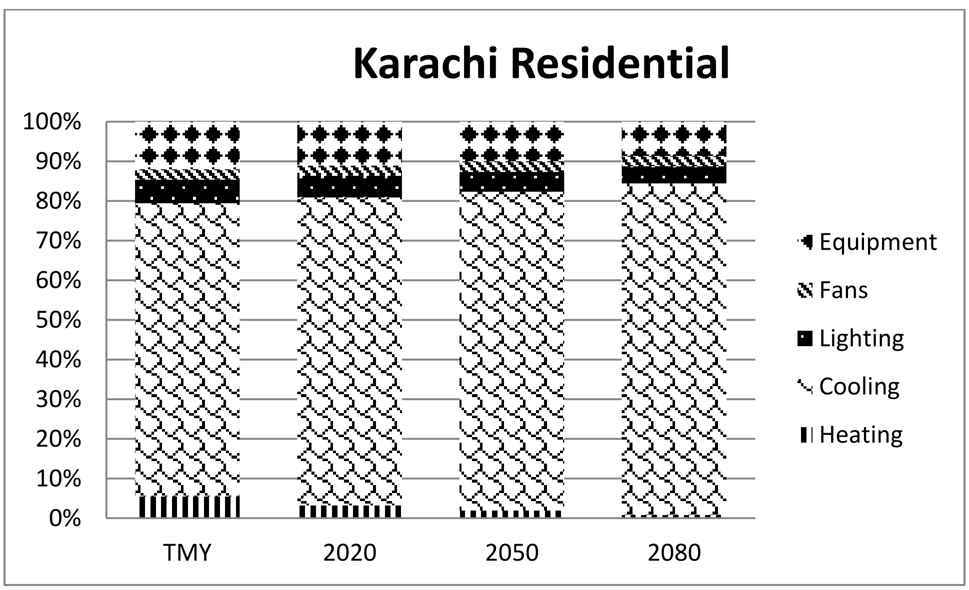

Figure 26: Energy Breakdown for Karachi Residential Model

Table 8: Annual energy Breakdown

	Residential					**Office**			
Lahore	**TMY**	**2020**	**2050**	**2080**		**TMY**	**2020**	**2050**	**2080**
Heating	0.72%	0.18%	0.04%	0%		0%	0%	0%	0%
Cooling	81.82%	84.04%	85.64%	87.56%		60.17%	62.68%	64.57%	66.49%
Lighting	4.88%	4.32%	3.84%	3.21%		17.56%	16.40%	15.54%	14.67%
Fans	2.74%	2.76%	2.75%	2.75%		1.78%	1.78%	1.75%	1.72%
Equipment	9.84%	8.70%	7.73%	6.48%		20.49%	19.14%	18.13%	17.12%
Islamabad	**TMY**	**2020**	**2050**	**2080**		**TMY**	**2020**	**2050**	**2080**
Heating	37.61%	22.00%	15.58%	8.04%		3.13%	0.90%	0.38%	0.13%
Cooling	43.01%	60.76%	67.67%	76.50%		44.84%	53.16%	56.54%	61.30%
Lighting	5.61%	4.83%	4.66%	4.23%		23.35%	20.48%	19.14%	17.03%
Fans	2.46%	2.66%	2.70%	2.71%		1.43%	1.56%	1.61%	1.66%
Equipment	11.32%	9.75%	9.39%	8.52%		27.25%	23.89%	22.33%	19.87%
Karachi	**TMY**	**2020**	**2050**	**2080**		**TMY**	**2020**	**2050**	**2080**
Heating	5.48%	3.26%	1.98%	0.81%		0.04%	0.02%	0.01%	0.00%
Cooling	73.92%	77.60%	80.35%	83.64%		56.40%	59.54%	62.49%	66.91%
Lighting	5.97%	5.48%	4.99%	4.29%		19.37%	17.94%	16.60%	14.58%
Fans	2.60%	2.61%	2.62%	2.62%		1.59%	1.56%	1.54%	1.51%
Equipment	12.03%	11.05%	10.06%	8.64%		22.60%	20.93%	19.36%	17%

5.5 Annual Load (kWh/m²)

Another aspect of energy consumption can be quantified as energy per unit area. Per unit area, energy consumption can be calculated as kWh/m². A percent change is calculated for different cities. All the changes are changes from the TMY value. Tables below represent the change that will possibly occur in total annual energy per square meters.

Table 9: Annual Energy per meter square and Percent Change for Residential Model

	TMY	**2020**	**% Change**	**2050**	**% Change**	**2080**	**% Change**
Lahore	89.10	100.74	13.06	113.39	27.26	135.30	51.85
Islamabad	77.49	89.98	16.12	93.40	20.53	102.92	32.82
Karachi	72.88	79.39	8.93	87.14	19.57	101.45	39.20

Table 10: Annual Energy per meter square and Percent Change for SMME Model

	TMY	**2020**	**% Change**	**2050**	**% Change**	**2080**	**% Change**
Lahore	97.11	103.97	7.06	109.71	12.97	116.24	19.70
Islamabad	73.02	83.27	14.04	89.09	22.01	100.11	37.10
Karachi	88.04	95.06	7.97	102.76	16.72	117.00	32.89

CONCLUSION AND FUTURE RECOMMENDATIONS

This section concludes this study and gives a brief account of how this study can be expanded further for Pakistan.

6.1 Conclusion

Effect of climate change on future energy demand of buildings in Pakistan was studied in this work. Three cities of Pakistan were selected based on their climate difference according to Köppen-Geiger Climate Classification. For those cities, future climate variables were predicted through the downscaling of the Global Climate Model HadCM3. Downscaling was carried out by a method known as Morphing. Changing patterns of temperature along with other weather variables like dry bulb temperature, relative humidity, direct and diffused irradiance, sky cover and wind speed were studied.

Through modeling program, the geometry of 2 buildings was modeled. Energy simulation software EnergyPlus was used to add the building's structural and constructional parameters. Various energy loads like cooling, heating, lighting and equipment were added to show the effects of climate change on these buildings and their energy needs. To study the effects of climate change on different buildings one building was designed as a residential building and other as a university block.

- Results from morphing were studies to have a varying pattern for different cities. Some weather variables were found to have a decreasing pattern others had an increasing pattern. Dry bulb temperature for all cities had an increasing temperature. The annual average dry bulb temperature for Lahore has a difference of 4.38°C; Islamabad has a difference of 4.8°C and Karachi 3.3°C from the current weather. Annual average relative humidity was observed to be having an increase of 2.95 and 2.41 for Lahore and Karachi respectively. Islamabad's annual average relative humidity had a decrease of 2.44% in 2080 as compared to the present weather value of 63.48. Atmospheric pressure trend is found to be increasing for 2020 and then dropped again for the next two time periods for Lahore.
- Building energy simulation results had a pattern of decrease in heating requirements and cooling had an exponential increase in summer months. Since the cities that were selected

are in relatively moderate climates heating is not a big factor. The amount of energy that is saved from heating is not nearly enough that cooling will require in the future. So the total energy need will increase in the future. A house located in Lahore will need 51.85% more electric energy in 2080 compared to the current time. As can be seen in the breakdown figure 87.56% of annual energy will be dedicated to cooling to provide a comfortable environment. As a whole, it was observed that the heating required for all the buildings in all the cities were decreasing. Cooling pattern, on the other hand, showed that instead of June being the hottest month in Islamabad July will require more energy in the future.

6.2 Future Recommendations

This study takes into account only one emission scenario as it is projected over several years. A different emission scenario will result in different weather in the future. For this study, A2 emission scenario was selected as it is the representation of current global emissions. For another study, another scenario like A1F1 can be used to predict the future. That result can then be compared with this one to determine the differences. Another study can be done to utilize the results of this research to better design a building with changes in energy as a major component. The model used in this can be modified with those passive measures to study the changes in energy use. Different features like natural ventilation, building orientation and other passive measures can be introduced to optimize the use of energy. A model can be simulated at different orientations to minimize the effect of solar radiation and help decide the best orientation according to future changes. Values calculated to represent vegetation at the roof can be studied with this model.

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