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GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

MASTER THESIS

IMPACT OF BUILDING SHAPE ON THERMAL PERFORMANCE OF OFFICE BUILDINGS IN KARACHI, PAKISTAN

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We certify that we have read this thesis and that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science / the Doctor of Philosophy.

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ABSTRACT

IMPACT OF BUILDING SHAPE ON THERMAL PERFORMANCE OF OFFICE BUILDINGS IN KARACHI, PAKISTAN

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March 2018

More than one-third need of the energy of developed countries is due to attaining suitable conditions of thermal comfort and lighting in buildings. Energy demand in buildings is determined by an arrangement of such parameters as climate, envelope typologies, and occupant behavior. Accordingly, energy has been a very active area of research in the domain of built environment for the last decades. Some statistical methods have been developed to estimate building energy demand. In line with the previous work, this study aims to evaluate the impact of building form on energy use intensity of office buildings in Karachi, Pakistan. To achieve, relative compactness metric which is derived by building form was calculated for various design alternatives. Along with relative compactness, such envelope parameters as window to wall ratio and glazing type were considered as independent variables. Next, required data to develop the statistical model is obtained by complete building energy simulations. Later, a predictive model is developed using regression modelling technique. Last but not least, sensitivity analysis was performed to assess the effect of an independent variable on the response. Results of the analysis revealed that the set of independent variables considered in the current study is able to explain significant portion of variance in the energy use intensity of office buildings in Karachi. Resulted simplified equation is appropriate for designers and architects during the initial design phase to estimate the impact of shape on the energy performance of office buildings in Karachi, Pakistan

Key Words: building shape, relative compactness, building energy performance, office buildings, simulations, multiply linear regression modelling, Karachi-Pakistan

ÖZ

BİNA ŞEKLİNİN OFİS BİNALARININ TERMAL PERFORMANSI ÜZERİNDEKİ ETKİSİ: KARACHI, PAKISTAN VAKASI

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Gelişmiş ülkelerin enerji ihtiyaçlarının üçte birinden fazlası binaların termal konfor ve aydınlatmalarından kaynaklanmaktadır. Binalarda ihtiyaç duyulan enerji ihtiyacını bir takım parametreler belirler. Bunlar iklim, cephe tipolojisi ve kullanıcı ihtiyaçlarıdır. Enerji konusu günümüzde çok aktif bir araştırma alanı olmuştur. Bina enerji taleplerinin saptanmasi için bazı istatistiksel yöntemler geliştirilmiştir. Ayrıca, bu yaklaşımların çoğu özelleştirilmiş yazılım araçlarında test edilmiş ve uygulanmıştır. Bununla birlikte bu çalışma, Karaçi'deki bir ofis binası için enerji verimliliği üzerine binanın etkisine yardımcı olmak için temel bir analiz yöntemi sunmaktadır. Yöntem bir binanın tamamen enerji simülasyonundan elde edilen sonuçlarla oluşturulmuştur. Analiz farklı bina şekillerini yani; L-şekli, T-şekli, U-şekli ve dikdörtgen şekli oluşturmanın yanı sıra bina bağıl kompaktlık, pencere-duvar orantıları ve cam çeşitleri de düşünülmüştür. Bu strateji, bina şeklinin veya cephesinin geliştirilmesiyle, enerji ihtiyacını azaltmanın yolunu göstermektedir. Bu basitleştirilmiş yöntem, tasarımın ilk aşamasında, ofis binasının enerji performansı üzerindeki etkisini değerlendirmek için tasarımcılar ve mimarlar için elverişlidir.

Anahtar Kelimeler: bina şekli, bağıl kompaktlık, bina enerji performansı, ofis binası, simülasyonlar, çoklu doğrusal regresyon modeli, Karachi-Pakistan

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KHAN, Shahrukh Hussain

İzmir, 2018

TEXT OF OATH

I declare and honestly confirm that my study, titled "IMPACT OF BUILDING SHAPE ON THERMAL PERFORMANCE OF OFFICE BUILDING IN KARACHI, PAKISTAN" presented as a Master of Science Thesis, has been written without applying to any assistance inconsistent with scientific ethics and traditions. I declare, to the best of my knowledge and belief, that all content and ideas drawn directly or indirectly from external sources are indicated in the text and listed in the list of references.

Khan, Shahrukh Hussain

Signature

……………………………..

April 6, 2018

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SYMBOLS AND ABBREVIATIONS

ABBREVIATIONS:

f'_c	Concrete Compressive Strength
psi.	pounds per square inch
mm.	millimeter
LPD	Lighting power density
EPD	Equipment power density
W	Watt
m.	Meter
K	Kilo
RC	Relative Compactness
WWR	Window to Wall Ratio
V	Volume
A	Area
EPW	EnergyPlus Weather Data
SHGC	Solar Heat Gain Coefficient
SVC	Single Clear Glazing
DBR	Double Brown Glazing
SBR	Single Brown Tint Glazing
CBD	Central Business District
P	Parameters
MLR	Multiple Linear Regression
E_t	Energy use intensity
E_{ref}	Energy use intensity of reference building

EUI	Energy Use Intensity
kWh	kilo Watt-hour
DV	Dependent Variables
IV	Independent Variables
S. No.	Serial Numbers
N	Number of Observation
Approx.	Approximately

SYMBOLS:

%	Percentage

CHAPTER 1
INTRODUCTION

1.1. BACKGROUND

In 2009, building energy consumption corresponds to 41% of total energy consumption, while transportation and industry accounted for 28% and 31% respectively (EIA, 2011). Energy is considered as an important factor of any economy and play a vital role on socio-economic progress of country. Energy mostly required in running machines in factories and industries, for lighting the cities *etc*.

In Pakistan, due to the population growth and industrial development the call of energy is increased broadly. Supply of energy is, therefore, very low as compare to original demand, resultantly crisis has begun. In the supply of energy resources to an economy, this energy crisis can be termed as bottleneck as rise in price.

Pakistan energy infrastructure is not well established, rather it is considered underdeveloped and unwell succeeded. Right now, the country is facing critical energy problem. Despite of strong economic growth and rising energy demand during past years, they have not taken any solid effort to install new capacity of generation. Furthermore, according to Khan (2013) Pakistan needs around 15,000 to 20,000 MW electricity per day. Presently it is able to produce about 11,500 MW per day hence there is a deficit of about 4,000 to 9,000 MW per day.

Generally, at present day, petroleum products, natural gas and coal are the leading resources in Pakistan for generation of energy. In which gas resources sharing production about 45% of energy. Although, Pakistan also relies on renewable resources as well like hydropower, wind, solar, tidal and agricultural biomass/biodiesel.

As in Pakistan, energy crisis was very high till 2010. After that, major private sectors start using photovoltaics systems privately. Which become major change of constructing high-rise office buildings. Especially in the city Karachi as it is major cosmopolitan city of Pakistan and central business district (CBD) of the country. That is the reason to bring this thesis research regarding the effect of building shape on energy performance for the office building in hot-dry climate of Karachi.

1.2. STATEMENT OF THE PROBLEM

According to the previous study by Parasonis and Keizikas (2010), buildings of similar areas but different external envelope has different demand of energy. It tracks that the efforts meant at constructive the most appropriate geometry of building and their effect on the energy demand of a building, as well as options to use them for sustaining this demand within practical limits. Further to this, Roberts Riekstiņš (2011) measured different shape and typology of building like residential, public and high-rise in different region and studied the effect of shape through sun, wind, precipitation and natural lighting. Studying on building energy and architectural form relationships Roberts Riekstiņš (2011) concluded that it is the best way to utilize extensive amount of energy by nature through making building shape or form reasonably practical.

In continuation of above studied, Ramzi and Moncef (2012), after analyzing different type of building geometry, glazing type, window area and climate detailed, they provided a method to calculate the shape for an office building. After the result of analyzed building shape, glazing area and type impact, they established analysis method which can indicate strong correlation between shape and its energy consumption. Further, studying the effect of the building compactness on the energy gain, Depecker *et. al.* (2008) evaluate the two-basic case for analysis effect of the building shape to understand solar gain and energy performance by mention building compactness. And finally comes up with the result that energy intake is inversely proportional to the compactness. By this statement, building compactness, defined as a function of building shape, also play important part to evolve the final building shape with area.

The architectural design community has realized that future buildings must incorporate sustainable design practices to reduce impact to the environment, while maintaining the occupant’s wellness and productivity. Reducing building energy use is the main emphasis in this process. *The current work investigates the role of building shape on building energy demand, with a special emphasis on Pakistan.* It is mention that the applications marked at defining the correct geometry of building and their effect on the demand for energy resources of a building, as well as potentials to use them for sustaining this demand within sensible limits.

1.3. RESEARCH FRAMEWORK: OBJECTIVES

Computational design approach is expected and important for this research in order to overcome with complexity of office building with regard of suitable energy performance. From this perspective steps, which are “building shape generation” and “performance evaluation” are described in further detail here below:

Building Shape Generation step of the model has been developed to be capable of generating different plan shape for office buildings. In this way, the most suitable design solution are searched among several alternatives.

Relative Compactness: The relative compactness is used to know shape of building to help the proportionate study when determining the effect of shape on the building energy performance. It shows the geometric dimension of the building floor plans.

Performance evaluation consists performance criteria which have been applied in the computational design model of this study. These are as follows:

- Building Shape: Building form and shape are significant while considering heat loss or gain in buildings. They play an important role in the thermal process-taking place within the buildings well as with the building and its environments. To calculate energy, developing several different shapes for office building to get best suitable shape.
- Energy Performance: The main important factor to maintain comfort level condition in buildings are mainly depend on usage of heating, cooling, its equipment’s and lighting load which is considered as energy performance of building. Mostly, building external envelope play focus factor impacting on energy consumption. This include both interior and exterior aspect of building such as, walls, doors, windows and roof etc. these all component must work together to keep building effective in all seasons through the year.

The consumed energy of any building varies on the envelope design of that building which also include building`s operation system. By designing like gaining maximum daylight inside the building can marginally reduce the load of energy use, which mostly taken by heating and cooling system of building.

1.4. RESEARCH AIM AND QUESTIONS

According to the statements as discussed above, the *primary aim* of this research is to develop a predictive model for office buildings with different plan solutions to calculate their energy performances. By doing this, it is expected that this simplified model will be useful to support design decision process to achieve suitable building alternatives at initial pre-design phase.

Concerning to the main aim, which is stated above, the research questions to be addressed in this thesis are follows:

- How the shape of the building effects energy performance for the building with different arrangement of plans solution?
- How can we determine the most effective plan solution for office building at the pre-design stage by solving problem of energy demand?
- How to maintain the maximum energy performance and the lowest consumption of the buildings and determine the limits of the potential?

1.5. RESEARCH METHODOLOGY AND DESIGN

The research adopts a quantitative approach for evaluating energy performance for the office building at the initial conceptual design phase. This strategy required to understand causes and effects of each different plan solutions for the building. It proposes a computational framework for the brief study of calculations including building`s relative compactness (*RC*), window-to-wall ratio (*WWR*) and Glazing Type effects on building final energy consumption. The focus is on: (1) developing multi-performance based computational design model for office building by using Sefaira Architecture online plug-in for SketchUp program; and (2) using statistical methods to establish the predictive model for energy use intensity by the help of dataset obtained in the step (1). The first (1) step consists three modules:

- <u>Design Requirements for Office Building</u>: This module is occurred by basic design requirements of office buildings and design approach. Design requirements of office building have been researched according to develop the reproductive and evaluation step of the model. The data that has found in this, applied to generative principle and performance criteria steps in the model of singular high-rise office building.

- <u>Developing performance based computational model</u>: In this module that include the computational design model, generate different shape of buildings, window to wall ration, daylight factor analysis and heating/cooling as energy will express in detail.
- <u>Results of model</u>: In this last phase that include the result of all factor which is mentioned in above section. There are several different alternative results and figure which will widely discuss and compare with the best solution goal of this research to be achieve.

In the second part of the research (2), using the data set obtained from the step (1), a general multi linear regression model has been assumed among independent and dependent variables. Accordingly, the parameters (coefficients) of this assumed model were estimated using ordinary least square method. Next, residual analysis has been performed to control model assumptions. Lastly, to observe the effect of an independent variable, considered in the current work, on the dependent variable, sensitivity analysis has been performed. This process finalized execution of the research.

1.6. OUTCOMES AND CONTRIBUTION

With extensive simulation cases, a better understanding of the effect of building shape on energy use intensity for office buildings in Karachi, Pakistan was the expected outcome. Building design practitioners and building owners as well as electric utility companies who are the expected audiences of this study can select the best strategies that fit their objectives and budgets.

1.7. OUTLINE OF THE THESIS

The thesis is composed of five chapters. After the Chapter 1 introduction, Chapter 2 appraisals the literature review for the study. First, the studies of energy with different aspect of the building has been confer extensively. Then, the implications of computational design in architecture are examined, particularly, office building and integrated design approach, which thoroughly focuses on design requirement of an office building, including office building basic planning and design considerations. In Chapter 3, the methodology of the thesis is described in detail. The chapter validates the computational approach for decision-making of parameters and performance assessment for the energy for the building. The processes of parameter initialization, data base generation, model development, and test of sensitivity analysis are revealed in this section. The results that are obtained through the processes of chapter 3 are demonstrated in Chapter 4. Finally, in Chapter 5, a summary of the complete research process and analyses are illustrated briefly for the future result.

CHAPTER 2
LITERATURE REVIEW

This chapter seeks to review various literature on building form and building energy to relate the research with the current state of knowledge. Accordingly, a general introduction on energy conservation was presented. Following, the topic is narrowed to energy efficiency in building design. Later, to support for the research question, aim and problem statements, the state of the art in building envelope's relation with building energy demand was reviewed. This also formed the foundation for the subsequent research design to be employed in the current work. Last, a specific investigation to office developments was conducted. The aim in the last section was to outline energy efficient design considerations inherit in office developments.

2.1. ENERGY CONSERVATION

The term conserves energy is old as the use of energy. According to human history, use of energy was depended on the amount of work that could be done by the human being as the individual or sometimes in groups. Later, human used animal and teams of animal for their work like carrying heavy materials for lifting and hauling. Then as intelligence evolved, human tried to find more comfortable or easiest way to get work done. For example, the most famous and useful invention is the wheel, which started as the advance in energy conservation at that time. Before muscle, fire is the source of energy, that controlled by human (Wulfinghoff, D. R., 2000). Global energy demand is predicted to continue its growth trajectory onwards to 2035 according to the International Energy Agency (IEA) in their World Energy Outlook report for 2013.

Through the review of building energy consumption information, Pérez-Lombard et al. (2008) observed that global primary energy consumption grew by 49% between 1994 and 2004, attributing this to the rapid growth of developing economies and their resulting improved living conditions. They concluded that current energy and socio-economic systems are unsustainable. Continue to this; they also suggested that it would be business as usual despite an increased emphasis on energy efficiency minimum requirements, unless regulation steps into both raise social awareness of sustainability issues, and to enable new technologies for energy production and energy conservation to enter the market.

In a review of the current status and future potential of the building sector, Clarke et al. (2008) highlighted the fact that many buildings have very poor energy performance due to being constructed before building energy standards were developed. This, combined with increases in electrical energy use, leads to the potential for significant improvements in the efficiency of current building stock. The need for upskilling in the industry to cope with new building technologies is identified by the authors.

Parasonis, Andrius & Kalibatiene (2012) studied the effect of architectural volumetric design solution on the conservation of energy and material resources for a building. The compactness and geometric efficiency of a building as well as the criteria for their evaluation are considered while performing the comparative analysis of building shapes. The objective was to determine the potential of reducing the energy losses of buildings without improving thermal properties of external envelope. The study carried out under the international project 'LONG LIFE' under the Baltic Sea. The project objective is to design an energy-efficient residential building based on the technologies, legal and administrative procedures, cultural and demographic needs.

After a later (2013) Granadeiro, Duarte, Correia, & Leal added further as their proposal presented a methodology to assist design decisions regarding the building envelope shape considering its implication by its energy conservation. The methodology involves a flexible design system to generate alternative envelope shape design, with integrated energy simulation to calculate the energy demand of each design. They used shape grammar for architectural design system as encoding to compositional design principles. Later these framer turns parametric design and illustrates with the grammar for Frank Lloyd Wright`s project prairie houses.

2.2. ENERGY EFFECIENCY IN BUILDINGS

Due to increased growing demand for energy in terms of heating and cooling loads of buildings from recent years, people are more concerned about this. Therefore, without energy, it is impossible for buildings to be operated or occupied. So detailed study has been made on the effective use of insulation, lighting and controls and these all valuable features can help achieving energy efficiency level in buildings. At this stage, it is good to know the term “energy efficiency”.

Generally, energy efficiency can be termed as, by using less energy for heating, cooling and lighting equipment’s to get enough suitable comfort level inside the building. An important factor impacting on energy efficiency is the external building envelope. This envelope includes all building components like walls, windows, doors, roof and foundation. Because these all elements considered responsible for providing warm atmosphere in winter and cold in summer.

The design of building external skin and its system of operation is correlated to the amount of energy consumed. Simulations were performed by Ren et al. (2011) on existing and new commercial buildings in eight varying zones throughout and identified potential adaptation pathways to mitigate the effects of energy change and maintain current cooling/heating energy requirements. It was concluded that a good level of adaptive capacity was possible through energy efficiency measures for heating-dominated buildings. For cooling dominated buildings, additional measures are needed such as renewable energy to offset the energy required by the larger cooling load.

In a study, Griffith et al. (2007) found that energy efficiency improvements in commercial buildings can on average reduce consumption. This agrees with the previous trend in the literature that buildings with the greatest potential for energy conservation and efficiency improvements are the most likely to achieve status.

One of the major factors in a building not achieving optimal status is that the required roof area for an adequately sized passive system was too small. Through energy consumption reduction, the required passive capacity becomes smaller, reducing the required area. By designing of manageable mechanism like programmable thermostats and building energy management system can considerably reduce the energy load. Making of zone heating and cooling system can also minimize the heating and cooling in the vacant spaces.

Masoso and Grobler (2009) stated the phenomena to “increase cooling load insulation”. The investigation concludes “thermal inflexion” because fixed cooling temperature and internal loads. EnergyPlus plugin has been used under hot climate region for analysis. In the results, solar diffusion and internal heat gain are resultant as measurement data.

Further to save energy, Becker and Goldberger (2008) studied thermal comfort indoor quality for energy efficiency in buildings. National Research Program conducted this study to established Building Energy Code for all types. Due to high internal gain thermal comfort in the summer period typical office building has been considered an evaluation purpose. Several different components have been under simulate like indoor climate control, occupancy period, the location of the building, lighting control etc. results show that if the application of ventilation is fine design than the building itself lead to saving about 18% to 30% of entire building energy.

According to Baird et al. (2001) in office buildings, it can be the best solution for energy efficient heating by making space and water heating system as a combined method. For example, utilizing shielding water pipes to cut heat loss and water heater can be convenient to reduce energy to heat water. Each building must have to go through by energy audit to ensure that how energy efficient building is or also to aware of improvement if required. An examination should be done under the effective and efficient working of heating, cooling, equipment's and lighting all work together. Carbon Dioxide (CO_2) emission is also by the buildings. However, this emission has fewer consideration as related to other factors such as conveyance and manufacturing sector. Building renewable energy would be an improvement for the building sector as it can reduce the carbon dioxide emanation for energy conservation perspective. And along with other benefits it also could be used for heating, cooling, ventilation and lighting.

Generally, energy performance of the building can be categorized in several different steps. Energy simulation tools are used to measure energy performance, demand and need for a building by all means and calculate actual requirements. This calculation can also be done by the computational method and statistical studies established on the properties of external wall or envelope by considering window-to-wall ratio, glazing type and by include orientation. Mungwititikul and Mohanty (1996) stated that about 25% of energy could be saved by managing the time of working hour's schedule of office space by effective use of equipment. They stated this by doing some energy investigation by an operational pattern of occupants.

The envelope of the building separates it from the surrounding environment and its shape impacts on the urban scale. It is also the decisive step for energy performance while considering as appropriate features for it. Baird, Donn and Williams (2006) explained, it is the best-allowed distribution of annual energy use per unit area by a factor that is constructed by activity in the building or around working hours.

Building energy performance increasingly becoming the important issue as sustainability aspect demand. As far as sustainability, energy performance of any space or building plays the important role overall. Crawley et al. (2008) covered several simulation software which is using commonly such as Ecotect, DOE, ESP-r, EnergyPlus and TRNSYS and compared their proficiencies and features. These programs are also capable of generating result in detail about modelling features, building envelope, daylight, electrical equipment's, energy analysis, climate data, Heat Ventilation Air Conditioning (HVAC) system and validation of results. Energy performance main purpose is to attain the suitable degree of application for identifying materials, modules and system. Arguably the most advanced of all tools discussed, EnergyPlus was developed from a arrangement of the best features from BLAST and DOE-2, while including the addition of a range of unique new features. Like BLAST and DOE-2, EnergyPlus is primarily a simulation engine with little in the way of a graphical user interface. However, third party graphical user interface such as DesignBuilder have been developed to take advantage of EnergyPlus's capabilities. One feature of EnergyPlus that was lacking in both BLAST and DOE-2 was the ability for the simulation to provide feedback between the HVAC module and the load calculations module. This lack of feedback leads to inaccurate temperature prediction which has a large influence on HVAC systems sizing, occupant comfort, and energy use. For the related experience of the program, Conceição and Lúcio (2008) investigated effect of thermal performance of a commercial building with maximum level of solar radiation in mild climate. By considered real occupancy, infiltration and ventilation records to forecast mean thermal comfort index for various zones. They concluded with two different solution to improve thermal ease i.e. electrical air heaters and solar air collectors.

The intention of energy performance is to organize everything which is compulsory towards energy consumption. Torcellini & Pless (2006) studied four of the more common definitions in the literature and discussed their applications, advantages, and disadvantages. They stated that a suitable energy consumption definition must first prioritize energy efficiency over renewable energy capacity. A reduced load will lead to a reduced required installed capacity of renewable energy, leading to significant cost savings and making the net zero goal more achievable. It is also claimed that around 30% of a buildings' energy use can be attributed to artificial lighting. One important consideration with regards to lighting is the influence that it has on the thermal load of the building. Artificial lighting generates heat which then creates follow-on effects for the HVAC system in the building. While this thermal load effect may be of benefit in winter, it will come as a disadvantage during hot periods, Franzetti, & Fraisse, (2004).

Energy has different ratings: the higher the rating, the higher environmental impact. To reduce the impact on the environment, it is the task of the designer to inspect enough suitable level of energy, which is recommended by the user, by their comfort level Crawley et al. (2008). The low-rating task, such as heating rooms, should be as the low-rating source like passive solar gain. It doesn't mean low-energy result must have the expensive solution, they surely are cheaper by assignment and maintain than other options. Wilkinson et al. (2009) argued that by decarbonizing the built environment through strategic changes to the way we use building elements such as insulation, ventilation, fuel switching, and behavioral change, there is potential to prevent 5500 premature indoor environment related deaths every year, as well as save 41 % of carbon dioxide emissions. Since Boyle (1996) stated that, it could be also possible to create the comfortable environment for users as well as can make the considerable saving by adopting the conventional design with the alternative energy source.

Architectural practice is increasingly taking environmental aspects into account, but the focus is also on better energy performance. Envelope shape is usually defined in the early design stages, although little changes until the end of the design process. Designers can only use design rule of thumb to get an idea of energy efficiency to assist envelope design at initial design stage because it is almost impossible to calculate energy values in an early design phase. According to the previous study and also discussed in introduction chapter, Parasonis and Keizikas (2010) indicated that buildings in similar areas but different external envelope have the different demand for energy. For further extended work by Corgnati et al. (2012) indicated simulation-based performance evaluation study by internal thermal condition impact on building energy demand. Added this to further clarifies, in the paper Givoni (1981) it is also on its shape, orientation and arrangements of transparent envelope elements which energy efficiency majorly depends, not only on thermal properties and heating capacity of the material used. Parasonis and Keizikas (2010) in their work also found that changes in the shape of the building cause changes in energy losses.

The Building Research Establishment Environmental Assessment Methodology (BREEAM) has been operating since 1990 and is widely considered the world's most popular scheme. BREEAM was developed by the Building Research Establishment (BRE). It enables developers, designers, and building managers to improve the environmental performance of their buildings through a rating system that considers energy and water use, occupant health, pollution, transport implications, building materials, and building waste, as well as the environmental ecology impacts and building management processes. Leadership in Energy and Environmental Design (LEED) is a certification scheme developed by the US Green Building Council (USGBC) that considers the design, construction, operation, and maintenance of green buildings. Similar to the BREEAM system, LEED is flexible to different project development and delivery processes by having different rating systems depending on the type of project being considered. LEED's five rating system groups include Building Design and Construction, Interior Design and Construction, Building operations and Maintenance, Neighborhood Development, and Homes.

Mostly, commercial building categorized as offices, hospitals, shopping malls etc. these all have different requirements of energy needs (Figure 2.1), but as the overall scenario, these buildings consume energy as heating/cooling and lighting more than half percent of entire consumption, EPRI (EM-4195). This is most prominent and important issue as in big busy cities the buildings are built quite closely to each other and their heating/cooling system distribute energy in the form of hot steam. According to National Renewable Energy Laboratory, NREL (www.nrel.gov) stated that it has fully beneficial by all means by making energy system of building as a region within the building and it can also reduce cost.

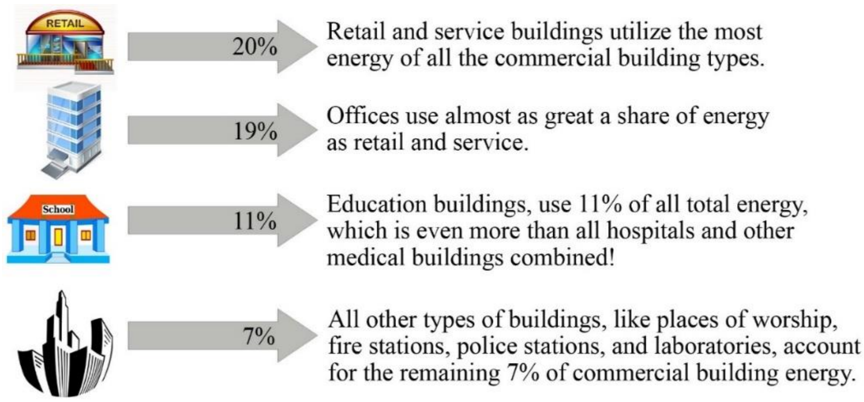

Figure 2.1. Share of energy consumption, according to Aymen (2005).

It is also very challenging to find out about how to get "fewer energy buildings" and how to get "energy efficient buildings". Energy efficient building can be solved by assessing the sensible application of resources within lowest conceivable energy supplies. One way to reduce the thermal effects of artificial lighting is to introduce more daylight. It has been suggested through simulation in Bodart & De Herde (2002) that through optimizing the amount of daylighting in the building, the artificial lighting required to be reduced. Introducing daylighting eliminates the electrical energy required to power the light, as well as the additional energy required to remove waste heat generated by the light. The effect of daylighting on building energy savings was investigated in Krarti et al. (2005). As far as concerned about identifying and rating of low energy and energy efficient buildings, its installed equipment's approach is to define what shall be conserved and the purpose for it. Also, by looking at simulations programs Tronchin and Fabbri (2008) conducted the study between software and real consumption in relationship to flexible architecture solution by reflected single-standing building in hot climate area. They resulted three different energy models after calculation were developed to analyze and compared to compute their gap with definite energy performance. Rating of building code is related to certification. Certification means assessing the building in the design stage by precise worldwide authorities.

Fumo et al. (2009) considered EnergyPlus model simulation of a hypothetical office building in different cities by combined heat and power systems. Total energy consumption of heating, cooling and other equipment's are resultant from EnergyPlus simulation and scaled to primary energy. Different control approaches for power generation unit indicate that options based on primary energy, not only economic possibility, results in energy saving. To identify essential properties parametric and statistical studies on building are performed which affect the energy performance of the building. Andersson and Olofsson (2007) directed a methodology on multi-used Buildings grounded on monthly electricity and fuel intake data. Missing data is recompensed with expected consumption outlines. Results show that overall heat transmission coefficient is the most substantial output for energy performance. When used collected with total energy consumed, it can vigorously calculate the indoor air temperature. It is also concluded that energy consumed per m² of the building is an uncertain display of the performance of the building because it is directly attached to the operation profile accordingly changing comfort levels.

2.3. BULDING ENVELOPE

The building envelope serves as the interface with the outside environment. It controls the physical factors such as temperature, humidity, and lighting. A high performance, the engaging building envelope is central to the comfort of its occupants and the overall energy use of the building. An efficient building envelope should allow natural ventilation when outside conditions are conducive to occupant comfort. The building envelope is defined as the barrier that separates the indoor space from the outdoors and is considered critical to the comfort of occupants, and to energy and thermal efficiency. According to Oral, Yener, & Bayazit (2004), the envelope varies significantly based on the climatic conditions of the site. A non-engaging envelope maintains a solid, separate barrier between internal and external environments. This is used where the outdoor climate is typically not hospitable such as in very low or high temperatures. An engaging envelope is one which allows interaction between occupants and the outdoors, such as operable windows and doors when the climate is comfortable. An engaging envelope typically results in a more efficient building, with reductions in HVAC loads by Syed (2012).

A study of a hotel building in the Mediterranean by Sozer (2010) found that heating/cooling energy savings of 40% could be achieved by applying passive design principles such as appropriate thermal insulation, glazing and shading elements. The effectiveness of shading was examined in Pacheco et al. (2012). A disadvantage highlighted was that they limit the availability of daylight, increasing the need for artificial lighting. An increase in artificial light leads to an increase in heat generation within the building. It is important that these implications are considered when designing shading elements for the building envelope to ensure that excessive shading doesn’t have detrimental effects on the building energy efficiency or occupant comfort.

In a hot, arid climate, Bambrook et al. (2011) recommended high levels of insulation in the building envelope, as well as low U-values in window assemblies to minimize heat transfer. Windows should also be sized to suit their orientation and have appropriate shading. Pacheco et al. (2012) were able to conclude that the factors that had the most influence on the ultimate energy demand of a building are the placement, the shape, and the compactness of the building (the ratio among external surface area and building volume). It was also found that design measures that may contribute to benefits in one season may be detrimental in another season. More research was recommended into the estimation of solar radiation in urban areas due to influences of surrounding buildings. Natural lighting helps to reduce energy use, as well as to contribute to occupant comfort; however, a balance between natural lighting, shading, and artificial lighting must be found. Too much natural lighting and the building may overheat – requiring HVAC systems to consume energy. Too much shading to prevent overheating, and more artificial lighting is needed.

2.4. DESIGN REQUIREMENTS OF AN OFFICE BUILDING

The office building is one of the great signs of the twentieth century. Office towers lead the skylines of cities. Office buildings basically serve for people in order to fulfil their expectations of working atmosphere. In addition to this, functionality can be shown as key causes of formation of these buildings. In this respect, it is possible to express that buildings include many criteria that belongs to different design considerations. The earliest efforts to define the design process were focused on approaching design using the classic scientific methodology in an attempt to justify design as an academic, scientific discipline. These so-called first-generation design methods were formulated in the 1960s by early pioneers like Archer and Asimov according to Carrol and Hitchcock (2005). The methods were constructed with a focus on optimization using the term ‘method’ in its classic scientific meaning where a ‘method’ is considered to be a systematic, rational and logical way of approaching a problem in this case design problems. All these statements bring out that high-rise buildings are one of the most difficult designs in the built environment.

This is true because it has been seen since many years that the office building is the clearest image of an extreme change in employment. In present-day Karachi, at least half percent of the working people is working in office settings. In this regard, architects are liable for the addition of energetic aims into design procedure and explaining such a difficult design problem. There are also unlike reports in the literature, which emphases on different features due to the assessment of the studies. In the context of this research, design requirements of high-rise buildings were examined as basic planning and design considerations.

To attain this, the buildings must rate from an integrated design approach that emphases on gathering a list of objectives. Through integrated design, a new generation of high-performance office buildings is beginning to develop that offers owners and users increased worker fulfilment and efficiency, improved energy and environmental performance. Normally, these projects relate life cycle analysis to adjust primary savings in architectural design.

2.4.1. BASIC PLANNING

Apart from design considerations, the planning method is also of great significance which simplifies the informal and smooth operative of an office. For effective office planning, combination and interconnection will enable easy program, save time and locating a thing and help cut the additional staff.

Building function is the main determinant criterion for whole planning considerations of mainly office buildings. Sev (2001), expresses the function types of tall buildings in two main subtitles, which are single-function high-rise designs" and "multi-function high-rise designs. These single or multi-function buildings may be designed as office, residential, hotel, and commercial buildings. Due to different types of functions, high-rise designs require different standard measurements to reach suitable spaces. Floor planning of single-functional high-rise such as an office building, is capable to repeat the same floor type for whole floors whereas this situation is not suitable for multi-functional high-rises.

Architects and designers have recognized two main types of office systems over a period of time, open office and closed office. The main preparation for any office is the organization of work space for the staff. Especially when, the office building is tall structure or high-rise. And to achieve these the most important role is of overall lighting for the space. The area should be well lit-up so that the inner environment will be progress positively. The period of balance can have an impact on the achievability of the goal given the seasonal variability of renewable energy resources. Sartori et al. (2012) argued that a yearly balance covering all seasonal conditions is most suitable. Longer periods in the order of decades may be selected to account for embodied energy; however, it is possible to annualize this contribution to retain a yearly balance period. These findings are generally in keeping with those found by Marszal et al. (2011). Including this, as we know about the relation of daylight and energy consumption are indirectly proportional to each other. So, in that case daylight play a vital role to achieve suitable results in planning.

2.4.2. DESIGN CONSIDERATION

Basic design thoughts include main objectives, which are also amazing goals in tall structure design process. In opinion, these attentions show a modification on design problem, construction area and environment. It is possible to say that the most important consideration in design is sustainability and location among many consideration of tall office buildings.

In a study of the relationship among climate change, the indoor thermal environment and building energy use, Guan (2012) found that building energy use could be expected to rise by 0.4-15.1% depending on climate scenarios and building location and design, based on global warming predictions to the year 2070. Various adaptation strategies were examined, and it was suggested that the required heating and cooling loads, and ultimately the overall energy use, could be reduced if the internal load density of the building was reduced.

Marszal et al. (2011) argued that for a grid connected, there are two possible types of balance: energy use/renewable generation, and energy delivered from grid/energy fed into grid. It was stated that energy use/renewable energy generated is more applicable for the design phase of a building while the delivered/exported balance should be used in operational monitoring. Despite this, it was concluded that the most popular balance in the literature at the time was energy use/renewable energy generated. Sartori et al. (2012) concurs with the study by Marszal et al (2011).

Sustainability

Sustainability has become more vital design thought for all types of buildings in 21th century. Yeang (2007) states the organic role of high-rise buildings in his words, as the tower structure is not an ecological building type. In fact, it is one of the most un-ecological of all building types. In this respect, design areas associated to sustainable issues, should be placed in appearance in design process. According to Ilgm (2006), sustainability of buildings should be established on "minimization of energy consumption, protection and use of environmental-friendly products, enhancement of indoor environmental quality, day lighting, natural shading, energy efficient and photovoltaic facades, wind power systems and the sky garden concept. All these features have typical significance in order to reach sustainable buildings.

Location

Location of high-rise buildings has a basis role in the urban situation. Due to their scale and would-be of having many people, buildings make new focus points in cities wherever they are built. According to this, it is clearly seen that these buildings affect cities in both positive and negative means in terms of new traffic streams and pedestrian movements around their site areas specially during working office hours. And as Karachi is vast populated and financial hub of Pakistan, city`s skyline has dominant figure about buildings and it also affect urban context.

2.4.3. INTEGRATED DESIGN APPROACH

Architecture includes many aspects from different professions due to complexity of design. As a consequence of that different aspects, which belong to other professions have begun to integrate into design and construction processes by reason of achieve more efficient design alternatives. Thus, integrated design approach came up in the architecture. Ali and Armstrong (2008) express the difference between conventional design and integrated design, as integrated design is different than conventional design in its focus on active relationship within a multidisciplinary team especially by means of climate. A related study into the relationship between buildings and climate change was performed by de Wilde and Coley (2012). The authors warned that existing rules and regulations in the building sector are based on historical climate data and are therefore not necessarily well suited to the future in a warmer climate. They also suggested that existing performance metrics should be considered carefully to account for human perception of thermal comfort and their adaptation to wider temperature bands.

In Bachman (2003) further expand integration in two points, Hardware integration (Integration among building system) and Software integration (Integration in the design process). Both aspects have an important role in entire design process. However, the part of Software: Integration in the Design Process, comes step forward due to including the conceptual phase process. Turrin (2014) states the importance of conceptual phase by defining as the most influential design decisions are actually taken during early phase. Within the context of this statement, it is likely to express that integration at the conceptual design phase plays a vital role in order to reach suitable designs among defined goals in design process.

Sariyildiz et al. (1997), explains the status of integrated design approach in the design process, as integrated design care environments are a possible to improve the quality and to increase the efficiency of architectural design. Getting suitable results in order to defined objectives is one of the most important targets of architects. In this context, decisions that are taken in conceptual process affect the final product. It is possible to say that, integrated approach should be started in the early design stage, especially when it comes the issue of sustainability in architectural design since so long. And to deal with this issue is must prior task for the architects as well as challenging target.

In the perspective of previous statements, this fact has a remarkable role in order to get effective architectural designs in the best interests of design goals. This statement brings the importance of tools which are used in conceptual phase. A Microsoft Excel based tool was developed by Belleri *et al*. (2013) which assessed the balance, operating costs, and load match index for net zero base on a set of pre-defined definitions. It is suitable for designers, managers and policy makers in gauging the potential success, as well as monitoring the building during operation. In general, engineering or architectural computer aided design programs focus on specific topics. Fasoulaki (2009), points out this Generative Design System focuses on energy efficiency and form on structural efficiency. Integrated Design approach fills this gap by overview of more than one building performance from different disciplines at a time. According to this statement, it can be said that it is possible to integrate different design or engineering components in computational environment.

It has to focuses on integrating components based on different expertise areas in same environment. So, data are transferred among components without any method such as import or export, as shown in Figure 2.2 below. The advantage of this tactic is to provide an environment, which updates data for changes of the building form. The designer is able to observe the changes when design variables are changed. In addition, due to the flexible user interface of these environments, designer is able to develop and integrate new components depending upon necessities such as daylight factor, useful daylight illuminance, heating/cooling demand and energy performance or energy usage demand. There are also many components, which have been developed by architects and engineers, capable to integrate in these computational environments. This open source approach gives an extra power to architects in order to integrate different components especially in the phase of conceptual design process.

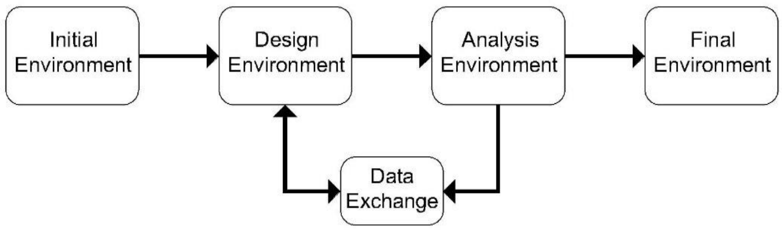

Figure 2.2. Diagrmatic presentation of integrated design approach.

CHAPTER 3
METHODOLOGY

The current research adopted a quantitative approach for evaluating the performance of office building at the conceptual design stages. A unique regression model was proposed for the investigation of energy performance factor of the office buildings in Karachi, Pakistan. To develop the model, a framework was implemented in a comparative study between reference building as base case and actual proposed building which is in under study. Starting by simulation of energy of reference office building to figure out values under the suitable climate of city Karachi with the given performance criteria. For simulations of that building, a computational model was generated using the computational tools and measured the effect of quantitative variables.

This study was based on computational tools and techniques for the aim of establishing a new framework for predicting the working of performance base and responsive design strategy for the designer in the world. Parametric modeling, environmental simulation and computational decision tools were incorporated in an automated workflow for generating and exploring the design space of the office building.

At first, the parameter initialization process was conducted for the base case. Then, parametric models were established for the base case office building, which have fixed fenestration ratio and glazing type on all sides of façade. Same design parameters controlled both observations of energy performance. For next stage of hypothetical consideration of building, the variable randomization process simplified the simulation model by generating random values for relative compactness, window to wall ratio, and glazing type. The impact of these parameter which were the main important variables were selected as performance base result. The values for the energy use intensity (kWh/m^2/year) of alternatives building options were stored in worksheets by each of its parametric models for analysis.

3.1. BASE MODEL

3.1.1. LOCATION AND CLIMATE

Pakistan's cosmopolitan city Karachi, is located on the eastern coast of the Arabian Sea. It is the capital of the province of Sind and the former capital of Pakistan. With a population of nearly 18.5 million Karachi is the largest city of Pakistan. And importantly, the financial capital of Pakistan. It is Pakistan's premier center of banking, industry, and trade. It is also Pakistan's largest corporations, including those that are involved in shipping, automotive industry, entertainment, the arts, fashion, advertising, software development and medical research.

Climate of Karachi is Hot-Dry. The temperature levels usually remain high especially from March to November. Average temperature of the city is between 24°C to 26°C.

3.1.2. FUNCTION AND STRUCTURE

The building is in a densely populated area of Karachi. It is a reinforced concrete framed building with ten stories above ground and twelve stories total, including two basements. The building is being used as an office building, therefore it is evaluated for the Life Safety (LS) level of seismic performance, meaning that its occupants should survive the design level earthquake and be able to exit the building safely. The reinforced concrete frame consists of flat slab with drop panel and having outer peripheral beams. The building construction was completed in 2011.

The building system consists of flat slabs with drop panels and outer peripheral beams. RCC wall lift cores are eccentrically placed at the back side of the building (way from the street shown below). The foundations are reinforced concrete isolated spread footings with retaining walls on the periphery. The building is relatively new and is in reasonably good condition. No condition assessments or repairs have been made.

Typical stories height is 10’- 0” (3 meters). The strength of concrete and reinforcement are taken as: f'_c = 4,000 psi (slabs, beams and columns), f'_c = 5,000 psi.

3.1.3. BUILDING ORIENTATION

Orientation of building is one of the most important and curial features in high-rise building design. An appropriately orientated building can save a lot of money in no longer required heating and cooling costs spending. But sometimes, orientation of building awarded fixed due to the road excess. Same case has been considered in this research as the building faces towards south as shown in Figure 3.1 because of having main excess to the site. And as we fully aware that the south part of the building has faces most of sun light to the maximum time periods. The area of this particular site is called central business district (CBD) and have mostly high-rises building around which either faces towards south or north direction.

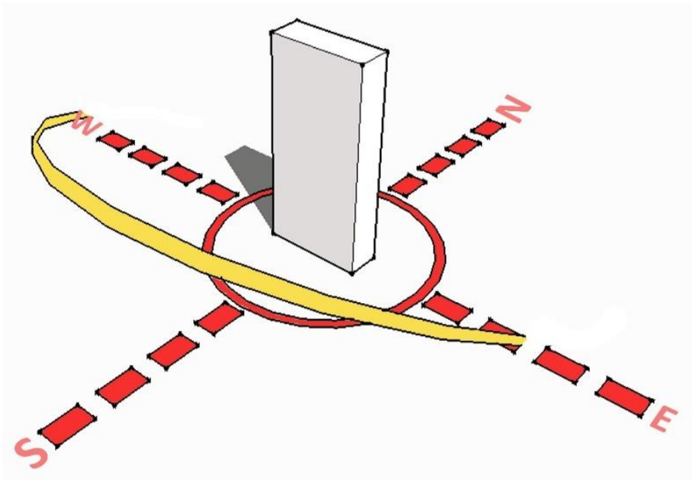

Figure 3.1. Showing the solar direction for the selected case

3.2. DEVELOPMENT OF COMPUTATIONAL PERFORMANCE MODEL OF AN OFFICE BUILDING

After the expression of fundamental components and goals of office buildings and integrated design approach (see 2.4), this part of chapter presents how integration of multi-performance criteria can be applied and how usage of computational methods be implemented in the conceptual stage of design. It is significant that knowledge and the key points of buildings stated already have been applied in this chapter in order to develop the model. Within this framework, there are two main steps that establish the model: “shape of building” and “performance evaluations” (Figure 3.2).

Among these steps, the system of model work. Moreover, when its steps are put in order as a principle, it can be said that first of office building`s different shapes were generated according to generative functions, which were controlled by design variables (particular spaces). In second stage, each shape was assessed by the performance criteria, which were defined according to defined design goals. Finally, data that were attained by performance evaluations of each shape were noted as information component in order to discover for suitable design alternatives.

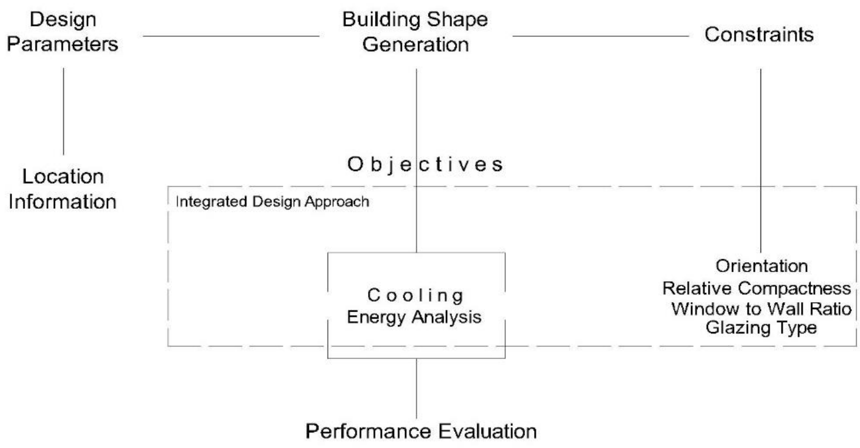

Figure 3.2. Development of integrated model by multi-performance based computational design

3.2.1. GENERATIVE BUILDING MODELS

Development of the generative model takes the first stage of the process. One of the most important focus points of this stage is to develop a model as flexible as possible. In this context, the model can adapt typical situations as an office building design with different shape such as rectangular shape, L-shape, U-shape and the T-shape, along with the different ratios of window wall (WWR) or fenestration ratio.

In addition to this, developing a generative high-rise office model plays a key role to have same spaces and as well as sub-spaces with identical areas throughout each shape as design parameters that define the geometry of computational model. Based on these findings, generative computational model is reviewed in different steps that are expressed in the following part.

Building Form

If we look at this issue from the fact of built environment, it is seen that there are different types of high-rise buildings exist. In general, these types can be mentioned as singular high-rises, twin high-rises or connected high-rises. In this study, singular high-rise buildings were selected as a focus point that was already mentioned in the first chapter. So as considering singular high-rise office building, four different shape is developed like simple *Rectangular shape, L-shape, U-shape* and *T-shape* as shown in Figure 3.3. Each shape has been considered **as same spaces and areas** for comparative analysis for its multi performance integrated design as results.

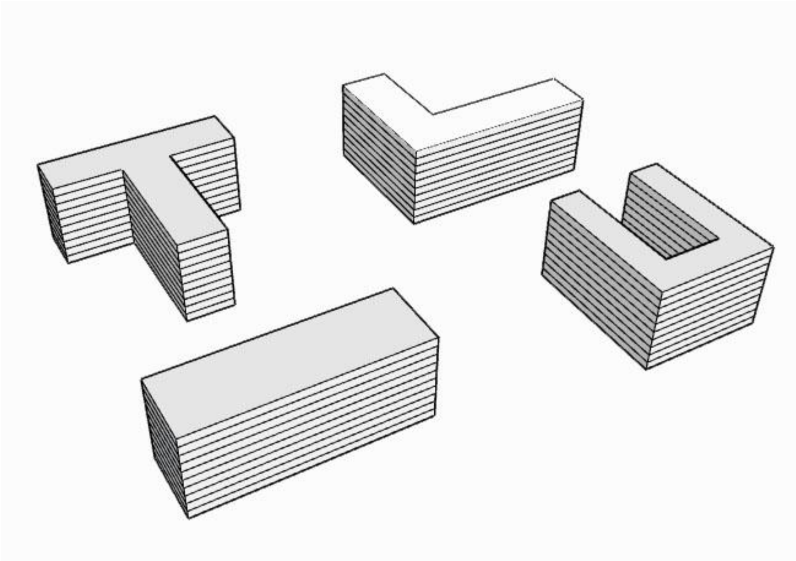

Figure 3.3. Typical Office Building Models for all the Shapes Used in the Study

Construction Properties

For all the building models, the roof is made up of 200mm thick RC slab normal weight concrete having 150mm concrete screed, 4mm-2ply bituminous water proofing membrane, plus 75mm polystyrene insulation, while the walls are made up of 200mm normal construction met the IFC drawings and specification which has been prepared as per client requirement. More information on construction properties of the base model can be found in Table 3.1.

Occupancy Loads

Further, for all models, typical office space occupancy pattern and schedules appropriate for Karachi are applied. Precisely, these office occupancy pattern are listed in Table 3.2

Table 3.1. Construction properties of the base model

Construction set	Material	Thickness	U-Value
Roof	Concrete screed	200mm	0.27 W/m^{2}K
Walls	Concrete block	150mm	3.29 W/m^{2}K
Glazing	Single brown tint	8mm	2.84 W/m^{2}K
Foundation	Reinforcement Concrete (Pile/Raft foundation)	1800mm	1.83 W/m^{2}K

Table 3.2. Office occupancy loads employed in the current work

Description	Value
Lighting power density (LPD)	12.3 W/m^2
Equipment power density (EPD)	2.6 W/m^2
Average occupancy density (m^2/person)	26 m^2/person
Glazing distribution	Uniform glazing distribution

3.2.2. VARIABLES

In this part, planning considerations of model, which have an important role for developed computational model are mentioned. These considerations describe the main shape of building. That is why these definitions make the basic outline of the model. The main and important planning considerations of developed model have been defined as:

- Relative Compactness – Independent Variable
- Window to wall ratio (WWR) – Independent Variable
- Glazing type – Independent Variable
- Energy Use Intensity – Dependent Variable

Relative compactness

Relative compactness is used in this study as a mark of building shape to help the relative study when evaluating the impact of shape and geometric dimension on the building energy performance. Relative compactness is expressed as follows:

$$RC = \frac{\left(\frac{V}{A_S}\right)_{building}}{\left(\frac{V}{A_S}\right)_{reference}} \tag{3.1}$$

where $(V/A_s)_{building}$ is the compactness of a generated building; and $(V/A_s)_{reference}$ denotes the compactness of the reference building which has a rectangular floor plan. Note that V and A_s refer, correspondingly, to the conditioned volume and envelope surface area facing to the outside area (exterior wall area). As specified by (3.1) the relative compactness *(RC)* does not imply any measurements. Since the floor area and total height of any building are constant, the building volume is also perpetual for all generated buildings. So, equation (3.1) can simply become as:

$$RC = (A_s)_{reference}/(A_s)_{building}$$

Figure 3.4 shows the geometric features for various building shaped used in the study. These geometric characteristics include: the dimension of the bounding rectangle, width (*W*) and depth (*D*), the perimeter (*P*), and the relative compactness (*RC*). An interesting observation from the figure is that the perimeter values of the L and T-shaped buildings are same for the similar bounding rectangle dimension (W and D). Another thing, the values shown in Figure 3.4 indicate that higher RC is associated with lower perimeter.

Bound Rectangle

no.	W (m)	D (m)
BR_001	27.00	239.72
BR_002	28.00	221.89
BR_003	29.00	206.25
BR_004	30.00	192.39
BR_005	31.00	180.00
BR_006	32.00	168.86
BR_007	33.00	158.80
BR_008	34.00	149.65
BR_009	41.00	135.30
BR_010	36.00	133.60
BR_011	35.00	128.50
BR_012	37.00	121.00
BR_013	80.00	75.30
BR_014	40.00	112.90
BR_015	43.00	105.21
BR_016	47.00	96.90
BR_017	50.00	89.90
BR_018	53.00	83.20
BR_019	56.00	76.80
BR_020	59.00	70.62
BR_021	63.00	63.70
BR_022	57.00	68.29
BR_023	66.00	57.94
BR_024	70.00	51.42
BR_025	66.00	54.18
BR_026	76.00	43.00
BR_027	82.00	34.77
BR_028	50.00	65.72
BR_029	87.00	27.69
BR_030	65.00	73.01

L Shape

t (m)	P (m)	RC
7.00	533.44	0.45
7.50	499.78	0.48
8.00	470.50	0.51
8.50	444.78	0.54
9.00	422.00	0.57
9.50	401.72	0.59
10.00	383.60	0.62
10.50	367.30	0.65
11.00	352.60	0.68
11.50	339.20	0.70
12.00	327.00	0.73
12.50	316.00	0.76
12.75	310.60	0.77
13.00	305.80	0.78
13.50	296.42	0.81
14.00	287.80	0.83
14.50	279.80	0.85
15.00	272.40	0.88
15.50	265.60	0.90
16.00	259.24	0.92
16.50	253.40	0.94
16.75	250.58	0.95
17.00	247.88	0.96
17.50	242.84	0.98
17.75	240.36	0.99
18.00	238.00	1.00
18.50	233.54	1.02
18.75	231.44	1.03
19.00	229.38	1.04
14.75	276.02	0.87

T Shape

t (m)	P (m)	RC
7.00	533.44	0.45
7.50	499.78	0.48
8.00	470.50	0.51
8.50	444.78	0.54
9.00	422.00	0.57
9.50	401.72	0.59
10.00	383.60	0.62
10.50	367.30	0.65
11.00	352.60	0.68
11.50	339.20	0.70
12.00	327.00	0.73
12.46	316.00	0.76
12.75	310.60	0.77
13.00	305.80	0.78
13.50	296.42	0.81
14.00	287.80	0.83
14.50	279.80	0.85
15.00	272.40	0.88
15.50	265.60	0.90
16.00	259.24	0.92
16.50	253.40	0.94
16.75	250.58	0.95
17.00	247.88	0.96
17.49	242.84	0.98
17.75	240.36	0.99
18.00	238.00	1.00
18.50	233.54	1.02
18.75	231.44	1.03
19.00	229.38	1.04
14.75	276.02	0.87

Rect Shape

W (m)	P (m)	RC
7.58	494.61	0.48
8.19	460.17	0.52
8.82	430.13	0.56
9.45	403.68	0.59
10.10	380.20	0.63
10.77	359.25	0.67
11.45	340.50	0.70
12.15	323.60	0.74
13.44	297.47	0.80
13.61	294.42	0.81
14.15	285.30	0.84
15.03	272.05	0.88
24.14	198.89	1.20
16.10	258.01	0.93
17.28	244.98	0.98
18.76	231.32	1.03
20.22	220.25	1.08
21.85	210.10	1.14
23.67	200.95	1.19
25.74	192.73	1.24
28.54	184.48	1.30
26.62	189.82	1.26
31.38	178.64	1.34
35.36	173.55	1.38
33.56	175.47	1.36
42.28	170.56	1.40
52.29	174.12	1.37
27.66	186.77	1.28
65.66	186.69	1.28
24.90	195.82	1.22

U Shape

t (m)	P (m)	RC
3.6	989.47	0.24
3.9	919.41	0.26
4.1	858.12	0.28
4.4	803.94	0.30
4.6	755.65	0.32
4.9	712.36	0.34
5.2	673.39	0.35
5.5	638.05	0.37
5.8	588.03	0.41
6.0	576.40	0.41
6.2	555.23	0.43
6.5	527.52	0.45
7.9	389.08	0.61
6.8	498.44	0.48
7.2	471.01	0.51
7.6	442.15	0.54
7.9	417.51	0.57
8.3	394.09	0.61
8.7	371.87	0.64
9.1	350.56	0.68
9.5	327.35	0.73
9.4	339.55	0.70
10.0	307.76	0.78
10.5	286.20	0.83
10.4	293.15	0.82
11.2	259.22	0.92
12.0	233.08	1.03
10.0	322.90	0.74
12.8	210.53	1.13
8.6	365.66	0.65

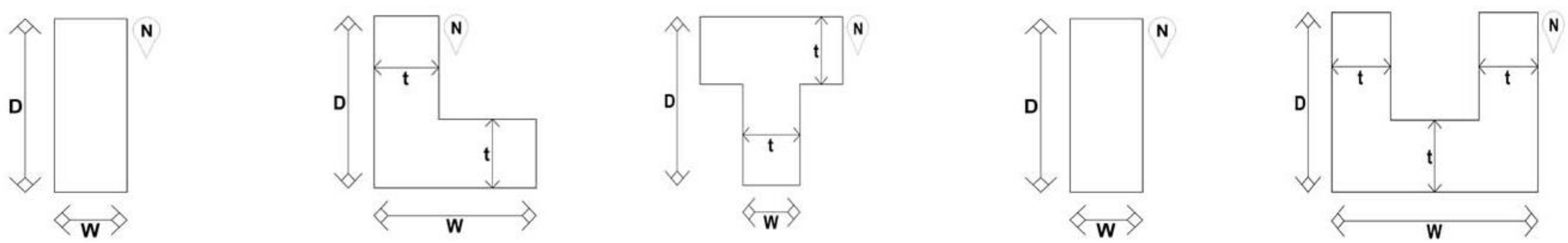

Figure 3.4. Geometric dimension for building floor plans with Rectangle, L, T, and U shapes

Window to Wall Ratio

Window to wall ratio (WWR) is a most major component affecting energy performance in a building. On heating, cooling and lighting window area have impacts on the building as well as relating it to the natural environment in terms of access to daylight and ventilation. The window-to-wall ratio is the percentage area between building`s total glazed area and exterior envelope wall area. The analysis in this study is carried out for different window sizes and glazing type. In specific case, considered all four shapes was been set window to wall ratio to vary from 0.1% (openings) to 0.9%. For clear understanding of window wall ratio Figure 3.5 below is mentioned.

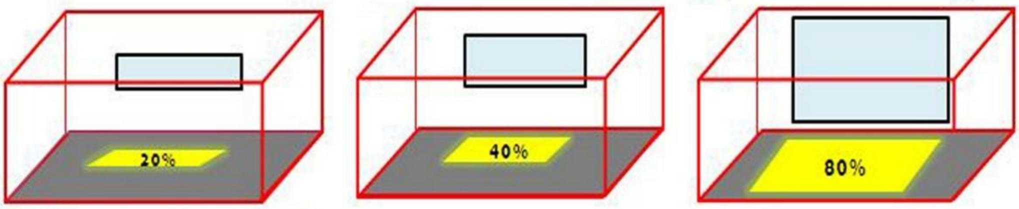

Figure 3.5. Diagrammatic understanding of Window to Wall Ratio

Glazing Type

Models for office building with several shapes have been established by using SketchUp program. For all models, typical office space pattern and programs meet for Karachi condition used. Several constraints are varied to assessment the energy performance with dissimilar buildings shapes and relative compactness. The inquiry also considered several window ratio and glazing types. Specifically, window to wall ratio was set to 0.1% to 0.9%. Various glazing types with different solar heat gain coefficient were analyzed. Table 3.3, summarizes the glazing types by its solar heat gain coefficient and window to wall ratio.

Table 3.3. Types of glazing and WWR considered in the simulation process

Glazing	**Label**	**Solar Heat Gain Coefficient**	**Window to Wall Ratio**
Single Clear 8 mm.	(1) SVC	0.815	0.1-0.9
Double brown	(2) DBR	0.492	0.1-0.9
Single Brown Tint	(3) SBR	0.252	0.1-0.9

Energy Use Intensity

Energy use intensity (*EUI*) can be explained as a calculation of a building`s yearly energy performance comparative to its floor area. It is typically measured in $kWh/m^2/year$.

The EUI usually express as, energy use as a purpose of the building size by classifying the building`s energy use per square meter per area. By dividing the total energy that building consumes in a year by the building total gross floor area. EUI helps to understand better if the building using extreme level of energy. This EUI is also useful to decide which faces or sides of the building functions need consideration in terms of reduce the energy use overall. **Therefore, *EUI* of reference building is 154 kWh/m²/year**

The total energy use E_t, for building configuration is normalized relative to the total energy use, E_{ref} obtained for the reference building (with a square floor plan) to simplify the analysis, reasonably. This forms the response variable (E_t/E_{ref}). A comparable normalization is performed for the overall energy use.

3.3. BUILDING ENERGY SIMULATIONS

In the scope of generative principles of model mentioned in the previous part, this section focuses on evaluation of that model within the framework of multi-performance criteria, which have also an important place for tall buildings. It is obvious that buildings are under the influence of many criteria that have an impact on their performances as well. Regarding to reach better buildings, which also mean better performances, performative architecture notion has come up. Kolarevic (2013) states performative architecture can be defined as the one in which building performance, broadly understood, and becomes a guiding design principle. In other words, it can be said that the role of architect is to multi-performance criteria into design process. Hensel (2013) points out the importance of this multi-performance continues as, architecture is urgently in need of integrative approaches that begin to combine specialist discourses for the sake of encouraging determined efforts towards improving the built environment and its weakening impact on the natural environment. According to these accepted senses, it is possible to say that integrating performance aspects have a remarkable role in the process for all building types.

This integration should be started at the earliest design stage, which is called as conceptual phase and also kept on further progresses. The further steps in the context of specialization and continue as, Architects should be in collaboration with professionals from other disciplines in order to criteria that they focus, require a specialization. Based on this theory, it can be said that, collaboration among professionals brings more realistic alternatives.

In accordance with these arguments, the generative model was evaluated by series of performance criteria, which have a remarkable role in terms of sustainable and economical aspects in this research. In this regard, performance criteria have been integrated and evaluated in the developed model.

3.3.1. SUSTAINABLE CRITERIA

Based on the previous statements, this part focuses on reaching sustainable building at the initial design process, which is also called as conceptual phase. Yeang (2007) expresses the reason why high-rise buildings are un-ecological and continues as. Its un-Eco logicalness is of course largely due to its tallness which requires for instance larger material content in its system to bear the higher bending moments caused by the forces of the high speeds at the top reaches of its built form, greater energy demands to transport and push materials and services up the building's floors working against gravity, additional energy consumption for the mechanized movement of people up and down its elevators, and other enhanced aspects arising from its excessive verticality. Within this context, it can be said that high-rise buildings have no enough capability to become 100% sustainable buildings. However, there are some criteria which have a remarkable role in the protection of nature may be applied to protect the built environment. Using less artificial light, smaller footprint, gaining solar energy, using wind energy or wasting less energy for heating and cooling are shown as basic sustainable factors in high-rise designs. In this respect, evaluations of daylight factor and solar radiation are defined in the developed model.

3.3.2. ENERGY PLUS

Energy has a major role in improvement of environmental quality relate to overall building efficiency evaluation system and has also bi impact to decrease of cost. Energy consumption of the building depends on working hours and duration of occupants. In this reference, Baird and Donn (2006) explained, it is the best allowed distribution of energy use per unit area by a factor that is constructed based on activity in the building or around working hours. Being considering the most relevant characteristics in a building it is also decisive for its energy consumption.

In the direction of the statements, energy performance of developed office building model is evaluated in Sefaira Architecture component in SketchUp program. This component includes all calculations about how to calculate heating and cooling as energy loads. As this component is integrated to SketchUp program, evaluation of the model is updated in real-time. As can be seen in Figure 3.6 the method of evaluation is illustrated.

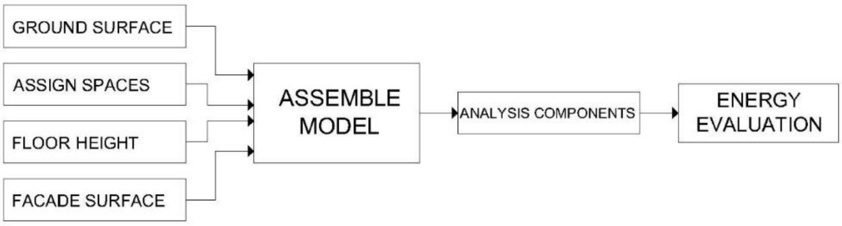

Figure 3.6. Sefaira Architecture Energy Evaluation Calculation Process in Computational Model.

In the first step, surfaces are created according to the specific spaces and sub-spaces areas of the building plan that are considered as useable boundary. By doing this, materials of surfaces were also defined within the context of material library depending upon floor types, glass type façade. It is important to express that materials have an influence on the calculation of energy consumption because of different material properties.

As a second step, the weather data file of actual region was added depending on location of evaluated building. At this stage, it can be helped from the web site of EnergyPlus™ (https://energyplus.net) which is a whole building energy simulation program that engineers, architects, and researchers use to model both energy consumption for heating, cooling, lighting loads use in buildings.

As a final step, after assigned all basis necessary components like spaces, floor height, openings and type of glazing, simulation is run and collect result of energy analysis. In this manner, these all factor count influences solutions to reach detailed results. These factors have given the related result which is needed for the conclusion.

However, assessment of energy may require the selection of specific hours, days and months to run the module. In the context of this study, annual (yearly) evaluation was applied for evaluation of energy performance for an office building.

3.4. DATABASE GENERATION

For the current research, a performance base parametric model was generated for exploring the alternatives in the design for office building and the response variables has been set for each of the shape in Microsoft Excel by randomized values of window to wall ratio (WWR) and glazing types along with the relative compactness (RC), which already calculated above. For all four Rectangular, L, T and U shape building, these classified under the Table 3.4, Table 3.5, Table 3.6, and Table 3.7 established parametric model has three independent variables, and only one response variables that are performance. The next step was automating the process of recording random independent variables performance for each building shape with its geometric dimension.

Table 3.4. Rectangle shape with assigned WWR and Glazing type.

S. No.	D (m)	W(m)	P (m)	RC	WWR	Glazing Type
R_S_001	239,72	7,58	494,61	0,48	0,09	3
R_S_002	221,89	8,19	460,17	0,52	0,66	1
R_S_003	206,25	8,82	430,13	0,56	0,32	1
R_S_004	192,39	9,45	403,68	0,59	0,56	2
R_S_005	180,00	10,10	380,20	0,63	0,41	2
R_S_006	168,86	10,77	359,25	0,67	0,65	3
R_S_007	158,80	11,45	340,50	0,70	0,27	3
R_S_008	149,65	12,15	323,60	0,74	0,55	1
R_S_009	135,30	13,44	297,47	0,80	0,19	3
R_S_010	133,60	13,61	294,42	0,81	0,20	1
R_S_011	128,50	14,15	285,30	0,84	0,84	3
R_S_012	121,00	15,03	272,05	0,88	0,73	1
R_S_014	112,90	16,10	258,01	0,93	0,49	3
R_S_015	105,21	17,28	244,98	0,98	0,30	1
R_S_016	96,90	18,76	231,32	1,03	0,56	1
R_S_017	89,90	20,22	220,25	1,08	0,47	2

R_S_018	83,20	21,85	210,10	1,14	0,76	2
R_S_020	76,80	23,67	200,95	1,19	0,94	3
R_S_019	75,30	24,14	198,89	1,20	0,75	3
R_S_021	70,62	25,74	192,73	1,24	0,04	1
R_S_022	63,70	28,54	184,48	1,30	0,39	2
R_S_023	68,29	26,62	189,82	1,26	0,20	2
R_S_024	57,94	31,38	178,64	1,34	0,43	1
R_S_025	51,42	35,36	173,55	1,38	0,87	2
R_S_026	54,18	33,56	175,47	1,36	0,22	1
R_S_027	43,00	42,28	170,56	1,40	0,86	2
R_S_028	34,77	52,29	174,12	1,37	0,58	1
R_S_029	65,72	27,66	186,77	1,28	0,10	3
R_S_030	27,69	65,66	186,69	1,28	0,89	2
R_S_031	73,01	24,90	195,82	1,22	0,84	3

Table 3.5. L - shape with assigned WWR and Glazing type.

S. No.	W (m)	D (m)	t (m)	P (m)	RC	WWR	Glazing Type
L_S_001	27,00	239,72	7,00	533,44	0,45	0,41	2
L_S_002	28,00	221,89	7,50	499,78	0,48	0,39	2
L_S_003	29,00	206,25	8,00	470,50	0,51	0,55	3
L_S_004	30,00	192,39	8,50	444,78	0,54	0,43	3
L_S_005	31,00	180,00	9,00	422,00	0,57	0,53	2
L_S_006	32,00	168,86	9,50	401,72	0,59	0,51	3
L_S_007	33,00	158,80	10,00	383,60	0,62	0,33	3
L_S_008	34,00	149,65	10,50	367,30	0,65	0,42	1
L_S_009	41,00	135,30	11,00	352,60	0,68	0,08	2
L_S_010	36,00	133,60	11,50	339,20	0,70	0,15	2
L_S_011	35,00	128,50	12,00	327,00	0,73	0,78	1
L_S_012	37,00	121,00	12,50	316,00	0,76	0,87	2
L_S_013	80,00	75,30	12,75	310,60	0,77	0,75	2
L_S_014	40,00	112,90	13,00	305,80	0,78	0,55	3
L_S_015	43,00	105,21	13,50	296,42	0,81	0,22	2

L_S_016	47,00	96,90	14,00	287,80	0,83	0,81	1
L_S_017	50,00	89,90	14,50	279,80	0,85	0,05	1
L_S_018	53,00	83,20	15,00	272,40	0,88	0,27	2
L_S_019	56,00	76,80	15,50	265,60	0,90	0,14	2
L_S_020	59,00	70,62	16,00	259,24	0,92	0,21	3
L_S_021	63,00	63,70	16,50	253,40	0,94	0,74	1
L_S_022	57,00	68,29	16,75	250,58	0,95	0,57	3
L_S_023	66,00	57,94	17,00	247,88	0,96	0,87	2
L_S_024	70,00	51,42	17,50	242,84	0,98	0,84	3
L_S_025	66,00	54,18	17,75	240,36	0,99	0,93	1
L_S_026	76,00	43,00	18,00	238,00	1,00	0,97	2
L_S_027	82,00	34,77	18,50	233,54	1,02	0,52	2
L_S_028	50,00	65,72	18,75	231,44	1,03	0,80	2
L_S_029	87,00	27,69	19,00	229,38	1,04	0,13	1
L_S_030	65,00	73,01	14,75	276,02	0,87	0,10	2

Table 3.6. T - shape with assigned WWR and Glazing type.

S. No.	**W (m)**	**D (m)**	**t (m)**	**P (m)**	**RC**	**WWR**	**Glazing Type**
T_S_001	27,00	239,72	7,00	533,44	0,45	0,33	2
T_S_002	28,00	221,89	7,50	499,78	0,48	0,07	3
T_S_003	29,00	206,25	8,00	470,50	0,51	0,77	1
T_S_004	30,00	192,39	8,50	444,78	0,54	0,66	2
T_S_005	31,00	180,00	9,00	422,00	0,57	0,26	1
T_S_006	32,00	168,86	9,50	401,72	0,59	0,10	3
T_S_007	33,00	158,80	10,00	383,60	0,62	0,03	2
T_S_008	34,00	149,65	10,50	367,30	0,65	0,13	1
T_S_009	41,00	135,30	11,00	352,60	0,68	0,81	3
T_S_010	36,00	133,60	11,50	339,20	0,70	0,50	2
T_S_011	35,00	128,50	12,00	327,00	0,73	0,31	1
T_S_012	37,00	121,00	12,46	316,00	0,76	0,65	2
T_S_013	80,00	75,30	12,75	310,60	0,77	0,06	2
T_S_014	40,00	112,90	13,00	305,80	0,78	0,21	1
T_S_015	43,00	105,21	13,50	296,42	0,81	0,52	2

T_S_016	47,00	96,90	14,00	287,80	0,83	0,28	2
T_S_017	50,00	89,90	14,50	279,80	0,85	0,38	3
T_S_018	53,00	83,20	15,00	272,40	0,88	0,10	2
T_S_019	56,00	76,80	15,50	265,60	0,90	0,72	1
T_S_020	59,00	70,62	16,00	259,24	0,92	0,48	2
T_S_021	63,00	63,70	16,50	253,40	0,94	0,36	1
T_S_022	57,00	68,29	16,75	250,58	0,95	0,28	3
T_S_023	66,00	57,94	17,00	247,88	0,96	0,57	3
T_S_024	70,00	51,42	17,49	242,84	0,98	0,74	2
T_S_025	66,00	54,18	17,75	240,36	0,99	0,53	3
T_S_026	76,00	43,00	18,00	238,00	1,00	0,93	1
T_S_027	82,00	34,77	18,50	233,54	1,02	0,14	1
T_S_028	50,00	65,72	18,75	231,44	1,03	0,58	3
T_S_029	87,00	27,69	19,00	229,38	1,04	0,80	2
T_S_030	65,00	73,01	14,75	276,02	0,87	0,28	2

Table 3.7. U - shape with assigned WWR and Glazing type.

S. No.	W(m)	D(m)	t(m)	P(m)	RC	WWR	Glazing Type
U_S_001	27,00	239,72	3,6	989,47	0,24	0,90	3
U_S_002	28,00	221,89	3,9	919,41	0,26	0,46	3
U_S_003	29,00	206,25	4,1	858,12	0,28	0,17	1
U_S_004	30,00	192,39	4,4	803,94	0,30	0,05	1
U_S_005	31,00	180,00	4,6	755,65	0,32	0,01	2
U_S_006	32,00	168,86	4,9	712,36	0,34	0,64	3
U_S_007	33,00	158,80	5,2	673,39	0,35	0,92	1
U_S_008	34,00	149,65	5,5	638,05	0,37	0,34	3
U_S_009	41,00	135,30	5,8	588,03	0,41	0,75	2
U_S_010	36,00	133,60	6,0	576,40	0,41	0,82	1
U_S_011	35,00	128,50	6,2	555,23	0,43	0,39	2
U_S_012	37,00	121,00	6,5	527,52	0,45	0,06	3
U_S_013	80,00	75,30	7,9	389,08	0,61	0,20	1
U_S_014	40,00	112,90	6,8	498,44	0,48	0,70	2
U_S_015	43,00	105,21	7,2	471,01	0,51	0,45	1

U_S_016	47,00	96,90	7,6	442,15	0,54	0,30	3
U_S_017	50,00	89,90	7,9	417,51	0,57	0,10	2
U_S_018	53,00	83,20	8,3	394,09	0,61	0,42	1
U_S_019	56,00	76,80	8,7	371,87	0,64	0,25	2
U_S_020	59,00	70,62	9,1	350,56	0,68	0,20	1
U_S_021	63,00	63,70	9,5	327,35	0,73	0,11	3
U_S_022	57,00	68,29	9,4	339,55	0,70	0,17	1
U_S_023	66,00	57,94	10,0	307,76	0,78	0,27	2
U_S_024	70,00	51,42	10,5	286,20	0,83	0,81	3
U_S_025	66,00	54,18	10,4	293,15	0,82	0,15	1
U_S_026	76,00	43,00	11,2	259,22	0,92	0,90	3
U_S_027	82,00	34,77	12,0	233,08	1,03	0,60	3
U_S_028	50,00	65,72	10,0	322,90	0,74	0,57	1
U_S_029	87,00	27,69	12,8	210,53	1,13	0,71	2
U_S_030	65,00	73,01	8,6	365,66	0,65	0,48	3

3.5. MULTIPLE LINEAR REGRESSION MODELLING

Regression analysis has been used to calculate the relationship among two or more variables, calculating the performance of a dependent or endogenous variable according to one or more independent variables. Multiple linear regression (MLR) models are often used as experimental models or approaching meanings and to create a mathematical model to describe a practical method. Mostly, the relationship between the dependent and the independent variables is given as offered as in equation.

$$Y = \beta_0 + \beta_1 \times X_1 + \beta_2 \times X_2 + \beta_3 \times X_3 + \cdots + \beta_n \times X_n + \varepsilon \qquad (3.2)$$

Where, Y is the dependent variable, β_0 is a constant, X_1, X_2, X_3 and X_n are independent variables, and $\beta_1, \beta_2, \beta_3$ and β_n are regression coefficients.

The regression coefficients were estimated using 120 data points obtained from Database Generation step. *RC, WWR, and Glazing type* were used as independent variables to develop the model, and E_t/E_{ref} act as dependent variables. Where, E_t is total energy of building shape, and E_{ref} is total energy of reference building. More information on multiple linear regression modelling can be found elsewhere (Chatterjee & Hadi, 2015)

3.6. SENSITIVITY ANALYSIS

Sensitivity Analysis is defined as the method used to determine how different values of an independent variable will affect a particular dependent variable under a given set of assumptions. It is used within precise restrictions that will depend on one or more input variables. It helps in analyzing how sensitive the output is, by the alterations in one input while keeping the other inputs constant.

Sensitivity analysis is used in the study to calculate the change of differences in energy value while implementation of different scenario within independent variables. Sensitivity analysis usually works on the simple principle: *Change the model and observe the behavior.*

CHAPTER 4
RESULTS AND DISCUSSION

The chapter introduces the results of the processes defined at Chapter 3. The first section overviews the result of the data generation process. Also showed the descriptive statistics for considered variables in the current work. The second section validates model selection process of regression analysis, which helped us to find out significance relation between dependent and independent variables according to the climate of Karachi, Pakistan.

4.1. DESCRIPTIVE STATISTICS OF THE GENERATED DATA

To generate the dataset, an automated process has been employed, as it was explained in 3.4. At the end of the dataset generation process, 120 data points were obtained for the development of simplified method. This section demonstrates the descriptive statistics of the generated data.

Four different floor plan shapes, namely Rectangular, T-shape, L-shape, and U-shaped, has been considered in the simulation runs. Each of these plan shapes was iterated for 30 times and therefore was represented equally in the sample. That is, the final sample to develop the predictive model consisted of 120 observations in total.

Recall the sample consisted of four variables (see 3.2.2). Of these, Glazing Type (*GT*) is a categorical one whereas, relative compactness (*RC*), window to wall ratio (*WWR*) and energy use intensity (*EUI*) are in continuous domain.

Figure 4.1, Figure 4.2, Figure 4.3, and Figure 4.4 illustrate the descriptive statistics of the continuous variables. According to Anderson-Darling Normality Test, one can deduce that *EUI* and *WWR* violates the normality whereas *RC* shows normal distribution. Note that *EUI* is positively skewed. Variable *GT* has *three* groups as indicated in 3.2.2. Out of 120 observations, 38, 45, 37 data points belong to Single clear 8 mm., Double brown, and Single brown tint groups, respectively.

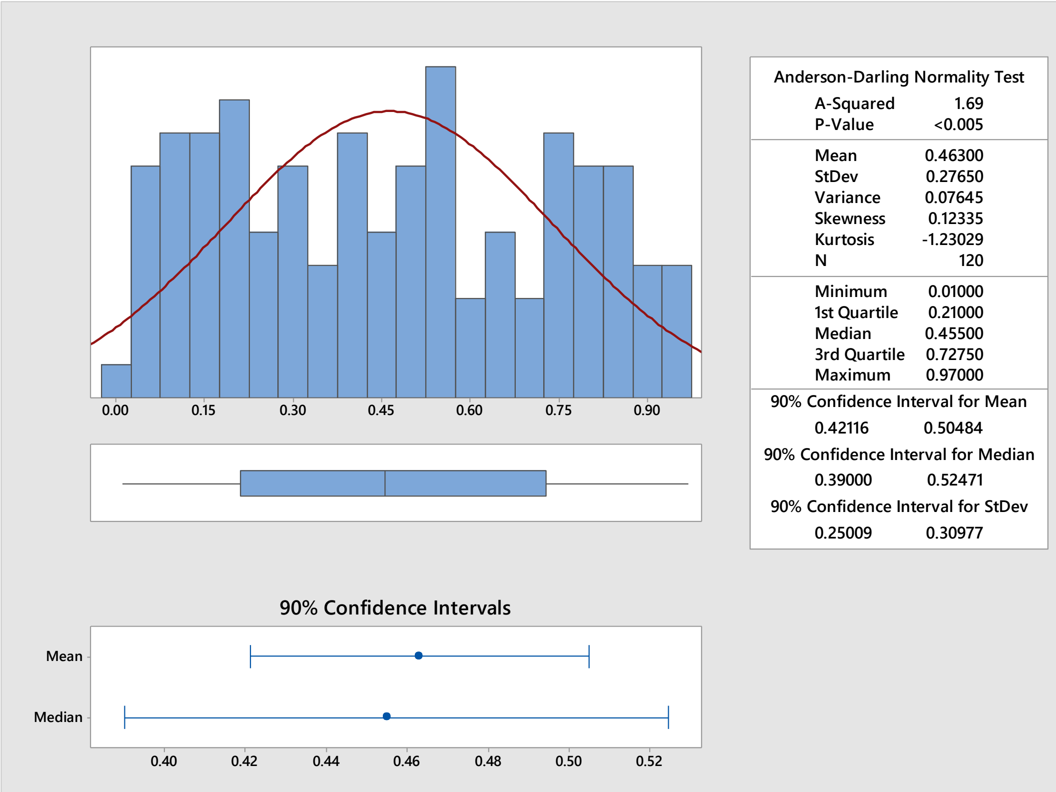

Figure 4.1. Descriptive statistics of window to wall ratio

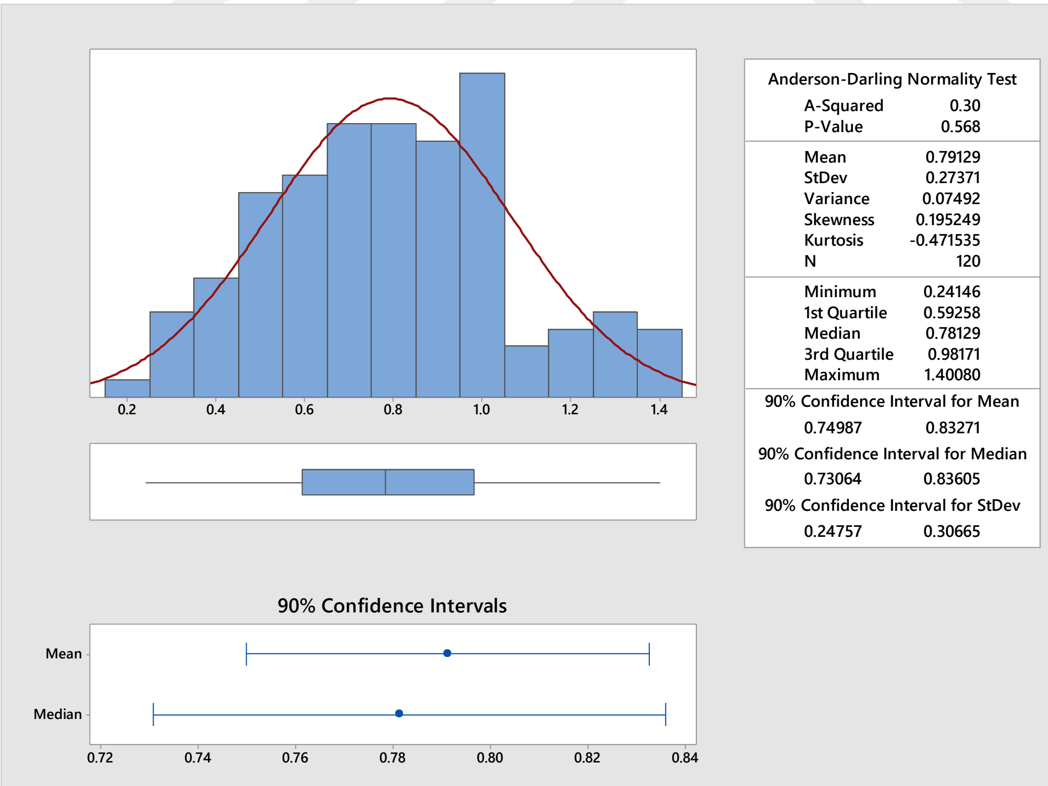

Figure 4.2. Descriptive statistics of relative compactness

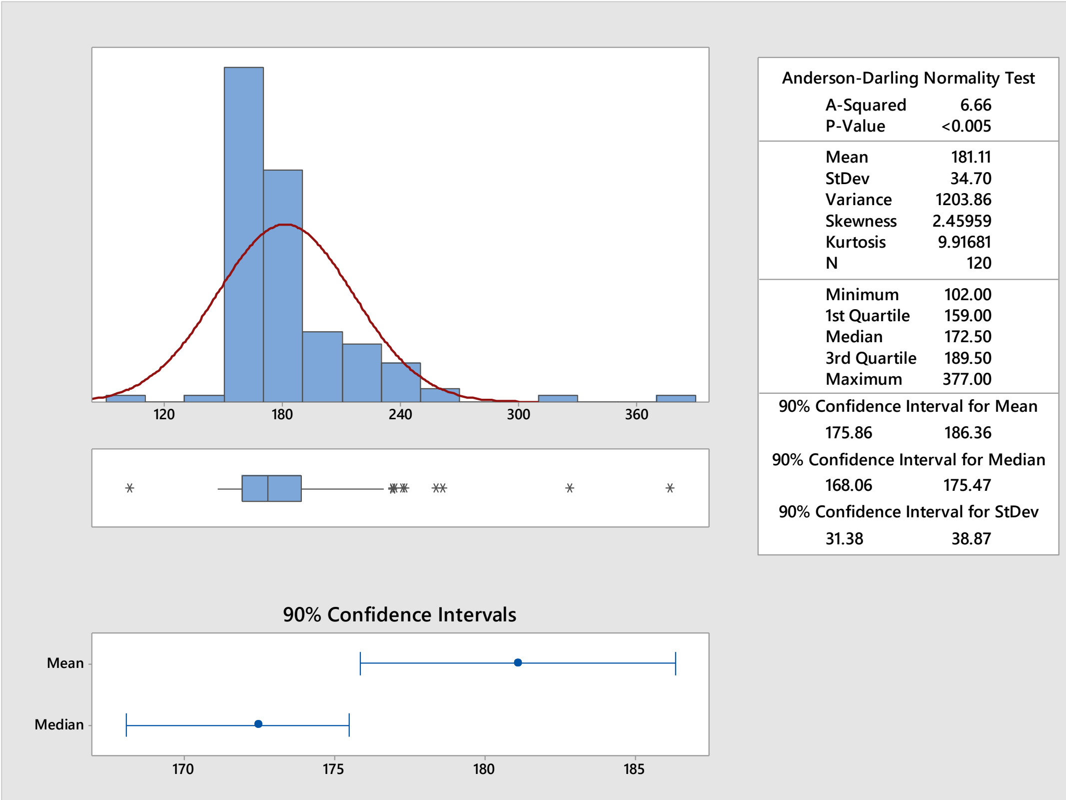

Figure 4.3. Descriptive statistics of energy use intensity

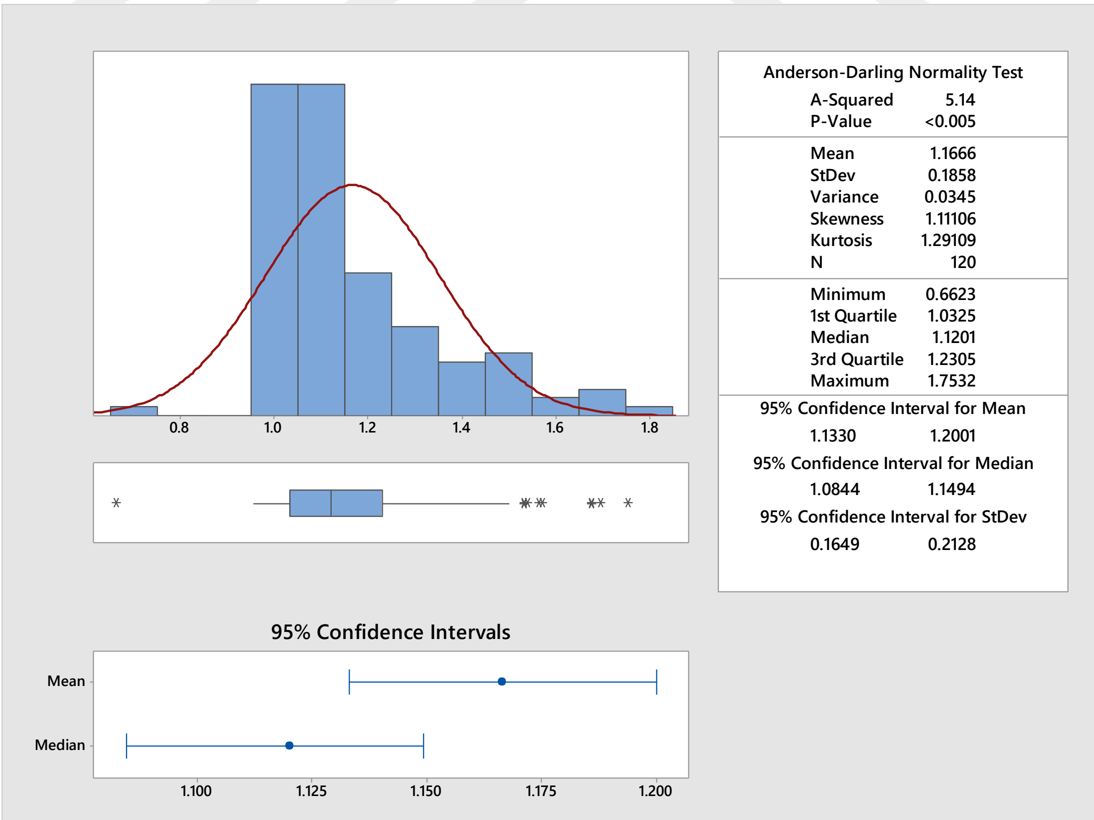

Figure 4.4. Descriptive statistics of the response variable (E_t / E_{ref})

Note that through development of regression models, the total energy use E_t, for building configuration is normalized relative to the total energy use, E_{ref} obtained for the reference building (with a square floor plan) to simplify the analysis, reasonably. This forms the response variable (E_t/E_{ref}). A related normalization is executed for the overall energy use.

Figure 4.5, illustrates the effect of the relative compactness (*RC*) on energy use ratio of studied shape and reference (E_t/E_{ref}) buildings in this analysis. All the figures indicate that the energy use decreases as the relative compactness increases. Certainly, as the relative compactness (*RC*) rises, the exterior wall area exposed to ambient condition decreases and accordingly the building energy load decreases.

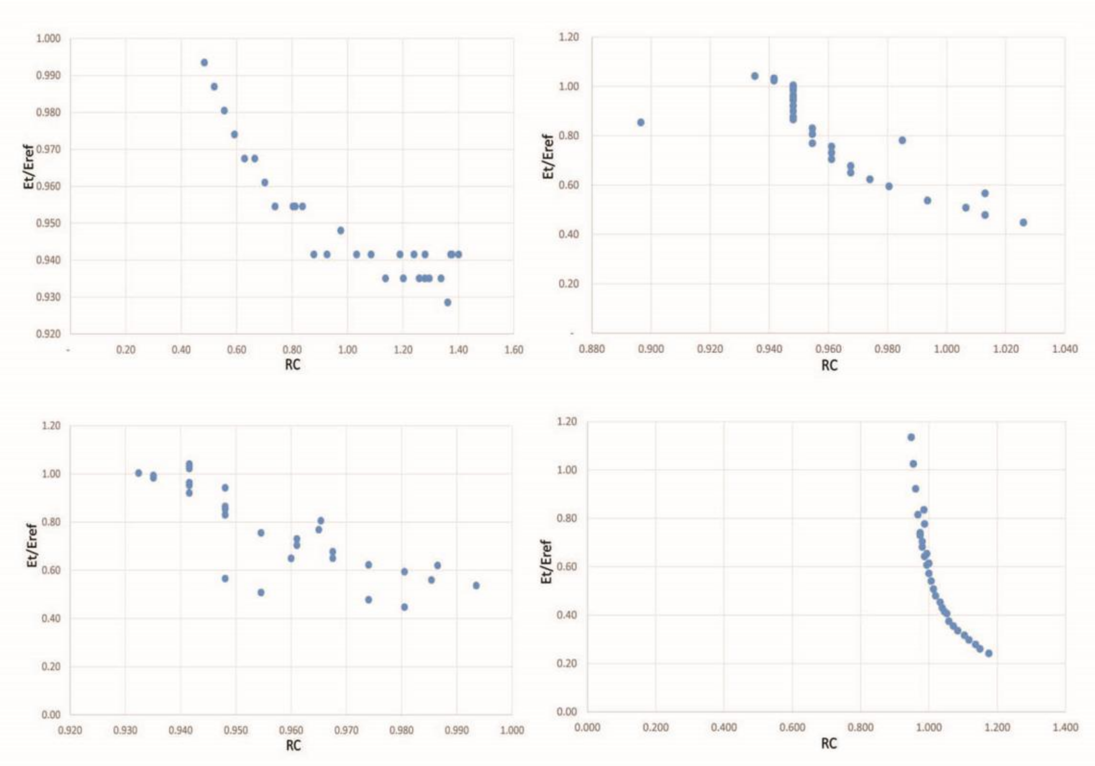

Figure 4.5. E_t / E_{ref} vs. *RC* values for plan shapes considered in the current work

4.2. DEVELOPMENT OF SIMPLIFIED METHOD

A multiple linear regression was calculated to predict dependent variable based on independent variables under study. In the current work, to develop a model for predicting total energy for the office building, the data from 120 different plan solutions by the four different shapes and following independent variables have been considered: Relative Compactness (*RC*), Window-to-Wall ratio (*WWR*), and *Glazing*

Type. Following below are question to research also by defining Null Hypothesis and Alternative Hypothesis.

Research Question:

- Q: Do *RC, WWR,* and *Glazing Type* cover a significant portion of variance in E_t/E_{ref}?
- H_o: *RC, WWR,* and *Glazing Type* DO NOT cover significant portion of variance in E_t/E_{ref}
- H_a: *RC, WWR,* and *Glazing Type* DO cover significant portion of variance in E_t/E_{ref}

To inspect the research question, a multiple linear regression will be developed to evaluate if the independent variables can explain the significant amount of variance in the dependent variable. A multiple linear regression calculates the relationship among a set of predictor variables on a criterion variable. In this case, the independent variables include RC, WWR, and Glazing type and the dependent variable is total energy building. Regression equation considered as it mentioned in equation number (3.2). Below are the results of overall regression model.

Table 4.1. Model summary of multiple linear regression analysis

S	R^2	$R^2_{(adj.)}$	$R^2_{(pred.)}$
0.086	79.17%	78.63%	77.90%

S is measured in the units of the response variable and represents the regular deviance of how far the data values decrease from the fixed values. R^2 is the percentage of variation in the response that is described by the model. The higher the R^2 value, the better the model fits data. R^2 is always between 0% and 100%. The Adjusted R^2 is used to compare models that have different numbers of predictors. R^2 always increases when you add a predictor to the model. Use predicted R^2 is to decide how well your model calculates the response for new interpretations. Models that have more predicted R^2 values have improved analytical capability.

In Table 4.1, R^2 = 79.17%, whilst the adjusted R^2 = 78.63%, which means that the independent variable (*RC, WWR,* and *Glazing type*), explains 79.17% of the variability of the dependent variable (E_t/E_{ref}). Adjusted R^2 is also an estimate of the effect size, which at 78.63%, is suggestive of a large effect size accordingly. This indicates that, overall, the model applied can statistically significantly predict the dependent variable (E_t/E_{ref}).

Table 4.2. Analysis of Variance results of the developed model

Source	*d.f.*	Adj. SS	Adj. MS	*F*-Value	*p*-Value
Regression	3	3.2532	1.08440	146.97	0.000
RC	1	1.1540	1.15402	156.40	0.000
WWR	1	1.6571	1.65711	224.59	0.000
GT	1	1.2356	1.23557	167.46	0.000
Error	116	0.8559	0.00738		
Total	119	4.1091			

Analysis of variance was conducted to determine the effect of *RC*, *WWR*, and *Glazing Type* towards explaining variance in the response variable, namely E_t/E_{ref}. The results (see Table 4.2) suggest, there was a significant effect of *RC*, *WWR*, and *Glazing Type* on E_t/E_{ref}. at the $p<0.001$ level for the conditions, [$F\ (3,116) = 146.97$, $p = 0.000$]. By reporting the degrees of freedom (*d.f.*), the *F* value (F) and the Sig. value (often referred to as the *p* value).

Table 4.3. Estimated coefficients of developed model

Term	Coef.	SE Coef.	*t*-Value	*p*-Value	VIF
Constant	1.5123	0.0325	46.59	0.000	
RC	-0.3687	0.0295	-12.51	0.000	1.05
WWR	0.4385	0.0293	14.99	0.000	1.06
GT	-0.12902	0.00997	-12.94	0.000	1.01

Taken together, these results suggest that *RC*, *WWR,* and *Glazing Types* do significantly influence on building`s Energy Use Intensity. Specifically, the current results suggest that when these all three variables implement together while designing office building, they can easily identify the effect on overall energy demand. However, it should be noted that variables level must be high to experience an effect. To sum up, with estimated *p*-value as smaller than 0.05, the null hypothesis is rejected, and the model seems suitable for predictions.

4.3. MODEL DIAGNOSIS

Established on the simplicity and accuracy, the total building energy demand from any building shape can be achieved from the following regression analysis equation:

$$E_t / E_{ref.} = 1.5123 - 0.3687 \times RC + 0.4385 \times WWR - 0.12902 \times GT \quad (4.1)$$

In equation (4.1) E_t and $E_{ref.}$ denote total energy demand of the building to be predicted, and reference building, respectively.

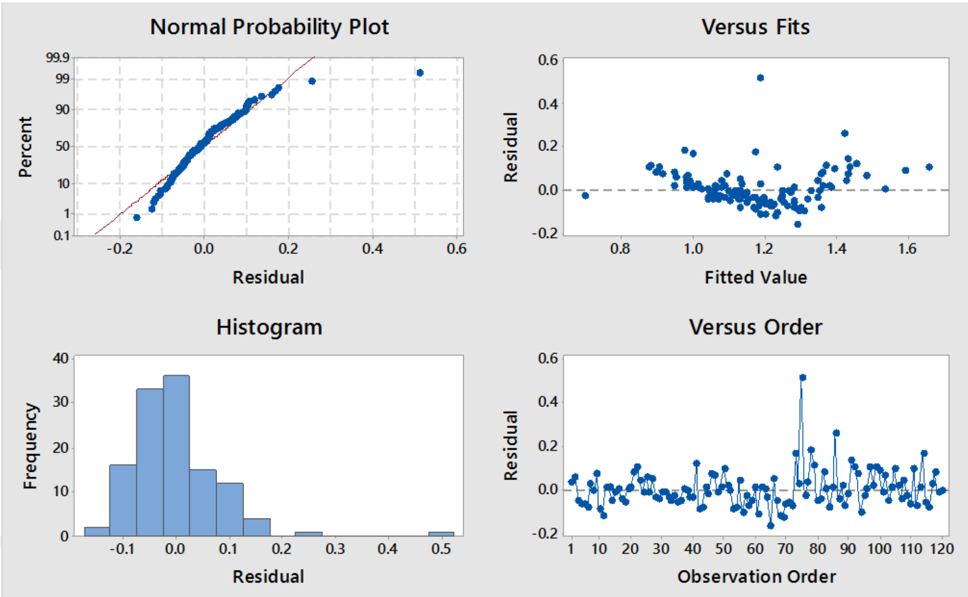

Figure 4.6. Residual graphs of the developed model

Figure 4.6 demonstrates the residual analysis conducted for the developed regression model. The intent of such analysis is to observe if there are any violations in model assumptions. Accordingly, one can see that:

- The graph on top left, suggested the assumption of normality of error. In this case, most of the points are collected around ref line suggesting that the error terms are normal.
- The graph on top right, plots the error terms against the fitted values. There are around half of them are above and half are below the zero-line indicating that assumption of error terms having mean zero is usable.
- The bottom left graph, again re-emphasizes the normality assumption. Sample size is about 120 values.

- The bottom right graph, is also important in this case because data is a relation between dependent variable and independent variables. A pattern shows that error terms are dependent on the variables.

4.4. SENSITIVITY ANALYSIS

The sensitivity analysis is a two-step method: first, one shall create base case for the particular model of building, then run computationally alternative scenarios based on altered values of independent variables to observe the change in the dependent variable. Table 4.4 summarizes the process as the base case model and created scenarios for comparison aims were outlined. 10 different scenarios were generated to assess the effect of change in relative compactness (*RC*) on energy use intensity while keeping window to wall ratio (*WWR*) and categorical variable glazing type constant (*GT*). In Table 4.5 the same process is repeated for *WWR*. One can see that, increasing and decreasing the value of *RC* and *WWR* has a significant impact on the outcomes of energy. The results are further illustrated in Figure 4.7 and Figure 4.8

Table 4.4. Observe change in EUI by consider different ratio of RC values on model equation

Tag	Scenarios	*RC*	*WWR*	*GT*	EUI (kWh//year)	Change in EUI
-------	Base Values	0.79	0.46	2	179.49	-------
Sc_01	RC +10%	0.87	0.46	2	175.00	**- %3**
Sc_02	RC +25%	0.99	0.46	2	168.26	**- %6**
Sc_03	RC +50%	1.19	0.46	2	157.03	**- %13**
Sc_04	RC +75%	1.38	0.46	2	145.80	**- %19**
Sc_05	RC +90%	1.50	0.46	2	139.06	**- %23**
Sc_06	RC -10%	0.71	0.46	2	183.99	**+ %3**
Sc_07	RC -25%	0.59	0.46	2	190.73	**+ %6**
Sc_08	RC -50%	0.40	0.46	2	201.96	**+ %13**
Sc_09	RC -75%	0.20	0.46	2	213.19	**+ %19**
Sc_10	RC -90%	0.08	0.46	2	219.93	**+ %23**

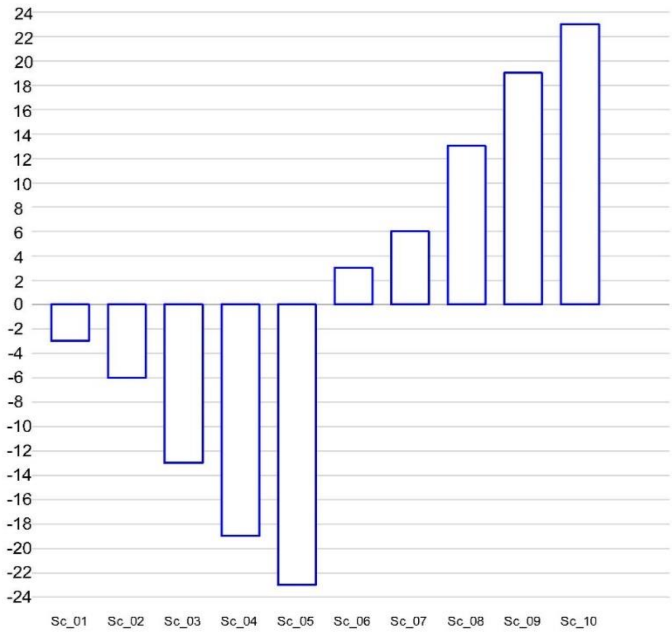

Figure 4.7. Graphical representation of change in *RC* values on model equation

Table 4.5. Observe change in EUI by consider different ratio of WWR values on model equation

Tag	**Scenarios**	***RC***	***WWR***	***GT***	**EUI (kWh)**	**Change in EUI**
-------	Base Values	0.791	0.463	2	179.49	-------
Sc_01	WWR +10%	0.791	0.509	2	182.62	2%
Sc_02	WWR +25%	0.791	0.579	2	187.31	4%
Sc_03	WWR +50%	0.791	0.695	2	195.13	9%
Sc_04	WWR +75%	0.791	0.810	2	202.94	13%
Sc_05	WWR +90%	0.791	0.880	2	207.63	16%
Sc_06	WWR -10%	0.791	0.417	2	176.37	-2%
Sc_07	WWR -25%	0.791	0.347	2	171.67	-4%
Sc_08	WWR -50%	0.791	0.232	2	163.86	-9%
Sc_09	WWR -75%	0.791	0.116	2	156.04	-13%
Sc_10	WWR -90%	0.791	0.046	2	151.35	-16%

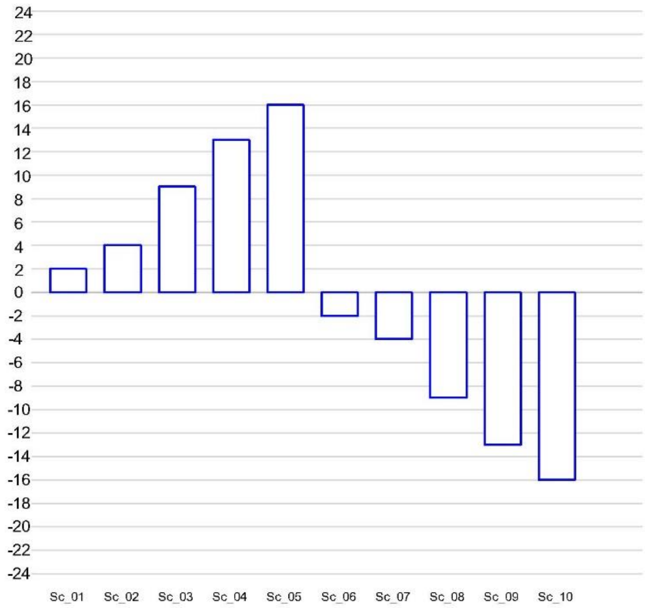

Figure 4.8. Graphical representation of change in *WWR* values on model equation

4.5. DISCUSSION OF THE RESULTS

The research established a basis for sufficiently recommending design alternatives and performance of control parameters of responsive variables with respect to the proposed goals. The need for developing a method restricted from the nonexistence method for exploring and evaluating the performance of office building respect to energy usage in the early design phases. Furthermore, a formal comparison of total energy usage between reference building (which is a square floor plan) and proposed or predict building shape was presented.

Understanding of energy use in buildings requires knowing the amounts of energy and of different fuels consumed for various end uses. These data are needed to evaluate the potential effects of energy efficiency improvements. Much less detailed information is available on energy consumption in buildings, which includes different types of buildings and variations of activity within buildings. Buildings require energy for heating, cooling, lighting, refrigeration, ventilation and other services. These uses combined with applications and office equipment, account for about half of total demand for energy and a similar proportion of all energy related CO2 emissions. Improvements to the efficiency with which energy is used in buildings could offer considerable opportunities for reducing those emissions.

Figure 4.5, present relationships between quantitative variables when the relative compactness (independent variable) on the x-axis has number of levels. Each point in a scatterplot represents an individual rather than the mean for a group of individuals. Fig. 4.5, illustrate the overall impact of the relative compactness (RC) on normalized total energy for all the shape considered in the analysis. The results indicate that the energy use decreases as the relative compactness increases. Indeed, as the relative compactness (RC) increases, the exterior wall area exposed to ambient conditions decreases and consequently the building cooling load decreases. By observe each shape individually, energy is going low as the relative compactness increasing, however some of the observations has little variations in energy demand, this is because role of window to wall ratio (WWR) as the second independent variable in this current work along with the solar heat gain coefficient of different glazing types. Generally, all four shape expressing same situation of relation between relative compactness and energy demand for office buildings. Although, U-shape has little dissimilar outcome of energy as compared to other three shape. This is because of effect of relative compactness of U-shape building, Fig 3.4 indicated the values of RC, due to low RC value the energy outcomes is high in the particular shape.

The results of comprehensive parametric analysis specify that the effect of building shape on energy use intensity be contingent on mainly three factors, the relative compactness (*RC*), the Window to Wall Ratio (*WWR*), and glazing type distinct by its Solar Heat Gain Coefficients (*SHGC*). For buildings with small window to wall ratios, it is found that the total energy use is contrariwise proportionate to the building relative compactness liberated of its form. Based on regression examination, it is found to offer a solid relation between the entire cooling energy use and the three parameters *RC*, *WWR*, and *SHGC*. The correlation equation (4.1) can be use by architects during initial design phase to calculate the impact of shape on the energy efficiency of office buildings in Karachi, Pakistan.

By using regression equation for the energy in development of simplified method section cleared that the effect of variables on final outcomes have significant impact on overall building energy use. Using correlation equation is convenient method for designers and architects while at initial design phase. Secondly, after successfully test of sensitivity analysis also clarified the impact of relative compactness (*RC*) and window to wall ratio (*WWR*) have enough impact on energy result. As it is clearly described in Table 4.4 , Table 4.5 and explained that by increasing and decreasing in small amount of independent variable ratio have definite change in energy use intensity (*EUI*). Figure 4.7 and Figure 4.8 are further provided for graphical expression. 10 different scenarios for each variables were generated to assess the effect on change in energy as shown in Figure 4.7 and Figure 4.8. By comparing both variables, it is clear that the change in energy is mainly depend by increasing/decreasing in relative compactness of the building.

CHAPTER 5
CONCLUSION

As peak of the reviews in this thesis validate intensely, there is a necessity to study energy effectiveness. There are marks that energy efficiency is now being extra valued and considered by the community. The consciousness and the different operations helped appeal for more devotion to the matter of the growth of carbon dioxide. Hence buildings should be planned to improve energy in use and without negotiating enactment concerning comfort conditions.

The current research initially introduced the aim to predict the energy use intensity of high-rise office developments in Karachi, Pakistan. We achieved this goal by investigating on the energy performance of the building by consideration of different sets of three main parameters. These variables established as the main responsive aspect for the energy use intensity. Prior to prediction model, several simulations were conducted by using computational methods. In these tests, we calculated different solutions with altered values of independent variables under study for such alternative plan shapes as Rectangular, L, T, and U-shape. On the other hand, when utilizing computational models for such kind of study it reduced time and reduced the computational cost significantly. The computer conducted most of the process in an automated fashion. The investigation of the energy performance for the office building is remain constant 24 hours a day.

Considerate of energy use in buildings needs significant the amounts of data points. These data are needed to evaluate the possible effects of energy efficiency developments. Much less detailed information is available on energy consumption in office buildings, which includes different types of working hours and variants of activity within buildings. Buildings want energy space for heating, water heating, lighting, refrigeration, ventilation and further facilities. These uses collectively with confined utilizations and office equipment, interpretation for about half of total request for energy and a comparable ratio of all energy related CO_2 releases. Enhancements to the effectiveness with which energy is used in buildings could offer substantial chances for reducing emissions.

Performance base design approach offers a great potential for investigating alternative designs in a timely efficient manner. When coupled with performance simulation tools, the approach becomes even more powerful. Although the nature of performance-based design approach is very suitable for energy usage, after a comprehensive review of the literature, we had the opinion that there is a basic lack in utilizing the full potential of the approach in conceptual design of energy usage in the region Pakistan.

Utilization of computational problem-solving techniques in the research of energy usage intensity for high-rise is far more satisfactory. Using regression equation for significance as models offers a time-efficient way for performance assessment of relation. The reason for this is not just because regression provides better results, but also the technique has a much lower computational task, solutions can be obtained in a much faster manner. Therefore, regression techniques can offer an even wider investigation possible in the conceptual design of energy evaluation phase. However, there is a gap in the literature about the use of regression analysis technique at the conceptual design. The design and arrangement of buildings to make the most of the sunlight is deliberated as ecologically responsive and has achieved enormous influence on cities and cities. From an engineering point of opinion, it is measured of extreme interest, and the inactive solar methods have been widely expected by the tenants.

The current research developed a regression equation as it’s discussed above, this technique is for investigating performance of the proposed dependent variables and responsive variables. By doing this, we were able to explore the performance of these variables under different solution values which is in an efficient manner. The analysis yielded in following equation:

$$E_t / E_{ref.} = 1.5123 - 0.3687 \times RC + 0.4385 \times WWR - 0.12902 \times GT$$

Using sensitivity test at the end, further clarified the effect of each independent variable on dependent variable. It can be seen clearly that the change in value by certain ratio has a change in effect of energy.

Within the scope the research, we examined around 120 different options for four building shapes. However, further research can easily apply the method to all several other options for the building form or shape over the course of a year. In this way, the annual performance of energy use intensity can be observed and analyzed.

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