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The Potential for Energy Saving through a Simplified Prescriptive Method as an Alternative to the Performance-Based Approach to Buildings' Thermal Quality

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Disclaimer

I hereby declare that this dissertation is my own original work and has not been submitted before to any institution for assessment purposes. The collection and analysis of the data set used in this dissertation is a joint work with a study of my colleague (Wadi 2019). Further, I have acknowledged all sources used and have cited these in the reference section.

Signature

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Kurzfassung

Wohngebäude verursachen einen seit Jahren größer werdenden Anteil am globalen Energieverbrauch, aktuelle Studien nennen Werte um 25%. Im Gaza Streifen (Palästina) fließen durchschnittlich 70% des elektrischen Stroms, der in Gebäuden verwendet wird, in die Gebäudekühlung. Da hier eine ansteigende Bauaktivität von Wohngebäuden zu verzeichnen ist, steigt dementsprechend auch der Energieaufwand für die Gebäudekühlung. Der Kühlbedarf wird wesentlich von der Art und Weise wie Gebäude errichtet werden beeinflusst. Dabei gibt es eine Anzahl von Design Parametern die starken Einfluss haben, wie z.B. Gebäudeform, Anteil von transparenten Gebäudeelementen, Fensterorientierung und thermischer Hüllqualität. Eine Berücksichtigung von Performance-Kriterien sollte bereits in frühen Phasen des Gebäudeentwurfsprozesses erfolgen, nachdem in diesen Phasen eine starke Beeinflussung möglich ist. Zur Abschätzung des Energieverbrauchs bzw. der Gebäudeperformance gibt es eine ganze Reihe von Verfahren. In den frühen Entwurfsphasen ist eine Verwendung von leistungsstarken Simulationswerkzeugen oftmals problematisch, daher sind hier andere Verfahren durchaus als sinnvoll zu betrachten. In dieser Arbeit wird die Entwicklung eines präskriptiven Abschätzungsverfahrens via statistische Regression beschrieben, welche anhand eines Gebäudesamples aus dem Gazastreifen entwickelt wurden. Die Idee dahinter ist ein robustes und nicht zu aufwendiges Verfahren zur Abschätzung des Kühlbedarfs von Gebäuden in dieser klimatischen Region zu erstellen.

Zunächst wurde mittels Korrelationsanalyse untersucht, in wie weit verschiedene Parameter betreffend Morphologie und Gebäudehülle im Vergleich zu Ergebnissen von numerischer Simulation verhalten. Unter 10 untersuchten Variablen konnten mit dem *Building Shape Factor (SF)* und einem betreffend Verschattung und Orientierung gewichteten Verhältnis von Fensterfläche zu Wandfläche (*Window to Wall area ratio adjusted for orientation and fixed shading* (WWR_{os})) zwei identifiziert werden, die gut geeignet als potentielle präskriptive Parameter schienen. Mittels einer Regressionsanalyse konnten Formeln erstellt werden, mit deren Hilfe der Energieverbrauch basierend auf diesen Variablen abgeschätzt werden kann. Dabei schwanken die Differenzen zwischen simulierten Energieverbräuchen und präskriptiv-errechneten Energieverbräuchen zwischen einem und fünfzehn Prozent. Der Bestimmtheitsgrad (R^2) ist höher als 0,8, damit kann gesagt werden, dass sich die Ergebnisse beider Verfahren eine recht gute Übereinstimmung zeigen, bzw. dass der Kühlenergiebedarf mit einer recht annehmbaren Genauigkeit vorhersagen lässt. Damit lässt sich in frühen Entwurfsphasen relativ einfach eine Abschätzung des zukünftigen Kühlbedarfs durchführen und dies für viele verschiedene Varianten und Design-Optionen.

Zur Absicherung der Resultate wurden die Überlegungen anschließend mit Variation der thermischen Hüllqualitäten angereichert, so dass drei unterschiedliche Regressionsmodelle zur Erstellung des präskriptiven Index herangezogen werden konnten. Es bleibt zu hoffen, dass die in dieser Master-Arbeit dargestellten Bemühungen für die Erhöhung der Energieeffizienz im Gaza-Streifen herangezogen werden können.

Schlüsselwörter: präskriptiver Ansatz, performance-basierter Ansatz, multiple, lineare Regression, Kühlbedarf, Wohngebäude, Gebäudeperformance Simulation, Building Design Parameter

Abstract

The global contribution from residential buildings towards energy consumption has steadily increased reaching figures around 25% (IEA 2016). Surprisingly, the energy consumption for space cooling accounts for more than 70% of the overall electricity use in a typical building in the Gaza Strip (Muhaisen 2007). Recently, construction of residential buildings in Gaza Strip has significantly increased and consequently, the demand for space cooling has increased. This energy demand is significantly affected by "Building design variables", such as building shape, glazing area, windows orientation and thermal characteristic of building envelope. Thus, it is essential to estimate the energy required for space cooling based on those variables at the early-stage building design in order to obtain less energy consuming buildings. Building simulation models can accurately quantify building energy loads but are not amenable to the early design phases. On this note, this study presents a new modeling approach to quantify building energy performance in early design stages through the development of multiple linear regression model. The resultant multiple linear regression model is based on a set of detailed simulations that consider the complex thermal interactions represented within a full-scale energy simulation engine, but once developed, can operate independently of the original, full scale model. This model was developed for the prediction of annual cooling loads in representative residential buildings across the climate of Gaza Strip, Palestine.

A correlation analysis was conducted for ten different building envelope parameters: Thereby, two of these parameters have been identified as significant: the building Shape Factor (SF), and Window to Wall area ratio adjusted for orientation and fixed shading (WWR_{os}). Subsequently, the results of the energy simulations were implemented into a regression equation to predict the energy consumption. The differences between regression-predicted and simulated annual cooling energy requirements were in the order of one to fifteen percent. The coefficient of determination (R^2) exceeded 0.8, and thus indicating a good agreement between simulation results and the regression model. Based on the findings it can be said that the annual cooling energy requirements can be forecasted using the regression model with an acceptable accuracy. It is envisaged that the developed regression model can be used to estimate the total energy consumption in early stages of the design process when different building schemes and design concepts are being considered.

In order to set a future target for building envelope upgrade, two more scenarios with different thermal characteristics of building envelopes were studied. Based on that, three regression equations were used to develop the prescriptive index. Such a streamlined method will hopefully encourage the decision makers to integrate the prescriptive approach, through developing regulations regarding building energy efficiency in Gaza Strip, Palestine.

Keywords: Prescriptive Approach, Performance-Based Approach, Multiple Regression, Cooling Demand, Residential Buildings, Energy Simulation, Building Design Variables.

Contents

Nomenclature

Acronyms

IEA	International Energy Agency
BEECs	Building Energy Efficiency Codes
EBC	Energy Building Codes
BPS	Building Performance Simulation
EU	European Union
EUI	Energy Use Intensities
PEBC	Palestinian Energy Buildings Code
GHG	GreenHouse Gas
HVAC	Heating Ventilation and Air Conditioning
GEDCO	Gaza Electricity Distribution Company
IEC	Israel Electric Company
ISO	International Organization for Standardization
ACH	Air Changes per hour [h^{-1}]
LI	Labelling Index
MEC	Model Energy Code
LEK	Line of European K-values
SPSS	Statistical Package for the Social Sciences
SHGC	Solar Heat Gain Coefficient
AISR	Annual Incident Solar Radiation [$W.m^{-2}$]
FSC	Fixed Shading Coefficient
SEF	South Equivalent Factor
WWR	Window to Wall Ratio [%]
WWR_o	Window to Wall Ratio weighted for Orientation [%]
WWR_{os}	Window to Wall ratio weighted for Orientation and fixed shading [%]
WFR	Window to Floor Area Ratio [%]
BEI	Building Energy Index

Symbols

SF	Shape Factor [m^{-1}]
L_b	Characteristic Length [m]
A_i	Thermal Component's Area [m^2]
V_b	Conditioned Volume [m^3]
C_t	Thermal Compactness [m]
f_i	Temperature Correction Factor
R_c	Relative Compactness
S	Separation Dimensions [m]
W_o	Overhang Width [m]
U	Thermal Transmittance value [$W.m^{-2}.K^{-1}$]
U_w	Area weighted average U value [$W.m^{-2}.K^{-1}$]
U_e	Effective Average Envelope U value [$W.m^{-2}.K^{-1}$]

1. Introduction

1.1 Overview

The global contribution from residential buildings towards energy consumption has steadily increased reaching figures around 25% and about 17% of greenhouse gas emission (GHG), and as such represent a key target for efficiency improvements (IEA 2016). Reducing energy demand in buildings has been identified as one of the most cost-effective method according to the International Energy Agency (IEA 2016). At the same time, reducing energy demand in buildings can play one of the most important roles in solving many challenges, such as reducing carbon dioxide CO_2 emissions (IEA, 2010). Lechtenböhmer et.al (2011) found that up to 80% of residential GHG emission production could be avoided using relatively simple measures and baselines, e.g. better insulation of the different components of the existing building stock as well as the new buildings.

One of the essential parts of building energy managements and establishing baselines is the modeling of energy consumption, which enhance the estimation of building energy consumption. Although the prediction of building energy demand is the key tool to minimize energy consumption and its related emissions. However, predicting the current and future energy demands loads for buildings is a complex task that involves significant knowledge and expertise, since it depends on multiple variables such as such as ambient weather conditions, building structure and characteristics, the operation of sub-level components like lighting and HVAC systems, occupancy and their behavior (Asadi et al. 2014).

In the last decade, industry and government initiatives have catalyzed the design of energy efficient buildings through high visibility efforts such as Energy Building Codes (EBC). Most EBC nowadays offer two paths for compliance: Performance-based or Prescriptive approach.

The Performance-based approach allow the building to be constructed in a way to satisfy specific measurable or predictable performance requirements, such as energy efficiency, without prescribing exactly how these outcomes are achieved. The results of performance approach are determined using computer modeling software that predicts building energy consumption based on inputs data including: (1) systems variables, (2) internal loads, (3) internal load schedules, (4) systems schedules, (5) building geometry, (6) real time weather data, (7) thermal characteristic of building envelope, (8) urban environment influence (Heidarinejad, 2014). After entering the collected building data in the appropriate energy simulation tool (e.g., EnergyPlus, TRNSYS), the components and systems are manipulated until the desired efficiency goal is achieved.

On the other hand, a prescriptive approach used different alternatives describing limit values for various elements in a construction project which the designer or building owner can choose from. Common prescriptive measures include minimum thermal transmittance (U) values for insulation or wall assemblies, acceptable infiltration rates, recommended glazing area, etc.

Despite the significant benefits of adopting a performance-based approach, it is widely recognized that utilizing a performance-based approach is more complex, expensive and time consuming than using the less complex prescriptive route. Besides, energy simulation is not often used to provide feedback during the early stages of design, even though decisions at this stage have the biggest influence on energy and cost. The great benefit of prescriptive approach is eliminating the great costs and time that are related to the energy model that must be developed and simulated in performance-based approach. Although, that may result in less accurate energy consumption.

This study presents a practical and realistic approach to quantify building energy performance in early design stages. A multiple regression model has been selected to find a compromise between the simplicity of the evaluation method and the accuracy in the result without requiring a considerable amount of input data and simulation energy. Through identifying explicative variables to develop a model in which the chosen variables influence the response and the variables that do not contribute relevant information are rejected. The regression model is developed by regressing data points from runs with EnergyPlus, an existing building energy simulation engine. The resultant multiple linear regression model is based on a set of detailed simulations that consider the complex thermal interactions represented within a full-scale energy simulation engine, but once developed, can operate independently of the original, full scale model.

The developed regression model can be used as a design tool that provides fast and accurate method to estimate the energy consumption of residential buildings at the design stage. Through examining that meeting certain prescriptive standards can be assured of designing a building that is truly energy efficient. Unlike existing tools such as EnergyPlus, a designer can simultaneously use the regression model without the need to rerun the energy simulation for each design iteration. The current regression model is limited for residential buildings in the climate zone of Gaza Strip (Palestine).

1.2 Motivation

The energy sector in Palestine faces significant challenges, basically the complete dependence on the external sources (mainly from the Israeli sources for the supply of electricity, gas, and fuel), the high financial costs to import these energy sources and finally, the environmental risks arising from the use of traditional sources of energy (AlArda et al. 2015). According to (Muhaisen 2007), more than 70% of the total annual electricity is consumed by domestic buildings. Such challenges must lead us to establish certain guidelines to improve the building towards energy efficiency, through setting up a simple, fast and conservative approach for buildings related to thermal envelope design. However, Palestine as a developing country must benefit from the accumulated best practice experiences of many countries in these fields.

Since 1970s, countries have been looking for solutions to improve energy efficiency in buildings and their systems. As the requirements of sustainability has increased, architect and engineers has prompted to pay more attention of energy performance of their design. The design decisions, such as building form, orientation, fenestration, and construction materials, made in the early design stages have the most impact on the building energy performance (Hong et al. 2000). According to (Ad-Hoc. 2012), more than 80% of the building performance, in terms of energy savings, generation, and cost, is set during the design phase**.** In other words, designing for energy efficiency – at the earliest possible stage of the design process – is the most cost-effective means of enhancing energy performance in buildings.

The complexity of this task is more than one individual can handle and requires input from multiple disciplines (Kalay 1998). Frequently, however, in a conventional design approach, the architectural team determines the building shape and façade’s design, including orientation, glazing area, and window placement. This happens without sufficient design-support environment for exploring the impacts of choices on indoor comfort, building services and energy performance (Bambardekar et al. 2009). Besides, most of simulations tools are not in tune with the architect’s approach and not suitable for early design stages when major decisions are made (Weyjens 2010). These Architectural designs are then passed on to HVAC engineers, who perform a thermal analysis and design the necessary systems to ensures compliance with applicable energy codes and achieves acceptable levels of environmental comfort for building occupants (Todesco. 1998). From an engineer's perspective, energy efficiency occurs by improving the design of the HVAC system. It is then the engineer's goal to create an efficient system within the context of the building envelope that has been previously designed. According to (Holm. 1993), the thermal analysis is done at a stage when major design decisions have already been made. It is then difficult for the architect to change his design based on the thermal analysis results. Therefore, it is essential that architects are able to evaluate their designs before important building characteristics are frozen.

In the past few years, BPS has rapidly increased. The US Department of Energy created the building energy software directory, which lists more than 175 BPS (US Dept. of Energy, 2018). The utilization of BPS can obtain an accurate prediction result. However, a BPS usually requires a plenty of inputs. Establishing those inputs for a BPS is quite time consuming (Attia et al. 2012). Another limitation of implementing a BPS in the early design stages is the necessity of detailed information as input which can only be obtained in further design stages (Weyjens 2010). Uncertainty of inputs may cause doubtful simulation outcomes that produce incorrect information for decision making (Bazjanac et al. 2011). In addition, to perform a BPS, a good understanding of the thermal processes and simulation tool is required. However, in early design stages the performers are usually architects. Unlike the professional engineers, these architects have limited knowledge in this professional field. Hence, despite the rapid advancement in the application of BPS, architects still suffer from the barriers of employment of such complex BPS (Poerschke 2009).

Consequently, developing a simplified prescriptive approach can provide an easy and quick energy consumption prediction, thus assisting architects in considering design alternatives. Although the prescriptive option establishes limits of physical properties of envelope materials and components and equipment efficiency. However, such a simple path which does not require much detailed information as inputs, can perform preliminary energy performance prediction and inform early design decisions without the aid of any software. Furthermore, construction market professionals and users without any specific technical knowledge on simulation can optimize the design of the building regarding energy efficiency in a quick and straightforward way. Such a streamlined method will hopefully enhance the buildings energy efficiency in Gaza Strip.

2. Background

2.1. Energy in Buildings

2.1.1. Overview

Building sector consumes more than the third of the total energy worldwide (IEA, 2015). Driven by the rising population, expanding economy and a quest for improved quality of life, energy consumption has increased, and the growth rates are expected to continue. This, in turn is the major contributor affecting the environmental sustainability through producing GHG emissions, causing climate change and consuming non-renewable resources. In responding to these challenges brought by the increasing energy consumption, countries are independently designing and implementing energy efficiency policies and programs in residential and commercial buildings to decrease energy waste in the new and existing building stock.

2.1.2. Building Energy Codes

Nowadays, the development of low energy buildings is currently one of the most important goals in many environmental programs worldwide. Establishing standards for the evaluation and classification of buildings in terms of energy performance consider as one of the alternatives to reduce building energy consumption. Building energy codes -also referred to as building energy regulation- are often used to underpin labeling or disclosure programs and as a technique to define minimum energy performance standards for buildings. The main objective of building energy codes, however, is usually to assist reduce energy consumption in the building sector or any related parameter such as CO2 emissions without compromising comfort, health and productivity levels. Building energy codes have served save 6–22% of average annual energy consumption in buildings of the European Union (IEA, 2013). Therefore, Countries have developed diverse approaches to implementing building energy codes.

2.1.2.2. Different Approaches of Energy Building Codes

The different types can be simplified into two basic forms. Building codes which are based on energy efficiency requirements for individual building parts - “Prescriptive Codes” - and the codes for which these requirements set the overall frames in order to calculate energy consumption - “Performance based building codes”.

Prescriptive Code

Prescriptive code seems to be a preferred approach exercised by government agencies in developing countries. The prescriptive scheme uses the simplified method to calculate the energy performance of the building envelope and to assess the energy efficiency level (Melo et al. 2014). Through provide minimum standards for the materials, equipment and methods of efficient design and construction that must be met to qualify for an energy efficiency rating. Although the prescriptive path perceived to provide better certainty as to how excessive energy use in buildings can be addressed, in most cases they fall short of economically and technically optimal levels of energy savings. Besides, the ability of the simplified method for determining energy efficiency levels showed inaccurate estimates for residential buildings compared with building performance simulations as investigated by (Van 2011). The most serious problem with the prescriptive approach is that it serves as a barrier to innovation. Improved and/or cheaper products may be developed, yet their use might not be allowed if construction is governed by prescriptive codes and standards. Another problem with the prescriptive approach is that it makes it very difficult to cost-optimize building construction. For example, "in the prescriptive approach, a specific set of framing and construction details for houses in a high-wind region would be required. This prescriptive solution would "imply" a certain level of performance, but this is not explicitly or quantitatively stated. Thus, it would take a tremendous amount of work to demonstrate that another solution (e.g., a framing system with fewer members but with innovative configuration and connections) would equal this unspecified performance level" (Foliente 2000).

Performance-Based Code

To evaluate whole building level performance, the performance-based compliance path is well adopted by many countries' code development and is especially widely used in evaluating energy savings potential of green buildings. The performance-based approach is a more cost-effective alternative to pure prescriptive approach for they offer greater flexibility to designers, contractors and operators in choosing technical solutions. The performance-based method utilizes actual building energy consumption data to evaluate building energy efficiency, which is then compared with the required standards of the program.

If a building is viewed as a matrix of parts and attributes, the main difference between the traditional prescriptive approach and the performance approach can be illustrated as shown in Figure 1 below. In the prescriptive path, the building components are qualified, and acquired, which result in a building with an implicit set of attributes (Figure 1a). In the performance approach, the building attributes are described and specified, and many combinations of different building parts can be procured for which it can be demonstrated that the specified attributes will be provided (Figure 1b).

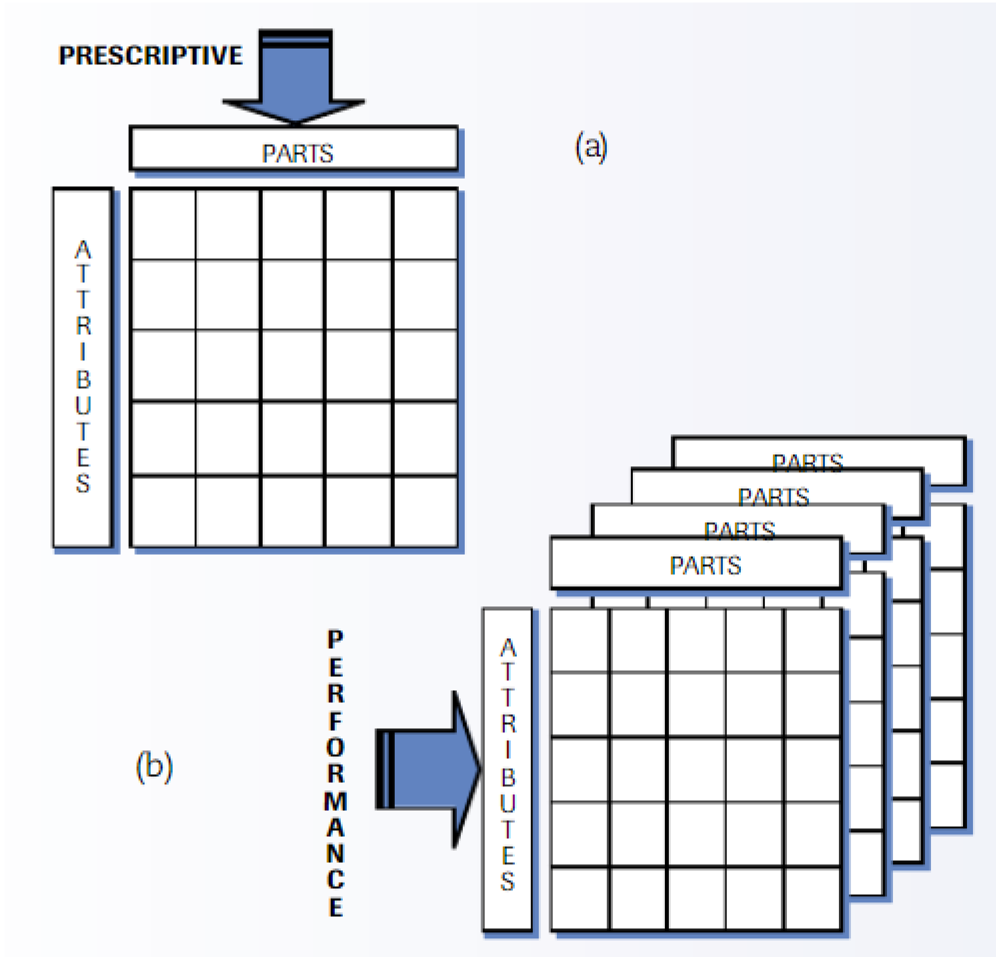


Figure 1 A matrix of parts and attributes: (a) Prescriptive; and(b) Performance approach
Source: (Hattis 1996)

Performance and Prescription Mix

Most design briefs agreed between building owners/clients and designers are a mixture of prescriptive and performance specifications. The more performance-oriented the specification is, the more freedom the designers have to provide alternative solutions. A lower-level specification is more prescriptive and constraining. But the higher the level of specification in terms of performance, the more difficult it is to find a universally acceptable method for the verification of performance (Pham and Boxhall 1999). Australia established the energy efficiency component of its building code in 2003, and it allows for either a performance-based approach to compliance or a prescriptive approach based on requirements for specific building components (Evans et al. 2009). In Japan, there are two energy codes for residential buildings or houses, both launched in 1999. The design and construction guidelines on the rationalization of energy use for houses is a prescriptive-based method, including insulation of the building envelope, HVAC and water heating, as well as guidance on maintenance and operations. The criteria for clients on the rationalization of energy use for house is a mix of performance and prescriptive-based building energy codes and has a focus on HVAC. It also provides performance-based annual heating and cooling loads according to building type (PNNL 2009).

However, according to (Feng et al. 2017), the prescriptive and performance-based standards also exhibit issues in following circumstance:

- Prescriptive and performance-based standards are often applied to permit new construction, but not often used in existing building.
- Prescriptive and performance-based standards tend to focus more on energy conservation measures and model energy performance, than on the actual energy use.
- There are unregulated measures, such as occupant's behavior, which are difficult to regulate through the prescriptive and performance-based standards.

As a result of the drawbacks of prescriptive and performance standards, some countries have developed outcome-based energy codes and standards.

Outcome-Based Code

Outcome based codes and standards regulate one building's performance in its operation stage. It establishes a target energy use level and provide for measurement and reporting of energy use to assure that the completed building performs at the established level. "*Such a code can have significant flexibility to reflect variations across building types and can even cover existing or historic buildings. Most importantly, it can address all energy used in buildings and provide a metric to determine the actual quality of the building construction*" (Colker 2017). The actual energy use of a building is highly variable and depends upon numerous factors that not traditionally addressed in an energy code, such as operations and maintenance practices, quality of installation, and systems-level interactions. The addition of an outcome-based compliance path to existing codes would establish a mechanism for codes and code departments to help support achievement of community-level goals and the code departments that would deliver on such results. For example, outcome-based often requires buildings to continuously operate for at least one year after its occupation and use the measured performance data obtained in that period to compare with targets set by the outcome-based standard in order to achieve compliance. Table 1 below summarized the main differences between different buildings' energy codes.

Table 1 Comparison of Different Energy Codes Approaches. Source: (IMT 2017)

Prescriptive	Performance	Outcome
• Sets minimum characteristics for individual components • Easy to use/enforce • Slow to incorporate new technologies • Depends on increasing efficiencies in individual components • Do not reward efficient design decisions • No assurance or requirement to measure results are met	• Set desired end-state—often based on anticipated results from prescriptive code • Flexibility for the design team (but more difficult for code officials) • Technology neutral • Based on building energy models • No assurance or requirement to measure results are met	• Establish a target energy use level and measurement and reporting to assure performance at established level • Includes all energy uses • Flexibility for design team • Assure actual results • Can recognize diversity across building types, even existing and historic buildings

2.1.2.2. Building Energy codes in developing countries

In developed countries, the introduction of energy efficiency codes for residential and non-residential buildings started around the time of the first oil crisis in the mid-70s (EC 2002). In relation to developing countries, the first regulation for the energy efficiency of residential buildings was approved in China in 1986 (Lee and Chen 2008) .However, in most countries, for instance, Brazil, India, Iran, Hong Kong, Egypt and Mexico, such regulations were implemented after the mid-90s (Carlo 2008).

Iwaro and Mwasha (2010) analyzed the status of 60 developing countries through an online survey, the number of developing countries, which are advancing the terms of their building energy efficiency regulations, continues to grow. Their study demonstrated progress in the development and implementation of building energy efficiency regulations in Africa, Latin America and the Middle East. However, the countries of these regions are still far behind developed countries. Moreover, the government in most cases takes the decisions related to the regulations, with little or no participation from non-governmental entities. As a result, there is slow development of the regulations in these regions compared with those with an integrated approach and consensus.

Main Challenges of implementing Building Energy codes in developing countries

Compliance enforcement is one of the major challenges that encounter BEECs realization. Even in industrialized countries, enforcement still disparate and inconsistent mainly due to variations in local government political and resource support, robustness of the enforcement infrastructure, and conditions of the local construction market. With few exceptions, compliance enforcement of building energy efficiency codes in developing countries is either seriously lacking or nonexistent (Liu et al. 2010).

Compliance implementation in turn is confronted by several barriers, including technical barriers such as the absence of energy records and data for simulation and evaluation, institutional barriers such as the lack of evaluation and monitoring mechanisms to assess the BEECs implementation rate and the absence of government support for energy efficiency programs. In addition to other factors such as the lack of funding systems and the refusal of the people to comply with these regulations. For example, in Jordan, most of buildings owners lack the awareness about energy efficiency and how to benefit from the technology in this aspect. While designers mostly focus on architectural prospects without considering energy efficiency, and contractors aim to lower build cost and are reluctant to cope with time consuming energy efficiency constraints. Building owners think that adapting energy efficiency measures will increase the cost of their buildings, so they tend to cut corners and try to reduce their cost as much as possible (Mourtada 2016).

Depending on the compliance path, some implementation methods might be more significant in one country than others. For example, implementation of building energy codes that rely on simulated performance to establish energy efficiency characteristics requires adequate training to ensure that the software is properly used, and that buildings' actual characteristics correspond to the simulated ones. Such training might not be required for prescriptive codes, which are typically easier to implement, albeit with less flexibility. For uninitiated designers and builders, prescriptive requirements make compliance simpler to understand and execute.

Consequently, "*Offering simple compliance options in a clear code language will better convey the intent of the BEEC to enforcement officials, as well as to others. These increases compliance as enforcement officials have a better grasp of the energy efficiency features expected in a building. With this knowledge, they will be better able to assist designers and construction trades who are less knowledgeable about energy efficiency, and enforcement agents will have greater confidence in enforcing the BEEC. Ultimately, and especially as the stringency increases, it is important that BEECs contain multiple compliance option so as to maximize effective compliance by satisfying the varying needs and preferences of different users. More comprehensive tradeoff compliance options provide flexibility for innovation form or sophisticated designers*" (Liu 2010).

Most EU countries introduced BEECs in the 1970s and have since updated them many times. The staged introduction of BEECs for new buildings had a strong influence on energy consumption. New residential buildings in the European Union today are estimated to consume about 60 percent less energy on average than those buildings constructed before the mid-1970s (Liu 2010). Most countries started with simple prescriptive standards for building envelope components and later added performance compliance paths, requiring certain minimum values for net and primary energy demand.

2.2. Energy Performance Assessment

2.2.1. Overview

Poel et al. (2007) defined the Energy performance as "a term to indicate the quality of a building in energy use". Energy performance indicators (EPI) are quantifiable measures to assess energy performance. The most commonly used EPI for many building types is Energy Use Intensities (EUI), i.e. $kWh.m^{-2}$. Building energy performance is mainly determined by six factors: (1) climate, (2) building envelop, (3) building services and energy systems, (4) building operation and maintenance, (5) occupants' activities and behavior and (6) indoor environmental quality provided, as summarized in IEA Annex 53 project (Annex 2016).

The energy performance assessment approaches in building sector can be classified into two major categories, namely performance-based and feature-specific approaches. Using performance-based approach, assessment results are obtained by comparing the performance indicators (e.g. EUI or CO2 emission) against established benchmarks. While using feature-specific approaches, credits are awarded when criteria of specified features are met. The final score will be graded according to the total awarded credits of all items assessed (Lee et.al 2003).

2.2.2. The objectives of building energy performance assessment

Energy performance assessment methods are established for two purposes: energy classification and energy performance diagnosis. Energy classification provides uniform or authorized means to communicate a building's relative energy efficiency and carbon emissions to both the owners and the public to encourage ongoing efficiency and conservation gains. Energy performance diagnosis aims at detecting faults and diagnosing the causes of poor performance in buildings, and accordingly providing specific energy efficient measures to improve energy performance (Wang et al. 2012).

2.2.2.1. Energy performance assessment for classification

Energy classification is an information tool, which provides building owners or publics with information, regarding the energy performance of the assessed buildings. Such information is usually expressed in a very practical and understandable forms (1–100, or A–M, or poor–

excellent), which encourages the better performance with higher acknowledgement and motivates building owners to improve the energy performance. Over the last 30 years, different approaches and methodologies have been developed to evaluate the energy performance of buildings. (Borgstein et al. 2016) provide a comprehensive review of all available methods for analyzing, classifying, benchmarking, rating and evaluating energy performance in non-domestic buildings.

Several typical energy classification instruments have emerged in practice, including energy benchmarking, energy rating, energy labeling and energy certification. Each of them has its uniqueness in classifying the quality and displaying the level of energy performance while sometimes they have overlapping meanings and even can be replaced by each other (Lombard et al. 2009). Generally speaking, all energy rating scheme evaluate building performance within the scope of a program that has been developed by the authorities of a country to promote efficiency in building design.

Energy Benchmarking

To assess the energy consumption performance of a building, energy benchmarking is a necessary step. Energy benchmarking is extremely important for tracking, monitoring and detecting abnormal energy consumption behavior of a building, through assessing the energy performance of buildings of similar type. Djuric and Novakovic (2009) defined Energy benchmarking as “a macroscopic level of performance assessment, using metrics to measure its performance relative to other building or its previous performance”. Basically, it consists of a comparison of the energy performance indicator of a building with a sample of similar buildings. Through benchmarking process, energy consumption indicator (often expressed in terms of energy consumed per unit of some activity measures, e.g. energy consumed per unit floor area per year, expressed in units like $MJ.m^{-2}.a^{-1}$ or $TJ.m^{-2}.a^{-1}$ or $kWh.m^{-2}.a^{-1}$) can be worked out. With the aid of some statistically representative models, one can determine the energy performance and ranks relative to the peers in the same group and be able to set future targets and identify measures to reduce energy consumption.

Energy Rating

The rating systems are generally divided into two types: (i) methodologies that simulate energy use (asset rating) calculated by the demand for energy based on the building characteristics - mainly for new buildings; and (ii) performance of the building in operation (measured or operational rating), based on the current energy consumption of the building - mainly for existing buildings (Leipziger 2013).

A brief review of recent approaches to energy rating shows that, strategies for defining energy efficiency in buildings are essential for successful energy rating (Olofsson et al. 2004). The energy rating of a residential building can provide detailed information on the energy consumption and the relative energy efficiency of the building. It is performed through standard measurements carried out under specific regulations and experimental procedures by specialists (Santamouris 2005).

Whilst environmental issues were the main reason for developing energy rating scheme, financing and marketing have become the major motivations for promoting it. According to (SRC 1991), the main impetus behind most of the rating systems has been to inform consumers about the relative energy efficiency of homes, and to encourage home-owners to use this information in making their purchasing decisions.

Globally, various governments established energy rating systems to measure energy performance in both residential dwellings and commercial buildings (Brounen and Kok 2011). The schemes vary in practice, from simply a paper-based check-list, to full thermal simulations. A good example of a paper-based check-list is the Model Energy Code (MEC) (Andersen et al. 2004), which was developed for the department of energy building standards and guidelines program in the United States. MEC focuses on the insulation of the envelope and windows of a building, the cooling and heating system, the water heating system, and air leakage.

Most of these rating schemes use a grading scale to score buildings. One hundred-point scales and star rating systems are common, while some use either a pass/fail system, or simply classify by terms such as bronze, silver, or gold. MEC is a simple pass or fail scheme (US Department of Energy 1995).

Rating schemes are generally associated with either certification or labelling. The former refers to the evaluation of building performance at the design stage, while labelling assesses in-use performance of the building when it is compared with other similar buildings (Kordjamshidi 2010). The success of building energy regulation in effectively controlling the energy consumption will be associated to the adopted energy performance indicator and to the promoted energy assessment tools.

Energy labeling

Building energy labelling, consisting of assigning an energy performance class or label to the building, requires the development of a scale related to a Labelling Index (LI) (Lombard et al.

2009). The labeling scale determines the percentile intervals (bands) to energy classes, for instance, top 10% for A, or awarding credits according to energy reduction percentages. It addresses how to display the assessment results with distinctive levels, comparing with referenced performance. It is worth noticing that setting a labeling scale is a quite subjective process which is more likely to be a policy decision rather than a technical analysis.

Energy Certification

A typical energy certification provides a mean of rating individual buildings such as current legal standards and benchmarks. That allows for consumers to compare and assess the energy performance of a building – whether they be residential, commercial or public – on how efficient (or inefficient) they are in relation to the amount of energy needed to provide users with expected degrees of comfort and functionality (Fabbri et al. 2011). An energy performance calculation method is central to certification. As well as with energy regulation, the indicators implemented in the energy certification will condition its capability to reach the pretended objective. The indicator implemented in the energy regulation should be included among the indicators provided by the energy certification in order to clearly situate the certification on the reference regulated level of energy performance. In the last 30 years, voluntary and mandatory environmental or energy certification schemes have been introduced in the building sector in most developed countries (Wonga and Krügerb 2017). Generally, all developed rating schemes around the world appear to be similar in their objectives, but different in programming and details.

The degree of efficiency is influenced by many factors, such as ambient weather conditions, building structure and characteristics, the operation of sub-level components like lighting and HVAC systems, occupancy and their behavior. Obviously, Certification is a complex procedure, requiring in-depth knowledge of building components. This complex situation makes it exceedingly difficult to accurately implement the prediction of building energy consumption.

Energy performance assessment methodologies generally use software tools to calculate energy performance and ratings, which will often be based on annual energy use in specific terms, such as the number of kilowatt hours used per square meter ($kWh.m^{-2}.a^{-1}$). A comprehensive software system can also help provide recommendations for upgrading the building to improve efficiency (Maldonado et al. 2008).

2.3. Energy Consumption Modeling Effort

The significant amount of energy consumption related to the building sector justifies energy consumption modeling efforts. Most of energy consumption in these buildings is associated to space heating and cooling. As already mentioned, more than 80% of the building performance, in terms of energy savings, generation, and cost, is set during the design phase (Ad-Hoc. 2012). Figure 2 below shows the relationship between the building phases and energy efficiency impact.

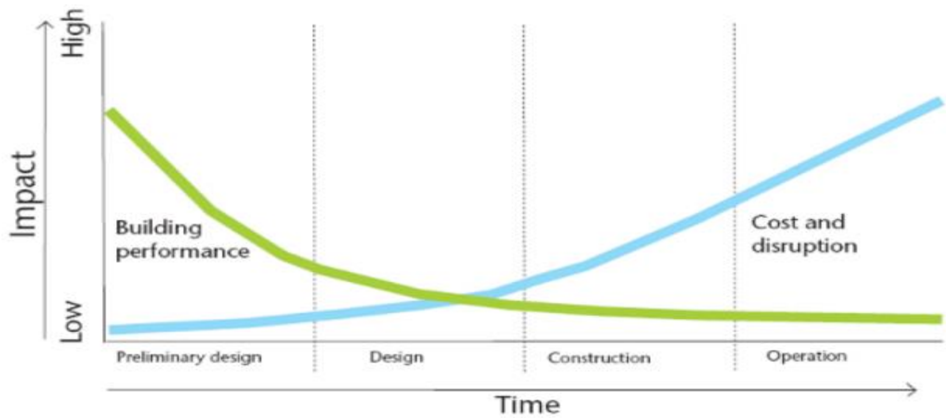


Figure 2 Relation of Energy efficiency impact and building phases. Source: WBSCD

Therefore, predicting energy consumption in the early stages of building design is important for energy and emissions reduction efforts. However, predicting building energy consumption is a complicated task since it depends on various variables such as building characteristics, energy systems characteristics, control and maintenance, weather parameters, and behavior of occupants. The ways in which a building and its services operate in practice are overly complicated. Consequently, modeling for achieving an accurate prediction of the energy consumption is challenging to accomplish. Hence, despite the abundant research studies which have attempted to develop energy simulation models, there is still the need for a systematic approach capable of unifying all the diverse phenomena underlying energy performance. In the past, various methods for energy assessment have been developed. These methods can be categorized into white box method, gray box method and black box method. White box or forward modeling approach uses detailed physics-based equations to model building components, sub-systems and systems to predict whole buildings and their sub-systems behaviors, such as their energy consumption and indoor comfort. Due to the detailed dynamic equations in white box models, they have the potential to capture the building dynamics well, but they are time consuming to develop and solve. In white box method, the modeler submits a set of input parameters (typically building design parameters) to a calculation tool which then does the calculation and send monthly or hourly energy consumption as output. One of the examples of this type is detailed energy simulation method (Crawley 2000). On the contrast, a black box method uses data fitting techniques rather than physical knowledge, therefore requires a pre-selected statistical model and training data. Due to its convenience and quick modelling, black box methods are good alternatives to detailed energy simulation method. In the category of black box method, lies multiple linear regression, which is the simplest technique, and has been adopted by ASHRAE as a standard Measurement & Verification (M&V) technique (ASHRAE 2002). The principle of gray box method lies in the middle between white box method and black box method, it combines both physical knowledge of the system and data fitting techniques to derive a useful energy model. The main differences between above stated modelling approaches to building energy simulation are presented in Table 2 below.

Table 2 Comparison between white, black and grey box techniques. Source: (Foucquier et al. 2013)

Methods	*Building geometry*	*Training data*	*Physical interpretation*
Physical or " White box" method	*A detailed description of the building geometry is required*	*No training data are required*	*Results can be interpreted in physical terms*
Statistical or "Black box" method	*A detailed description of the building geometry is not required*	*A large amount of training data collected over an exhaustive period of time is required*	*There are several difficulties to interpret results in physical terms*
Hybrid or " Grey box" method	*A rough description of the building geometry is enough*	*A small amount of training data collected over a short period of time is required*	*Results can be interpreted in physical terms*

The investigation and prediction of the building energy performance associated with different design parameters have become the major focus of many recent studies. The prediction of the energy savings would be a good indicator for the choice between different energy solutions according to the building features and the local climate. But these savings are hard to predict because the efficiency of the system is directly influenced by the heating-cooling demand. Moreover, predicting building energy demand is a complex problem since it is practically impossible to model a correct level of occupancy, lighting, and equipment loadings. Therefore, making a model to predict accurate energy consumption is very difficult.

2.3.1. Detailed Energy Simulation

Building simulation expands the concept of performance prediction further. The philosophy of building simulation is to create a virtual building where the user can specify in detail parameters that influence the building performance, with resulting performance predictions that are as close to reality as possible. Detailed simulation method is probably the most widely used method for energy estimation in design stage. Due to its comprehensiveness and wide acceptability, it is often used as a comparison case when testing new benchmarking methods (Zhengwei et al. 2014). The general data flow and main procedure of white-box model development and simulation are summarized in Figure 3 below.

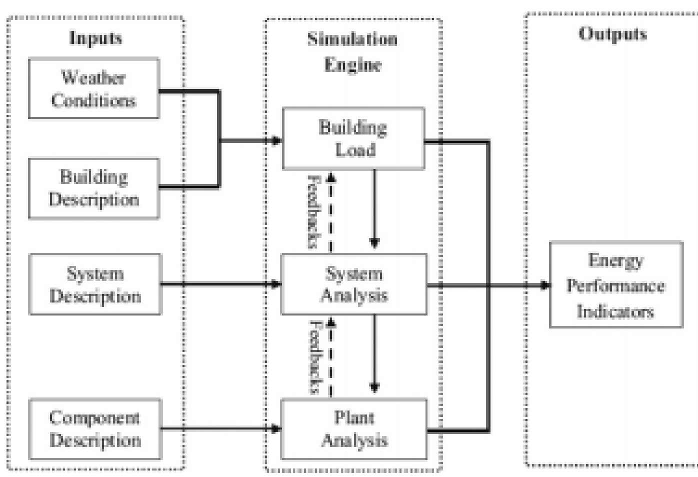


Figure 3 General data flow and main procedure of detailed simulation. Source: (Wang et al. 2012).

Energy simulation is a powerful computational tool that enables a user to model the building as a system, thereby capturing the complex dynamic thermal interactions between a building and its outdoor and indoor environments (Morbitzer 2003). Although, these elaborate simulation tools are effective and accurate, in practice, there are some difficulties. Since these tools are based on physical principles. To achieve an accurate simulation, they require details of building and environmental parameters as an input data. These parameters in turn are unavailable to many organizations. This lack of precise inputs will lead to a low accurate simulation. In addition, operating these tools normally requires tedious expert work, making it difficult to perform and cost inefficient. Hygh et al. (2012) stated that conducting energy simulation in the early design stages requires significant time, resources, and technical expertise. Furthermore, building energy simulation models require a high degree of technical specification to characterize a building, which limits their application during the early stages of design. For these reasons some researchers have proposed simpler models to offer alternatives to certain applications.

2.3.2. Steady-state methods

A method to balance between simple and complicated models of assessing the heating and cooling demand is to utilize energy estimation models that can predict accurate results from the model to the data obtained from simulations or experimental measurements. Simplified simulation methods or a simplified user interface for a complex energy simulation engine could enable more effective energy estimation. Through reducing the number of required inputs, thereby making the process more intuitive for designers, reducing the burden associated with constructing an energy model, and allowing for faster generation of results. Steady-state methods are developed mainly for simplified building energy calculation and have the advantages of high computation speed and simplification in modeling due to ignoring of dynamic characteristics.

Different simplified building energy simulation methods have been proposed to minimize the inputs required by detailed simulation tools, such as the simple hourly method per ISO 13790 (Nielsen 2005) and the MIT Design Advisor (Urban and Glicksman 2007). While simplification of building energy simulation can aid the design process, such tools offer a limited set of design options and do not capture the full thermal interactions over a whole year.

Furthermore, various simplified methods have been developed to assess the heating and cooling demand, such as the degree-day method (Santamouris 2005) .These methods are not sufficiently accurate, and, in most cases, they are over assessing the required energy without considering important aspects such as the true thermal inertia. The degree-day method is a traditional method that has been in use for decades, in both the academic and industrial worlds. The concept mainly shapes on the temperature difference between indoor temperature and the outdoor temperature, multiplied by the duration of the temperature difference. One of the drawbacks of this method that it does not consider the solar gains or internal gains effect on the energy demand (Santamouris 2005).

2.3.3. Statistical Method

Statistical regression models simply correlate the energy consumption or energy index with the influencing variables. This simplified evaluation method consists of a simple regression model that estimates the thermal performance based on parameters of the envelope. Simplified models can be used for predicting energy performance in buildings due to features such as less complexity compared to energy simulation models, ease of use and speed of calculation (Borgstein et al. 2016). These models usually developed by multiple regressions based on many cases simulated in energy simulation tool e.g. Energy Plus.

Much research on regression models has been carried out to predict some useful energy index. For example, In Brazil, the original simplified method for determining energy efficiency levels as proposed in the Brazilian building energy efficiency regulation is developed based on a multiple linear regression approach (Wonga and Krügerb 2017). Dong et al. (2008) developed linear and non-linear regression models from EnergyPlus simulation to predict the energy consumption index of office buildings in Hongkong. The statistical results indicate that these regression models could be used to evaluate the energy performance of different building envelope designs with daylighting controls. Aghdaei et al. (2017) developed a methodology of linear regression models for the prediction of annual thermal loads in representative residential buildings across three major climates in New South Wales, Australia, and the assessment of the impact of building envelope upgrades. They envisaged that the developed regression models can be used as a quick alternative to building simulation for residential buildings, and the annual heating and cooling energy requirements can be forecasted with an acceptable accuracy. Wang et al. (2005) developed an energy assessment tool using multivariate regression model to quantify building energy performance in early design stages, where 27 building parameters have considered including size, geometry, and location. Their results suggested that a linear regression model can serve as the basis for an effective decision support tool in place of energy simulation models during early design stages.

2.3.3.1. Variables affecting energy efficiency in building

To have energy efficient buildings, it is important to focus on the basic principles that have impact on energy efficiency. A lot of researches have been conducted to evaluate the influencing factors of building energy consumption by multiple regression analysis by the establishment of linear regression equations. Carlo and Lamberts (2008) analyzed the effects of different building envelope influencing factors on the electricity consumption in commercial buildings of Brazil. The building volume indicator, the roof heat transfer coefficient (U-value), the Solar Heat Gain Coefficient (SHGC) and the Window to wall area ratio (WWR) were considered in regression equations. Catalina et al. (2008) developed regression models to estimate the monthly heating demand of residential buildings in France. The inputs for regression models contain the building envelope U-values, WWR, the building time constant and the building shape factor. They found that the developed model could properly estimate the future heating demand.

Ourghi et al. (2007) established a simplified analysis method to predict the impact of building morphology on its annual cooling demand. This method was carried out based on detailed simulation using several scenarios of building geometry, glazing type, window area and climate. A direct correlation has been found between relative compactness and total building energy consumption as well as the cooling energy demand. They concluded that optimizing the shape of a building is an essential part if we want to minimize construction costs or to find the minimum seasonal demand of heating energy. In Kuwait, (AlAnzi et al. 2009) performed a similar study on an office building but with an extended database and special building shapes (i.e. H-shape). The simplified method that they found is appropriate for architects during first design phase to evaluate the effect of shape on the energy efficiency of office buildings.

The first records concerning dedicated investigations into the impact of the WWR on the energy balance of a building showed that selecting an optimal WWR value would have halved the energy use (Arumi 1977). In general, the early research showed that for each climate and orientation it was possible to find an optimum WWR that minimized the annual energy use. A study by (Alwetaishi 2017) has established to investigate the influence of glazing to wall ratio in different microclimate regions in Saudi Arabia which has been introduced by the author hot dry, hot humid and moderate climates. The research suggests that glazing to wall ratio is recommended to be 10% in both climate conditions hot and dry and hot and humid.

Andrea et al. (2011) has concluded that not only the size of window, but also orientation has a great effect on internal condition. Lee et al. (2013) has suggested that all windows in each direction should be minimized in all warm and hot regions. In another study done by (Francesco 2016) in various climatic region in Europe to investigate optimal window to wall ratio in office building. The research revealed that even though there is an optimal glazing to wall ratio in each climate, orientation was found the most value especially in warm climates. Moreover, only south orientation in freezing regions or in hot climates require quite sensitive percentage of glazing to wall ratio. In contrast, (Soojung et al. 2016) findings suggest that the energy load increases as window to wall ratio increases and that window position has the largest influence on load when glazing to wall ratio is greater than 20%. The work also highlights that west orientation is the worst directions.

2.4. Energy Demand in Gaza Strip

2.4.1. Overview

In Palestine, energy sources consist of the 1) energy generated by petroleum and natural gas derivatives 2) electricity and 3) renewable energy particularly solar power, which represent 51%, 31% and 18% of the total energy sources respectively. Apart from renewable energy, Palestinians do not produce oil or natural gas and are almost dependent on the imported electricity, mainly from Israel Electric Co. (IEC) for nearly all their electricity needs. The multi-source amount of electricity available in Palestine was 5,370 GW/hour in 2012 (3,700 in the West Bank and 1,670 in Gaza), while the annual per capita consumption of electricity (after deducting transmission loss) is 950 kilowatt/hour. With an annual electricity consumption level of 583 kWh/person, the lowest consumption level in the region, Palestine barely manage to satisfy their electricity needs, whereas in Israel electricity consumption exceeds 6,000 kWh/person. This gap can be mainly explained by the inadequate electricity infrastructure. Externalities such as Israeli restrictions and its control of Palestine's imports, exports, and borders, as well as internal reasons, such as political, legal, technical, and financial factors, hamper the development of Palestinian energy sector (MoPAD 2012).

2.4.2. Gaza Energy Crisis

According to the Gaza Electricity Distribution Company (GEDCO), statistics show that the Gaza Strip needs a monthly average of **450 MW** of electricity. Figure 4 below shows the average monthly electricity supply during 2017 (OCHA 2017). The average available quantity per month is amount to 146 MW, which most of it is imported from the IEC (64%), Gaza Power Plant generate up to 45 MW (31%), while the Egyptian lines share a small amount of less than 10%. Therefore, the Gaza Strip shortage of electricity is about 32%, assuming that all current sources work up to standard. Figure 4 below illustrate the average monthly electricity supply from different sources.

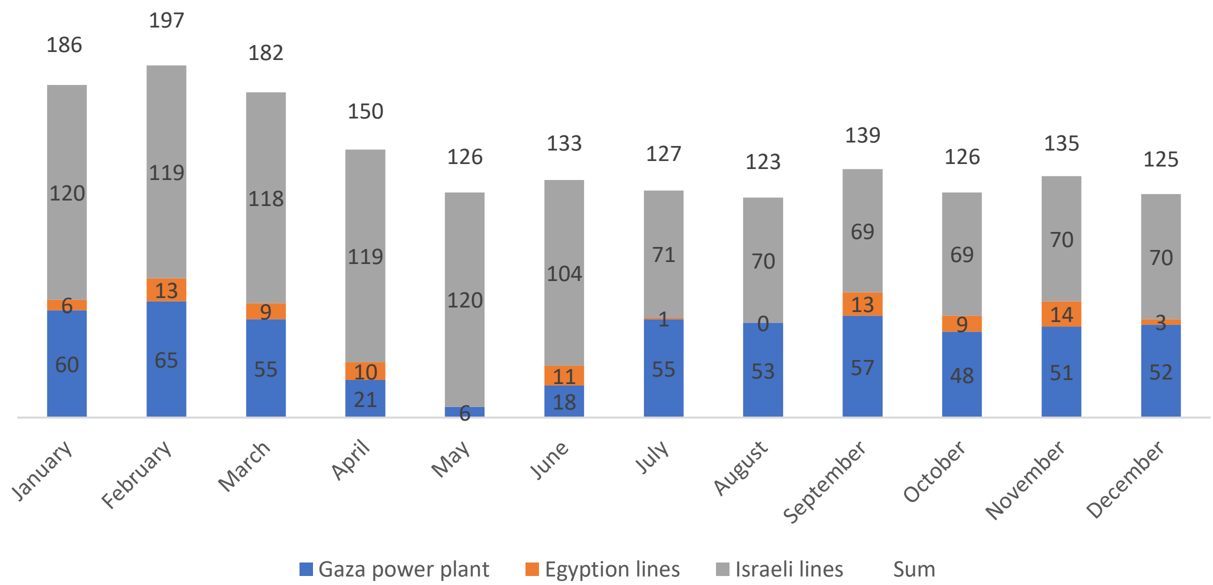


Figure 4 Electricity supply per Month (average Megawatt). Source (OCHA 2017)

The Gaza electricity crisis is an ongoing and growing electricity crisis faced by nearly two million citizens of the Gaza Strip, with regular power supply being provided only for a few hours a day on a rolling blackout schedule as shown in Figure 5.

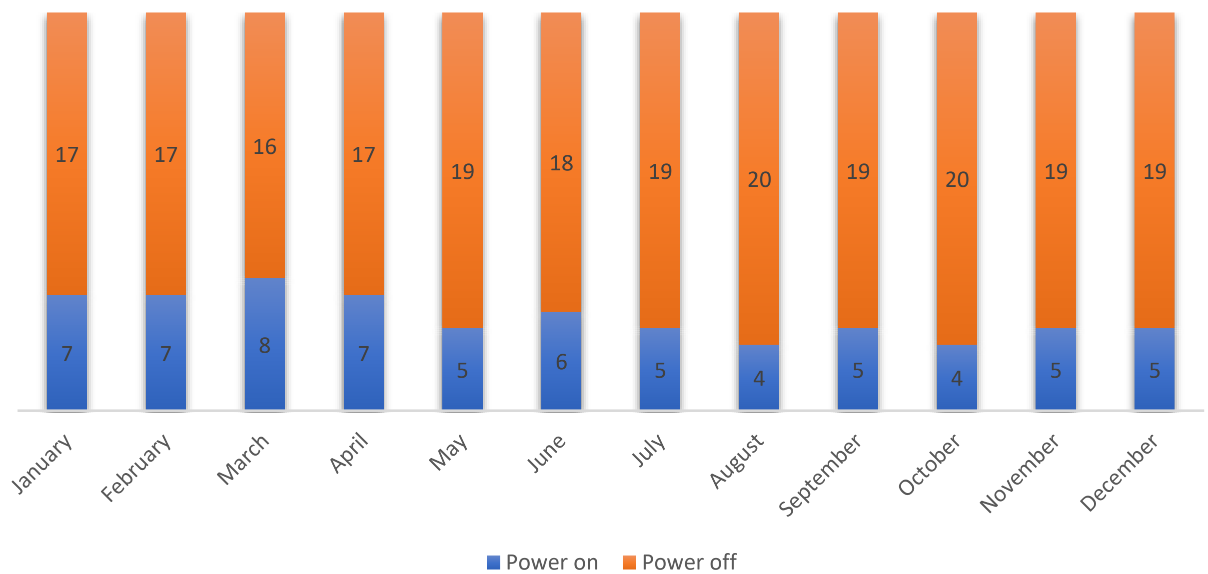


Figure 5 Availability of electricity per Month (average hours per day). Source: (OCHA 2017)

According to (Muhaisen 2007) residential buildings in Gaza Strip come in at the top of buildings that consume the largest share of energy which is estimated at about 70% of the total amount of energy consumed according to the 2009 estimations of the GEDCO. Furthermore, electricity demand increases by about 7.5% MW annually, as a result of the natural population growth and the expansion in different sectors requiring electricity supplies.

These problems in addition to the environmental risks arising from the use of traditional sources of energy impose challenges in front of the Palestinian decision-maker for the preparation and implementation of the Palestinian energy strategy. Such strategies are based on improving energy efficiency in buildings, utilizing alternative energy sources to generate uninterrupted, safe and more economical supply, as well as reducing greenhouse gases emission. One of the established strategies was the National Green Buildings Guidelines (NGBG). Which is lunched by the Palestinian engineer's association in partnership with the Palestinian higher green building council on the 23rd of May 2013, in Ramallah. NGBG lay the foundations for a green building code and encourage the implementation of eco-sustainable infrastructure, using environmentally friendly materials and deploying renewable energies. It will also benefit the infrastructure sector in terms of improved architectural quality, reduced energy consumption, better quality of life, health and security (AlArda et al. 2015).

3. Method

3.1 Overview

This study presents the development methodology of a Multiple linear regression models that were developed for the prediction of annual thermal loads in representative residential buildings across the region of Gaza Strip. A typical residential building was selected and the effect of the major key building design parameters on its energy performance was investigated.

To quantify building energy consumption, EnergyPlus, which is a building energy simulation software program, was used to develop the building profile and perform annual energy simulation. The energy load for cooling demand ($kWh.m^{-2}.a^{-1}$) could be taken as representatives of performance indicators. Based on the simulated results, the next step in the analysis is to check the impact of several building design parameters on the energy consumption. Through study the effect of several input variables including (Characteristic length, relative compactness, glazing area, orientation, and thermal transmittance of buildings components) on cooling load of residential buildings.

The association strength of each input variable with each of the output variables will be investigated through Stepwise regression that will be utilized to reduce the number of parameters and only include the most effective ones. After finding the critical parameters, a multiple linear regression models will be developed to predict annual energy consumption for a given set of values as independent variables.

After calculating the regression equation, the next process is to analyses confidence interval for the model’s residual. The aim of this step is to clarify the residual of the output of multiple regression model for different confidence levels, so the user can know that under a certain confidence level there is an error with a specific range.

Finally, based on the developed multiple regression model, a simplified prescriptive index will be established, which can provide an easy and quick energy consumption prediction, thus assisting architects in considering design alternatives. It is believed that the prescriptive index developed in this study can be used to estimate the energy consumption of residential buildings in Gaza Strip. Moreover, this could be the start point of decision support tools that will assist the designers and architects to take decisions upon the optimum economic, environmental and energy solution. Figure 6 below illustrate the framework of methodology.

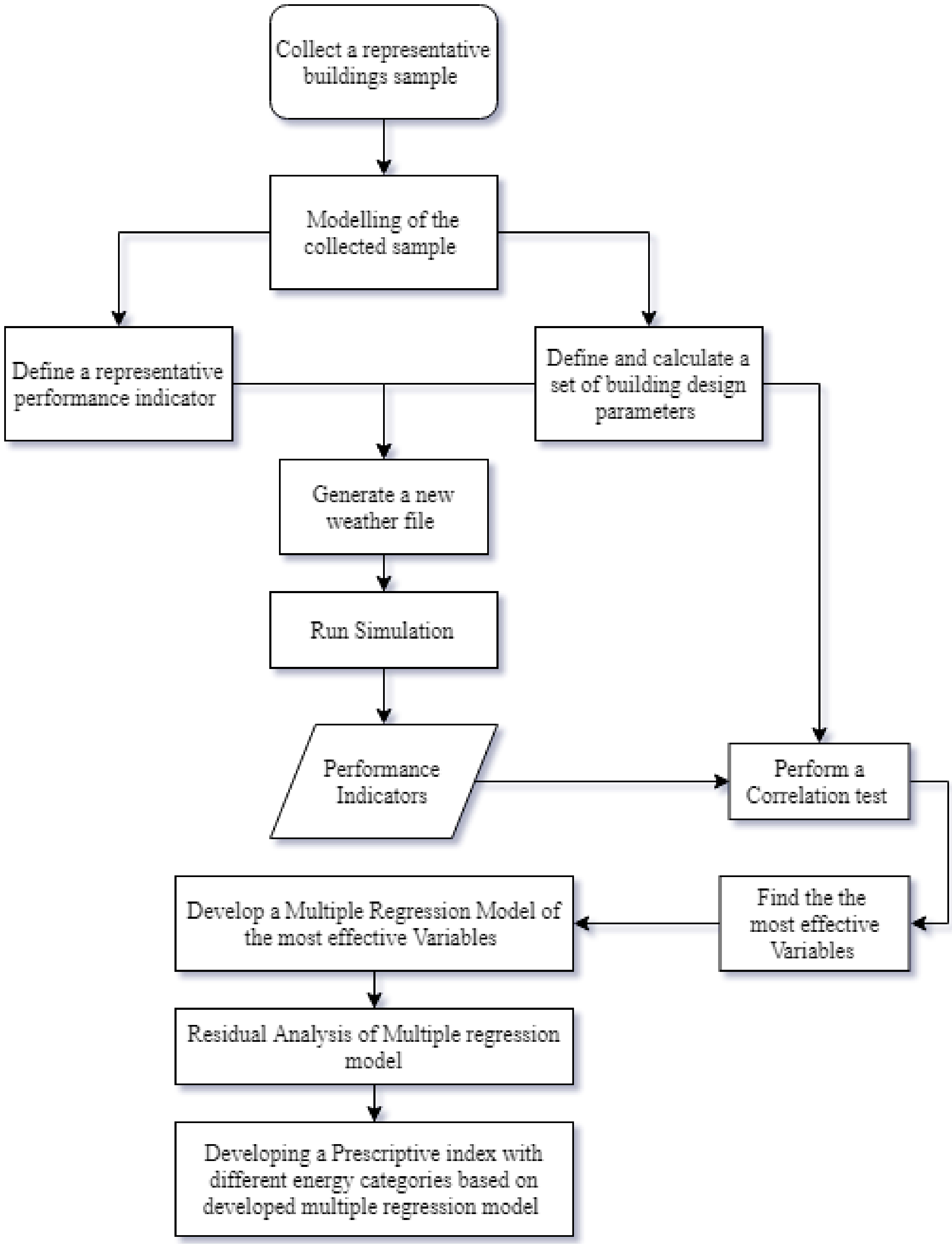


Figure 6 framework of methodology for this study.

3.2 Hypothesis

This research is based on hypothesis that the prescriptive approach is almost equivalent to the performance-based approach in case of energy assessment of buildings particularly in early design stages. It is believed that the simple prescriptive path encourages designers and decision makers to predict the energy consumption without extensive analysis and proposes energy saving measures that possibly reduces energy consumption at the early stages of the design.

3.3 Research question

1. Is there another approach for energy estimation that it can be in close agreement with sophisticated modeling software commonly utilized by architects and engineers?

2. Is there a way to reduce decision conflict and the need for tedious design iterations to maintain the performance goal, which can be more time and cost effective?

3. To what extent could the different design parameters be utilized for analysis and prediction of the building energy performance in early design stages?

3.3 Data

3.3.1. Study place

Gaza Strip is located at the south-west area of Palestine. It is a narrow strip that stretches along the south-east corner of the Mediterranean Sea. The territory is 41 kilometers long, and from 6 to 12 kilometers wide, with a total area of 365 square kilometers. The geographical coordinates of the Gaza Strip are 31° North, and 34° East.

Figure 7 Geographical location of the Gaza Strip
source: (Wikivoyage 2018)

3.3.2. Climatic Zone of Gaza Strip

Gaza strip or simply Gaza (365 km²) is a coastal area along the eastern Mediterranean Sea. Along the Mediterranean coast the winters are short, mild and rainy and the summers long, hot and dry. Gaza Strip is in a transitional zone between the arid desert climate of the Sinai Peninsula and the temperate and semi-humid Mediterranean climate along the coast. According to the Koeppen system for climatic zoning, Gaza has a Mediterranean dry summer subtropical climate with mild winters. This climate is classified as C_{sa} indicating that the warmest month has a mean temperature above 22°C. Because of surrounding zones, there are two different climatic zone in Gaza strip. The climatic zone that extends along the coast including most of the northern, middle and southern parts of Gaza has climate properties of the sub humid coastal zone with mean annual rainfall of 459 mm and mean annual temperature average of 18°C. This zone has a population density around 97.2 % of the total population of Gaza. The second climatic zone in Gaza can be categorized under the semiarid loess plains of the northern Negev Desert in the east with 316 mm mean annual rainfall and population comprising 2.8 % of the total population in Gaza (ARIJ 2003).

3.3.3. Average weather in Gaza strip

The average daily mean temperature ranges from 25°C in summer to 13°C in winter. The hot season lasts for 4.0 months, from June 10 to October 10, with an average daily high temperature above 28°C. The hottest day of the year is August 8, with an average high of 34°C and low of 23°C. The cool season lasts for 3.1 months, from December 12 to March 16, with an average daily high temperature below 20°C. The coldest day of the year is January 26, with an average low of 10°C and high of 17°C.

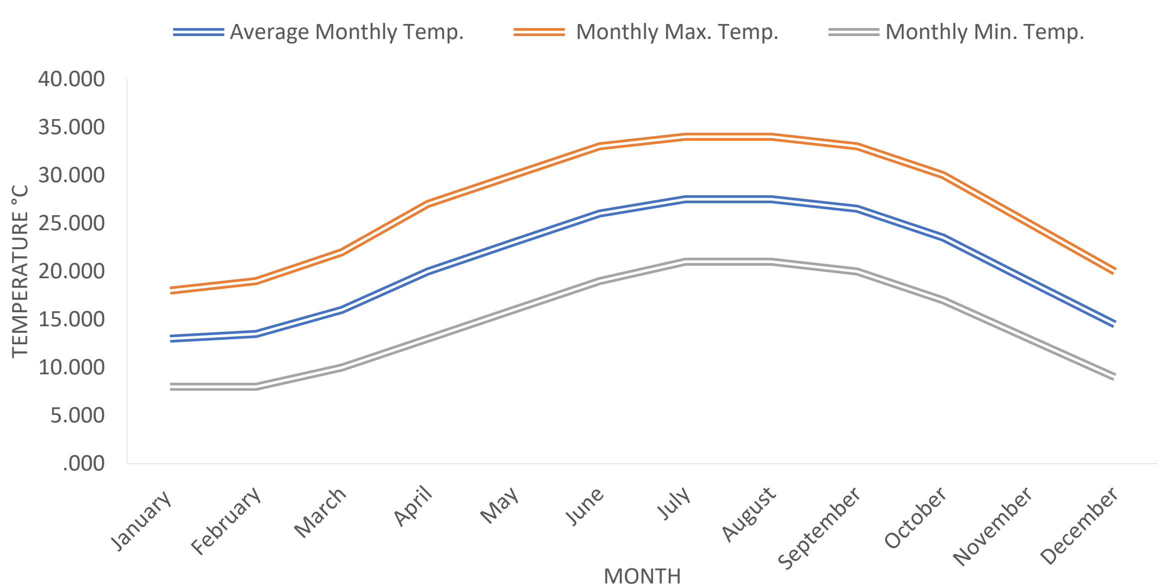


Figure 8 Average Monthly Temperature of Gaza City. Source: (National Center for Environmental Information NOAA)

Daily relative humidity fluctuates between 65 % in the daytime and 85 % at night in the summer, and between 60 % and 80 % respectively in winter. The daily average maximum wind velocity reaches 3.9 m/s in the afternoon of summer months while it reaches to the half of this value at night. In winter the average wind velocity is about 4.2 m/s. The prevailing winds during the summer come from the northwest while the most frequent direction is southwest in winter. (ARIJ 2003).

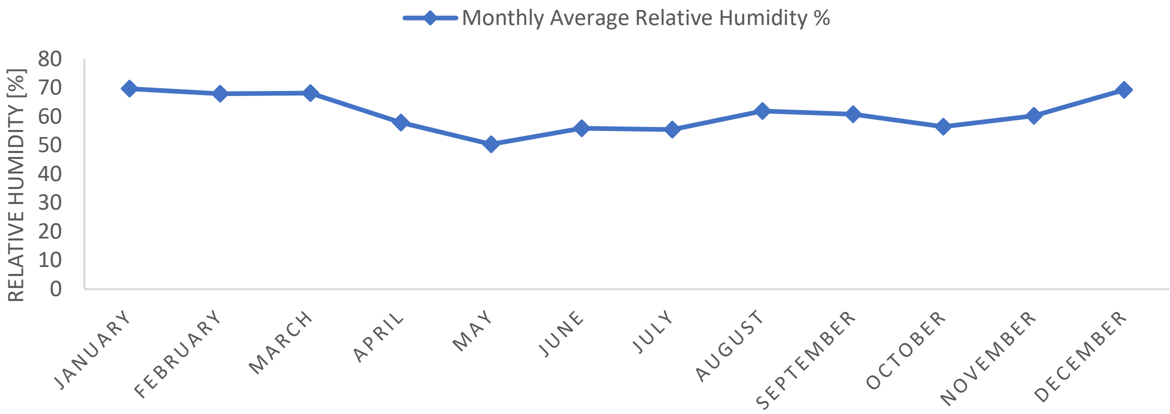


Figure 9 Average Monthly Relative Humidity of Gaza. Source: (Palestinian Energy Efficient Building Code 2004)

3.3.4. Type of Buildings in Gaza Strip

Residential buildings are the main sector of buildings in Gaza. Detached houses are the most commonly used style in residential complexes. While the attached style exists only in the old town of Gaza city and its rarely used in the current architecture of the Gaza Strip. Residential buildings in Gaza strip can be classified into two main types which are separate house and apartment building (Hadid 2002). The separate house is a popular style in the cities, towns and campus of the Gaza Strip. The high population density and the limited area in Gaza strip rise the need for vertical expansion of building. Therefore, residential apartment is the most common buildings form in recent years. Residential apartment can be classified in two categories, low apartment building and tower apartment. In most of the low-apartment buildings, 1-4 apartments in the same level is the typical example, while the number of floors can reach up to 6 floors.

Figure 10 An overview showing part of the Sheikh Zayed City charity housing project against the skyline of the densely populated Gaza Strip. Source: (Heidi Levine for The National)

3.3.5. Climatic Design of Residential Buildings in Gaza Strip

Hadid (2002) establish a survey to study several design parameters of Gaza's building, such parameters can be utilized as a passive design element to achieve thermal comfort. The parameters including balconies, shading devices, opening, insulation and colors. Hadid survey prevailed that elements were not selected according to thermal design but rather for aesthetic value. Orientation of the buildings and their openings does not take sun movement and solar radiation in consideration. Furthermore, shading devices are installed into different oriented facades with the same form and dimensions. As a result, buildings don't achieve the acceptable level of thermal comfort. Hence, people tend to use active systems such as air conditioning and mechanical ventilation that consume a large amount of energy.

3.3.6. Description of the Collected Sample

Based on the building's typology in Gaza Strip, most of the residential buildings are either multifamily houses or Apartment. The selected sample was collected to represent the most common residential buildings in Gaza strip in recent years, which also provide enough variance in building design variables regarding buildings morphology, glazing area and number of stories. The overall characteristics of the buildings sample are shown in Table 3 below. Regarding the building typology, more than half are apartments, whereas 46% are classified as detached houses, represented by Multi-family houses as illustrated in Figure 11. The average conditioned net floor area of the apartments is 409.90 m^2 while for the detached houses is 262.70 m^2.

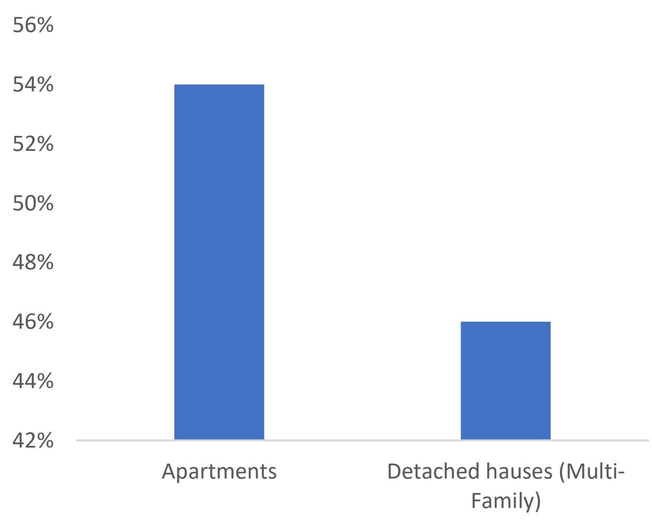
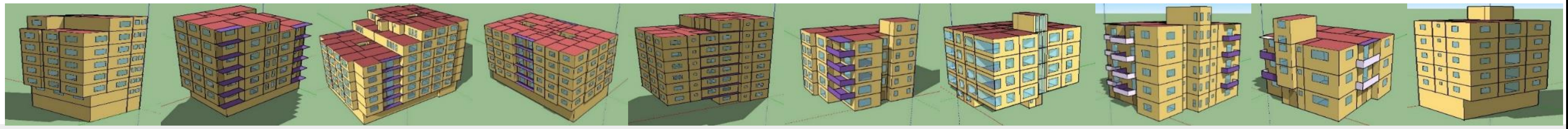
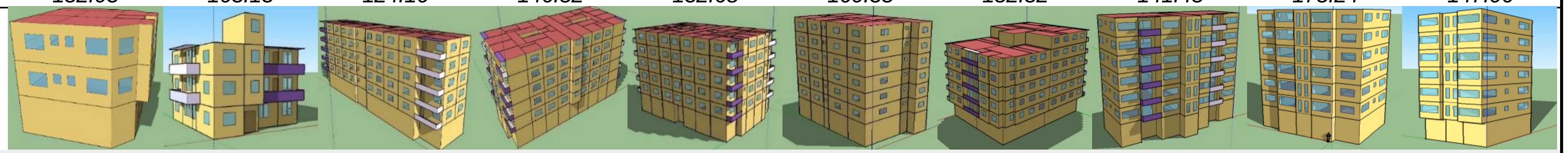


Figure 11 Buildings typologies of the selected sample.

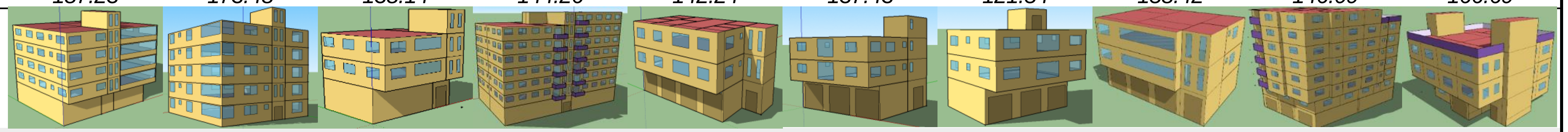
Table 3 Design Variables of the Buildings Sample details.



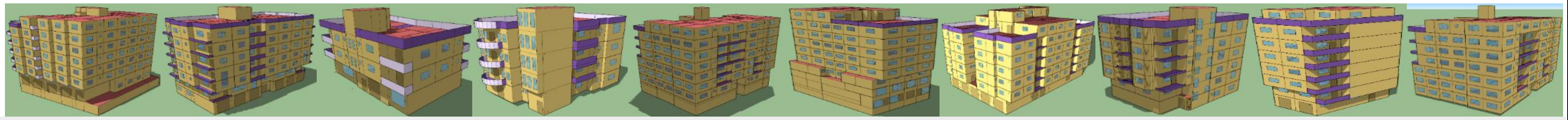
Building Charchterstic	Unit	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Shape factor (SF)	m^{-1}	0.54	0.55	0.34	0.47	0.4	0.5	0.48	0.41	0.6	0.48
Charcterstic Length (lc)	m	1.86	1.81	2.93	2.14	2.51	1.98	2.1	2.44	1.67	2.09
Relative compactness (Rc)	-	0.87	0.83	0.83	0.77	0.92	0.86	0.83	0.89	0.91	0.95
Window to Wall ratio WWR	%	11.28	15.55	16.69	13.08	12.48	19.13	25.81	11.77	11.76	13.21
WWRo south equivalent	%	8.39	12.54	13.5	11.67	10.1	14.83	21.96	9.65	6.69	9.97
WWRos south equivalent weighted for shading	%	8.39	12.41	12.86	10.05	9.26	13.06	21.96	8.12	6	9.97
Window to Floor Ratio WFR	%	12.14	13.76	8.15	8.51	10.67	18.31	20.73	10.39	11.51	11.16
Thermal Compacntess Ct	m^{-1}	0.46	0.49	0.3	0.41	0.35	0.45	0.44	0.36	0.51	0.42
Effective Envelope U value	$W.m^{-2}.k^{-1}$	1.69	1.85	1.8	1.79	1.78	1.9	1.94	1.82	1.83	1.76
LEK value	-	152.03	163.13	124.16	146.52	132.68	160.35	152.52	141.45	175.24	147.06



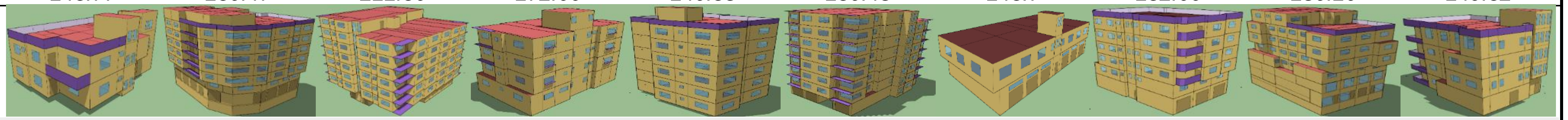
Building Charchterstic	Unit	B11	B12	B13	B14	B15	B16	B17	B18	B19	B20
Shape factor (SF)	m^{-1}	0.73	0.56	0.41	0.46	0.44	0.42	0.34	0.55	0.48	0.62
Charcterstic Length (lc)	m	1.36	1.77	2.46	2.18	2.26	2.39	2.95	1.8	2.1	1.6
Relative compactness (Rc)	-	0.98	0.91	0.8	0.77	0.79	0.95	0.78	0.82	0.94	0.92
Window to Wall ratio WWR	%	18.45	15.15	13.07	12.13	17.21	9.89	16.53	21.82	25.06	22.89
WWRo south equivalent	%	10.76	8.82	8.47	7.1	10.27	8.75	14.45	15.81	20.14	19.1
WWRos south equivalent weighted for shading	%	10.76	6.15	7.87	6.83	9.82	8.75	12.33	13.27	20.14	19.1
Window to Floor Ratio WFR	%	20.01	13.18	7.54	8.19	8.33	6.66	7.91	19.92	19.36	25.54
Thermal Compacntess Ct	m^{-1}	0.63	0.48	0.35	0.39	0.39	0.36	0.3	0.47	0.42	0.54
Effective Envelope U value	$W.m^{-2}.k^{-1}$	1.82	1.87	1.81	1.73	1.79	1.76	1.8	1.74	1.77	1.74
LEK value	-	187.23	173.48	138.14	144.26	142.24	137.43	121.54	158.42	146.09	166.69



Building Charchterstic	Unit	B21	B22	B23	B24	B25	B26	B27	B28	B29	B30
Shape factor (SF)	m^{-1}	0.45	0.88	0.73	0.31	0.68	0.67	0.82	0.71	0.45	0.58
Charcterstic Length (lc)	m	2.24	1.13	1.36	3.19	1.48	1.5	1.22	1.42	2.24	1.73
Relative compactness (Rc)	-	0.96	0.49	0.97	0.96	0.91	0.93	0.92	0.79	0.77	0.66
Window to Wall ratio WWR	%	27.92	18.27	11.77	23.53	17.92	19.41	19.03	20.66	12.45	16.62
WWRo south equivalent	%	17.82	12.82	9.65	18.93	9.36	12.88	11.14	13.47	11.36	9.26
WWRos south equivalent weighted for shading	%	17.82	12.82	8.12	17.55	9.36	12.88	11.14	13.47	10.81	8.96
Window to Floor Ratio WFR	%	15.48	6.68	16.38	10.26	15.78	12.57	23.73	18.72	9.6	12.4
Thermal Compacntess Ct	m^{-1}	0.38	0.73	0.59	0.24	0.59	0.57	0.74	0.61	0.38	0.49
Effective Envelope U value	$W.m^{-2}.k^{-1}$	1.79	1.96	1.73	1.64	1.96	1.84	1.89	1.85	1.76	1.81
LEK value	-	146.01	235.13	188.65	119.22	182.15	181.74	194.19	186.76	143.81	171.11



Building Charchterstic	Unit	B31	B32	B33	B34	B35	B36	B37	B38	B39	B40
Shape factor (SF)	m^{-1}	0.4	0.34	0.72	0.57	0.39	0.47	0.38	0.48	0.75	0.5
Charcterstic Length (lc)	m	2.52	2.93	1.38	1.75	2.57	2.13	2.61	2.08	1.34	2.02
Relative compactness (Rc)	-	0.63	0.83	0.57	0.81	0.7	0.63	0.61	0.79	0.61	0.78
Window to Wall ratio WWR	%	12.62	12.24	7.47	11.81	17.9	13.11	8.56	12.92	6.36	17.09
WWRo south equivalent	%	7.44	7.62	5.65	8.63	14	8.55	6.68	12.2	6.5	14
WWRos south equivalent weighted for shading	%	7.33	6.24	5.65	7.84	12.95	8.3	6.68	12.02	5.67	12.76
Window to Floor Ratio WFR	%	7.74	8.29	4.7	13.1	10.2	10.88	4.81	12.96	12.06	11.72
Thermal Compacntess Ct	m^{-1}	0.34	0.29	0.62	0.51	0.3	0.4	0.31	0.42	0.65	0.41
Effective Envelope U value	$W.m^{-2}.k^{-1}$	1.85	1.84	1.9	1.92	1.68	1.77	1.82	1.8	1.76	1.68
LEK value	-	143.77	130.47	211.36	172.66	140.58	150.48	143.7	152.66	180.16	149.32



Building Charchterstic	Unit	B41	B42	B43	B44	B45	B46	B47	B48	B49	B50
Shape factor (SF)	m^{-1}	0.69	0.38	0.37	0.63	0.5	0.52	0.54	0.53	0.55	0.71
Charcterstic Length (lc)	m	1.44	2.64	2.73	1.59	2	1.94	1.84	1.88	1.81	1.4
Relative compactness (Rc)	-	0.68	0.72	0.79	0.8	0.82	0.73	0.78	0.57	0.8	0.96
Window to Wall ratio WWR	%	15.66	11.12	16.82	8.52	14	22.11	12.76	11.92	11.36	18.98
WWRo south equivalent	%	12.47	8.57	13.46	6.99	11.09	17.28	11.55	7.71	8.31	12.14
WWRos south equivalent weighted for shading	%	12.47	6.54	12.31	6.48	11.09	16.3	10.87	7.08	7.84	12.14
Window to Floor Ratio WFR	%	15	5.98	8.27	10.1	14.51	18.05	9.27	10.39	12.08	20.38
Thermal Compacntess Ct	m^{-1}	0.56	0.33	0.32	0.55	0.43	0.45	0.44	0.46	0.49	0.65
Effective Envelope U value	$W.m^{-2}.k^{-1}$	1.78	1.87	1.85	1.75	1.7	1.76	1.79	1.77	1.8	1.93
LEK value	-	190.35	139.95	133.88	167.35	147.51	152.81	171.85	161.82	161.96	184.58

3.3.7. Urban morphology

3.3.7.1. Overview

In fact, the buildings are clustered together in urban configurations composed of spaces between them, which forms an urban morphology. Goulding et al. (1992) mentioned that building and its plot are an entity in the urban context and cannot be treated in isolation. For a given sun position, the extent of shading on a building in a given area depends to a large extent on the urban morphology and the density of building development in that district, the relative heights of the building and its adjacent structures and the building form and orientation. Nikoofard et al. (2011) evaluated the site shading effects of neighboring buildings and trees on annual heating and cooling energy requirements. It is found that the annual heating and cooling energy requirement of a house in Canada may be affected by as much as 10% and 90%, respectively, by the existence as well as the orientation, size and distance of an adjacent obstruction. Factors influencing the impact of shading are site-specific such as the latitude and climate, as well as the direction, number, size and distance of surrounding structures. OK (1992) developed a model to calculate the effect of shading due to adjacent or nearby buildings on the cooling load taking into consideration settlement density, as well as the shape, distance and orientation of the obstruction. A multi-story residential building located in Istanbul was simulated for July 21st as a case study. The results showed that the effect of shading is more significant for the west and east oriented surfaces primarily due to the lower angle of solar radiation in the afternoon that results in a significant heating effect. Although potentially significant, the impact of neighboring structures on the heating and cooling energy requirement of houses is often neglected in building energy analysis. Therefore, it is recommended that in building energy simulation studies, site external shading should be taken in consideration.

3.3.7.2. Urban Morphology of Gaza City

Most areas in Gaza city show a fairly consistent street and block pattern as shown in Figure 12. The principal streets run parallel and perpendicular to the coast (north eastern- south western) and (north western- south eastern). The building blocks are normally following the same orientation of buildings plot, which is in turn take the same orientation of the main streets. The main form of buildings range between the cube (square in plan) and cuboid (rectangular in plan). The rectangular shape is the most popular geometric shape in parcels while other forms such as circular, L shape and U shape represent a very small percentage (Muhaisen and Huda 2014).

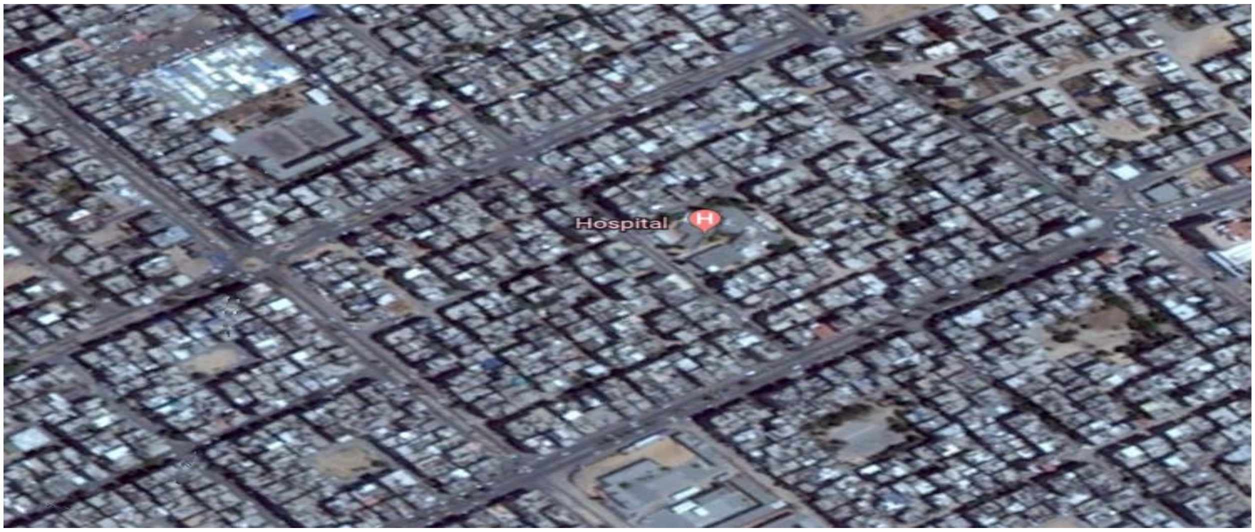


Figure 12 Aerial photo shows the common Distribution of Building in Gaza City. Source: (Google Earth)

Studying the effect of shading from neighboring structure is a complex task, because of the lack of the full knowledge of the buildings surrounding the studied building. However, in Gaza city, building's density, height, area and spacing between them are determined according to the zoning district regulations. In order to fairly equalize the effect of adjacent buildings on each building of the sample, the adjacent buildings were imposed to be the same size and height of the building under study. The side and rear setback of buildings is taken to be 3m, while the main façade of the building is located at a main street of 20 m width which could be facing one of four orientation (E, W, N, S) as illustrated in Figure 13 below. One of the factors that significantly affected by the orientation is building glazing area which is mostly described by WWR%. This parameter is further detailed in next sections.

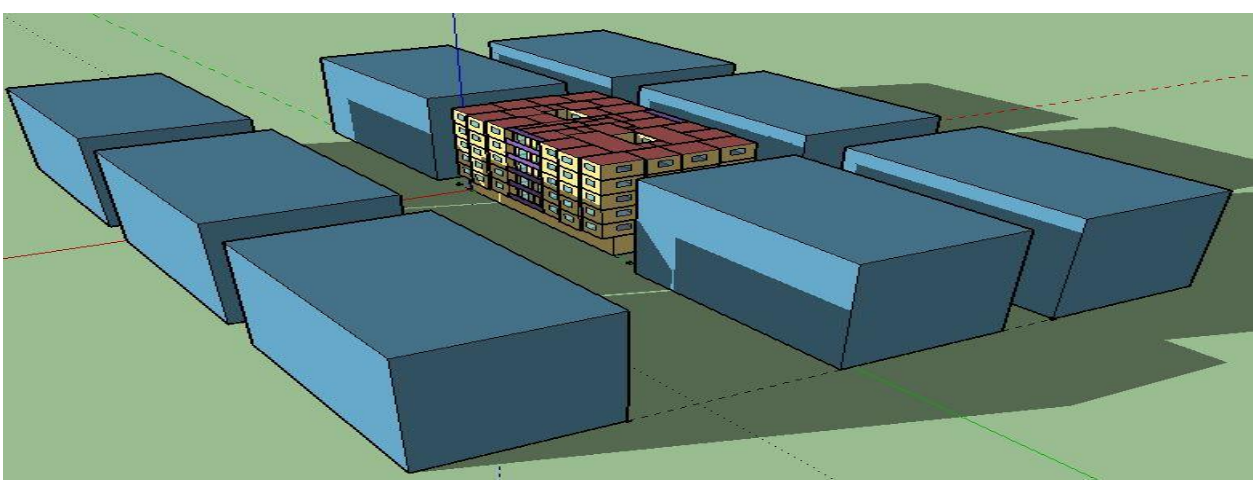


Figure 13 Assumed Urban morphology of buildings in Gaza city. Source: (Adopted by the Author)

3.4. Energy Simulation

3.4.1. Software

EnergyPlus 8.8.0 simulation software was used to perform annual dynamic thermal simulation for the chosen sample. The geometrical models of analyzed buildings were first created in OpenStudio SketchUp Plug-in 2.3.0. The building envelope is then exported to EnergyPlus as an IDF file to be completed with weather file, construction types, space schedules.

3.4.1.1. EnergyPlus

EnergyPlus is a modular whole-building energy analysis application that, unlike most other simulation tools, can perform calculations at time steps of less than one hour, passing results from one interval to the next to generate more accurate predictions of space temperature and comfort. EnergyPlus is chosen as the energy simulation tool in this analysis since it is the official energy analysis and thermal load simulation program of the U.S. Department of Energy. EnergyPlus is a highly extensible and customizable simulation application with text input and output that is easy to integrate into an automated workflow, besides it allows for visualization and limited modification of an energy model using OpenStudio, a plug-in for Google SketchUp. Using EnergyPlus avoids inaccuracies introduced by simplifying algorithms, and because it is a highly configurable tool, can be used for detailed design. Furthermore, EnergyPlus has been widely reviewed and validated using the ASHRAE/BESTEST evaluation protocol (ANSI/ASHRAE Standard 140-2001). In this study, EnergyPlus is used to calculate the idealized cooling, which serve as the relevant building energy performance metric. The idealized load represents the amount of energy that must be added to or extracted from the conditioned space to meet the thermostat settings.

3.4.1.2. OpenStudio Sketchup Plugin

OpenStudio developed by the National Renewable Energy Laboratory (NREL) For the United States Department of Energy. OpenStudio is a collection of software tools that interface with the EnergyPlus simulation engines to support whole-building energy assessment, using SketchUp as the graphical modelling environment for describing building geometry through adding space types and thermal zones to existing model.

3.4.1.3. Sketchup

SketchUp is a 3D modeling computer program for a wide range of drawing applications, it has been used due to the fact that's the OpenStudio SketchUp Plug-in requires SketchUp as a base. Additionally, SketchUp is an intuitive, powerful and simple-to-learn 3D drawing tool.

3.4.2. Input parameters

3.4.2.1. Weather file

Climate has a major impact on the energy use of most commercial and residential buildings. The analysis of climate is the starting point for a design that maximizes comfort and minimizes the energy consumption for heating and cooling. weather data are necessary in evaluating the thermal energy demand in buildings by using EnergyPlus software. The weather data are obtained using simulated data obtained using the dedicated software MeteoNorm 7.1.11.

MeteoNorm

The MeteoNorm database is based on combination of measured and modeled solar radiation data. In MeteoNorm, the key approach for an estimate at a specified location is interpolation of long-term monthly-averaged values from nearby meteorological stations. The modelled data based on satellite imagery is incorporated as support information and used mainly when no meteorological station is available within a distance of 10/20/30 km. Figure 14 below illustrate the location of the nearest weather station that has been used for temperature interpolation: Ben-Gurion airport (69 km), El Arish (80 km), Ghor El safi (108 km).

Figure 14 location of weather stations that used to generate a weather file for Gaza Strip. Source: (Google Earth, Adopted by Author)

For the comparative analysis of the meteorological parameters given by Palestinian Energy Buildings Code (PEBC) 2004 and the values for the same parameters generated using METEONORM (for Gaza city), monthly values of the temperature are presented in Figure 15 below.

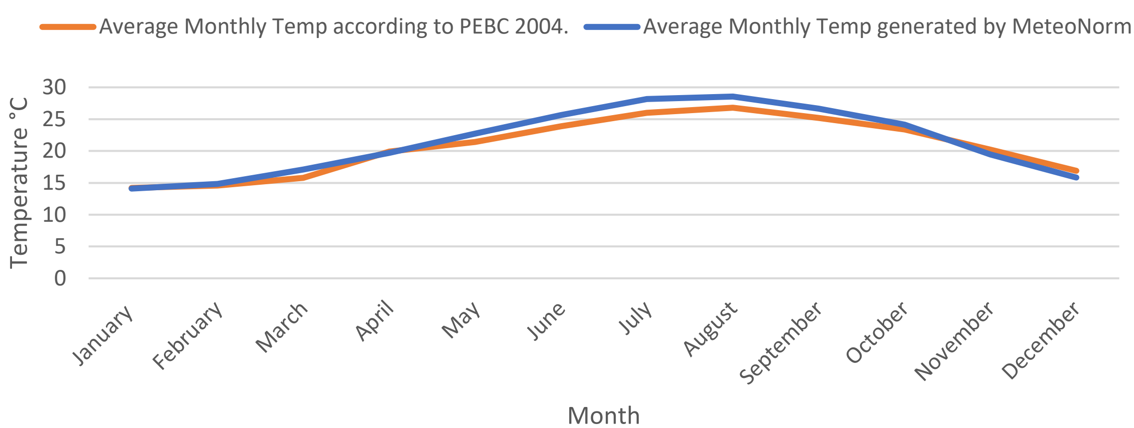


Figure 15 Comparative Analysis between Average Monthly temperature value of PEBC 2004 and the values generated by MeteoNorm

The comparative analysis of average monthly temperature variations leads to the conclusion that the generated data are similar to a large extent with the measured values. The highest differences between the measured and the generated values being recorded for hot season of 2° C difference.

3.4.2.2. EnergyPlus input parameters

Before conducting the simulation and subsequent analysis, it is important to understand what input parameters are to be studied. Selecting and defining the input parameters is often a difficult task that requires sound engineering judgement and a good understanding of the simulation system. A list of the input parameters was prepared, and they represented a variety of different factors encountered in building design. These were the design parameters that architects, and engineers would consider during various stages of the design process. The parameters categorized into two main groups: building envelope and HVAC system. By categorizing the input design parameters, a clear picture of the energy-related factors was established. Table 4 below shows summary of the main building load inputs parameters.

Table 4 summary of building load inputs parameters

Input parameters	Unit	Value
Building envelope		
Exterior Wall U-value	$W.m^{-2}.k^{-1}$	1.784
Roof U-value	$W.m^{-2}.k^{-1}$	2.668
Window U-value	$W.m^{-2}.k^{-1}$	5.894
Ground floor U value	$W.m^{-2}.k^{-1}$	2.338
Space load and space conditions		
Air-conditioning design temperature	°C	25
HVAC system	Default Ideal loads air system	
Infiltration rate	h^{-1}	0.2
Ventilation rate	h^{-1}	0.4
People	$m^2.person^{-1}$	20
Occupancy Activity level	$W.person^{-1}$	100
Lighting load	$W.m^{-2}$	1.3
Electric Equipment load	$W.m^{-2}$	3
Shading	Horizontal overhang for windows (Balconies)	
Thermal zoning	One floor Zoning	

To run an energy simulation model, an extensive set of inputs are required to define the building geometry, internal loads, outdoor environment, equipment, and schedules. In conceptual design, only a small subset of these inputs namely the building form, orientation, fenestration, materials, and shading is under consideration. The remaining inputs required to run an annual simulation can be fixed at default values based on the building type. Therefore, fixed internal loads were modelled under the following assumptions: 20 $m^2.person^{-1}$, 1.3 $W.m^{-2}$ for artificial lighting, 3 $W.m^{-2}$ for electrical equipment. For simplicity, the artificial lighting requirement was fixed and did not respond to variations in the amount of daylighting. As a result, variations in artificial lighting density and associated heat gain in response to changes in daylighting were not captured. Air flow rate due to infiltration and ventilation is set constant of 0.2 and 0.4 h^{-1} respectively. Setpoint for cooling is 25 °C throughout the whole year.

The configuration of Building envelopes includes the most common materials that used in buildings in Gaza Strip nowadays. The main used materials are the concrete and hollow blocks walls, which are plastered and painted from both sides with light colors. The most common configuration of the building components of Gaza strip are illustrated in Table 5 below

Table 5 Configurations of main building envelopes components

Configurations of building envelopes	
Components	Configuration
Exterior Wall	Outside Plaster of 2.5 cm
	Block Wall of 20 cm
	Inside Plaster of 2.5 cm
Exterior Flat Roof	Reinforced concrete 8 cm
	Hollow concrete block 17 cm
	Inside Plaster of 2.5 cm
Ground Floor	Tiles of 5 cm
	Sand with gravel of 7 cm
	Reinforced concrete 8 cm
Glazing	Simple Glazing - clear 3 mm

3.5. Critical Input Parameters for a simple prescriptive index

Numerous factors may influence the energy performance in buildings, such as: the outdoor weather conditions, building's architecture, building's thermal characteristics, the operation of sub-level components like HVAC systems and the way the building is used by the occupants. However, there are two elements that need to be considered when establishing the critical input parameters for a simple prescriptive index. The First consists of determining whether the parameter has a significant effect on the thermal response of the building. The second involves focusing on parameters that are directly influenced by architectural design decisions. During the preliminary design stages, architectural design decisions consist mainly of defining the building size, form, glazing and general construction. According to (Dolinar et al. 2010), there are two main variables influencing the energy demand for the heating and cooling of the building: climatological conditions and building's architecture along with its structure properties. Identifying the important parameters however is not that simple since they can influence each other. Parameters such as internal loads, ventilation, temperature setpoints and operating hours can be modified during the final design stage without compromising other design features. They thus require little attention and can be specified using default values.

Regardless the interest and the considerable work done so far, there is no common consensus among the researchers on which are the best inputs to be used in the models or what is the most suitable model to be used by the designers. Therefore, identifying these most important building components is critical from the perspective of the building designers and owners as they want to examine the possibilities of reducing building energy consumption, through both efficient systems and management and with building architectural characteristics. As for the building parameters the current literature points us to the following inputs:

3.5.1. Building morphology

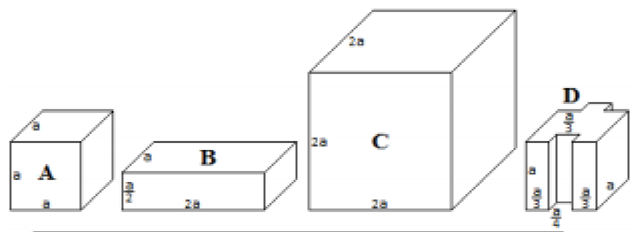
3.5.1.1. Shape Factor

Although the literature review indicated set of factors influencing the cooling energy demand of buildings in different terminologies, most of these factors could be gathered under the term 'Building morphology'. Building morphology is an important factor that could influence an increase/decrease of energy required to heat or cool the occupied space. Besides, it has also an important impact on the energy consumption and implicitly on the energy costs (Pessenlehner and Mahdavi 2003). Based on a literature review it was found a pertinent solution to define the building geometry and implicitly the heat loss surfaces, by using the building **Shape Factor** (SF) (also called building **Characteristic Length** L_b). The shape factor of a building is a measure of the building's compactness and expresses the ratio between the building's thermal envelope area ($\sum_{i=1}^{n} A_i$) and its volume V_b. The thermal envelope area is the area that separates between the conditioned and unconditioned areas or alternatively, the indoor and the outdoor environment

$$L_b = \frac{V_b}{\sum_{i=1}^{n} A_i} \; [m] \tag{1}$$

$$SF = \frac{\sum_{i=1}^{n} A_i}{V_b} \; [m^{-1}] \tag{2}$$

As illustrated in Figure 16. building A and B has the same volume but with different thermal envelope area which results in different SF. The size of the building also affects the SF. A smaller building with similar shape will have larger SF as illustrated by building A and building C. Irregular façades with trenches and bulges, e.g. heated balconies that extend beyond the façade, may also increase the SF as illustrated by buildings A and D.



	A	B	C	D
Volume	a^3	a^3	$8a^3$	a^3
Thermal envelpe	$6a^2$	$7a^2$	$24a^2$	$7a^2$
Shape factor	6/a	7/a	3/a	7/a

Figure 16 The shape factor of buildings with different sizes and shapes. The parameter 'a' symbolizes a unit of length. Source:(Danielski et al. 2013)

3.5.1.2. Thermal Compactness

Correcting the SF for adjacencies result in another variable called **Thermal Compactness** C_t, which was established in a study conducted by (Ghiassi et al. 2015). Thermal compactness defined as the ratio of heated volume to thermally effective envelope area, which is the sum of areas of heat loss surfaces, corrected for adjacencies, which can be calculated by the following equation.

$$C_t = \frac{V_b}{\sum_{i=1}^{n}(A_i \times f_i)} \; [m] \qquad (3)$$

Where V_b is the conditioned volume of the building, A_i represent the thermal component's area, and f_i is the temperature correction factor that vary according to the adjacent of heat emitting building elements (i.e. exterior, ground or adjacent non-heated spaces). f_i in this study is assumed to have the same value that mentioned in the Austrian Standards (ÖNORM B 8110-6) as shown in Table 6 below.

Table 6 Temperature Correction Factor fi for different building component (ÖNORM B 8110-6)

Building component	***f (temperature correction factor)***
Outside wall	*1*
Wall to unheated space	*0.5*
Wall to unheated barn	*0.5*
Ceiling to unheated cellar	*0.5*
Ceiling to ground	*0.5*
Flat roof	*1*
Windows	*1*
Attic Floor	*0.9*
Basement Wall	*0.6*

3.5.1.3. Relative Compactness

Another indicator of the form is the building **Relative Compactness** (R_c), which indicates the relationship between the designed building's shape factor $(A/V)_{building}$ and the minimum shape factor of the rectangular (reference) building of the same volume $(A/V)_{ref}$ (Mahdavi and Gurtekin 2002). In this analysis, the reference building is assumed to be a cube having the same building volume as the actual building. Therefore, the R_c can be expressed by the following equation:

$$R_c = 6 \times {V_b}^{0.66} \times \sum_{i=1}^{n} A_i \tag{4}$$

3.5.2. Building glazing area

Among all the aspects involved in the design of a façade system, the **Window-to-Wall Ratio (WWR)** – i.e. the ratio between the transparent area and the opaque surface – is a parameter that has a deep impact on energy demand (Lee et al. 2013). WWR has an important effect on building energy consumption for heating and air conditioning. For one thing, solar heat gains will be increased as the WWR ratio increasing, on the other hand, the heat exchange will be also increased for the heat transfer coefficient of window is usually larger than wall. The WWR is the measure of the percentage area determined by dividing the building's total glazed area by its exterior envelope wall area.

3.5.3. Windows Orientation

The distribution of the glazing area on the facade in terms of orientation plays also an important role in the energy demand assessment and, therefore it must be considered in the development of the prediction model. A first main challenge is to express this distribution of the glazing area as this is not simple and deciding to build a model for certain orientations, may introduce high errors of the predictions. This issue is common for most of the prediction models found in literature and therefore a viable solution must be found.

In this study a reference building has modeled with an area of 360 m^2 and a height of 22.20m (6stories). The selected area as well as the height of the reference building are the average area and height of the studied buildings sample. Four cases of main orientation have been studied which is North, East, West and South. The building is assumed to be in high populated area and surrounded from three orientation by similar building with rear and side setback of 3m for each one, while the 4^{th} orientation is located on a street of 20m width. Figure 17 below shows the reference model and the surrounding building, with building main façade directed to the south.

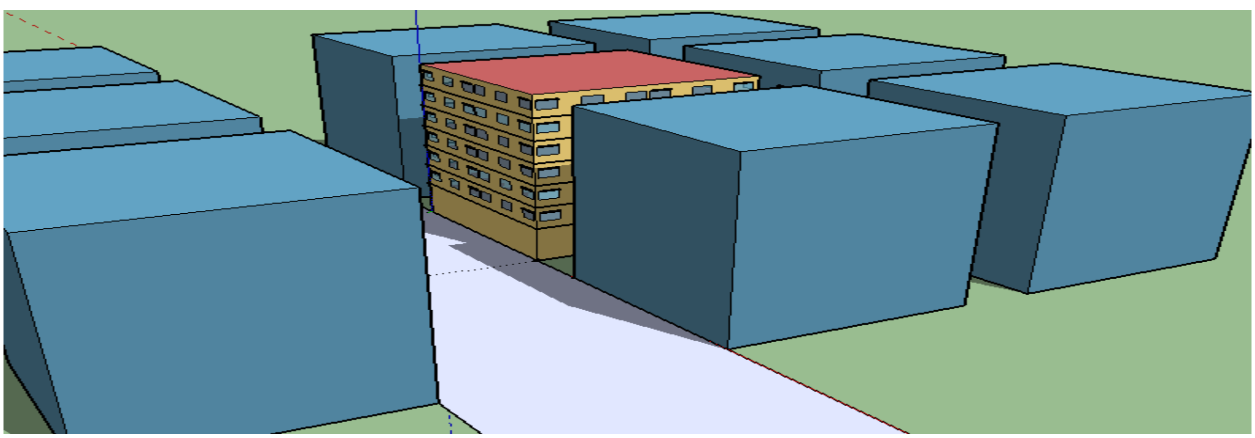


Figure 17 Reference model to study the effect of orientation on the received amount of solar radiation by windows.

The total Annual Incident Solar Radiation AISR [$W.m^{-2}$] on each window of the building is calculated using EnergyPlus simulation tools. AISR has been calculated in presence of surrounding buildings therefore it captures the effect of the surrounding obstructions in reducing solar gains. For each orientation and each floor, the average value of 3 windows positions is calculated. Since the orientation factor for each orientation is almost similar for different stories, the average value of 6 stories is taken as final weighting factor. Afterwards, the South Equivalent Factor (SEF) is taken as a good representation of the glazing area and its distribution for different orientations. This factor can solve the mentioned issue and it may be considered as an input in the prediction model. It should be noted that g-value for windows remain constant for the whole buildings sample. Therefore, it will not affect the WWR% ratio by the amount of solar gain.

WWR weighted for the orientation can be calculated as:

$$WWR_O = \sum_{i=1}^{n}(WWR\%_i \times SEF_i)\ \ [\%] \tag{5}$$

Where WWR% is the window to wall ratio of certain facade, SEF is the south equivalent factor and (i) is the façade index. These coefficients are summarized in Table 7.

Table 7 South Equivalent Factor (SEF)

South equivalent Factor				
Main Façade to street	*Façade's Orientation*			
	N	*E*	*S*	*W*
South	0.26	0.51	1.00	0.53
North	0.62	0.79	1.00	0.80
West	0.44	0.71	1.00	1.21
East	0.44	1.22	1.00	0.70

3.5.4. External Fixed Shading

The building energy performance community has well understood the effect of external solar shading on fenestration. Existing literature suggests that there is a difference between the amount of heat gained by an indoor space through fenestration having an external shade as compared to a fenestration not having an external shade (Kaftan and Marsh 2005). The solar radiation incident on a glazed window can be reduced considerably by using external shadings. The external shading reduces the area of the window exposed to solar radiation, and thereby reduces the heat transmission into the building. A very common method of providing external shading is to use overhangs. The principle of overhangs for solar heat gain control is known for thousands of years. Fixed overhangs are among the simplest, yet an effective method to control the solar heat gain into a building. By proper design of the overhangs it is possible to block the solar radiation during summer and allow it into the building during winter. This shading element affects both the direct radiation from the sun and the diffuse radiation from the sky. Depending on the geometry it might even affect the amount of reflected diffuse solar radiation that a window receives from the ground. (Kohler et al. 2017).

Figure 18 below shows the effectiveness of external shading on solar penetration. In this example the low sun angle on December 21st allows the sunlight to illuminate approximately 2/3 of the window and penetrate the space. On June 21st however, no direct sun is striking the window or entering the space. The effect of external shading can vary according to the orientation. This simply due to the fact of the sun path and latitude during the day. Figure 19 below illustrates the low latitude position of the sun in the morning and the evening of summer periods which increase the incident solar radiation on the east and west façades comparing with the high latitude position of the sun on the south façade.

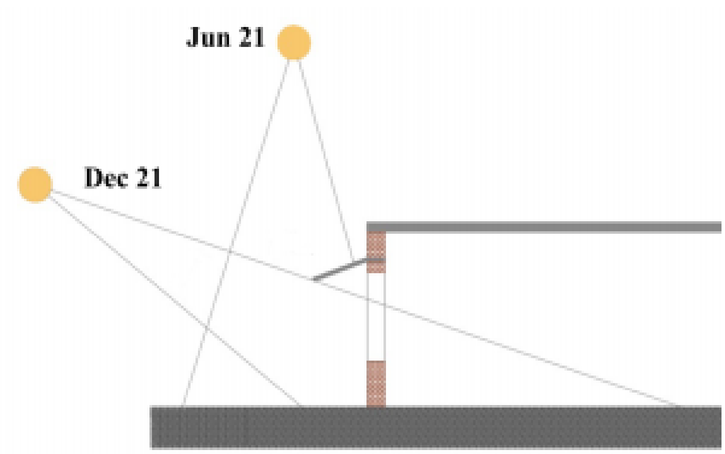


Figure 18 Effect of an awning on solar shading in summer and winter

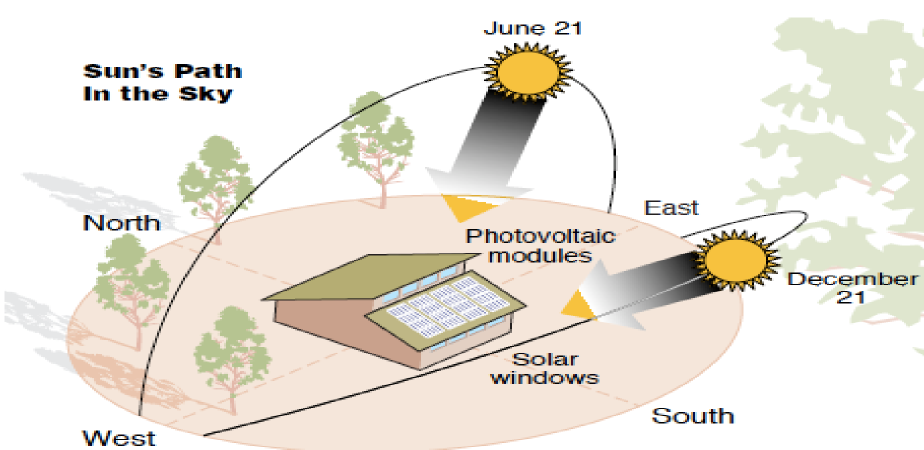


Figure 19 movement of sun in summer and winter period. (Source: Green Passive Solar Magazine)

Using a separation between the top of the window and the overhang, it is possible to completely shade the window in summer and completely unshaded it in winter. Complete shading of the window can be provided by selecting infinite combinations of overhang width (W_o) and separation dimensions (S), as shown in Figure 20. It should however be noticed that for complete shading as the separation distance S increases, the width of the overhang W_o should also increase and vice versa.

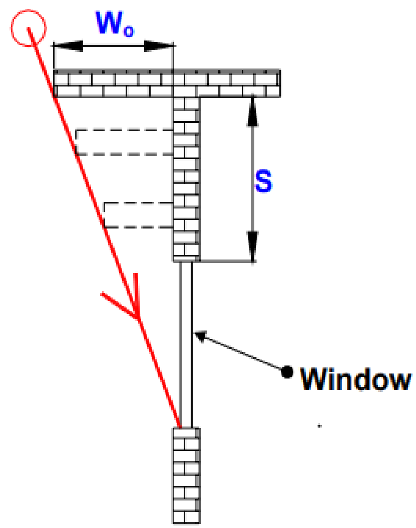


Figure 20 Variation of overhang width with separation for complete shading

For the ease of communication this study uses ‘Fixed Shading Coefficient’ (FSC) to indicate the window area that subjected to solar gain in the presence of a fixed external shade. Whole building performance simulation tools EnergyPlus are capable of calculating energy consumption of buildings with external shades. However, these tools do not provide output indicating shading factor specifically for each window. For external horizontal shades, the FSC takes the following two dimensions in account (i) vertical distance between top of window and bottom of overhang and (ii) horizontal distance from the edge of the fenestration and the outside edge of the overhang. Therefore, a parametric study of different overhang shading depth W_o and different separation dimension (S) is established for the reference building model that previously mentioned. Windows orientation is considered for each case, due to the significant of orientation on the perceived solar radiation by windows as illustrated in Figure 19.

The aim of this parametric study is to provide a simple and fast way to calculate the effective window to wall ratio in the presence of external fixed shading (overhang). FSC is determined by calculating the total incident solar radiation on windows with and without fixed shading.

AISR [W.m^{-2}] is calculated for each floor of the reference building, and for each façade orientation. As a reference for calculating the shading factor, the AISR is determined as a first case without applying fixed shading. Figure 21 below shows the relationship between AISR and orientation for different latitude.

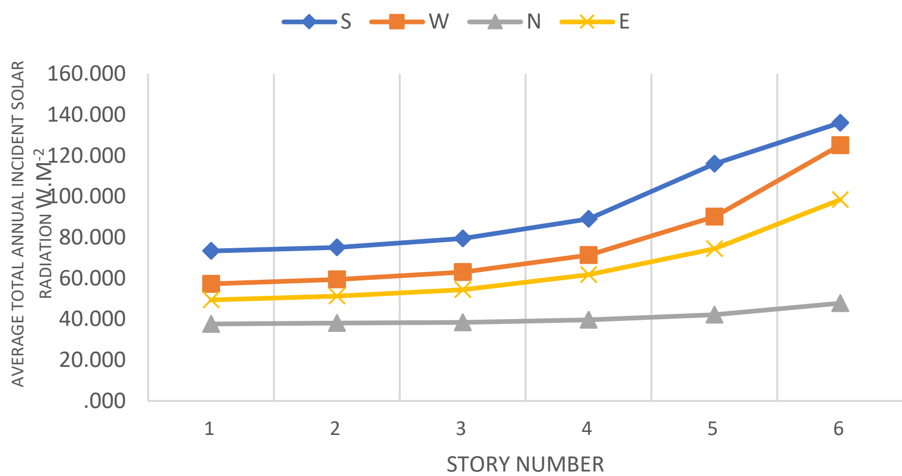


Figure 21 Average Total Annual Incident Solar Radiation W.m^{-2} for different orientation and latitude with no fixed shading

Although the AISR is vary according to different latitude, however for each latitude the decreasing in AISR is almost the same with and without fixed shading. Table 8 below shows the AISR with and without fixed shading for different orientation and different latitude.

Table 8 AISR with and without fixed shading for different orientation and different latitude

Story	AISR [W.m-2] without fixed shading				AISR [W.m-2] with fixed shading 0.2 m directly above the window				Fixed shading Factor FSC			
	S	W	N	E	S	W	N	E	S	W	N	E
6	136.07	125.10	47.80	98.43	110.03	107.93	43.71	83.77	0.81	0.86	0.91	0.85
5	116.00	90.17	42.13	74.47	90.27	75.37	39.43	63.17	0.78	0.84	0.94	0.85
4	89.00	71.37	39.63	61.78	68.83	59.37	36.63	50.85	0.77	0.83	0.92	0.82
3	79.47	62.93	38.33	54.33	61.63	53.07	36.58	45.33	0.78	0.84	0.95	0.83
2	75.03	59.33	38.03	51.27	58.23	50.67	34.62	43.33	0.78	0.85	0.91	0.85
1	73.33	57.27	37.63	49.40	57.53	49.43	33.37	43.03	0.78	0.86	0.89	0.87

It can be noticed from Table 8 that for specific orientation, the FSC is almost the same for different latitude when it's related to AISR. Therefore, an average value of each orientation is taken in the following calculation, without taking the latitude of window in consideration.

As shown in Figure 22 the effect of external shading is considerably obvious for the south orientation. Which returns to the sun path and latitude during the day. The high latitude position of the sun on the south façade result in significant decreasing of solar radiation perceived by south oriented windows. While the West and East orientations are less influenced by horizontal external shading compared with south orientation as shown in Figure 24 and 25 respectively. This is due to the low latitude position of the sun in the morning and the evening of summer periods which result in high incident solar radiation for east and west orientation respectively. The effect of overhang on North oriented window is almost negligible even for large overhang shading depth 1.2 m (balcony) that have a separation dimension of 1m. Table 9 below summarizes the FSC for different orientation, different shading depth and different separation dimension.

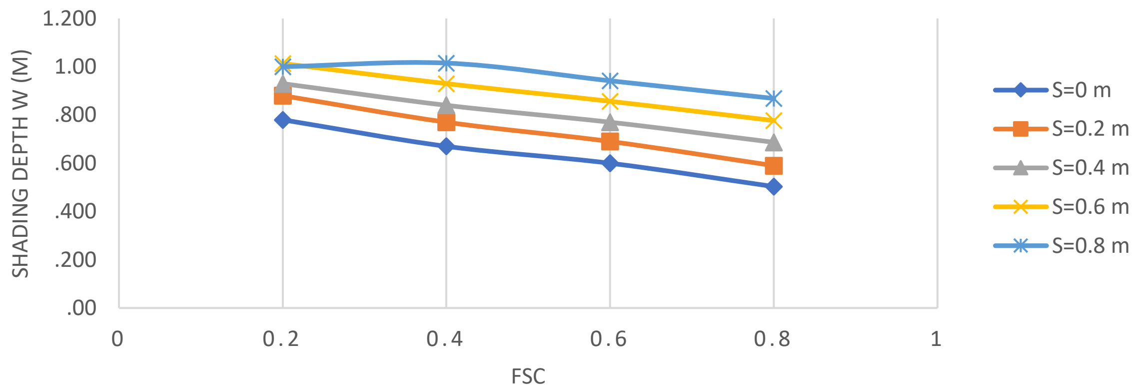


Figure 22 FSC coefficient for different shading depth and for each separation dimension for South orientation

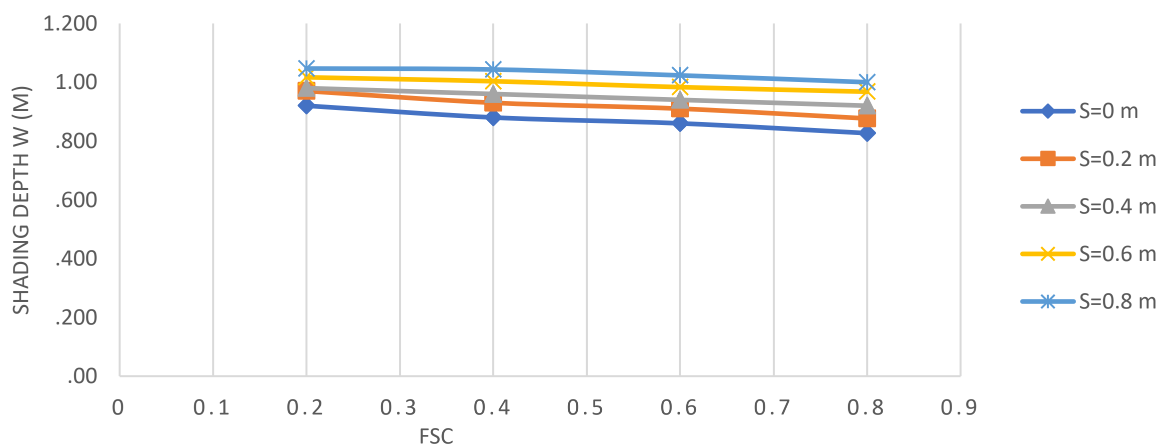


Figure 23 FSC coefficient for different shading depth and for each separation dimension for North orientation

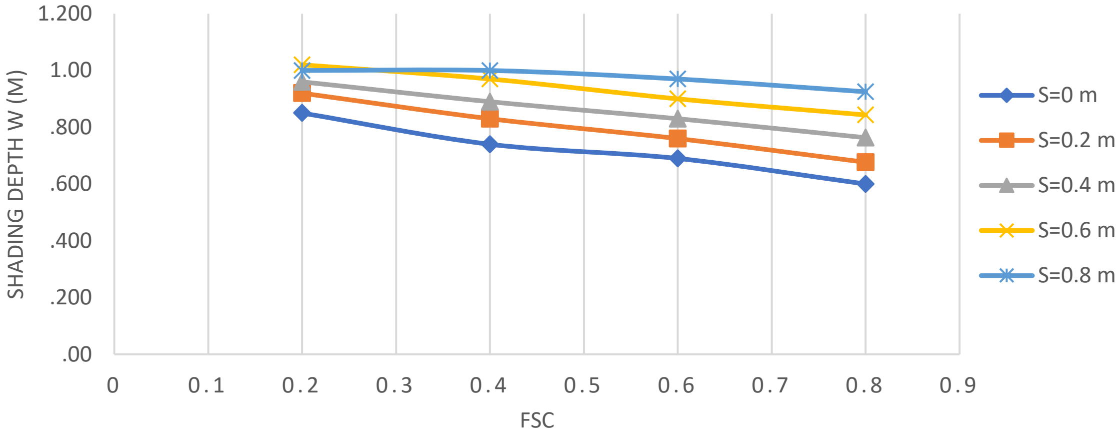


Figure 24 FSC coefficient for different shading depth and for each separation dimension for West orientation

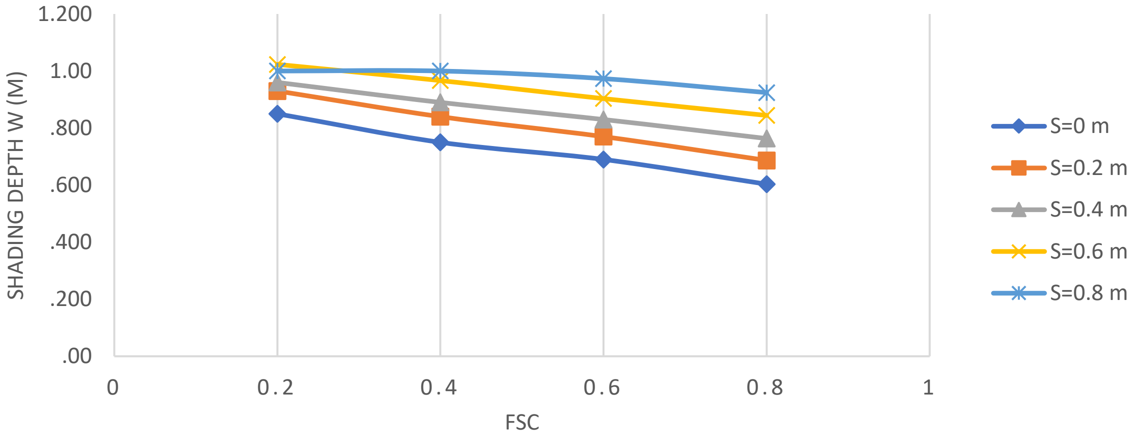


Figure 25 FSC coefficient for different shading depth and for each separation dimension for East orientation

Table 9 FSC for different shading depth and different separation dimensions.

Façade orientation	Separation dimension [m]	Horizontal overhang shading/Balconies depth [m]						
		0.2	**0.4**	**0.6**	**0.8**	**1.0**	**1.5**	**2.0**
E	**0**	0.9	0.7	0.7	0.6	0.5	0.3	0.1
	0.2	0.9	0.8	0.8	0.7	0.6	0.4	0.2
	0.4	1.0	0.9	0.8	0.8	0.7	0.5	0.4
	0.6	1.0	1.0	0.9	0.8	0.8	0.6	0.5
	0.8	1.0	1.0	1.0	0.9	0.9	0.7	0.6
W	**0**	0.9	0.8	0.7	0.6	0.5	0.3	0.1
	0.2	0.9	0.8	0.8	0.7	0.6	0.4	0.2
	0.4	1.0	0.9	0.8	0.8	0.7	0.5	0.4
	0.6	1.0	1.0	0.9	0.8	0.8	0.6	0.5
	0.8	1.0	1.0	1.0	0.9	0.9	0.7	0.6
S	**0**	0.8	0.7	0.6	0.5	0.4	0.2	0.0
	0.2	0.9	0.8	0.7	0.6	0.5	0.3	0.0
	0.4	0.9	0.8	0.8	0.7	0.6	0.4	0.2
	0.6	1.0	0.9	0.9	0.8	0.7	0.5	0.3
	0.8	1.0	1.0	0.9	0.9	0.8	0.6	0.4
N	**0**	0.9	0.9	0.9	0.8	0.8	0.7	0.6
	0.2	1.0	0.9	0.9	0.9	0.8	0.8	0.7
	0.4	1.0	1.0	0.9	0.9	0.9	0.9	0.8
	0.6	1.0	1.0	1.0	1.0	1.0	0.9	0.9
	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0

It should be mentioned that the FSC values in Table 9 are location specific and are prescribed for a range orientation of fenestration. Such prescriptive values are limited in terms of their accuracy and only apply to a limited range of external shade designs and environmental parameters. Hence, WWR weighted for the orientation and fixed shading can be calculated using the following formula.

$$WWR_{O+S} = \sum[(\sum_{i=1}^{n}[A_i \times FSC] \times SEF_i)] \quad [\%] \qquad (6)$$

Where A_i refers to the windows area, FSC is the fixed shading coefficient and SEF_i is the South equivalent factor which can be found in Table 7.

3.5.5. Window to floor area ratio

Another studied variable is Window to Floor Area ratio (WFR) which can be translated by a percentage of heated floor area of the total glazing area. This parameter is important for architects due to its potential on reducing the cooling and demand in summer and winter respectively. The most appropriate size of a window for energy smart design depends on building orientation and the amount of thermal mass in the internal building materials. Previous literature suggested that utilizing the optimum WFR allows buildings to obtain more solar gain in winter and shading in summer, decreasing the demand for heating and cooling. Moreover, the inclusion of optimum WFR in building design will have a lifelong impact on the future energy demand of buildings.

3.5.6. Thermal Transmittance of Building's Envelope Components (U-Value)

The building envelope is the physical separator between the interior and exterior of a building. Components of the envelope are typically: walls, floors, roofs, fenestrations and doors. Fenestrations are any opening in the structure: windows, skylights, clerestories, etc. Hua and Wua (2015) have established a study on Building's Envelope in Beijing as a typical hot summer and cold winter area, whose building energy consumption is very significant. The results show that the transfer coefficients of the outside windows have largest effect on indoor thermal load, the roof is secondary, and exterior walls are weakest. Thus, the thermal performance of the building envelope and energy efficiency have a great relationship. The main property of the building envelope to look at is the thermal insulation capability, usually expressed by the thermal transmittance U, [$W.m^{-2}.k^{-1}$]. Thermal transmittance, is the rate of transfer of heat through a structure (which can be a single material or a composite), divided by the difference in temperature across that structure. The unit of measurement is $W.m^{-2}.k^{-1}$. The better-insulated a structure is, the lower the U-value will be. In order to calculate one U value for the entire envelope, the variable namely area weighted average U value (U_w) is calculated. $\boldsymbol{U_w}$ calculate the mean U value for the whole thermal envelope of the building, weighted to the total area of building's thermal components, which is given by the following expression.

$$U_w = \frac{\sum_{i=1}^{n}(U_i \times A_i)}{\sum_{i=1}^{n} A_i} \qquad (7)$$

Where U_i is the U value of each thermal component and A_i represent the thermal component's area.

The shortcoming of this variable is its inability to take the effect of surrounding environment in consideration. For that reason, Ghiassi et al. (2015) proposed the Effective Average Envelope U value $\boldsymbol{U_e}$, which is defined as" the average U-value of heat loss surfaces weighted by area of the respective building components and corrected for adjacency relationships".

$$U_e = \frac{\sum_{i=1}^{n}(U_i \times A_i \times f_i)}{\sum_{i=1}^{n} A_i} \tag{8}$$

Where U_i is the U value of each thermal component, A_i represent the thermal component's area, and f_i is the temperature correction factor that vary according to the adjacent of heat loss surfaces (i.e. exterior, ground or adjacent non-heated spaces). f_i values can be found in Table 6.

3.5.7. Line of European K-values (LEK value)

Some endeavors of European context tried to establish a simple-to-use approaches to describe and prescribe the overall heat transfer coefficient of building envelopes. One method indicates the use of what is referred to as LEK value (Line of European K-values). LEK value is one of the variables that tried to capture the geometric and semantic characteristic of the building envelope through U_w and l_c to establish a relationship between building geometry and the mean heat transfer coefficient of the building envelope. LEK value can be expressed by the following equation,

$$LEK = 300 \times \left(\frac{U_w}{2 + l_c}\right) \tag{9}$$

Even though LEK is prescriptive in nature, however it allows for significant degrees of freedom in design, as they do not enjoin any particular thermal performance requirements for the sub-elements of the building envelope. The shortcoming of this variable is that the transparent building envelope elements are described only in terms of their U-value without considering the solar loads and the related building mass effects (Mahdavi et al. 1996).

3.6. Statistical Analysis and Data Evaluation

Statistics is an integral part of the quantitative approach to knowledge. The field of statistics is concerned with the scientific study of collecting, organizing, analyzing, and drawing conclusions from data. This is termed descriptive statistics. Statistics benefits all of us because of its ability to predict the future based on data we have previously gathered. Statistical methods help us to transform data to information and knowledge. In the process of solving a real-life problem using statistics, the following three basic steps may be identified. First, consistent with the objective of the problem, through identifying the model using the appropriate statistical method. Followed by justifying the applicability of the selected model to fulfill the aim of certain issue. Finally, applying the related model properly to analyze the data and make the necessary decisions, thus answering the question of our problem with minimum risk.

In this study, the collected data would be statistically analyzed with the Statistical Package for the Social Sciences (SPSS). SPSS "is a package of programs for manipulating, analyzing, and presenting data; the package is widely used in the social and behavioral sciences" (Landau and Everitt 2004). Of central importance here is the choice of such a tool that it offers the maximum ease of interactive use and a solid connection between data, graphs, analysis, and transferability. In the present study, the following statistic filed would be used for analyzing the study data.

3.6.1. Descriptive statistics

Descriptive statistics are used to characterize the basic features of the data in a study. They provide simple summaries about the sample and the measures. Together with simple graphics analysis, they form the basis of virtually every quantitative analysis of data.

One of the most common ways to describe a single variable is with a frequency distribution. The most used properties of distributions are dispersion (variability) and location (central tendency). The central tendency of a distribution is an estimate of the "center" of a distribution of values. There are three major types of estimates of central tendency including Mean, Median and Mode. Where the Mean or average is probably the most commonly used method of describing central tendency. dispersion (also called variability, scatter, or spread) is the extent to which a distribution is stretched or squeezed. Common examples of measures of statistical dispersion are the variance, standard deviation, and interquartile range.

3.6.2. Correlation

Correlation is a bivariate analysis that measures the strength of association between two variables and the direction of the relationship. In terms of the strength of relationship, the value of the correlation coefficient varies between +1 and -1. A value of ± 1 indicates a perfect degree of association between the two variables. As the correlation coefficient value goes towards 0, the relationship between the two variables will be weaker. The direction of the relationship is indicated by the sign of the coefficient; a + sign indicates a positive relationship and a – sign indicates a negative relationship. The most widely used correlation statistic to measure the degree of the relationship between linearly related variables is the Pearson *r* correlation. For the Pearson *r* correlation, both variables should be normally distributed (normally distributed variables have a bell-shaped curve). Other assumptions include linearity and homoscedasticity. Linearity assumes a straight-line relationship between each of the two variables and homoscedasticity assumes that data is equally distributed about the regression line. Consequently, and before any evaluation of the data, SPSS was used to determine if a data set is well-modeled by a normal distribution and to compute how likely it is for a random variable underlying the data set to be normally distributed. SPSS was also used to interpret a data set and identify and remove outlying values. Outliers in statistical analyses are extreme values that do not seem to fit with most of a data set. If not removed, these extreme values can have a large effect on any conclusions that might be drawn from the data in question, since they can skew correlation coefficients and lines of best fit in the wrong direction.

3.6.3. Regression Analysis

Regression analysis is one of the statistical methods used for developing models for prediction of energy consumption in buildings. Regression analysis is one of the most used statistical tools to describe the variation of a dependent variable (often denoted by y) whose value depends on that of another to explanatory variables (often denoted by x) which is a variable that is suspected to affect dependent variable. Several provisions of the dependent variable in the regression analysis can only be one variable and the data scale are interval / ratio so that data can only be in the form of numerical data. While the independent variable can be more than one variable and the data scale can be nominal / ordinal i.e. categorical data or interval / ratio of numerical data. If the number of independent variables used only one variable then called simple linear regression analysis, whereas if the number of variables used more than one is called by multiple linear regression analysis (Fumo and Biswas 2018). There are three objectives in linear regression analysis, (i) form regression model to know the relation between dependent variable and independent variables, (ii) to test whether there is influence of independent variables to dependent variable, and (iii) to predict the value of variable dependent based on independent variables that have been determined.

Formation of the regression model is done by estimating the parameters of the regression model. So that can yield regression coefficient for every experimental variable.

After testing whether the relationship between independent variables with variable dependent using correlation test. A multiple linear regression model was developed with SPSS for predicting the total annual cooling energy requirements in the climate of Gaza Strip. Multiple linear regression models can be used to evaluate the relationship between dependent variables with two or more independent variables. Compared with nonlinear models, linear regression models are easier and more practical in solving problems (SAFA et al. 2014).

3.6.3.1. Multiple Regression Model

Multiple regression technique was adopted in the present study to develop simple energy estimation models for residential buildings in Gaza Strip. Multiple linear regression was used to model the relation-ship between the 10 explanatory variables and the annual energy consumption which is the response variable by fitting a linear regression. The following form of the regression equation was used to predict the cooling consumption:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_\rho \beta_\rho$$

where y is the response variable (cooling demand), x_i presents the predictor variable and β_i the corresponding regression coefficient.

3.6.3.2. Quality of the model

The accuracy of the regression models was determined using coefficient of determination (R^2). R^2 is a correlation coefficient specific to the regression modelling. The value of R^2 varies between 0 and 1 the closer the R^2 to the 1, the more accurate the data is. A value of R^2=0.9 indicates that 90% of the total variability in the response variable is accounted for by the predictor variables.

3.6.3.3. Residual Analysis

After calculating the regression equation, the next process is to analyses confidence interval for the model's residual. In this study, a confidence interval represents a closed interval where a certain percentage of the residuals is likely to lie. For example, a 90% confidence interval with a lower limit of A and an upper limit of B implies that 90% of residuals lies between the values of A and B. Out of the remaining 10% of the residuals, 5% is less than A and 5% is greater than B. The aim of this step is to clarify the residual of the output of multiple regression model for different confidence levels, so the user can know that under a certain confidence level there is an error with a specific range.

4. Results and Discussion

4.1. Overview

The current chapter illustrate the study's finding and discussion in four section. In the first section, the impact of the ten building design variables on the cooling energy is investigated. Annual cooling demand as the performance indicator is taken as a benchmark for thermal design quality of the studied buildings sample. In the second section, the developed multiple regression model will be established based on the evaluation of the most influencing factors that discussed in the first section. As model users may be more concerned about the level of error that the regression models may cause if used in place of dynamic simulation models. Analysis of relative differences between regression model predictions and results from dynamic simulation is carried out in the third section. Finally, based on the calculated cooling demand using the regression equation, enough data has been assembled to predict the energy efficiency category of a design for different values of input design variables

4.2. Analysis of influencing factors of annual cooling energy consumption per unit area

This section is focused on the buildings sample and correlation analysis between annual cooling energy consumption of the buildings and the factors. The analysis is carried out using SPSS statistical analysis software. Collected ten building design variables from 50 buildings were correlated with the total annual cooling energy demand to identify design variables, which are significantly influencing the energy demand for space cooling of buildings in Gaza Strip. The results obtained from the correlation analysis are presented in Table 10. The Table depicts the Pearson correlations coefficient (R) and coefficient of determination (R^2) of the building design variables with respect to the annual cooling energy demand of the buildings sample.

Table 10 correlations of total annual cooling energy consumption and building design variables.

Building Design Variable		Total annual cooling energy demand		
		R	R^2	Sig
1	SF	0.743**	55%	0.000
2	lc	0.715**	51%	0.000
3	RC	0.285*	8%	0.045
4	WWR	0.538**	29%	0.000
5	WWRo	0.614**	38%	0.000
6	WWRos	0.66**	44%	0.000
7	WFR	0.748**	56%	0.000
8	Tc	0.75**	56%	0.000
9	Ue	0.453**	21%	0.001
10	LEK	0.794**	63%	0.000

***. Correlation is significant at the 0.01 level (2-tailed).*

**. Correlation is significant at the 0.05 level (2-tailed).*

As observed from Table 10, based on the Pearson correlation coefficients and the significance of correlations at 5% and 1% significant levels, most of the variables resulted in significant correlation values with the cooling energy demand. All correlations except relative compactness are significant at the 0.01 level. Influence of buildings design variables on cooling energy demand are discussed in more detail below.

4.2.1. Impact of building morphology

4.2.1.1. Shape Factor

Building compactness can be expressed by using shape factor SF [m]. Figure 26 illustrates the impact of SF on annual cooling energy use for all buildings considered in the analysis. As shown in Figure 26, there is a fairly high correlation between cooling demand and shape factor, with R^2 of 0.55, indicates that 55% of the sample can be represented by this regression line. Deviation of the data from the fitted regression line results in a standard error of estimation of 14.26. A highly significant ρ value of 0.001 and correlation coefficient R of 0.743 indicates that there is a significant relation between shape of the building and its cooling demand. The other way to express building compactness is by using characteristic length l_c [m^{-1}], which is 1/SF. Figure 27 illustrate the relation between characteristic length l_c and cooling demand, which as expected from SF result in R^2 of 0.511 and a Pearson's correlation of -0.715. Negative correlation means that as the characteristic length l_c increase, the cooling demand decreases, and vice versa. Generally, the larger the envelope surface area, the higher the amount of heat gains through the building skin. As a result, compact shapes are more desirable for energy saving.

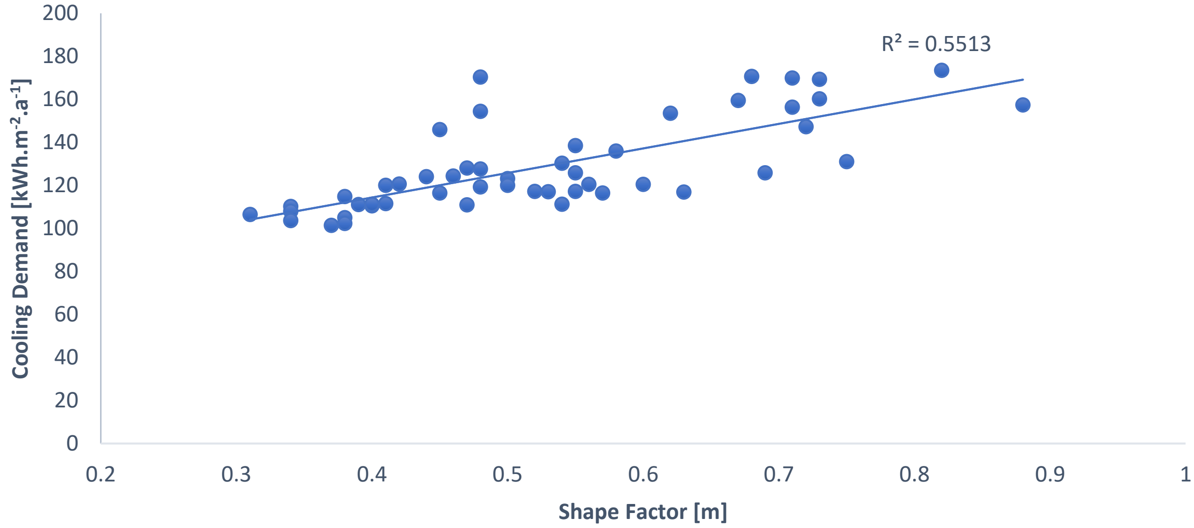


Figure 26 Impact of Shape factor on Cooling Energy demand.

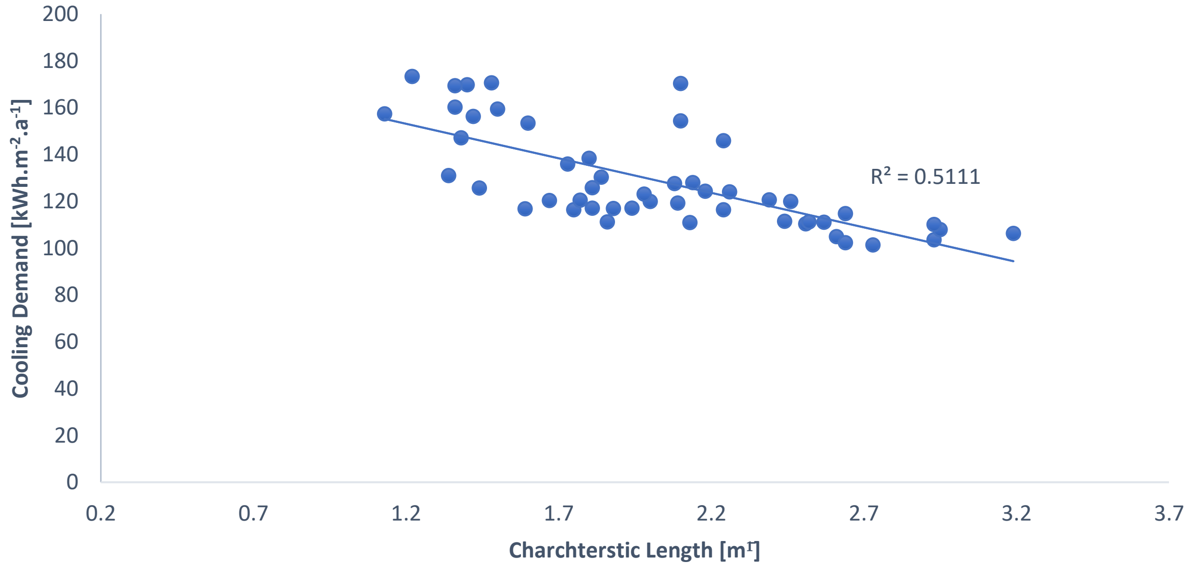


Figure 27 Impact of Characteristic Length on Cooling Energy demand.

The results of Figure 26 indicate that the energy demand increases as the SF increases. Indeed, as the SF increases, the exterior wall area exposed to ambient conditions increases which results in rising of the cooling demand. Further finding points to a slight decrease of the SF influence at a higher WWR%. Evaluation of the results in Figure 26 shows a considerable deviation from the fitted regression line for some buildings. The analysis of those buildings demonstrates that despite of its lower shape factor (SF < 0.5), they have a larger glazing area (WWR% > 25), which is the reason for higher cooling demand compared to the values of other buildings with similar SF.

Therefore, in further analysis, the results are sorted in term of total glazing area WWR%, where the buildings with higher glazing area (WWR >25%) are eliminated from the buildings sample. Thus, a higher correlation emerges between SF and cooling demand up to R^2 of 0.70 as shown in Figure 28. Due to long periods of sunshine, the incident solar energy flux through glazing is high; hence, heat gains from the building skin have a smaller impact on the energy balance for buildings with high glazing area. Furthermore, the results showed that building shapes with lower total area of glazing had less deviation from the regression line.

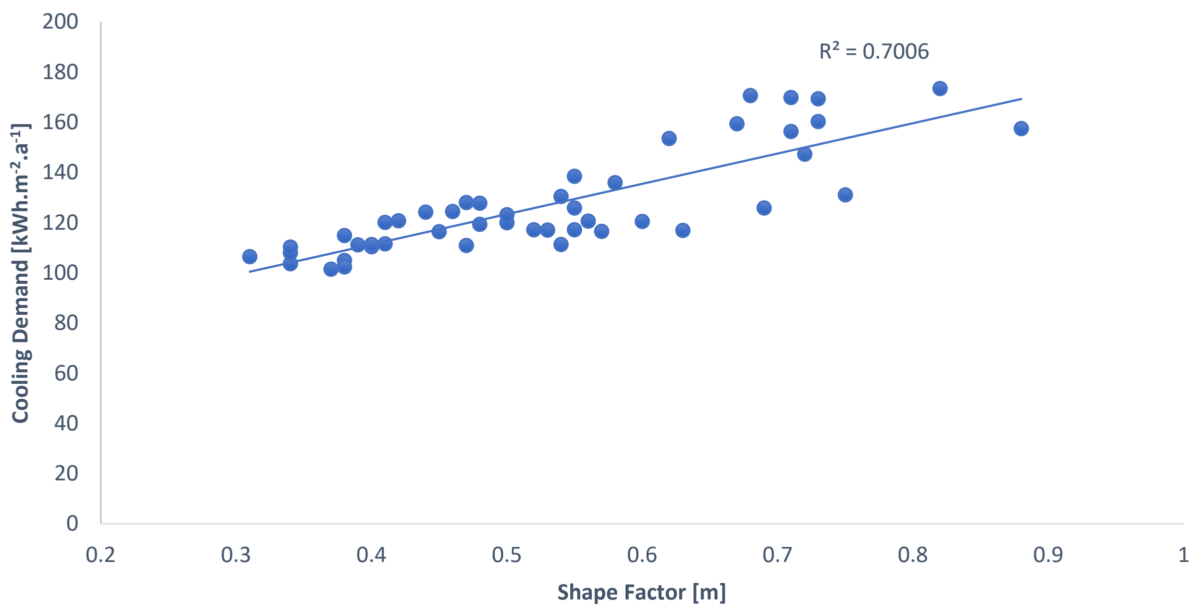


Figure 28 Impact of Shape factor on Cooling Energy demand for buildings with WWR <25%.

Furthermore, simulation results confirm that SF is not always a reliable indication of the cooling energy demand, and other factor such as the number of stories and the high of interior space could play a significant role in changing energy consumption. SF shows good correlation with the simulated cooling energy demand, when the floor height (h) remains the same (h=2.8m) for most of the buildings in the analyzed sample as shown in Figure 26. However, for different buildings with different floor height (h= 3m), a higher cooling demand emerge, even if they have a lower SF, which return to the fact that increasing the height of the interior space increases the cooling energy demand but decreases the SF.

In addition, (Danielski et al. 2012) found that the SF has higher impact on the specific heat demand in buildings with lower thermal envelope properties. Therefore, the high correlation between SF and the simulated cooling demand can be explained by the lower thermal envelope properties of the buildings sample. Increasing the thermal properties of the building will decrease the effect of SF on the cooling demand as shown in a study conducted by (Wadi 2019).

4.2.1.2. Thermal compactness

One of the shortcomings of shape factor or characteristic length that they do not consider the adjacency of building envelope. Therefore, adjusting the component of building envelope regarding the adjacencies (Ground, Exterior, conditioned, unconditioned, etc.) will increase the correlation further as illustrated in Figure 29 below. The feature of Thermal Compactness C_t that it takes the thermally effective envelope area instead of building envelope area.

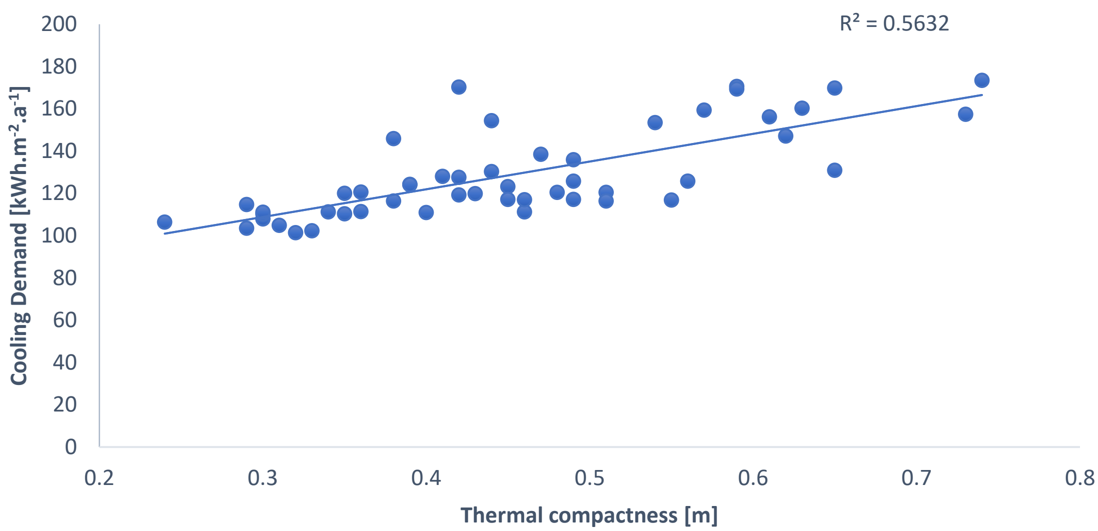


Figure 29 Impact of Thermal compactness on Cooling Energy demand.

Thermal compactness C_t gives a noticeable prediction of cooling demand with a statistically significant R value of 0.75 and R^2 value of 0.56. The indicator gives a higher correlation with the annual cooling demand compared with shape factor or characteristic length. The slight increment of correlation can be explained by the similarity of building in term of adjacencies. Since all the analyzed buildings (Apartments and Multi-family houses) are separated buildings, which means that all building's facades are exposed to exterior. However, some building's floor located directly on the ground, while other buildings have floor to unconditioned ground floor.

4.2.1.3. Relative compactness

Relative compactness shows the deviation of the compactness of a building from the most compact shape. Using the cube as a reference shape, the relative compactness of the analyzed buildings sample is in a range between 0.49 and 0.98 with an average value of 0.81. Simulation result shows almost no correlation between relative compactness and cooling consumption for the buildings sample as illustrated in Figure 30 below.

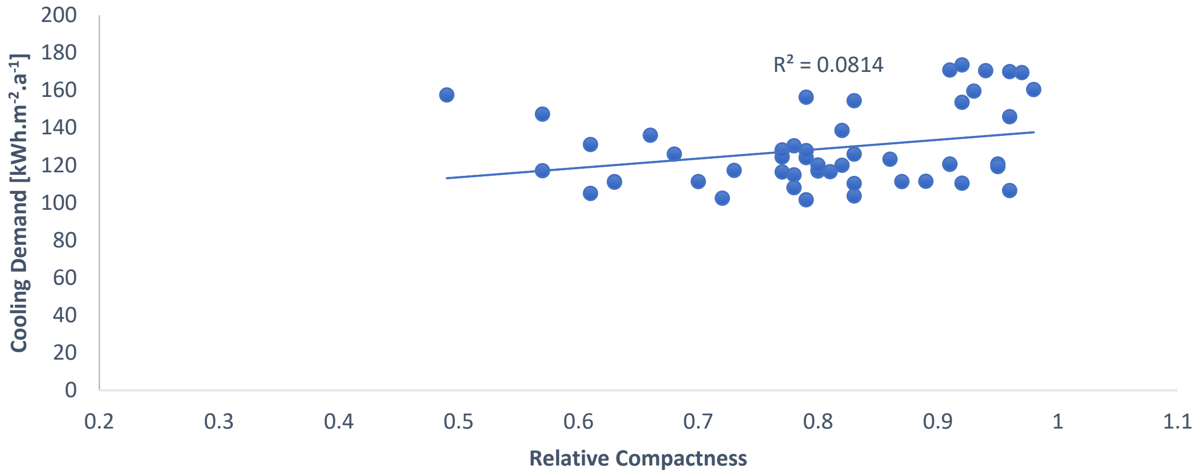


Figure 30 Impact of Relative compactness on Cooling Energy demand.

Several studies researched the application of the relative compactness (RC) coefficient for creating predictive equations. (Pessenlehner and Mahdavi 2003) examined the reliability of the relative compactness indicator for the evaluation and prediction of annual heating loads and the total number of overheating hours by running several thermal simulations on hypothetical buildings with residential use in Vienna. They found that the respective correlation between heating load and relative compactness (RC) is reasonably high (R^2= 0.88). Furthermore, they explored the accuracy of the proposed regression equation to predict the heating load of five distinct shapes with the same RC value (0.86). The simulated results deviated from the predicted values in a range between −15% and +10%, which indicates the reliability of RC for assessing heating loads in buildings. However, the predictions showed a large deviation (−80% to +130%) in case of overheating predictions.

Ourghi et al. (2007) developed a calculation method that can predict the annual total energy use of different building forms using the energy results obtained from a reference shape with a square floor plan. For all building configurations, the total building volume of conditioned space remained constant. They found that the impact of building shape on total building energy demand depends on three factors, which are the relative compactness, the window- to-wall ratio and glazing type defined by SHGC. The lower impact of relative compactness (RC) in this case can be explained by the type of the glazing type, which can be defined by the transmission value of the window (g-value) or SHGC. A high g-value up to 0.85 was used in this study increases the solar gain by the window particularly for temperate climate with an intense solar radiation. Consequently, results in lower influence of the RC on the cooling demand.

4.2.2. Impact of glazing area

4.2.2.1. Window to Wall ratio

Window to Wall ratio shows to some extent a correlation with cooling demand with an R^2 of 0.29. Figure 31. shows that the annual energy load increases as the window size gets bigger, regardless of the window orientation.

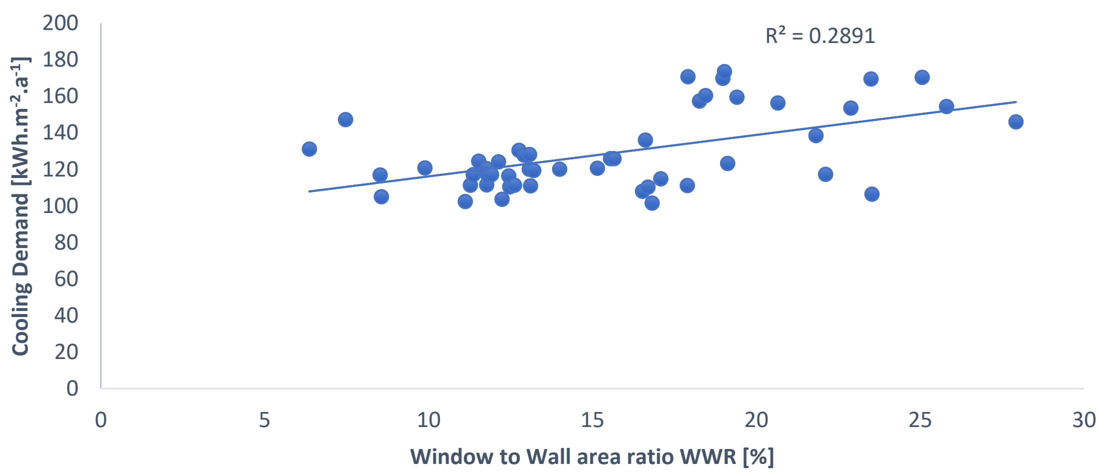


Figure 31 Impact of total Window to Wall ratio WWR% on Cooling Energy demand.

The lowest total energy load is 104 $kWh.m^{-2}.a^{-1}$ when WWR is around 8%, and the biggest load is 170 $kWh.m^{-2}.a^{-1}$ when WWR is nearly 25%. The gap between the two loads is 65 $kWh.m^{-2}.a^{-1}$, which is 60 percentages of the lowest, indicating that window size largely impacts the energy load of the building. Therefore, designers should carefully consider the impact of the window size, not simply increasing the size to achieve view and daylight. However, Figure 31 shows a high cooling demand up to 147 $kWh.m^{-2}.a^{-1}$ for some buildings with WWR< 8%, which can be explained by the high SF of those buildings which is around 0.75.

Although the high conductivity of clear glass windows with U-value of 0.58 $W.m^{-2}.K^{-1}$ and high transmission value g-value of 0.85, still the WWR did not give an expected correlation for such warm climate with high levels of incident solar radiation. This can be demonstrated by a combination of three main factors. Firstly, the effect of the surrounding buildings in obstructing the incident solar radiation through windows which lower the impact of WWR% on energy use. Secondly, the lower thermal proprieties of the entire façade which increase the effect of SF on cooling demand; hence, decreasing the effect of WWR%. Finally, the effect of different orientation and shading on the solar gain received by glazing.

The correct proportion of window to external wall will reduce cooling loads and increase thermal comfort. However, finding the optimal value of WWR% is quite hard to achieve, since it depends on many factors, including thermal properties of the envelope, climate and orientation.

Kheiri (2013) found the optimal value of WWR in the range of 20–32% for a building that was featured by a low-performance façade (U values for windows and walls were 2.4 $W.m^{-2}.K^{-1}$ and 2.6 $W.m^{-2}.K^{-1}$ respectively) and had no shading system. However, according to (Goia et al. 2013), the optimal value in the range of 35–45% through the integration of external solar shading devices with a high-performance façade (U values for windows and walls were 0.7 $W.m^{-2}.K^{-1}$ and 0.15 $W.m^{-2}.K^{-1}$ respectively). Therefore, it can be inferred that the optimal WWR value depends on the envelope properties employed in the simulations and can influence the results to some extent. The higher thermal resistance of the envelope, the lower impact of WWR on total energy use; hence, building can take advantage of larger windows for energy saving. As for this study, it can be recommended that the WWR% which results in lower cooling demand, range from 10-18%.

4.2.2.2. Window to wall area ratio weighted for Windows Orientation and Fixed shading

Since the distribution of the glazing area on the façade in terms of orientation plays also an important role in the energy demand assessment, considering the effects of different orientation result in higher correlation with R^2 of 0.38, which indicates that as the WWR_o increases, the cooling demand increases for almost one third of the buildings sample as shown in Figure 32 below. Furthermore, the effect of external fixed shading on the WWR emerges even in higher correlation of R^2 of 0.44 as shown in Figure 33.

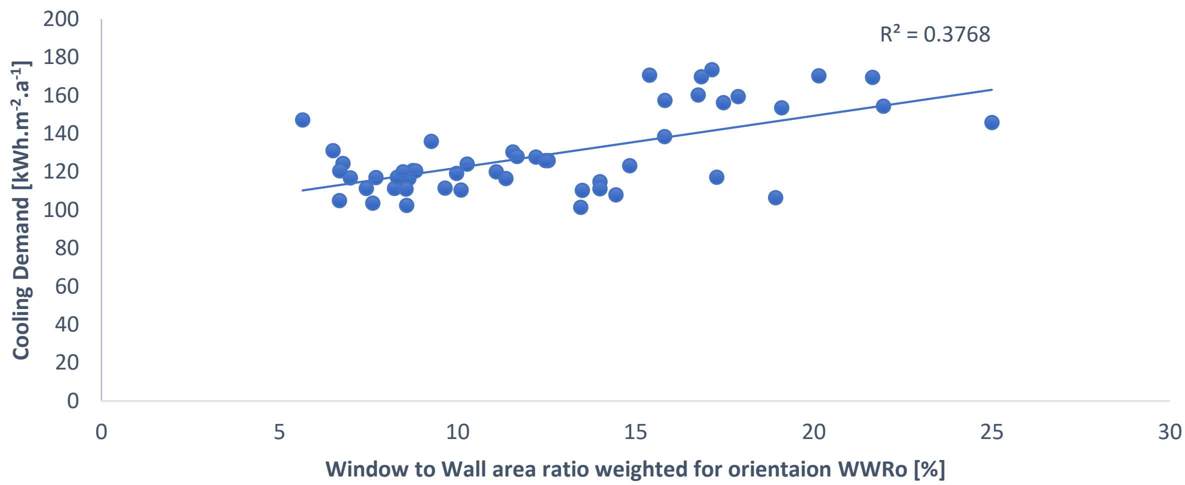


Figure 32 Impact of Window to Wall area ratio weighted for orientation WWRo% on cooling energy demand.

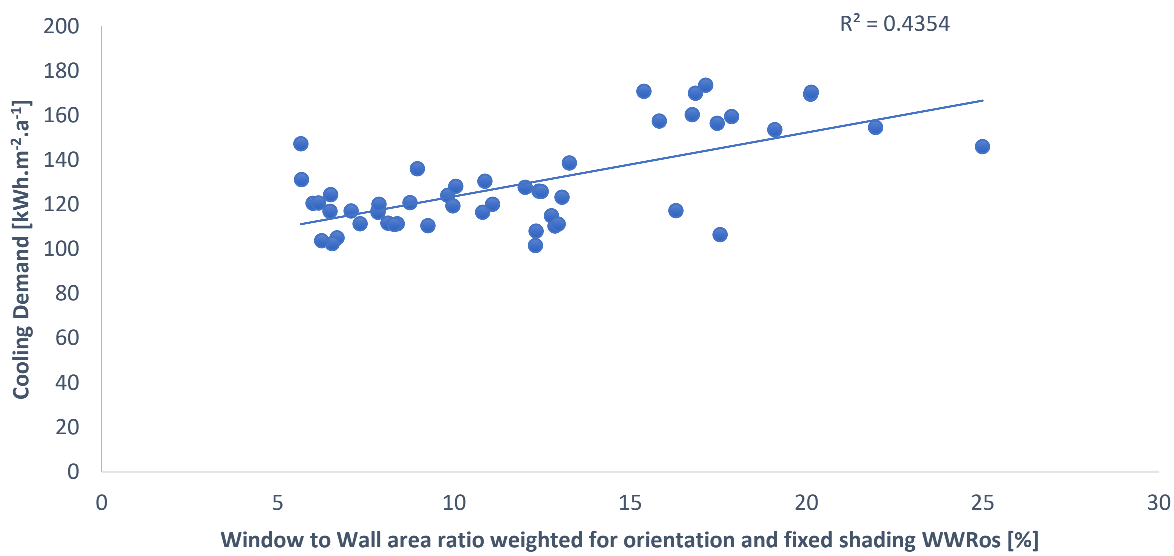


Figure 33 Impact of Window to Wall area ratio weighted for orientation and fixed shading WWRos% on cooling energy demand.

Building with higher south glazing area results in higher cooling demand compared with different orientation. Since the very long cooling season provides abundant opportunity for solar gain from south to produce higher cooling demand. On the other hand, buildings with higher north glazing area shows the best performance in term of energy saving. Since the solar effects on North windows are minimal as shown in previous chapter (Figure 23). They receive no beam sunlight in winter, and only a small amount in summer. Differences between east/west orientation and south orientation are largely the result of two solar effects: (1) solar gain through east or west windows is lower than through south windows during winter, resulting in higher cooling loads for south glazing, and (2) solar gain through east or west glazing is higher than through south windows during summer, resulting in higher cooling loads for east and east glazing.

Since not all the analyzed buildings have overhang shading, the cooling demand not significantly varied because of external shading. The Effect of the external shading is particularly pronounced for south windows with overhangs, because overhangs are most effective in shading south windows from direct sun as illustrated in previous chapter (Figure 22).

4.2.2.3. Window to Floor ratio WFR%

The WFR results in a noticeable positive correlation with cooling energy demand with a Pearson's correlation of 0.743. Accordingly, increasing WFR, will results in increasing of the cooling energy demand. The coefficient of determination of WFR is 56%, which means 44% of the cooling energy demand of analyzed buildings will be determined by other factors.

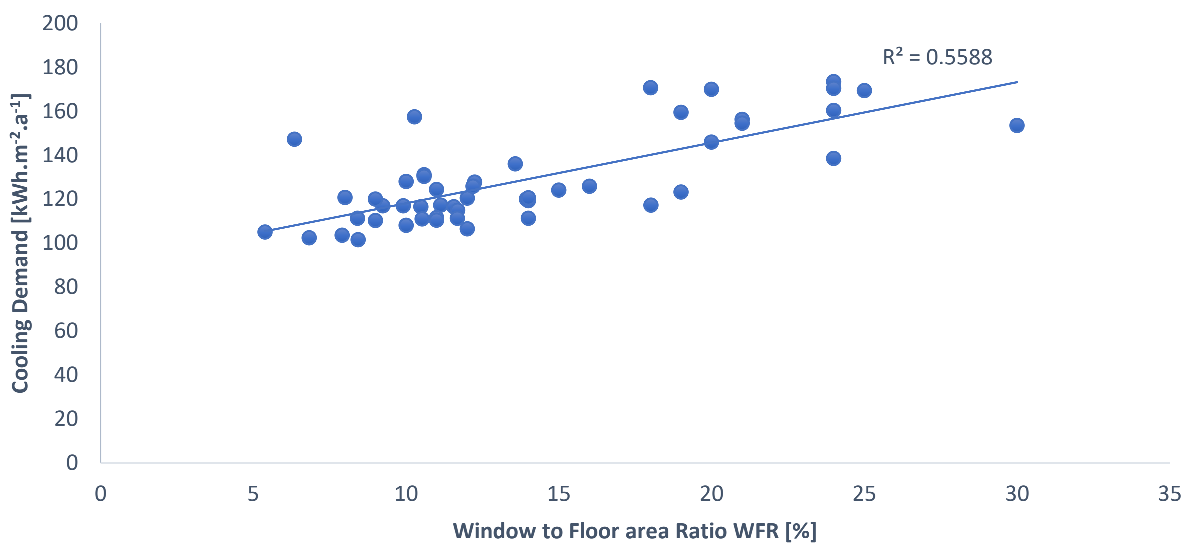


Figure 34 Impact of Window to Floor area ratio WFR% on cooling energy demand.

4.2.3. Impact of thermal transmittance of building's envelope

4.2.3.1. Effective average U value of building envelope

Thermal transmittance of building's component considers as one of the most important indicators of the thermal performance of the building. However, the factor gives a weak correlation compared with other variables with an R^2 of 0.21 as shown in Figure 35. This can be explained as the consequence of low variance of the analyzed values, since the thermal transmittance (U-value) of building's component are constant for the whole analyzed sample.

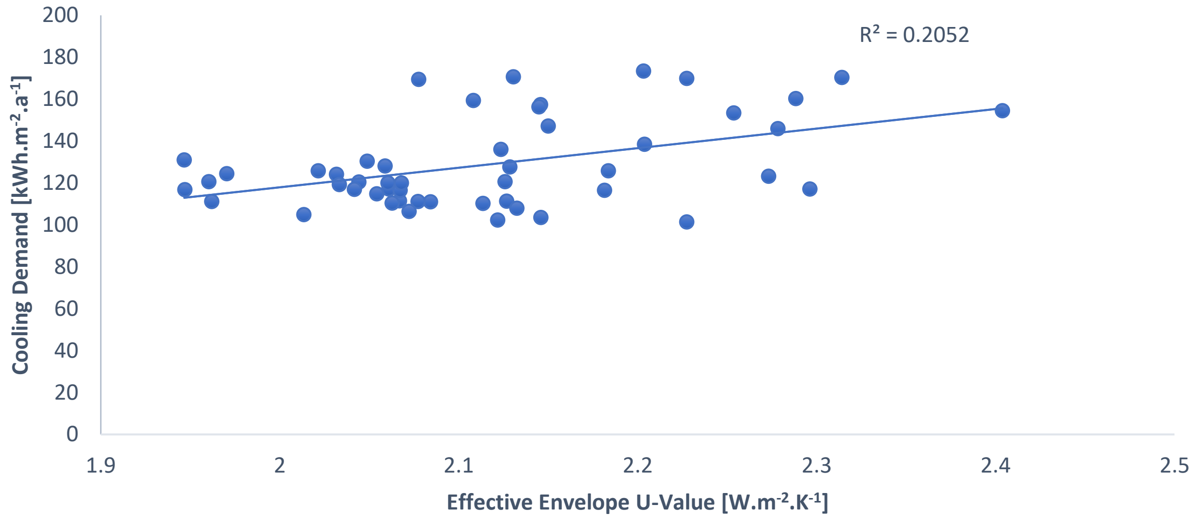


Figure 35 Impact of effective envelope U-value of building envelope on cooling energy demand.

4.2.3.1. Lines of European K-Value (LEK-value)

LEK value is one of the variables that tried to capture the geometric and semantic characteristic of the building envelope through average mean U-value (U_w) and characteristic length (l_c). The factor showed the highest correlation in the analyzed sample with an R^2 of 0.63 and significance level of 0.001.

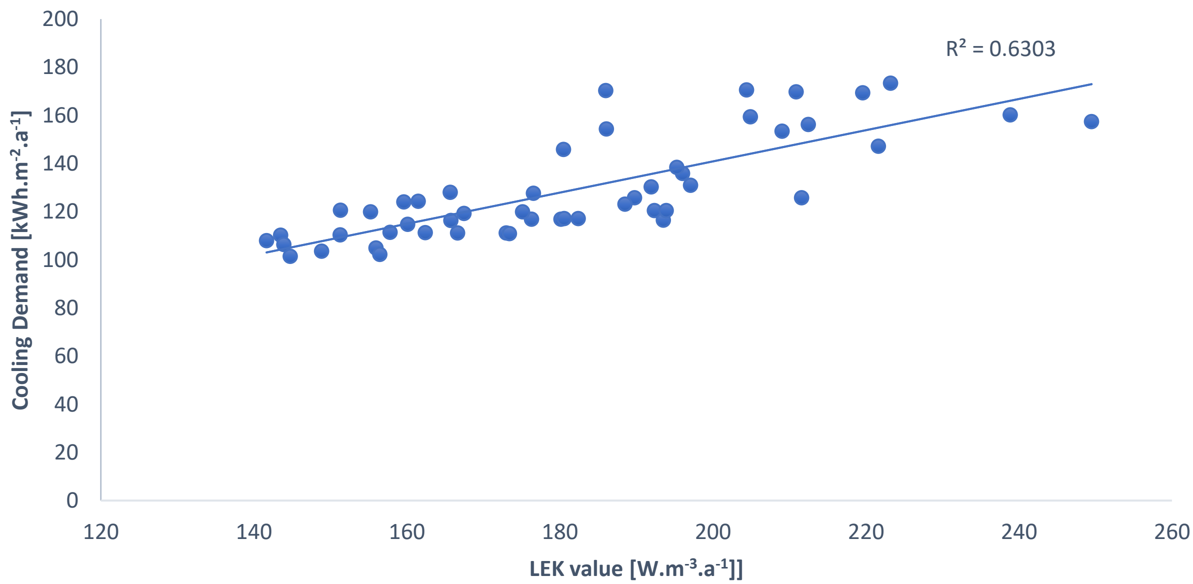


Figure 36 Impact of LEK value on cooling energy demand.

It can be noticed from Figure 36 the high effect of characteristic length or shape factor on the LEK value, since the average mean U-value $U_w$are varying with very small variance of the buildings sample. However, the results confirm that taking the thermal transmittance of building component together with the building compactness will increase the correlation further.

4.3. Multiple Regression Model for cooling energy demand estimating

Regression analysis is one of the more feasible solution to different problems compared to other methods. Linear regression models are easier and more practical in solving problems (SAFA et al. 2014). Besides, it's one of the most used statistical tools to describe the variation of a dependent variable y (annual cooling energy demand) to explanatory factors (shape factor, Window to Wall ratio, thermal transmittance etc.) used as inputs in the function. The aim of the regression analysis is to find a suitable mathematical model and to identify the best fitting coefficients of the model from the given data set. Using the regression method is a clear applicable solution to develop the prediction model, since the output variables spans a continuous range of values and that the pattern of inputs influence on the output is known. Multiple regression shares all the assumptions of correlation including the linearity of relationships, the same level of relationship throughout the range of the independent variable, absence of outliers. The major challenge of the study was to identify the models input parameters in order to best describe the building energy consumption. The principle of a "black-box" was used in this part where the inputs and outputs where first identified and then the process continued with the research of the "black-box" structure model. A "black-box" model of a system is one whose internal structure is unknown, while the inputs/outputs are known and, therefore, there is only a question of "curve-fitting" whose answer relies on finding the most appropriate function.

In the previous chapter were shown the most relevant design parameters that could lead to a significant change in the cooling energy consumption. Based on their impact on building performance, a small set of test variables was selected. Avoiding the possibility of multicollinearity between chosen variables is an important step in this part. Multicollinearity is a phenomenon in which one predictor variable in a multiple regression model can be linearly predicted from the others with a substantial degree of accuracy. The basic problem is multicollinearity results in unstable parameter estimates which makes it very difficult to assess the effect of independent variables on dependent variables. One of the examples of multicollinearity are characteristic length l_c and shape factor SF, they both define the compactness of the building, therefore cannot be taken into a same set of variables when developing the prediction regression model.

From the overview of previous studies, the energy consumption is mainly influenced by the thermal transmittance of the building envelope, shape factor and the glazing area. Those factors are normally identified in the early design stages. Since decisions made at early stages of the design are of the utmost importance for the energy-efficiency of buildings, a simple regression model which contained the mentioned variables as inputs will provide an easy and a quick method for designer to minimize the energy use.

From the previous section, it can be highlighted that compactness -described by shape factor or characteristic length- is not the only building layout measure influencing energy consumption, although it might be the most influential parameter in climates that have a high demand for heating or cooling. Compactness does not reflect the transparency of the building enclosure (e.g., amount and distribution of windows), and the orientation of a building; hence, corresponding gains and losses are not being accounted for, even if they might have impact on energy consumption.

In the buildings, most of the heat gain or loss comes from openings such as windows. It is clear, therefore, that windows are the main element in the transfer of huge amounts of heat between a building and the exterior environment, and so the most important objects for effective strategies to make use of solar gain and limit energy loss. When the sun is low in the sky, (close to the horizon) the light hits the window almost perpendicular to the glass. In this case, the heat gain is at a maximum, and when the sun is higher in the sky, the angle is increased, the glass reflects more of the light. In this instance, less heat is transferred to the building. The main factors affecting the solar gain through the window within the building are orientation, size, type of solar glazing, and of course the shading. One of the key factors in glazing system design is the orientation and the WWR of the building.

Different studies have ensured the significant impact of thermal transmittance of building envelope on thermal performance of the building, however for the analyzed buildings sample, thermal transmittance of building envelope does not give the expected correlation. This can be easily explained by the small variance and the high values of average thermal transmittance values $U_w$of the analyzed sample, since the typical residential buildings in Gaza strip do not pay attention to insulation materials which enhance the thermal quality of building envelope through reducing the amount of heat gain in summer and the heat loss in winter. This can maintain the indoor air temperature within the thermal comfort thus reducing the heating and cooling requirements.

Based on that, several models were tested to find the best fit between the simulated data and the model results, and it was found that a two-input model is the most appropriate solution for the problem. These inputs are shape factor and window to wall ratio adjusted for orientation and fixed shading. Multiple regression based on this dataset provides an approximate equation that can predict the energy consumption as a function of the key parameters. The analysis suggests that a linear regression model can serve as the basis for an effective decision support tool in place of energy simulation models during early design stages. The standardized regression coefficients can be used directly by designers to target building design parameters in early design that drive energy performance.

The following form of two input regression equation was used to predict the cooling consumption:

$$y = B_0 + B_1 x_1 + B_2 x_2$$

where y is the response variable (cooling demand), x_1 presents the Shape Factor (SF), x_2 presents the Window to Wall Ratio weighted for orientation and fixed shading (WWR_{os}) and β_i the corresponding regression coefficient. Table 11 illustrates the regression coefficients of the developed Multiple regression model.

Table 11 Regression coefficients

Coefficients[a]

Model		Unstandardized Coefficients: Regression Coefficient B	Unstandardized Coefficients: Std. Error	Standardized Coefficients: Beta	t	Sig.
1	(Constant)	51.765	5.827		8.884	.000
	SF	95.867	10.201	.624	9.398	.000
	WWR_{os}	2.244	.288	.516	7.780	.000

a. Dependent Variable: Cooling Demand

Table 11 presents the t-statistic and standard error values of regression coefficients. The t-statistic indicates the statistical significance of the relationship between dependent and independent parameters. Results showed that the regression coefficients are statistically significant at 95% confidence level. The 'B' column in the coefficients Table, gives us the coefficients for each independent variable in the regression model. A p-value < 0.05, provides evidence that the coefficient is different to 0. SF ($p < 0.001$) and WWR_{os} ($p < 0.001$) are all significant predictors of cooling demand.

Based on that, the regression equation can be expressed as follow:

$$Cooling\ Demand\ (y) = 51.765 + 95.867(SF) + 2.244(WWR_{os}) \quad (10)$$

Table 12 Multiple Regression Model Summary

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.897[a]	.804	.796	9.53018

a. Predictors: (Constant), WWR_{os}, SF

b. Dependent Variable: Cooling Demand

The R² value of 0.804 indicates that 80.4% of the variation in cooling demand can be explained by the model containing SF and WWR_{os}. This is quite high so predictions from the regression equation are fairly reliable. It also means that 19.6% of the variation is still unexplained so adding other independent variables could improve the fit of the model. Figure 37 plots the predicted values obtained via multiple regression versus the EnergyPlus simulation results for the buildings sample in the validation set for cooling energy demand. The strong linear fit obtained suggests that the regression models can serve as an effective substitute for energy simulation during early design stages

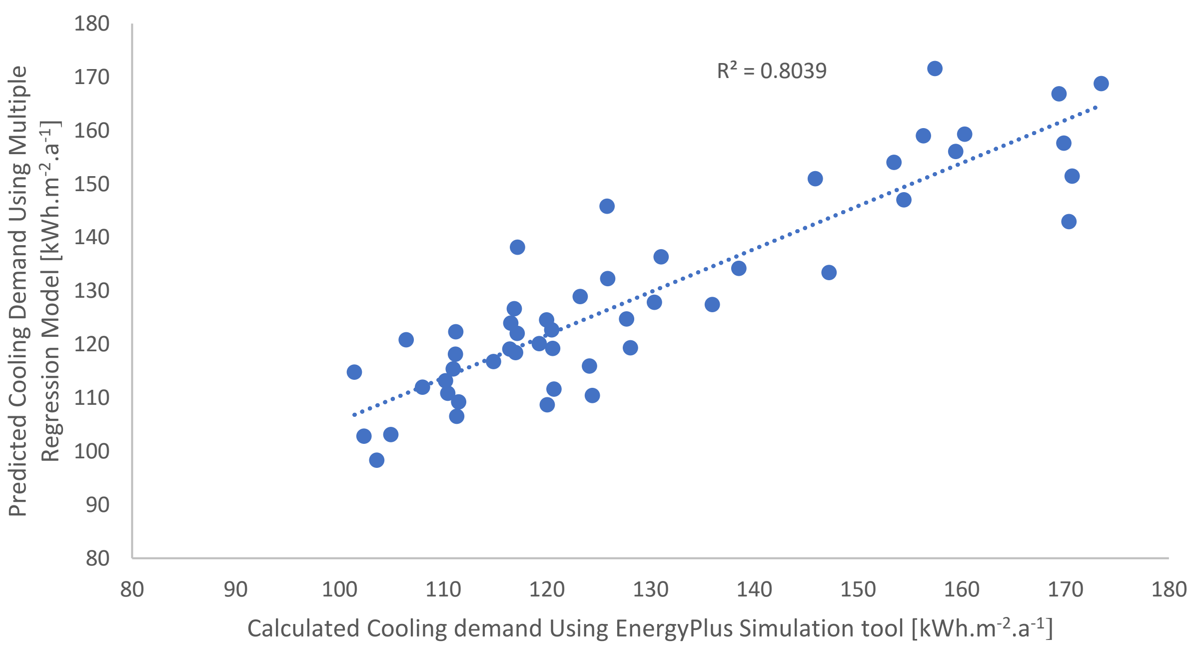


Figure 37 Validation of the cooling energy regression models. Lines represent perfect agreement between the results from EnergyPlus (vertical axis) and predictions by the regression models (horizontal axis).

Careful attention to the analysis of residuals was implemented due to its importance to give evidences about the appropriateness of the model used to fit the data. Figure 38 shows residual scatter for regression model. The residuals from a fitted model are the differences between the responses observed at each combination values of the explanatory variables and the corresponding prediction of the response computed using the regression function. Scatter plots of residuals were studied to investigate the distribution of residuals. It was found that the residuals are randomly distributed around zero and show no discernable pattern, without any relationship to the value of the independent variable, which means that the data met the assumptions of homogeneity of variance and linearity. Furthermore, the residuals were approximately normally distributed as shown in Figure 39.

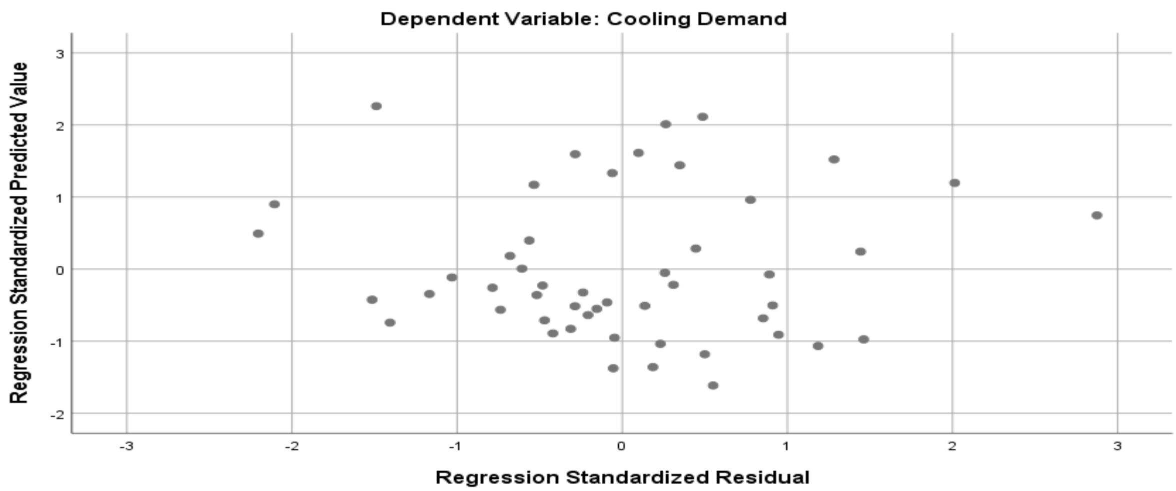


Figure 38 Residual scatter for the developed Multiple Regression Model.

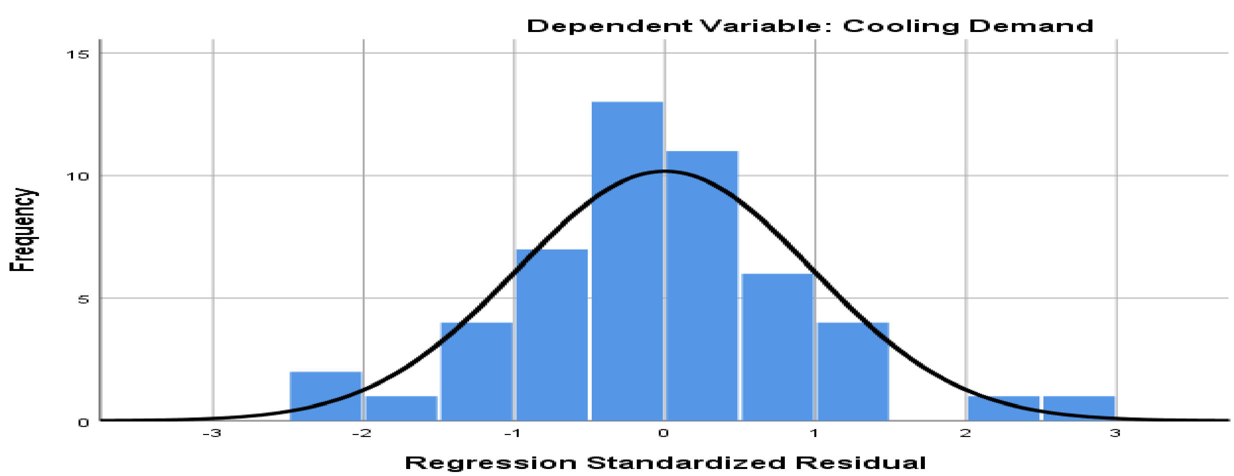


Figure 39 Normality of residuals

4.4. Multiple model accuracy and error analysis

Model validation is the important step in developing a model especially when dealing with multiple parameters. Solely depending on R^2 to determine the quality of the model is not enough. Model users may be more concerned about the level of error that the regression models may cause if used in place of dynamic simulation models. Analysis of relative differences between regression model predictions and results from dynamic simulation is carried out. The relative difference between regression model and dynamic simulation are calculated for different probabilities. Figure 40 below shows the results of relative error analysis for different probability levels.

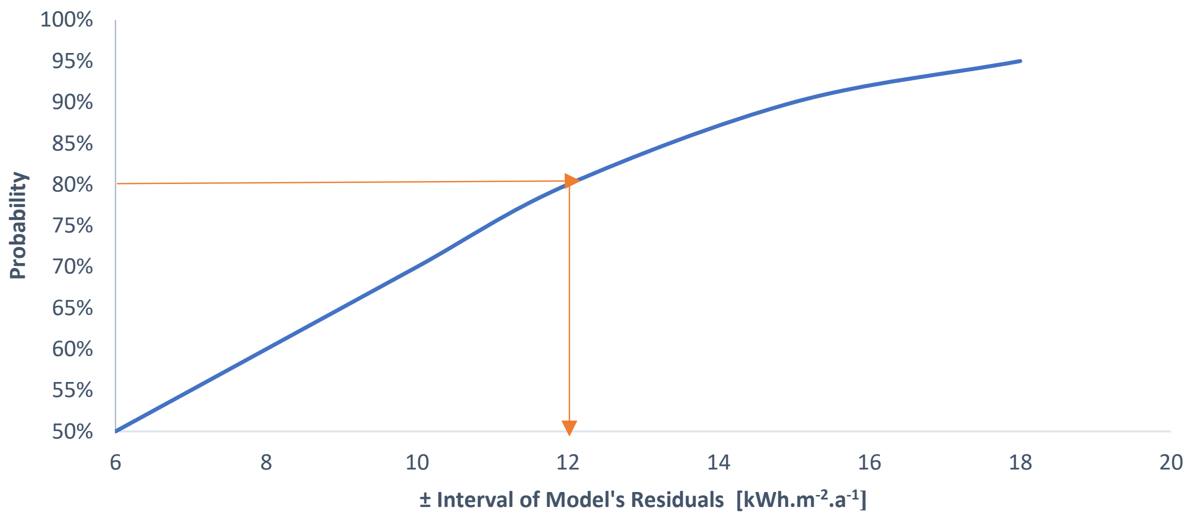


Figure 40 Relative error analysis for different probability levels.

For example, the developed model can predict cooling demand within ± 12 $kWh.m^{-2}.a^{-1}$ relative difference for 80% of the buildings sample. In other words, there is a probability of 80% that the calculated cooling demand using the developed regression equation will be in a range of ±12 of the one which calculated using detailed dynamic simulation tool.

Further analysis of buildings that show a large deviation from the fitted regression line was implemented due to its importance when utilizing the developed model. Through analysis it was clear that some Multi-family houses which have SF greater than 0.70 [m^{-1}] have a relative error greater than ±12 up to ±18. In addition, apartments buildings with a very high glazing area (WWR >25%) could results in relative error greater than ±18 up to ± 21 . Therefore, in future work, it's recommended to explore the possibility of developing a set of proxy variables to represent the type of the building (Single-family, Multi-family house, Apartments, etc.), and then include those variables within the regression. If a set of generalized variables result in unacceptably high inaccuracy, it may be preferable to develop a limited number of regression models, each specific to a particular type of buildings.

However, it can be said that both high coefficients of determination and acceptable relative differences proved that the cooling energy demand of residential building can be predicted with a high accuracy by simplified regression models. Such models allow more rapid determination of energy requirements based on the input predictors without the need for time-consuming reconfigurations and runs of the simulation program.

4.5. Prescriptive index for energy efficient building design

The following section will discuss the possibility of developing a perspective index which describe the building energy performance. Building Energy Index (BEI) namely "cooling demand" is the ratio of a building's cooling energy usage (kWh) per year to the building floor area m^2. The BEI will be based on the most influencing factors on the energy consumption which were discussed in the previous sections. The annual cooling demand is calculated based on the developed multiple regression model for the input variables SF and WWR_{os}. The values of SF and WWR_{os} shows a good variance within the buildings sample, where SF range from 0.31 to 0.88 m^{-1}, while the WWR_{os} have a value between 5.65 and 25%. Consequently, the limits of SF and WWR_{os} are set based on the minimum and maximum values of those variables of the chosen representative sample. As the study is based on the residential buildings which are categorized as either multi-family houses or apartments, which are mostly represented by the scale shown in the index in terms of the two variables, there was no need to extend the range of the index.

As already mentioned in previous chapters, the following BEI is established to meet the current building construction practices of Gaza Strip. Although the base case scenario describes to a high extent the current construction practices in Gaza strip, however it is believed that setting a future target regarding refurbishment of the existing building will serve to a great degree in reducing the energy demand.

The cooling demand of the base case scenario shows a very high cooling energy demand ranging from 91 to 194 $kWh.m^{-2}.a^{-1}$. According to that, and to set a future target, the rating of buildings will be based on the possibility of enhancing the building envelope quality through two stages as shown in Table 13. Firstly, improving the windows quality through decreasing the SHGC, and secondly improving the quality of the whole building envelope. Therefore, in a further study by (Wadi 2019), different scenarios are studied to provide information about the energy consumption for the same buildings sample. As a result, three regression models were used to establish the perspective index which predict the energy consumption of residential buildings as a function of its construction characteristics.

The study found that improving the window's SHGC will results in a noticeable decrease of the cooling energy consumption, which vary between 83 and 156 kWh.m^{-2}.a^{-1}., this can be explained by decreasing the solar gain through glazing for lower SHGC. Furthermore, it was found that a significant reduction of cooling energy demand is possible to achieve through enhancing the whole building envelope by adding insulation materials. The cooling demand for the third scenario scores a value between 69 and 107 kWh.m^{-2}.a^{-1}, with a reduction range between 22 and 87 kWh.m^{2}.a^{-1} respectively compared with the base case scenario.

Table 13 Different scenarios for building envelop thermal quality

Building envelope components	*U value [W.m^{-2}.k^{-1}]*		
	Base Case scenario No insulation	*Improved window scenario*	*Improving the Whole building envelope*
Exterior Wall	*1.784*	*1.784*	*0.535*
Exterior Roof	*2.668*	*2.668*	*0.414*
Ground Floor	*2.338*	*2.338*	*0.441*
Window	*5.894*	*5.894*	*2.559*
Window SHGC	*0.82*	*0.35*	*0.35*

The effect of the influencing factors is investigated for each scenario. Through analyzing, it was clear that the SF and WWR_{os} are the most influencing factors on the cooling energy consumption for different scenarios. However, for each scenario, the regression equation's coefficients of SF and WWR_{os} are different. The effect of WWR_{os} is reduced in the second scenario, because of decreasing the window's SHGC of the building sample, while a noticeable reduction of the SF effect on energy consumption is found in the third scenario with a fairly high envelope quality.

The final step of analyzing consists of rating the buildings based on the input variables value for different scenarios. The aim of this step is to classify the buildings based on their energy consumption. Which in turn is influenced by the building characteristic (SF, WWR_{os}) and thermal characteristic of the building envelope. The challenge of this step rises from the absence of any energy ranking policies in Palestine regarding the energy consumption. Therefore, and to find a reasonable solution, the classification of buildings is set based on the calculated values of cooling demand with the help of regression equations for all studied scenarios as shown in Table 14 below.

Table 14 Buildings efficiency scale ranking

Building Energy efficiency Categories	*Cooling demand kWh.m^{-2}.a^{-1}*
A++	<70
A+	70-95
A	96-120
B	121-145
C	146-170
D	171-195
E	>195

Table 15 below illustrates the energy efficiency category that would be achieved by certain values of SF and WWR_{os} for the climate of Gaza Strip. SF values ranging from 0.3 to 0.9 m^{-1}, while WWR_{os} varied between 5 and 25%.

Generally, the created index reveals that the best performing buildings have the lowest SF and WWR_{os} for the base case scenario. Although the higher the SF and WWR_{os}., the worst the building will perform in terms of the required annual cooling energy. However, increasing the thermal properties of the envelope (opaque and transparent components), will improve the buildings performance particularly the ones with higher SF and WWR_{os} as shown in Table. 15 below.

Given the fact that window glazing is one of the weakest thermal control points in buildings, higher glazing area will increase the solar gain which in turn results in a high cooling demand. On the other hand, since SF represents the ratio between the thermal envelope of a building and its conditioned volume, higher SF values indicate higher envelope area exposed to outside environment, which results in higher heat gains. The developed index points out that buildings with higher glazing ratio can perform better in cases where the thermal properties of windows are enhanced. Besides, buildings with higher SF can have a better performance when the thermal properties of the building envelope are convenient. This indicates that buildings with higher SF and/or WWR_{os} have to strictly comply with requirements of the building envelope in order to achieve an appropriate performance level. As the developed perspective index in the current study is based on only two simple predictors: SF and WWR_{os}, which are frequently known at the pre-construction stage of buildings. It is hoped that these findings would provide useful knowledge towards energy efficient building design in Gaza Strip.

Table 15 Prescriptive index with energy labels for the three cases investigated

Scenarios	WWRos [%]	Shape factor [1/m]																														
		0.3	0.32	0.34	0.36	0.38	0.4	0.42	0.44	0.46	0.48	0.5	0.52	0.54	0.56	0.58	0.6	0.62	0.64	0.66	0.68	0.7	0.72	0.74	0.76	0.78	0.8	0.82	0.84	0.86	0.88	0.9
Base Case scenario "No insulation for Building Envelope components"	5	A+	A+	A	A	A	A	A	A	A	A	A	A	A	A	A	B	B	B	B	B	B	B	B	B	B	B	B	B	C	C	C
	7	A	A	A	A	A	A	A	A	A	A	A	A	A	B	B	B	B	B	B	B	B	B	B	B	B	B	C	C	C	C	C
	9	A	A	A	A	A	A	A	A	A	A	B	B	B	B	B	B	B	B	B	B	B	B	B	C	C	C	C	C	C	C	C
	11	A	A	A	A	A	A	A	A	B	B	B	B	B	B	B	B	B	B	B	B	B	C	C	C	C	C	C	C	C	C	C
	13	A	A	A	A	A	A	B	B	B	B	B	B	B	B	B	B	B	B	B	C	C	C	C	C	C	C	C	C	C	C	C
	15	A	A	A	B	B	B	B	B	B	B	B	B	B	B	B	B	C	C	C	C	C	C	C	C	C	C	C	C	C	D	D
	17	A	B	B	B	B	B	B	B	B	B	B	B	B	B	C	C	C	C	C	C	C	C	C	C	C	C	C	D	D	D	D
	19	B	B	B	B	B	B	B	B	B	B	B	B	C	C	C	C	C	C	C	C	C	C	C	C	C	D	D	D	D	D	D
	21	B	B	B	B	B	B	B	B	B	C	C	C	C	C	C	C	C	C	C	C	C	C	D	D	D	D	D	D	D	D	D
	23	B	B	B	B	B	B	B	C	C	C	C	C	C	C	C	C	C	C	C	C	D	D	D	D	D	D	D	D	D	D	D
	25	B	B	B	B	B	C	C	C	C	C	C	C	C	C	C	C	C	C	D	D	D	D	D	D	D	D	D	D	D	D	D
Improved Window SHGC	5	A+	A+	A+	A+	A+	A+	A+	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	B	B	B	B	B	B	B	B	B
	7	A+	A+	A+	A+	A+	A+	A	A	A	A	A	A	A	A	A	A	A	A	A	A	B	B	B	B	B	B	B	B	B	B	B
	9	A+	A+	A+	A+	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	B	B	B	B	B	B	B	B	B	B	B	B
	11	A+	A+	A+	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	B	B	B	B	B	B	B	B	B	B	B	B	B
	13	A+	A+	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	B	B	B	B	B	B	B	B	B	B	B	B	B	B
	15	A+	A	A	A	A	A	A	A	A	A	A	A	A	A	A	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	C
	17	A	A	A	A	A	A	A	A	A	A	A	A	A	A	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	C	C
	19	A	A	A	A	A	A	A	A	A	A	A	A	A	B	B	B	B	B	B	B	B	B	B	B	B	B	B	C	C	C	C
	21	A	A	A	A	A	A	A	A	A	A	A	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	C	C	C	C	C
	23	A	A	A	A	A	A	A	A	A	A	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	C	C	C	C	C	C
	25	A	A	A	A	A	A	A	A	A	B	B	B	B	B	B	B	B	B	B	B	B	B	B	C	C	C	C	C	C	C	C
Medium Insulation for Building Envelope components	5	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+
	7	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+
	9	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+
	11	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A
	13	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A	A	A	A
	15	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A	A	A	A	A	A	A
	17	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A	A	A	A	A	A	A	A	A
	19	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A	A	A	A	A	A	A	A	A	A	A	A
	21	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	23	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	25	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A+	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A

4.6. limitation of the study and possible source of error

Although the assumed surrounding buildings represent to a high extent the current architectural practices in Gaza Strip. Such supposition may result in a noticeable error for buildings with different urban topography in Gaza Strip. Since the surrounding buildings play a significant role in reducing the solar gain that being received by building envelope, different urban topography could result in different cooling demand in such a hot climate with high levels of incident solar radiation. Therefore, its recommended in future studies to analyze the effects of urban topography variables (Aspect ratio, plot ratio) on the cooling demand and trying to include it in the regression model. Furthermore, the studied shading devices is limited to the horizontal external shading (Overhang), since it's commonly used in buildings of Gaza Strip and due to its high effectiveness in reducing the solar radiation in summer time. However, different shading devices such as vertical or inclined shading devices may result in a slightly different cooling demand. Besides, the glazing distribution on the facades of the buildings sample is restricted to the four main orientation (S,W,E,N), and it was found that different orientations (e.g. SE, WN, etc.) could result in a very slight error that can be neglected.

Regarding the thermal characteristic of building components, and as already mentioned in previous chapter, the building component is constructed in a way to meet the current construction practices in Gaza strip. However, in a further study (Wadi 2019) confirmed that different thermal properties of building envelope will results in significant difference of cooling demand values for the same buildings sample. Although the developed perspective index is included the current state of buildings and the future targets of buildings construction. However, it's limited to a certain thermal characteristic of building envelope. Such limitation is one of the main disadvantages of perspective index compared with the performance-based method.

Furthermore, it should be highlighted that; the multiple regression model is developed based on the calculated data using the performance-based method. However, compared with the site-measured data, the performance-based method could result in a noticeable error, due to multiple factors, such as the occupant's behavior, weather data, and internal heat gains. Such factors are assumed to maintain to a high degree the current statues and the widely known specific criteria as illustrated in previous chapters.

5. Conclusion

Building simulation model can accurately quantify building energy, however it's not amenable for use in the early design stages when it would be useful to have a rough characterization of building energy performance that can respond to changes in high level design parameters. The work described in this study represents the using of a building energy simulation engine to develop a multiple linear regression model based on ten building design parameters. The developed model is a simple and intuitive model that provides estimates of annual building energy consumption, which can easily be modified to account for changes in key parameters relevant to the conceptual design stage.

Although the results showed that building's morphology (e.g. SF, l_c) have the most impact on building thermal quality, however simulation results confirm that SF is not always a reliable indication of the cooling energy demand, and other factor such as the number of stories and the high of interior space, and glazing area could play a significant role in changing energy consumption.

Based on the correlation assessment of design variables, the level of energy consumption in buildings in the studied climate can be largely attributed to the building compactness SF and WWR_{os}. Compact buildings consume less energy, and lower WWR results in lower cooling energy demand. Therefore, taking in consideration the most influencing factors, a regression model was developed for a generic, representative residential building based on exhaustive simulation runs with EnergyPlus. The regression was performed in the climate zone of Gaza Strip. R^2 values obtained from the Multiple regressions exceeded 80%, which indicates an excellent fit to the EnergyPlus simulation results. Although coefficient of determination is an excellent measure of model's overall goodness of fit. We further evaluated the relative errors between the models' predicted and observed values (from detailed simulations). The multiple regression model predicted cooling energy requirements within ±12 $kWh.m^{-2}.a^{-1}$ relative difference range for more than 80% of data. The results suggest that a linear regression can serve as an effective, reduced-form model in place of energy simulation models during early design stages. It is important to note that, once created, the regression model can function independently of the full-scale energy simulation model. A regression model can easily be programmed into a spreadsheet or standalone software tool that can provide real-time feedback to designer.

With the help of the developed regression model, a perspective index has been established, which describe the level of energy efficiency that could be achieved for a certain value of design variables. The Building energy index is based on the most influencing factors on the energy consumption (SF and WWR_{os}). Although the studied base case scenario describes to a high extent the current construction practices in Gaza strip, however it is believed that setting a future target regarding refurbishment of the existing building will serve to a great degree in reducing the energy consumption. Based on that, the index is expanded to include different scenario of building envelope upgrades. For the base case scenario, the created index reveals that the best performing buildings have the lowest SF and WWR_{os}. Although the higher the SF and WWR_{os}., the worst the building will perform in terms of the required annual cooling energy. However, increasing the thermal properties of the envelope (opaque and transparent components) results in a better performance of buildings particularly the ones with higher SF and WWR_{os}.

It should be highlighted that the study assumed a specific urban topography surrounding the studied buildings. However, such supposition may result in a noticeable error for buildings with different urban topography in Gaza Strip. Furthermore, Although the developed perspective index is included the status quo of buildings and the future targets of buildings construction. However, it’s limited to a certain thermal characteristic of building envelope. Such limitation is one of the main disadvantages of perspective index compared with the performance-based method. Therefore, its recommended in future researches to analyze the effects of urban topography variables (such as aspect ratio, plot ratio) on the cooling demand and trying to include them in the regression model, and further expanding the number of inputs to implicate the effect of thermal properties of construction materials on energy consumption.

All in all, it is hoped that these findings would provide useful knowledge towards energy efficient building designs. Building design variables could then be appropriately varied for buildings in line with passive energy conservation strategies, consequently, reducing the cooling energy consumption.

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7. References

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