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Overheating and cooling demand in residential buildings: a simplified index for the early stages of the design process

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Zusammenfassung

Wohngebäude, welche vermutlich die größte Gruppe aller Bauwerke darstellen, sind für einen großen Teil des globalen Energieverbrauchs verantwortlich. Solche Bauwerke besitzen aber in der Regel auch ein großes Potential hinsichtlich Energieeinsparung. Es gibt ganz unterschiedliche Ansätze, den Energieverbrauch von Bauwerken zu determinieren und damit zu senken. Einer dieser Ansätze ist der performance-basierte Ansatz, welcher zumeist unter Einsatz von state-of-the-art Simulationswerkzeugen durchgeführt wird. Die Ergebnisse von solchen simulations-basierten Performance-Evaluierungen können nützlich sein um optimale Gebäudeplanung und Energieeinsparung anzunähern. Jedoch sind solche Performance-Untersuchungen mittels Simulationswerkzeugen oftmals sehr aufwändig und damit zeit- und kostenintensiv. Eine mögliche Alternative stellt der präskriptive Ansatz dar. Dieser Ansatz ist im Vergleich zum performance-basierten Ansatz reduziert hinsichtlich des Aufwandes, aber auch im Anwendungsbereich bzw. der Aussagekraft. Im Prinzip wird über die Beurteilung von verschiedenen, einfach zu ermittelnden Kombinationen von Gebäudegestaltungsparametern die sich daraus ergebende Performance-Implikation dargestellt. Auf diese Wese können ArchitektInnen eine grobe Abschätzung der Auswirkung von Design-Entscheidungen bereits in frühen Phasen des Gebäudeentwurfs vornehmen. Der Ansatz eignet sich auch gut um in Regionen oder unter Umständen, wo eine Durchführung des performance-basierten Ansatzes aus Ressourcen-, Zeit-, oder Kostengründen schwierig ist, dennoch energieeffiziente Bauwerke zu planen.

In der vorliegenden Master-These werden die Bemühungen dokumentiert, einen präskriptiven Index zu erstellen, welcher als Instrument dient, anhand verschiedener Gebäudeparameter Performanceabschätzungen vornehmen zu können. Dieser Index ist das Ergebnis eines linearen Regressionsmodels. Zur Erstellung dieses Index wurde ein Gebäudesample erstellt, welches für eine spezifische Region auf der Welt – nämlich den Gaza-Streifen / Palästina – eine gute Annäherung an den Gebäudebestand darstellt. Der Fokus dieser Master-These liegt auf (sommerlicher) Überhitzung bzw. dem Kühlbedarf dieser Bauwerke. Der via Simulation errechnete Kühlbedarf wurde im Regressionsmodel Eingabedatenkombinationen gegenübergestellt, so dass der präskriptive Index hierfür erstellt werden konnte.

Bestimmte Gebäudecharakteristika konnten für das gewählte Gebäudesample und das vorherrschende Klima als wesentlich für die Energieeffizienz identifiziert werden. Überhitzung und Kühlbedarf konnten hierbei als sehr ähnlich abhängig von verschiedenen Eingabedaten verifiziert werden. Design-Entscheidungen hinsichtlich bestimmter Gebäudecharakteristika, allen voran die geometrischen und semantischen Daten der Verglasungen / Fenster, beeinflussen die Performance signifikant.

Der erstellte Index kann für die Gebäudeplanung in der Region ein wertvolles Hilfsmittel darstellen und speziell in den frühen Design-Phasen den/die ArchitektIn unterstützen.

Keywords

Gebäude-Performance-Simulation, präskriptiver Ansatz, Gebäudecharakteristika, Gebäudehülle, Kühlbedarf, Gebäudeüberhitzung, lineare Regression, Gebäudeperformance-Indikator

Abstract

Residential buildings consume a considerable amount of energy, but regularly such buildings are considered to possess a large potential for reducing their energy demand without neglecting the required comfort levels for occupants. There are several, in-part very different approaches that address the reduction of energy use in buildings. One approach is the so-called performance-based approach, which regularly requires the application of sophisticated simulation tools to evaluate buildings. The results of this approach can help to approximate optima regarding lowest cost and energy saving. However, given the level of detail and the extensive structure of state-of-the-art simulation tools, the performance-based approach often is time-consuming and cost-intensive. One alternative to this approach is the so-called prescriptive approach. This approach can be associated with less complexity in comparison to the performance-based approach. The main idea of this approach is to define levels for prescriptive performance data of buildings that can be influenced in early design stages. As such, it can provide valuable support to architects, who can use the approach to roughly estimate the performance of buildings without performing advanced calculations or simulations. In this context, this approach could be beneficial to improve the energy performance of buildings in regions and settings, where adopting the performance approach faces obstacles such as lack of resources, or large time and cost pressure.

The main objective of this master thesis is to create a prescriptive building energy index which could be used as an instrument to determine the future building's energy demand during the early stages of the design process. Thereby, the created index is based on the results of a linear regression model. This model is the result of extensive simulation efforts of a large set of buildings. The chosen building sample was based on the idea of representing the majority of residential buildings in the Gaza strip. The linear regression analysis is used to identify the most influencing descriptive building quality parameters on selected aspects of the building performance. This master thesis is thereby focused on overheating and cooling energy demand, the (simulated) cooling energy demand results of the building sample were used in the created linear regression equation, and utilized to generate a reference for the index.

As compared to the outcome obtained from the simulation, the results show that buildings, which comply with certain characteristics, can achieve high energy efficiency levels (in these specific climatic boundary conditions). The results reveal that multiple performance indicators can be almost predicted interchangeably, as the overheating indicator was found to be highly correlating to the cooling energy demand of buildings. The results also prove that setting a future target regarding enhancing thermal characteristics of the current state of buildings would result in achieving apparent reductions in cooling demand requirements, as geometric and semantic properties of fenestration / glazing materials were found to be crucial within such context. While incorporating the current construction practices in addition to potential future enhancement targets, the created index could serve as a valuable indicator tool for architects, designers and engineers during the early stages of the design process.

Keywords

Performance simulation, prescriptive approach, building design variables, thermal envelope, cooling energy demand, overheating indicator, linear regression, Building Energy Index.

Disclaimer

I hereby declare that this dissertation is my own original work and has not been submitted before to any institution for assessment purposes. Beside the mentioned references, no additional material has been used. The collection and analysis of the data sample is a joint work with the study conducted by Al Hayek (2019).

Further, I have acknowledged all sources used and have cited these in the reference section.

Signature:

Table of Contents

ABBREVATIONS

BECs	Building Energy Codes
BEI	Building Energy Index
EPBD	Energy Performance of Building Directive
EPI	Energy Performance Indicator
ERS	Energy Rating System
EUI	Energy Use Intensity
GHG	Green House Gases
HVAC	Heating, ventilation and air conditioning
LEED	The US Green Building Council Leadership in Energy and Environmental Design
LEK	“Linien europäischer Kriterien”
NAZCA	Non-State Action Zone for Climate Action
NDCs	Nationally Determined Contributions
OHI	Overheating Index
RC	Relative Compactness
SF	Shape Factor
SHGC	Solar Heat Gains Coefficient
SPSS	Statistical Package for Social Sciences
UNFCCC	United Nations Framework Convention on Climate Change
WFR	Window to Floor Ratio
WWR	Window to wall ratio
WWR_{os}	Effective Window to Wall Ratio

NOMENCLATURE

A	Area [m^2]
V	Volume [m^3]
f_{oi}	Correction factor for orientation [-]
S_{fi}	Correction factor for shading [-]
U	Thermal transmittance value [$W.m^{-2}.k^{-1}$]
l_c	Characteristic length
T	Temperature [^oC]

1. Introduction

1.1. Overview

The contribution of buildings with regarding to the total energy consumption is substantial, therefore, great attention should be paid to regulate and adopt energy efficiency measures within the buildings sector. The position of the developed countries regarding this issue is already at high levels as they achieved advanced measures and techniques. Taking Austria as an example, which has achieved significant energy-efficiency improvements over the past 20 years, by continuously urging the most proactive and comprehensive approaches to reduce energy usage in buildings (Mourtada 2016). On the other side, developing countries need to accelerate their efforts and to overcome several barriers.

Nevertheless, the disadvantages associated with high energy usage in buildings have several dimensions; including environmental and economic factors. Thus, achieving acceptable energy efficiency measures in buildings using the minimum amount of energy, while at the same time fulfilling the indoor comfort standards requirements for occupants, is of great importance.

Accordingly, decision makers have focused on providing instruments aiming at evaluating energy efficiency in buildings. Regularity instruments including buildings energy codes are considered as the most effective and cost-effective policy mechanism category, if enforcement can be secured (Koeppel and Ürge-Vorsatz 2007).

On the one hand, the performance-based approach of evaluating energy efficiency of buildings provides accurate results, which leads to obtaining the lowest cost and optimum energy saving by considering a whole building approach and allowing more flexibility to design strategies. On the other hand, the requirements of such approach with regarding to the high costs and time associated with its application, in addition to the high level of experience required, makes its applicability demanding, especially in the developing countries context.

Therefore, it could be more convenient to adopt the application of prescriptive approaches as a baseline towards enhancing energy efficiency measures in buildings, as it can provide a simple and easy to use approach to classify buildings energy efficiency. Despite the fact that such codes may lead to missing opportunities to increase energy efficiency in some cases, as they do not consider an overall building approach, they still contain the results of experts supported by detailed parametric simulations and reviewed by a panel of experts (Higa et al. 2012).

The situation of Gaza Strip with regarding to the very limited availability of energy resources and the total dependency on importing such resources from neighboring countries, which is subject to complex and unstable political conditions, makes it essential to develop energy efficiency measures in buildings towards creating a more sustainable built environment. To urge the application of energy efficient buildings within such context, prescriptive method accounting for energy efficiency measures would definitely represent an appealing approach.

The goal of the current research is to create a prescriptive building index based on the results of a linear regression model. The index will provide a rating system that can be used by architects and engineers during the early stages of the design process to account for energy efficiency in buildings, such rating will be dependent on simple characteristics of building envelope that can be easily calculated.

1.2. Motivation

A prescriptive index of buildings describes how a building should be constructed in order to achieve certain requirements regarding its energy efficiency. While it may be argued that such approach may inhibit creativity in comparison to the performance based approach, where focus is towards the direction of what the building is required do, however, the prescriptive code can still form a baseline for the performance approach and is able to highlight measures that otherwise might be overlooked (Higa et al. 2012). Additionally, the prescriptive approach could overcome the complexity, high time and costs associated with the usage of the performance based approach by providing a simple approach which is able to provide reliable results.

Although there are several parameters that affect the energy performance of a building, however, the importance of the building envelope with regarding to achieving acceptable thermal performance levels is significant. Conventionally, the design of the thermal envelope is done by architects during the early stages of the design process, this preliminary design is then forwarded to other designers including structural and HVAC system designers (Ellis and Mathews 2001). Using of energy simulations is currently limited to evaluate energy performance of a building, and not the design of the building envelope (Yi and Malkawi 2012). Consequently, thermal analysis is performed on a stage where many design decisions have already been taken (Holm 1993). Therefore, it is evident that setting requirements related to the building envelope design during the early stages of the design process is of a great importance.

The early integration of simulation software faces several challenges, which include time consuming modeling, rapid change of the design, conflicting requirements, input uncertainties, and large design variability (Ostergard et al. 2016).

The costs associated with design changes at later stages of any project can be significantly high. Whereas these costs are minimal during the early stage of the design process. Perspective approaches address specific characteristics of a building at the early stage of the design process.

Therefore, developing a building quality index to be used at such stages could be crucial in reducing the overall costs associated with buildings' construction projects.

Overheating can occur in new and existing buildings as well. There exists a well-established relationship between extremely high temperatures and human morbidity and mortality (The lancet Commission 2015). Increased heat can cause severe health problems and also affects their comfort, especially if sleep is degraded. In extremis, the heat stress caused can lead to premature mortality, especially amongst more vulnerable members of society (Luterbacher et al. 2004). Such concern may arise given the fact that the required mechanical cooling devices or electricity supply may fail, which is common in the current state of the residential buildings in such region.

Gaza strip is located in a hot humid region where the weather conditions are between the coastal area wetlands and the dry desert region. In such conditions, the cooling energy loads are dominant, in contrast to the cold regions, where heating loads are significantly higher. The application of energy efficiency standards for buildings in this region is still very limited, despite the fact that it is highly required, given the scarcity of energy resources. The potential for reducing environmental impacts and enhancing indoor comfort levels for the residential buildings in Gaza is promising, as the current construction practices are insufficient in terms of fulfilling the aforementioned criteria. As a result, recent research efforts have been intensively oriented towards this field.

Therefore, the final goal of this thesis is to develop a building quality index based on certain characteristics of the building envelope, and will be aimed at enhancing the cooling energy demand of the residential buildings. The output of the created model will be then compared to the performance results.

2. Background

2.1. Buildings and Energy

Energy consumption in buildings

Buildings account for almost 40% of the total primary energy consumptions in most countries, therefore, they are considered one of five main consumers of energy (WBCSD 2010). The buildings consumption of energy can be significantly reduced by improving their efficiency levels (Lee and Yik 2004). The potential of the built environment in saving energy is well-demonstrated in the literature. Therefore, this important sector has been a focus point towards less energy use.

"*The oil crisis in the 1970s was the main motive for developed countries to reduce the consumption of energy, there was serious attempts within these countries to find a solution. They started in two ways: reducing the use of energy (demand side) and trying to find another source of renewable energy (supply side)*" (Awawdeh and Tweed 2014, p.38).

Effects of high energy usage in buildings

The potential of climate change is highly related to increased energy use in buildings and the continuous increase of new buildings. The environmental impact of buildings is widely acknowledged and in the past three decades' progress has been made in developing ways to reduce this (Roaf 2003).

Buildings use a considerable amount of non-renewable energies; such resources are limited and have high Co_2 footprint. In order to retain those resources for upcoming generations, enhancing energy efficiency measures in buildings shall be further stressed. This would also contribute in creating environmentally-friendly buildings, while at the same time, minimum indoor comfort levels for occupants should be also achieved.

"In addition to the above, the economic factors cannot be neglected, as the economy drives our life and is strongly dependent on the price of oil. Saving energy is beneficial for both the end users and the economy of each country. Improving the energy efficiency of buildings would result in savings on energy bills for the occupants. Additionally, these improvements would reduce electricity peak load, thus reducing the country's need for new power stations, and resulting in savings that could be used for other important human development" (Awawdeh and Tweed 2014, p.38).

Buildings' Energy efficiency

Energy efficiency in buildings requires achieving an acceptable energy efficiency measures using the minimum amount of energy while at the same time meeting the required indoor comfort standards for occupants, it also includes minimizing the energy used in manufacturing building materials and in the construction process.

Energy utilization in buildings has rapidly came into focus as among the critical challenges to address in order to meet the climate change issue. There is no other individual field contains the exact influence with regards to energy use and related greenhouse gas emissions. No other industry has this sort of great possibility of extreme emission reductions through energy efficiency improvement in buildings. With the increasing building energy consumption, the improvement of building energy efficiency becomes a key part of the reduction of energy use levels (Umar et al. 2013).

There is no specific definition of the Energy Efficient Building; this term has been used to describe a variety of buildings worldwide (Lowe and Bell 2000). According to Meier et al. (2002), an energy efficient building must be above the average of the following aspects: firstly, the equipment used must be efficient and the materials suitable for the climate conditions, secondly, the amenities and services provided must fulfill the building use, finally, the consumed energy of the building must be lower than similar buildings. In addition, they considered the embodied energy in both construction and demolition of the buildings as the fourth important aspect, which shall be considered in the future.

Buildings energy efficiency assessment

Evaluating energy efficiency of buildings is not a straightforward task, as buildings consumption of energy is a result of a complex interaction between the building, climate and user (Roaf 2003).

Energy efficiency of a building is evaluated using the energy performance indicator, which is either compared to other standard building, or evaluated through indicators such as annual energy consumption per floor area and compared to a target value.

According to Casalst (2006), Energy efficiency within a building is addressed using two mechanisms:

1. Energy regulations

Energy regulation is a perspective character that aims to limit the upper bound for the buildings' energy consumption. The use of a proper energy performance indicator and energy assessment tool are the basis for the effectiveness of the energy regulations in controlling the energy consumption in buildings.

2. Energy certification

Energy certification is a market mechanism aims to promote higher energy efficiency standards than the regulated ones. It provides detailed information about the buildings' energy performance (energy labeling), which allow for the possibility of making a comparison between different buildings. Energy certification should include the indicators included within the energy regulations as a reference for the energy performance level.

Energy certification scheme must allow for a clear quantification of design concepts with potential for building energy consumption reduction, such as bioclimatic architecture, passive solar heating, passive cooling, passive ventilation, integration of renewable energies, . . ., always guaranteeing some given comfort levels.

A good energy certification scheme, with a compulsory character, allows for quantifying the actual energy level of the building sector, as well as promoting and evaluating the energy efficiency measures introduced in it. A proper energy certification scheme gives an added value to the building and allows the assignment of economic incentives to drive the building sector towards sustainability.

Barriers to energy efficiency

"The barriers to energy efficiency have been discussed widely in the literature to explore suitable policy measures or to find out the reasons behind the failure of implemented measures" (Deringer, et al. 2004). The existence of barriers within the building sector is higher than other sectors (Koeppel and Ürge-Vorsatz 2007).

Although barriers to energy efficiency in building would normally exist in developing countries, Carbon Trust (2005) and Metz et al. (2007) have also mentioned some barriers that could arise in the developed countries, which are related to the behavioral characteristics of individuals and companies that hinder energy efficiency technologies and practices, i.e. tendency to ignore small energy saving opportunities, organizational failures (e.g. internal split incentives).

Several barriers to the adoption of energy efficiency regulations exist the developing countries, where the governmental entities fail to provide the appropriate polices in addition to the required financial support. Additionally, lack of interest between governmental bodies does not encourage adoption of energy standards. Moreover, technical barriers exist where there is a lack of experience and knowledge required to adopt such measure. One could find several justifications to such situation in developing countries, where the high capital cost of efficient technology is also considered as the main economical barrier (Levine et al. 1995).

The attitude of the users and their lifestyle are considered cultural barriers to energy efficiency (Levine et al. 1995). In developing countries, the lack of awareness of the means of conserving energy and the importance of saving energy is a major barrier (Koeppel and Ürge-Vorsatz 2007).

Policy Mechanism to Adopt Energy Efficiency Measures in Buildings

Energy efficiency measures can be applied in buildings using either a technical approach where designers are provided with techniques guided towards to a more energy-efficient design, or a political approach which enforces the use of specific measures.

There are several international mechanisms used to achieve energy efficiency in buildings (OECD 2002, IEA 2005):

- Mechanisms that control and regulate the energy efficiency in buildings. These mechanisms are subdivided into normative and informative regulatory mechanisms. The BECs are an example of the normative type which must be followed. While the informative mechanisms provide the end user with information which he is not forced to consider, such as labeling programs
- Mechanisms that consider the economic and market methods, these had voluntary elements.
- Mechanisms that employ fiscal and incentive tools to conserve energy in buildings. This mechanism is applicable for different sectors and technologies.
- Mechanisms that provide information and support to increase the public awareness and enhance voluntary work.

The environmental impact of buildings is highly proportional with energy consumption levels, which are highly influenced by policy considered by governmental bodies. Therefore, the nature of the different policy instruments must be understood by the policymakers, so they can choose the most suitable mechanism to achieve efficient policy package (Awawdeh and Tweed 2014). Additionally, building techniques differ from region to region, which should also affect governmental policies.

Regulatory instruments are used in most countries with legislation on energy efficiency in buildings, but often in combination with other instruments. Main problems are the lack of enforcement and the rebound effect, on the other hand, most of these policy instruments achieve high savings at low costs, often at negative costs to society. They can overcome many of the numerous barriers in the buildings sector, such as information barriers, market failures and financial/economic barriers as well as hidden costs. For example, regulatory instruments help to reduce transaction costs, one of the major problems in this sector, by simply imposing standards which eliminate the need for information-searching (Koeppel and Ürge-Vorsatz 2007).

With regarding to the situation in most of the developing countries, Umar et al. (2013) study revealed that the development towards energy-efficient buildings has obtained push in recent years, including the creation of considerable various federal governmental campaigns promoting energy efficiency. However, minimal knowledge exists regarding the influence of the several policy instruments and particularly the causes for this effect. Therefore, research gaps continue to exist. Also, the circumstance in developing countries evidently demands additional implementation of policy steps to present tools for reducing GHG emissions from buildings.

Deringer et al. (2004) argue that while building energy efficiency codes exist in a number of developing countries, but they are often only on paper due to insufficient implementation and enforcement, corruption and other problems.

Koeppel and Ürge-Vorsatz, (2007) report aimed to provide an assessment of the instruments available for improving energy efficiency in buildings in order to assist policy-makers in the decision process. Results indicated that many of the 20 policy instruments evaluated in the study can achieve high savings at low or even negative costs for society. Regulatory and control instruments such as building codes and appliance standards were revealed as the most effective and cost-effective category of instruments in the sample, if enforcement can be secured. It has also revealed that financial incentives can be helpful to kick-start the market for new energy efficient products as well as for developing countries where funding is not always available. The effectiveness of voluntary instruments such as voluntary labelling and agreements depends on the context as well as on accompanying policy measures. Information instruments such as information programs are moderately effective alone which depends also on their design, but can successfully reinforce other instruments. Finally, the report states that regulatory instruments seem to be the most effective as they can overcome some of the most important barriers, for example reduce the transaction costs since they eliminate the need to search for information and negotiation, they also could be most effective if combined with incentives and measures which evoke attention such as information programs.

2.2. Methodologies on buildings' energy efficiency classification

The process of classifying buildings based on their energy usage includes any procedure that allows for the determination of the quality of a building in comparison with others. With relation to this, the terms building energy benchmarking, energy rating, and labeling are considered as the main methodologies used for buildings energy classification.

<u>Benchmarking methods</u>

"*Benchmarking consists of a comparison of the Energy Performance Indicator (EPI) or Energy Use Intensity (EUI) of a building with a sample of similar buildings or with the best-practice building. A common EPI or EUI used for many building types is annual energy use normalized with floor area but others such as energy per worker or energy per bed may also be used. Energy services companies use the EPI as a starting point in energy audits and assess saving opportunities by comparing with existing references (benchmarks) of average (typical)*" (Lombard et al. 2009, p.274).

Kinney and Piette (2002) study proposed that that benchmarking methods are used for two main reasons:

- Identifying how good is a buildings performance in comparison with other similar buildings, and classifying it based on such result. This is a robust indicator of whether the building should be prioritized for action. For this purpose, empirical benchmarks derived from energy statistics for the stock (or analysis of the stock) are applicable.
- Identifying whether the building reaches its potential with regarding to the energy performance and what are the required cost-efficient measure need to be taken to reach such target. For this purpose, a realistic model of the building and its systems is theoretically more applicable.

Li and Li (2018) presented a multi-level building energy consumption benchmarking index system for cooling in eight large commercial buildings based on detailed sub-metering system data and building operational data. The results indicated several saving energy potentials with regarding to cooling energy. It has also pointed out that cooling energy saving potential via envelope improvements is limited.

<u>Energy rating methodologies</u>

"In general, the expression energy rating system (ERS) may be used as a synonym of energy classification, that is, a method for assessing energy quality" (Lombard et al. 2009, p.275). The US Green Building Council Leadership in Energy and Environmental Design (LEED) building rating system is one example of the energy rating systems.

Roulet et al. (2002) study developed a multi-criteria rating method (ORME) to be used in office buildings. This technique is based on a rating method that uses principal component analysis and aims to qualify and sort various retrofitting scenarios based on energy use and thermal comfort condition. The result of the rating method is a single indicator that combines energy and comfort parameters. This score globally characterizes the performance of the building under defined conditions regarding the parameters: energy use for heating, cooling, and other appliances, impact on external environment, indoor environment quality and cost. ORME also includes a ranking method that uses partial aggregation techniques and purposes to rank buildings or retrofitting scenarios according to their performance with regard to several aspects. It requires a list of criteria along with an assignment of weight to each of them and allows the user to provide his scale of values.

Energy Labeling

"It was in the early 1990s when the EU introduced energy labeling with a double objective: to inform consumers about the energy performance of energy-consuming devices and to promote energy savings and energy efficiency. Following the success of its application to domestic appliances (Directive 92/75 1992), energy labeling was extended to buildings a decade later" (Lombard et al. 2009, p.275).

The aim of the energy labeling is to create an energy performance class (label) for any building, to achieve this, a related scale to the labeling index should be developed. In relation to this, the definition of such scale requires making a choice for the comparison scenario. For instance, a statistical analysis of the Energy performance indicators by the cumulative frequency distribution curve is appropriate to used when there is a sufficient number of comparable buildings, consequently, the percentile could be used as an indicator to label the energy performance of a building.

2.3. Building energy codes

Building codes are a regulatory instrument for the design and construction of buildings, such codes are adopted both at different levels. The goal of building codes is to achieve the minimum level of energy efficiency for new and renovated buildings. They improve efficiency by mandating performance through careful construction and proper systems design (City Energy, 2017, p.5). Creating Building Energy Codes was one of the policy instruments used by the developed countries to reduce the consumption of energy in the building sector (Deringer et al. 2004, IEA 2005, Koeppel and Ürge-Vorsatz 2007).

Building energy codes are an effective instrument for addressing energy efficiency in buildings and to support the achievement of the targets set by several international initiatives such as energy-related Sustainable Development Goals (SDGs), the Sustainable Energy for All (SE4ALL) initiative of the United Nations Secretary General, and the Geneva UN Charter on Sustainable Housing (UNECE 2018).

Moreover, the increasing awareness of the additional costs and environmental impacts associated with inefficient use of energy has risen the demand for more stringent energy codes, especially in buildings, where the possibilities for increasing their energy efficiency at early design process through such codes is very high. Therefore, energy requirements in building codes ensure that the energy efficiency measures are taken into account from the very beginning.

The economic, social and environmental benefits of ambitious, well implemented building energy codes and supporting policies are well documented. This may account for the high level of awareness and policy activity on building energy performance in local, regional and national economies. For example, 88 countries have mentioned the buildings and construction sector in their NDC's, while more than 3,000 municipalities and over one hundred-business organizations have registered buildings-related commitments on the UNFCCC NAZCA database (GABC 2016, UNFCCC 2017).

Energy building codes provide several significant benefits in addition to the energy-related cost savings, including the following (City Energy 2017, p.6):

- Increasing durability of the building envelope, preventing air leaks that could potentially bring contaminants and pollutants that are stored outside of the conditioned space into the building
- Improving fires safety
- Protection from extreme temperatures and storms
- Preventing potential moisture, mold, and rot problems

- Reducing water use via hot water piping insulation
- Increasing the comfort and safety of the building's occupants

It's obvious that amongst energy efficiency regulations; building energy codes are considered as the most implemented one. Therefore, most of the developed countries have already applied such codes since decades. To achieve enforcement and compliance of energy codes, there exists three methods; prescriptive, performance-based and outcome-based approach. Currently, the prescriptive and the performance-based approaches are the most common used and they could be ideally used together to ensure energy efficiency in a building.

Prescriptive codes

Prescriptive codes require a particular defined component quality, such as insulation R-value in a wall of a particular framing type. More generally, the prescriptive section of the code also contains component performance items like a required U-factor for wall assemblies or an energy efficiency ratio (EER) for an air conditioner. There may also be built-in trade-off approaches based on system or partial system performance, such as an envelope trade-off that allows more insulation in one area to be traded for less in another (Hogan 2013). A building is considered to comply with the code in case the mandatory prescriptive requirements are met.

The major advantage for the prescriptive codes is that they are simple and easy to be followed. Additionally, they provide different levels of energy saving depending on different characteristics of each building (i.e. building type, orientation, …), and can therefore be used to achieve optimum energy efficiency level for a certain types of buildings. They are also commonly used and their compliance can be simply verified by inspectors. On the other hand, as prescriptive codes provide value to be met for a specified component of the building and do not consider an overall building approach, this can lead in some cases to missing opportunities to increase energy efficiency as opposed to the whole building approach. Another disadvantage is the components functionality over time, which is not addressed by such codes. They also assume that equipment is installed and performs correctly which is overly optimistic. Finally, such codes should be regularly updated as efficiency targets become more stringent.

Despite the argument that prescriptive codes may inhibit creativity and innovation; which is considered by many individuals as a drawback for such codes. However, they still provide a good starting place for energy efficiency. This was reinforced by a study done by Higa et al. (2012), which showed that prescriptive codes often contain the results of experts supported by detailed parametric simulations and reviewed by a panel of experts; this level of expertise, innovation and efforts is often not available for the 73% of nonresidential buildings with floor area below 930 m^2, and even when the performance approach is used to comply with building energy codes, the perspective codes still forms the baseline for energy efficiency and highlights measures that otherwise might be overlooked (Higa et al. 2012).

Examples include the Commercial BEES and the New Buildings Institute (NBI) Core Performance protocol.

<u>Performance-Based codes</u>

Performance-based codes are typically expressed in terms of "percent better than" energy use in comparison to a baseline. This is determined through the use of computer modeling software that forecasts building energy consumption based on inputs describing materials, systems, climate, and expected use (e.g. occupancy schedules and internal gains). Building data is entered into the appropriate software and components and systems are manipulated until the desired efficiency goal is met. Code officials review energy efficiency results computed by preapproved modeling software to verify compliance (CGBCR 2011).

Such codes consider a whole building approach and supports the evaluation of measures which results in obtaining the lowest cost and optimum energy saving. They also allow more flexible approach to design strategies. However, they have also disadvantages. As such codes require significant staff experience to review the modelling process, they also require more time to be implemented. Additionally, the quality of the model results depends significantly on the input data. They also more expensive as considered to the prescriptive approach as they require specialty software and energy modeler. Moreover, they consider that an equipment is perfectly installed and performs correctly. Finally, such codes include no enforcement mechanism to ensure that the building will achieve the simulated energy use level.

Examples of Performance-based codes include ASHRAE 90.1 – Appendix G, California Title 24 and Oregon State Whole Building Approach.

<u>Outcome-Based codes</u>

An emerging alternative to prescriptive and performance-based energy codes is outcome-based codes. This framework considers the whole building's energy use over a consecutive 12-month period including end uses that are currently unregulated. Outcome-based codes will require that buildings not exceed a maximum annual operating energy use. This pathway guarantees that actual energy efficiency is achieved by requiring a one-time reporting for compliance verification, though it may take a few years to obtain a consecutive 12-months of qualifying energy data (CGBCR 2011).

While this pathway has the potential to help buildings achieve energy savings by assuring performance, it is still under development and has yet to be adopted by any jurisdiction. However, outcome-based paths appear well suited to federal, state, and local agencies that own their own buildings since they have long-term commitments to ensure that their buildings function properly over time (Alaska Housing Finance Corporation 2011).

Outcome-based is an inclusive approach which accounts for the whole building energy use and consider inherently all passive design strategies. This approach also combines the measures and standards outlined by perspective and performance-based approaches for selecting the most appropriate energy efficiency improvement strategies for existing buildings. Additionally, it is considered a flexible approach which encourages design innovation and also allows for the use of new technologies. Moreover, the monitored data provided can be used to inform building energy improvements and also update future energy codes.

Benchmarking and disclosure allow building owners to evaluate their building's performance and identify system problems in a timely manner; this compliance path makes the building itself the energy-use reference point. Metering and sub-metering are essential tools for this path; however, sub-metering can be challenging to install in existing buildings (CGBCR 2011).

Outcome based codes would require substantial new enforcement paradigms and infrastructures. The necessity of post-occupancy evaluations, uncertainties related to occupants and their habits, issues of building energy data confidentiality, and the potential requirement for corrective post-occupancy reconstructions makes this option difficult to envision in the near term for private sector buildings (Rosenberg et al. 2015).

2.4. Energy efficiency requirements in Austria

"*A range of measures is available to the Austrian government in the area of energy efficiency policy, including regulatory measures (such as minimum efficiency standards or energy taxation rules); research, technological development and demonstration, and promotion of market penetration; dissemination of information to energy consumers; and subsidies for the implementation of energy-saving measures*" (Austrian Energy Agency 2012, p.9).

Energy strategy in Austria is founded in three basic principles; securing of energy supply, energy efficiency and renewable energies. Based on those principles, the strategy is mainly directed at enhancing energy efficiency at each level where energy is supplied or consumed (Austrian Energy Agency 2012).

"In Austria, the implementation of the EU Directive on the Energy Performance of Buildings required regulations at both the federal government and the state levels. The federal Energy

Performance Certificate Presentation Law was published in April 2012. It mandates that the energy performance certificate is presented upon a change in the ownership or tenancy of a dwelling. The certificate is based on the state-level regulations. Furthermore, some provinces have implemented energy performance requirements for buildings within the scope of building codes in the form of the heating energy demand (in kWh.m²a^{-1}) or the LEK-values (non-dimensional). All federal provinces have specified exactly in which cases the energy performance has to be calculated for reconstructed or extended buildings" (Austrian Energy Agency 2012, p.18).

In combination with energy efficiency requirements, subsidies are offered as incentives in some regions of Austria, and are offered for fulfilling requirements which are stricter than those outlined by the building codes. For instance, such requirements could be improving windows, installing renewable energy resources such as solar collectors or improving insulation of opaque building envelope components. In some Austrian provinces this has led to nearly all buildings being constructed with an energy efficiency which is better than the requirements in the codes, but as a minimum the requirements are fulfilled (UNECE 2018).

"*As a federal country, Austria produced the document "Austrian Institute for Structural Engineering Guidelines—Cited standards and other technical regulations"drawn up by the Austrian Institute for Building (Österreichisches Institute für Bautechnik—OIB) in order to harmonize the nine building codes ''and other laws. This document set out the current standards and technical regulations that would serve as a common starting point. The system to calculate energy demand for heating and cooling, in compliance with the OIB-Guideline'', includes nine laws and over 200 mathematical algorithms in order to provide a detailed specification of a building's characteristics. The methods adopted apply to both residential and nonresidential buildings, with the latter being divided into 12 categories: office buildings; nurseries and compulsory schools; secondary schools and colleges; hospitals; care homes; guesthouses; hotels; bars and restaurants; event venues; sports facilities; sales outlets; indoor swimming pools and other air-conditioned structures. Those eligible to issue certificates (generally architects, engineers, master builders and other specialists) are authorized by law to practice this profession, for this reason, there are no provisions made for other specific professional training or examinations; any training, albeit on-compulsory, to be provided by regional Governing bodies together with Chambers of Commerce and civil engineers*" (Andaloro et al. 2010, p.5848).

Energy performance certificate

"*According to Concerted Action (2010) the owner must "present a valid certificate to the building authority or to the buyer when the selling or renting contract is established." For new construction and major renovations, there is a description of how first a temporary and then a final certificate is produced and finally uploaded to the central database of the province or of Statistics Austria. The regulations simply require the EPC to be presented at the time of establishing the contract"* (Bio Intelligence Service et al. 2013, p.56).

Accordingly, Austrian standards OIB-Richtlinie 6 (2015) requires an energy certificate for each new or renovated residential and non-residential buildings. The heat energy demand of the building (HWB) is used as the main factor for labeling the building classification. Additionally, other factors including the primary energy demand, the Co_2 emissions and the total energy efficiency factor are considered in the classification system. This certificate is valid for 10 years. The labeling system is shown in Table 1.

Table 1 Energy label criteria (OIB-Richtlinien 6)

Class	$HWB_{Ref,SK}$ (kWh.m^{-2}a^{-1})	PEB_{SK} (kWh.m^{-2}a^{-1})	CO_{2SK}(kg.m^{-2}a^{-1})	f_{GEE}
A++	10	60	8	0.55
A+	15	70	10	0.70
A	25	80	15	0.85
B	50	160	30	1
C	100	220	40	1.75
D	150	280	50	2.50
E	200	340	60	3.25
F	250	400	70	4
G	>250	>400	>70	>4

The Austrian standards sets a maximum value for the permitted annual heating demand ($HWB_{max,REF,RK}$) per m^2 of the heated gross area for new constructed buildings based on the following equation:

$HWB_{Ref,RK} = 14*(1+3/l_c)$ and NOT more than 47.6 kWh.m^{-2}.a^{-1}

Moreover, and for newly constructed or renovated buildings or building components in conditioned spaces, maximum heat transfer coefficients (U-value) are specified for different building components.

2.5. Buildings' energy regulations in Palestine

Energy codes and regulations are well implemented in most of the developed countries. However, the documentation of energy regulations and its implementation in developing countries is still very limited and does not even exist is some regions. In addition, there is a lack of consistent data, which makes it challenging to understand the underlying changes that affect energy regulation implementation in most of the developing countries (Markovic 2017).

Iwaro and Mwasha (2010) investigated the progress of building energy regulations in 60 of the developing countries and its implication for energy conservation and efficiency. Using an online survey of building energy regulations, it was shown that a total of 25 of the developing countries surveyed do not have building energy regulations. Additionally, major findings indicated that the level of progress on energy regulation activities in Africa, Latin America and Middle East is increasing in view of the higher number of energy standard proposals recorded in these regions. However, they are still far behind in building energy regulation development, implementation and compliance when compared to developed nations.

As it the case in most developing countries, the implementation of energy regulations in the country of Palestine is still very limited and there is still no official certification method that regulates the implementing of energy efficient buildings standards. Except in rare cases where the project is funded by an international agency that pays attention to encouraging the implementation of energy efficient buildings; aspects of good wall insulation could be considered.

Palestinian code of energy

Despite the complexity and challenges that surrounds the building sector, the Global Environment Facility (GEF) has in 2004 funded the project entitled "Capacity Building for the Adoption and Application of Energy codes for Buildings" which has been executed by the United Nations Development Program/Program of Assistance to the Palestinian People (UNDP/PAPP), and implemented by the Ministry of Local Government in Palestine (MLG). After this project, the "Energy Efficient Building Code" has been created. However, the created buildings' energy code hasn't been update since 2004.

Requirements for building components

The code specifies the maximum allowed heat transfer coefficient (U-value) for different components of the building envelope by dividing buildings into two categories (Ministry of Local government 2004):

- Category A: Includes all buildings which contain occupants and provided with HVAC system, or has an area of more than $120m^2$ and not provided with HVAC system.
- Category B: Includes all buildings which contain occupants that has an area less than $120m^2$ and not provided with HVAC system.

According to the categories shown above, the maximum U-values are shown in Table 2.

Table 2 Requirements for heat transferring components of building envelope (Energy Efficient Building code)

	Building component		***U-Value [$W.m^{-2}.K^{-1}$]***	
			Category A	***Category B***
1	*CEILING to outside air*	*Upward heat transition*	*0.9*	*1.8*
		Downward heat transition	*1.2*	*2.2*
2	*CEILING between parts with different heating system.*		*1.2*	-
3	*CEILING to unheated*		*1.2*	-
4	*Envelope components (Walls, doors and windows)*		*1.8*	*2.5*
5	*WALLS between parts with different heating system.*		*2.2*	
6	*WALLS to unheated*		*2.2*	-

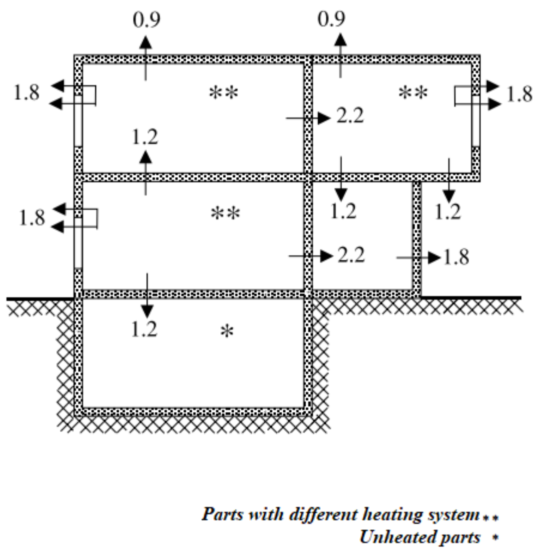


Figure 1 U-value for category A buildings (Energy Efficient Building code)

Additionally, the energy efficient building code includes a catalogue for local insulation materials that may be used to increase the efficiency of the building envelope, it also provides general guidelines to control condensation in buildings.

<u>Green Buildings Guidelines Handbook</u>

The Palestinian association of engineers has issued the Green Buildings Guidelines handbook, which is a voluntary instrument, to provide guidelines for urging the community trends towards a more sustainable building environment. This handbook provides a green buildings' rating system which is based on six main parameters as shown in Table 3. Depending on the number of points collected, a rating is given for a certain system according to Table 4. For each main parameter, there are several sub-parameters and a number of points is given to each one. For example, site sustainability parameter includes the sub-parameters which are shown in Table 5, as shown the first sub-parameter is required, and the other sub-parameters are rated based on the maximum points shown. For each sub-parameter, the handbook specifies requirements, methodology and a reference documents, though the rating is evaluated based on fulfilling those requirements.

Table 3 Points system (Green buildings Guidelines-State of Palestine)

Parameter	**Number of points**	**Percentage**
Site sustainability	30	15%
Energy Use Efficiency	60	30%
Water use efficiency	50	25%
Indoor environment quality	30	15%
Materials and resources	20	10%
Innovation and Building Integrated design	10	5%
Total	200	100%

Table 4 Green buildings classification (Green buildings Guidelines-State of Palestine)

Level	**Rating**	**Points collected**
****	Diamond	>160
***	Golden	140-159
**	Silver	120-139
*	Bronze	100-119

Table 5 Site sustainability sub-parameters (Green buildings Guidelines-State of Palestine)

Number	Parameter	Points
1	Construction activity pollution prevention	Required
2	Site selection	4
3	Building accessibility	3
4	Site development	5
5	Outdoor thermal comfort strategy	4
6	Urban heat island effect	4
7	Alternative transportation	4
8	Storm water design	4
9	Light pollution reduction	2
Total		30

2.6. Current energy situation in Gaza Strip - Palestine

"The annual energy consumption per inhabitant in Palestine is the lowest in the Middle East region. While energy consumption in kWh.capita^{-1} in Israel was 3,955, in Jordan 1426 in 2013, the annual energy consumption in Palestine was 790 kWh.capita^{-1}. Also, the energy resources in Palestine is less affordable than anywhere else in the Middle East countries". (Juaidi et al. 2016, p. 944).

"The total electricity load supplied to the Gaza Strip today is about 197 MW coming from three sources as follows: The Gaza power plant (60 MW), the Israeli electric company (120 MW) and Egypt (17 MW)30. The actual requirements for electricity in the Gaza strip are however estimated to be about 300 MW, which means that there is a shortage of about 100 MW (34% of the total needs)" (Muhaisen and Ahlbäck 2012, p. 15). This number is increasing annually due to the vast growth in the population numbers each year.

The World Bank (2016) report has stated that about two thirds of the electricity produced in Palestine is consumed by the residential sector.

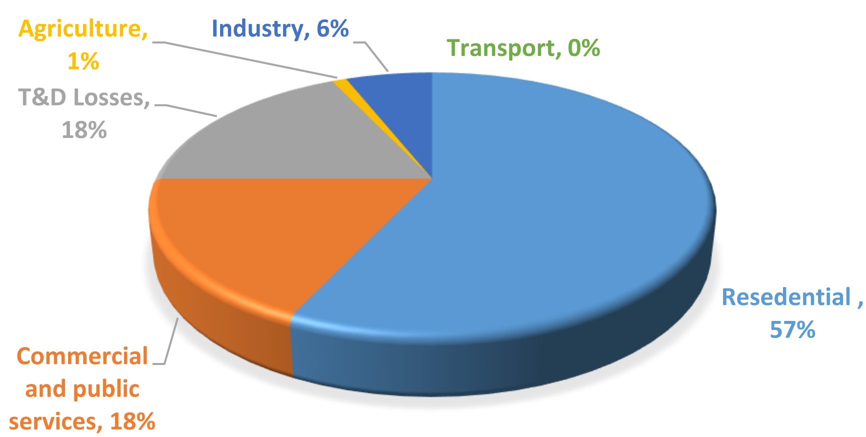


Figure 2 Electricity usage by sector in Palestine

The Gaza Strip is a high-density populated area with very limited energy resources, which makes it totally dependent on importing fossil fuel required to generate electricity from neighboring countries. This problem has increased over time due to the rapid population growth and unstable political situation that has negatively affected development in the Gaza Strip. Currently, the region depends mainly on fossil fuel to produce electricity from a local generating plant, in addition to small portions of electricity imported from Israeli and Egyptian electricity companies.

Statistics clearly indicate that efforts should be directed towards the residential sector as one of the major consumers of energy resources. Also, enhancing the energy efficiency of buildings should contribute to mitigate the overall problem effects, this could be achieved by applying energy efficiency measures to the building sector. Such trend, would reduce the need for traditional energy resources in addition to reducing the environmental impact of buildings (Muhaisen and Ahlbäck 2012).

2.7. Prediction of buildings' energy consumption

"Since energy consumption is a function of a great amount of information regarding (a) building characteristics, (b) energy systems characteristics, control and maintenance, (c) weather parameters, and (d) occupants' behavior, among other sociological parameters, forecasting buildings energy consumption is not an easy task. In this sense, a lot of efforts from the scientific community, governments, and industry have originated multiple research efforts that have given origin to several approaches and methods as well as multiple tools for estimation of building energy performance" (Fumo 2014, p.53).

Due to the complexity of building energy behavior and the uncertainty of the influencing factors, many models were proposed for this application aiming at accurate, robust and easy-to-use prediction (Zhao and Magoules 2012).

(Zhao and Magoules 2012) defines five groups for prediction methods of building energy consumptions:

1. <u>Engineering methods</u>

In those methods, thermal dynamic and energy behavior for the building or for a sub-component of the building are calculated using physical principles. Engineering methods are classified into two categories, the detailed comprehensive method and the simplified method. The comprehensive methods use very elaborate physical functions or thermal dynamics to calculate precisely, step-by-step, the energy consumption for all components of the building with building's and environmental information, such as external climate conditions, building construction, operation, utility rate schedule and HVAC equipment, as the inputs.

Therefore, software tools are required to calculate energy efficiency of a buildings. However, such tools require a detailed information about the building characteristics, usage and the environmental parameters in order to achieve accurate results. Such information is not always available and could be difficult to be achieved. Additionally, using such tools requires an in-depth knowledge and experience to obtain acceptable results.

AL-Hamoud (2001) study outlined that simplified analysis results are acceptable for the purpose of studying trends or comparing alternatives, while comprehensive tools should be used for a detailed energy analysis of buildings.

Many considerations can be involved in developing the engineering model. It can be a very elaborate, comprehensive model which is applicable for accurate calculations. In contrast, by adopting some simplifying strategies, it can become a light-weight model and is easy to develop while maintaining accuracy. A commonly accepted drawback of this detailed engineering model is that it is difficult to perform in practice due to its high complexity and the lack of input information.

Yao and Steemers (2004) study developed A simple method of formulating load profile (SMLP) for domestic buildings. Domestic space heating load profile for different types of houses has been produced using thermal dynamic model, which has been developed using thermal resistant network method. The daily breakdown energy demand load profile of appliance, domestic hot water and space heating can be predicted using this method. The method can produce daily load profile from individual house to urban community, and it is suitable to be used at renewable energy system strategic design stage.

2. Statistical methods

Statistical regression models simply correlate the energy consumption or energy index with the influencing variables. Such empirical models are developed using enough historical performance data that should be collected prior to the models training. The literature includes several studies carried out on several problems using regression models. For instance, predicting the energy usage over simplified variables such as one or more weather parameters. Also, is predicting some useful energy index. Moreover, estimating crucial parameters of energy usage, which are useful in analyzing thermal behavior of building or sub-level systems, such as total heat loss coefficient, total heat capacity and gain factor.

Lei and Hu (2009) has developed a baseline model for office building energy consumption in hot summer and cold winter region by using energy bills analysis method. By analyzing the data of eleven office buildings, the results showed that monthly mean outdoor dry-bulb temperature was the most important variable and the others weather variable, such as relative humidity and global solar radiation showed weak correlations with the whole building energy consumption. It was also shown that single variable linear model based on outdoor dry-bulb temperature is sufficient and practical to track and baseline energy use in the hot summer and cold winter condition.

Temperature dependent regression models are strongly influenced by the length period of measurements. This was approved by a study done by (Chao et al. 2004) which examined the temperature dependent regression models of energy consumption as a function of the length of the measurement period. The methodology applied was to construct linear regression models of daily energy consumption from 1 day to 3 months' data sets and compare the annual heating energy consumption predicted by these models with actual annual heating energy consumption. A commercial building in Daejon (South Korea) was selected, and the energy consumption was measured over a heating season. The results from the investigation show that the predicted energy consumption based on 1 day of measurements to build the regression model could lead to errors of 100% or more. The prediction error decreased to 30% when 1 week of data was used to build the regression model. Likewise, the regression model based on 3 months of measured data predicted the annual energy consumption within 6% of the measured energy consumption.

3. Neural networks

Artificial neural networks, as artificial intelligence, are used to solve nonlinear problems to predict building energy consumption.

Ekici and Akosy (2009) study aimed to predict buildings energy needs benefitting from orientation, insulation thickness and transparency ratio by using artificial neural networks. A backpropagation neural network has been preferred and the data have been presented to network by being normalized. The numerical applications were carried out with finite difference approach for brick walls with and without insulation of transient state one-dimensional heat conduction. Three different building samples with different form factors (FF) were selected. For each building samples 0–2.5–5–10–15 cm insulations are assumed to be applied. Orientation angles of the samples varied from 0° to 80° and the transparency ratios were chosen as 15–20–25%. A computer program written in FORTRAN was used for the calculations of energy demand and ANN toolbox of MATLAB is used for predictions. As a conclusion; when the calculated values compared with the outputs of the network, it is proven that ANN gives satisfactory results with deviation of 3.43% and successful prediction rate of 94.8–98.5%.

Also, Ben-Nakhi and Mahmoud (2004) study aimed to predict cooling loads for three buildings of various densities of occupancy and orientation characteristics using general regression neural networks. Cooling load data for 1997-2000 were used for training the model, while testing the model was done using 2001 data set.

4. Support vector machines

Involve methods of machine learning that are effective in solving nonlinear problems even with small quantities of training data.

5. Gray models

When the information of one system is partially known, we call this system a grey system. The grey model can be used to analyze building energy behavior when there is only incomplete or uncertain data.

Zhou et al. (2008) study developed a model to predict cooling load by integrating two weather prediction modules into a simplified building thermal load model, one is the temperature/relative humidity prediction which is achieved by using a modified grey model, the other is solar radiation prediction using a regression model. Results showed that the performance of the simplified thermal network model is improved as long as the predicted weather data from the first module is used in the training process.

It is obvious that each model has its own advantages in certain cases of applications. For instance, simplified engineering model can be easily developed. Statistical approach can be also easily developed but also has some level of inaccuracy. Neural networks and support vector machines are efficient in solving non-linear problems which is adequate to predict building energy consumption, however, such models are very complex.

2.8. Simplified models for estimating buildings' energy performance

Simplified models are one of the methods used to analyze thermal performance of buildings, several studies aimed to create a simple model for predicting energy demands for buildings based on certain characteristics. Following section represent related research.

Petersen and Svendsen (2010) presented a method for making informed decisions in the early stage of building design to fulfill performance requirements with regard to energy consumption and indoor environment. A program utilizing simple simulation tool to make performance predictions of user-defined parameters was developed, allowing the possibility to perform parameter variations to form the basis for informed design decisions, which then presents the results in a way that enables designers to make such decisions. The developed tool was tested on a case study two-person office building in Danish climate, which was designed to meet the required energy performance and indoor comfort levels after two iterations.

Muhaisen and Abed (2013) investigated the thermal performance of building form in the Mediterranean climate of Gaza Strip. Generic forms of buildings including circular, square, rectangular, trapezoidal and other building shapes were created. It was concluded that surface to volume ratio is the most important aspect affecting thermal performance of geometric shapes. However, having the same surface to volume ratio in the same shape with various proportions creates a variety in thermal response and energy consumption. It was also shown that Self-shading of different geometric shapes with the same surface to volume ratio has a considerable impact in affecting heating and cooling energy requirements.

McKeen and Fung (2014) studied the effect of building aspect ratio on energy efficiency on multi-unit residential buildings in Canada. The methodology used in the study was creating a base model, then permutations on the aspect ratio were created in order to produce 13 varying building geometries of different aspect ratios, simulations were done using eQUEST energy simulation software. The results indicated that the optimal aspect ratios were generally found to be between 1:1 and 2.7:1. However, it was noted that the optimal aspect ratio for heating efficiency is not necessarily optimal for cooling efficiency. Therefore, the optimal building geometry will form a balance between the two energy demands. Additionally, the results showed that utilizing the optimal aspect ratio allows buildings to receive more solar gain in winter and shading in summer, resulting in decreasing the demand for heating and cooling. Finally, it was proved that optimal aspect ratio has decreased peak loads; which could save many capital and operating costs.

Nagendahl and Nielsen (2015) provided a simplified method for building energy optimization in the early design stages. Multi-objective genetic algorithms for holistic building design were applied, taking into multiple criteria consideration, including building energy use, capital cost, daylight distribution and thermal indoor environment. The focus of the optimization was related to building envelope parameters. It is concluded, that quasi-steady-state methods (Used to estimate thermal loads) implemented as part of integrated dynamic models are fast and flexible enough to support building energy, indoor- environment and cost-optimization in the early design stages.

Premrov et al. (2016) explored the influence of building shape on the energy performance of timber-glass buildings in different climatic conditions. The research was based on a case study of one-storey timber-frame house, and by applying climate data for three different European cities; Ljubljana, Munich and Helsinki. The investigate factors were the shape factor of the building in addition to the glazing to wall area ratio in the south façade of the building. The results point out that the total annual energy demand for heating and cooling depends on the increasing shape factor to a considerably higher extent in cold climate conditions with a lower solar potential (Helsinki). On the other hand, the analysis of the regions with a higher average annual temperature (Ljubljana) and solar potential in the heating period shows that the influence of highly attractive building shapes on the energy demand is evidently less important, especially when using the appropriate size and position of the insulating glazing. This fact was also confirmed by another study done by Albatici and Passerini (2011) in Italy, where it was also proved that compactness of passive building is more important in cold climates.

Markovic (2017) explored the potential of descriptive building quality specifications as an alternative to the detailed calculation. By comparing the results of both detailed calculation method of energy certificates and perspective method in view of consistency of their outcome using the output of energy certificates; namely the heating demand of 16 buildings sample (Vienna) as a reference. The created perspective index is based on the correlation results between the reference and several building quality characteristics. Results showed that the characteristic length of the building showed a high linear correlation to the heating demand. Therefore, it was used in addition to the mean area weighted U-value of buildings, to create a linear regression model (Coefficient of determination 90%), which was then used to create a perspective index that predicts heating energy demand of buildings based on the two variables chosen.

Geekiyanage and Ramachandra (2018) developed a model for estimating cooling energy demand at early design stage of condominiums in Sri Lanka based on building design variables such as building size, shape, orientation and window and roof area. The study adopted a quantitative approach involving a questionnaire survey and document review of data from 30 condominiums. Results of correlation analysis performed showed that number of floors, window to wall ratio and gross internal floor area parameters have significant correlations with the cooling energy demand. Subsequently, a stepwise multiple linear regression was performed and showed that only number of floors and window to wall ratio (WWR) are responsible for over 91% of fluctuation in cooling energy demand.

Al Qadi et al. (2018) developed a regression model to estimate the heating energy consumption of the residential buildings in Hebron (Palestine). The study used socioeconomic and physical parameters such as building typology, heated area, total monthly income and number of months in which heating systems are used. The data were collected using a survey and the total number of respondents was 322. The actual heating energy consumption was taken as the main indicator. The coefficient of determination for the created model which includes several parameters such as housing typology, housing age, heating months, type of settlement and occupancy period is 60.6%.

Yoon and Moon (2018) established a model to estimate energy consumption in commercial buildings in Seoul using Gaussian process regression. Survey was used to collect energy related information of buildings such as building characteristics, occupants, equipment. The electricity energy consumption was used as an indicator based on the electricity bill obtained from each tenant. The study focused on studying the energy use factors of individual tenants, such as occupant behavior (working people, working days and working hours) and plugged loads. The results indicated that power of the lighting system and the number of monitors as the most significant factors for electricity energy consumption, as they account for about 30% of the electrical energy consumption of an office tenant in commercial buildings.

2.9. Overheating risk in buildings

A free-running building (Passive cooling building) does not make any use of mechanical heating or cooling. Accordingly, the free-running temperature represents the indoor temperature of the building in thermal balance with the outdoor environment when neither heating nor cooling is used.

There is growing evidence of an increased incidence of overheating during warm weather in buildings without air conditioning, especially homes in temperate climates where the retention of winter heat has been the principal focus of thermal design (Lomas and Porritt 2017).

Overheating can occur both in new and existing buildings as well. Increased heat can cause severe health problems and also affects their comfort, especially if sleep is degraded. In extremis, the heat stress caused can lead to premature mortality, especially amongst more vulnerable members of society. During the sweltering summer of 2003, which was the hottest summer in the last 500 years (Luterbacher et al. 2004), over 35,000 people died across Europe from heat-related causes (Brücker 2005).

"In territories where air-conditioning is already used, or even essential to maintain comfort, there is an interest in the indoor temperatures that might occur should the mechanical cooling equipment or the electricity supply fail" (Lomas and Porritt 2017, p.1).

*"Two types of thermal comfort temperature limits are used for quantifying the overheating risk in free-running buildings according to different thermal comfort standards and/or approaches. The first is a fixed temperature limit, while the second is an adaptive temperature limit" (*Hamdy et al. 2017, p. 309).

There are several indices that are used to examine the overheating likelihood in buildings, the following are highlighted:

- Percentage outside the range (POR), or the percentage of occupied hours, with operative temperatures outside the upper range of the adaptive comfort model, this method is referred to as adaptive method overheating index (CEN 2007, category II-Equation 1).
- Degree hours outside the upper range of the adaptive comfort model (CEN 2007, category II-Annex F-Equation 1).

These indices were introduced by ISO 7730 (2005) standards, and were re-proposed by EN 15251: 2007. These indices represent the percentage of the occupied hours and the degree hours where the operative temperature of the house is higher than the upper boundary of the adaptive comfort model range.

- Exceedance of a fixed threshold, 25 ^{o}C, measured during the occupied and non-occupied hours (% hours over the benchmark).
- Exceedance of a fixed threshold, 25 ^{o}C, measured only during the occupied hours (CIBSE 2013) (% hours over the benchmark).
- Exceedance of a fixed threshold, 26°C, measured only during the occupied hours, (CIBSE 2013) (% hours over the benchmark).
- Exceedance of a fixed threshold, 28°C, measured only during the occupied hours, (CIBSE 2013) (% hours over the benchmark).

Those indices calculate the percentages of hours (occupied or during the whole day) with temperatures above fixed thresholds. These indices-methods are static, simple and easily understandable for owners and designers. In addition, these are the most widely used indices for long-term assessment of overheating likelihood and occurrence in the literature and the regulation guidelines from various countries (Carlucci et al. 2014).

- DT index, or the difference between peak indoor and annual average outdoor dry-bulb temperature (Carlucci et al. 2012)

This index is rather simple. However, it does not provide any information about the severity or the duration of the occurrence. There are several studies exist concerning the assessment of overheating risk in buildings.

Pessenlenhner and Mahdavi (2003) examined the reliability of geometric compactness indicators for energy-related evaluative assessments based on extensive parametric thermal simulations. Two performance indicators were used, namely the annual heating load ($kWh.m^{-2}.a^{-1}$) and overheating index ($Kh.a^{-1}$). The latter was defined as the sum of hourly temperature differences between the room temperature and an overheating reference temperature (27°C during day and 25°C in the night). With relation to the relative compactness variable, the heating load showed much higher correlation values (0.88) in comparison to the overheating index (R^2 = 0.59).

Peacock et al. (2010) investigated the potential of overheating in UK dwellings as a consequence of extent climate change. By using two main indicators to highlight uncomfortable internal temperatures, the first one is the percentage of average internal temperatures during occupied hours that exceed 28°C, the second indicator is the number of cooling nights as judged by the temperature of the bedroom at 11 pm and using 23.9 °C as the internal temperature beyond which an occupant in a bedroom during sleeping hours might act. Assuming no action is taken by the occupant to reduce the temperature, the London climates (2005 and 2030 having average annual external temperatures of 11.4 and 12.4 °C, respectively) show considerable overheating of between 11% and 18%.

Nicol et al. (2009) suggested an approach for overheating diagnostics, which is based on the concept of adaptive comfort in buildings based on the results of field studies of thermal comfort. Based on such approach, the risk and magnitude of overheating can be calculated according to the amount by which the operative temperature for any given hour or day exceeds the predicted comfort temperature for that day. The predicted level of discomfort is related to the difference between the two.

According to Hamdy et al. (2017), poorly ventilated dwellings are vulnerable to overheating and are the most sensitive to climate change, particularly if their windows are not well protected against direct solar radiation. As an indicator, the Indoor overheating degree (IOD) was introduced so that different thermal comfort limits for different zones of a dwelling could be considered, taking into account the particular occupant's behavior and the adaptation opportunity he/she has in each identified zone. Such indicator quantifies the overheating risk, taking into account both the intensity and the frequency of indoor overheating. The intensity is quantified by the temperature difference between the free-running indoor operative temperature and a chosen thermal comfort temperature limit, whereas the frequency is calculated by integrating the intensity of overheating during the occupied period into the different building zones, to present the overall overheating in a building.

3. Methodology

3.1. Overview

The goal of the current thesis is to validate the outcome of the prescriptive based approach of building quality variables as compared to the performance-based approach using performance simulation tools. A representative building sample in terms of the building quality indicators has been selected.

The first step is to perform energy simulations for the selected building sample. During this stage, the U-values of the building envelope components for all of the buildings were assumed constant due to the lack of data related to such characteristic. The assumption was based on the common construction practices in the region.

The second step is creating a list of descriptive building indicators and calculating a set of chosen indicators for the whole sample using the output data for buildings provided by performance simulation tool. This step is done with the intention to examine which of these descriptive indicators gives the most information about building thermal quality and to examine their influence on building performance. The performance results, namely the overheating index [kh. a^{-1}] would be taken as representative of performance indicator and will be discussed and compared in the context of the sample's geometry and material design variables. The goal of this step is to test if calculated building indicators give the same level and information regarding the thermal quality of a building as a performance-based method.

After finding the valid set of building indicators, the next step is a statistical evaluation of the data and finding statistically and practically the best fitting set of variables and creating a multiple regression equation. This equation could deliver the possibility to predict building's thermal behavior based on those simple descriptive indicators if we would eliminate the step of the thermal simulation.

After finding the best two set of variables, the overheating index performance indicator is tested against the annual cooling demand [$kh.m^{-2}.a^{-1}$], the goal of this step is to find if it is possible to predict cooling demand of a conditioned building based on the overheating index of the same building under passive cooling mode. Furthermore, parametric analysis is conducted to test the effect of different levels of insulation for the same buildings sample on the chosen building quality variables and on the cooling energy demand indicator.

After finding the best fitting model, the next step in this research is creating a prescriptive based index which would consist of different values for chosen variables and would give the information, which combination of these values would give a certain level on energy efficiency scale.

3.2. Hypothesis

The main hypothesis of the current research is that the ability of the prescriptive methods for building energy efficiency to provide reliable results, and at the same time, can save time and costs in comparison to the performance based approaches. It is supposed that the provided building index will be a useful tool to be used by architects in the early stages of the design process to provide informed decisions regarding the cooling energy demand.

<u>Research questions</u>

1. How do simple building quality indicators affect overheating index of the building?
2. Is it possible to predict the cooling energy demand based on the temperature of a passive cooling building?
3. Is it possible to predict the thermal quality of a building based on simple indicators, without the need to perform energy simulations?
4. If the method is shown to work, is it possible to simplify building performance standards and apply it to standards in developing countries, where there is no standardization regarding performance criteria?
5. How could the current construction practices in Gaza be developed towards achieving a more energy efficient design?

3.3. Building sample

Verification of the hypothesis drawn above requires a practical approach. Therefore, a building sample has been selected in order to test the hypothesis. The total set of 50 residential building has been collected.

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. In particular, this study sought to evaluate the relationship between a series of typical parameters of the buildings and the information's that can be inferred from the performance- simulation tool (EnergyPlus). The overall characteristics of the buildings sample are shown below. Regarding the building typology, more than half are apartments, whereas 46% are classified as detached houses, including multi-family houses as illustrated in Fig.3.

In terms of the glazing properties of the building envelope, the WWR of the building sample ranges from 6.36% to 27.92%, with an average value of 15.9%. Regarding the thermal properties of the building envelope, it was set constant for all of the buildings sample according to the common construction practices in Gaza, which means that the investigated sample represents the actual construction practices in such region.

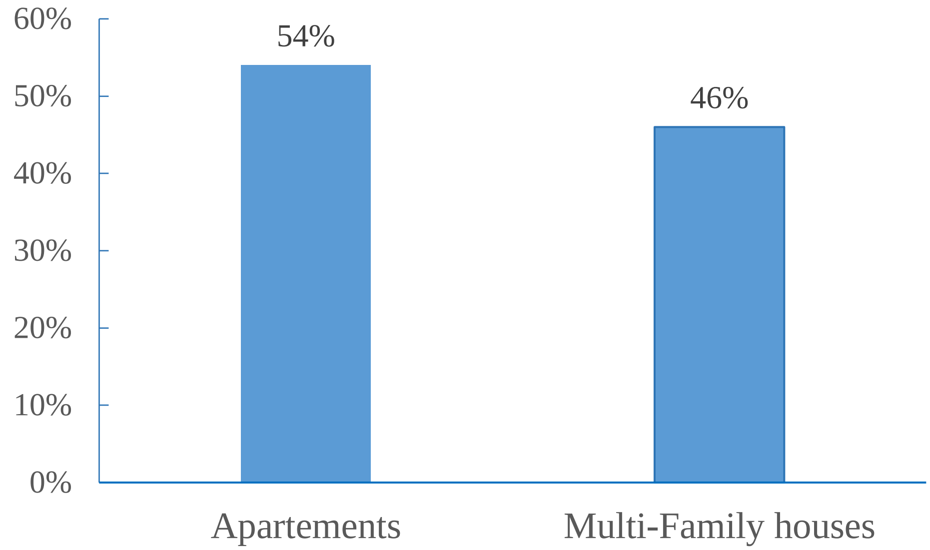


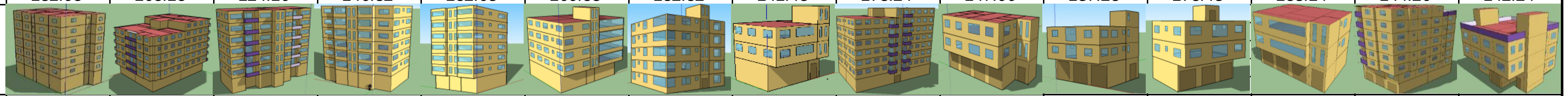
Figure 3 Buildings typologies of the selected sample.

Table 6 shows detailed information about the investigated buildings sample, including the chosen building quality variables (will be explained later).

Before any evaluation, all data were checked to verify normal distribution using SPSS. Moreover, outliers identified by means of boxplot diagrams, were removed from the data set to avoid distortions in the results, thus reducing the sample. Therefore, no anomalous values appear in the considered data set.

Table 6 Design Variables of the Buildings Sample details

Building Charchterstic	Unit	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15
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	0.73	0.56	0.41	0.46	0.44
Charcterstic Length (lc)	m	1.86	1.81	2.93	2.14	2.51	1.98	2.1	2.44	1.67	2.09	1.36	1.77	2.46	2.18	2.26
Relative compactness (Rc)	-	0.87	0.83	0.83	0.77	0.92	0.86	0.83	0.89	0.91	0.95	0.98	0.91	0.8	0.77	0.79
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	18.45	15.15	13.07	12.13	17.21
WWRo south equivalent	[%]	8.39	12.54	13.5	11.67	10.1	14.83	21.96	9.65	6.69	9.97	10.76	8.82	8.47	7.1	10.27
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	10.76	6.15	7.87	6.83	9.82
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	20.01	13.18	7.54	8.19	8.33
Thermal Compacntess Ct	[m]	0.46	0.49	0.3	0.41	0.35	0.45	0.44	0.36	0.51	0.42	0.63	0.48	0.35	0.39	0.39
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	1.82	1.87	1.81	1.73	1.79
LEK value	-	152.03	163.13	124.16	146.52	132.68	160.35	152.52	141.45	175.24	147.06	187.23	173.48	138.14	144.26	142.24



Building Charchterstic	Unit	B16	B17	B18	B19	B20	B21	B22	B23	B24	B25	B26	B27	B28	B29	B30
Shape factor (SF)	$[m^{-1}]$	0.42	0.34	0.55	0.48	0.62	0.45	0.88	0.73	0.31	0.68	0.67	0.82	0.71	0.45	0.58
Charcterstic Length (lc)	m	2.39	2.95	1.8	2.1	1.6	2.24	1.13	1.36	3.19	1.48	1.5	1.22	1.42	2.24	1.73
Relative compactness (Rc)	-	0.95	0.78	0.82	0.94	0.92	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	[%]	9.89	16.53	21.82	25.06	22.89	27.92	18.27	11.77	23.53	17.92	19.41	19.03	20.66	12.45	16.62
WWRo south equivalent	[%]	8.75	14.45	15.81	20.14	19.1	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	[%]	8.75	12.33	13.27	20.14	19.1	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	[%]	6.66	7.91	19.92	19.36	25.54	15.48	6.68	16.38	10.26	15.78	12.57	23.73	18.72	9.6	12.4
Thermal Compacntess Ct	[m]	0.36	0.3	0.47	0.42	0.54	0.38	0.73	0.59	0.24	0.59	0.57	0.74	0.61	0.38	0.49
Effective Envelope U value	$[W.m^{-2}.K^{-1}]$	1.76	1.8	1.74	1.77	1.74	1.79	1.96	1.73	1.64	1.96	1.84	1.89	1.85	1.76	1.81
LEK value	-	137.43	121.54	158.42	146.09	166.69	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	B41	B42	B43	B44	B45
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	0.69	0.38	0.37	0.63	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	1.44	2.64	2.73	1.59	2
Relative compactness (Rc)	-	0.63	0.83	0.57	0.81	0.7	0.63	0.61	0.79	0.61	0.78	0.68	0.72	0.79	0.8	0.82
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	15.66	11.12	16.82	8.52	14
WWRo south equivalent	[%]	7.44	7.62	5.65	8.63	14	8.55	6.68	12.2	6.5	14	12.47	8.57	13.46	6.99	11.09
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	12.47	6.54	12.31	6.48	11.09
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	15	5.98	8.27	10.1	14.51
Thermal Compacntess Ct	[m]	0.34	0.29	0.62	0.51	0.3	0.4	0.31	0.42	0.65	0.41	0.56	0.33	0.32	0.55	0.43
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	1.78	1.87	1.85	1.75	1.7
LEK value	-	143.77	130.47	211.36	172.66	140.58	150.48	143.7	152.66	180.16	149.32	190.35	139.95	133.88	167.35	147.51

Building Charchterstic	Unit	B46	B47	B48	B49	B50
Shape factor (SF)	$[m^{-1}]$	0.52	0.54	0.53	0.55	0.71
Charcterstic Length (lc)	m	1.94	1.84	1.88	1.81	1.4
Relative compactness (Rc)	-	0.73	0.78	0.57	0.8	0.96
Window to Wall ratio WWR	[%]	22.11	12.76	11.92	11.36	18.98
WWRo south equivalent	[%]	17.28	11.55	7.71	8.31	12.14
WWRos south equivalent weighted for shading	[%]	16.3	10.87	7.08	7.84	12.14
Window to Floor Ratio WFR	[%]	18.05	9.27	10.39	12.08	20.38
Thermal Compacntess Ct	[m]	0.45	0.44	0.46	0.49	0.65
Effective Envelope U value	$[W.m^{-2}.K^{-1}]$	1.76	1.79	1.77	1.8	1.93
LEK value	-	152.81	171.85	161.82	161.96	184.58

3.4. Performance Simulation

3.4.1. Software

Meteonorm

Meteonorm software (Version 7.1.3) has the ability to provide annual weather data for any place on earth. It uses the information of available weather stations, in case of absence of such stations, the software uses sophisticated interpolation models between different stations to derive weather data. For the purpose of the current thesis, the software was used to generate weather data file for Gaza Strip.

SketchUp and Open studio

SketchUP (Version 2017) is a 3D modeling computer program used for a wide range of drawing applications. The program was used to create the geometry of each building. The program provides an easy to us interface which allows for importing and exporting to various other programs. The Open Studio plugin within this software was used to create a thermal model using the creating geometry. Building surfaces, thermal zones and shading objects were all created using this plugin. The plugin also provides the possibility to export the created model to the energy simulation software.

Energy Plus

EnergyPlus™ (Version 8.9) is a whole building energy simulation program that engineers, architects, and researchers use to model both energy consumption—for heating, cooling, ventilation, lighting and plug and process loads and water use in buildings. Based on the weather data provided by Meteonorm software, EnergyPlus™ was used to run annual simulation to calculate the indoor temperature values and/or energy consumption of each building. Additionally, the software provides outputs to a text file in a form of tables. Those output files were also used to extract the basic geometrical and material related properties of each building envelope.

3.4.2. Input parameters

Location and Weather data

The location has been fixed for all of the simulations. Gaza's geographical coordinates are 31° 30′ 5.8″ N, 34° 28′ 0.2″ E, 31.4, 34.3, with an elevation of reference place used for simulation 14 m.

Gaza Strip in Palestine is considered a transition zone between the coastal area wetlands and the dry desert region (Sinai desert in the south-west and Negev desert in the southeast). It is located in hot humid region on longitude 340 26’ east and latitude 310 10’ north. The climate in the Gaza Strip is mild rainy in winters, and hot dry in summers subject to drought. Temperatures are generally high with a daily average of 24°C in summer (from May to August) and 15°C in winter (from November to February). However, the daily average maximum temperatures are 27° C in summer and 19° C in winter, whereas the daily average minimum temperatures are 21° and 11° C in summer and winter respectively. The average number of yearly sunshine hours is 2863, and the sun shines in 300 days a year. The daily average solar radiation on a horizontal surface is about (222) W/m^2. The average relative humidity ranges between 65% in winter and 73% in summer, with September and October the most humid, whereas, January and February are the less humid. Rain falls only in winter with a yearly average of about 271.5 mm (Muhaisen and Dabboor 2015).

Weather parameters are some of the most important factors that influence the load and energy demand on buildings. For whole building energy simulations, a suitable weather file is a major component that allows reliably analysis of energy savings from energy management practices and retrofits. Due to the unavailability of a weather data file for Gaza strip within the Energy Plus weather files database, a weather data file had to be created. For this purpose, Meteonorm software was used to create weather data for Gaza Strip and the file was later used in simulations. Meteonorm uses sophisticated interpolation models between different stations to derive weather data for any place with no weather stations, which allows for a reliable calculation of solar radiation, temperature and additional parameters.

The created weather data were compared to the average monthly temperatures provided by the Palestinian code of energy as shown in Figure 4. The slight increase of temperatures; especially in the summer period in the data provided by Meteonorm in comparison to the data provided by the Palestinian code refers to the fact that Meteonorom calculates the temperatures based on the period 2000-2009, while the data available in the code are from 2004.

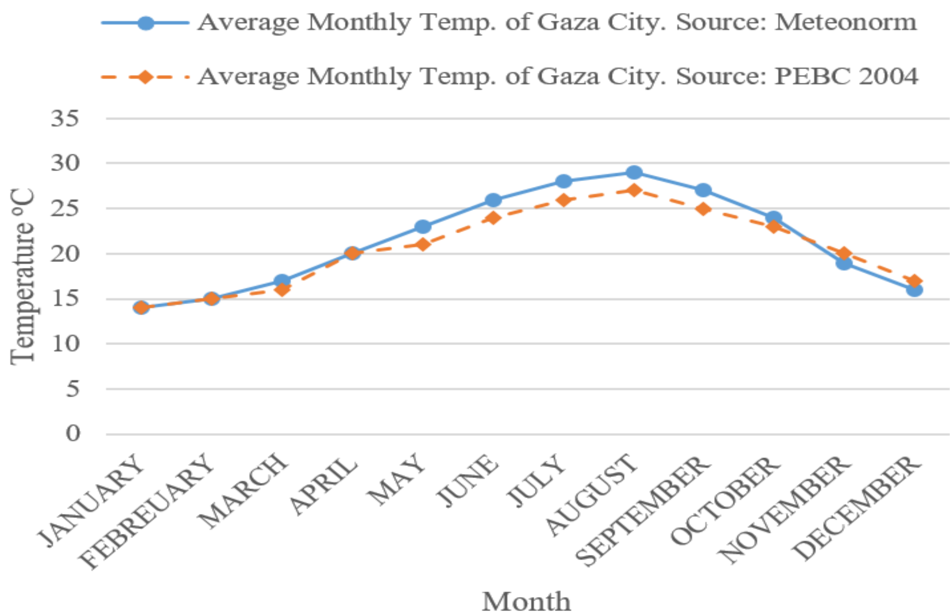


Figure 4 Weather data of Gaza City developed using Meteonorm software compared to Weather data mentioned in the Energy Building Code

Thermal properties of building components

The assumptions regarding thermal properties, namely U-values [W.m^{-2}.K^{-1}] of the primary building components of the building envelope are summarized in Table 7. It should be noted that such assumptions were made constant for all buildings, based on the common construction practices in Gaza Strip. According to Muhaisen (2015), concrete blocks are considered the most widely used building material for walls construction in residential buildings in Gaza strip. It is used either with or without cement plaster as an external finishing surface.

Table 7 Base case building component properties

Building Element	***Construction layers - Outside to Inside - Top to bottom***	***Thickness [m]***	***Thermal conductivity [W.m^{-1}.K^{-1}]***	***U-value [W.m^{-2}.K^{-1}]***
External Roof (Ribbed slab system)	Reinforced concrete	0.08	2.3	2.668
	Hollow block with reinforced concrete	0.17	0.92	
	Plaster	0.025	1.4	
External Wall (Hollow Block Wall)	Outside Plaster	0.025	1.4	1.784
	Block Wall	0.2	0.56	
	Inside Plaster	0.025	0.7	

Building Element	***Construction layers - Outside to Inside - Top to bottom***	***Thickness [m]***	***Thermal conductivity [W.m^{-1}.K^{-1}]***	***U-value [W.m^{-2}.K^{-1}]***
Floor to Ground	Tiles	0.05	1.3	2.338
	Sand with cement	0.1	2	
	Reinforced concrete	0.08	2.3	
	Hollow block with reinforced concrete	0.17	0.92	
Interior ceiling	Tiles	0.05	1.3	1.462
	Sand with cement	0.1	2	
	Reinforced concrete	0.08	2.3	
	Hollow block with reinforced concrete	0.17	0.92	
	Inside Plaster	0.025	0.7	
Interior Wall	Outside Plaster	0.025	1.4	2.028
	Block Wall	0.1	0.56	
	Inside Plaster	0.025	0.7	
Ceiling to unheated	Reinforced concrete	0.08	2.3	2.668
	Hollow block with reinforced concrete	0.17	0.92	
	Plaster	0.025	1.4	
Wall to unheated	Outside Plaster	0.025	1.4	1.784
	Block Wall	0.2	0.56	
	Inside Plaster	0.025	0.7	
Windows (Single glass layer)	Clear glass	0.003	0.9	5.894
Doors (Wooden doors)	Wood	0.0254	0.15	6.68

Regarding the parametric analysis cases for improved insulation of the building envelope, the U-values [W.m^{-2}.K^{-1}] of the enhanced building components are shown in Table 8.

Table 8 Thermal transmittance (U-values) for the three cases

Building component	***U-value [W.m^{-2}.K^{-1}]***		
	Base case (No insulation)	***2nd Case- Improved windows only***	***3rd Case- Medium insulation***
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

Other simulation inputs

For the purpose of this thesis, some other parameters were kept constant for all the buildings. Lighting and equipment loads for all the building are the same. Since all the buildings are small scope residential buildings, it is assumed that they are naturally ventilated. Shading coefficients, measure of solar energy transmittance through windows, g-value was kept constant for all the glazing in the building sample and amounts 0.82 initially. For simplification purposes, shading devices were not taken into account. Table 9 shows assumptions regarding other values required for the simulation.

Table 9 Other simulation input parameters

Input parameters	***Unit***	***Value***
Air-conditioning design temperature	^{o}C	25
Heating design temperature	^{o}C	20
HVAC System	Default Ideal loads air systems	
Infiltration rate	h^{-1}	0.2
Ventilations 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	

External shading from neighboring buildings

Gaza strip is considered as one of the most densely areas around the world, it has an area of 365 km^2 with a total population of 1.9 million. Gaza is a highly urbanized region with 74% urban population and with an urbanization rate of 3.1% per annum (United Nations Human Settlements Program 2014). Therefore, the arrangement of residential houses provides the minimal spacing between dwellings.

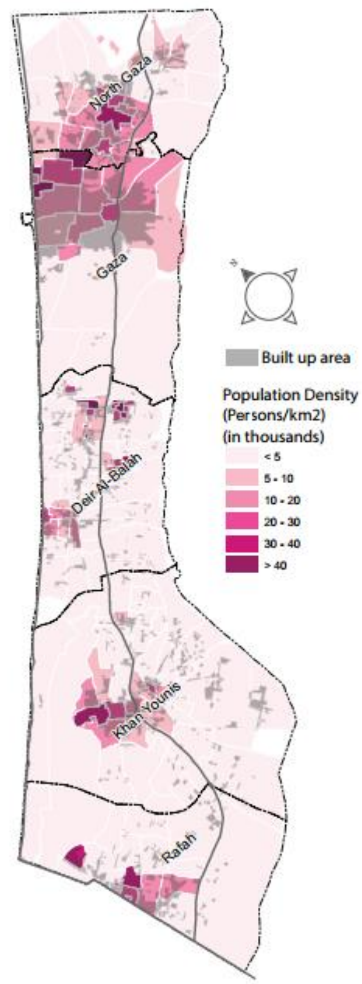


Figure 5 Population density in Gaza Strip (United Nations Human Settlements Program, 2014)

Accordingly, in order for the assumptions regarding the shading buildings to represent the actual situation in such area, the effect of neighbored buildings cannot be ignored. Due to the fact that such data couldn't be obtained from the available data sources, the following assumptions were made:

- For each building, there is a main elevation which faces a main street of width 20 m, each of the other three elevations face a minor street of width 6 m.

- The dimensions of the neighboring buildings were taken equal to those of the main building (Height, width and length).

Figures 6 and 7 clarifies such assumption.

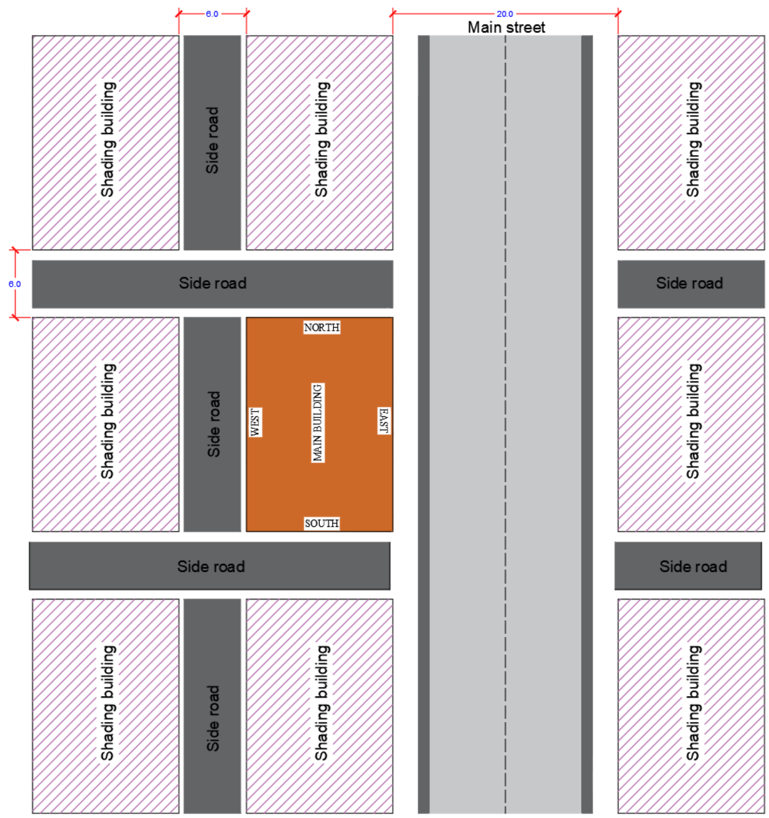


Figure 6 Shading buildings assumption

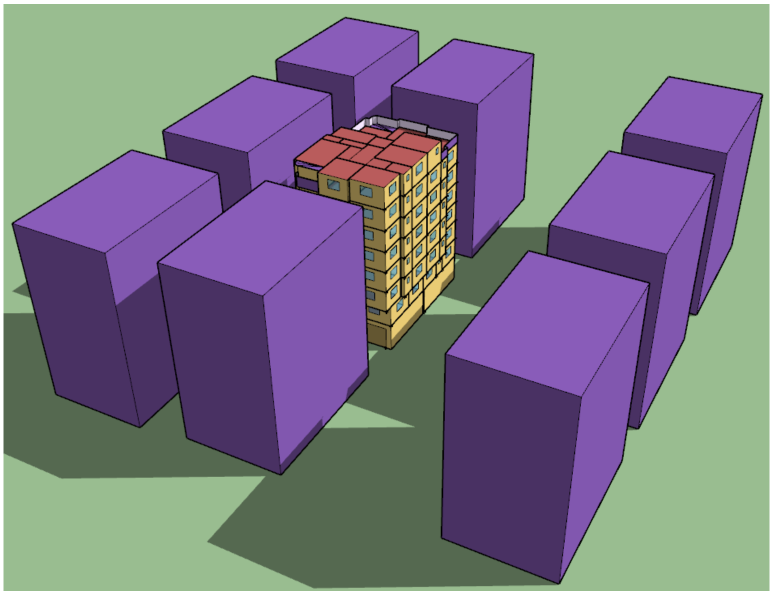


Figure 7 Shading buildings - 3D - Sketch UP

3.5. Descriptive building variables

According to Mahdavi and Gurtekin (2002), building design variables capture either geometric or non-geometric (semantic) information on the building. There are many variables that could contribute to the energy consumption within a building. Variables related to occupant behavior, mechanical and electrical systems, control systems, building envelope, building geometry, site environment, building management or demographics could all be involved.

In this study, the variables examined have been limited to those related to the building geometrical and material properties. Such variables have been proved in the research to affect thermal performance indicators of a building. Additionally, variables that would normally be expected to have the greatest effect on the variation in energy consumption were investigated.

design variables that are analyzed and annotated as significant are finally separated in following categories shown in Table 10.

Table 10 Building design variables

Physical properties of the building envelope	
Shortcut	**Description**
V	Conditioned volume [m^3]
A_{cn}	Conditioned floor area [m^2]
A	Thermal building envelope area [m^2]
A_w	Window area [m^2]
A_{wall}	Area of wall [m^2]
Form factors	
C	Compactness (German "Kompaktheit" or surface area to volume ratio [m^{-1}]
RC	Relative compactness
l_c	Characteristic length
Properties of transparent elements of building envelope	
WWR	Window to wall ratio [%]
WWR_{os}	Effective window to wall ratio [%]
WFR	Window to floor ratio [%]
Thermal properties	
U_e	Effective average envelope U-value [$W.m^{-2}.K^{-1}$]
C_t	Thermal compactness [m]
LEK	LEK Value
A_e	Effective envelope area [m^{-2}]

Following is a short description of each variable considered:

1. Shape factor and characteristic length

The shape factor is defined as the ratio between the conditioned volume of a building and the area of its envelope.

Shape factor (SF) = A/V [m^{-1}]

Another commonly used factor to describe such geometrical property is the characteristic length (l_c) which is simply the ratio of the building's volume (V) to its envelope area (A) (Mahdavi et al. 1996).

$l_c = V \bullet A^{-1}$ [m]

Such factors have been used widely in the literature with relation to the energy performance of buildings. For example, the characteristic length is embedded within the OIB-Richline 6 code equation that limits the heating energy demand for newly constructed buildings.

2. Relative compactness (RC)

Mahdavi and Gurtekin (2002) derived the Relative Compactness of a shape by comparing its volume to surface area ratio to that of the most compact shape with the same volume. The most compact shape in geometry is the sphere. Therefore, when the volume to surface area ratio of another shape is compared with the one of a sphere, the following relationship can be established:

$RC \cong 4.84 \bullet V^{2/3} \bullet A^{-1}{}_{Sphere}$

Since buildings have orthogonal polyhedronal shapes, a cube should be used as a reference shape, though the equation becomes as following:

$RC = 6 \bullet V^{2/3} \bullet A^{-1}{}_{cube}$

The relative compactness has been used in the literature for the purposes of predicting energy demand. Pessenlehner and Mahdavi (2003) used such variable to predict the heating demand of buildings located in Vienna.

3. Window to wall ratio (WWR)

Window to wall ratio is one of the most commonly used indicator with regarding to the transparent elements of the building. It represents the ratio between the glazing area and its exterior envelope area. Such factor has a significant effect on the overall energy demand of buildings. Several studies have also proved its influence with regarding to the cooling energy demand (Geekiyanage and Ramachandra 2018, Yu et al. 2017, Yang et al. 2015).

To capture the effect of the orientation and climatic conditions on the WWR factor, a modification is required. Therefore, Ghiassi et al. (2015) developed the effective window to wall ratio, which is defined as the average window to external wall ratio, corrected for orientation, shading and g-value (Ghiassi et al. 2015).

$WWR_e = (\Sigma(WWR_i \bullet A_{walli} \bullet f_{oi} \bullet gi \bullet SVF_i))/(\Sigma A_{walli})$

WWR_e : Effective window to wall ratio

WWR: Window to wall ratio of the building

A_{walli} : Area of the external wall facing a certain orientation (4 Orientations were considered)

f_{oi} : Correction factor for the orientation. In this study, this factor would be obviously dependent on the orientation of the main street of the building. The values were calculated according to the annual solar radiation values for different orientations based on a simulation of a representative building of the sample in Energy Plus software. The values are shown in Table 11.

Table 11 WWR Orientation factor (f_{oi})

Main street orientation	**Window orientation**			
	North	**South**	**East**	**West**
	South equivalent factor			
North	0.56	1	0.78	0.78
South	0.27	1	0.51	0.51
East	0.41	1	1.21	0.77
West	0.43	1	0.77	1.2

g_i: g-value of window

SVF_i: Value of the sky view factor on a point on the ground close to the building's façade. This value is used as an approximation of the shading factor, to account for the impact of the surrounding obstructions in reducing solar gains (Ghiassi et al. 2015).

To account for the shading caused by the balconies, which are parts of the existing buildings structure and cannot be ignored, a new factor (Shading Factor – S_{fi}) was added, which is also based on the annual solar radiation on windows taking into account the height and width of the shading element, and is also based on simulations run on Energy Plus software for a representative building. The values of the shading factor are shown in Table 12.

Table 12 WWR shading factor (S_{fi})

Main street Orientation	*Balcony height (h) [m]*	*Horizontal overhang shading/Balconies depth (D) [m]*						
		0.2	***0.4***	***0.6***	***0.8***	***1.0***	***1.5***	***2.0***
East	***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*
West	***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*
South	***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*
North	***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*

To fit the purpose of this study, the g-value of the windows was set constant for all of the buildings in the sample. However, the shading factor of balconies (S_{fi}) was used to account for shading caused by balconies (horizontal components). Therefore, the effective window to wall ratio was calculated using the following equations:

- Window to wall ratio weighted to orientation:

$$WWR_e=(\Sigma(WWR_i \bullet A_{wall,i} \bullet f_{oi}))/(\Sigma A_{wall,i})$$

- Window to wall ratio weighted to orientation and shading:

$WWR_{os}=(\Sigma(WWR_i \cdot A_{wall,\,i} \cdot f_{oi} \cdot S_{fi}))/(\Sigma A_{wall,\,i})$

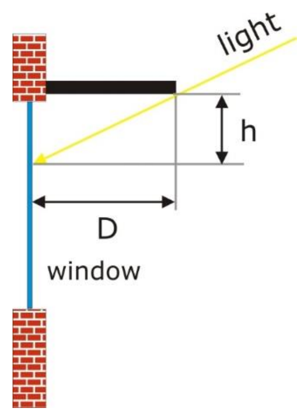


Figure 8 Shading factor parameters

4. Window to floor ratio (WFR)

Window to Floor represents the ratio between the glazing area of the envelope and the total floor area. This factor is commonly investigated in terms of daylight factor and illumination (Nedhal et al. 2016). However, Al-Tamimi and Fadzil (2016) showed that such factor can affect cooling energy of buildings. Additionally, Amaral et al. (2015) showed that WFR correlates with the cooling degree hours, although it varies significantly according to orientation. For the purpose of this research, this variable would be put under test with regarding to the performance indicators.

$WFR= (\Sigma A_{w,\,i}) /(\Sigma A_{cn,\,i})$

All the variables introduced above only capture building geometry or some aspect of build form, but do not include any of the thermal properties. Therefore, the following variables try to capture some of the thermal properties of the building envelope and built form.

5. Average effective envelope U-value (U_e)

U-value is a measure of the heat transfer in a building component construction and describes how well a building element conducts heat or the rate of transfer of heat (in watts) through one square meter of a structure divided by the difference in temperature across the structure [$W.m^{-2}.K^{-1}$]. Such factor does not account for the surrounding environment.

Ghiassi et al. (2015) developed the average effective envelope U-value indicator, which is defined as the average U-value of heat emitting building enclosures weighted by the area of the respective building components and corrected for adjacency relationships.

$U_e = (\Sigma (U_i \bullet A_i \bullet f_i))/(\Sigma A_i)$

U_e : Effective average envelope U-value.

U_i: U-value of a building component.

A_i: Area of heat emitting building components

f_i : Temperature correction factor which is based on the position of the heat emitting enclosure with relating to the surrounding conditions (ground, outdoor space, unheated space, …). The values are taken from the ÖNORM B 8110-6 standards and are shown in Table 13.

Table 13 Temperature correction factor (f_i) (ÖNORM B 8110-6)

Building component	**f (temperature correction factor)**
Wall to outside air	1.0
Wall to unconditioned space	0.5
Floor to ground	0.5
Flat roof	1.0
Floor to outside	1.0
Ceiling to unheated	0.5
Windows	1.0
Doors	1.0

6. Thermal Compactness (C_t)

Thermal compactness is defined as the ratio of heated volume to thermally effective envelope area, which is the sum of areas of heat emitting building elements, corrected for adjacencies (Ghiassi et al. 2015).

Thermal effective envelope area (A_e) is defined as the sum of heat emitting building components; corrected for adjacency.

$A_e = \Sigma A_i \bullet f_i$

$C_t = V/(\Sigma A_i \bullet f_i)$

7. LEK Value

The LEK variable captures both the geometric and material related properties of the building envelope.

The LEK (Lines of European K-values) establish a relation between the characteristic length of a building and the mean heat transfer coefficient of the building envelope based on the following equation, and assuming c_2=0.5 c_1 = LEK • 300^{-1} (Panzhauser 1993, ÖNORM Vornorm B 8110-l 1994).

$U_{max} = c_1+c_2 \bullet V \bullet A^{-1}$

Therefore, the LEK concept can be defined in terms of the following equation:

$LEK = 300 \bullet (U/(2+l_c))$

The LEK value is a measure of the thermal quality of a building, but it is rarely used because of some weaknesses. The weakness assessment of such criterion is that ventilation losses, internal and solar gains are not taken into account. However, this indicator would be also put under test for the purpose of this study.

3.6. Summer Overheating Inputs and Indicator

3.6.1. Inputs

Initially, the building sample was tested for overheating assessment. All of the simulation inputs mentioned previously were considered, except the following:

- Ideal air system for heating or cooling loads (Mechanical systems): For the purpose of simulating buildings in passive cooling/heating state, the system was removed.
- Ventilation rate: the air change rate was increased from 0.4 hr^{-1} to 3 hr^{-1} to account for the cross natural ventilation state, which exposes the building to excessive air change rate per hour.

"*For cooling calculations, the ventilation rate is set equal to the hygienic ventilation flow, which is lower than the intensive ventilation flow rate considered for the overheating indicator. This reflects the different user behavior. If a cooling system provides comfort, the building users will not normally recur to intensive ventilation*" (Laskari and Santamouris 2010, p. 4).

3.6.2. Indicator

Pessenlehner and Mahdavi (2003) defined the overheating index (OHI_a) [$Kh.a^{-1}$] as the sum of hourly temperature differences between the room temperature and an overheating reference temperature (27^{o}C during day and 25^{o}C in the night). Such reference temperatures are defined according to the ÖNORM B 8110-3 (1999) standards. Similar threshold values are also specified in the CIBSE (20006) standards, which specify discomfort temperature thresholds for overheating in non-air-conditioned buildings of 28^{o}C (except for bedrooms where a lower threshold of 26^{o}C is specified).

The used indicator is annual, however the values above the reference temperature outside the summer term are minimal. The chosen indicator represents a simple static method that could be easily understood by architects, designers and engineers.

The day interval is assumed from 07:00 AM to 23:00 PM. Accordingly, the remaining period of represents the night interval.

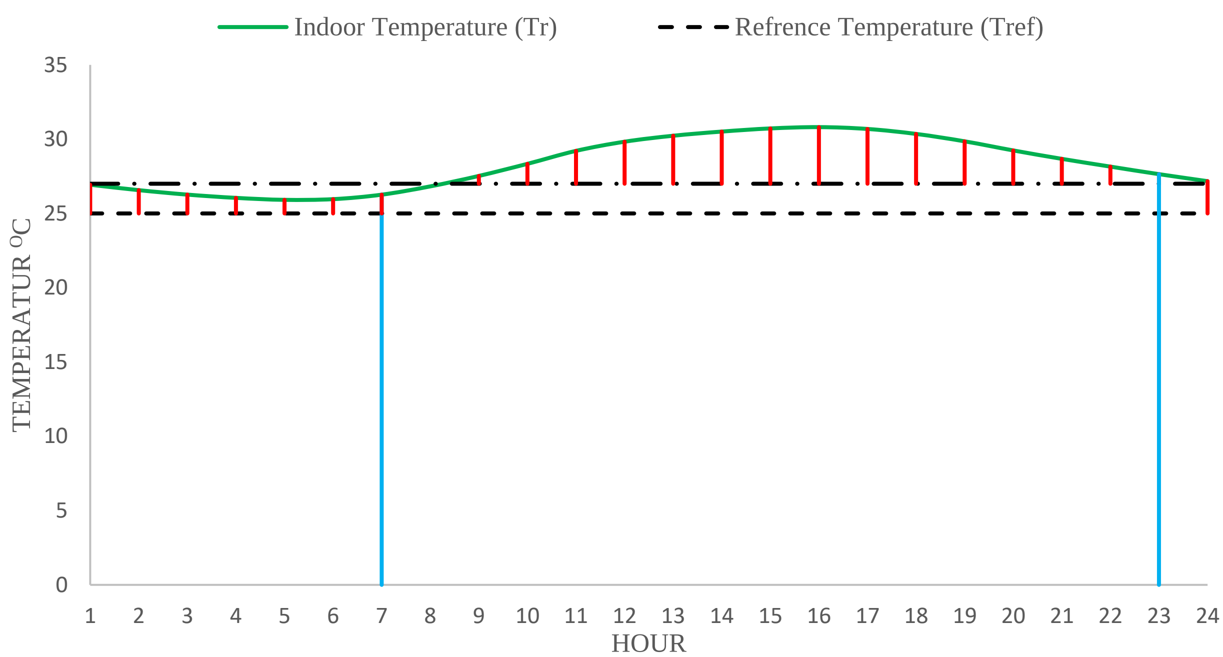


Figure 9 Calculation method for Overheating index indicator (OHI_a) [$Kh.a^{-1}$]

If $T_r > T_{ref}$ Then $OHI_a = \Sigma (T_r - T_{ref})$

T_{ref} = 25 ^oC (Night Interval)

T_{ref} = 27 ^oC (Day Interval)

This indicator represents the exceedance of a fixed threshold during occupied and non-occupied hours. To account for the variations in areas of different zones in the building, the value of OHI_a was weighted to the area of each respective zone.

Therefore, the OHI_a was calculated according to the following equation:

$OHI_a = ((\Sigma (T_r - T_{ref})) \cdot A_i) / (\Sigma A_i)$

T_{ref} = 25 ^oC (Night Interval)

T_{ref} = 27 ^oC (Day Interval)

A_i : Area of each zone

Although most of the existing literature concerning the overheating assessment of passive-cooling buildings, and specially in residential buildings is based on the adaptive comfort model range, where the percentage of hours when the operative temperature of the house is higher than the upper boundary of the adaptive comfort models range is represented, however, and for the purpose of this study, the Kelvin hours overheating indicator, which is initially developed by (Pessenlehner and Mahdavi 2003), and is principally based on the exceedance of a fixed threshold, would be put under test versus all of the descriptive design variables. As such indicator represents a static and simple methodology to asses overheating occurrence in buildings.

3.7. Statistical analysis

Statistics is a set of procedures for gathering, measuring, classifying, computing, describing, synthesizing, analyzing and interpreting systematically acquired quantitative data.

SPSS (Statistical Package for the Social Science) Software will be used to analyses the collected data of buildings as well as the output data of Energy Plus. SPSS Software has the ability to produce charts, plots and tables for any type of data. SPSS is one of the most popular statistical packages which can perform highly complex data manipulation and analysis with simple instructions. The following fields of statistical analysis are examined:

- Descriptive Statistics,
- Pearson's Correlation (Continuous data, parametric statistics), and
- Numerical outcome prediction – Multiple linear regression.

Descriptive statistics provides both numerical and graphic measures to summarize a collection of data in a clear and understandable way. It also helps to simplify huge amount of data in a sensible way, and reduces lots of data into a simpler ways of interpretation. Accordingly, there are two basic methods: numerical and graphical. The numerical approach allows for calculating and computing statistics such as the mean and standard deviation. Such statistics deliver information concerning the average. Whereas plots contain detailed information about the distribution of data. For the purpose of identifying patterns in the data, graphical methods are preferred over numerical methods. However, numerical methods can be considered to be more precise and objective. Though, it is useful to use the both methods as they complement each other (Jaggi n.d.).

To describe a data set, measures of central tendency and measures of variability are commonly used. Measures of central tendency include the mean, median and mode, while measures of variability include the standard deviation (or variance), the minimum and maximum values of the variables (Trochim and Fabbri 2006).

Pearson’s product moment correlation coefficient, or Pearson’s r was developed by Karl Pearson (1948) from a related idea introduced by Sir Francis Galton in the late 1800’s. In addition to being the first of the correlational measures to be developed, it is also the most commonly used measure of association. All subsequent correlation measures have been developed from Pearson’s equation and are adaptations engineered to control for violations of the assumptions that must be met in order to use Pearson’s equation (Burns and Grove 2005, Polit and Beck 2006).

A Pearson's correlation attempts to draw a line of best fit through the data of two variables, Pearson’s coefficient “r” is a measure of the linear relationship between two interval or ratio variables, and can have a value between -1 and 1. By squaring the correlation coefficient r, the total variability in Y can be accounted for after regressing Y on X; r^2 (Coefficient of determination) can be considered to be a measure of the strength of the linear relationship. The resulting value when multiplied by 100 results in a percent variance, e.g., if the correlation coefficient for X and Y is r = .50, then $r^2 = (.50)\ (.50) = .25 = .25(100) = 25\%$. X explains 25% of the variability in Y (Zar 1999).

The advantage of using Pearson’s r is that it is a simple way to assess the association between two variables; whether they share variance, if the relationship is positive or negative, and the degree to which they correlate. The disadvantages of using Pearson’s r is that it cannot identify relationships that are not linear, and may show a correlation of zero when the correlation has a relationship other than a linear one. Additionally, the types of variable that can be evaluated are limited.

When performing such correlation, some assumptions has to be made (Markovic 2017):

- Two variables must be measured on an interval or ratio level; they have to be continuous.
- There should be a linear relation between the two variables.
- Significant outliers, which represent points within the data that don not follow the usual pattern should be identified and excluded.
- Variables should be approximately normally distributed.

All of the chosen design variables will be tested against the overheating indicator. Accordingly, the best fitting variables, which show to have the most impact on that indicator, would be used for the regression analysis. This step would test the possibility for prediction of the overheating indicator based on some of the analyzed variables. That should be done via the method of regression analysis.

Regression is a statistical technique to determine the linear relationship between two or more variables. Regression is primarily used for prediction and causal inference. Regression analysis is used to analyze the relationship between an independent variable and one or more dependent variables.

In its simplest (bivariate) form, regression shows the relationship between one independent variable (X) and a dependent variable (Y), as in the formula below:

$Y = \beta_0 + B_1X + u$

The magnitude and direction of that relation are given by the slope parameter (B_1), and the status of the dependent variable when the independent variable is absent is given by the intercept parameter (β_0). An error term (u) captures the amount of variation not predicted by the slope and intercept terms. The regression coefficient (R^2) shows how well the values fit the data.

*"If the goal is a prediction, or forecasting, or error reduction, linear regression can be used to fit a predictive model to an observed data set of y and X values. After developing such a model, if an additional value of X is then given without its accompanying value of y, the fitted model can be used to make a prediction of the value of y. As X variable, or independent predictors variable, building design indicators should be tested one by one" (*Markovic 2017, p.41). As a dependent variable, or outcome variable, whose value is expected to be predicted, overheating indicator would be used.

Based on R^2 values, and fitted R-value, as well as the significance level p, the best fitting model would be chosen. That should be done by finding set, of most probably two variables, and based on the line of best fit; the regression equation would be derived. Some additional steps would be done in order to analyze the consistency and credibility of the outcome of this step. Variables would be examined for the possible errors, the integrity of linearity and constant variance, and lack of multicollinearity among predictor variables.

The same variables used for the regression analysis would be then put under test for another indicator; namely the cooling energy demand. This step would be done after conducting correlation analysis between the overheating index and the cooling energy demand of the buildings' sample, based on the expectation that both variables would correlate significantly. Accordingly, parametric analysis would be conducted afterwards to create different perspective indexes.

The data obtained in this step would help understand the thermal quality of the sample and how increasing and decreasing values of design variables affects the performance of the building. The final goal is to create a simple prescriptive index, based on analyzed sample, using results of both building performance simulation and multiple regression equation; with a table of different values for chosen most significant variables. This index should serve as a guideline for energy efficient design of a building in early stages of design. Furthermore, the index would provide information, which simple set of values for design variables, gives a certain level of cooling demand energy scale. Following this prescriptive index would lead to an energy efficient design of a building, with information on expected building's thermal performance, and would spare time and costs related to the method of building performance simulation.

4. Results and Discussion

4.1. Overview

All buildings from the sample were analyzed and obtained data were evaluated. Results of this research are presented in following chapters. The first section contains results for overheating index which are obtained after processing the temperature values based on the simulation results in EenrgyPlus. Firstly, overheating index of buildings in passive mode as the performance indicator, would be taken as a benchmark for quality of thermal design of the inspected building sample. The second part presents an evaluation of correlation of each design variable with calculated overheating index. Consequently, the data obtained in previous two steps were used to create a regression equation, which gives an opportunity to estimate the overheating index using a set of independent variables.

Furthermore, the relationship between two performance indicators for the same building sample is investigated, namely the overheating index, which represents buildings under passive cooling mode, and the annual cooling energy demand, which represents buildings running under mechanical system (HVAC). Consequently, one performance indicator will be used for further investigation.

After this, the properties of thermal envelope of building sample are enhanced, and two new cases of the same sample are created, the overall sample is extended to 150 buildings during this case. The effect on these changes on the cooling demand as well as the chosen design variables is investigated.

Based on the calculated cooling demand with the help of cooling demand values estimated from three regression equations, enough data has been assembled to predict the energy efficiency category of a design for different values of input design variables.

4.2. Annual Overheating Index calculation

As described above, the overheating index will be first used as an indicator for the performance based approach of buildings in case of passive cooling mode.

Figure 10 shows the calculated overheating index for the sample, the minimum value calculated is 9838.76 $Kh.a^{-1}$, while the maximum value is equal to 16449.43 $Kh.a^{-1}$ and the average value is 12138.28 $Kh.a^{-1}$. The standard deviation is equal to 1692.96.

For the purpose of providing a better interpretation of the above numbers concerning the overheating index, which generally represent high occurrence of overheating during the year. The result of building number 30, which has an overheating index of 12320 $Kh.a^{-1}$, would be interpreted in another way. In terms of the exceedance of a fixed threshold, which is 27^{o} during day and 25° in the night. Accordingly, as the mentioned building has three zones, for each one the percentage of hours exceeding the temperature threshold throughout the year is 44.65% (3911 hours), 40.64% (3560 hours) and 31.94% (2798 hours) respectively, which represents a high occurrence of overheating throughout the year. If such values are compared with the previous CIBSE (2006) approach which requires the following thresholds to be met:

- Not more than 5% of the occupied hours exceeds 25 °C.
- Not more than 1% of the occupied hours exceeds 28 °C.

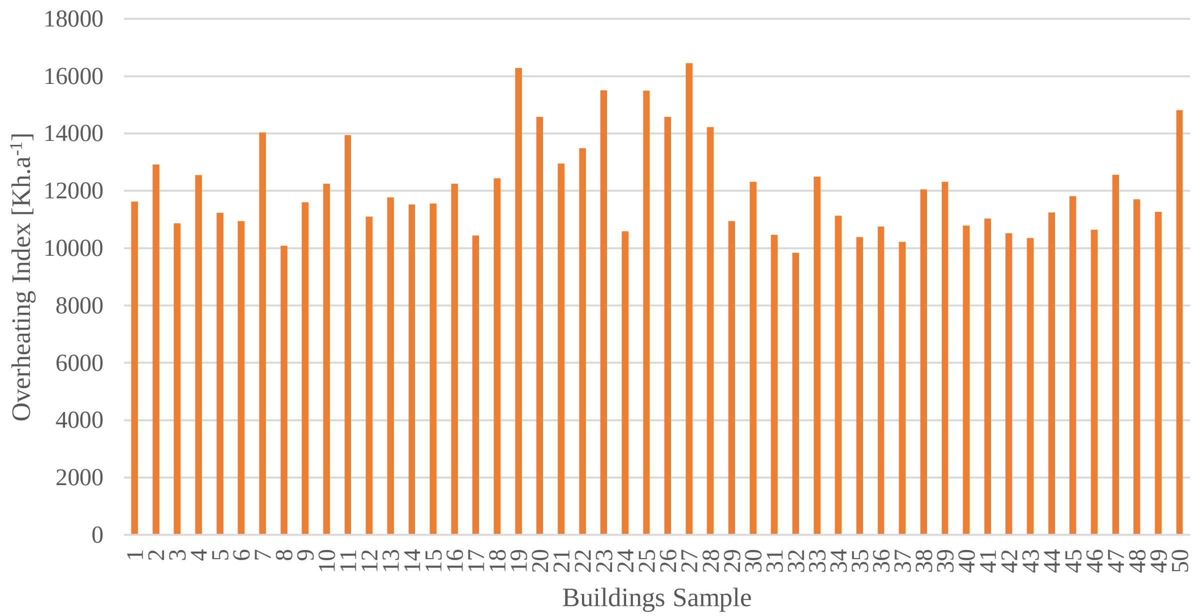


Figure 10 Calculated Overheating Index for Building Sample

It is then evident that the current buildings involve severe overheating conditions for occupants. Therefore, it can be concluded that the current construction practices in such region does not ensure adequate indoor comfort levels, which necessitates the need for enhancements.

The high occurrence of overheating in the dwellings refer to several reasons. Including the weather condition in such area which is between the coastal area wetlands and the dry desert region. Such weather includes larger temperature variations. Therefore, the heavy weight and non-insulated thermal mass of the investigated buildings, makes the regulation of the indoor temperature highly influenced by the variation of the outside temperature during the passive cooling mode. As all of the buildings are not provided with insulation layer, there occurs a great amount of heat exchange with outside. Therefore, thermal mass becomes less efficient.

Indeed, the importance of buildings' thermal mass in stabilizing indoor temperature is crucial. However, its potential is maximized when coupled with natural ventilation strategies, as alone it is not sufficient to keep the indoor environment within comfort thresholds defined by the norms (Brambilla et al. 2018).

Figure 11 represents the variation of the indoor temperature with relation to the outdoor temperature for a given day of the year (15th – July) for building 3. It shows clearly that indoor temperature values follow the pattern of the outdoor temperatures, but with higher values during the day.

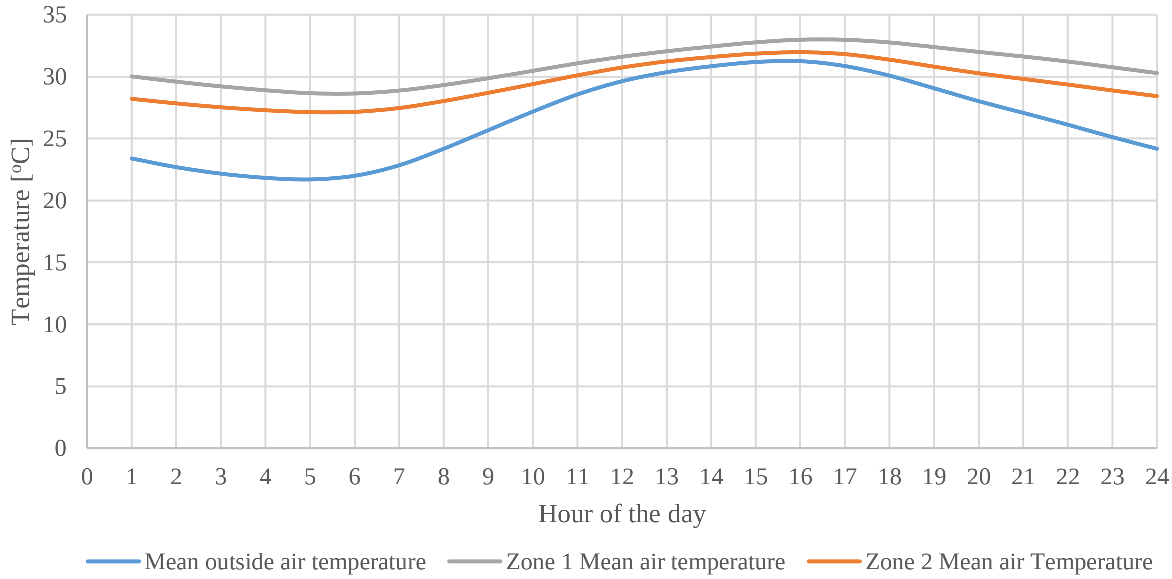


Figure 11 Variation of Indoor temperature with outdoor temperature

4.3. Descriptive design variables

Correlation between building's shape factor which represents surface area to volume ratio and Overheating index (Figure 12) is good, with an R^2 of 0.44 and adjusted R^2 of 0.433. This value indicates that based on chosen sample, 44% of a sample can be explained by this regression model, which has fairly acceptable predictable power. The standard error of estimation is 0.103, this value shows the average distance of data points from the fitted regression line. Based on the sample it can be noticed that the more compact the building, the lower the calculated overheating index. More compact buildings result in lower compactness value; therefore, this is a strong positive linear relationship. The shape factor is one of the most important indicators for the quality of the building, and is used in some codes and standards to address energy efficiency of buildings. For instance, China has integrated the shape factor of buildings into its design standard for energy efficiency of public buildings, by stating maximum value of 0.4 (Danielski et al. 2012).

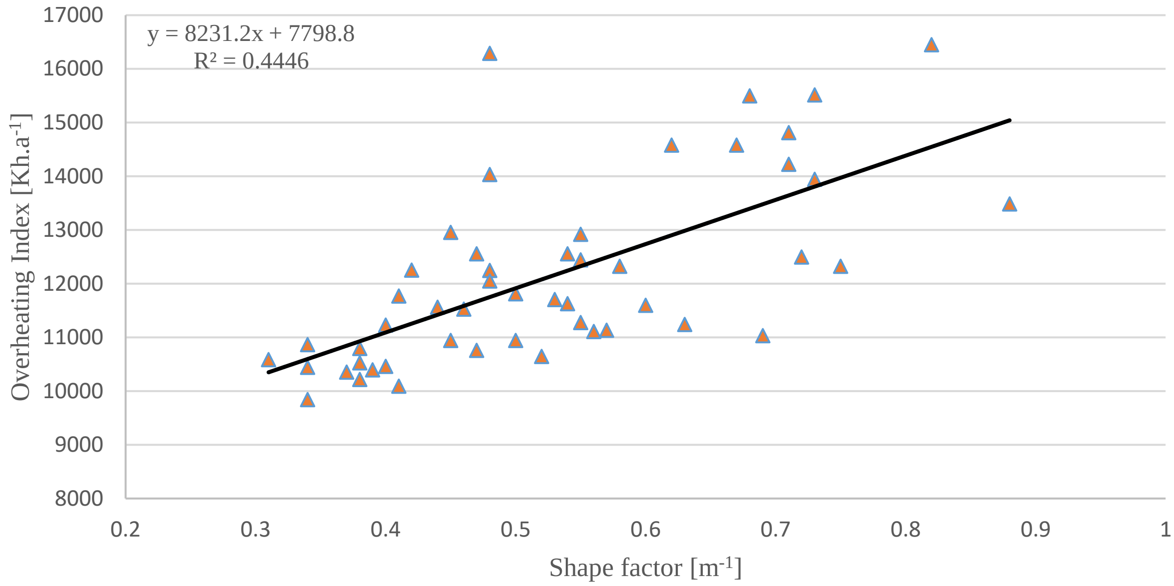


Figure 12 Overheating Indicator Vs Shape factor

Characteristic length (which is another form to express the compactness of the building – reciprocal of the shape factor-) is often used as an indicator in buildings standards, including OIB Guideline 6 which gives a simple formula for calculating heating demand. Figure 13 shows a correlation in the analyzed sample between characteristic length (l_c) and the overheating index. The value of R^2 is 0.42 with fitted R value 0.651. Meaning that correlation is statistically significant. The correlation is fairly high negative or downhill correlation, and as expected from correlation with compactness, buildings with a larger value for characteristic length result in lower overheating index.

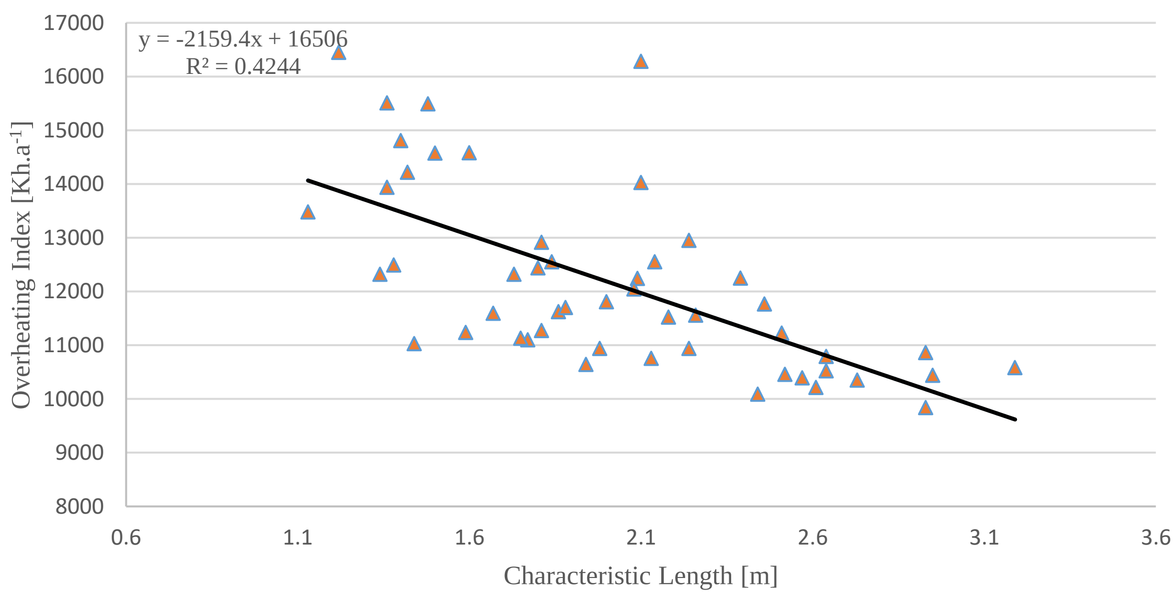


Figure 13 Overheating Indicator Vs Characteristic length

The significance of the compactness of buildings with regarding to its performance is evident, and it is well demonstrated by several studies, it is also commonly incorporated within energy standards. In comparison to studies conducted to analyze the effect of such characteristic on the performance of a buildings, it is noticed that the correlation value in the current study with the chosen performance indicator is lower than expected. Marcovic (2017) study showed that the value of R^2 for similar correlation between characteristic length and heating energy demand is 0.746. Also, Catalina et al. (2011) showed that the impact of building shape factor is more important for hot climates with solar radiation and outdoor temperature values higher.

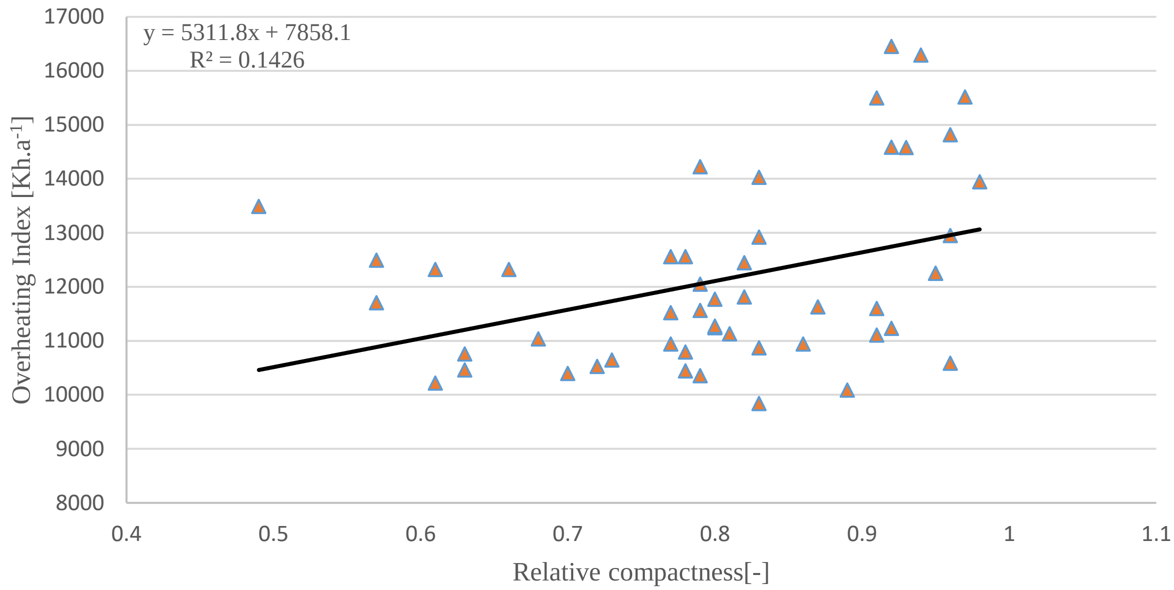


Figure 14 Overheating Indicator Vs Relative compactness

With regarding to the relative compactness variable, it showed weak association with the calculated overheating index, with R^2 value of only 0.142. A better correlation was showed in (Pessenlehner and Mahdavi 2003) study, where the R^2 value was up to 0.59. The reason for this could probably be the insufficient variance of the building sample in this study, as the investigated sample does not include buildings which considered as low compacted buildings.

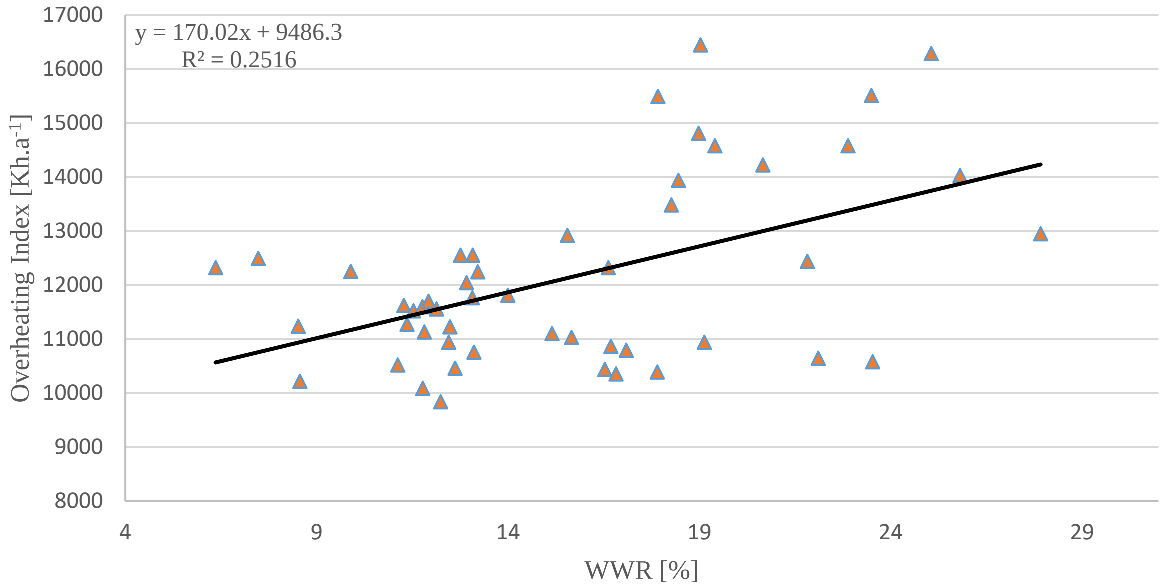


Figure 15 Overheating Indicator Vs Window to wall ratio

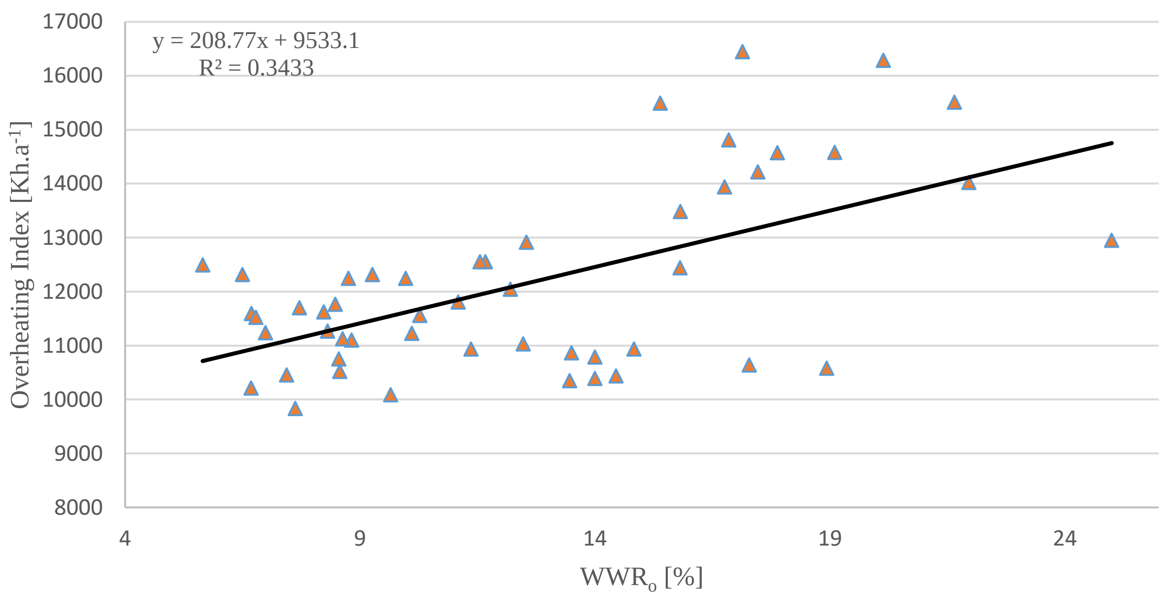


Figure 16 Overheating Indicator Vs WWR weighted to orientation

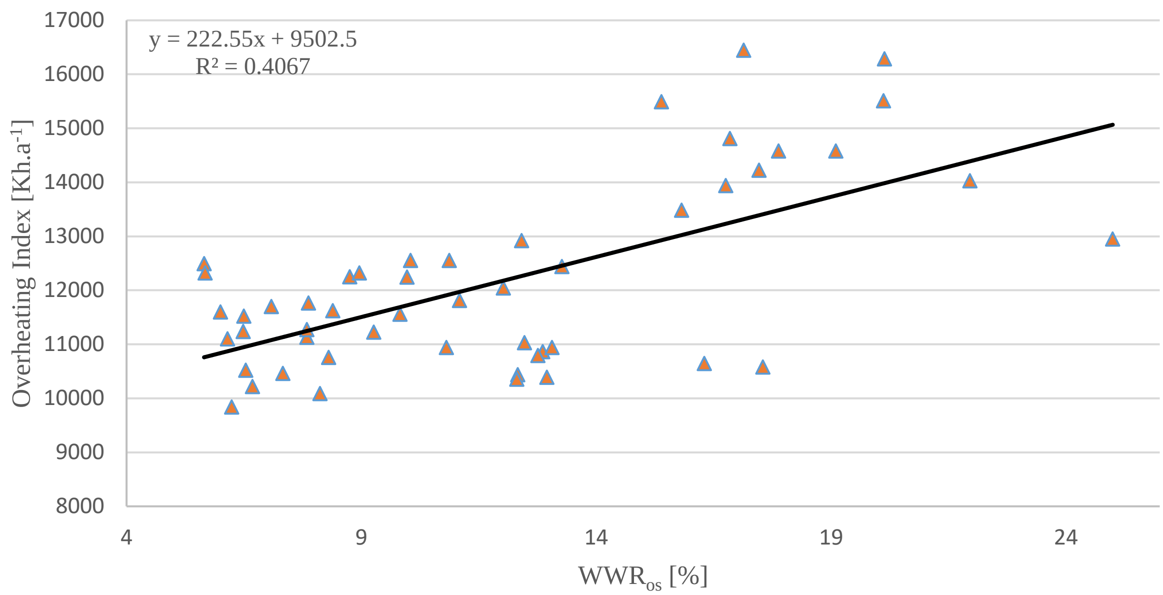


Figure 17 Overheating Indicator Vs WWR weighted to orientation and shading

In terms of properties of transparent elements of building envelope WWR, window to wall ratio variable, the correlation in this case showed a positive linear relationship with the calculated overheating index. The basic WWR variable showed a coefficient of determination (R^2) of 0.252 with the calculated overheating index. The relationship is a positive linear.

When accounting for the orientation factor while calculating the WWR, the correlation improves significantly to 0.407. This shows the significance of the orientation of the glazing components of the building envelope. As the four considered orientations differs significantly in the amount of the annual solar radiation received for each, as it appears in Table 11, though each orientation should be weighted accordingly, therefore, it is evident that accounting for the orientation factor regarding the glazing components would present a better interpretation to this variable.

Finally, the effective WWR, which takes into account the orientation, in addition to the shading factor caused by the external shading components (Balconies, overhangs, …) of the building. This results in improving the correlation value, and the R^2 becomes 0.407.

The range of the Building sample with regarding to this variable is considerably limited, as all of the sample has a low glazing to wall ratio, which is, however, representative for the residential buildings in Gaza Strip. The minimum value for the WWR is 6.63 and the maximum value is 27.92, the average value is 15.6.

The effect of properties the of transparent elements of building envelope in terms of WWR on the performance of buildings is considerable, since the majority of heat loss and solar heat gain through the building envelope is often through the glazing. The correlation shows that the larger the fenestration ratio, the higher the overheating index will be. Since other properties of the glazing could govern the indoor conditions, namely the solar heat gain coefficient (SHGC), such factor will be investigated later in this research.

It is then evident, that accounting for the different orientations of the glazing components, in addition to the shading caused by external shading elements (i.e. Balconies), will provide a better representation of the geometric properties of the glazing components (WWR). Indeed, the significance of such parameter with regarding to the energy performance of buildings can't be overlooked. Goia (2016) showed that the total energy use may increase in the range of 5–25% when the worst WWR configuration is adopted, compared to when the optimal WWR is used.

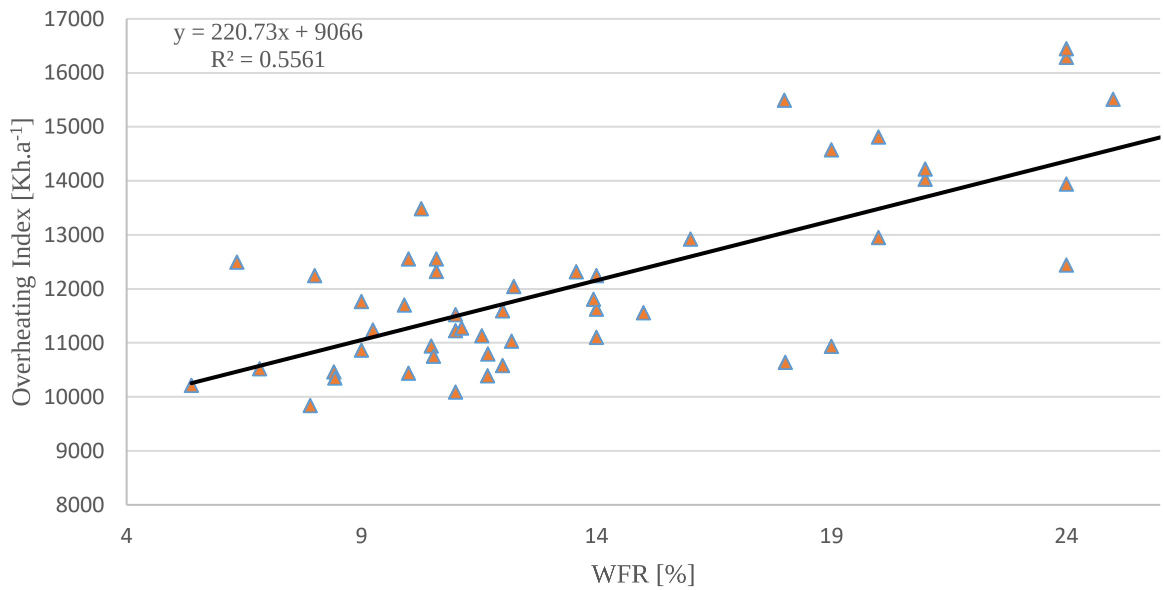


Figure 18 Overheating indicator Vs Window to Floor ratio

Window to floor ratio represents another methodology to express the glazing parts of the buildings, but with relation to the floor area instead of wall area. According to the researcher knowledge, the application of such variable with regarding to the thermal energy performance of buildings is very limited, as it is more commonly used to define visual parameters indoors (i.e. Dyalight factor). However, the variable in this research achieved the highest correlation among other variables, with R^2 of 0.556, which represents a better correlation than the effective WWR (WWR_{os}). The relation is also a positive linear relationship.

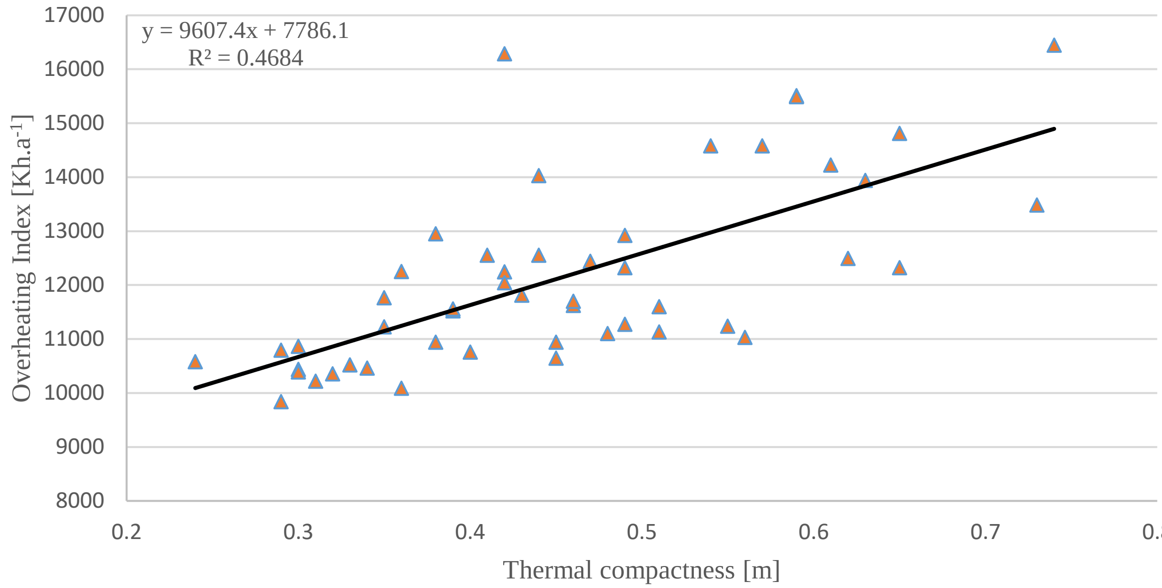


Figure 19 Overheating indicator Vs Thermal compactness

Thermal compactness (Figure 19) shows a good correlation with the overheating index, the correlation value is just above that of the shape factor. Thermal compactness can also be noted as effective characteristic length, where (l_c) stands for the ratio of a building 's volume to its envelope area, so effective characteristic length can be defined as the ratio of buildings volume to envelope area corrected for adjacencies. The indicator has good predictable power with a statistically significant R value of 0.684 and R^2 value of 0.468 with standard error of estimation of 0.08884. The improved value of correlation for the thermal compactness in comparison to the conventional shape factor or characteristic length indicators refer to the fact that such variable takes into account the condition of the surrounding environment with regarding to the thermal envelope area calculation.

With regarding to the average effective envelope U-value, the result didn't report expected correlation as shown in Figure 20. The R^2 value was only 0.147. This may refer to the fact that variance of the average effective envelope U-value within the analyzed sample is not good enough, where the minimum and maximum values are 1.95, 2.4 respectively. As the initial U-values of the building components were assumed based on the common practices in the region, and were equal for all of the buildings sample.

In fact, thermal properties of the building envelope are considered as one of the most influencing factors on the performance of the building. Most of building standards and codes set minimum values for such variable for the building envelope. However, the assumed values don't represent good values according to the Palestinian code of energy, as they represent only the common practices.

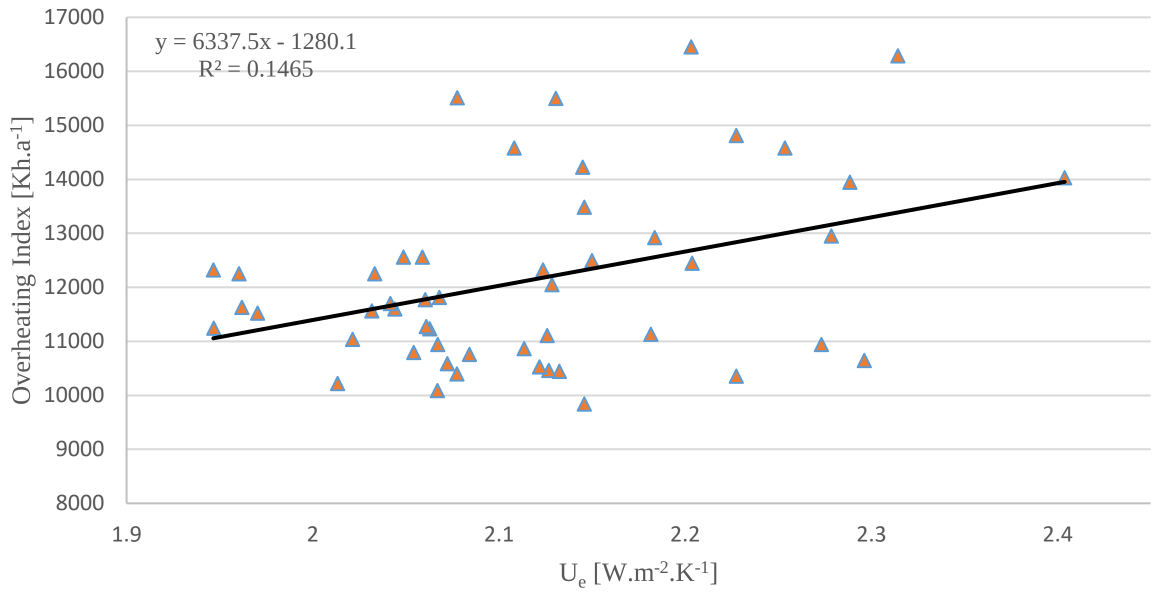


Figure 20 Overheating Index Vs Average Effective Envelope U-value

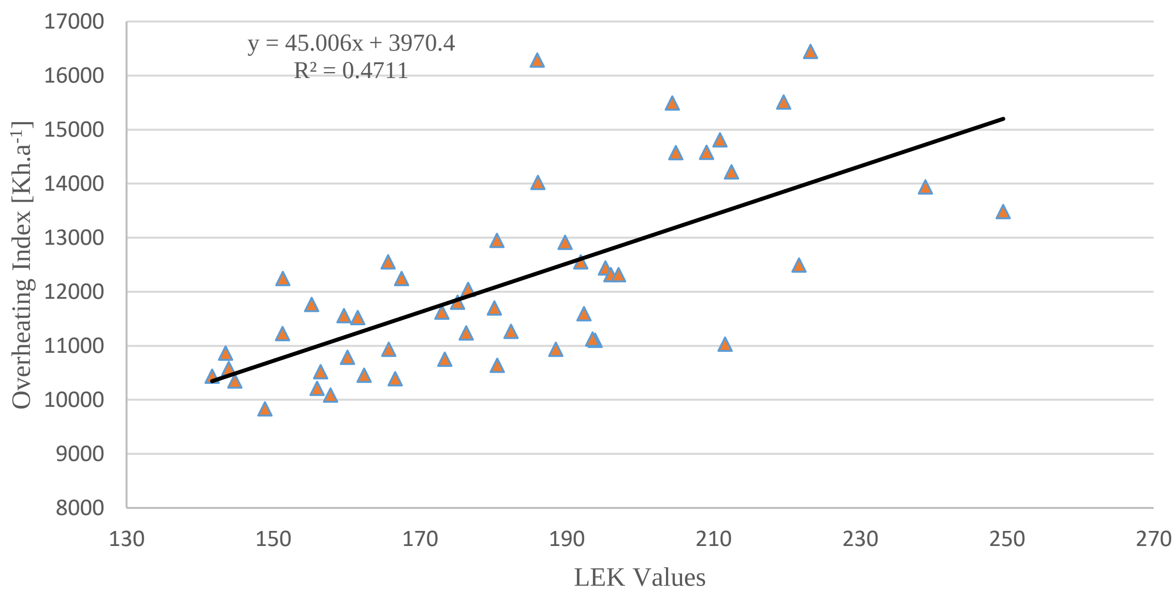


Figure 21 Overheating Index Vs LEK values

Finally, the correlation between the LEK value and the created overheating index was the second best value, with R^2 of 0.471. The LEK combines both the characteristic length of a building and the mean area weighted U-value of the envelope. The correlation value is slightly better than that of the characteristic length and also much better than the average effective envelope U-value alone. The relation is a linear relation where higher LEK values correspond to higher overheating index.

4.4. Multiple regression model for predicting overheating indicator

Energy codes and standards aim to set minimum requirements with regarding to the thermal properties of the building in order to provide the possibility of predicting the performance level of a building during the early stages of the design process. The U-value of the building envelope components is a common property that is normally prescribed. However, several other properties of the building are normally regulated depending on their significance to the performance of the building, which implies that that performance requirements differ drastically between countries.

Based on the analysis of the chosen set of the design variables, and studying their influence on the calculated overheating index, different of variables have been selected to create the regression models. One of the important aspects considered within this step was excluding variables which could be highly correlated, which represents variables that define similar form property. Which means that one can be linearly predicted from the others with a substantial degree of accuracy. Examples of such variables are characteristic length and compactness, they both define similar form property, and therefore both of them cannot be taken into a same set of variables.

Analysis inspected previously showed highest correlation to building performance for WFR, WWR (but for test purpose, only one of them would be validated) and Shape factor, thermal compactness and LEK value. On the other hand, relative compactness and average effective U-value didn't show that much of a correlation, however, thermal characteristics of the building envelope, which are mainly represented in terms of the U-value, are of great importance and all of the prescriptive standards, such as ASHRAE 90.1 and the International Energy Conservation Code (IECC), prescribe maximum permitted values for such variable. Their influence will be investigated later during this study.

Based on regression analysis, a correlation is found to provide the best curve fit between the calculated overheating index and the two parameters: Shape factor (SF) and effective Window to Wall ratio (WWR_{os}).

The shape factor is one of the most important properties of the building envelope, it is commonly used in different standards and codes. For instance, OIB Guidelines 6 sets an equation which is based on the characteristic length (another form to represent the shape factor) for limiting the heating demand of newly constructed buildings. Also, a threshold value of 0.4 is defined within the energy regulations in China. Also, the Window to wall ratio is an important property of the building envelope, especially in hot climates. As it represents the weakest thermal point within the envelope, through which high solar gains could be accompanied, which is a crucial factor in determining thermal performance of buildings within such regions (Ayyad 2011). Such variable is also prescribed, as most prescriptive standards give values for maximum permitted WWR, it goes from 10%, 20% till 40% (Markovic 2017).

The correlation equation shown below can be utilized during the preliminary design phase to assess the impact of building shape and properties of the glazing components for multi-family and apartment residential buildings.

The objective of multiple regression analysis is to predict the single dependent variable Y (overheating index) by a set of independent variables Xi. When having a large database of values, the regression techniques could be applied with success and with good results on the correlation between the model and the analyzed data set.

With two independent variables the prediction of Y is expressed by the following equation:

$$Y' = b_0 + b_1X_1 + b_2X_2$$

Y' is the predicted value, which is the overheating index, while X_1 represents the shape factor (SF) and X2 represents the effective Window to Wall ratio (WWR_{os}). Table 14 shows the coefficients of the created fitting model.

Table 14 Optimal weights of the regression model

Coefficients[a]

Unstandardized Coefficients			Standardized Coefficients		
	Regression coefficient B	Standard Error	Beta	T	Sig.
Constant	6450.359	586.247		11.003	0.000
Shape factor	6779.444	1026.261	0.549	6.606	0.000
WWR_{os}	178.476	29.012	0.511	6.152	0.000

a. Dependent Variable: Overheating index

The regression equation will be as follows:

$$Y' = 6450.359 + 6779.444X_1 + 178.476X_2$$

Table 15 shows that regression model has an R^2 value of 0.692, meaning that 69% of the data is explained by the model. A significance level of the model is significant on 0.05 level with Sigma value for the model being 0.000. The standard error of estimate is a measure of error of prediction, and for this model, it accounts for 958.815.

Model Summary[b]

Table 15 Correlation coefficients

R	**R Square**	**Adjusted R Square**	**Std. Error of Estimate**
0.832[a]	**0.692**	**0.679**	**958.815**

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

b. Dependent Variable: Overheating index

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. Figure 22 shows residuals of fitted model.

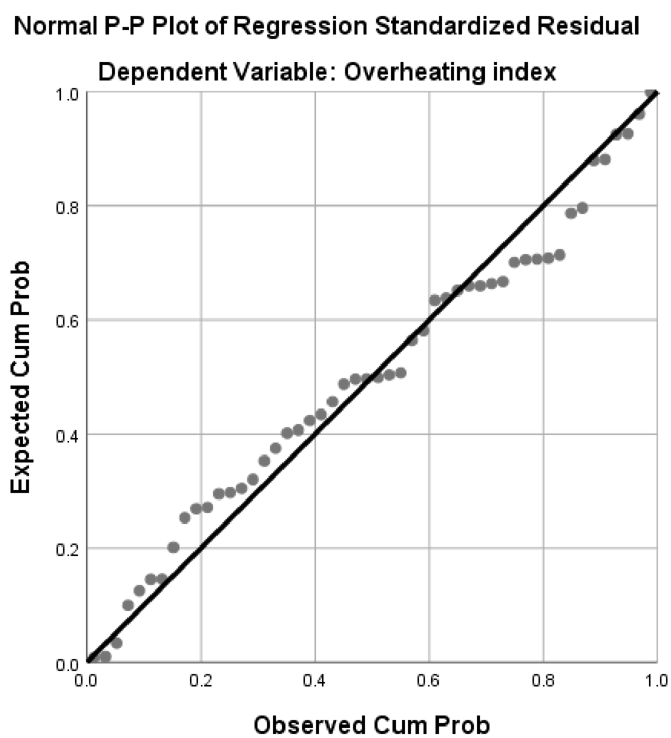


Figure 22 Normal probability plot of regression standardized residuals

Figure 24 shows the relative deviation of individual simulation results for overheating index from the corresponding predictions based on linear regression. Deviations lie between -21% and 18%, with an absolute average error of 5.5% For the purposes of validating the created model, the R^2 value has been checked (Figure 23) within the model and further standard error of deviation has been looked upon.

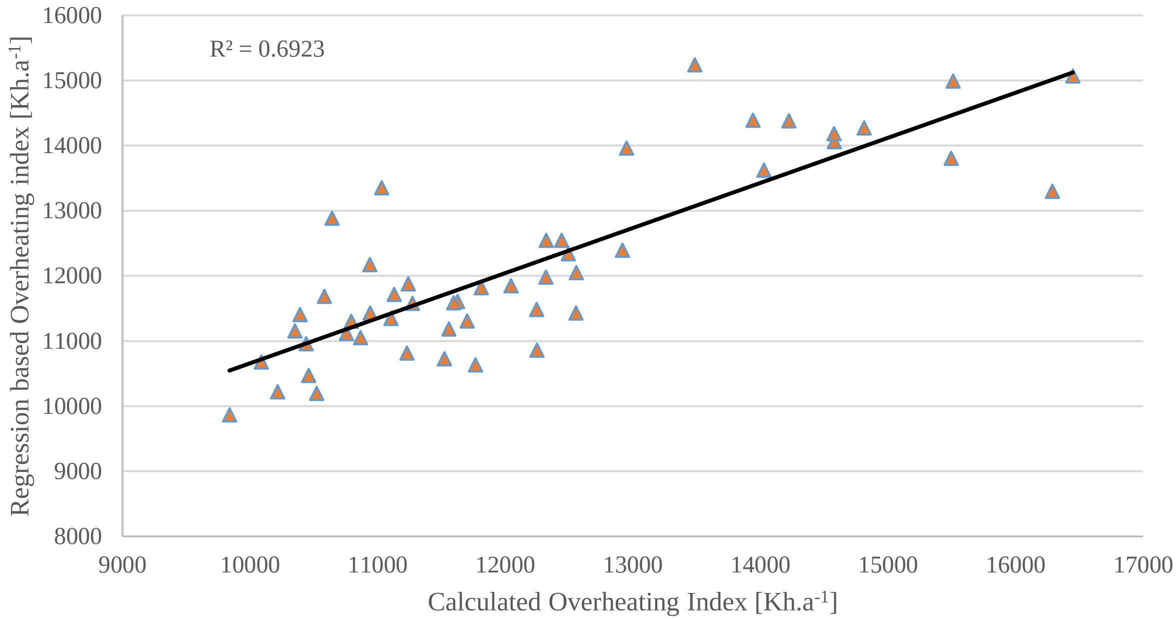


Figure 23 Calculated Overheating Index Vs Regression based overheating index

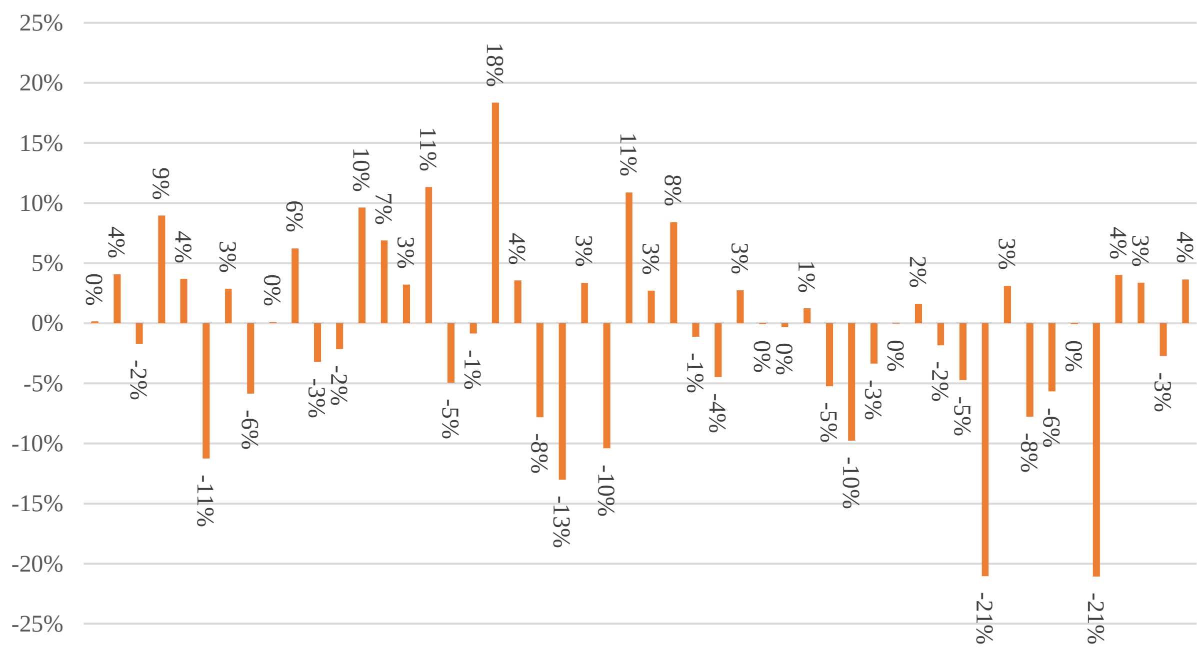


Figure 24 Deviation of regression based overheating index from calculated overheating index

Despite the fact that the created regression model takes into account only two properties of the building envelope, which demonstrated to have the highest effect on the performance indicator. However, other factors have also significant influence on the performance level of a building, including the effective average U-value, which didn’t respond properly due to its limitation in the study.

4.5. Overheating Indicator and Cooling Demand

One of the most important objectives of this research was to prove the possibility of predicting the cooling demand of a conditioned building based on the overheating index of the same building under passive cooling mode. Figure 25 illustrates this relationship and shows a strong correlation between the two performance indicators, with R^2 value of 0.911, which is sufficient enough to provide the possibility of predicting either of the two indicators based on the other one. This shows that the dynamic behavior could be described by using steady-state concepts in this case, which is only dependent on the temperature.

When performing the simulations of the free running buildings, the same zonal distribution for each building was kept the same as performed during the cooling demand energy simulations. Such assumption would result in one value of temperature for each single storey of a building, and would be valid under the assumption of considering that the floor is under cross ventilation state, which involves wind entering through a vent (or a window or door), and allowing air to flow directly through the house and out through an opening on the other side of the home. Such situation considers that inside rooms doors inside the storey are kept opened. Such technique can be a promising passive solution for summer thermal comfort in buildings. It takes advantage of the night temperature of the air to cool the walls of the building**.**

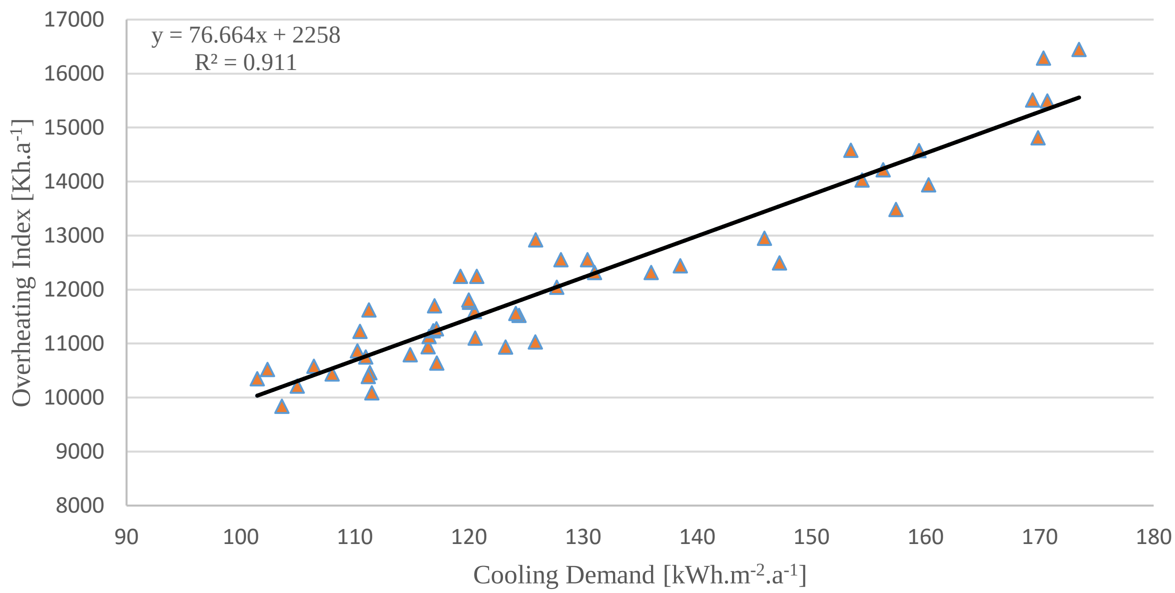


Figure 25 Overheating Index Vs Cooling demand

Cross-ventilation is not always related to a decrease in discomfort hours compared to the single-sided ventilation because of the discomfort generated by extreme air changes per hour (and therefore by an excessive air velocity). Energy consumption with cross ventilation instead decreases on average by 7% compared to single sided ventilation (Calcerano and Cecchini 2014, p.142).

Indoor comfort temperature in fully HVAC controlled building can be easily determined. However, and because people adapt themselves to the environment, thermal comfort in naturally ventilated buildings has larger seasonal ranges than assumed by the standards, including ISO 7730 and ASHRAE 55 Standards (de Dear et al. 1997, Brager and de Dear 1998, Nicol and Humphreys 2002). For the purpose of this study, a threshold values have been considered (27^o during day and 25^o in the night). Therefore, the possibility changing indoor comfort temperature with relation to the outside temperature, which forms the basis of the adaptive approach, is not taken into consideration.

"*The adaptive' approach to thermal comfort shows that the temperature at which the majority of people are comfortable 'tracks' the mean indoor temperature because of the correlation between indoor and outdoor temperature in free-running buildings. This means that comfort temperature also varies with outdoor temperature in buildings in free-running mode*" (CIBSE 2013, p. 7).

This result agrees with other studies conducted in the same area, as showed by Psomas et al. (2015) study, which proved that the overheating indicators, which are based on the exceedance of a fixed threshold, showed a coefficient of determination up to 85% with relation to the annual heating losses and gains. Additionally, Allard and Ghiaus (2006) showed that free-running temperature is an equivalent form of the load curve which may be applied to calculate the energy consumption.

Additionally, the investigated overheating index was calculated for the whole year and for the occupied and non-occupied hours. Given the fact that values outside the summer period are minimal, then the annual period would be convenient to be used in order make a correlation with the cooling demand which is also based on annual basis. Additionally, Psomas et al. (2015) study showed that indices that measure overheating during the occupied and unoccupied hours (total hours; and refer to that period) are highly correlate with indices that measure overheating solely during the occupied period (and refer to that period).

Due to economic reasons, most of the existing residential buildings in Gaza strip do not have HVAC system. Even in rare situations where the HVAC system is available, the energy source (electricity) required for air conditioning is absent for long periods of the day (Up to 8 hours). Therefore, it can be said that almost all of the residential buildings in region are under the free running temperature (Passive cooling) mode. Given that, it was essential to prove the possibility of predicting the cooling energy demand based on the free running temperature.

The results from the simulation showed that indoor conditions follow those outdoors, but were modified to some extent due to the physical properties of the building in addition to the use which building occupants make use of controls which are available to them. With regarding to this context, some variables which could affect the results were not taken into consideration, including operable shading devices and fans. However, such assumptions were made equally constant when performing the simulations of buildings in both states.

The indoor temperature in passive mode can be calculated for new buildings or can be easily measured for existing ones. Based on the free running temperature, the ventilation air change rate can be optimized with regard to passive cooling. Hence, it can be favorably used as a pre-design tool in order to estimate input parameters for a building simulation model and as a performance evaluation method for existing buildings.

Based on this method, we can obtain quick estimations of energy need for cooling and of the potential of energy savings for cooling by using indoor temperature of free running buildings under natural ventilation. Therefore, for the purpose of creating a unified building perspective index with (Al Hayek 2019) study, the cooling energy demand will be used further in this research, given the fact that it could be used interchangeably with overheating index indicator.

4.6. Cooling Demand calculations

As mentioned previously, and for the purpose of creating a unified perspective index, the cooling energy demand of buildings will be looked upon as an indicator for energy performance. Figure 26 shows the cooling energy demand for the base case, which represents the same building sample used for the simulation in the passive cooling mode, and is analyzed in the study done by (Al Hayek 2019). Additionally, the results for two improved cases are shown, which represents the improvement scenarios mentioned in Table 8.

For the base case, the minimum cooling demand was 101 $kWh.m^{-2}.a^{-1}$, and the maximum value was 173 $kWh.m^{-2}.a^{-1}$. The standard deviation of the values is 21.077. This case represents the actual current construction practices in the region and most of the residential buildings in Gaza are presented within this scale.

Unfortunately, the existing standards do not provide a reference scale for rating the performance of buildings based on their energy demands, as it only provides threshold values for the envelope components. However, the cooling energy demand at this stage is considerably high. Therefore, the additional two cases will aim at reducing the cooling load by improving specific parameters related to the building envelope, the aim will be to set a future target for improvement, and to expand the range of the perspective index that will be created.

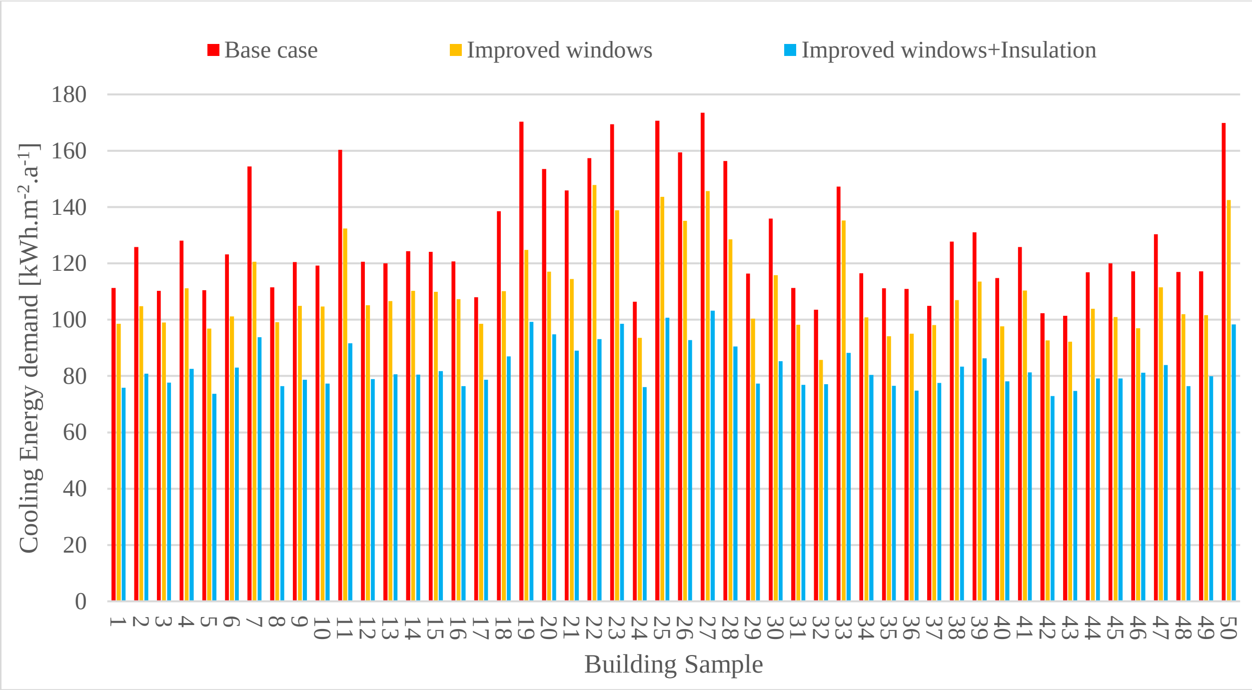


Figure 26 Cooling energy demand for all cases

The first case will involve improving only the solar heat gain coefficient (SHGC) of the windows. In hot climates, the solar heat gains are a crucial factor with regarding to the energy performance of buildings. Perspective codes often set a limit for such value, for example, The Pearl Building Rating System (2016) standards in Abu Dhabi, sets a threshold values for the SHGC, and allows for a maximum value of 0.30. The SHGC is proved to be a more determining actor than the U-value for cooling load reduction (Dutta and Samanta 2018). Therefore, the SHGC of the building sample was optimized to a value of 0.35 instead of 0.82. The range of the resulting cooling loads was from 86 $kWh.m^{-2}.a^{-1}$ to 148 $kWh.m^{-2}.a^{-1}$. The minimum reduction value of the cooling compared to the base case was 7 $kWh.m^{-2}.a^{-1}$ and the maximum was 46 $kWh.m^{-2}.a^{-1}$, while the average reduction in the cooling demand among the whole sample was 19 $kWh.m^{-2}.a^{-1}$. In such case, the cooling demand reduction associated is found also to be positively correlated with the WWR_{os}, i.e. the higher WWR_{os}, the higher cooling demand reduction associated.

The second case aimed at optimizing the U-values of the opaque and transparent components of the building envelope. The improved values represented those which are provided by the Green Buildings Guidelines handbook. In such case, the average cooling demand of the building sample dropped to 83 $kWh.m^{-2}.a^{-1}$.

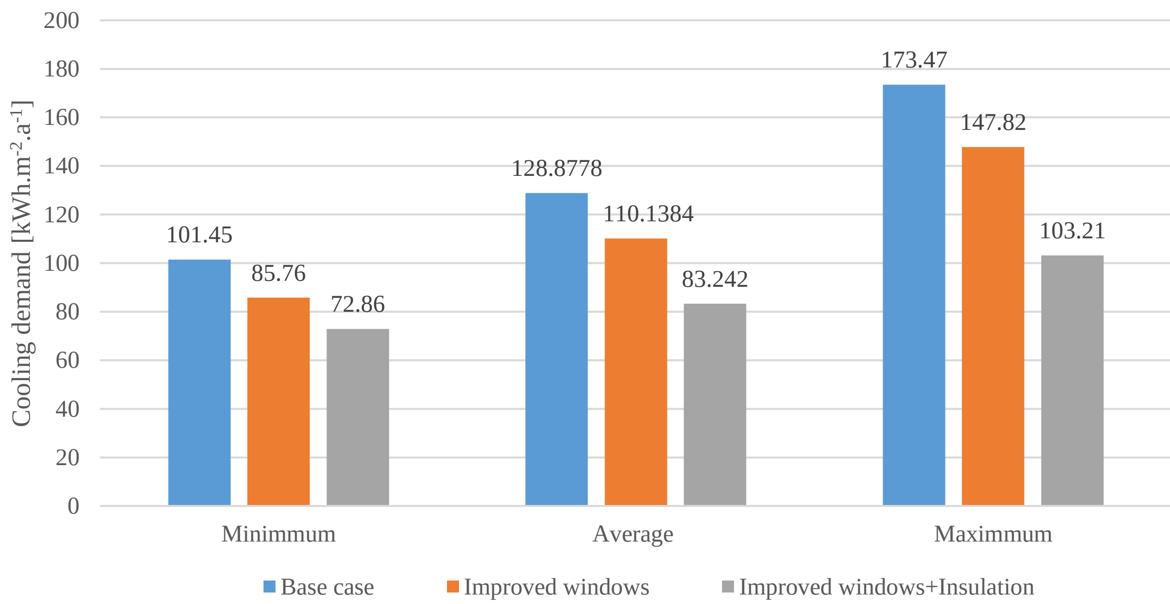


Figure 27 Minimum, average and maximum cooling energy demand for the three cases

The results show that both the SHGC of windows and the thermal properties of the opaque building components have a significant effect on reducing the cooling energy demand of buildings. The SHGC defines how well a window blocks the heat coming from the sun, the less the value the less heat is absorbed and transmitted, which results in lower solar heat gains and therefore, less cooling demand will be required. Changing only this property resulted in lowering the cooling demand by 46 kWh.m^{-2}.a^{-1} in one building of the sample, which indicates a promising potential for achieving a good level of energy performance. Indeed, the characteristics of the opaque envelope components play an important role in reducing the cooling loads. Also, in terms of implementation cost and return of investment, wall insulation has the most economical effectiveness as compared to other methods (Venkiteswaran et al. 2017). Actually, the improvement insulation of the opaque building components involved also the improvement of the roof, which plays crucial factor in reducing the cooling loads due to its long exposure to solar radiation as compared to the exterior walls.

4.7. Parametric Analysis

The same two factors used in creating the regression model for the overheating case will be also investigated under the effect of the improved cases. It is found that both the shape factor and WWR remains the dominant factors with regarding to the cooling energy demand, but their influence will differ according to the two improvement scenarios considered.

The following equations show the linear regression equations of the three cases respectively:

$Y' = 51.765 + 95.867X_1 + 2.244X_2$

$Y' = 52.396 + 84.844X_1 + 1.099X_2$

$Y' = 55.102 + 33.438X_1 + 0.888X_2$

Y' is the predicted value, which is the annual cooling energy demand ($kWh.m^{-2}.a^{-1}$), while X_1 represents the shape factor (SF) and X_2 represents the effective Window to Wall ratio (WWR_{os}).

As it was shown previously, the two indicators; the overheating index and cooling energy demand correlate significantly. Therefore, one indicator could be used calculate the other one based on the correlation equation shown in Figure 25. As the created index at the end of the study will be based on the annual cooling demand, the effect of different scenarios of insulation improvement will be investigated with regarding to the cooling demand indicator.

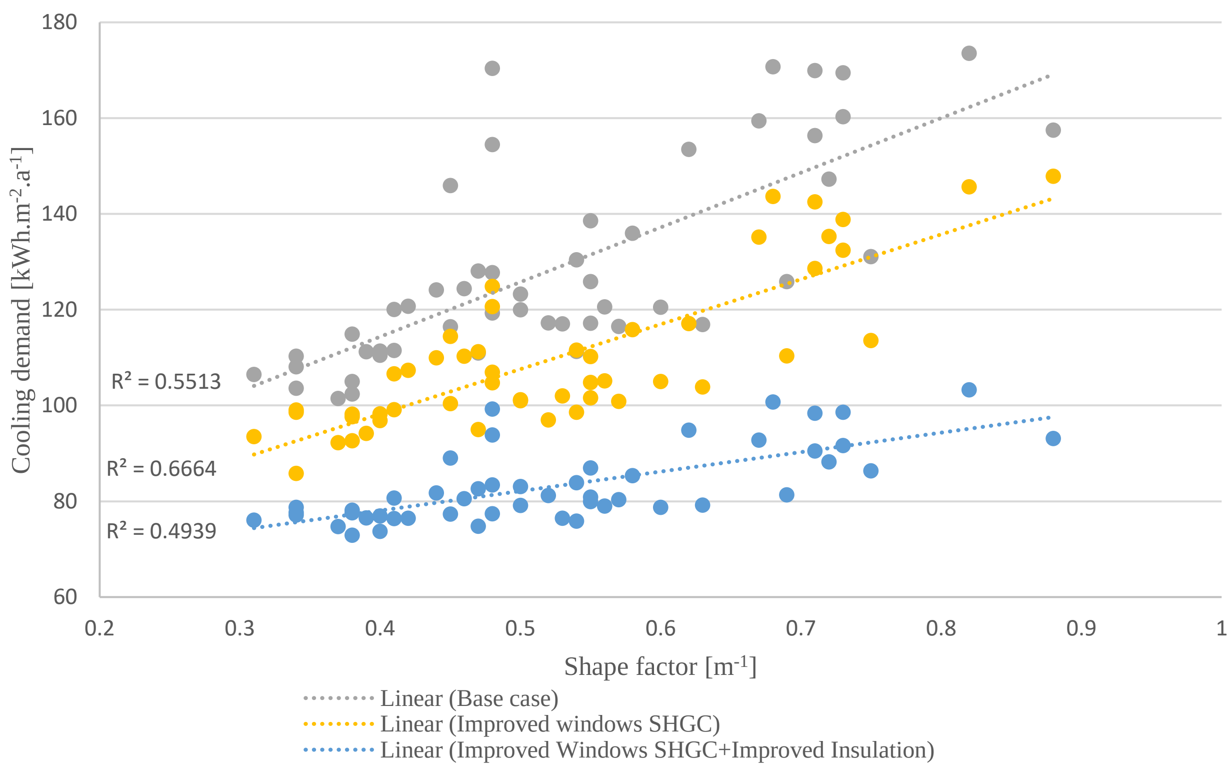


Figure 28 Shape factor Vs Cooling demand for different levels of insulation and Winnows properties

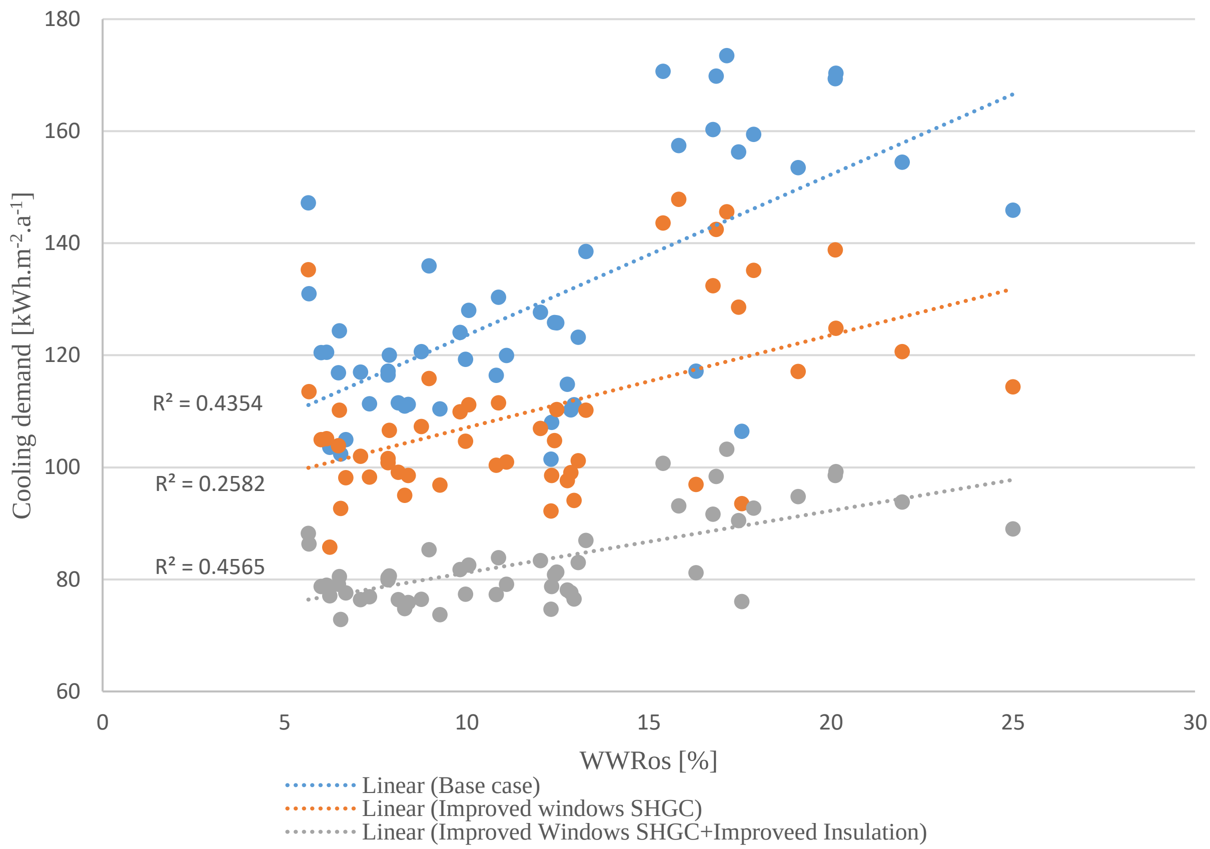


Figure 29 WWR Vs Cooling demand for different levels of insulation and Winnows properties

As shown in Figure 28, with regarding to the shape factor, it showed a correlation of 0.551 with the calculated cooling energy demand for the base case. The correlation value increased to 0.666 when only optimizing the SHGC of the windows was considered. However, while keeping the improved SHGC and improving the U-value of the envelope components in the second case, the correlation value drops to 0.494, which is less than the first two values.

Buildings with higher shape factor have a larger surface area in proportion to their volume, which results in higher heat gains in hot climates, and therefore higher cooling loads. Shape factor property normally shows higher correlations with energy demand of buildings located in cold climates. Danielski et al. (2012) showed also that the impact of the shape factor reduces linearly with higher average outdoor temperatures.

The results reveal that increasing the insulation levels of the building envelope would decrease the effect of the shape factor. A similar result was also achieved in (Danielski et al. 2012) study, where it was also proved that the impact of the shape factor is higher in buildings with lower thermal envelope properties. Catalina et al. (2008) study also established that the impact of the shape coefficient on the energy demand also depends on U-values of the envelope, the smaller the U-values the lower the impact.

The analyzed buildings in the sample has low values of glazing, which is typical for the residential buildings stock in such region. Whereas the envelope area takes into account the ground floor, roof, external windows, external doors and external walls areas. Therefore, the percentage of glazing components with regarding to the overall envelope area is minimal. However, such components are still considered as one of the weakest thermal control points in building.

Though, increasing the thermal properties of the overall building envelope results in decreasing heat gains through it. Therefore, the effect of shape factor (which is a property of the building envelope) would decrease (0.5513 to 0.4939). On the other hand, reducing the SHGC of the windows means that less heat gains will be transported through windows, which would subsequently increase the effect of the shape factor variable.

It can be also seen that the drop difference level of the value of R^2 (0.0574) in case of increasing the insulation is lower than the increase difference level of R^2 (0.1151) in case of only enhancing the SHGC of windows. A trend which could explain the significance of the glazing components with regarding to the inspected performance indicator and in such region.

As shown in Figure 29, a different pattern observed for the WWR variable, where the improvement of the windows has decreased the correlation with the cooling demand drastically from 0.435 to 0.258. On the other hand, increasing the insulation level of the building envelope has increased the WWR correlation with the cooling demand to 0.457.

A similar explanation regarding the effect on the WWR variable is also presented. Where WWR ratio represents a characteristic of the glazing components, as it represents the ration between the external glazing components and external walls.

Therefore, enhancing the SHGC of the windows would mean less heat gains through such components, though their effect on the cooling demand would decrease (0.4354 to 0.2582). On the other hand, their influence would increase (0.4354 to 0.4565) in case of enhancing the overall properties of the building envelope. Regarding to this variable, it can be also noted that the increase difference level of R^2 (0.0211) in case of enhancing the thermal properties of the building envelope is much less than the drop difference level of the value of R^2 (0.1772) when enhancing the value of the SHGC only.

Therefore, it can be concluded that enhancing the thermal properties of the building envelope will affect other geometrical properties. Although SF and WWR_{os} are purely geometrical properties that are related to the area of the thermal building envelope, conditioned volume of the building and the glazing area of the envelope, however, it is found that the effect of changing the thermal properties of the envelope will result in changing the energy requirements and therefore, the correlation with the geometrical design variables will change accordingly.

Thereafter, we can conclude the significance of the glazing components with regarding to the energy performance of buildings in that region, as it is responsible for a large percentage of the heat gains through the envelope.

It is hence proposed that for any future considerations that could incorporate renovation scenarios, a great attention has to be made to the glazing components of the envelope. Even in cases where only such components would be considered for renovations, they could show a great potential for improvements.

Given the potential the two cases -considered in the parametric analysis- can have on reducing the cooling demand requirements, they will be also incorporated within the perspective index that will be created by the end of this study. This will expand the range of the perspective index to include additional future renovation scenarios that could be incorporated in order to enhance the efficiency levels of the building sector.

4.8. Building energy index

In the following section, the prescriptive index, which is aimed at rating the buildings energy performance, will be introduced. The Building Energy Index (BEI) will be based on the “cooling demand” indicator, which is defined as the ratio of a building's cooling energy usage [kWh] per year to the building floor area [m²]. The BEI will be based on the most influencing factors on the energy consumption, which were discussed in previous sections.

The annual cooling demand indicator is calculated based on the developed multiple regression models equations, 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} has a range between (5.65-25)%. Consequently, the BEI 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, and 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 state of building construction in Gaza strip, however it is believed that setting a future target regarding refurbishment of the existing building will provide an extended index, which increase the range of buildings that could be described by the index.

The cooling demand of the base case scenario shows high values ranging from 92 to 194 $kWh.m^{-2}.a^{-1}$. According to that, and to set a future target, the rating of buildings will be additionally based on the possibility of enhancing the building envelope quality through two cases as shown in Table. 8. Firstly, improving the glazing components quality through decreasing the SHGC, and secondly improving the quality of the whole building envelope.

The effect of the two cases with regarding to the energy cooling demand has been investigated within this study. And it was found that improving the window's SHGC will results in a noticeable decrease of the cooling energy consumption, which vary between 83.3 and 156.2 $kWh.m^{-2}.a^{-1}$., this can be explained by less solar gain through glazing. Furthermore, it was found that a significant reduction of cooling energy demand is possible to be achieved through enhancing the thermal properties of the whole building envelope. The cooling demand values for the final case varies between 72.86 and 103.21 $kWh.m^{-2}.a^{-1}$. An average reduction of 18.74 and 54.64 $kWh.m^{-2}.a^{-1}$ was achieved for the second and third cases as compared with the base case scenario.

The effect of the influencing factors is also 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 the decreased SHGC of windows 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 chosen design variables and for different scenarios considered. The aim of this step is to classify the buildings based on their cooling 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 based on the regression equations for all studied scenarios. The rating system is developed based on the values of the cooling demand, and is shown in Table 16 below.

Table 16 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 17 shows which combination of values for SF and WWR_{os}, for reference Gaza climate data, would give the desired category of energy efficiency mentioned above (Table 16). On one axis, the values for shape factor are plotted, ranging from 0.3 to 0.9 m. The other axis represents values for WWR_{os} with the lowest value of 5% and highest 25%, and is showed for the three cases investigated.

Generally, the created index reveals that the best performing buildings are the ones with the lowest shape factor and WWR. However, increasing the thermal properties of the envelope (opaque and transparent components), will result in a better performance of buildings with higher SF and WWR_{os}. It is also clear that the higher the SF and WWR_{os}., the worst the building will perform in terms of the required annual cooling energy.

On the one hand, high number of WWR represents high percentage of glazing components in the building envelope and subsequently, high solar gains will be accompanied. As window glazing is one of the weakest thermal control points in a building, and is responsible for high percentage of heat gains. On the other hand, since shape factor represents the ratio between the thermal envelope of a building and its conditioned volume, higher values indicate higher envelope area exposed to outside environment, which results in higher heat gains.

The index also reveals that for lower U-value and high SHGC of the glazing components, higher glazing percentage is accompanied with low performance levels, which means higher heat gains will occur in such cases. However, increasing the percentage of glazing will be accompanied with good performance levels for glazing which have good thermal properties.

Though, it can be noted that buildings with high glazing ratio can perform very well in cases where the thermal properties, in terms of the SHGC of such components are enhanced. Whereas building of higher shape factors can also perform better, if the thermal properties of the building envelope are convenient. This indicates that buildings with higher shape factor and/or WWR have to comply with stricter requirements of the building envelope in order to reach appropriate performance levels.

According to the proposed rating, category D of buildings represents those with a cooling demand values higher than 171 $kWh.m^{-2}.a^{-1}$, such category exists initially within the base case buildings sample. However, such category does not exist considering the improvement of windows scenario. Similarly, buildings of categories B and C which represents those with a cooling demand values higher than 121 $kWh.m^{-2}.a^{-1}$ does not exist within the third case.

The created index is based on purely geometrical properties of the building envelope; namely SF and WWR_{os}. However, other properties that are related to the material properties of the envelope should not be neglected due to their significance to the performance levels as shown in the sensitivity analysis cases. The developed index therefore is based on the assumptions of the U-values of the building envelope foe all cases.

The significance of the SHGC factor with regarding to thermal properties of the glazing components in such climatic conditions has been demonstrated. Especially in summer period, as high values of such factor contribute significantly to adding large amounts of undesired heat to buildings. However, the Palestinian code of energy, which has been created since 2004 and was not updated since then, disregards limiting the value of the SHGC for the glazing components, as it only limits U-value of such components.

Additionally, and according to the Palestinian cod of energy, the total U-value of external envelope components (opaque and transparent) shouldn't exceed 1.8 $W.m^{-2}.k^{-1}$, and does not specify separately a threshold values for the opaque and transparent components. Such approach also ignores the effect of the SHGC. Prescriptive codes in hot climates normally set maximum values for such variables, taking the Pearl energy rating system of Abu Dhabi as an example, where the U-value of the fenestration components is limited to 2.2 $W.m^{-2}.k^{-1}$, and a maximum value of 0.3 is set to the SHGC (Pearl Building Rating System 2016).

The derived index is easy to follow for designers, and for buildings that do not undergo the step of energy simulations, gives an overview which category of energy label the building would potentially have.

Table 17 Prescriptive index with energy labels (Reference climate Gaza, Palestine)

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	C	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

4.9. Limitations of the study

The research framework and the building code used framed the analysis on reliable references, however, they also represent a limitation of the study, as the results are strictly dependent upon the assumptions made.

During the simulation process, an assumption has been made regarding the geometry of the surrounding shading buildings. Although such assumption represents -to a high extent- a large percentage of the residential buildings in Gaza, which is considered as a very densely populated region, it still however limits the results to be applicable to the exact assumption that was made.

Moreover, the thermal characteristics of the building envelope have been initially assumed according to the common construction practices in such region, although such values don't satisfy the minimum requirements according to the Palestinian cod of Energy.

Such assumption, has also limited the variance of descriptive building variables which are dependent on thermal properties of the building envelope, which in turn, didn't show expected results in relation to the chosen performance indicator. Consequently, the derived index by the end of the study was based only on purely geometrical properties of the buildings under such assumptions.

The building sample is a representative sample for the residential buildings in Gaza which are categorized as either multi-family houses or apartments, which leaves a space for further research, on investigation of the buildings considered as single-family houses.

For simplification purposes, the calculated overheating indicator was based on exceeding a threshold values of reference temperatures, despite the fact that most perspective codes use the adaptive comfort model to assess overheating in passive heating/cooling buildings.

5. Conclusion

The goal of this thesis was to develop a prescriptive Building Energy Index (BEI), which is aimed towards enhancing the energy efficiency of buildings in Gaza city. As the weather in the region is classified as hot humid, the cooling energy demand was found to be the dominant energy demand and therefore, was taken as an indicator for the created BEI. The index is based on the results obtained from the thermal simulation tool (EnergyPlus). This created index would serve as a tool to be used by architects, designers and engineers during the early stages of the design process, where no thermal simulations have been executed. Buildings which comply with the prescribed values shown in the index, can reach high energy efficiency levels.

The study was conducted on a representative sample of the residential buildings in Gaza city, incorporating those considered as either multi-family houses or apartments. Due to the lack of some required data, educated assumptions has been made regarding several inputs required for the simulation process. A set of building quality variables that are related to both the geometry and material properties of the building envelope has been selected. The initial assumption with regarding to the U-value of the building envelope components, which were made constant for all of the sample, has limited the variance of variables related to the material property of the building envelope. Therefore, the results of the study would be exclusively based on such assumption.

Due to the fact that almost all of the existing residential buildings in Gaza have no HVAC system, and therefore are described as passive cooling buildings, it was essential to develop an indicator that could be used to describe the same building sample, in case the HVAC system is used. Accordingly, the chosen overheating index indicator, which is fundamentally based on the exceedance of a reference temperature values, showed high correlation with the cooling energy demand, which gives the possibility to predict either of the two variables based on the other one. Therefore, the cooling energy demand was used an indicator for further purposes in this thesis, and the index was also based on it.

The combination of Shape factor (building compactness) (SF) and Effective Window to Wall ratio (WWR_{os}) variables was found to have the most effect, amongst other variables, on the chosen building energy indicator. Therefore, the created index was based on those two variables. And it was found that buildings with lower SF and WWR_{os} are the best performing in terms of the required annual cooling demand, buildings with higher values of those variables have to comply with stricter requirements of the building envelope in order to reach appropriate performance levels.

It was found that the current existing construction practices involve high values of required cooling energy demand. For that purpose, two case studies aiming at improving the thermal properties of the building envelope of the base sample were developed, such cases resulted in significant energy demand reductions. Moreover, such cases would be beneficial for any future possibilities of performing renovations works. For such purposes, both cases were also incorporated within the created BEI.

The BEI is based on a purely geometrical properties of the building envelope, however, other material properties of the building envelope are also of great importance. Such limitation was mainly due to the initial assumption of the thermal properties of the building envelope. Such factor was investigated in the parametric analysis, where it was shown that improved thermal properties affect the geometrical properties of the building envelope, and result in significant energy demand reductions.

Due to the lack of an energy rating system which labels buildings according to their energy demand –as the case in most of the developed countries-, the rating system was based on the range of the calculated cooling energy demand for the whole buildings (120 building – 3 cases). Where a category of A++ represent the best performing buildings with an energy cooling demand less than 70 $kWh.m^{-2}.a^{-1}$, whereas E category represents the worst performing buildings with a cooling energy demand requirements higher than 195 $kWh.m^{-2}.a^{-1}$.

It was found that specific characteristics of the glazing properties of the building envelope are of great importance to achieve good energy efficiency levels, such characteristics are disregarded in the current building energy code.

Although prescriptive methods can be a bit rigid and limit designer's freedom, the prescriptive index derived in this study serves more as an indicator, which combination of values for the two variables mentioned above, gives a certain level on energy scale, and therefore, does not limit designer's choices to a large extent. As compared to the performance based approach, which is more time and cost consuming, it is found that the simplified regression based approach gives results with a good level of accuracy for tested residential buildings. Moreover, it requires low time and is easy to be used during the very first stage of the design process. Such approach, would be beneficial to be used in Gaza Strip, given the fact that energy codes are not well implemented in such region.

Where the main barriers to achieving energy efficiency in buildings are represented by economic aspects, the created index would represent a valuable tool that can be deployed overcoming the mentioned hurdles.

For the purpose of this thesis, few assumptions were made that could represent a limitation of the study, as the results are strictly dependent upon the assumptions made. Including the geometry of the surrounding buildings and thermal properties of the building envelope. Also, the building sample is only representative for the residential buildings which are considered as either multi-family houses or apartments, and does not include single family houses category.

The developed BEI in this study can be used as a guide for prescriptive based requirements in evaluating the quality of buildings during the early stages of the design process. It is especially beneficial in developing countries, where its application would definitely require less time and costs as compared to other approaches related to enhancing energy efficiency in buildings.

6. Index

6.1. List of tables

6.2. List of Figures

7. References

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