Building Practices Enhancements in Relation to Thermal Performance and Energy Saving. A Case Study of Residential Building in Cairo, Egypt

تعزيز ممارسات البناء فيما يتعلق بالأداء الحراري وتوفير الطاقة. دراسة حالة المبنى السكني في القاهرة ، مصر

by

MAY MOHAMED DIAA EL-DIN EL-ATTAR

A dissertation submitted in fulfilment

of the requirements for the degree of

MSc SUSTAINABLE DESIGN OF THE BUILT ENVIRONMENT

at

The British University in Dubai

Prof Bassam Abu-Hijleh
April 2018

DECLARATION

I warrant that the content of this research is the direct result of my own work and that any use made in it of published or unpublished copyright material falls within the limits permitted by international copyright conventions.

I understand that a copy of my research will be deposited in the University Library for permanent retention.

I hereby agree that the material mentioned above for which I am author and copyright holder may be copied and distributed by The British University in Dubai for the purposes of research, private study or education and that The British University in Dubai may recover from purchasers the costs incurred in such copying and distribution, where appropriate.

I understand that The British University in Dubai may make a digital copy available in the institutional repository.

I understand that I may apply to the University to retain the right to withhold or to restrict access to my thesis for a period which shall not normally exceed four calendar years from the congregation at which the degree is conferred, the length of the period to be specified in the application, together with the precise reasons for making that application.

____

Signature of the student

COPYRIGHT AND INFORMATION TO USERS

Abstract

The global climate changes have been affecting Egypt with rising temperatures in the summer for the past 10 years all over Egypt, which lead to exponential increase in energy demand to achieve thermal comfort. This trend is expected to continue, as the demand for mechanical cooling will rise especially in the main cities and would lead to higher emissions. However, Egyptian recent studies on residential building designs and construction materials do not take into consideration the climate conditions and various environmental factors. One of the main reasons behind this is the local regulations, which are not reflecting the local climate conditions and environmental conditions. Also, it was stated that residential buildings in Egypt has low thermal performance quality and low indoor air levels as there is no use for building air tight envelops, insulation to walls, shading objects or double-glazed openings.

The aim of this study was to investigate the impact of different building envelop treatments on the energy consumption in residential building in Cairo, Egypt. The study was done through analyzing the relation between each treatment and energy consumption by using IES-VE computer simulation software, in addition to an economic study. A residential building in Cairo, Egypt was selected to investigate the building construction practices in Egypt and how this can be improved in order to save electricity consumption in cooling, and heating.

The study was divided into three steps. First step was conducted in the form of test matrix of simulations that consists of three main strategies diverted from the parameters of the study. Each strategy was covered by a number of simulations using different configurations for each parameter, 8 simulations were tested for external walls, 5 scenarios for external glazing and three scenarios for exposed roof treatments. In addition to calculation the payback period for each scenario depending on the simulation's energy consumption results. While in the third step, the most energy saving scenario and the shortest payback period scenario were selected from each parameter and combined in a new matrix to investigate the impact in a form of combined matrix.

Results showed that simple enhancements in the current building envelop of residential buildings can save 18% of electricity consumption with a payback period of 5 years. On the other hand, using more sustainable building materials can save more energy however it would extend the payback period. In combined matrix simulations, annual electricity savings percentages ranged between 18% and 22%, with a corresponding payback periods between 5 years and 11.6 years.

Keywords: Energy Saving, Thermal Performance, Thermal Insulation, Building Envelop, Residential Building.

الملخص

لقد أثرت التغيرات المناخية العالمية على مصر مع ارتفاع درجات الحرارة في الصيف على مدى السنوات العشر الماضية، مما أدى إلى زيادة هائلة في استهلاك الطاقة لتحقيق الراحة الحرارية. ومن المتوقع أن يستمر هذا الاتجاه ، حيث سيرتفع الطلب على التبريد الميكانيكي خاصة في المدن الرئيسية وسيؤدي إلى زيادة الانبعاثات. ومع ذلك ، فإن الدراسات المصرية الحديثة بشأن تصاميم المباني السكنية ومواد البناء لا تأخذ في الاعتبار الظروف المناخية والعوامل البيئية المختلفة. أحد الأسباب الرئيسية وراء ذلك هو قوانين البناء المحلية ، التي لا تعكس الظروف المناخية المحلية والظروف البيئية. كما ذكر أن المباني السكنية في مصر لها جودة أداء حرارية منخفضة ومستويات هوائية داخلية منخفضة حيث لا يتم يوجد تصميم لغلاف مبنى يمنع تسرب الهواء أو عزل الجدران أو أجسام تظليل المباني أو الفتحات ذات الزجاج المزدوج.

الهدف من هذه الدراسة هو دراسة تأثير معالجات غلاف المبنى الخارجي المختلفه على استهلاك الطاقة في المباني السكنية في القاهرة ، مصر. وقد أجريت الدراسة من خلال تحليل العلاقة بين كل معالجه واستهلاك الطاقة باستخدام برنامج المحاكاة الحاسوبية IES-VE ، بالإضافة إلى دراسة اقتصادية. تم اختيار مبنى سكني في القاهرة، مصر للتحقيق في ممارسات البناء في مصر وكيف يمكن تحسين هذا من أجل توفير استهلاك الكهرباء في التبريد ، والتدفئة.

تم تقسيم الدراسة إلى ثلاث خطوات. تم إجراء الخطوة الأولى على شكل مصفوفة اختبار المحاكاة التي تتكون من ثلاثة استراتيجيات رئيسية تم تحويلها من معلمات الدراسة. تمت تغطية كل استراتيجية من خلال عدد من عمليات المحاكاة باستخدام تكوينات مختلفة لكل معلمة ، وتم اختبار 8 سيناريوهات للجدران الخارجية ، و 5 سيناريوهات للتزجيج الخارجي وثلاث سيناريوهات لعلاج الأسطح المكشوفة. بالإضافة إلى حساب فترة الاسترداد المادي لكل سيناريو بناءً على نتائج استهلاك الطاقة للمحاكاة. بينما في الخطوة الثالثة ، تم اختيار سيناريواعلى توفير للطاقة وأقصر فترة استرداد من كل معلمة وتم دمجها في مصفوفة جديدة للتحقيق في التأثير في شكل مصفوفة مدمجة.

وأظهرت النتائج أن التحسينات البسيطة في المباني الحالية للمباني السكنية يمكن أن توفر 18٪ من استهلاك الكهرباء مع فترة استرداد من 5 سنوات. من ناحية أخرى ، يمكن أن يؤدي استخدام مواد بناء أكثر استدامة إلى توفير المزيد من الطاقة ، إلا أنه سيمدد فترة الاسترداد. تراوحت معدلات الادخار السنوي للكهرباء في عمليات محاكاة المصفوفة مجتمعة بين 18٪ و 22٪ ، مع فترات سداد مقابلة بين 5 سنوات و 11.6 سنة.

Dedication

I would like to dedicate my work to my Parents, Sister, Husband and my son Yusuf. You are my biggest blessings in Life.

Acknowledgment

First of all, I have to thank Allah for all his blessings, mercifulness, grace and the help of making one of my biggest dreams come true. I pray Allah that what I have reached would benefit my country, Egypt.

A special sincere admiration and respect to my supervisor, Professor Bassam Abu Hijleh, for his kind support, guidance and enormous knowledge.

I gratefully thank Dr Hanan Taleb for being such an amazing professor, and for her advices on both academic and professional levels.

I would like to thank my parents for Believing in me and being by my side all the journey long. Without their unconditional love and support, I wouldn't have achieved anything in my life. My sister, dearest Maryam ever, thanking her for being there bearing with me in my hard times, and her endless help and support throughout this dissertation.

My husband and soulmate, Khaled, thanking him for the moral support and reminding me of my goals and dreams each and every time I feel down.

Thank you so much my dearest friends Asmaa, Rabab, Radwa and Sarah for being there for me all the time.

Finally, I would like to thank each and everyone I met in The British University in Dubai during the last 2 years.

Table of Contents

List of Figures

List of Tables

1 Introduction

ASHRAE Standard 55 user manual defines thermal comfort as, "that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation". When starting a new project design, it is essential to take occupants' satisfaction into consideration. Satisfied occupants and comfortable indoor areas must be achieved using energy efficient strategies. There are different factors affecting the thermal behaviours of a building, such as: weather conditions, characteristics of design, and user profiles. The relation between energy consumption rates and indoor thermal comfort defines the building's thermal performance.

In hot arid climate, Thermal comfort is essential for energy conservation in hot arid climates. Climate in Egypt is in hot arid climate zone. Minimizing the energy consumption rate of a residential building in Egypt requires considering climate conditions affecting energy consumption using two main strategies; passive strategies such as enhancing building envelop, and active systems depending on intensity of solar radiation. The essentiality of thermal comfort in hot arid regions arises from the high electricity consumption in such regions used for cooling. Moreover, higher energy demand is challenging to the environment, which is due to the enormous increase in Egyptian population yearly.

The global climate changes have been affecting Egypt with rising temperatures in the summer for the past 10 years all over Egypt, which lead to exponential increase in energy demand to achieve thermal comfort. This trend is expected to continue, as the demand for mechanical cooling will rise especially in the main cities and would lead to higher emissions, grid feeding instability and heat island effect (Attia, Evrard & Gratia 2012).

Low financial resources, radical environmental conditions and obsolete construction technologies are all factors challenging Developing countries like Egypt. Improving the quality of indoor environment using high investment technologies is a big struggle under such conditions. In Egypt, residential buildings consume up to 70% in heating and cooling out of the total energy consumption to maintain the thermal comfort (Aldali & Moustafa 2016).

The Egyptian Electricity Holding Company (EEHC) in their 2015/2016 annual report stated that electricity generation depends mainly on fossil fuel by more than 89%, while renewable resources are generating less than 11%. Leading to growing shortage in fossil fuel and electric power outages. It also stated that from 2011/2012 to 2015/2016 the average electricity generation growth rate is 4.3% (Ministry of Electricity 2018).

Recently, investment rates in residential sector have been doubling up to match the rapid increase in population. The total population of Egypt reached 96,858,581 according to the Countrymeter in 2018. This investment led to huge expansions in the housing sector to meet the demand, neglecting the living quality and environmental conditions. As a result, artificial cooling and artificial lighting are the only way to achieve indoor thermal comfort, which has led to massive increase in total energy consumptions. Knowing that 72% of the built environment in Egypt goes to the residential sector which consume 54.9% of the total generated electricity as per the last report of The Egyptian Electricity Holding Company (Figures 1.1 & 1.2) (EEHC 2015/2016).

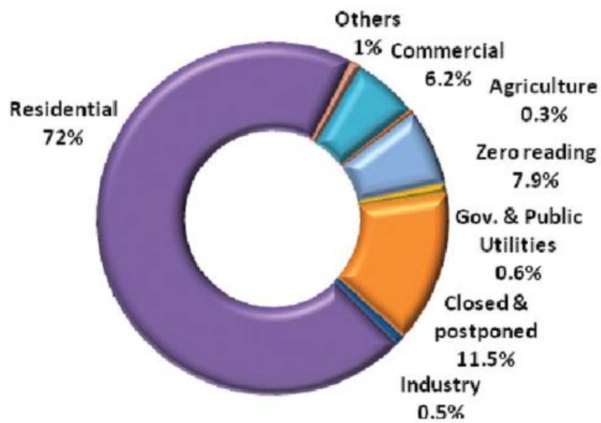

Figure 1.1: Number of Costumers (EEHC 2016)

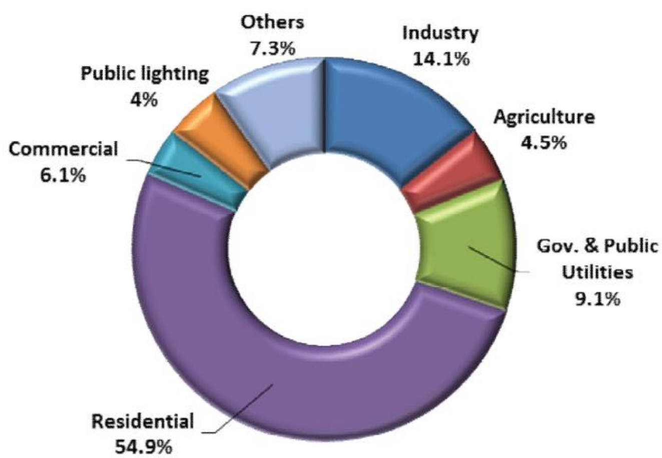

Figure 1.2: Consumption percentage per Costumer Type (EEHC 2016)

1.1 Current Situation

In a study that aimed to showcase the energy consumption and occupants' behavior in residential buildings in Egypt, Attia, Evrard & Gratia (2012) selected three main cities that have different climatic conditions in Egypt in 2008. A field study was conducted on building characteristics and energy consumption patterns. Then, computer energy simulations were used to model the field study results. In order to create a base study, over 1,500 apartments in Alexandria, Cairo and Asyut were included in the sample group. Challenges, limitations and areas of development were derived from analysing the patterns of energy consumption and building construction structure. The areas of apartments surveyed were classified into 4 categories as per the census from A to D; Category (A) had a share of 7% and have gross floor area of more than 130sq.m. Category (B) had a share of 47% and its gross areas ranged between 110sq.m. to 130sq.m. Followed by category (C) with a share of 23% and areas ranging between 90sq.m. and 110sq.m., while category (D) had a share of 11% and areas between 60sq.m. and 90sq.m.

According to results, residential blocks surveyed were mostly rectangular. Two residential blocks types were listed under category B and were selected to be studied where the first type was six floors blocks with two flats on each floor, while the second type was 12 floors blocks with four flats on each floor. More than 250 apartments of the survey sample in the three cities were under the first type while 240 were under the second type. Consuming behaviour of occupants was also taken into consideration in the study, which showed that there is a common trend to the consumption that the authors referred to as 'national character'. The survey results showed that occupancy per air-conditioned apartment was 4 to 5 individuals and an average density of 24 to 28 meters square of each individual on used areas.

The study also investigated the electricity consumed from lighting, suggesting that the lighting used specifically in living rooms and bedrooms varied substantially depending on the number / types of lamps installed. Incandescent lamps and fluorescent tubes were the main types used with an average intensity of 17 w/m2 for the living room, 13 w/m2 for the bedroom and 9w/m2 for the rest of the apartment.

Historical billing was also captured in the survey that was done on two types of residential buildings, the average consumption was found to be 22.4 kWh/m2/year in Alexandria, 26.6 kWh/m2/year in Cairo and 31 kWh/m2/year in Asyut for the first type apartments. It was also found that the average consumption of the first type apartments was higher than the second type of apartments as their average consumption was recorded to be 11 kWh/m2/year in Alexandria, 14 kWh/m2/year in Cairo and 18 kWh/m2/year in Asyut. This difference was a result of lower heat gain in second type apartments due to less areas of the external walls 2exposed to sun (Attia, Evrard & Gratia 2012).

The Ministry of Electricity and Renewable Energy in Egypt ("MOEE") published the electricity prices for the residential uses. It is divided into 7 consumption segments, slaps, as shown in Table 1.1 (Tariff & Electricity Prices 2018). In a written interview with the minister of Electricity and Renewable Energy in one of the local journals, he stated that the first 6 consumption segments of electricity are subsidised and the actual cost of generating 1 kWh is 102.2 Piasters, while the highest segment pays 135.0 Piastres/ kWh. Which translates into that the 7th segment is paying more than the initial cost, as he said, taking from the rich to subsidize the poor. However, the consumption rate is the only way of measuring the richness or poorness, if a villa is closed for 20 days a month, the electricity bill will be subsidised if the consumption rate is less than 1000 kWh/ Month. He also declared that the government is paying more than 47 Billion EGP subsidies for the residential segment per year (ElMasry 2017).

Table 1.1: Electricity Segments Pricing in Egypt (ElMasry 2017)

Consumption Segment (kWh/Month)	Price** (Piastres*/ kWh)
From 0 – 50	13.0
From 51 – 100	22.0
From 0 – 200	27.0
From 201 – 350	55.0
From 351 – 650	75.0
From 651 – 1000	125.0
From 0 – greater than 1000	135.0

*1 USD = 17.72 EGP (Feb 2018)

**1 EGP = 100 Piastres

1.2 Research Motivation

In Egypt, recent residential building designs and construction materials do not take into consideration the climate conditions and various environmental factors are also neglected. One of the main reasons behind this is that the local regulations, which are not reflecting the local climate conditions and environmental conditions (Aldali & Moustafa 2016).

In 2008, the Egyptian code “efficiency of energy use in buildings for residential buildings” was published. However, it is not mandatory; it only provides some recommendations to be followed in order to reduce the energy consumption in residential buildings, which is all about the corresponding U-values for different elements for each climate zone in Egypt (Reda et al 2015).

Attia, Evrard & Gratia (2012) claimed that the low quality of construction of similar non-environmentally friendly construction blocks used in Egypt is a result of the non-sustainable designs and construction knowledge negligence for the past 60 years. That also led to the growing dependence on the mechanical cooling systems, which in turn lead to high rates of energy usage.

Also, it was stated that residential buildings in Egypt has low thermal performance quality and low indoor air levels as there is no use for building air tight envelops, insulation to walls, shading objects or double-glazed openings. 80% of the surveyed apartments in the study had at least one air-conditioner, which could not be covered by the existing electricity grid. Electricity blackouts was increasingly happening in Cairo in summers since 2004, therefore, there is a pressing need for energy conservation.

1.3 Aims and Objectives

The aim of this study is to investigate the impact of different building envelop treatments on the energy consumption in residential building in Cairo, Egypt. The study will be done through analyzing the relation between each treatment and energy consumption, in addition to an economic study. The findings will be in a form of building envelop enhancement recommendations for the

Egyptian government for the purpose of building and energy regulations enhancement. The main objectives of this study are:

1. Select the base case building for the study.
2. Identify construction components and building conditions.
3. Record energy consumption rates and thermal comfort performance.
4. Validate the energy consumptions results.
5. List building requirements as per the building code and materials in terms of building envelop treatments.
6. Derive strategies to minimize energy consumption and achieve advanced thermal comfort
7. Analyse the viability of recommended strategies economically by using payback period calculations.
8. Propose the strategy that result in the optimal degree of thermal comfort and lowest rate of energy consumption.
9. Provide a combination of recommendations to enhance the current Egyptian building and energy codes.

1.4 Dissertation Outline

The research will be consisting of six chapters, which will be divided as follows;

Chapter One: Introduction: general introduction on the main topic, it covers thermal comfort and its relation to energy efficiency and building envelop. In addition to addressing the demographics and socio-economic factors as well as the climate conditions in Egypt.

Chapter Two: Literature Review: this section will be covering previous studies done on the same topic, the work done will be addressed in terms of research aims covered and results reached. It is important to mention that the main research question is highlighted mainly from pointing out the knowledge gap from other researches. Main topics to be covered are thermal comfort, building materials, building envelop characteristics, external walls, roof treatments and glazing types. As the location of the study is Cairo, Egypt, the climate conditions will be studied. It is essential to get a closer look on the current Codes and regulations in Cairo, Egypt, which will be highlighted as well.

Chapter Three: Methodology: previously used research methodologies will be covered and analysed. Then the appropriate methodology for the research question will be chosen and justified.

Chapter Four: Simulation Preparation: the case study will be introduced. User profiles will be defined in addition to other parameters that will affect the simulation results. The research matrix will be displayed. A closer look on the local market of building materials in Egypt will be covered as well.

Chapter Five: Simulation Results and Discussion: the simulation results will be displayed and analysed in terms of tables and charts. Comparisons will be done in terms of energy consumption reduction percentages, in addition to heating and cooling loads. all the simulated options of single matrix building envelop treatments will be covered in an economic study to investigate the relation between different material prices based on the current local market situation. The calculation will be presented in terms of payback period to get real time value of expenses. The results will be derived in a new matrix after being compared and discussed. Further simulations will be done based on the economic study done. To get the best results out of each building envelop element and combine them in a new matrix.

Chapter Six: Conclusion and Recommendations: based on the work done on the previous five chapters, a clearer vision would be available to answer the research question and come out with recommendations in relation to a new regulation to be introduced and enforced by the Egyptian government.

2 Literature Review

The relationship between exteriors of a building and indoor thermal comfort was analysed by Manzano-Agugliaro et al. (2015) who conceptualised this relationship as bioclimatic architecture. Through achieving a sustainable strategy for the outdoor conditions an enhanced indoor thermal comfort can be achieved which he referred to as 'vernacular architecture'. He claimed that the industrial revolution and technology integration with thermal comfort strategies, lead to a significant increase of energy consumption. By the 1980s, environmental impact started to get attention and more focus was given to sustainable solutions; referred to as vernacular architecture and taking it to another level by finding the right strategy depending on the climate which is bioclimatic architecture.

Bioclimatic strategies are categorized according to temperatures and humidity levels into 14 different conditions and zones of climate. The study also investigated the use of vernacular architecture strategies in building design, as such climate, solar radiation, most desired wind direction and construction materials thermal performance are to be included in the building analysis.

They have emphasized on the importance of bioclimatic architecture and the role it is playing in the sustainable development. The higher the public awareness on the energy conservation, the more regulations on energy consumption, will all eventually lead to a more sustainable environment (Manzano-Agugliaro et al. 2015).

2.1 Thermal comfort

Abdullah (2015a) explored the use of thermal comfort and energy conservation in big educational halls in Egypt. Through conducting field study, six factors of thermal comfort and air quality were analyzed. The six factors analyzed through recording for two hours a day during morning and afternoon were CO_2 concentration, indoor / outdoor temperatures, and humidity levels, speed of wind, globe temperature and clothing. A survey was conducted with a sample size of 331 of which 269 were considered for analyzing. The survey was targeted at gathering information on three points: indoor air quality, students' satisfaction with the thermal comfort and dissatisfaction reasons. While thermal comfort was studied through field measurements

The results have shown that student's satisfaction rate in relation to the indoor thermal comfort and air quality was low. According to the results, the author suggested that temperatures need to be lowered and relative humidity needs to be increased which requires further exploration of passive cooling systems (Abdullah 2015a).

Tejero-González et al. (2016) studied applicable passive cooling / heating strategies based on climatic data recording and previous research work done. The authors studied the energy conservation targets that can be achieved through using passive techniques on not only yearly data but also on collected daily data. To enhance the accuracy of the study, the data collected was used to derive heat and cool loads estimates and system sizing calculations.

The paper suggested that dynamic building simulation is imperative to establish the correlation between energy consumption rates, passive techniques used and climatic conditions in order to achieve lower rates of energy consumption. “Climatic Cooling Potential”, Degree Days (DD) and Bin-method can be also used in the assessment. Authors have also highlighted the importance of the role the climatic changes play in affecting the coefficient of performance (COP) of the passive heating / cooling technique to be used, as changes in levels of relative humidity and temperatures directly influence COP. Suggested passive strategies were: evaporative and free cooling and solar heating, and natural ventilation as well.

This study also serves as a guideline to methods of data collection and representation. Psychometric Chart compiles the data including the missing captured data for a specific location; it also defines the limitations of different passive techniques depending on their relevant climatic conditions. Moreover, Climate Consultant software can accommodate more data input such as the psychometric chart including solar, cloud and wind roses data (Tejero-González et al. 2016).

Chandel, Sharma & Marwah (2016) investigated the use of vernacular architecture strategies in the modern architecture to achieve higher quality of indoor air. A combination of three methodologies; literature review, field study and survey, were used in this paper. Vernacular architecture consisting of four main components: architecture, design, planning and construction, was also presented as a modern bioclimatic solution for energy conservation. Factors affecting Vernacular were also categorized into the pillars of sustainability: climatic, geographical, economic and cultural factors.

Room shape, materials, structure and location were the main points of analysis in relation to the correlation between energy saving and vernacular architecture. Earth is considered as sustainable construction material by previous research and codes and regulations as an aspect of vernacular architecture that achieves energy conservation. The paper also discussed the limitation to traditional architecture being social and institutional aspects.

The paper was done on Himachal Pradesh in India, with a general summary on the state, climate conditions, and vernacular architecture per zone. A phased approach focused on Hamirpur district as the climatic zone, field study was conducted followed by a survey to assess the satisfaction level and limitations. Authors recommended that further research is needed on advanced architecture and thermal comfort techniques to achieve energy efficiency (Chandel, Sharma & Marwah 2016).

Reda et al (2015) aimed to investigate how to reduce the energy consumption of residential buildings in the weather conditions of New Burj Al Arab area in Alexandria, Egypt. The study was done in three successive stages, the first stage was a survey to investigate the user profile of different building occupants of residential building. The main addressed topics in the conducted survey were domestic hot water, usage of shadings systems and windows’ openings profiles. The findings of the first stage were reflected in the simulation models of stages two and three. While the second and third stages were done using dynamic simulation methodology by analysing the energy model of the base case, low investment model, high investment model, and the net zero – active system- building model using computer simulation software. The findings of the first stage were reflected in the simulation models of stages two and three. The results were compared in terms of cooling loads, heating loads, and total energy consumption of each apartment of the building. All the simulations were done on the fifth floor of the building after inserting all the required parameters, occupancy, lighting, heating and cooling profiles and temperature set point of summer and winter. In addition to the building envelop materials and design.

Local market research was essentially done to know the availability of different materials and their thermal properties, in addition to active system technologies. It is important to mention that the low investment model only contains low initial cost materials and technologies. While the high investment model has net-zero building technologies that are known with their high initial cost. While the base case or as they named it "business as usual" BaU model is done based on the minimum requirements of the Egyptian code.

There was a set of technologies and solutions selected for each scenario, based on the local market research. In the base case model, fluorescent and Incandescent lighting were used. Cooling system was depending on natural ventilation only. While in terms of building envelop solutions, external walls were made up of double half red-brick with an internal 5 cm air gap. In the low investment scenario, the air gap was replaced with thermal insulation of 3 cm in external walls, and 5 cm in ground floor and roof, in addition to reflective external paint, shading system, and unglazed solar thermal collectors. Higher system technologies were used in the high investment scenario, expressed in LEDs and mechanical ventilation systems. In addition to PV panels and using low-e coated glazing. Moreover, thermal insulation thicknesses were increased to 5 cm in external walls and 6 cm on the roof and ground floor.

The results showed that the overall energy consumption of the low investment model was reduced by 26% compared to base case model. While the high investment model showed that the total energy consumption has been reduced by further 28% than the low investment model which is 54% than the base case model (Reda et al 2015).

Attia, Evrard & Gratia (2012) study results showed that the air-conditioning is the main contributor to the energy consumption in residential buildings in the three cities under study which in turn is reflected in the electricity consumption rates in the summer (April to October). The authors suggested that the air-condition usage and electricity consumption patterns should be a part of future studies analyzing thermal comfort. They have also claimed that occupant's behaviors are hard to capture specially in summer as they tend to use multiple mechanical cooling equipment at the same time or combine it with natural ventilation at times. Occupants did not maintain constant temperature target, therefore applying the Fanger's or ASHRAE's comfort model did not reflect the actual patterns of energy consumption. This study was the first to capture occupant's behavior in relation to thermal comfort and therefore it was imperative to compare the actual consumption to the simulation results.

In relation to occupant's behaviour, the study also found that occupants were aware of the increased use of air-conditioning through the utility bills that increase 6 to 8 times during summer months June to August. It was also noticed that the electricity consumption peaks when Ramadan falls in the months of summer as the hours of TV and air-conditioning increase. In order to shorter working hours, which increases the hours of occupants staying in the apartments which is reflected in the increased hours of consumption (Attia, Evrard & Gratia 2012).

2.2 Building Envelop

Attia & Wanas (2012) Stated that 50% of the total energy is lost through the three main heat transfer outlets in residential and commercial building; which are walls, roof and openings. Aldali & Moustafa (2016) stated that the building envelop is the center of the integrated design process. The building envelop has six different sub-elements that have to be considered in integrated designs: Orientation and building shape, site design, artificial lighting and daylighting, ventilation, heating and cooling loads, and finally, building materials selection. Moreover, the importance considering building problems through the combination of architectural and engineering knowledge.

The researchers aimed to analyze the energy consumption, interior space view and daylighting. The analysis was done in four main steps. The strategies worked on changing the window wall ratio, windows orientations, locations and arrangements. Then an integrated design approach was implemented on the best strategy results, they worked on applying it to different building materials for external walls, windows and roofs, changing windows sizes and orientations, in addition to the number of building occupants as well. In the fourth and final step, a renewable energy resource was added as an upgrade to the building.

The results showed that the heating and cooling loads varied in a range between 88% to 109%. While the total energy consumption of the building varied between 94% to 105% (Aldali & Moustafa 2016).

Wu et al. (2017) aimed to achieve self-sustained buildings in hot-humid area through using a cooling building envelope which can achieve energy conservation and lower life cycle cost. Different building characteristics were studies through using EnergyPlus simulation. While Life cycle analysis was used to derive the best structure to be used for the exterior window, insulation thickness of exterior wall and roof as well as the exterior shading length.

Cooling loads were calculated using different building envelops and insulation thicknesses for the exterior walls and roof in the simulation varying from 0 to 100 mm. Also, it was found out that specifically in low-latitude and hot-humid areas, cooling load is highly correlated with the exterior window. Roof, west, east, north, south was the order of energy conservation possibility for exterior wall and roof as shown by the results. Results also showed the following optimum data to achieve energy conservation and lower costs:

- 40 mm – thickness of east wall
- 30 mm – insulation thickness of south and north walls
- East, south, north – order for exterior window
- Low-e glass – windows structure

2.2.1 Roof Treatments

Dabaieh et al. (2014) stated that the roof has the maximum direct sun exposure compared to other building envelop parts. The study was concentrating on roof effect on indoor thermal comfort in Cairo, Egypt, by simulating a total different roof shapes and materials combined in a matrix that was designed by the author. Simulation of a total 37 roof combinations concluded that the vault roof with high albedo coating caused the maximum reduction in cooling hours and indoor discomfort during summer. However, the results showed that in the case of a flat roof, the flat roof with high albedo added saved the cooling hours in August nearly to the half. Then, the author contradicted his findings with limitations, in his case study it was found that by decreasing the cooling hours by 53%, the heating hours have increased by 24%.in addition to that albedo needs high maintenance and cleaning, especially in a dusty weather like Cairo. Also, it was recommended that albedo can be enhanced by using a final layer with gravel or lime with mineral granules as a final finishing layer.

Roofs account more than 30% of the building envelop horizontal areas and are the most exposed to direct solar heat gain. Both mass and reflective insulation can be used in the case of hot climate, to maintain the maximum reduction of heat loss or heat gain. That will lead to less energy consumption in achieving desired thermal comfort indoor (Aditya et al. 2017).

2.2.2 Thermal Insulation Materials

Thermal insulation has a great effect on heat or cool transfer between the building interiors and the surroundings. That is why insulation is considered one of the most effective strategies in increasing energy efficiency of buildings.

Adiytya et al (2017) examined the effect of using insulation materials on energy consumption arguing that through using environmentally –friendly insulation to achieve thermal comfort would reduce the use of air-conditioning systems, which are the major contributor to the residential energy consumption. The authors gathered the recent developments and studied the effect of using insulation materials on the life cycle and emission reduction in a review study.

Building insulation materials were classified according to the heat transmission properties, form and structure. Insulation materials have different characteristics when it comes to their function in minimizing heat gain/loss classified into two categories: mass insulation and reflective insulation. Mass insulation is preferred and most used method in hot climate as it works on setting back the flow of heat, specifically when used exteriorly to reduce thermal mass and conductivity to achieve low thermal mass. Thickness of the mass insulation is the key in the performance in achieving lower heat conductivity. Mass insulation functionality also depends on the trapped air pockets density of the material which if condensed reduces the insulation effectiveness. Reflective insulation works by reflecting the heat radiation and preventing it from reaching to the other side. The effective of the reflective insulation depends mainly on the emissivity of the material, which is the ability on emitting higher amount of energy. There are four forms of insulations: Loss-fillers spray foam, batts, blankets and rigid board; however, there are several considerations to the insulation choice such as the construction type, rehabilitation plan and the code requirements (Adyitya et al. 2017). Composition of the insulation can be inorganic (i.e. mineral wool, perlite, aerated concrete, foamy glass, etc.) or organic materials (i.e. wood wool, cellulose, expanded rubber, wood fiber, sheep’s wool, etc.) or combined. Organic composed insulation is more environmentally friendly however, inorganic insulation is usually more effective and cost efficient. There are also combined insulation to increase the effectiveness of isolation at a feasible cost. Recently new technology materials are being used to replace the traditional materials such as transparent insulation materials are replacing the traditional opaque insulation materials due to their ability in thermal insulation and heat collection. Insulation materials can be also classified on the raw resource they are derived from. Conventional materials are derived from petro-chemicals such as fiber glass, mineral wool, polystyrene, etc. which is convenient because it can be derived into different compositions.

Insulation can be applied to different parts of the building envelop. walls have the greatest percentage of the building envelop exposed area, that’s why insulation of exterior walls would highly affect the thermal performance of the building. Thermal insulation layer is usually applied in between the layers of different materials of exterior walls for a practical insulation. However, it should be applied on the side that is highly affected by heat, whether it is outflow in case of cold climate or inflow in case of hot climate (Aditya et al. 2017).

El Garhy analyzed energy conservation and thermal comfort in hot arid climate, examining internal wall insulation on indoor thermal performance in Egypt. He claimed that energy can be reduced by replacing energy consumption systems (such as Air conditioning, lightening and other equipment) by using natural building comfort mechanics. In countries with scarce or limited energy, ventilation could be used to replace air conditioning through naturally removing heat gain (El Garhy 2014). He studied a residential flat in Cairo with three rooms with the same orientation and each has with same wall constructions, but different interior walls finish; (i) the wall of the first room (living room) constructed cement plaster followed by 20 cm hollow cement block, plaster of 2cm internally, the same outside construction was applied to the second room (bedroom) and internally gladded

While external wall insulation is considered more effective Al Garhy was rather analyzing the effect of the internal insulation for a number of reasons: (i) inaccessibility of the external wall, (ii) internal insulations prevent heat load from being transmitted to the indoors from the outer space, while (iii) it can also maintain thermal mass inside. (Al Garhy 2014)

Al Garhy also investigated the cost difference between using mechanical cooling methods in comparison to insulation. Through taking into consideration several factors of insulation such as cost of materials, advantages and disadvantages, consumption of natural resources affects the long-run in comparison to the cost of energy consumption using the mechanical means.

Through recording temperatures and the temperature distribution among the three rooms. The results showed that using insulation is key specifically for the roof and sunny facades, in order to achieve thermal cooling without using electricity-consuming systems. Results also suggested that shading is not captured as a key method to reduce energy consumption as it is only used on the building openings but not the sunny facades that contributes most to the heat gain inside the building and therefore the need for higher rates of consumption energy for cooling.

A study was conducted on four buildings in Ras Al Khaima, United Arab Emirates, to examine the usage of solid concrete and dry insulation on thermal comfort performance. The selected buildings had different construction materials. The study was done on a span of two years 2012 and 2014 with cross building examination was done at the same points of time of which a week in summer and another week in winter were selected. The results showed that the heat flux reduction percentages ranged between 22% and 75%, while the average measurements of energy consumption reduction ranged between 7.6% and 23% (Rehman 2016).

2.2.3 External wall treatments

Indoor over heating is a highly concerning issue in some areas of Europe. Heat is retained indoors through radiation, heat gain especially during summer. Hudobivnik et al. (2016) analysed solving this issue by using passive cooling techniques such as shading, ventilation during night, and high thermal load. The study was done on Ljubljana, Slovenia climate zone in Summer, using computer simulations to assess the thermal performance of different building envelops including high / low weight walls construction in response to high intensity passive cooling, ventilation in response to indoor heat mass.

Four phased approach was followed, selection of material thickness / specification and systems and Low / high weight coating systems was followed by collecting the climate data and time periods. In the third phase, limitations and factors affecting the simulation were identified. In the last phase the model was created, and simulation results were obtained. Authors only presented two systems out of all results which were low weight coating system (LWC) and high weight coating system (HWC) and were analysed in relation to the limitations and conditions affecting the model. The two systems' performances were compared to each other given the climate conditions with a focus on HWC system insulation.

The authors have done this study to serve as a guideline to make an informed decision in relation to construction materials based on their reactions to the climate conditions. Further studies is recommended to have a specific guide on the thermal performance of LWC systems to climate conditions (Hudobivnik et al. 2016).

Correlation between passive designs and materials characteristic was investigated through analyzing three building materials: cellular concrete, solid brick and silicate blocks. Simulations concluded that the higher heat accumulation capacity of building blocks, the better the material capability of thermal stability improvements in buildings. It was recommended to assign different wall materials combinations for different elevations' orientations and room uses by testing them using computer simulations first (Dudzińska & Kotowicz 2015).

2.2.4 Glazing

Mahdy & Nikolopoulou (2013) aimed to assess regulatory recommendations to fill in the gap in the EREC Egyptian Residential Energy Code. The did a study in three different locations with a different climate conditions for each location. Cairo, Alexandria and Aswan were the three zones selected, as more than 50% of the built-up area of Egypt is distributed among Cairo and Alexandria locations. While Aswan is known of its unique climate conditions.

some of the glazing parameters of the EREC were investigated using a computerized tool, keeping two types of the most commonly used external wall material combinations in Egypt fixed over the process. Combining the parameters of building envelop elements is considered as an add-up to the Egyptian code, as it only contains separated information for each element.

The research was done on 4 different glazing types in different window wall ratio according to the Egyptian residential energy code. In addition to an economic study for the life cost analysis of each glazing type according to the consumption results of the simulations. The selected glazing types selected in the research are single glass, single reflective glass, double glass with air gap, and double reflective glass with air gap. All reflective glass selected had an 8% stainless steel cover. Keeping in mind that the exterior walls had two main configurations.

An economic study was conducted to validate the most efficient glazing type in terms of energy cost savings compared to the initial cost and the running cost over 88 years, having a simulation using the weather file of every 30 years up to 2080. The simulations were done for the year 2002.

The results were discussed in two different ways; one way was to compare the wall window ratios for each glazing type used. While the other way was to compare different glazing types for each wall window ratio. However, it was stated that the most efficient glazing type is the single clear reflective glass 6.4 mm and 8% cover of stainless-steel, as it showed the highest energy savings compared to its relatively low initial cost compared to double clear glass 3.2 mm (Mahdy et Nikolopoulou 2013).

Windows have the most negative effect on indoor thermal comfort. However, it is still needed for daylighting and view purposes. It is commonly known that windows are insulated by having a double panel sections filled in-between with a gas of a lower thermal conductivity than are, most commonly argon. Besides, low-E coating films, which are known to be invisible metallic oxide layers that are being applied on the exterior side of the window glass panels to reduce solar gain (Adiytya et al 2017).

2.3 Life Cycle Assessment and Life Cycle Cost

Islam et al (2014) analyzed the effectiveness of wall assemblage designs on life cycle cost of buildings through reducing both initial and ongoing operational cost. The future prices are calculated while taking into account inflation and interest rate factor. Various methods of estimating building costs were also analyzed which mainly depends on the purpose of the building and related activities. In order to calculate amount needed for future building expenses during its lifetime, a discount rate was used to discount future costs to their present over a span of time. Islam et al also present previous studies done on lifetime costs of residential buildings, which were analyzing the thermal performance effect on the building / construction costs; however, the factor missing on these studies was the lifetime operational costs of a building and life cycle assessment implications. Future values were calculated through a discount rate recommended by the infrastructure authorities. Islam et al suggested that in order to identify costs in different points of time of the building life, using life cycle costing and life cycle assessment is key (Islam et al. 2014).

Udawattha & Halwatura (2017) studied the different walling materials to be used to achieve lower total costs of building. In order to identify the feasibility of the walling material, ratio of the walling material of the total cost was calculated. The higher the ratio the lower the cost reduction. They have also addressed the LCC which take into consideration the initial / construction, maintenance and disposal cost. The cost of materials which can be recycled were removed from LCC calculation, while omitting the recycling cost. Limitations of this study were the consideration of the environmental impact which helps in assessing the sustainability of the walling materials among other limitations such as the social factors, the availability of workers that are skilled to construct the walling material and manufacturing of walling types (Udawattha & Halwatura 2017).

Further to Islam et al 2014 study on wall assemblage ways to reduce life cycle costs ("LCC"), in another study Islam et al analysed reasons for using the life cycle cost approach for residential buildings. Several studies suggest that LCC is used for cost information consolidation purposes for both designers and clients to be able to make informative decisions on scenarios to use based on costs. Other reason would be to show energy conservation financial gain. Mainly LCC is a general tool to measure total investments, while annual maintenance, operational and disposal costs can also be included. As suggested by the other study of Islam et al (2014) both initial and ongoing costs can be combined using inflation and discounts rate to reflect real value of expenses over the lifetime of the building. Discount rate is used to calculate present value of the amount needed to finance the expenses over the lifetime of the building. Some LCC studies use both inflation and discount rate in while most commonly they drive the net discount rate. However, the estimated inflation and discount rates can be inaccurate considering the long lifetimes of buildings. Accuracy of the rates could also be affected by the market value of a property and individual prices of materials. Therefore, LCC could be misleading from the real future costs. Several studies explored the reduction of uncertainty to achieve higher accuracy. Some studies used sensitivity analysis to the effects of uncertainty to be able to make an informed choice of a more accurate discount rate. According to Davis Langston Management Consulting "DLMC" (2007), many LCC studies do not include the inflation rate, while other suggests that if real cost is used there would be no need to include the inflation rate in the discount rate. While another study used current cost for both initial and ongoing costs without taking into consideration inflation rate (Islam, Jollands & Setunge 2014).

2.4 Codes and regulations

Ayyad & Gabr (2012) analysed of both the enforced Unified Building Law No.119/2008 (the main building code in Egypt) and the potential of enforcement of the Green Pyramid Rating System through assessing its public review as a leading point to green building potential in Egypt. Comparing both codes with a focus on the already enforced Unified Building Law. International codes were also added to the analysis such as the International Green Construction Code (IGCC), which was the first to include the manual for sustainability for full projects. ASHARE standard also was included in the analysis, which supports designing Green High-performance buildings to examine the potential of adopting such green standards in the Egyptian code.

Review the current legislation would be an essential step towards the development of green codes in Egypt. Clauses of the Unified Building Law no.119 released 2008 and appendix do not address green aspects of building, many of which were rather included in the review done in April 2011 by Egyptian Green Building Council (EGBC) established in 2008 in cooperation with the Housing and Building Research Centre (HBRC) to the Green Pyramid Rating System (GPRS). However, there was nothing definitive in the review of when such finalised rating system would be released or implemented (Ayyad & Gabr 2012).

The Egyptian Unified Building Law no. 119/2008 was ratified on May 11th, 2008 by the house of parliament after being released by a presidential decree. Its main purpose was to have a reference of regulation for the building sector over the republic. The minister of housing released an executive appendix for the “Unified Building Law” in April 2009. On the same year, the Green Building Rating system was released by the Egyptian Building Counsel and House and Building Research Centre.

Moreover, the authors compared the two codes, Unified Building Code and Green Building Rating System Code, to each other and found out that there is huge inconsistency between them. As the articles of the Unified Building Code and its’ executive appendix gives permits that are not complying with the GPRS. In addition to that, the Unified Building Law is not referencing any green building regulations. On the other hand, the GBRS does not have any references to the unified building law being the main source of permits (Ayyad & Gabr 2012).

The Egyptian building code obviously needs to have some sort of modifications to be able to follow up with sustainable trends in the international scale. In order to do that, there are some recommendations in terms of building envelop. It is needed to classify the 8 bioclimatic zones of Egypt and create a guide for a set complying building envelop materials and techniques for each climatic zone. Moreover, Bioclimatic analysis and calculations must be an obligatory document that necessitates particular permissions.

Energy efficiency building code for residential and non-residential buildings was developed by the Egyptian Housing and Building National Research Centre through United Nations funding to raise awareness on energy consumption. Electricity consumption rate is increasing by an estimate of 8%, which is a high rate of demand to resource. A simulation analysis was conducted to identify energy conservation solutions as part of developing the code, where three buildings of different functions were studies: a hotel, office and residential. According to the results of the simulation, it was found out that building envelops, and fenestrations are solutions to achieve energy conservation in buildings. This study outlines the simulation outcomes and the suggested thermal comfort designs solutions and its influence on energy consumption rates for both residential and non-residential buildings in Egypt. VDOE was used as the simulation tool to test building specifications (Hanna 2011).

Residential Energy Efficiency Building Code (EEBC) was published in 2005 by the Building Research Council (HBRC), which gave specifications for U-values and R-values of opaque elements and glazing U-factor and Solar Heat Gain Coefficient (SHGC) for the wall to window ratio. However, the U-values of opaque elements were specified only for roofs and external walls but not for floors and ground decks. The code also lacked more detailed materials thermal properties. Producing this code was a first step toward enforcement of a law in relation to energy code. The main three steps toward enforcement of such law are development, implementation and administration and enforcement or voluntary compliance with incentives (Attia & Wanas 2012).

The following 11 chapters are included in the The New Egyptian Building Energy Codes which were published in 3 volumes (Hanna 2011):

(1) Scope and compliance;
(2) General requirements;
(3) Building envelope;

(4) Natural ventilation;
(5) Heating ventilation & air conditioning;
(6) Service water heating system;
(7) Day lighting;
(8) Lighting;
(9) Electrical power;
(10) Whole building performance;
(11) Definitions, abbreviations acronym.

Sheta & Sharples (2010) stated that as per the Building code in Egypt, the materials used in construction are traditional. For instance, building envelop structure would be as follows:

- Red brick (12 cm)
- Thermal plaster and acrylic based paint for contracting and expanding purposes for the exterior finish (5cm)
- Cement plaster and paint interior finish
- External walls total u-value is 2.35 w/m^2k
- Interior partitions are made up of: thick red brick (2 to 3 cm) & finishing of both sides by cement plaster and paint 3.242 w/m^2k
- Floors suspension thickness of finishing (10 cm)
- Insulation of roofs with: Mineral wood (7cm) and damp proof (2cm) 0.49 w/m^2k
- Windows are singly glazed by a clear layer (6mm) and aluminium frames; u-value is 6.144 w/m^2k
- Window to wall ratio of 20%
- Door are from wood

2.5 Climate in Egypt

Egypt is located in the warm dessert climate zone as shown in Figure (2.1) (Kamal 2016). The year is divided into two seasons only; in months May to October average temperatures hits 35°C in extremely hot summer season. While in months between November and April is the winter season, where the temperature reaches 5°C. The Precipitation rate in Egypt overall is very low, around 100 millimeters per year. In Cairo, the weather is mostly dry, however in summer, the humidity levels are relatively high due to the presence of the Nile River. Undesired wind of Dusty storms usually occurs between March and April. (World Travels 2018)

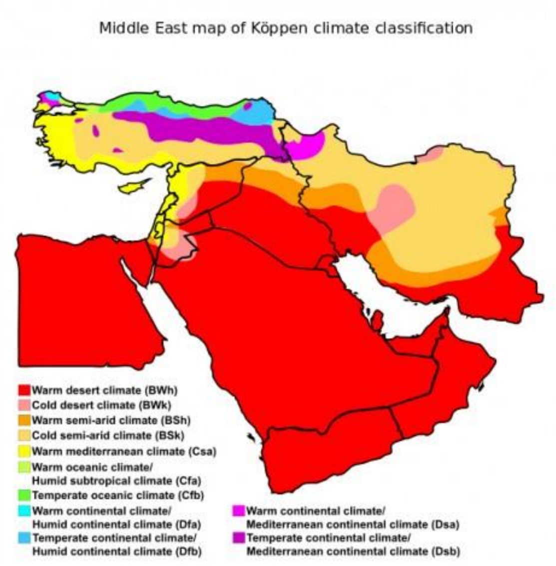

Figure 2.1: Middle East Climate Zones (Kamal 2016)

The climate characteristics in Egypt as per Koppen Climate Classification System (2018); Egypt is classified as hot climate arid. Except for few days of rain in the months of January and February and humidity in the winter, it is hot and dry most of the year. Winter months fall between December to February, which is featured by being cold, moist and rainy. Summer months fall between June to August with hot, dry and clear sky weather. While the Spring season falls on March to May which weather is characterised by hot and dry winds with dust or also called 'Khamasin' which is derived from the number 50 in Egyptian Arabic and refers to that It stays for 50 days. Khamasin increases air pollution as it is associated with dust. On the other hand, the favourable season of autumn falls on September to November with its moderate climate.

In Cairo the yearly average temperature is 21.7°C. July is recorded to be the warmest month where 28.3°C is the average temperature and the highest peak of the year which is 45°C. While in January is the coolest as the recorded average temperature is 13.9°C, 0°C is the lowest recorded temperature as the lowest peak of the year (Koppen 2018).

As per Climate Consultant software, the monthly temperature hits the maximum at 40 to 44°C in summer, while in winter the minimum temperature reaches 7°C. All values are measured in 50% relative humidity condition. In higher relative humidity ranges the temperature increases or decreases based on the season.

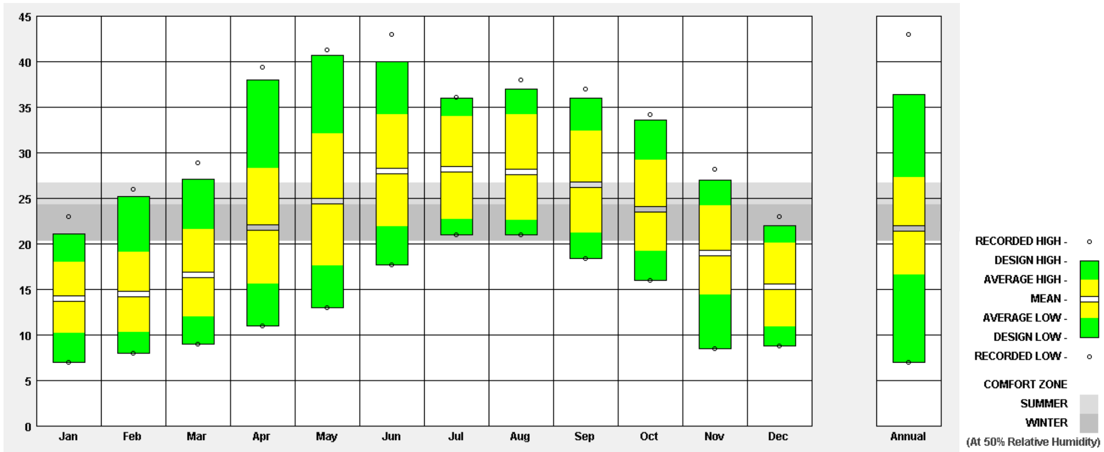

Figure 2.2: Monthly Temperature Ranges (Climate Consultant)

While the Sky cover range graph shows that the mean sky cover percentage us less than 20% over the year. However, it reaches the highest in January with 70% coverage. It is mostly sunny over the year.

Cairo's yearly precipitation rate on average is 25.4mm. January has the highest precipitation rate of 5.1mm. while the lowest precipitation rate is in May and June 0.0mm. it rains 17 days in average yearly, where 5 days of them occur in January (Koppen 2018).

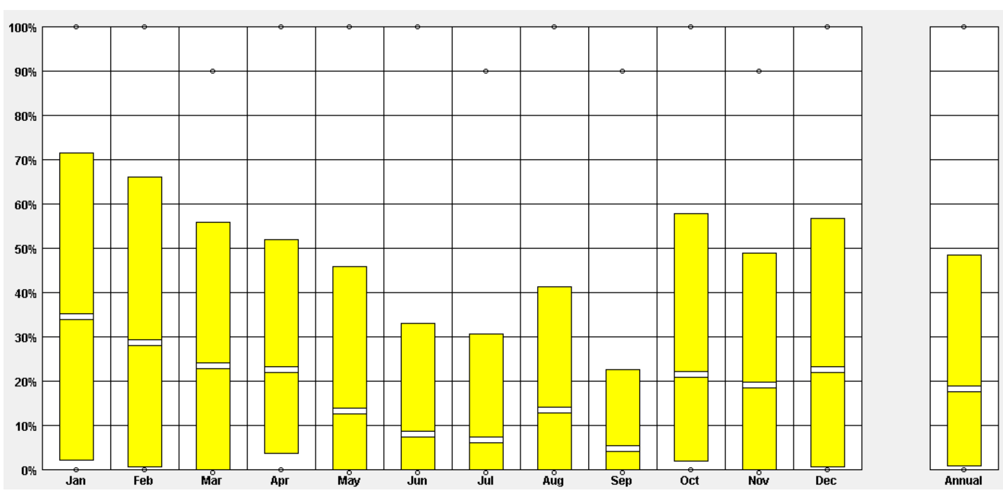

Figure 2.3: Sky Cover Range (Climate Consultant)

The climate conditions in Cairo, Egypt is really challenging in terms of achieving indoor thermal comfort with minimized energy consumption. It gets so cold in winter and extremely hot in summer, which means that both, heating and cooling loads have to be maintained or reduced using different combinations of building envelop elements that can work in both, passive cooling and passive heating and this would be the biggest challenge.

3 Methodology

Different approaches and methodologies were used to analyse the correlation between building materials characteristics, thermal comfort, and saving on energy consumption. Several aspects and perspectives on the effect of thermal comfort on energy consumption were studied; the choice of specific methodology was based on the main aim of the study. The performance of different construction material combinations and their features influence on thermal comfort in passive buildings was investigated. While other studies focused on the combination of various types and forms of insulating materials and its impact in optimizing on the cost of insulation and optimization of energy efficiency. While others investigated not only the recent trends in insulation materials, but also materials that are yet to be introduced to the market, through testing their behaviors and limitations. While literature review was commonly used across these studies, the main two methodologies used were computer simulation and experimental.

3.1 Studies based on Simulation

Simulation methodology is a more useful tool from the practical side. It can be used to analyse data from the start till the end of a project from the designing phase up until the construction and after it is actually built and in use. Simulation helps its users to make an informed decision from the designing phase and before proceeding with construction. It is an expensive software which is easy to access, however its physical / computer results would require validation as it can be unreliable due to the software limitations.

Simulation methodology using FORTRAN software was used to test perforated masonry red brick used in Egypt. The study examined the result of filling this brick with materials that have low thermal conductivity on its thermal comfort performance. The simulation was done through plugging in the dimensions of the brick assuming the rest of parameters in a numerical equation (Bassiouny, Ali & NourEldeen 2015).

Further studies were conducted using simulation; Dudzińska & Kotowicz (2015) studied the effect of thermal capacity of construction materials of a passive building of a school on thermal comfort. Silicate blocks, cellular concrete, and solid brick were the three materials studied using design-Builder software. The study was performed during the summer to find a solution for heat retention including other parameters such as the energy consumption, CO2 emissions, sun light, thermal conditions and microclimate analysis.

(Aldali and Moustafa 2016) Used computer simulation tool (ECOTECT) to analyse the thermal performance and lighting behaviours in a high-income house in Madenaty city in Egypt. The main purpose of the study was to test the energy performance and building behaviours in early design stages. Their main aim was to achieve lower energy consumption by enhancing Daylighting, View and thermal comfort so that heating, cooling and lighting energy would be reduced.

The paper stated that using integrating computer simulation methodology in the early design stages and powering Architects with such software will have a great impact in building more energy efficient and environment friendly residential buildings.

They considered parameters such as occupancy, internal gains, infiltration rate, clothing factor, humidity, air speed, and lighting level. The study was done in four successive stages. All the previously mentioned parameters were fixed throughout the first two stages of analysis, while in the third stage, different building envelop materials were tested in addition to varying the total number of building occupants (Aldali et Moustafa 2016).

3.2 Studies based on Field/Experimental Methodologies

As one of the two most used methodologies, several studies field / experimental methodologies such as field monitoring through which the influence of the materials on the thermal performance can be measured and examined.

Field monitoring was used by Tariq, Zebun & Ahmed (2013) to study the thermal performance in relation to different roof treatments. They have based their study on six residential buildings in Dhaka Bangladesh where they recorded temperatures using Pocket Weather Meter (Kesrel 3000) for 3 days in April 2011, focusing on three different spots: indoor, outdoor and roof surface. The effectiveness of the materials combination used was identified through the difference between the temperatures recorded for the outdoor and indoor roof surface. The six buildings were selected with similar physical characteristics in order to minimize the external effect of surroundings on the temperature differences. Recorded temperature reading were taken from three points of the buildings; first point was one meter above the roof to measure outdoor temperatures, and the second point was directly below the roof surface to measure the indoor temperatures. Temperatures recorded on the first point was compared to the second point and on through which lead to the optimal roof treatment.

Using field measurements Al-Garhy (2014) studied the effect of external walls insulation on the energy conservation. He studied three rooms (with the same dimensions and orientation) in a residential flat with three different internal walls construction. While the external wall constructions were the same, the internal wall constructions were different which in turn had different effects on the thermal conductivity. Using Thermocouple linked to a scanning thermometer, temperatures were recorded on four main spots per each room. Temperatures were recorded on a span of 14 days in the months of July and August which are the hottest in Egypt through which Al Garhy was able to identify the hottest two days out of the 14 days’ recordings.

A study was done in the UAE as a hot humid climate; field measurements were conducted on solid concrete and dry insulation as construction materials thermal performance (Rehman 2016). Four building were studied with four Calorimeters that were set 6 meters apart to record measurements. One of the four buildings served as a base case of the traditional façade building materials used in the UAE. The other three building had different materials: the first building had reflected coating layer, the second building had insulation layer, and the third had solid concrete wall which is traditionally used.

A study was done to examine the thermal conductivity of soil cement block with varying mix ratios. To measure the heat conductivity a QTM-500 meter was used which works through hot wire transited. Natural soil is made up from clay, sand and slit fractions. In the first phase of the study, the measurements were taken on different proportions. In the second phase the thermal performances were derived as well as the correlation between the time lag and decrement factor using different proportion. The results showed that the material's dry-density mainly lead to the thermal conductivity, the correlation for soil-cement blocks is 100 kg increase in density to 12.5% increase in thermal conductivity (C, K & Reddy 2015).

3.3 Literature review Methodology

Literature review is by default a basic component of any research study. It is critical at the initial phase of any study to have a research question, which mainly arise from the gaps found in previous studies done in the same field. In addition, literature review is a key to develop the necessary knowledge and background to be capable of conducting a study on the relevant research question. In this study, literature review has been done to identify the relevant methodology to use by reviewing methodologies used on similar studies. However, literature review known limitation is the lack of contributing additional knowledge or input to the subject under study; rather it is a mere combination of other studies previously done.

Manzano-Agugliaro et al. (2015) conceptualized the relationship between exterior climate conditions and indoor thermal comfort using literature review methodology. A review was done on the bioclimatic architectural strategies development. In addition to analyzing the effectiveness of bioclimatic different strategies on energy saving based on various building locations. The authors categorized the bioclimatic strategies into 14 different zones of climate depending according to temperature and humidity levels and investigated different building practices in terms of vernacular and bioclimatic architecture worldwide.

Applicable passive strategies in heating and cooling were studied based on previously climatic data recorded and research work done (Tejero-Gonzalez et al. 2016). The energy conservation targets that depend on using passive techniques were studied based on climatic data collected on both yearly and daily manners. The paper works as a guideline to data collection methods and representation.

Adiytya el al. (2017) reviewed building energy conservation and its relation to insulation materials. The authors classified insulation material based on several aspects, according to materials composition, form and heat exchange properties. Several thermal building insulation materials' state-of-art were reviewed, such as, phase-change materials, closed cell foam, gas filled panels and vacuum insulation panels. Moreover, an economic analysis was covered, in addition to different building practices in terms of thermal insulation applications.

3.4 Mixed Methodologies

Different research methodologies can be combined in one study, this is called mixed methodology. This combination provides more power to the researchers. It helps with validating the finding of any research. For instance, combining surveys and field measurements, or simulation and field measurements, actually there is much more probabilities in mixing methodology, as it depends on the research question and the addressed topic. However, Documentation and organizing tasks and findings is essential part in this kind of studies.

Reda et al (2015) used a combined methodology of survey and computer simulation to investigate the different factors of reducing the energy consumption of residential buildings in Alexandria, Egypt. The buildings Typology and the survey sample information was studied in terms of life standard of family, age, and occupation. While the survey was mainly done to collect data regarding how the occupants would deal with windows, operable shading systems, and domestic hot water usage. All the collected data was inserted in the energy models used in stage two and three of the research. The occupancy, cooling, heating and lighting profiles were inserted, in addition to cooling and heating set points and months. Two scenarios were analysed using TRNSYS and TRNBuild software in addition to Google Sketchup for building the main model.

In a study that aimed at identifying the energy consumption in relation to consumer behaviours of air-conditioned residential apartments. Attia, Evrard & Gratia (2012) used combined methodologies in this study. There were three steps: (i) literature review; on previously done surveys, (ii) field survey; to capture types of buildings, construction, dimensions and appliances, (iii) Bench-marking two samples of air-conditioned apartments to conduct parametric simulations on. Simulations were done using the Energy-Plus program to capture the energy performance of the sample apartments. Temperature hourly records for the three cities obtained from the Egyptian Meteorological Authority (EMA) were formatted as an input to Energy-Plus.

Attia & Wanas (2012) implemented three-phased methodology was used to develop an understanding of the building construction on the energy consumption. Firstly, data were compiled together on residential building envelops characteristics in Cairo and surrounding new districts. Secondly, commercial buildings in Cairo and Egypt were analysed. Thirdly, methodology and further steps to be taken in order to develop the database were explored. Authors suggested that four main steps as listed below were to be taken to be able to put the date base together (i) Review of standard construction materials used in Egypt. (ii) Conducting a field survey on the already used construction structures. (iii) Categorising data gathered on materials and construction structures. And (iv) Data modelling using simulations

3.5 Selection and justification of preferred methodology

Preferably, two stage approach would be the preferred for this study while using two different methodologies. First phase would be a field study to record all measurements on the building under study. The second phase would be to analyse the data collected through simulation. However, such approach requires extensive time for data recording and funding for a team of researchers and equipment required.

For that reason, simulation will be used for this study without the field study due to the previously mentioned limitations. It was also noted from the previously done research that it is the most feasible approach. As simulation methodology is a time efficient tool to asses more than one variable without a prerequisite for physical models.

In simulation methodology, more control is provided for parameters so that the unmanageable circumstances of field monitoring can be prevented. Moreover, the research question requires investigating the thermal performance of the building being affected by different building envelop treatments in a full year-round, in order to study heating and cooling behavioural changes. Such a study can be ideally done using simulation methodology.

Nevertheless, literature review is essential in reviewing previous work done and also to include codes developed in Egypt on building regulations and green building. Through this review all aspects of building in Egypt will be addressed covering materials used in construction, thermal comfort effectiveness and energy conservation strategies studied.

At last, the main methodology selected for answer the research question is mixed methodology, two methodologies will be used, literature review, and computer simulation methodologies.

3.6 Software Selection

The selected software for this study is IES-VE (Integrated Environmental Solutions – Virtual Environment). It is a software that tools up architects and engineers to test and investigate their designs from early stages. ApacheSim application is responsible for calculating building's energy behaviours, depending on the parameters entered to the model. The software is compatible ASHRAE standards. It gives the opportunity to investigate building and system relation to environment, which leads to more sustainable designs of high thermal performance, in other words energy efficient and high thermal comfort.

Various topics can be handled using ApacheSim application. The placement and type of thermal insulation materials, thermal mass of building envelop, orientation, shading design, glazing types, building configuration, sensible loads, latent loads, heat gains, internal gains, ventilation systems; natural, mechanical, mixed systems, and HVAC designs.

Building's exteriors and interiors heat transfer properties can be addressed. Real climate conditions can be applied to the simulation model by using AP-Locate built-in application. The simulation time laps can be detailed up to one-minute simulation in one day up to a full year time interval.

The results of ApacheSim simulations can be accessed through Vista, which is a tool used for presenting analysing data. It consists of six different categories, classified as follows, weather, building, room, surface, opening and systems. Building category is divided into 4 main sub-categories, loads, energy, carbon and cost. For each category or sub-category there is a set of variables that are being used to present the data in numerical way.

In a research done by Crawley et al. (2008) to review the capabilities of different simulation software tools, IES-VE has been compared with other software in terms of general modelling, building envelop, daylighting and solar, in addition to zone loads, electrical systems and equipment, environmental emissions and climate data availability. All these comparison data are attached in appendix (C).

3.7 Research Parameters

A residential building in a residential district named "Zaid Residence" in Cairo, Egypt is selected to be the base case of all the upcoming research strategies. To perform the study, several variables will be assigned to the simulation model, however, some other parameters will be neglected from the study, so that the output justifications would be visibly tracked. The main point of comparison between different treatments would be the total electricity consumption and the economic study represented in calculated payback period. Based on the research motivation and literature review done, the main focus of research parameters will be building envelop that is represented as follows;

- **External wall materials:** aside from the core and shell construction, The external wall brick will be assigned in two different materials to analyse the effectiveness of each
- **External wall thermal insulation**: an extra layer of thermal insulation will be added to the external walls. Three different materials will be assigned, each with two different thickness. The assigned thermal insulation materials will be selected based on a local market study in Egypt.
- **Exposed roof thermal insulation treatments:** an extra layer of thermal insulation will be added using two different materials. The investigations will be done in two cases; the full building and the last floor only (Fifth floor).
- **External Glazing:** five different glazing materials and combinations will be investigated in terms of electricity consumption, cooling and heating sensible loads on a monthly basis to get a closer look to the impact of each on indoor thermal comfort.

An economic study will be done for each of the above-mentioned parameters, by calculating the difference in material prices between the base case materials and the newly assigned materials in each case. The corresponding electricity consumed will be priced as well. A payback period equation will be conducted based on these two variables, material price difference, and savings in electricity consumption.

Based on the results of each simulation and calculated payback period, two cases will be selected from each parameter, wall materials, roof treatment and glazing: The one that has the highest energy savings, and the one that has the lowest economic impact.

A matrix of the previously selected options will be conducted to get the results of combined parameters in one simulation.

4 Simulation Preparation

4.1 Introduction

The study will be conducted on residential complex Zaid 2000 Residence located in El Sheikh Zaid, Cairo, Egypt. It consists of residential villas, town houses and apartment buildings. The apartment buildings are the selected zone of study. It was selected due to the author's experience of living in, and wide knowledge of various parameters from construction to environmental behaviours. In addition to that, the location of the project and the standard of living have the potential to be improved through implementation of the recommendations outlined by this study, which will make it a good example and real validation for the simulation results.

Various visits and site investigations have been done to get a complete image about the location and its surroundings. The building consists of ground floor and four typical floors; each floor contains four apartments with a total number of apartments per building of 20 apartments. In that project, each building is exposed to at least two elevations, while the selected building is a stand-alone building where its four sides are exterior elevations. Moreover, it has the widest setbacks to adjacent buildings, which makes it more exposed to sun radiations and other environmental factors that may affect indoor thermal comfort. Figures 4.1, 4.2, and 4.3 shows the location of the project and selected building.

Figure 4.1: Zayed Residence Compound (Dorra Group 2012)

Figure 4.2: Zayed Residence Location (Google Earth 2018)

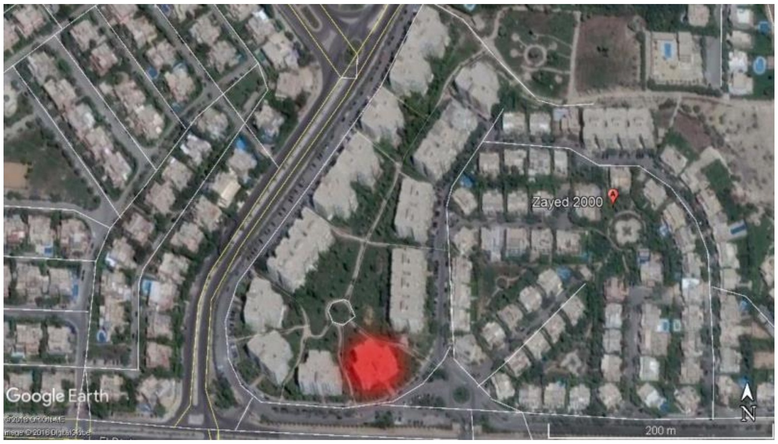

Figure 4.3: Selected Building Location (Google Earth 2018)

4.2 Actual Built Project

As a preliminary stage, a base case model must be created in a way that complies with the actual case study conditions. The simulation will be done in a scale of a full residential building, which is selected as mentioned above. However, it would be challenging to validate the actual energy consumption of the case study to the virtual environment.

For validation purposes of energy consumption, electricity bills of year 2016 was collected from a tenant of a three-bedroom apartment of total area 190 square meters that was selected to be the base case of validation process. The apartment is located on the third floor with two exterior elevations; the main elevation is north west with a total Wall Window Ratio, WWR 31.6%, while the side elevation is south west with no openings at all. The total internal height of the apartment is 3 meters. Figure 4.4 shows a detailed plan of the building's typical floor with the selected flat highlighted in red. The occupants of the apartment area family of four; two adults and two kids.

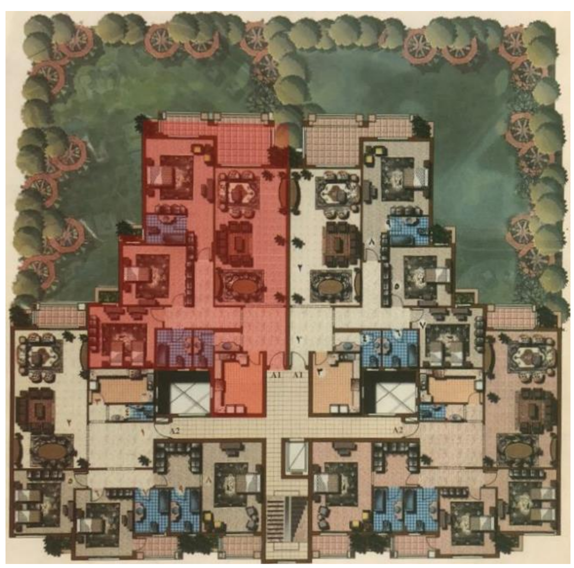

Figure 4.4: Typical Floor Plan

4.3 Base Case Construction Materials

Construction materials have been identified through the author's investigation during the site construction. In addition to that, an interview has been done with one of the consultant team members who worked on this project (Farouk 2017).

In order to validate the IES-VE model, real construction materials were assigned to the model to get the same u-values of building envelop components. Table (4.2) shows the materials that have been assigned for the base case model based on the real base case, each with its corresponding thermal specifications and thicknesses (Farouk 2017).

Table 4.1: Base Case Construction Materials

	Total Thickness (mm)	Total U-value (W/m^2K)	Materials (outside to inside)	Thickness (mm)	Thermal conductivity (W/m.K)
External walls	290	2.35	Plaster	20	0.5
			Hollow Cement Block	250	1.6
			Plaster	20	0.5
Internal walls	165	2.39	Plaster	20	0.5
			Hollow Cement Block	125	1.6
			Plaster	20	0.5
Roof	562	0.49	Cement Tiles	20	1.1
			Tile bedding	20	1.4
			Sand	150	0.35
			Bitumen layer	2	0.5
			Screed	100	1.15
			Thermal insulation (EPS)	50	0.0393
			Reinforced Concrete	200	2.3
			Plaster	20	0.42
Internal ceiling/ floor	290	2.06	Marble Tiles	20	2.77
			Tile Bedding	20	1.4
			Reinforced Concrete	200	2.3
			Plaster	20	0.42

	Total Thickness (mm)	Total U-value (W/m^2K)	Materials (outside to inside)	G-value (EN 410)
External glazing	6	5.60	Clear Glazing	0.82

4.4 Climate Conditions and User Profile Details

AP Locate is used in IES-VE to select the weather file and location. By selecting Cairo, Egypt as a location, the weather file uploads an hourly calculated weather conditions for a full calendar year from the software system to the simulation model, Figure (4.5). All the simulations are done on a full year bases, so that the difference in total energy / electricity consumption is monitored in addition to cooling and heating plant sensible loads.

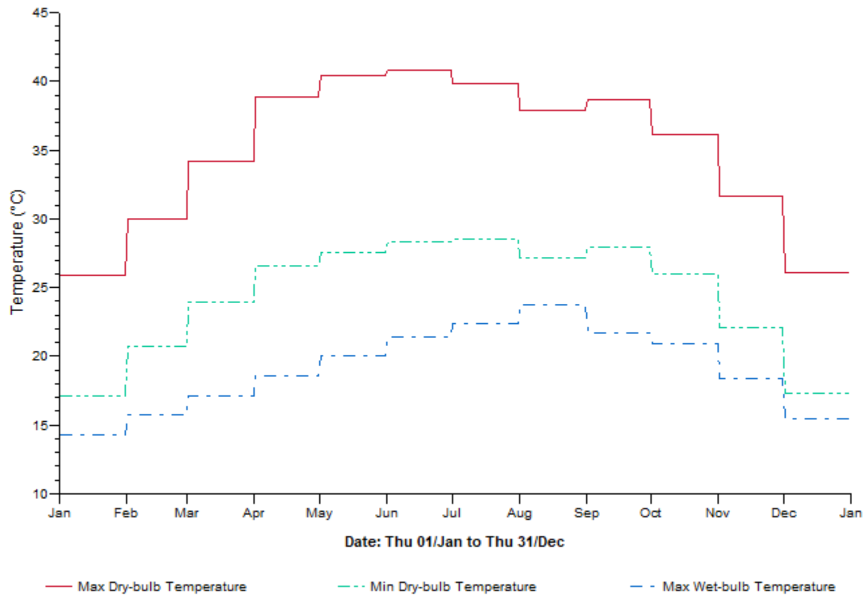

Figure 4.5: Annual Graph of Weather Data for Egypt (IES-VE)

As mentioned before, the occupants of the apartment selected for validation are a family of four, two adults and two kids. The tenants were interviewed regarding their actual detailed user profile in cooling, heating, lighting, occupancy and the appliances used inside the apartment. All the reported details have been imported to the IES-VE system in the form of different thermal profiles, having different internal gains, depending on the room type and usage.

It should be also considered that the heating system in the IES-VE is depending on Natural gas. As such, its calculation is done separately from the electricity meter. While all the heating systems in Egypt depend on electricity including all types of heating devices. Therefore, the initial source of heating energy in residential buildings is electricity. So, in the model, the heating energy source has been converted Natural gas meter to the electricity meter of the apartment.

A normal family in Egypt would have 3 different occupancy profiles over the year, academic year days, holidays or vacations, and Ramadan. Ramadan takes a month each year and the occupancy profile changes depending on the season that Ramadan fall on, changes in working timings and overall Egyptian traditional behaviours during that month. Occupancy profiles affects all other variables such as cooling, heating and artificial lighting profiles.

Moreover, each zone of the apartment has a different occupancy profiles; the living room bedrooms, and kitchens. Internal gains differ in each zone depending on the number of people occupying the space, profile of occupancy, lighting type, appliances and their sensible and latent heat gains. All these variables have been set up on IES-VE for each zone; living room, bedroom, kitchen, bathrooms and common areas like corridors, entrances and service rooms.

In validation step, the user profiles were applied on the selected flat in addition to adding adjacent buildings on the project layout. In step two, the simulations will be done to the full building, it has been applied to each zone for all the flats in the building assuming that all flats fall under the same profile.

Appendix (A) shows all the daily, weekly and yearly profiles assigned to the project base case, in addition to the internal gains for each thermal template, shown in Table 4.2. While the following Figures 4.5, 4.6, and 4.7 show different profiles assigned for the full project.

Table 4.2: Thermal Templates applied to the project

Thermal Template	Cooling	Heating	Occupancy	Internal Gains
Living Room	✓	✓	✓	✓
Bed Room	✓	✓	✓	✓
Kitchen			✓	✓
Bath				✓

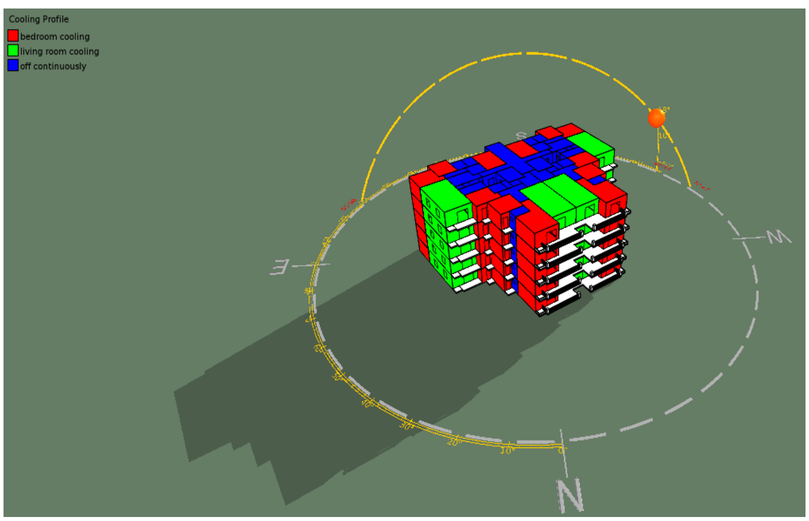

Figure 4.6: Cooling profiles assigned to the project (IES-VE)

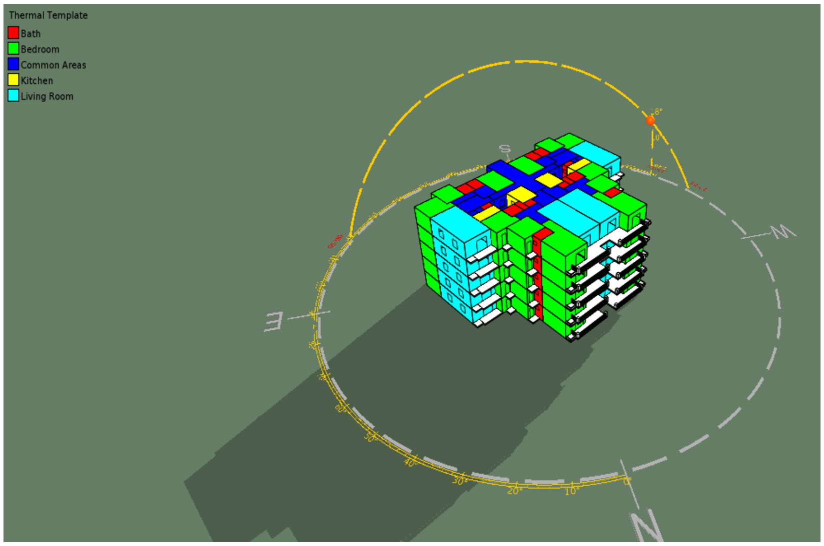

Figure 4.7: Thermal Templates assigned to the project (IES-VE)

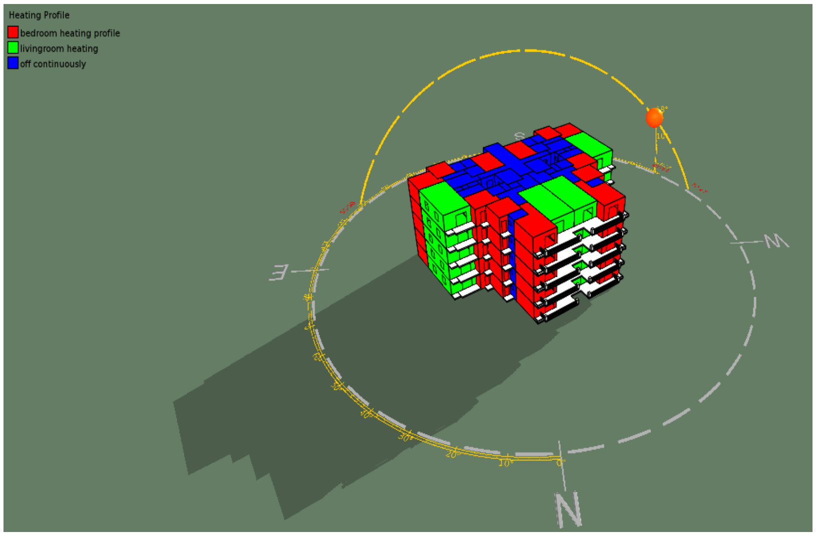

Figure 4.8: Illustrates Heating profiles assigned to the project (IES-VE)

4.5 Base Case Validation

As mentioned before, only one flat in the third floor is used for validation process. The selected building has been modelled on IES-VE software. Ture north has been inserted along with the adjacent buildings, and local shades. As per the feedback from the tenant internal gains, occupancy, cooling, heating, and lighting profiles have been inserted as well. The real monthly electricity consumption in (Appendix B) is compared to the simulated model. Figure 4.8 shows the location of the selected flat and thermal templates of each zone.

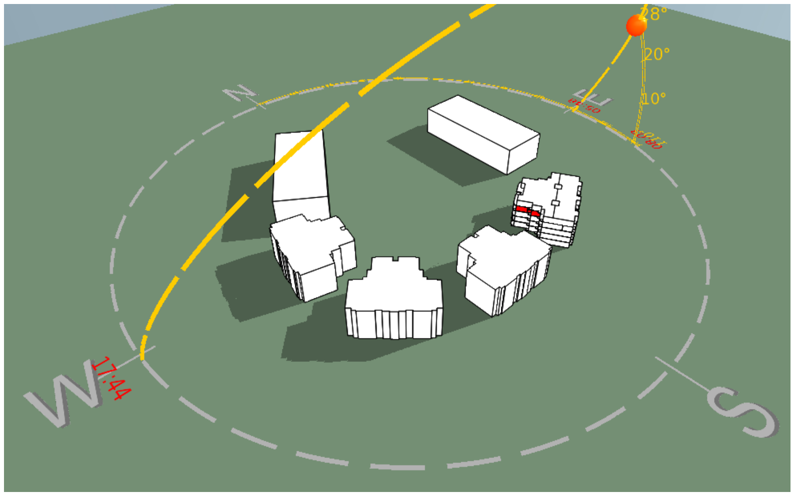

Figure 4.9: Selected Flat Location and Orientation (IES-VE)

The real consumption of the apartment has been tracked over the year 2016 by viewing the electricity bills. The base case Apache Simulation results showed the model total electricity consumption, which has been compared to the base case for each month and the total over the year within an allowed tolerance 5% difference (Taleb 2017). Table 4.3 shows the total electricity consumption both real and simulated along with the tolerance percentage for each. The comparison shows that the summed total consumption over the year has 0.59% to that of the actual consumption.

The tenant mentioned that the apartment was completely closed in the timings between 11th of February until the 8th of March, and again between 11th until the 26th of May. While in October and November there were extra 3 people in a long stay visit, which made it challenging to capture the actual consumption profile of the original occupants for cooling, lighting, and occupancy.

Table 4.3: Real Electricity Consumption Monthly Rates

Date	Real Consumption	Simulated Consumption	Difference Percentage	Notes
Jan 01-31	0.57	0.60	-5%	
Feb 01-28	0.20	0.57	-189%	Travelled 19 Days
Mar 01-31	0.23	0.33	-46%	Travelled 9 Days
Apr 01-30	0.36	0.38	-5%	
May 01-31	0.33	0.81	-145%	Travelled 16 Days
Jun 01-30	0.61	0.93	-54%	Average tolerance = -3%
Jul 01-31	1.28	1.06	17%	
Aug 01-31	1.13	1.04	8%	
Sep 01-30	0.77	0.87	-12%	
Oct 01-31	1.32	0.61	54%	extra 2 people
Nov 01-30	0.77	0.32	58%	extra 2 people
Dec 01-31	0.43	0.44	-1%	
Summed Total	**8.00**	**7.95**	**0.59%**	

Several newspapers stated that the electricity meter readings in Cairo, Egypt are not recorded monthly, instead they are derived by calculating the average consumption and read the actual consumption every 2 to 4 months (Ramadan 2015). In addition to that, on the IES forum page (JosephG 2009), it was stated that using only electricity bills for validation process is not recommended due to the difference in time scale of calculating energy consumption. On IES-VE it is calculated in an hourly basis, while the real consumption bills are monthly estimates and the actual consumption rates are only monitored every 2 to 4 months by utilities. For this reason, summer months (June, July, August and September) have been validated together assuming that the readings have been taken as average. The results are shown in Table 4.4, the average tolerance difference is found to be 3%.

Table 4.4: Validation of Summer Season

Date	Real Consumption	Simulated Consumption	Difference Percentage
Jun 01-30	0.61	0.93	-54%
Jul 01-31	1.28	1.06	17%
Aug 01-31	1.13	1.04	8%
Sep 01-30	0.77	0.87	-12%
Summed Total	**3.78**	**3.89**	**-3%**

4.6 Full Building Results

Following the validation process, a full building analysis is done. To do the analysis of the project from the practical point of view, all the probabilities will be applied on the full building simulation and compared to the base case results.

All the thermal profiles created for the base case apartment is applied to the full building apartments with the same details of user profiles mentioned above in section (4.4). Only the adjacent buildings parameter is excluded, while the north direction is set to the true north of the building case.

Table 4.5 shows the results of simulating the building as a base case before applying any scenarios. The total electricity consumption is 218.52 MWh.

Table 4.5: Full building base case simulation results

Date	Room heating plant sens. load (MWh)	Room cooling plant sens. load (MWh)	Total electricity (MWh)
Jan 01-31	0.36	0.00	12.84
Feb 01-28	0.06	0.00	11.94
Mar 01-31	0.00	0.00	11.22
Apr 01-30	0.00	2.53	12.12
May 01-31	0.00	22.36	22.40
Jun 01-30	0.00	28.70	25.21
Jul 01-31	0.00	34.27	28.35
Aug 01-31	0.00	33.77	28.11
Sep 01-30	0.00	26.73	24.23
Oct 01-31	0.00	15.60	19.02
Nov 01-30	0.00	1.12	11.42
Dec 01-31	0.04	0.00	11.64
Summed total	0.45	165.09	218.52

4.7 Limitations

- Most of the companies in Egypt do not make their data publicly available or maintain their updated contact details on their website. It was challenging to get companies to share information, and only few of the contacted companies were willing to help. In addition, there was a very high fluctuation in price of same material between different companies, as such it was not possible to get the market price and instead an average price is used for economic studies.
- The challenge with home appliances is that even though effort to reduce energy consumption is encouraged, appliances usually do not have energy consumption chart (Attia, Evrard & Gratia 2012).
- The changes to the user profile, such as closing the apartment for the purpose of traveling or expecting long stay visitors, cause changes to the total energy consumption, such as cases of travelling or long stay visitors.
- As mentioned before, the utility bills read the real consumption meters every 2 to 4 months, while in between the consumers pay for an average rate assumed by the authorities.
- Each apartment may have different user profile, due to changes in appliances or occupancy profile or number of people. The study is conducted assuming that all the apartments have the same user profile as the validated apartment.

4.8 Building Materials Market in Egypt

To get a proper view about the building materials' market in Egypt, a market research was done in addition to extensive phone interviews. Interviews were conducted with several companies working in the field for different materials supplies such as: thermal insulation materials for external walls and roofs, building blocks, windows and different glazing types.

The main purpose was data collection for different materials thermal specifications which will be included in the simulations. In addition, the local availability and corresponding price of each material that will be used, for the economic study to be included later.

4.8.1 Thermal Insulation for External Walls and Roofs

Three companies were contacted for thermal insulation materials through phone interviews, and chat conversations in addition to official emails. They all stated that the most commonly used thermal insulation materials are expanded polystyrene (EPS), extruded polystyrene (XPS), and rockwool, which are all used with different thicknesses and densities.

The Egyptian Insulation Foundation company (EIF 2018) recommended using Extruded Polystyrene of density 36 kg/m^3 and thickness 5 cm for external walls and roofs. Rockwool and Polyurethane were also suggested by the contacted specialist.

On the other hand, Engineering for Trade and Supply (ETS 2018) proposed manufacturing a special kind of block that is mixed with polystyrene particles or filling the hollow cement block openings with polystyrene injection. However, both options failed to have proper thermal specifications or prices; moreover, this suggestion does not comply with the approach and purpose of this study which is mainly to propose a new regulation using the building materials already available in the local market.

Chema-foam company provided the data sheets of EPS and XPS, which are attached in appendix (D), part 1. They stated that Expanded Polystyrene EPS, known also as White Foam, densities vary from 7kg/m^3 to 35kg/m^3, while Extruded Polystyrene, known as blue foam, densities vary from 32 kg/m^3 to 36 kg/m^3 ("Chema-Foam" 2018).

Table 4.5 shows a comparison between different thermal insulation materials selected for the study, including the price of each (Ctherm.com 2018).

Table 4.6: Thermal insulation materials specifications

	Density (Kg/m^3)	Thickness (cm)	Thermal conductivity (W/m.K)	Price (EGP)
EPS	7 – 35	5 & 10	0.0393	930/m^3
XPS	32 – 36	5 & 10	0.029	1420/m^3
Rockwool	70	5 & 10	0.0	100/m^2
Polyurethane	36	5 & 10	0.022	300/m^2

4.8.2 Building Blocks/Brick

It was essential to contact several building block suppliers to get information about hollow cement block that are used in the base case, in relation to the available sizes and corresponding prices for each size. Unicrete company was contacted to find out more information on hollow cement block. They have mentioned that there are four different sizes for the hollow cement blocks and the prices are measured per 1000 blocks. The following table (4.7) shows the different sizes and prices per m^2, the used sizes are highlighted as “Used” in notes column (Unicrete 2018).

Table 4.7: Hollow cement block sizes and corresponding prices

Block Size	Price per 1000 block	Notes
100*200*400	3000	Used
150*200*400	4200	
200*200*400	5250	
250*200*400	6250	Base case

*Hollow cement block thermal conductivity = 1.6 W/m.K

Delta Block was also contacted, the company stated that the AAC is the most advanced bricks in local market of Egypt as it has a very relative light weight that leads to an extremely high savings in initial construction cost. Moreover, it is considered an energy efficient construction material for its high thermal insulation properties. Its relatively big size promotes much more fast construction compared to other kinds of blocks. It enhances buildings sustainability and provides high comfort levels because it has a very high life cycle performance (Goneam 2018) (Appendix D, Part 2).

4.8.3 Glazing

Glass companies were the most challenging to contact, however Sphinx glass company was contacted successfully (Sphinxglass 2018) (Appendix D, Part 3). The interviewed specialist stated that single clear glazing is used mostly in external glazing of residential buildings. On the other hand, he recommended tinted grey glazing and low-E coated glazing for lower values of energy consumption due to solar gain.

Due to the limited resources of pricing in terms of external glazing, technical data are included which are obtained from other companies' websites where similar data were found. Table (4.8) shows the specifications of the recommended glazing combinations along with their corresponding prices.

Table 4.8: Different glazing specifications

Glazing Type	Total Thickness (mm)	Total U-value (w/m^{2}k)	Total G-value	Price per SQ.M. (EGP)
Clear single glass	6 mm	5.60	0.82	150
Double clear glass	28 mm	2.91	0.71	440
Tinted grey single glass	6 mm	5.60	0.56	220
Tinted grey 6mm/ 16mm air gap/ clear glass 6mm	28 mm	2.91	0.44	550
Solarlite single glass	6mm	5.60	0.24	250
Solarlite glass 6mm/ 16mm air gap/ clear glass 6mm	28 mm	2.91	0.15	600

4.9 Building Envelop Area Calculations

The areas of the three main parameters of the building envelop of the base case building are calculated for the purpose of simple payback period calculations for each proposed configuration.

- **External wall calculations:**

External wall area is calculated by multiplying the total length of external line of the building envelop and the total building height as follows:

External wall parameter (length) = 153.3 m

Total building height = no of floors * height per floor = 5 * 3 = 15 m

Total area of External walls (Including external glazing) = 153.3*15 = 2,300 m^2

- **External glazing calculation:**

There are 4 different types of windows:

Window 1 area = 2 m * 2.2 m = 4.4 m^2 *8 (no. of windows) = 35.2 m^2
Window 2 area = 0.9 m * 2.2 m =1.98 m^2 * 8 (no. of windows) = 16 m^2
Window 3 area = 1.2 m *1.3 m =1.56 m^2 * 10 (no. of windows) = 15.6 m^2
Window 4 area = 0.8 m * 0.6 m = 0.48 m^2 * 18 (no. of windows) = 8.64 m^2

Area of External Glazing per floor= 75.88 m^2

As a final result of building envelop area calculations, it was found that the areas are as follows;

- Total area of external glazing = 75.88 * 5 = 379.4
- Area of external wall (excluding glazing) = 2,300 – 379.4 = 1921 m^2
- Exposed roof total area = 805 m^2
- Wall Window Ratio (WWR) = 19.75%

4.10 Simulations Matrix Configuration

A simulation matrix is created for all the elements of building envelop, external walls, external glazing, and roof. Different thermal insulation, glazing and building materials are assigned based on the market analysis done on various materials availability and prices. The matrix has three main categories: external walls, external glazing (windows), and roof thermal insulation. External walls category has 9 different types of thermal insulation and brick combinations. While the external glazing category has 5 different options of glass materials, single and double panels. And the roof thermal insulation category has 3 different options of different thermal insulation materials and thicknesses. The following Tables (4.9, 4.10, & 4.11) shows the full matrix of simulations with the corresponding combination details, thicknesses, total u-value and g-value – in case of external glazing.

Table 4.9: External walls single matrix details

External Walls		
Materials	wall Thickness (mm)	Total U-value (W/m^2.K)
Base Case (Hollow Cement Block)		
Hollow Cement block	250	2.35
Insulation 1 Expanded Polystyrene (50mm)		
Base Case + Insulation 1	250	0.61
base Case + Insulation 1 Doubled	300	0.34
Insulation 2 Extruded Polystyrene (50mm)		
base Case + Insulation 2	250	0.48
base Case + Insulation 2 Doubled	300	0.26
Insulation 3 Rockwool		
base Case + Insulation 3	250	0.59
base Case + Insulation 3 Doubled	300	0.33
AAC Block		
250 Block	250	0.47
200mm block + Insulation 2	250	0.33
100mm block + Insulation 2+100mm hollow cement block	250	0.42

Table 4.10: External Glazing single matrix simulations

External Glazing		
Materials	Total U-value (W/m^2.K)	G-Value
Base Case		
Single Clear Glazing	5.60	0.82
Clear Glazing		
Double Clear Glazing	2.91	0.71
Tinted Gray Glazing		
Single Tinted Gray	5.60	0.56
Tinted Gray/Air Gap/Clear	2.91	0.44
Low-E Coated Glazing		
Single Low-E Coated Glazing	5.60	0.24
Low-E coated/Air Gap/Clear	2.91	0.15

Table 4.11: Exposed roof single matrix simulations

Roof Thermal Insulation	
Materials	Total U-value (W/m^2.K)
Base Case	
Expanded Polystyrene 50mm	0.49
Insulation 1 Expanded Polystyrene (50mm)	
Base Case + Insulation 1 Doubled	0.30
Insulation 2 Extruded Polystyrene (50mm)	
Base Case + Insulation 2	0.40
Base Case + Insulation 2 Doubled	0.24

The Impact of the test matrix configurations on the thermal performance of the building will be discussed. Each simulation will be done in a single basis, in which only one configuration will be addressed per simulation. For example, in external walls test matrix simulations, only the proposed configurations will be tested, while keeping external glazing and exposed roof on the same configuration of the base case model. While in testing the impact of glazing replacement scenarios, external walls and exposed roof configurations will be kept the same as the base case model. In each simulation the results will be discussed in terms of total electricity consumption savings, in addition to cooling and heating loads reductions achieved.

An economic study will be conducted. Increase in initial cost of the building will be calculated by subtracting the cost of materials used in the base case model from the cost of the materials used in each simulation configuration proposed. In addition to calculating the annual electricity cost savings by multiplying the net savings in electricity by the unit electricity cost.

After getting all the matrix simulations done -and calculating the corresponding payback period of each- two best cases of each category will be selected; the most economical (has the shortest payback period), and the highest in saving energy (has the lowest electricity consumption).

These two best cases of external walls, glazing, and roof treatments, will be integrated in a new matrix, in which the results will be discussed to get the best combination out of them.

As a result of all the simulations to be done, a recommendation will be raised to the Egyptian government regarding enhancing building regulations in terms of energy efficiency while achieving indoor thermal comfort.

5 Simulation Results and Discussion

5.1 Introduction

In this chapter, two levels of simulations will be addressed. First level of simulations will be discussing the impact of the test matrix different configurations on thermal performance of the case study building. In test matrix, a total of 17 simulations will be covering the three parameters being investigated, which are: external walls, exposed roof, and external glazing. Test matrix details are mentioned before in Tables (4.9, 4.10, & 4.11). Each simulation will be done in a single basis, in which only one configuration will be addressed per simulation. For example, in external walls test matrix simulations, only the proposed configurations will be tested, while keeping external glazing and exposed roof on the same configuration of the base case model. While in testing the impact of glazing replacement scenarios, external walls and exposed roof configurations will be kept the same as the base case model. In each simulation the results will be discussed in terms of total electricity consumption savings, in addition to cooling and heating loads reductions achieved.

Moreover an economic study will be conducted. increase in initial cost of the building will be calculated by subtracting the cost of materials used in the base case model from the cost of the materials used in each simulation configuration proposed. In addition to calculating the annual electricity cost savings by multiplying the net savings in electricity by the unit electricity cost. Then, a simple payback period will be calculated using the equation:

$$\text{Payback period} = \text{Increase in building's initial cost} \,/\, \text{annual electricity cost savings} \qquad (1)$$

Based on the net energy savings and payback periods calculated in the first level of simulations, two configurations will be selected from each parameter; the maximum energy saving configuration, and the minimum payback period configuration.

The second level of simulations will be conducted by combining the maximum energy saving and the minimum payback period configurations selected from the previous step in a matrix. In this matrix, 18 possible configurations will be simulated using different combinations of external walls, glazing and exposed roof scenarios in one simulations. The total impact in thermal performance will be recorded using the same variables as step one, which are savings in total electricity consumption, cooling and heating loads. In addition to calculating the expected payback periods using same equation (1).

As a result of this discussion, a conclusion will be conducted in the form of recommendations for enhancing the Egyptian building regulations.

5.2 Test matrix simulations

In this section, the three parameters will be investigated using 17 simulations as mentioned in section 5.1. External wall parameter will be tested in 9 different simulations. Base case external glazing will be replaced by 5 different configurations. While exposed roof thermal insulation enhancement will be tested in 3 simulations. After each set of simulations for each parameter, an economic study will be conducted.

5.2.1 External wall Test matrix simulations and results discussion

In external walls parameter, the full building is being tested under 9 different configurations that are selected based on the local market research done.

The impact of adding a thermal insulation layer to the base case building blocks used is simulated using 3 different thermal insulation materials. These materials are expanded polystyrene, extruded polystyrene and rockwool thermal insulations. Each of the selected thermal insulation materials are tested in two thicknesses, 50 mm, and 100mm.

In addition to that, changing the type of building blocks used will be investigated, hollow cement block will be replaced by AAC blocks. Moreover, an extra layer of thermal insulation will be combined with AAC block in one configuration. Another way is to combine AAC and cement block with a 50mm of thermal insulation layer in between. Table (4.9) in chapter 4 shows all the wall configurations in details. Simulation results will be discussed in detail in the following sections. While payback period calculations will be conducted as follows in wall construction 1 detailed example.

Wall configuration 1:

A combination of hollow cement block and expanded polystyrene thermal insulation is used. Expanded polystyrene EPS density is 20kg/m^3, while its thermal conductivity is 0.0393W/m.K (TDS 2017). The simulation is done on a wall section of 250mm thickness, composed of 200 mm of cement block, split by 50 mm of EPS. The total u-value of the proposed configuration is 0.61 W/m^2.K. The results are as follows;

Annual electricity consumption = 203.56 MWh

Annual electricity consumption of base case as per Table (4.10) = 218.52 MWh/yr

Amount of electricity savings = 218.52 – 203.56 = 14.96 MWh/yr

Electricity cost savings = amount of electricity savings * unit cost of electricity

Actual Unit cost of electricity as per Egyptian Ministry of Electricity and Renewable Energy (ElMasry 2017) = 102.2 Piasters/kWh

1 MWh electricity cost = 1.022 EGP * 1000 = 1022 EGP

Cost of electricity savings = 1022 * 14.96 = 15,289.12 EGP

Unit cost of wall configuration 1 = 124 EGP/m^2 ("Chema-Foam" 2018), (Unicrete 2018)

Total cost of insulating material = unit cost * external walls total area = 124*1921 = 238,204 EGP

Unit cost of base case wall configuration = 38 EGP/m^2 (Unicrete 2018)

Total cost of base case wall configuration = 38 * 1921 = 72,998 EGP

Difference in External wall cost = 238,204 – 72998 = 165,206 EGP

Simple payback period = 165,206/15,289.12 = 10.8 years

Applying wall configuration 1 reduced the total electricity by 7% as shown in Table (5.1). Cooling sensible loads is reduced by 17%, while the heating is turned off.

Table 5.1: External wall configuration simulation results with corresponding payback period calculations

Strategy 1: External wall configurations										
Wall configuration*	Base case*	Wall 1	Wall 2	Wall 3	Wall 4	Wall 5	Wall 6	Wall 7	Wall 8	Wall 9
Total U-Value ($W/m^2.K$)	2.46	0.61	0.34	0.48	0.26	0.59	0.33	0.47	0.29	0.42
Annual Electricity Consumption (MWh/yr)	218.52	203.56	201.33	202.5	200.7	203.5	201.3	201.9	200.4	201.9
Annual Electricity Savings (MWh/yr)	0	14.96	17.19	16.02	17.82	15.02	17.22	16.62	18.12	16.62
Annual Electricity Savings (Percentage)	0	7%	7.9%	7.4%	8.2%	6.9%	7.9%	7.6%	8.3%	7.6%
Electricity cost savings (EGP)	0	15,297	17,572	16,424	18,260	15,404	17,618	16,988	18,501	16,997
Unit cost of wall configuration materials (EGP/m^2) **	38	124	174	149	124	174	274	210	245	198
Total cost of wall configuration materials (External wall Area=1921)	72,998	238,204	334,254	290,071	430,304	334,254	526,354	403,410	470,645	380,358
Difference in Price (EGP)	0	165206	261256	217,073	357,306	261,256	453,356	330,412	397,647	307,360
Simple payback period (Years) ***	0	10.8	14.9	13.2	19.6	17	25.7	19.5	21.5	18.1

* Each wall configuration detail is listed in Table (4.9) including thicknesses, thermal conductivity, total u-values, and g-value of each. Base case configuration is listed in chapter 4 Table (4.1)
** all unit cost mentioned are the total cost of wall materials as provided by the manufactural. A detailed Table of materials price is listed in chapter four Tables (4.6, & 4.7)
*** Simple Payback period is calculated based on the actual price of electricity listed in section (1.1).
1 kWh = 102.2 Piasters

- Savings and difference in price are calculated compared to base case.

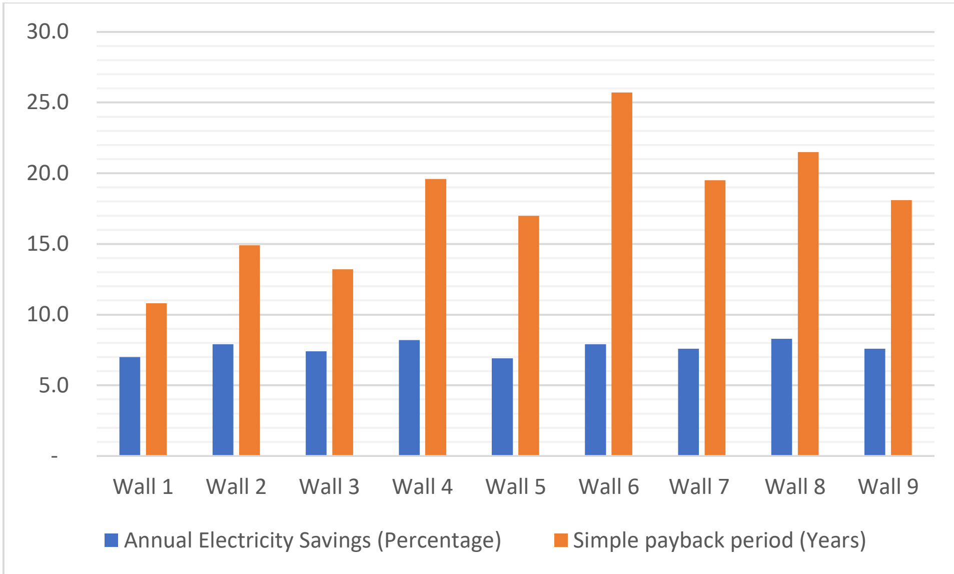

Figure 5.1: External walls' annual consumption savings percentage with corresponding payback periods calculated

After getting the simulation results, it is found that some of the wall configurations are giving nearly similar results in terms of amount of electricity saved annually (Figure 5.1). For example, wall 1 and wall 5 are resulting in electricity reduction percentages of 7% and 6.9% respectively, however there is a huge difference in the payback period calculated for each, as wall 1 payback period is 10.8 years while in wall 5 it is 17 years. Knowing that the thermal insulation material used in wall 1 is 50 mm of EPS, while in wall 5, 50 mm of rockwool thermal insulation is used. Similarly, wall 2 and wall 6 resulted in the same percentage of consumption reduction by 7.9%. However, the payback period calculated for wall 6 is much more longer than wall 2 by 10.8 years. In wall 2, 100 mm of EPS is used, and in wall 6 100 mm of rockwool is the thermal insulation used. This concludes that rockwool does not provide efficient results compared to EPS under the same conditions and having the same thicknesses.

In wall configuration 7, 8 and 9, AAC block is used. Wall 7 is composed mainly of AAC block with a thickness of 250 mm. Wall 8 is a combination between AAC block and 50 mm of XPS. While in wall 9, the configuration is in a form of 100 mm of AAC block, 50 mm of XPS and 100 mm of cement block, outside to inside.

AAC block manufactural stated that using AAC block can reduce the shell and core construction cost by up to 15%, due to its light weight (Goneam 2018). Although wall 4 and wall 8 are resulting in the same reduction percentage with a difference of 0.1% between them. And the payback period calculated shows that wall 8 has 2 years longer than wall 4. However, it is expected that wall 8 will act better and its payback period is less than wall 4. Keeping in mind that in wall 4, 100 mm of extruded polystyrene is used in combination with hollow cement block.

In a closer look to the impact of different wall configurations on the thermal performance of the building, cooling and heating loads are studied and compared to the base case results. An increase in cooling loads is observed in months April and November. The presence of thermal insulation layer and using brick that has lower thermal conductivity, while keeping the clear single glazing configuration of the base case that has high solar heat gain, resulted in increasing the heat content indoors. Table (5.2) shows the increase percentages in April and November, in addition to the total reduction of cooling loads for each wall configuration. Figure (5.2) illustrates the monthly results of cooling loads comparing wall configurations to base case. It shows that in months April and November the base case bar is shorter than wall configurations. Figure (5.3) shows the total reduction in cooling sensible loads compared to the base case. In Figure (5.4), annual cooling loads is illustrated, wall 4 and wall 8 configurations achieved the maximum reduction of 21%, while wall one achieved the minimum reduction of 17% compared to the base case annual cooling loads.

Table 5.2: External walls monthly results of cooling loads

Date	Base case	wall 1	wall 2	wall 3	wall 4	wall 5	wall 6	wall 7	wall 8	wall 9
Jan 01-31	0	0	0	0	0	0	0	0	0	0
Feb 01-28	0	0	0	0	0	0	0	0	0	0
Mar 01-31	0	0	0	0	0	0	0	0	0	0
Apr 01-30	2.53	3.01	3.26	3.12	3.36	3.02	3.27	3.08	3.30	3.16
increase%	0	16%	22%	19%	25%	16%	23%	18%	23%	20%
May01-31	22.36	19.96	19.74	19.83	19.70	19.95	19.74	19.65	19.53	19.78
Jun 01-30	28.70	22.46	21.34	21.91	20.98	22.40	21.30	21.77	20.99	21.67
Jul 01-31	34.27	25.85	24.32	25.11	23.83	25.77	24.27	24.93	23.87	24.77
Aug 01-31	33.77	25.48	23.97	24.75	23.49	25.40	23.93	24.54	23.50	24.39
Sep 01-30	26.73	21.23	20.24	20.75	19.92	21.18	20.21	20.58	19.89	20.51
Oct 01-31	15.60	14.47	14.27	14.38	14.21	14.47	14.28	14.27	14.13	14.33
Nov 01-30	1.12	3.82	4.69	4.23	5.00	3.87	4.74	4.15	4.81	4.37
Increase%		71%	76%	73%	78%	71%	76%	73%	77%	74%
Dec 01-31	0	0	0	0	0	0	0	0	0	0
Summed total	165.09	136.3	131.8	134.08	130.49	136.07	131.7	132.98	130.02	132.96
Total reduction percentage	0	17%	20%	19%	21%	18%	20%	19%	21%	19%

* All results are in MWh.

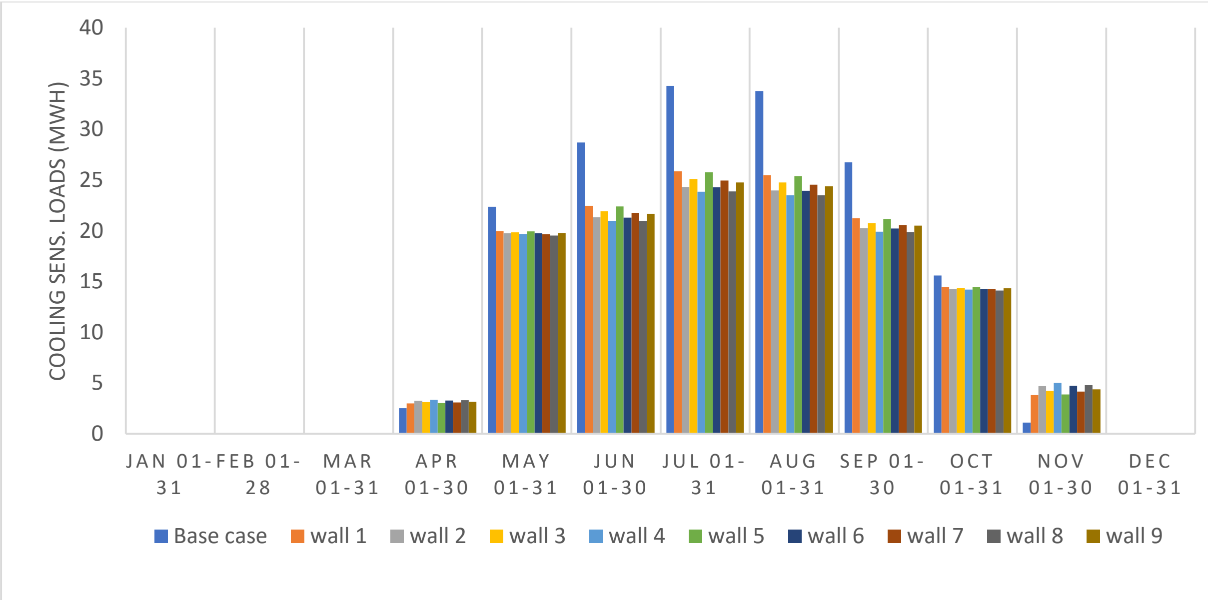

Figure 5.2: External wall comparison of monthly cooling loads

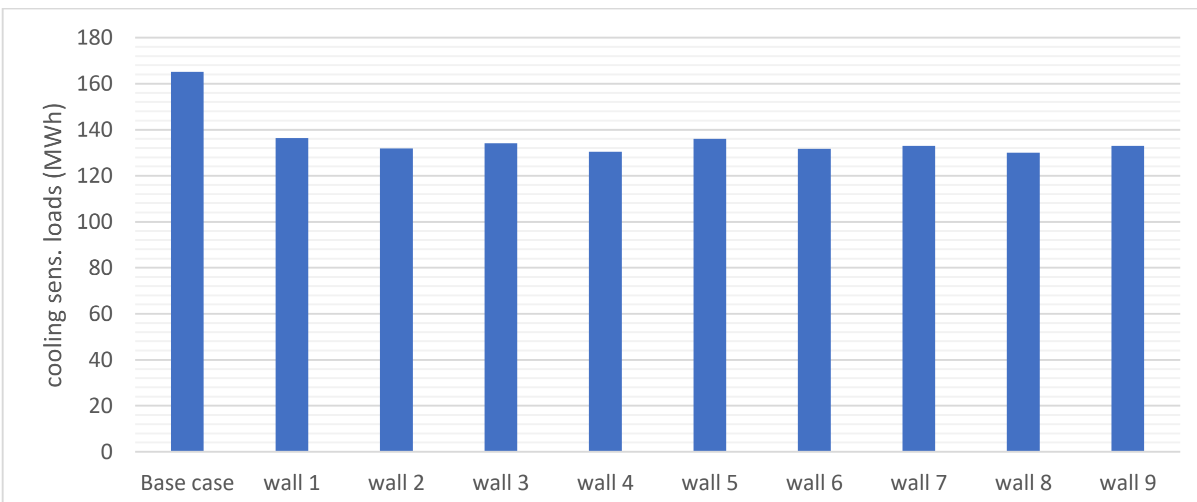

Figure 5.3: External walls annual cooling loads reduction

5.2.2 External Glazing Test matrix simulations and results discussion

In this section, external glazing replacement will be studied using 5 configurations listed in Table (4.10). Single and double glazing will be investigated. In the simulations clear, grey tinted, and low-e coating glazing will be tested based on the information collected from the local market research, that was highlighted in section (4.8.3). Total area of external glazing to be replaced is 379.4 square meters. And "Wall Window Ratio" WWR calculated is less than or equal 20% as calculated in section (4.9). For the purpose of payback period calculations, it is assumed that the aluminum frame that is fixed in the case study base case will remain unchanged, while the internal glazing configurations will be changed in accordance. Unit price for each glazing configuration used are listed in Table (5.3) (Sphinxglass.com 2018).

Glazing configurations 1, 3 and 5 are composed of double glazing with 16mm air gap in between. The internal layer of glass is 6mm clear glass. While glazing configurations 2, and 4 are basically 6 mm single glazing. In Table (5.3), the results show that double glazing configurations have significantly longer payback periods compared to single glazing configurations, due to the high differences in unit price. As double-glazing unit price ranges between 440 to 600 EGP/m^2 while single glazing unit price does not exceed 250 EGP/m^2, which makes the price difference almost doubled. Energy savings recorded the highest of 8.2% in glazing 5 simulation which is a low-e coated double glazing; and its corresponding payback period calculated is 9.3 years. While the lowest payback period calculated is 2.33, recorded in glazing 4, low-e single glazing; and its annual electricity savings is 7.3%. the longest payback period (24.5 years) and lowest annual energy savings (2%) are recorded in glazing 1, which is composed of double clear glazing (Figure 5.4).

Table 5.3: External glazing configuration simulation results with corresponding payback period calculations

Wall configuration*	Base case*	Glazing 1	Glazing 2	Glazing 3	Glazing 4	Glazing 5
G-Value	0.82	0.71	0.56	0.44	0.24	0.15
Annual Electricity Consumption (MWh/yr)	218.52	214.12	209.78	206.6	202.57	200.55
Annual Electricity Savings (MWh/yr)	0	4.4	8.74	11.92	15.95	17.97
Annual Electricity Savings (Percentage)	0	2%	4%	5.5%	7.3%	8.2%
Electricity cost savings (EGP)	0	4496.3	8,931.46	12,177.64	16,308.87	18,368.51
Unit cost of Glazing configuration (EGP/m^2) **	150	440	220	550	250	600
Total cost of glazing configuration (External glazing Area=379.4 m^2)	56,910	166,936	83,468	208,670	94,850	227,640
Difference in Price (EGP)	0	110,026	26,558	151,760	37,940	170,730
Simple payback period (Years) ***	0	24.5	3	12.5	2.33	9.3

* Each glazing configuration detail is listed in Table (4.8) including thicknesses, thermal conductivity, total u-values, and g-value of each. Base case configuration is listed in chapter 4 Table (4.1)
** all unit cost mentioned are the total cost of glazing section as provided by the manufactural. A detailed Table of materials price is listed in chapter four Table (4.8)
*** Simple Payback period is calculated based on the actual price of electricity listed in Section (1.1).
1 kWh = 102.2 piasters.

- Savings and difference in price are calculated compared to base case.

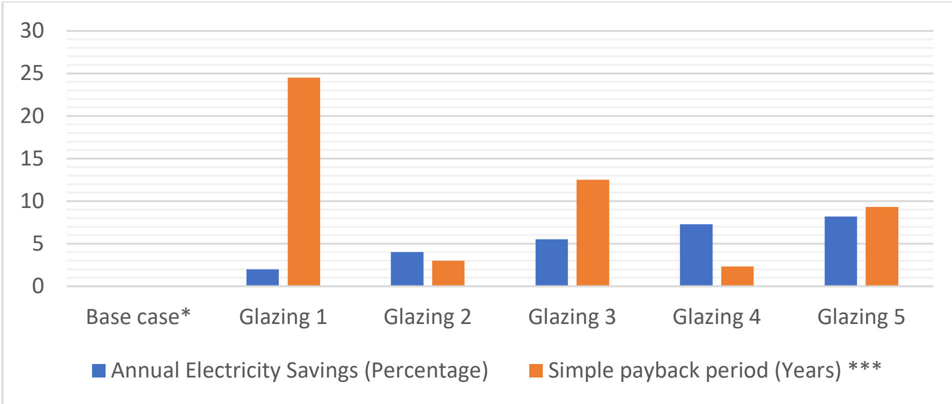

Figure 5.4:External glazing' annual consumption savings percentage with corresponding payback periods calculated

As mentioned in chapter 4 section 4, heating system in the case study is provided using electricity, so it would affect the consumption rates. Results of cooling and heating sensible loads are shown in Table (5.4, and 5.5). It is observed that using glazing configurations that have high ability in reducing solar heat gain caused an increase in heating loads of months January, February and December. Annual heating loads are increased by a range from 5% in glazing configuration 1 to 327% in glazing configuration 4, monthly results are illustrated in Figure (5.5). However, cooling loads are decreased by 5% in glazing 1 and 24% in glazing 5, monthly results are illustrated in Figure (5.6).

Table 5.4: External glazing monthly results of heating loads

Date	Base case	Glazing 1	Glazing 2	Glazing 3	Glazing 4	Glazing 5
Jan 01-31	0.36	0.37	0.67	0.66	1.15	1.08
Increase %		5%	47%	46%	69%	67%
Feb 01-28	0.06	0.06	0.19	0.18	0.52	0.46
Increase %		10%	69%	69%	89%	87%
Mar 01-31	0	0	0.00	0	0	0
Apr 01-30	0	0	0.00	0	0	0
May 01-31	0	0	0.00	0	0	0
Jun 01-30	0	0	0.00	0	0	0
Jul 01-31	0	0	0.00	0	0	0
Aug 01-31	0	0	0.00	0	0	0
Sep 01-30	0	0	0.00	0	0	0
Oct 01-31	0	0	0.00	0	0	0
Nov 01-30	0	0	0.00	0	0	0
Dec 01-31	0.04	0.04	0.11	0.10	0.27	0.24
Increase %		3%	63%	61%	85%	83%
Summed total	0.45	0.48	0.96	0.95	1.94	1.77
Total increase %		5%	112%	109%	327%	290%

* all results are in MWh.

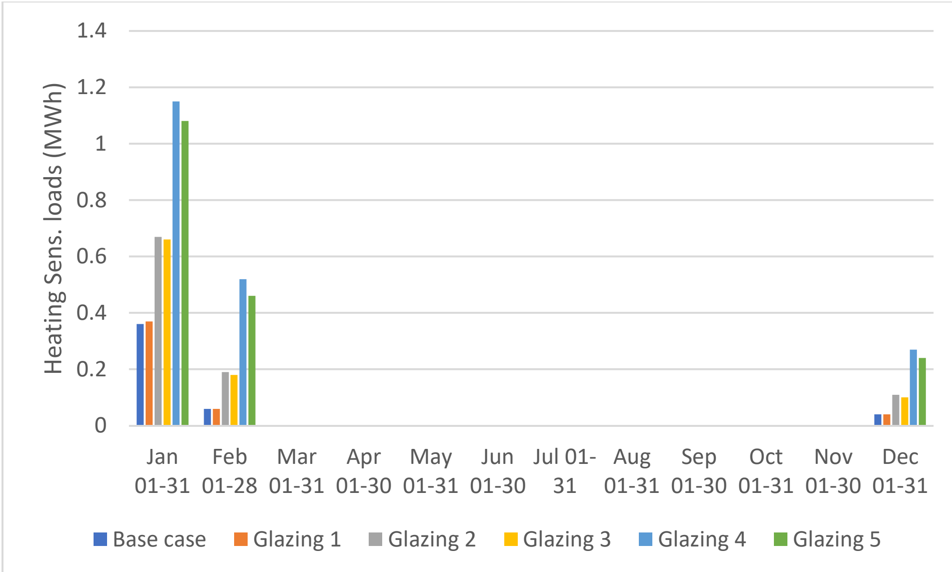

Figure 5.5: Illustrates external glazing monthly totals of heating loads

Table 5.5: External Glazing monthly results of cooling loads

Date	Base case	Glazing 1	Glazing 2	Glazing 3	Glazing 4	Glazing 5
Jan 01-31	0	0	0.00	0	0	0
Feb 01-28	0	0	0.00	0	0	0
Mar 01-31	0	0	0.00	0	0	0
Apr 01-30	2.53	2.33	1.96	1.82	1.44	1.37
May 01-31	22.36	21.03	19.08	18.18	16.07	15.65
Jun 01-30	28.70	27.16	25.67	24.55	22.89	22.23
Jul 01-31	34.27	32.56	31.29	29.10	28.53	27.68
Aug 01-31	33.77	32.12	30.90	29.64	28.25	27.43
Sep 01-30	26.75	25.38	24.01	23.03	21.50	20.91
Oct 01-31	15.60	14.70	13.08	12.50	10.74	10.52
Nov 01-30	1.12	0.9472	0.35	0.312	0.05	0.06
Dec 01-31	0	0	0.00	0	0	0
Summed total	165.09	156.23	146.34	140.03	129.47	125.85
Total reduction %		5%	11%	15%	22%	24%

* all results are in MWh.

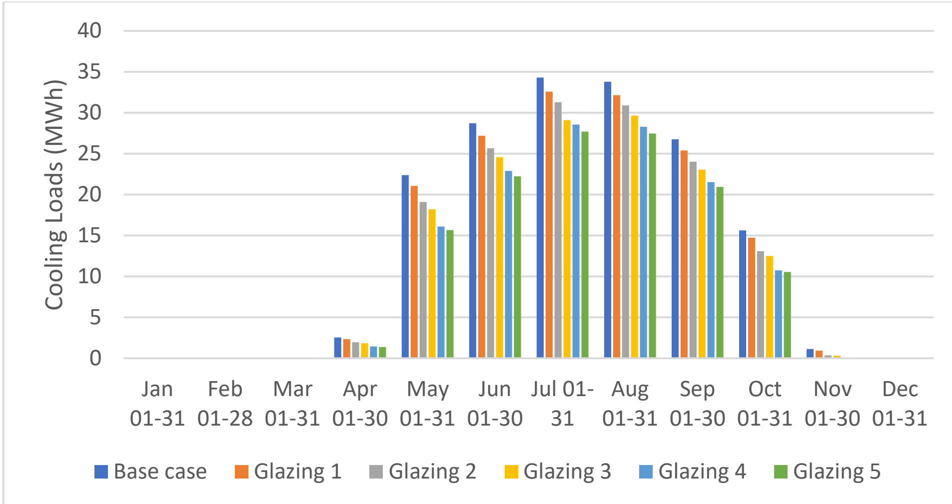

Figure 5.6: Illustrates external glazing monthly cooling loads

5.2.3 Exposed roof test matrix simulations and results discussion

The base case exposed roof is already treated with thermal insulation layer of EPS of 50 mm thickness and thermal conductivity 0.0393 W/m.K. Details of base case roof construction materials are listed in Table (4.1). Roof treatment enhancements are investigated in the test matrix using 3 simulations, using EPS and XPS insulating materials. Details of the test matrix are listed in Table (4.11).

As mentioned earlier, the case study building is composed of 5 typical floors. Total area of roof is 805 m^2. Which concludes that the ratio of building volume to exposed roof area is huge. For that reason, the exposed roof treatments will be investigated in two levels, on the full building consumption level and in the 5^{th} floor consumption level, only assuming that it is the only floor to be affected by the hear gained from exposed roof area. Moreover, the actual impact of adding the thermal insulating layer to the roof will be studied by simulating roof after excluding the thermal insulation layer. The actual impact will be studied in the same two levels assigned for the test matrix simulation. A total of 8 simulations will be covering this section.

For the payback period calculations, the treatment layer will be the only parameter of calculation, as the rest of the roof layers, thicknesses and area are constant, the only variable is the thermal insulating material type and thicknesses. However, the total roof treatment price will be the same in both levels of study, the payback period calculation will differ depending on the amount of electricity cost savings. Unit price for each type of thermal insulation are listed in Table (4.6) (Chemafoam 2017).

In the full building scale (Table 5.6), annual electricity savings percentages were all less than 1%, due to the huge difference between roof area and building volume, in addition to the presence of internal ceilings. While in the 5^{th} floor scale (Table 5.7), the treated roof area is tested in relation to the volume of the exposed floor only. Annual electricity savings showed 1.9% to 5.5% reduction.

In terms of payback period calculations, savings in full building scale resulted in payback periods of 47 to 151.2 years. And in the 5th floor scale it showed payback periods of 26 to 85.3 years. Which means that the investment as an initial cost is unworthy in terms of energy savings. Based on these results, the actual impact of thermal insulation treatment of the base case is needed to be studied.

Table 5.6: Exposed roof configuration simulation results of full building consumption level with corresponding payback period calculations

Roof treatment*	Base case*	Roof 1	Roof 2	Roof 3
Total U-Value	0.49	0.3	0.4	0.24
Annual Electricity Consumption (MWh/yr)	218.52	217.7	218.13	217.40
Annual Electricity Savings (MWh/yr)	0	0.82	0.39	1.12
Annual Electricity Savings (Percentage)	0	0.4%	0.2%	0.5%
Electricity cost savings (EGP)	0	855	399.3	1,157.82
Unit cost of roof configuration (EGP/m^2) **	50	100	75	150
Total cost of roof configuration (Exposed roof Area=805 m^2)	40,250	80,500	60,375	120,750
Difference in Price (EGP)	0	40,250	20,125	80,500
Simple payback period (Years) ***	0	47	151.2	104.3

* Each roof configuration detail is listed in Table (4.11) including total U-values. Base case configuration is listed in chapter 4 Table (4.1)

** all unit cost mentioned are the total cost of thermal insulation material as provided by the manufactural. A detailed Table of materials price is listed in chapter four Table (4.6)

*** Simple Payback period is calculated based on the actual price of electricity listed in section (1.1). 1 kWh = 102.2 Piasters

- Savings and difference in price are calculated compared to base case.

Table 5.7: Exposed roof configuration simulation results of 5th floor consumption level with corresponding payback period calculations

Roof treatment*	Base case*	Roof 1	Roof 2	Roof 3
Total U-Value	0.49	0.3	0.4	0.24
Annual Electricity Consumption (MWh/yr)	37.5	36	36.8	35.43
Annual Electricity Savings (MWh/yr)	0	1.5	0.7	2.07
Annual Electricity Savings (Percentage)	0	4%	1.9%	5.5%
Electricity cost savings (EGP)	0	1,551	716.42	2,113.6
Unit cost of roof configuration (EGP/m^2) **	50	100	75	150
Total cost of roof configuration (Exposed roof Area=805 m^2)	40,250	80,500	60,375	120,750
Difference in Price (EGP)	0	40,250	20,125	80,500
Simple payback period (Years) ***	0	26	84.3	57.1

* Each roof configuration detail is listed in Table (4.11) including total u-values. Base case configuration is listed in chapter 4 Table (4.1)

** all unit cost mentioned are the total cost of thermal insulation material as provided by the manufactural. A detailed table of materials price is listed in chapter four Table (4.6)
*** Simple Payback period is calculated based on the actual price of electricity listed in section (1.1).
1 kWh = 102.2 Piasters

- Savings and difference in price are calculated compared to base case.

- Actual impact of base case roof thermal insulation

As discussed, the results of roof treatment simulations did not provide good results in terms of annual electricity savings and payback periods calculated. It could be the case that the current insulation layer used for the roof is already designed as an optimum treatment for an efficient roof. For that reason, it is so important to investigate the actual impact of the current treatment of the base case exposed roof, to prove that the thermal insulation of roofs is an essential strategy in such a residential building.

In a simulation, the amount of heat gain is investigated while removing the thermal insulation layer from the exposed roof construction materials. The total u-value has jumped to 1.33 W/m^2.K compared to 0.49 W/m^2.K in the base case. Table (5.8) shows the results of exposed roof treated base case and untreated. Simulations are done in full building scale and 5th floor scale as well. Thermal insulation contributed by 2% in annual electricity saving of the full building and 12% reduction in the fifth-floor electricity consumption. These rates reflect the importance of thermal insulation in flat roofs of residential buildings.

Table 5.8: Actual impact of exposed roof base case thermal insulation treatment

Roof treatment*	**Full Building Scale**		**5th Floor Scale**	
	Treated*	Untreated	Treated*	Untreated
Total U-Value (W/m2.K)	0.49	1.33	0.49	1.33
Annual Electricity Consumption (MWh/yr)	218.52	222.12	37.5	42.75
Annual Electricity Savings (MWh/yr)	3.6	0	5.25	0
Annual Electricity Savings (Percentage)	2%	0	12%	0

* treated roof results are the same results of the base case.

5.3 Combined matrix simulations

After analysing the simulation results and calculating the payback periods of each of the 3 parameters of the study; external walls, roof, and external glazing, the most cost effective – that provides the minimum payback periods-, and the most efficient scenarios – that provides the maximum annual electricity savings- will be selected from each parameter then will be combined in a simulation matrix to investigate the results of combining them.

In Table (5.9) all strategies implemented are summarized in terms of annual electricity savings percentage and corresponding payback periods calculated. In this section, combined scenarios results will be discussed in order to get the impact of all strategies combined.

Table 5.9: Summary of implemented strategies' net electricity savings and their corresponding payback periods calculated

Strategies		Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8	Option 9
External walls	Net energy Savings	7%	7.9%	7.4%	8.2%	6.9%	7.9%	7.6%	8.3%	7.6%
	Payback period (years)	10.8	14.9	13.2	19.6	17	25.7	19.5	21.5	18.1
External Glazing	Net energy Savings	2%	4%	5.5%	7.3%	8.2%				
	Payback period (years)	24.5	3	12.5	2.33	9.3				
Exposed roof	Net energy Savings	0.4%	0.2%	0.5%						
	Payback period (years)	47	151.2	104.3						

5.3.1 Maximum annual electricity savings

In this section, configurations that provided the maximum electricity savings are highlighted as follows in Table (5.10);

External walls: wall configuration 8 – AAC Block 200 mm with an internal XPS layer 50 mm

External glazing: Glazing configuration 5 – 6mm low-e coated glass/16mm air gap/6mm clear glazing.

Exposed roof treatment: 50mm EPS thermal insulation layer.

- For the Exposed roof treatment, as discussed before that the best results provided was through the actual impact of the base case treatment, which is considered as option 1 in Table 5.10

Table 5.10: Summary of implemented strategies - Maximum annual electricity savings

Strategies		Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8	Option 9
External walls	Net energy Savings	7%	7.9%	7.4%	8.2%	6.9%	7.9%	7.6%	8.3%	7.6%
	Payback period (years)	10.8	14.9	13.2	19.6	17	25.7	19.5	21.5	18.1
External Glazing	Net energy Savings	2%	4%	5.5%	7.3%	8.2%				
	Payback period (years)	24.5	3	12.5	2.33	9.3				
Exposed roof	Net energy Savings	2%	0.4%	0.2%	0.5%					
	Payback period (years)	11	47	151.2	104.3					

After simulating the combination highlighted above, the results came out as follows

Annual electricity consumption = 170.45 MWh

Annual electricity consumption of base case as per Table (4.5) = 218.52 MWh/yr

Amount of electricity savings = 218.52 – 170.45 = 48.07 MWh/yr – a total reduction of 22%.

Electricity cost savings = amount of electricity savings * unit cost of electricity

Actual Unit cost of electricity as per Egyptian Ministry of Electricity and Renewable Energy (ElMasry 2017) = 102.2 Piasters/kWh

1 MWh electricity cost = 1.022 EGP * 1000 = 1022 EGP

Cost of electricity savings = 1022 * 48.07 = 49,127.54 EGP

Total cost of building envelop enhancement from Tables (5.1, 5.3, & 5.7) = 470,645+ 227,640 + 40,250 = 738,535 EGP

Total cost of base case configuration (wall, glazing, roof) = 72,998 + 56,910 +40,250 = 170,158 EGP

Difference in total cost = 738,535 – 170,158 = 568,377 EGP

Simple payback period = 568,377/49,127.54 = 11.6 years

Combining scenarios that have the maximum electricity savings in test matrix simulations saves 22% of the annual energy consumption, 58% reduction in cooling loads and 75% in heating loads, while having a payback period of 11.6 years approximately.

5.3.2 Minimum payback period

In this section, configurations that provided the minimum payback period are highlighted as follows in Table (5.11);

External walls: wall configuration 1 – Hollow Cement Block 200 mm with an internal EPS layer 50 mm

External glazing: Glazing configuration 4 – 6mm low-e coated single glazing

Exposed roof treatment: 50mm EPS thermal insulation layer.

- For the Exposed roof treatment, as discussed before that the best results provided was through the actual impact of the base case treatment, which is considered as option 1 in Table 5.11

Table 5.11: Summary of implemented strategies – Minimum payback period

Strategies		Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8	Option 9
External walls	Net energy Savings	7%	7.9%	7.4%	8.2%	6.9%	7.9%	7.6%	8.3%	7.6%
	Payback period (years)	10.8	14.9	13.2	19.6	17	25.7	19.5	21.5	18.1
External Glazing	Net energy Savings	2%	4%	5.5%	7.3%	8.2%				
	Payback period (years)	24.5	3	12.5	2.33	9.3				
Exposed roof	Net energy Savings	2%	0.4%	0.2%	0.5%					
	Payback period (years)	11	47	151.2	104.3					

After simulating the combination highlighted above, the results came out as follows

Annual electricity consumption = 178.72 MWh

Annual electricity consumption of base case as per Table (4.5) = 218.52 MWh/yr

Amount of electricity savings = 218.52 – 178.72 = 39.8 MWh/yr – a total reduction of 18%.

Electricity cost savings = amount of electricity savings * unit cost of electricity

Actual Unit cost of electricity as per Egyptian Ministry of Electricity and Renewable Energy (ElMasry 2017) = 102.2 Piasters/kWh

1 MWh electricity cost = 1.022 EGP * 1000 = 1022 EGP

Cost of electricity savings = 1022 * 39.8 = 40,675.6 EGP

Total cost of building envelop enhancement from Tables (5.1, 5.3, & 5.7) = 238,204 + 94,850 + 40,250 = 373,304 EGP

Total cost of base case configuration (wall, glazing, roof) = 72,998 + 56,910 +40,250 = 170,158 EGP

Difference in total cost = 373,304 – 170,158 = 203,146 EGP

Simple payback period = 203,146/40,675.6 = 5 years

Combining scenarios that have the minimum payback periods in test matrix simulations saves 18% of the annual energy consumption, 48% reduction in cooling loads and 5% in heating loads, while having a payback period of 5 years.

5.3.3 Different possible combinations

In Table (5.12), simulation results of different combinations are recorded. Annual electricity consumption has been decreased by 18% to 22%, and payback periods ranged between 5 to 11.6 year.

In terms of cooling and heating loads, combining the strategies together solved out the matter of increasing the cooling loads in external wall test matrix simulations (Table 5.2), and the heating loads in external glazing test matrix simulations (table 5.4). Annual cooling reduction ranged between 48% to 58%. While annual heating loads are reduced by a massively wide range from 5% to 75% (Table 5.12).

Combining wall configuration 1 and external glazing configuration 4 is highly recommended as it saves 18% of annual electricity consumption and having a payback period of 5years. Keeping in mind that the highest reduction percentage achieved is 22%. In addition to that, this combination matches the current popular building materials used in market. As wall configuration 1 is using the same building block of the base case, hollow cement block, with an extra intermediate thermal insulation layer of expanded polystyrene. And glazing configuration 4 is a single low-e coated glazing. Which is matching the base case glazing type, with an extra coating layer that provides better thermal properties to the external glazing in terms of reducing g-value and preventing solar heat gain.

On the other hand, Wall 8 configuration is made of AAC block that saves up to 15% from the cost of core construction due to its relatively light weight as per the manufactural technical sheet (Goneam 2018). Moreover, it has more sustainable environmental impact compared to cement block. For that reasons, the payback periods for wall 8 matrix combinations most likely will be less than the calculated results, in addition to having the maximum electricity savings provided from the simulations.

Table 5.12: Different possible combinations of selected minimum payback period and maximum annual electricity savings

Wall configuration*	Base case*	Wall 1		Wall 8	
		Glazing 4	Glazing 5	Glazing 4	Glazing 5
Annual Electricity Consumption (MWh/yr)	218.52	178.72	175.9	173.37	170.45
Annual Electricity Savings (MWh/yr)	0	39.8	42.62	45.15	48.07
Annual Electricity Savings (Percentage)	0	18%	19%	21%	22%
Annual cooling loads Savings (Percentage)	0	48%	51%	54%	58%
Annual heating loads Savings (Percentage)	0	5%	37%	57%	75%
Electricity cost savings (EGP)	0	40,675.5	43,545.78	46,143.3	49,130.1
External wall configuration cost (EGP)	72,998	238,204	238,204	470,645	470,645
External glazing configuration cost (EGP)	56,910	94,850	227,640	94,850	227,640
Exposed roof configuration cost (EGP)	40,250	40,250	40,250	40,250	40,250
Total cost	170,158	373,304	506,094	605,745	738,535
Difference in Price (EGP)	0	203,146	335,936	435,587	568,377
Simple payback period (Years) ***	0	5	7.7	9.44	11.6

5.4 Building Regulation Enhancements:

The findings of the study are based on only one prototype out of many other types of residential buildings in Egypt. However, it acts as an indicative investigation of the possible energy savings that can be achieved by implementing more sustainable building practices. Different building envelop configurations are tested in the study to investigate the energy reduction percentages that can be achieved in addition to an economic study expressed in the form of a simple payback period calculated for each configuration.

As mentioned in section (2.4) the external walls u-value recommended by the Egyptian building code is 2.35 W/m^2.K which is followed by the base case; while the external walls test matrix configurations - based on the available materials in the local Egyptian market - suggested u-values ranged between 0.61 to 0.26 W/m^2.K. Based on the final results of simulations in terms of annual electricity savings and simple payback calculations it is concluded that it is recommended not to increase the external walls u-value more than 0.61 W/m^2.K that will save up to 7% from the annual electricity consumption of the building. This result can be achieved by replacing 50 mm of external wall hollow cement blocks with 50 mm of EPS thermal insulation layer.

External glazing of the building code is single 6 mm clear glazing of g-value 0.82. Which is not recommended after conducting the study of different configurations of this parameter. The suggested configurations g-value ranged between 0.71 to 0.15. Results showed that the minimum payback period calculated can achieve up to 7.3% reduction in annual electricity consumption. Using single glazing showed better results than double glazing results. It is recommended to use tented or low-e coated 6 mm single glazing.

Exposed roof treatment of the base case using 50 mm of EPS achieved a u-value of 0.49 W/m^2.K that matches the regulations. Other configurations of exposed roof treatments did not show any further enhancements compared to the payback periods calculated. Therefore, it is recommended to follow the u-value recommended by the Egyptian building code.

Combining the maximum annual electricity savings showed that the building can save up to 18% of the annual electricity consumption. While the maximum reduction percentage achieved is 22%. Building regulation enhancements recommendations will be presented in the following chapter based on the findings of the study.

Building regulation enhancements recommendations will be presented in the following chapter based on the findings of the study. In addition to further studies recommendations.

6 Conclusion

A residential building in Cairo, Egypt was selected to investigate the building construction practices in Egypt and how this can be improved in order to save electricity consumption without affecting the user profile in cooling, and heating. The study was done specifically on the building envelop of the building in terms of different materials thermal specifications and their impact on energy efficiency. The building envelop was divided into three main parameters which are: external walls, exposed roof, and external glazing.

The study was conducted using computer simulation methodology and was divided into three steps. First step was conducted in the form of test matrix of simulations that consists of three main strategies diverted from the parameters of the study. Each strategy was covered by a number of simulations using different configurations for each parameter, 8 simulations were tested for external walls, 5 scenarios for external glazing and three scenarios for exposed roof treatments. Each scenario had a different total u-value. Simulations of the test matrix are done in a single basis where the simulations were done by changing only one variable in the base case model. An economic study was conducted for each scenario in the test matrix. The difference in material price was calculated, in addition to calculation the payback period for each scenario depending on the simulation's energy consumption results. While in the third step, the most energy saving scenario and the shortest payback period scenario were selected from each parameter and combined in a new matrix to investigate the impact in a form of combined matrix. Also, an economic study was conducted for each probability of combination to calculate the payback period estimated for each compared to the energy reduction results.

Maximum impact was achieved in external wall parameter simulations. The annual electricity consumption in external wall test simulations was decreased by a range from 6.9% to 8.3%. while payback periods ranged from 10.8 to 25.7 years. While in glazing, the annual electricity reduction ranged between 2% and 8.2% and payback periods ranged between 3 to 24.5 years. Single glazing configurations had an extremely shorter payback periods than that of double glazing configurations due to the high difference in market prices. While in exposed roof simulation it was found that the amount of thermal insulation that is already installed in the base case is enough as its actual savings in energy for the exposed floor - 5th floor- is 12% and 2% for the full building compared to the simulation done without the presence of thermal insulation layer. Extra thermal insulation thicknesses did not show better results compared to their high payback periods calculated.

In the test matrix, single simulations of external walls showed that adding a thermal insulation material may lead to almost total reduction in heating sensible loads reaching 100% during winter season, while on the other hand the cooling loads results recorded higher loads in April by 16% to 25% and in November by 71% to 78% than that of base case results due to the trapped heat as a result of the presence of thermal insulation material. Similar case was found in glazing simulations, cooling loads were significantly reduced even in months April and November, however, heating sensible loads were increased in months February by 10% to 89% and December by 3% to 85% because of less solar gain absorption by glazing scenarios used. While in exposed roof simulation it was found that the amount of thermal insulation that is already installed in the base case is enough as its actual savings in energy for the exposed floor - 5th floor- is 12% and 2% for the full building compared to the simulation done without the presence of thermal insulation layer. Extra thermal insulation thicknesses did not show better results compared to their high payback periods calculated.

Simulation results were investigated in terms of total energy consumption, cooling and heating loads. Combining wall and glazing scenarios solved out the increase of cooling/heating loads in each in test matrix results. Advanced glazing sections has reduced the solar heat gain, which reduced the heat trapped. Also, thermal insulation layer used in external walls insulated the cold from entering the building by conduction, eliminating the need of extra heating loads. It is concluded that enhancing only one of the building envelop parameters would not achieve the desired thermal performance for the building.

Results showed that simple enhancements (wall configuration 1 matrix) in the current building envelop of residential buildings can save 18% of electricity consumption with a payback period of 5 years. On the other hand, using more sustainable building materials (wall 8 configuration matrix) can save more energy however it would extend the payback period. In combined matrix simulations, annual electricity savings percentages ranged between 18% and 22%, with a corresponding payback periods between 5 years and 11.6 years.

6.1 Building code enhancement and further studies recommendations

Based in the simulation results investigations 3 probabilities of combinations were selected depending on the highest energy reduction percentage along with the shortest possible payback period calculated. Then, out of these probabilities a set of recommendations are concluded to enhance local building regulations as follows;

- Not to exceed 0.61 w/m^2k for the total u-value of external walls. In the Egyptian regulation code external wall u-value recommended is 2.35 W/ m2.K, while in the Egyptian energy code, the total u-value of external walls range between 0.74 to 1.82 w/m^2k, such a wall has been proven to consume high amounts of energy to achieve thermal comfort inside buildings. In the research done the wall scenario of u-value 0.61 achieved 7% of energy savings, and its payback period was estimated to be 10 years.
- To use single tinted glazing or low-e coated glazing, as it acts better than double glazing and have lower initial cost than that of double glazing. Using clear glazing is not recommended. The recommended glazing g-value is should be 0.56 or lower. It is important to mention that the case study window wall ratio (WWR) is 30%, other percentages ranges are not covered in the study that needs further studies to be done.
- To use the total u-value of the roof recommended by the Egyptian energy code. However, the resistance of the insulation material is calculated with reference to expanded polystyrene only. It is recommended to consider referring other types of thermal insulation materials for exposed roof treatments in the building regulations code.
- It is also recommended to mention a prototype of wall, roof, glazing section to be used in each climate zone inside Egypt, as it would make it easier and would have a great influence in moving the market towards more sustainable building materials to use.

- Instead of subsidizing the electricity cost, it is recommended to invest this money into enhancing the currently existing buildings in order to save more energy in the long run it would come over with benefits not only for the consumers but also for the government.
- It is more practical to recommend a constant u-value and specifications of external walls and glazing for all directions, north, east, west and south. Using different external wall combinations would lead to higher infiltration rates while connecting the external corners of the building due to the difference in the cross-sectional details of external wall for each elevation would lead to the presence of unwanted cracks in the building envelop. Moreover, in real construction different treatments for different elevations will consume more time and effort, as it would cause more probabilities of failure. However, further studies are needed to be done to investigate the actual impact of using different u-values for each elevation direction.
- To connect the building code to the local green rating system.
- To implement above mentioned recommendations in addition to the already present regulations through government enforcement for all new building permits. Also, further consideration of enhancing the current existing buildings is needed which can be done through applying carrot and stick rule.
- Further studies would be recommended to implement the same study on other climate zones in Egypt and different scales of residential buildings.
- Further research would be done on different types of shading. Daylighting and artificial lighting enhancements.
- Other topic that can be investigated is integration of photovoltaic systems to the building envelop.
- Considering double façade systems on future studies.

7 References

Abdallah, A.S.H. (2015a). Analysis of thermal comfort and energy consumption in Long Time large educational halls (studios), Assiut university, Egypt. *Procedia Engineering*, vol. 121, pp. 1674–1681.

Aditya, L., Mahlia, T., Rismanchi, B., Ng, H., Hasan, M., Metselaar, H., Muraza, O. & Aditiya, H. (2017). *A review on insulation materials for energy conservation in buildings* [online]

Aldali, K. & Moustafa, W. (2016). *An attempt to achieve efficient energy design for High-Income Houses in Egypt* [online]

Attia, S. & Wanas, O. (2012). *THE DATABASE OF EGYPTIAN 1 BUILDING ENVELOPES (DEBE): 2 A DATABASE FOR BUILDING ENERGY SIMULATIONS*. Fifth National Conference of IBPSA-USA. Viewed 15 February 2018.

Attia, S., Evrard, A. & Gratia, E. (2012). Development of benchmark models for the Egyptian residential buildings sector. *Applied Energy*, vol. 94, pp. 270-284.

Ayyad, K. & Gabr, M. (2012). *Greening Building Codes in Egypt*. Sustainable Futures: Architecture and Urbanism in the Global South. Viewed 17 February 2018.

Bassiouny, R., Ali, M.R.O. & NourEldeen, E.-S.H. (2015). Modeling the thermal behavior of Egyptian perforated masonry red brick filled with material of low thermal conductivity. *Journal of Building Engineering*, vol. 5, pp. 158–164.

Chandel, S.S., Sharma, V. & Marwah, B.M. (2016). Review of energy efficient features in vernacular architecture for improving indoor thermal comfort conditions. *Renewable and Sustainable Energy Reviews*, vol. 65, pp. 459–477.

"Chema-Foam". (2018). [Accessed 21 February 2018]. Available at: http://www.chema-foam.com/

Countrymeter. (2018). "Live Egypt population (2018). Current population of Egypt — Countrymeters". *Countrymeters.info* [online]. [Accessed 14 February 2018]. Available at: http://countrymeters.info/en/Egypt

Crawley, D., Hand, J., Kummert, M. & Griffith, B. (2008). Contrasting the capabilities of building energy performance simulation programs. *Building and Environment*, vol. 43 (4), pp. 661-673. [Accessed 17 February 2018].

Ctherm.com. (2018). "Thermal Conductivity of XPS (Extruded Polystyrene) Foam - C-Therm - Thermal Conductivity Instruments". *Ctherm.com* [online]. [Accessed 21 February 2018]. Available at: http://ctherm.com/resources/blog/thermal_conductivity_of_xps_extruded_polystyrene_foam2/

Dabaieh, M., Wanas, O., Hegazy, M. & Johansson, E. (2014). *Reducing cooling demands in a hot dry climate: A simulation study for non-insulated passive cool roof thermal performance in residential buildings* [online]

DLMC. (2007). *Life cycle costing (LCC) as a contribution to sustainable construction: a common methodology Final Report*. DLMC(Davis Langdon Management Consulting). Viewed 13 February 2018.

Dorra Group. (2012). "Dorra | Zayed Residence". *Dorra.com* [online]. [Accessed 20 February 2018]. Available at: http://www.dorra.com/portfolio-item/zaied-residance/

Dudzińska, A. & Kotowicz, A. (2015). Features of materials versus thermal comfort in a passive building. *Procedia Engineering,* vol. 108, pp. 108–115.

EGP-USD. (2018). "EGP - Egyptian Pound rates, news, and tools". *Xe.com* [online]. [Accessed 14 February 2018]. Available at: http://www.xe.com/currency/egp-egyptian-pound

EIF. (2018). "Egyptian Insulation Foundation". *Egyif.com* [online]. [Accessed 21 February 2018]. Available at: http://www.egyif.com/

ElMasry, I. (2017). "وزير الكهرباء: رفع الدعم عن محدودي الاستهلاك نهائيًا في 2022 «شائعة»". *Vetog Gate* [online]. [Accessed 15 February 2018]. Available at: http://www.vetogate.com/2796901

ETS. (2018). "Thermal Insulation Materials in Egypt". *Thermal Insulation Materials in Egypt* [online]. [Accessed 21 February 2018]. Available at: https://insulationservicesinegypt.wordpress.com

Farouk, K. (2017). [in person]. 2017.

Goneam, M. (2018). "Delta Mortar Product | Plena Egypt – Just another WordPress site". *Plenaegypt.com* [online]. [Accessed 21 February 2018]. Available at: http://plenaegypt.com/

Hanna, G. (2011). *Energy Efficiency Building Codes for Egypt*. 5th edn. Journal of Energy and Power Engineering - David Publishing. Viewed 17 February 2018.

Hudobivnik, B., Pajek, L., Kunič, R. & Košir, M. (2016). FEM thermal performance analysis of multi-layer external walls during typical summer conditions considering high intensity passive cooling. *Applied Energy*, vol. 178, pp. 363–375.

Islam, H., Jollands, M. & Setunge, S. (2014). *Life cycle assessment and life cycle cost implication of residential buildings—A review* [online]

Islam, H., Jollands, M., Setunge, S., Ahmed, I. & Haque, N. (2014). *Life cycle assessment and life cycle cost implications of wall assemblages designs* [online]. [Accessed 13 February 2018].

JosephG. (2009). "Creating a Weather File of Actual Weather Data - IES-VE User Forum". *Forums.iesve.com* [online]. [Accessed 20 February 2018]. Available at: http://forums.iesve.com/viewtopic.php?f=236&t=1017&p=2195&hilit=CONSUMPTION+VALIDATION&sid=826ef128c0ec80b3e641fe7784734325#p21953

Kamal, B. (2016). "Climate Change (I)Will the Middle East Become ‘Uninhabitable’? | Inter Press Service". *Ipsnews.net* [online]. [Accessed 13 February 2018]. Available at: http://www.ipsnews.net/2016/04/will-the-middle-east-become-uninhabitable/

Koppen. (2018). "Cairo, Egypt K�ppen Climate Classification (Weatherbase)". *Weatherbase* [online]. [Accessed 16 February 2018]. Available at:

http://www.weatherbase.com/weather/weather-summary.php3?s=66326&cityname=Cairo%2C+Muhafazat+al+Qahirah%2C+Egypt&units=

Mahdy, M. & Nikolopoulou, M. (2013). *Evaluation of fenestration specifications in Egypt in terms of energy consumption and long term cost-effectiveness* [online]. [Accessed 16 February 2018].

Manzano-Agugliaro, F., Montoya, F.G., Sabio-Ortega, A. & García-Cruz, A. (2015). Review of bioclimatic architecture strategies for achieving thermal comfort. *Renewable and Sustainable Energy Reviews*, vol. 49, pp. 736–755.

Ministry of Electricity. (2018). "Annual Report - 2015/2016". *Moee.gov.eg* [online]. [Accessed 12 February 2018]. Available at: http://www.moee.gov.eg/english_new/EEHC_Rep/2015-2016en.pdf

Ramadan, R. (2015). ""دخَّل" قراءة عدادك الكهربائى إلكترونيًا لتفادى مشاكل القراءات الخاطئة- اليوم السابع". *اليوم السابع* [online]. [Accessed 20 February 2018]. Available at: http://www.youm7.com/story/2015/1/4/%D8%AF%D8%AE%D9%91%D9%8E%D9%84-%D9%82%D8%B1%D8%A7%D8%A1%D8%A9-%D8%B9%D8%AF%D8%A7%D8%AF%D9%83-%D8%A7%D9%84%D9%83%D9%87%D8%B1%D8%A8%D8%A7%D8%A6%D9%89-%D8%A5%D9%84%D9%83%D8%AA%D8%B1%D9%88%D9%86%D9%8A%D9%8B%D8%A7-%D9%84%D8%AA%D9%81%D8%A7%D8%AF%D9%89-%D9%85%D8%B4%D8%A7%D9%83%D9%84-%D8%A7%D9%84%D9%82%D8%B1%D8%A7%D8%A1%D8%A7%D8%AA-%D8%A7%D9%84%D8%AE%D8%A7%D8%B7%D8%A6%D8%A9/2014507

Reda, F., Tuominen, P., Hedman, Å. & Ibrahim, M. (2015). *Low-energy residential buildings in New Borg El Arab: Simulation and survey based energy assessment* [online]. [Accessed 16 February 2018].

Rehman, H.U. (2016). Experimental performance evaluation of solid concrete and dry insulation materials for passive buildings in hot and humid climatic conditions. *Applied Energy*, vol. 185, pp. 1585–1594.

Sheta, W. & Sharples, S. (2010). *A BUILDING SIMULATION SUSTAINABILITY 1 ANALYSIS 2 TO ASSESS DWELLINGS IN A NEW CAIRO DEVELOPMENT*. New York City, New York:Fourth National Conference of IBPSA-USA. Viewed 15 February 2018.

Sousa, J. (2018). "Cite a Website - Cite This For Me". *Ceur-ws.org* [online]. [Accessed 16 February 2018]. Available at: http://ceur-ws.org/Vol-923/paper08.pdf

Sphinxglass.com. (2018). "Welcome to Sphinx Glass Official Website". *Sphinxglass* [online]. [Accessed 21 February 2018]. Available at: http://www.sphinxglass.com/2017/sphinxglass/en/Home

Taleb, H. (2017). [in person]. 2017.

"Tarrif & Electricity Prices". (2018). [Accessed 14 February 2018]. Available at: http://egyptera.org/ar/t3reefa.aspx#

Tejero-González, A., Andrés-Chicote, M., García-Ibáñez, P., Velasco-Gómez, E. & Rey-Martínez, F.J. (2016). Assessing the applicability of passive cooling and heating techniques through climate factors: An overview. *Renewable and Sustainable Energy Reviews*, vol. 65, pp. 727–742.

Udawattha, C. & Halwatura, R. (2017). *Life cycle cost of different Walling material used for affordable housing in tropics* [online]

Unicrete. (2018). "Welcome to Unicrete". *Unicrete.net* [online]. [Accessed 21 February 2018]. Available at: http://unicrete.net/

World Travels. (2018). "Word Travels - Travel Guide. Destination guides for the world traveller". *Wordtravels.com* [online]. [Accessed 13 February 2018]. Available at: http://www.wordtravels.com/#ixzz570Pwn6Dq

Wu, H., Wang, D., Liu, Y. & Wang, Y. (2017). Study on the effect of building envelope on cooling load and life-cycle cost in low latitude and hot-humid climate. *Procedia Engineering*, vol. 205, pp. 975-982. [Accessed 15 February 2018].