2-1-2020

Impact of autoclaved aerated concrete (AAC) on modern constructions: A case study in the new Egyptian administrative capital

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Recommended Citation

APA Citation

Khalil, E. (2020).*Impact of autoclaved aerated concrete (AAC) on modern constructions: A case study in the new Egyptian administrative capital* [Master's thesis, the American University in Cairo]. AUC Knowledge Fountain.
https://fount.aucegypt.edu/etds/804

MLA Citation

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The American University in Cairo

School of Sciences and Engineering

IMPACT OF AUTOCLAVED AERATED CONCRETE (AAC) ON MODERN CONSTRUCTIONS:

A Case Study in the New Egyptian Administrative Capital

A Thesis Submitted to
The Department of Construction Engineering

In partial fulfillment of the requirements for the degree of
Masters of Science in Construction Engineering

By
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June 2019

ACKNOWLEDGMENTS

I thank God for making the decisions I have taken to reach this stage in my life. I would like to express my gratitude in a few words to a number of people who helped me push through and complete this work.

First and foremost, I would like to express with a heart-felt of gratitude and love to my family, my parents, and my husband for their encouragement, understanding, support, patience, full dedication, and confidence in me which helped me throughout this process and gave me the full support to finish this work.

I sincerely would like to thank and appreciate Dr. Mohamed Abou-Zeid, thesis advisor, for his invaluable guidance, comments, encouragement, and continuous support which helped in building this work from the start. Dr. Mohamed not only encouraged me throughout this work but also throughout my graduate studies. I really appreciate him for being a considerate and understanding doctor. I really enjoyed working with him. I sincerely would like to thank and express my gratitude for his overall contribution in this work.

I would gratefully like to thank Engineer Dalia Wagdi for being such an awesome, understanding, caring and helpful person. She helped me endlessly during the different stages of this research. She provided me with all the support needed and the documents to find the right path to the work. I would like to sincerely thank her for her assistance throughout the whole process without any hesitation.

Special thanks to Engineer Amr Fahmy who is one of the project managers in the new Egyptian Administrative Capital; he helped me and supported me with providing the data associated to my work which I needed to build this research. It was a real honor meeting him. Also, Engineer Mohamed El Torgoman, owner of Torgo Block, for his full support with all the needed information to build my model. He really helped me as if I am his daughter. I am also thankful to Engineer Essam Samy, Technical Engineer in Delta Block, who didn't hesitate to help me and provide all the materials needed.

Last but not least, I would like deeply to thank my colleague Hoda Abouorban who helped me a lot during the preparation and data collection phase. She was supportive and I owe her; without her I couldn't have reached some of the data. She was such a good and supportive friend when needed.

ABSTRACT

Building materials selection is critical for the sustainability of any project. The choice of building materials has a huge impact on the built environment and the cost of projects. Building materials emit huge amount of carbon dioxide (CO_2) due to the use of cement as a basic component in the manufacturing process and as a binder which harm our environment. Energy consumption from buildings has increased in the last few years; a huge amount of energy is being wasted from using unsustainable building and finishing material as well as from the process of heating and cooling of buildings. In addition, the construction sector in Egypt is taking a good portion of the economy; however, there is a lack of awareness of buildings environmental impacts on the built environment. Using advanced building envelops can help in reducing heat consumption, projects initial and long-term costs, and minimizing environmental impacts. Red Bricks is one of the materials that are being used widely in Egypt. There are many other types of bricks such as Autoclaved Aerated Concrete (AAC); however, the use of Red Bricks is dominating the construction industry due to its affordability and availability.

This research focuses on the New Egyptian Administrative Capital as a case study to investigate the potential of the influence of using different wall systems such as AAC on projects cost and the environment. The aim of this research is to conduct a comparative analysis between the traditional and most commonly used bricks in Egypt which is Red bricks and AAC wall systems. Through an economic and environmental study, the difference between the two wall systems will be justified to encourage the utilization of uncommon techniques in the construction industry to build more affordable, energy efficient and sustainable buildings. The significance of this research is to show the potentials of using AAC in the construction industry and its positive influences. It analyzes the factors associated with choosing the suitable building without harming the environment and wasting materials that could be saved or recycled.

The New Egyptian Administrative Capital is considered as Egypt’s new heart, where ideas regarding energy savings and environmental benefits are taken into consideration. Meaning that, Egypt is taking good steps to move towards more sustainable construction. According to the analysis and simulations, there is a potential in reducing the construction initial costs of buildings of the residential and commercial buildings by 14.3% and 9.4% respectively and savings energy consumption, meaning the running cost savings, by 23.6% and 24.6% respectively. Interviews with the mega structures project engineers and managers reveal that they are more open to introducing sustainable building materials that will help in saving the environment and moving towards green construction as well as to studying more effective techniques for energy conservation.

Keywords: AAC, Building Materials, Energy Efficiency, Thermal Performance, New Egyptian Capital, Building Envelopes.

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LIST OF ABBREVIATIONS

AAC	Autoclaved Aerated Concrete
ALC	Autoclaved lightweight concrete
AC	Adaptive Comfort
ASHRAE	American Society for Heating, Refrigeration & Air Conditioning Engineers
AFA	Allergy Foundation of American
BPI	Building Physics and Environmental Institute
BEES	Building for Environmental and Economic Sustainability
CO_2	Carbon Dioxide
CAPMAS	Central Agency for Public Mobilization and Statistics
CPAS	Center for Planning & Architectural Studies
COP	Coefficient of Performance
DHW	Domestic Hot Water
EN	European Standards
EAQ	Environmental Air Quality
EEAA	Ministry of Environment-Egyptian Environmental Affairs Agency
EREC	Egyptian Code for Improving the Efficiency of Energy Use in Building
EPW	Energy-Plus weather file
HBRC	Housing and Building National Research Center
HVAC	Heating, Ventilation, and Air Conditioning
IAQ	Indoor Air Quality
IEA	International Energy Agency
ITC	Indoor Thermal Comfort
ISO	International Organization for Standardization
IWEC	International Weather for Energy Calculations
Kwh	Kilowatt Hour
LCA	Life Cycle Assessment
LC	Life Cycle
LW	Light Weight
LEED	Leadership in Energy and Environmental Design

LT	Light Transmission
MoLD	Ministry of State for Local Development
Mwh	Megawatt Hour
NIST	National Institute of Standards and Technology
NPV	Net Present Value
RH	Relative Humidity
SHGC	Solar Heat Gain Coefficient
STAT	Energy-Plus Weather Data Statistics
SRI	Roof Solar Reflective Index
USDOE	US Department of Energy
WYEC	Weather Year for Energy Calculations
WWR	Window to Wall Ratio
VAV	Variable Air Volume
VOC	Volatile Organic Compounds

CHAPTER 1: INTRODUCTION

1.1 Background

Thermal comfort and energy efficiency are two of the main approaches to reduce energy consumption in buildings. Buildings need to have a heating and a cooling system to reach the thermal comfort zone to occupy any space. Building envelope is one of the main factors that affect the indoor thermal comfort (Hashemi, 2015). Figure 1 is a representation of the sources of heat leakage in buildings by component . Walls and windows are considered the main source of heat leakage in a building (Duanmu, 2017).

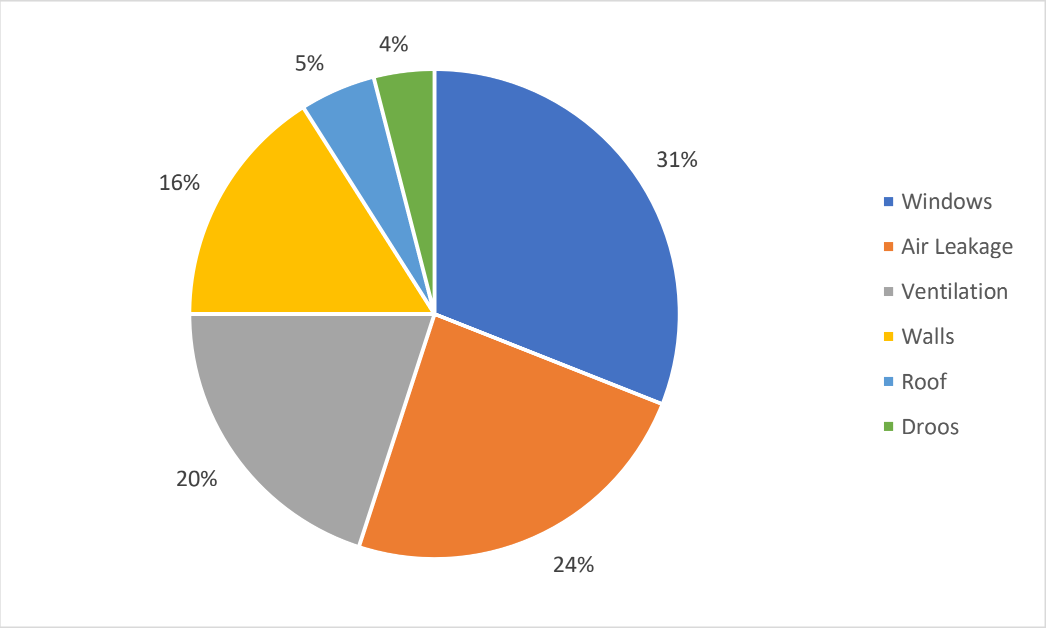


Figure 1: Sources of air leakage in buildings (Duanmu, 2017)

The air leakage through these sources cause the building in thermal discomfort for the occupants which leads to increase in demand to the heating and the cooling systems which increase the energy consumption of the buildings as well. Figure 2 demonstrates the total percentages of energy consumption in buildings by sector in Egypt (CAPMAS, 2018).

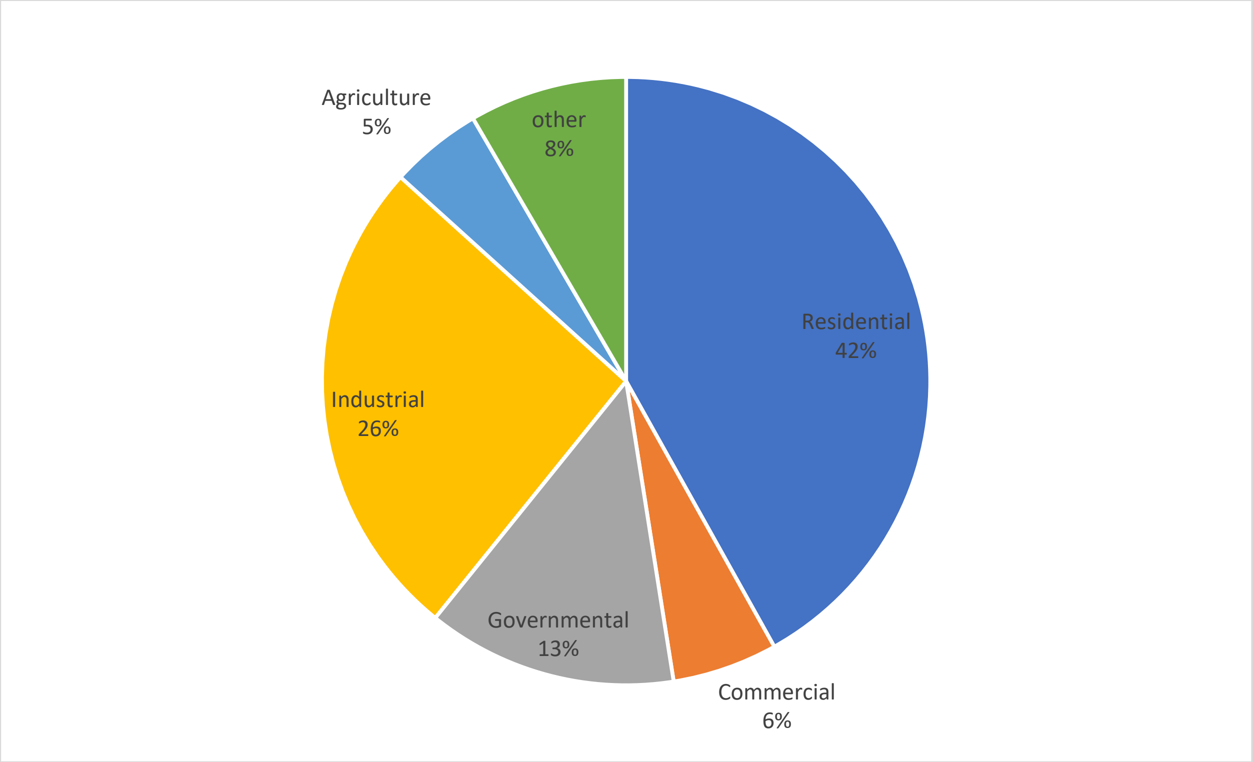


Figure 2: Egypt’s energy consumption by sector (CAPMAS, 2018)

The use of unsustainable building materials affects the environment and causes damages to it and causes an increase in the cooling and heating loads due to indoor thermal discomfort as shown in Figure 2. Building materials emits a lot of carbon dioxide (CO_2). There has been a strong evidence that the global climate is warming (Azouz, 2017). This change in the climate globally is due to number of factors, such as the greenhouse gases and others. Climate change must be addressed to avoid escalation of the problem and causing more harm to the environment. The CO_2 emission is one of these and it is affecting our environment negatively (Azouz, 2017). Furthermore, the construction industry is sharing a significant portion of this impact due to the huge emissions of CO_2 throughout the process of manufacturing and implementing the construction building materials. In addition, the construction works has been dominated by the use phase of the structure which accounted to almost 90% of the total environmental impacts which is being released by the construction works (Elattar, 2014).

The use of building materials in the construction industry has a significant effect on the cost and the environmental quality of the building experience. The construction sector in Egypt is taking a good portion of the economy; however, there is a shortage in the sustainability of the buildings. The building sector in Egypt has increased, the percentage of the total number of buildings constructed from 2006 till 2017 has reached 45.6% (Barakat, 2018).There are some efforts to improve the sustainability of the building sector in Egypt and the materials used which will improve, consequently, the quality, affordability, sustainability and experience of the built environment (El-Kabbany, 2013).

Knowing that the concept of go-green is one of the main topics that of great concern to the researchers worldwide, it shows its significance. In the past few decades, a lot of changes have happened to the construction industry which changed that way we see the environment. Some of these changes affect how we target to solve environmental problems or should solve it. Building envelop is one of the major and significant factors that contributes in these environmental issues. Additionally, the construction and finishing phase is becoming a crucial aspect of the shift to green buildings and design. Since these issues are diverse and have many different dimensions regarding the impact on the environment, the need for deeper analysis on the effect of building envelops on the energy consumption and total construction initial cost is significant (Azouz, 2017).

1.1.1 The New Egyptian Administrative Capital

Egypt is moving towards constructing one of the major mega projects which is the New Egyptian Administrative Capital. The proposed master plan has more than 40,000 residential units, commercial, governmental, industrial areas and others (Ministry of Housing, 2019).Two of the main concepts that are promising in the initial design state are being a green and sustainable city (Cube, 2019). There are some initial considerations towards energy conservation by using more uncommon building envelops. In the residential areas, a double wall red brick with air gap is used which will decrease the energy consumption more than the traditional single wall system, but it still is not sufficient to make a huge difference. However, the traditional building materials are yet being used.

1.2 Problem Statement

The choice of the materials affects the overall cost of the buildings and the indoor thermal comfort of the occupants. There are many materials that are being used in the construction industry and residential housing projects that affect the environment. One of these materials that are being used widely is Cement. Cement is one of the most polluting materials for the environment. Every year there are million tons of cement that are produced and used for different purposes (Naqi, 2019). The production process of cement not only emits toxic and hazardous wastes but also consumes huge amount of energy. The fact that this material is not sustainable means that it should be replaced or at least decrease its use. Besides, there are many other materials that can replace cement available in the market; however, the use of cement is dominating the construction industry (Brojan, 2014). Other material that are being used with huge numbers and is considered as one of the main building materials especially in Egypt is Clay Bricks. Even though the effect of clay bricks on the environment is huge, people still consider them as their main building material regarding wall systems. The process of producing clay bricks pollutes the environment and causes damage to the agricultural lands. There are many other types of bricks that are available in the market; however, the use of clay bricks is dominating the construction industry.

Energy efficient and long run low-cost buildings are achieved by the use of low-cost materials on the long-term or alternative construction materials and techniques. Besides, the selection of the building materials should meet the criteria of the local circumstances to improve the lives of the users and reduce the negative impact on the environment. Therefore, the significance of identifying the material related aspects of the design starting from the manufacturing phase till the assembling/finishing phase is becoming one of the most important research fields (Brojan, 2013).

Consequently, the current era of the use of materials in the construction industry has expanded. The use of other types of wall systems and the use of other sustainable materials are taking over the traditional ones. Clay bricks and mortar are not becoming the only options available in the market, but other brick types have been introduced such as Autoclaved Aerated concrete (AAC). Also, sustainable products are contributing to solve part of the problem of using other materials that affect the environment and the indoor air quality. By 2020, the global market for the sustainable products is estimated to be with a large value that could reach €200 billion per year (Elattar, 2014).

The use of AAC blocks faces some challenges especially in Egypt where the initial cost of the material determines the choice of the materials to be used. In spite of the fact that AAC blocks initial cost is higher, there are some benefits for using AAC blocks on the long-term that constitutes for this. Furthermore, internationally there is over 120 green labeling programs for building materials, locally there are no sufficient ones. This insufficient data makes it more challenging for the production process to proceed smoothly and makes the introduction of new sustainable building materials a challenge for the Egyptian market (Azouz, 2017). However, Egypt, like other countries, is suffering from the increase in electricity tariffs due to high energy consumption and thermal discomfort. Using new building envelops is promising because there is a strong demand to reduce energy consumption, hence cost. There are some attempts to use AAC blocks in some projects in Egypt such as 57357 Hospital, Sheraton hotel, and International medical center and few others; however, still the gains from the AAC blocks whether financially from the energy consumption and the initial construction cost savings or environmentally from the reduction of CO_2 emissions are not clear to the investors to make a move towards new sustainable building wall systems (Plena, 2018).

1.3 Research Objective and Scope

The aim of this research is to evaluate the impact of AAC blocks on the construction cost, the environment, energy consumption and the indoor thermal comfort using two different buildings from the New Egyptian Administrative Capital, a commercial and a residential building, as a case study. This will be done by conducting a comparative analysis and assessment between the traditional and most commonly used clay bricks and AAC blocks wall systems through assessing different building components in some cases using a mix of them. These components are as follows:

1. External Wall Systems
2. Fenestrations
3. Interior Finishing Materials

The significance of this investigation is that it should encourage investors to use more sustainable materials through highlighting the benefits of using new wall systems on the financial, the energy consumption and the thermal performance level. The research aims to define the initial construction cost, environmental impacts and the thermal performance of four wall systems through comparing the wall systems using both red bricks and AAC blocks within two buildings.

The objectives to reach the main goals of this research are:

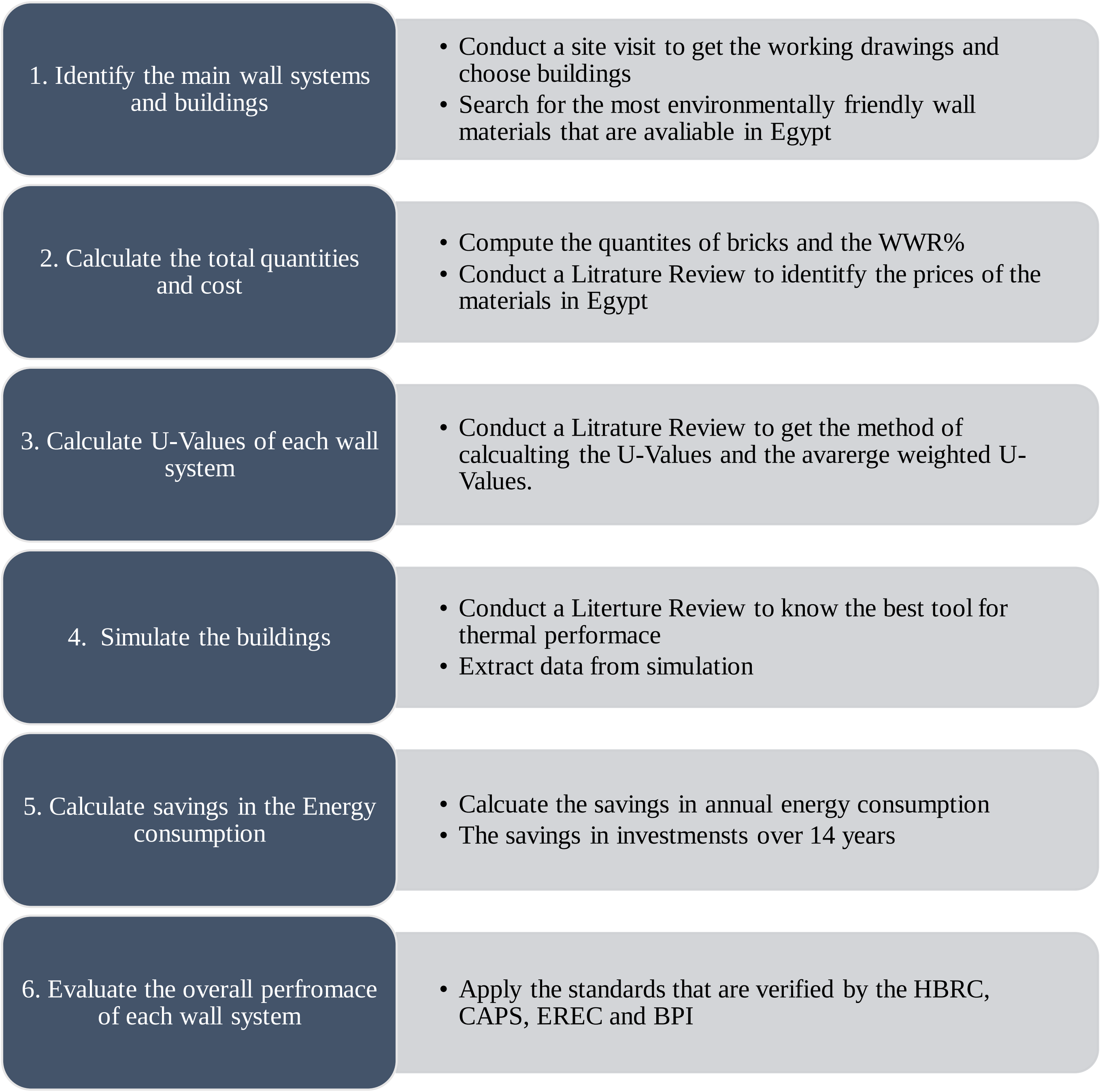
- Identify the main wall systems that are being used in the new capital
- Calculate the total brick and glass quantities of each building and compute the percentages of savings in the total initial construction costs.
- Calculate the U-Value and the average weighted U-Value of each wall system
- Simulate the two buildings on a thermal performance tool- DesignBuilder
- Compute the monthly and annually energy consumption of each building then calculates the percentages of savings in energy consumption and the return on investment over 14 years

1.4 Research Framework

The research framework that will be carried out to achieve the research goals is represented in Figure 3 as follows:

1. Literature review is conducted to gather information about similar analysis and the computational methods of the U-Values and the best tool for thermal performance.
2. Simulate the two buildings using thermal performance tool to test the effect of different wall systems on the indoor thermal comfort (ITC).

3. Analyze the simulated data to evaluate the performance of the wall systems and choose the best cost-effective and energy efficient one.
4. Compute the total savings in each wall system and the total savings of the operational costs over a period of time (payback period)
5. Develop a rating key to evaluate the overall performance of each wall system. This assessment is based on the life cycle assessment (LCA) of each wall system. This is a part of the framework to facilitate the evaluation of them.



1. Identify the main wall systems and buildings
   - Conduct a site visit to get the working drawings and choose buildings
   - Search for the most environmentally friendly wall materials that are avaliable in Egypt

2. Calculate the total quantities and cost
   - Compute the quantites of bricks and the WWR%
   - Conduct a Litrature Review to identitfy the prices of the materials in Egypt

3. Calculate U-Values of each wall system
   - Conduct a Litrature Review to get the method of calcualting the U-Values and the avarerge weighted U-Values.

4. Simulate the buildings
   - Conduct a Literture Review to know the best tool for thermal performace
   - Extract data from simulation

5. Calculate savings in the Energy consumption
   - Calcuate the savings in annual energy consumption
   - The savings in investmensts over 14 years

6. Evaluate the overall perfromace of each wall system
   - Apply the standards that are verified by the HBRC, CAPS, EREC and BPI

Figure 3: Proposed research framework

CHAPTER 2: LITERATURE REVIEW

2.1 Overview

The awareness to the global problem of the climate change, the carbon dioxide footprint and their relation to the construction works is becoming widely spread. The global measurements stated that the share of the building sector is 36% of the greenhouse gases emissions worldwide. In addition, the interference of the human factor in the climate system is causing damages to the environment and puts risk on the humans and the environment as well (Lumia, 2017). The conception about the idea that the main energy consumption is coming from the manufacturing phase while neglecting the operational and use phase is changing. Figure 4 shows the life cycle of each building material. It represents the main process of any building material and this process contains the installtion and use phase where it most affects the occupants and their thermal comfort (Wagdi, 2015).

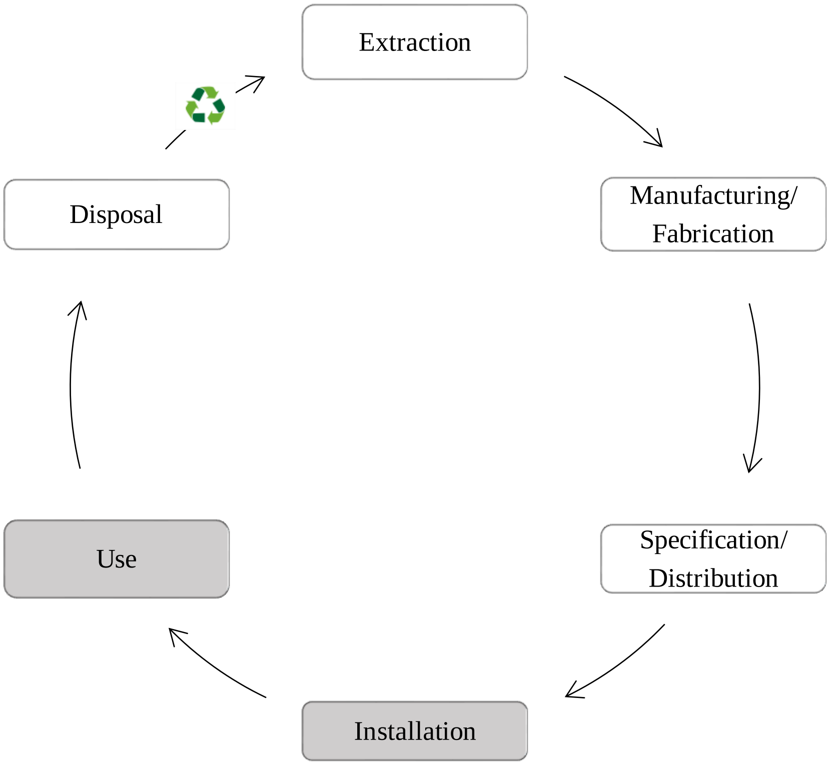


Figure 4: Materials life cycle (Wagdi, 2015)

There is a direct relation between the building material and the process that the construction carried out with. There are new technologies or materials that are being introduced in the market to change the construction industry perspective on the materials. The term alternative technology or material can be defined as “Alternative technology is defined by contrast from what are perceived to be prevalent environmentally destructive practices. Alternative technology is aimed to be environmentally friendly, affordable, and to offer people greater control over production processes”. To evaluate a building and determine whether it is appropriate for the environment or not, the process as a whole has to be evaluated from the start of the choice of a building material till the finishing and final stage of a building. There are some factors that contribute to the decision of evaluating a building material. These factors are related to (El-Kabbany, 2013):

- Locally produced and the required equipment to produce it
- Cost of production
- Waste management of this material and energy input
- Adjustability to climate differences
- Safety of its use; doesn’t contain hazardous materials.
- The know-how and it’s applicability
- Technologically feasible
- Easy installment, repairs, and maintenance
- Social awareness and acceptance

The greenhouse gas emissions have increased drastically in the last decades recording the highest emission rates ever annually. The global warming is the rising of the temperature of the Earth climate system throughout centuries. It is measured according to the level of temperature in the pre-industrial phases which acts as a reference level. Since the start of recording the global warming level, the universe is registering an unprecedent rise in its levels which is most likely due to the human influence on the Earth (Lumia, 2017). The rapid increase in the greenhouse gases is of a great concern to the world and one of these gases that is of huge concern is the CO_2. Figure 5 shows the increase in the CO_2 emissions concentration over the years. From 2000 till 2018 is the peak emissions of CO_2 where it raised from 360 ppm to over 400 ppm. This gives a clearer idea about the main problem we are living in and its continuation (Worldbank, 2018).

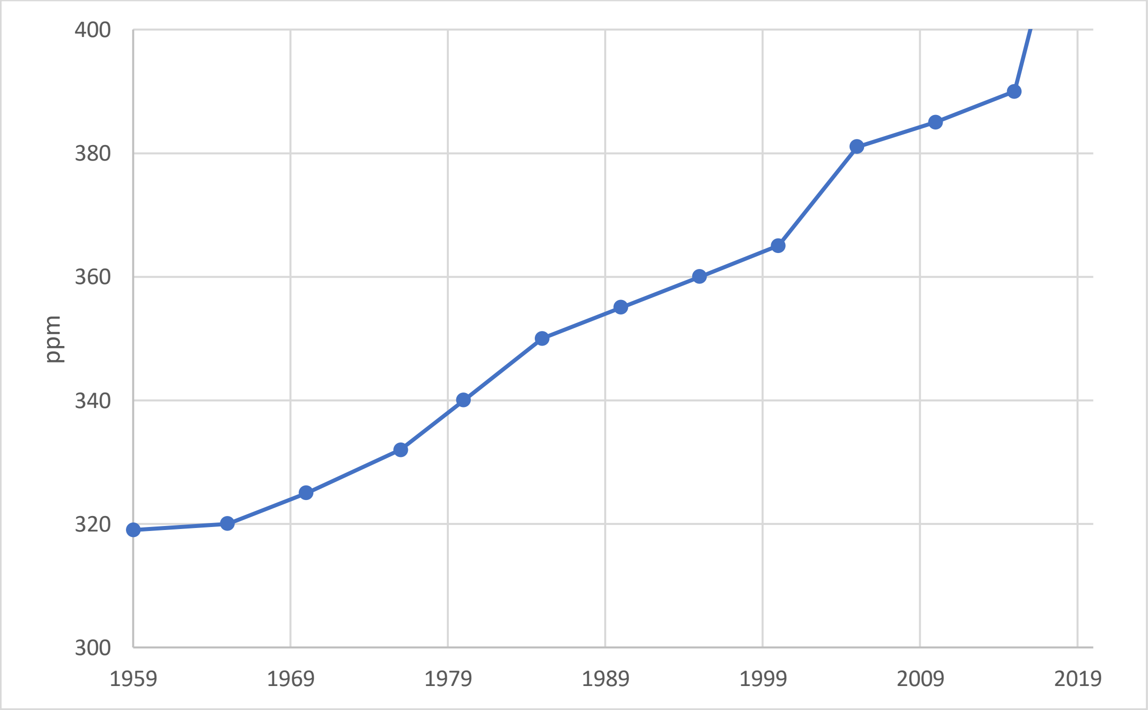


Figure 5: CO_2 emissions concentration (Worldbank, 2018)

Buildings and construction take a good portion of the CO_2 emissions worldwide**.** Figure 6 represents the emissions of CO_2 by sector till 2016 (CDIAC, 2017). Additionally, the amount of CO_2 emissions from the manufacturing and construction process, according to the World bank as shown in Figure 7, was 35 million tons in 2002 around 17.36% and it reached 403 million tones in 2014 around 19.96% as shown in figure (Worldbank, 2014).

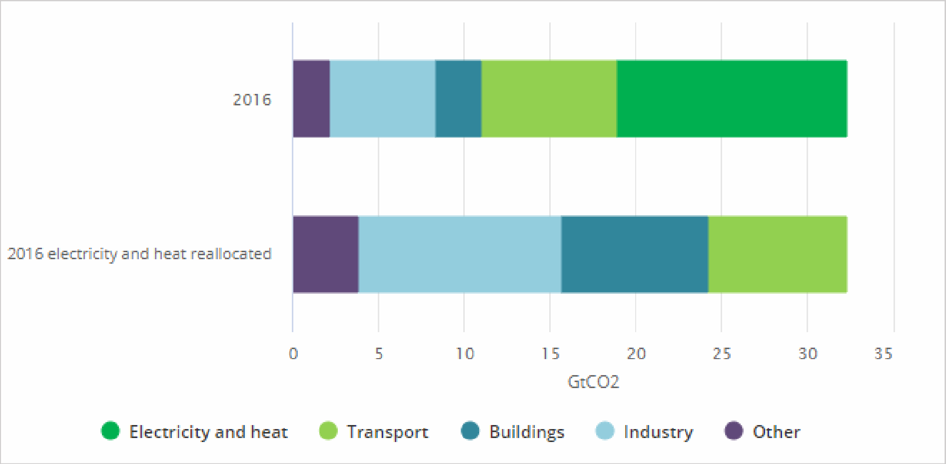


Figure 6: CO_2 emissions by sector (CDIAC, 2017)

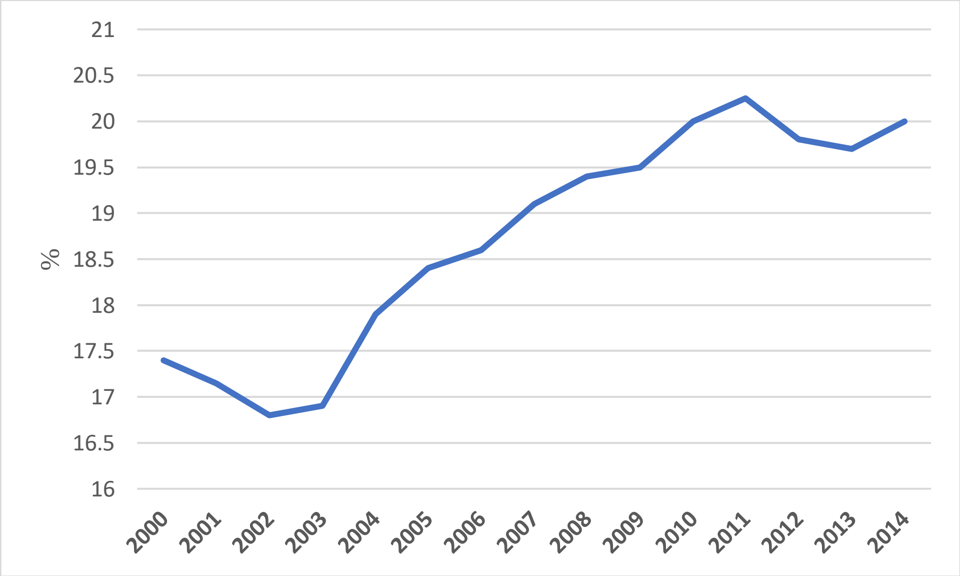


Figure 7: CO_2 emissions from manufacturing and construction process (Worldbank, 2014)

The dangerousness of such a phenomenon cannot be avoided, but there are remarkable efforts to decrease its effects and it is noticeable that its consequences can be controlled if we try to work on the level of temperature which leads to trying to control the thermal performance of buildings (Lumia, 2017).

2.1.1 History Behind the Research Problem

It can be seen that the architectural buildings in Egypt in the past were depending on the locally available raw materials and techniques. The potentials of using and building with local raw materials can be seen in the remaining of some buildings that were constructed using mud bricks. This demonstrates that the use of these materials can be utilized in buildings and provide their residences with affordable buildings and comfortable at the same time with respect to the climate. Rapidly this architectural style vanished this is due to the urbanization and the change in people socioeconomic status. With this change, people tend to move more towards a replacement of their mud houses and building concrete structures. Eventually, this became a sign of one being rich and modern. This became concurrent with the decision of the government in the 1980s, years after building the high dam, to criminalize the use of mud as a building material to produce bricks. Consequently, as an alternative solution for the mud bricks, other bricks were used such as limestone, cement blocks, desert clay bricks and others (El-Kabbany, 2013).

This was not the only change in the behavior of buildings in the late 90s. other changes were related to the decision of the government to limit the expansion of the agricultural land to preserve it. This decision forced people to think of alternatives and instead of building with the horizontal building style, they started to move vertically with the multi-story buildings to accommodate their entire family in one building. This vertical expansion changed the lifestyle of the residence which required different buildings materials to support it, hence different interior finishing materials as well. This caused the local building materials to get judged based on the market need and the mass production. Moreover, there was other efforts to use different materials and techniques to approach the concept of sustainability and green buildings and for building to be self-sufficient. These efforts can be spotted in the work of Hassan Fathy as well as Ramsis Wissa Wassef. They both were aiming to construct buildings that are affordable and provide in their designs local appropriate materials and techniques which help the construction sector to be more sustainable and save the environment. This can be seen in the Hassan Fathy's work for New Gourna village as seen in Figure 8 (El-Kabbany, 2013).

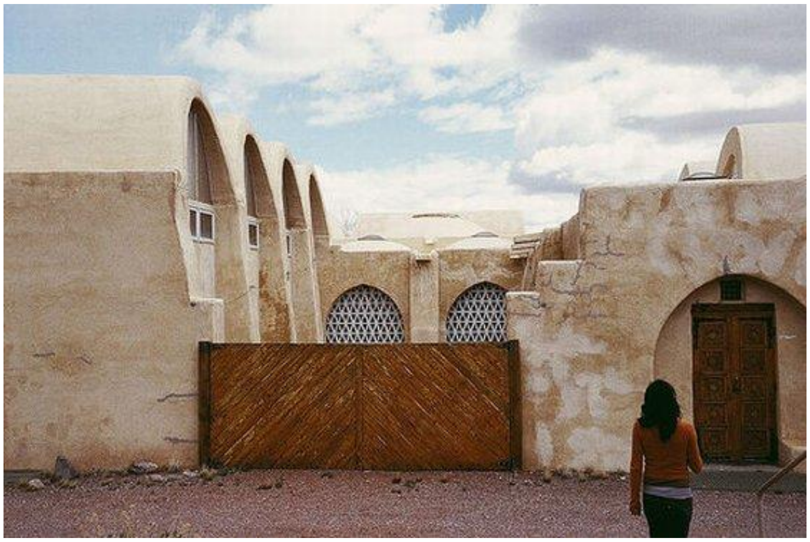


Figure 8: New Gourna village (El-Kabbany,2013)

On the other hand, there has been a great interest in the use of new construction materials. Researchers are focusing on the concept of sustainability and green architecture as well as protecting resources, and energy. All of these factors have contributed in the development of advanced technologies and techniques to better select building materials with respect to their properties and end of life treatments.

2.2 Egypt’s Construction Sector and The Environment

The construction process has many negative impacts on the environment from the very first phase till the final stage. These impacts include some major issues such as the construction on rural areas, the extraction of the raw materials, on the pollution level of air and water through emitting gasses to the environment, the production of cement industry which consumes a lot of energy and the end of life of the construction industry which generated a lot of waste making the construction sector one of the main polluters of the environment. Egypt’s CO_2 emissions is estimated by CAPMAS to be increased by 4.72% Figure 9 demonstrates Egypt’s CO_2 emissions till 2016 (CAPMAS, 2019a).

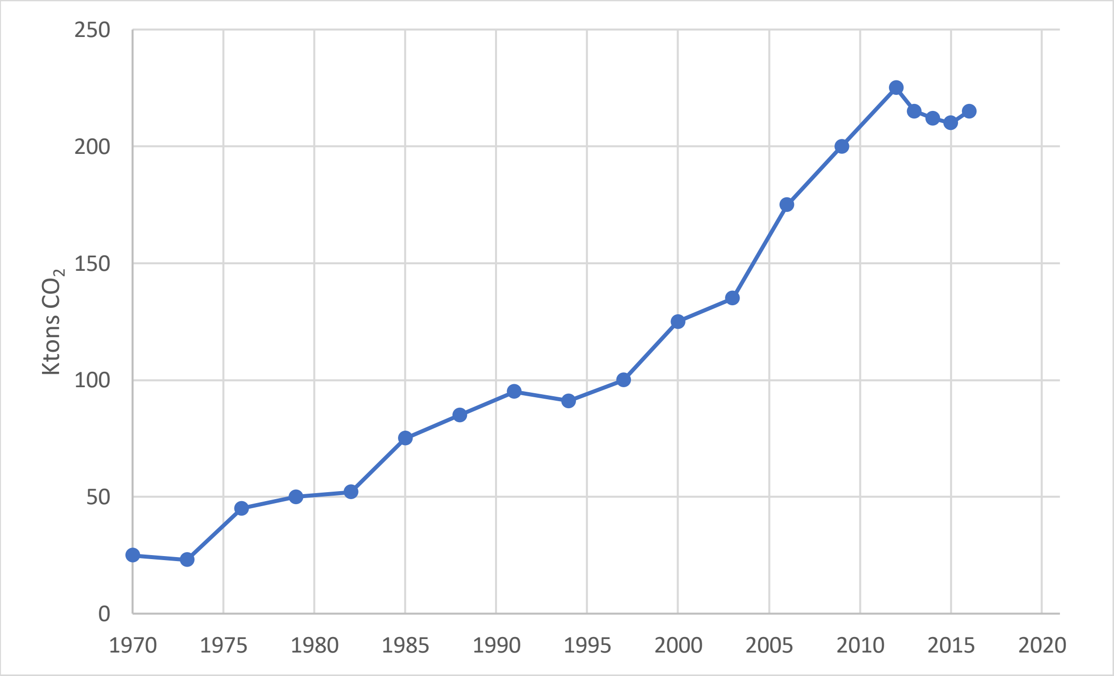


Figure 9: Egypt's CO_2 emissions (CAPMAS, 2019a)

There are some characteristics for the wastes generated from the building sector which are related to high level of recyclable materials, chemical wastes and hazardous materials. Consequently, the reduction of construction wastes is important and finding other ways for the end of life of the construction wastes is also significant to save the environment and reduce the CO_2 emissions from this sector (Talaat, 2013).The total consumption of CO_2 in Egypt is around 206.2 thousand tons. CO_2 emissions from the household and commercial building is around 8% as mentioned in Figure 10 (CAPMAS, 2019a).

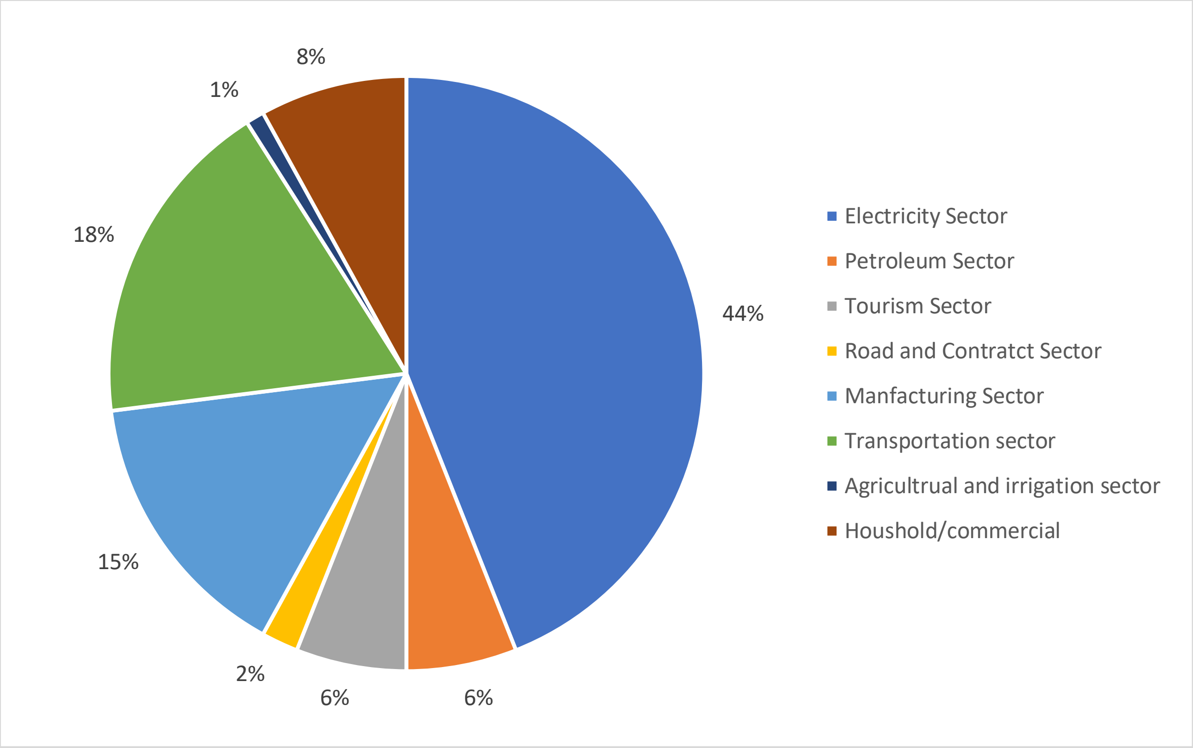


Figure 10: CO_2 emissions by sector in Egypt (CAPMAS,2019a)

The construction activities are increasing steadily which arises other related problems and one of these problems is the huge amount of waste generated from the construction sector (Zaki, 2013). According to the Ministry of State for Local Development (MoLD) and the Ministry of Environment-Egyptian Environmental Affairs Agency (EEAA), the estimated quantities of the generated solid wastes in Egypt can be illustrated as shown in the Figure 11. According to the

Annual report for Solid waste management in Egypt, it is shown that the generated quantities from the construction and demolition waste is 41,748,603 tones per year which is around 44% of the total solid waste (Zaki, 2013).

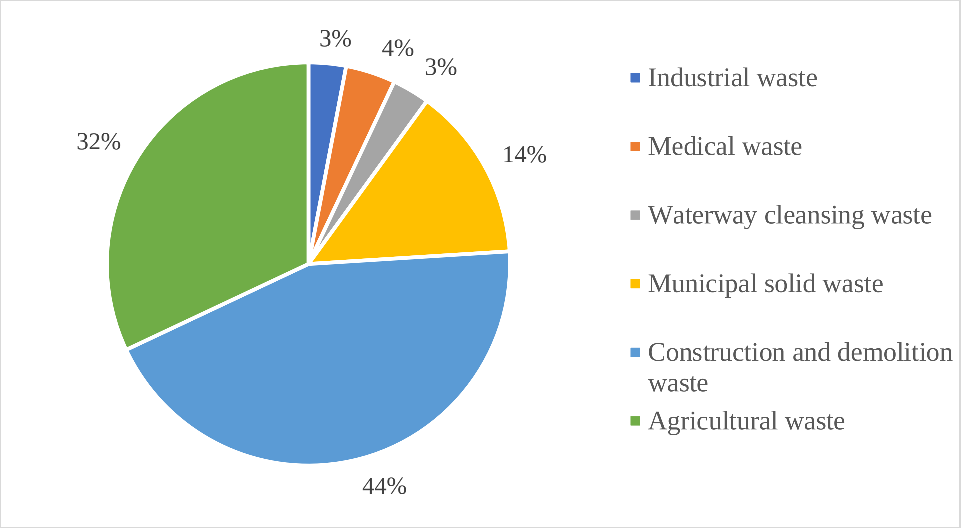


Figure 11: Solid waste generation in Egypt (Zaki, 2013)

Waste from demolition of buildings in the construction sector is increasing since the lifespan of building in developing countries is relatively short. Moreover, the percentage of construction and demolition waste is an indicator on how much energy is consumed in this sector and how much material is being wasted. In addition, according to the latest annual report by the EEAA in 2016 states that, there are some efforts to change the environmental policies to be more effective. The LECB project is in progress to decrease the carbon emissions and there is a progress in this project in 10 sectors (NAMA Mapping), especially in the housing and electricity sectors. Moreover, the report mentioned that there are some projects that decreased the use of cement to maintain a better environmental quality. Cement is the binder used for mostly all the building materials, decreasing cement production and usage means decrease the environmental impacts and improving the human health (EEAA, 2017).

Cement production globally has grown in a very rapid pace in the recent years according to the Global Carbon Project. The estimated values of the CO_2 that are being used for the development of the carbon budget globally are used by 'the global carbon modelling community'. The change in the land use and the fossil fuel makes cement production as the third largest sources of CO_2 emissions worldwide. Figure 12 shows the increase use of cement and fossil fuel production globally (Andrew, 2017).

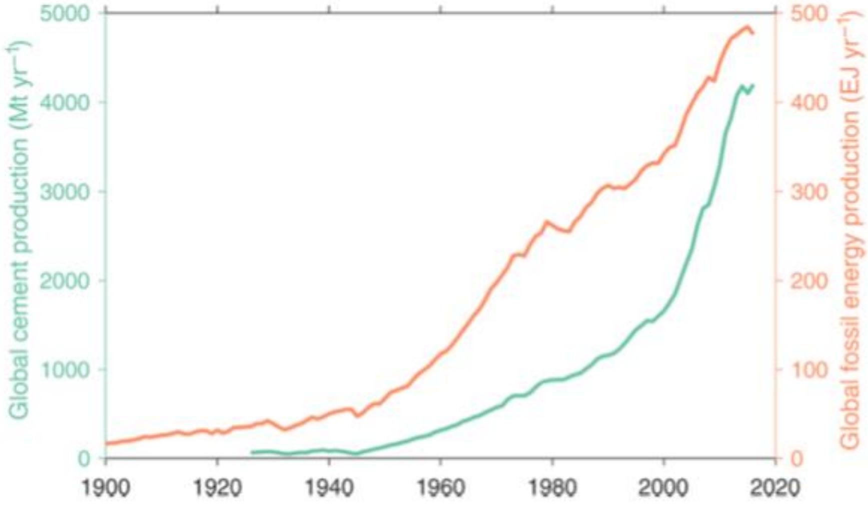


Figure 12: Cement production by year (Andrew,2017)

In addition, as a fact cement production is one of the most polluting productions worldwide and its manufacture is increasing due to the fact that in any construction project demolition and renovations are always taking place. This causes loss of materials which leads to loss of raw materials. In addition, the estimated cement quantities that are being produced every year is huge and for every 1 ton of cement there is around 0.8 tons of CO_2 produces (Zaki, 2013). This highlights the amount of damage that the use of cement causes to the environment.

2.3 Waste generation

The construction and demolition waste (C&DW) are not only a problem of dumping in our streets anywhere, but also it is a problem of the amount of raw materials that are being wasted due to demolition. Bricks when demolishes contain the mortar/binder which contains cement as well as concrete when demolishes cement quantities is lost since it is one of its main mix design components. Table 1 shows the most recent data available for the composition of the construction and demolition waste in Egypt where bricks, mortars, concrete and steel constitute on average 9%, 10%, 7% and 8% of the waste respectively (Talaat, 2013).

Table 1: Construction and demolish waste composition (Talaat, 2013)

Material	Minimum	Maximum	Average
Concrete	6%	9%	7%
Wood/Lumber	7%	15%	11%
Steel	6%	10%	8%
Excavated Soils	25%	48%	36.50%
Bricks	7%	11%	9%
Concrete Blocks	7%	13%	10%
Plastics	3%	5%	4%
Ceramics	6%	12%	9%
Chemicals	2%	3%	2.50%
Mortar	7%	12%	10%
Minerals	0%	5%	2.50%

The data for cement production can vary according to the country. China is the biggest country in cement production globally with a percentage of around 60% till the year 2017 at an estimate of 2.4 billion metric tons and followed by India with around 7% production at an estimate of 270 million metric tons by the year of 2017 as well (Lumia, 2017). Furthermore, the recent cement production globally is estimated to be 3.27 in the year 2010 and it is expected to increase to 4.83 by the year 2030. This will increase the problem of CO_2 emissions from the cement production, thus increasing the environmental problems worldwide (Andrew, 2017). Figure 13 a and b demonstrate a typical scene in the streets of Cairo where bricks with mortar binders and concrete are dumped with quantities in two places.

Figure 13: Demolished walls in two different places in Cairo (a) Nasr city (b) El-Tagmo’a (Author)

2.4 Green Certifications and Building Materials

This section is an introduction to the green certifications that addresses the building envelops and insulation materials to reduce energy consumption. The transition to eco-friendly societies with low carbon emissions is a need when combining the problems arise from the building sector. The change to a low carbon society is a long-term process and needs structural changes in resources and energy systems which leads towards a society where the carbon levels are neutral. The main challenge to our environment is the anthropogenic driven climate which should be overcome by the transition to zero carbon societies if it is possible (Lumia, 2017).

The need to reduce the greenhouse gasses and energy consumption in the building sector are major issues that needs to be solved. The Passive house and net zero emission buildings are concepts that are being introduced to the building sector. These concepts inspire the need to reduction of the heat that is being transfer from the building envelope to the indoor interior space. Currently, the building sector is moving towards the energy efficient designs that includes many factors. These factors are not only exclusive to the thermal transmission of the heat or the thermal performance of the building but also the reduction in the use of materials that consumes a lot of energy during the production and in the use phase (Palumbo, 2015).

The need for criteria to enhance the building sector is spreading widely in many countries worldwide in order to decrease the environmental impacts, energy consumption and cost. There are many certificates that evaluate the building and consider to which level of Green it is as mentioned in Table 2 (Sakr, 2017) . Building materials choice is a key factor in this evaluation. There are many buildings that applied this concept of going Green in both the design phase of the project and the construction phase. There are international and national Green certificates. LEED is one of the international certificates that evaluate the performance of the building. Green pyramid is one of the Egyptian certificates of evaluating buildings. This is a representation that Egypt is moving towards a greener building with less energy consumptions as shown in Table 3 and Table 4 (Sakr, 2017).

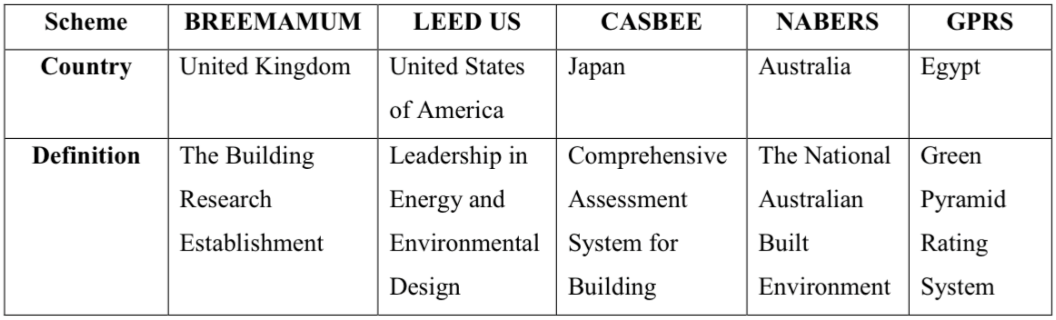
Table 2: Green building rating systems internationally (Sakr, 2017)

International System	Country	Introduced Data
BREEM	UK	1990
LEED	USA	1998
CASBEE	Japan	2001
GREEN STAR	Australia	2003

Table 3: Certified rating systems worldwide (Sakr, 2017)

National System	**Country**	**National System**	**Country**
GREEN GLOBES	Canada	Hkbeem	Hong Kong
GBAS	China	IGBC Tools	India
GREEN PYRMAID	Egypt	Protocolloitaca	Italy
PRMISE	Finland	Lider A	Portugal
HQE	France	Green Mark	Singapore
DGNB	Germany	Verde	Spain

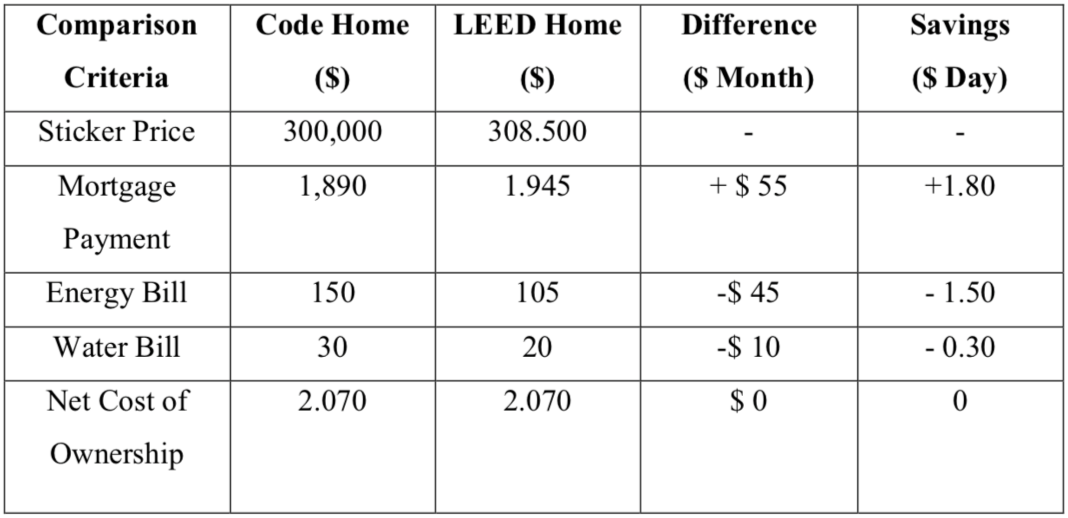
Table 4: Certified LEED systems worldwide (Sakr, 2017)



Scheme	**BREEMAMUM**	**LEED US**	**CASBEE**	**NABERS**	**GPRS**
Country	United Kingdom	United States of America	Japan	Australia	Egypt
Definition	The Building Research Establishment	Leadership in Energy and Environmental Design	Comprehensive Assessment System for Building	The National Australian Built Environment	Green Pyramid Rating System

There are some requirements by the LEED for the existing buildings to be certified. These requirements are shown in Table 5. There are some initiatives to change homes into more sustainable buildings. LEED for homes is one of these initiatives that works in the residential buildings industry (A. Mohamed, 2011). Table 3 shows a comparison between Code-home and LEED Home 2009 as a way to reflect energy savings in green buildings due to reduction in energy consumption. This comparison shows that the initial cost of the Code home is less than the LEED home; however, the energy consumption of the code home is higher than that of the LEED home (Sakr, 2017).

Table 5: LEED home and Code-home comparison (Sakr, 2017)



Comparison Criteria	**Code Home ($)**	**LEED Home ($)**	**Difference ($ Month)**	**Savings ($ Day)**
Sticker Price	300,000	308.500	-	-
Mortgage Payment	1,890	1.945	+ $ 55	+1.80
Energy Bill	150	105	-$ 45	- 1.50
Water Bill	30	20	-$ 10	- 0.30
Net Cost of Ownership	2.070	2.070	$ 0	0

2.5 Egypt's Energy Consumption

Energy consumption in Egypt is increasing more than the capacity of production which puts Egypt in an energy challenges to maintain the equation between production and consumption (Hegazy, 2015). The prices of electricity have increased due to the fact that the energy consumption is higher than the production. Table 6 represents the energy consumption in Egypt by sector and figure 14 shows the total energy consumption till 2018 (CIAworld, 2019). Table 6 shows that households consume the maximum amount of energy (CAPMAS, 2018). The increase in energy consumption caused an increase in electricity bills by around 33% last year and according to the minister of electricity decree 312-year 2017, the electricity tariffs increased by 28.7% which lead to an increase in electricity bills by 27% on average in 2018 (BEO, 2018).The difference between 2017-2018 electricity bill is shown in Figure 15. The electricity brackets and the corresponding range of Kwh used are shown in Table 7 and a comparison between the tariffs is shown in Figure 16.

Table 6: Energy consumption by sector in Egypt (CAPMAS, 2018)

List	Electrical Energy	Natural Gas
Industry	41479	12707
Transport	567	376
Households	64125	2277
Agriculture	6743	--
Other	38692	5255
Total	151606	20615

Table 7: Electricity brackets (BEO, 2018)

Brackets	Range	Usage
Bracket 7	0 to +1001 Kwh	High use
Bracket 6	651 to 1000 Kwh	High use
Bracket 5	351 to 650 Kwh	High use
Bracket 4	201 to 350 Kwh	Average use
Bracket 3	0 to 200 Kwh	Low use
Bracket 2	51 to 100 Kwh	Very low use
Bracket 1	0 to 50 Kwh	Very low use

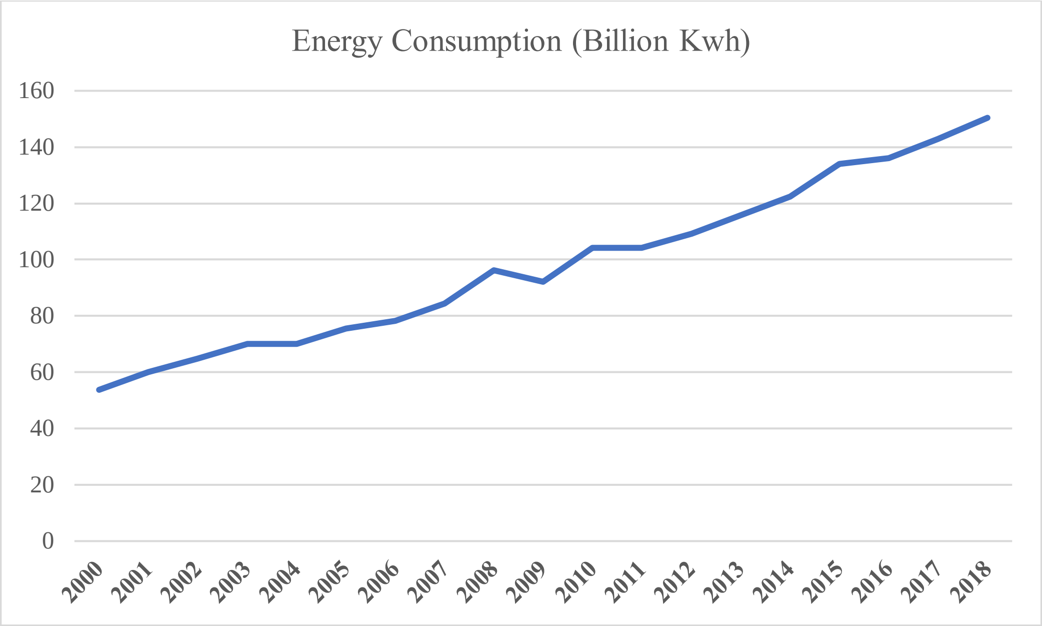


Figure 14: Egypt's energy consumption till 2018 (CIAworld, 2019)

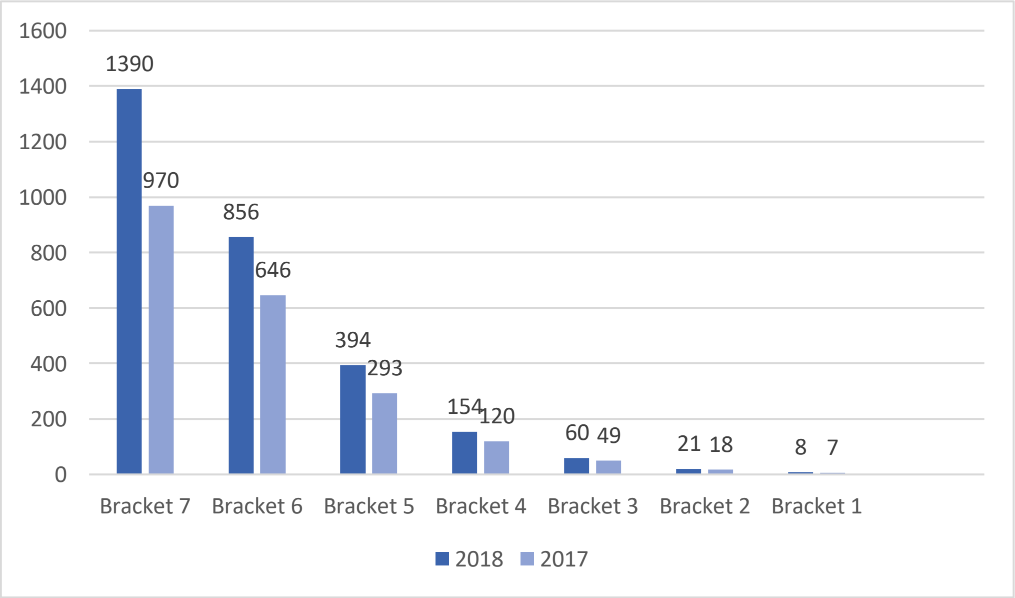


Figure 15: Increase in electricity bill between 2017 and 2018 (BEO, 2018)

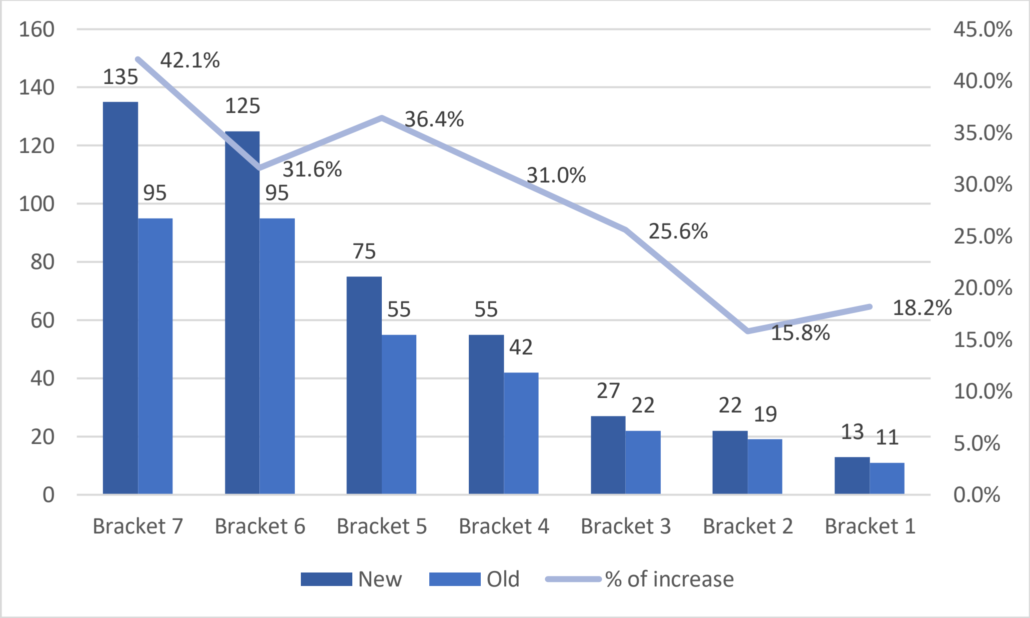


Figure 16: Comparison between old and new tariffs (BEO,2018)

The relation between the per-capita and the energy consumption levels in Egypt does not balance. The Egyptian population is over 90 million and they are almost all concentrated around the Nile makes 43% only of the Egyptian land urbanized (Wanas, 2012). This let people think of spreading horizontal, increasing the energy consumption per square meter. Moreover, the increase in climate changes and people sensitivity to different temperatures in Egypt led to increase in energy consumption to adapt to the needed cooling loads. This is clear in the fact that the need for Air conditioning units has increased in the past few years dramatically from 700,000 to 3 million units in the years 2006 to 2010 respectively and in a rapid increase in the last few years (Wanas, 2012). Figure 17 shows an overview of the air conditioning demand by region from 2012 to 2017 (JRAIA, 2018). The Middle East shows an increase in demand especially in the Residential sector.

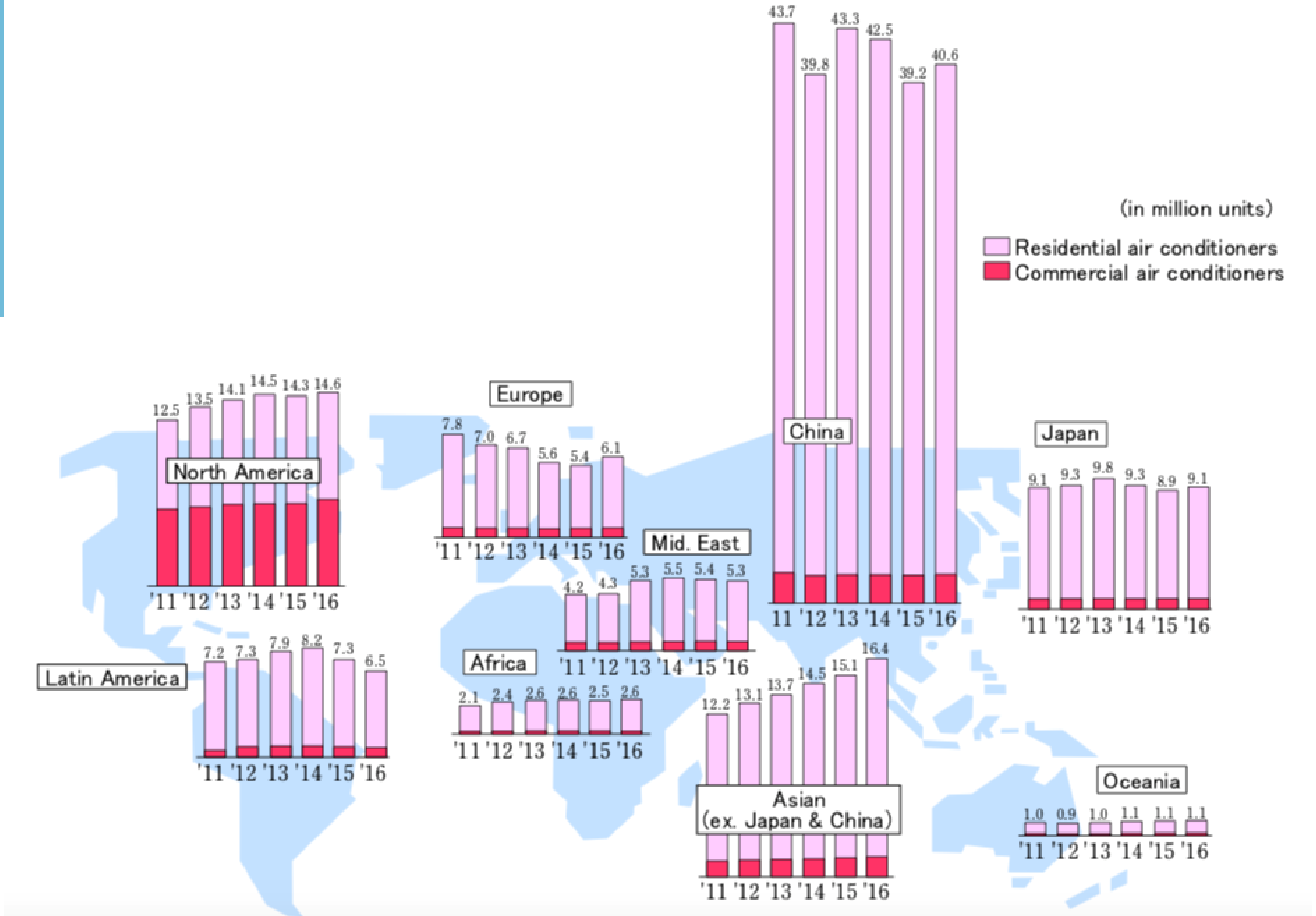
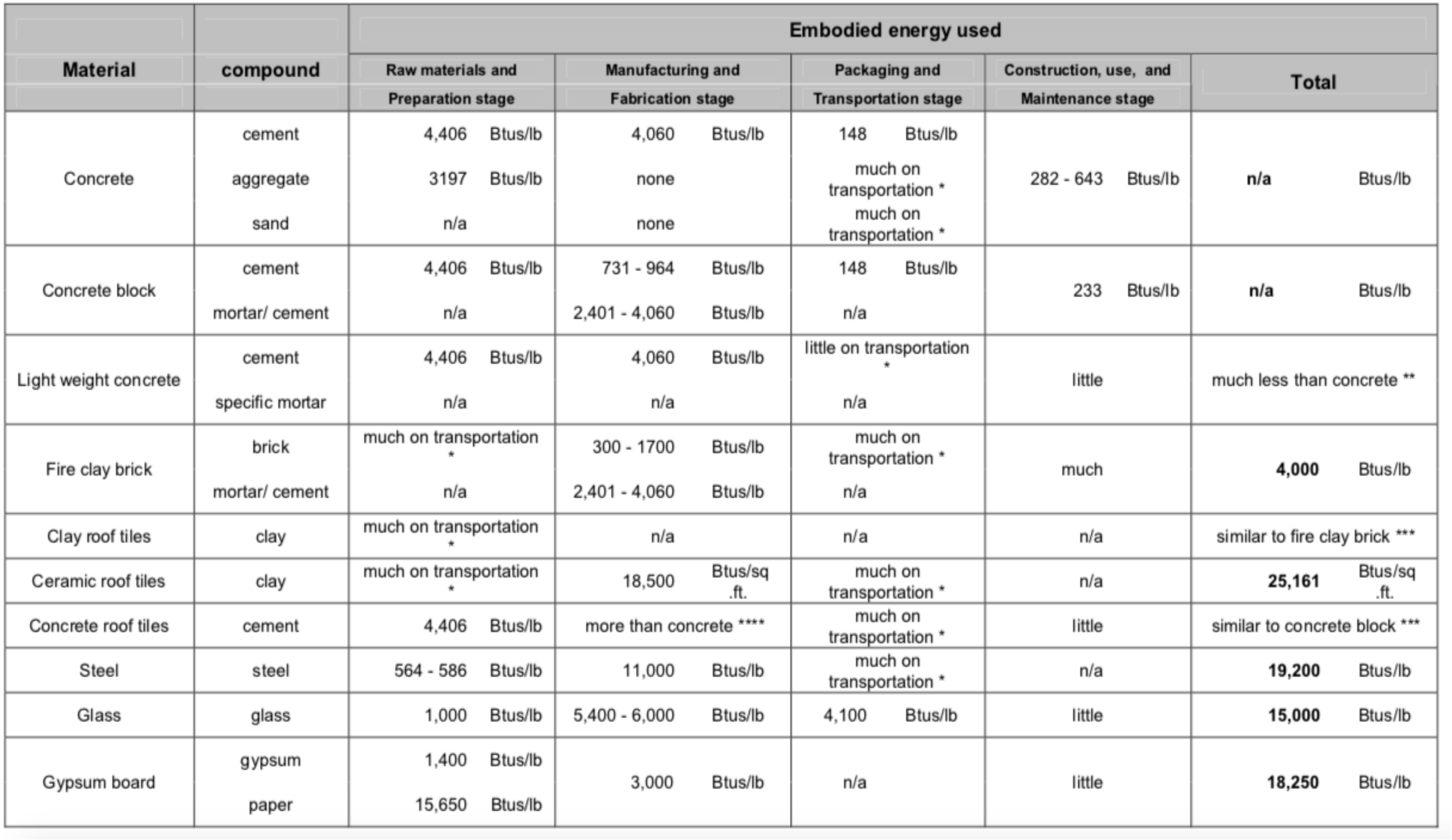


Figure 17: Air condition units demand (JRAIA,2018)

To illustrate, in Egypt 12% of the capacity of the power stations is consumed by the air conditioning units. Meaning that, the building sector consumes a total of 22% of the overall energy production in Egypt. This is a real concern that should be taken in consideration to be minimized. The choice of a need building envelope using innovative materials could help in minimizing this energy consumption. Therefore, how much energy is needed to produce a building material vary form one material to another (JRAIA, 2018).

The energy that is needed throughout the life cycle of a building material is significant which is called the ‘embodied energy’. The embodied energy of a material is an indicator for the environmental impact of a material on the environment (El-Didamony, 2017). For instance, the embodied energy needed to produce Cement is high because of a large amount of electricity for the manufacturing process. Table 8 shows the different embodied energies for different building materials. Thus, the choice of a building material with low embodied energy reduced the overall impact on the environment. Also, the choice of local materials helps in saving energy from transportation, hence the environment as a whole (El-Didamony, 2017). Generally, there is a direct relation between the energy consumption and the CO_2 emissions. According to the International Energy Agency (IEA), estimated that more than 40% of the energy consumption and 24% of the global CO_2 emissions is due to the current buildings (Abdel-Hadi, 2012).

Table 8: Embodied energies for different building materials (El-Didaminy, 2017)



Material	compound	Embodied energy used				
		Raw materials and Preparation stage	Manufacturing and Fabrication stage	Packaging and Transportation stage	Construction, use, and Maintenance stage	Total
Concrete	cement	4,406 Btus/lb	4,060 Btus/lb	148 Btus/lb	282 - 643 Btus/lb	**n/a** Btus/lb
	aggregate	3197 Btus/lb	none	much on transportation *		
	sand	n/a	none	much on transportation *		
Concrete block	cement	4,406 Btus/lb	731 - 964 Btus/lb	148 Btus/lb	233 Btus/lb	**n/a** Btus/lb
	mortar/ cement	n/a	2,401 - 4,060 Btus/lb	n/a		
Light weight concrete	cement	4,406 Btus/lb	4,060 Btus/lb	little on transportation *	little	much less than concrete **
	specific mortar	n/a	n/a	n/a		
Fire clay brick	brick	much on transportation *	300 - 1700 Btus/lb	much on transportation *	much	**4,000** Btus/lb
	mortar/ cement	n/a	2,401 - 4,060 Btus/lb	n/a		
Clay roof tiles	clay	much on transportation *	n/a	n/a	n/a	similar to fire clay brick ***
Ceramic roof tiles	clay	much on transportation *	18,500 Btus/sq .ft.	much on transportation *	n/a	**25,161** Btus/sq .ft.
Concrete roof tiles	cement	4,406 Btus/lb	more than concrete ****	much on transportation *	little	similar to concrete block ***
Steel	steel	564 - 586 Btus/lb	11,000 Btus/lb	much on transportation *	n/a	**19,200** Btus/lb
Glass	glass	1,000 Btus/lb	5,400 - 6,000 Btus/lb	4,100 Btus/lb	little	**15,000** Btus/lb
Gypsum board	gypsum	1,400 Btus/lb	3,000 Btus/lb	n/a	little	**18,250** Btus/lb
	paper	15,650 Btus/lb				

2.6 Selection of Building Materials in Egypt

The choice of building materials depends of many factors. These factors are related to the cost of this material, the aesthetics desired, and the budget of the project. Some studies show that building materials are considered as the largest input in the construction sector. In Ghana, it accounts for more than 60% of the total cost, in Tanzania around 76%, in Kenya around 68%, and in Nigeria around 65% (Adewale et al., 2018). However, other important factors must be taken in consideration such as the energy efficiency, sustainability, maintenance and the long-term cost of this buildings. The concept of thermal behavior in the indoors of a building is not taken in consideration in many cases and it varies according to the local climate. In Egypt, the climate is mostly very sunny which leads the thermal conditions of the indoors of a building and especially in the housing projects to be very uncomfortable. On the other hand, for the buildings where air conditioning is affordable, a lot of energy is consumed and consequently the running costs increase (Marincic, 2014).

Design concepts and strategies should take in consideration the local climate factor. This will have a massive impact on not only the design phase but also the energy consumption, the occupants experience inside the building and the choice of materials. Meaning that, the choice of suitable materials for the building envelope is extremely significant and affects the design strategies as well as the project components as a whole (Marincic, 2014).

2.6.1 External Wall Systems

Wall systems are different and there are many types of blocks that are being used widely as a construction material. The choice of wall system differs from one project to another according to the project concept and budget (see section 2.6). There are some blocks that are used widely in Egypt in both the residential and the commercial projects which are clay bricks, Hollow blocks, and other concrete blocks (Wagdi, 2015). Each one of these has its own uses and properties which means that the local situation guides which brick to be used when (Marincic, 2014).

Besides, the development of new building materials contributes to the environment a lot since their use will reduce the energy demand of the building, reduction of the waste generation, beneficial health, environmental aspects and the embodied energy as well. The use of new materials is increasing nowadays. There are some other building materials that are being used commercially but they are not common such as Autoclaved aerated concrete, Non-autoclaved aerated concrete, Cellular lightweight concrete and straw bale (El-Kabbany, 2013).

The field of green buildings, eco-friendly environment and sustainable construction are gaining a lot of interest in the research field and the construction industry in Egypt. This is due to the gap between the energy consumption, the rapid urbanization and high pollution rates. The real challenge is how to promote and raise people awareness towards the use of new building materials for the benefit of the environment. Still the construction sector doesn’t remarkably change on the common practice level which lead to shortage in the movement towards sustainability and sustainable materials. However, there are some projects that started to be more aware of the problem and consider the long-term benefits of the introduction of new building materials. In addition, there are many factors that influence the move towards sustainable construction such as the design strategy, the choice of materials, the selection of the best techniques for construction, and minimizing energy consumption (El-Kabbany, 2013).

Being aware that one of the main problems regarding energy loss in Egypt is through building envelops, various databases for the common construction materials have been established. These databases are specific to Egypt and cannot be used elsewhere since every country has its own thermal characteristics and construction materials. Besides, there are lots of building materials and techniques in Egypt. This diversity produces different building envelopes over time. Figure 18 the development of the buildings over time. Historically, around the 5550 BC the exterior walls were consisted of unbaked mud bricks and the Pharos reinforced them with organic materials, also they used of domes and vaults. Moving to the years around 1867 AD where the Khedives use other wall systems that were dominating which consist of high thermal mass stonewalls and concrete roofs. Recent days, the system of building materials that are used consist of a Skelton which is a reinforced concrete of slabs, columns, and beams as well as wall systems consist of backed red bricks for the interior and the exterior of a building (Wanas, 2012).

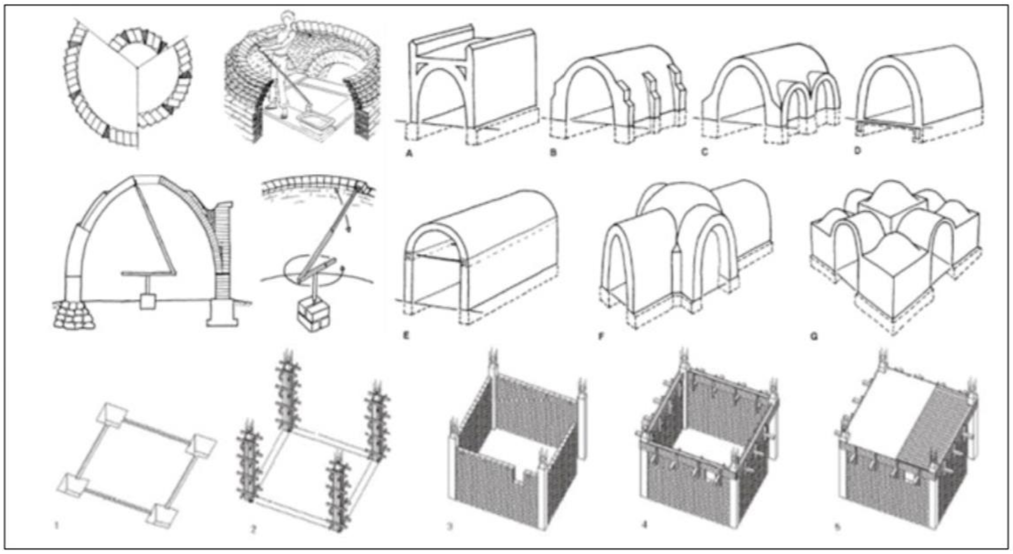
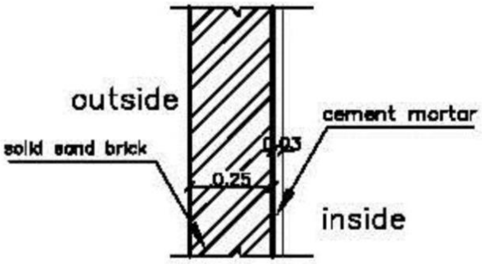
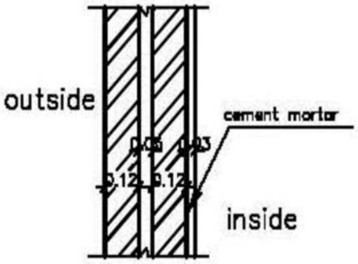
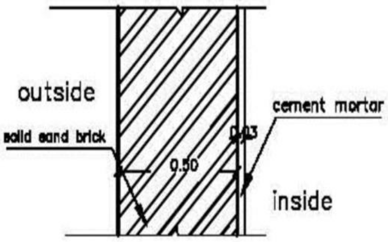
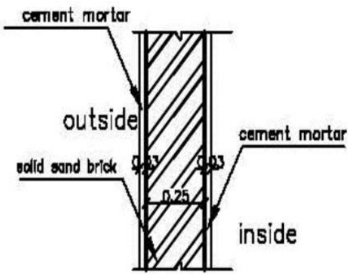


Figure 18: The evolution of building wall systems (Wanas, 2012)

The current climatic changes and energy supply issues encourages the search for solutions to improve the building envelopes. Building envelopes are the connectors between the exterior and the interior of a buildings where energy exchange with the environment. In order to reduce the energy consumption and make the use of building materials more efficient, one need to create a good wall system (El-Nadi, 2016).To improve a wall performance there are some techniques or parameters that are being used. Some of these techniques are related to the wall thickness, preforming a double wall system, or a cavity wall. There are some wall parameters that are already exist in Egypt and these can be shown in the Table 9 (M. Mohamed, 2014):

Table 9: Existing wall systems in Egypt (Mohamed, 2014)

Type	**Figure**	**Layers**	**U-Value (W/m^2.k)**
(25 cm) solid sand brick with internal painting (base case)		1- (25 cm) solid sand brick 2- (3 cm) internal cement plaster	1.827
(12 cm) solid double sand brick walls with 5 cm air cavity in between		1- (12 cm) solid sand brick 2- (5 cm) air gap 3- (12 cm) solid sand brick 4- (3 cm) internal cement plaster	0.942
(50 m) solid sand brick		1- (50 cm) solid sand brick 2- (3 cm) internal cement plaster	1.738
(25 cm) solid sand brick walls with external light-colored plaster		1- (3 cm) cement mortar 2- (25 cm) soild sand brick 3- (3 cm) cement plaster with light colored plaster	1.711

2.7 The Effect of Insulation Materials on Thermal Performance

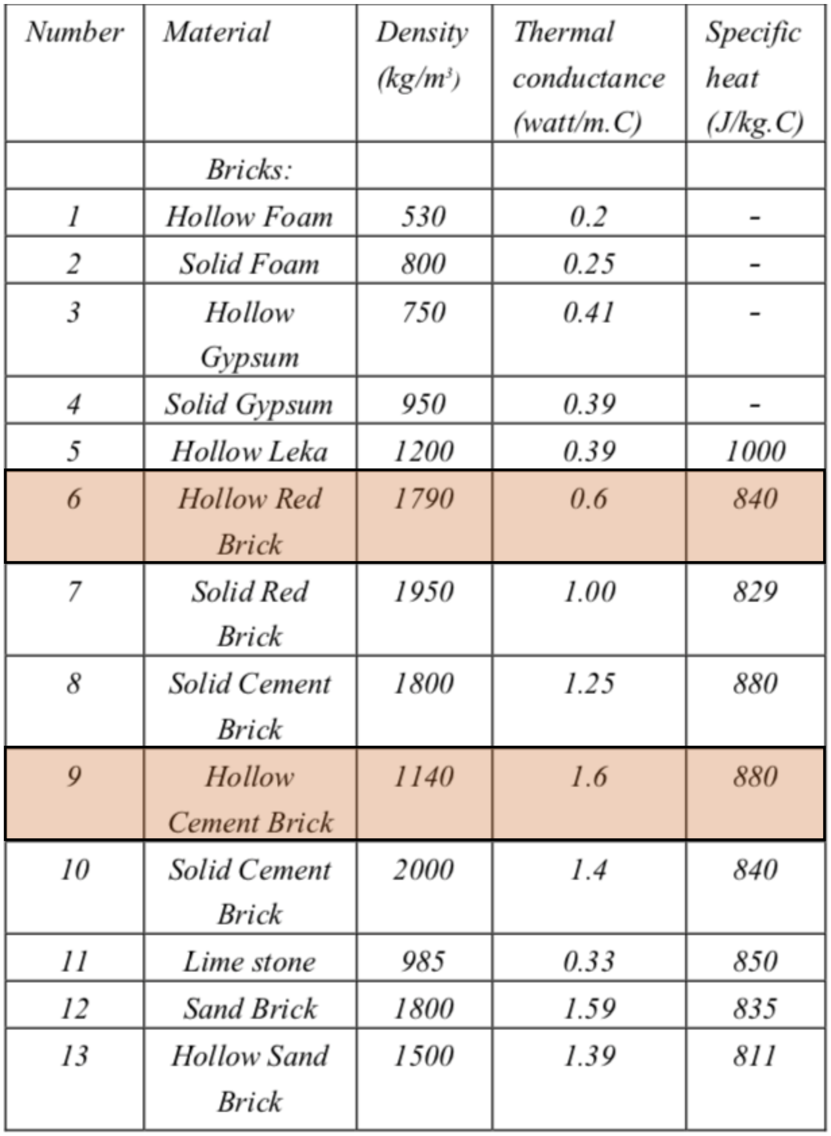
The skin of any building is the main consideration in any designing concept. The design phase starts with the outline of the building meaning that it starts with the outside of the building moving to the inside. The performance of a building is measured by its ability to effectively conserve energy and this depend of the elements of design of any building. To illustrate, this depend on the walls, windows, floors and roofs of buildings and their ability to impede any heat loss or gain from a building to the environment. These sources are accounted to 50% of energy loss in the commercial and residential buildings in Egypt. So, insulated walls will have a less U-Value than walls which are poorly insulated, which means to design an energy efficient building, the exterior of the building is very important. This element affects the performance of a building in many factors. These factors include natural ventilation, heat transfer, residence well-being, and filtering daylighting (El-Nadi, 2016).Furthermore, the type of building structure varies, and each building structure has its own thermal transmittance value. Table 10 shows the different types of building structures and their corresponding thermal value (Krivak, 2013).

Table 10: Thermal Transmittance for building structures (Krivak, 2013)

Types of Building Structures	Thermal Transmittance (W/m^2K)
Single glazed windows	4.5
Double glazed windows	3.3
Double glazed windows with advanced coatings	2.2
Triple glazed windows	1.8
Well-insulated roofs	0.15
Poorly insulated roofs	1
Well-insulated walls	0.25
Poorly insulated walls	1.5

Table 11 shows the thermal properties regarding the most commonly used building materials which is Bricks in Egypt. The heat transfer values for the common wall building materials has been a subject to the researchers in the past years. The data for the heat transfer of the exterior walls can be estimated since the U-value of materials are known or can be measured. It lists some properties for the building materials including the density, heat capacity, and thermal conductivity which (Wanas, 2012).

Table 11: Thermal properties for common materials in Egypt (Wanas,2012)



Number	Material	Density (kg/m³)	Thermal conductance (watt/m.C)	Specific heat (J/kg.C)
	Bricks:			
1	Hollow Foam	530	0.2	-
2	Solid Foam	800	0.25	-
3	Hollow Gypsum	750	0.41	-
4	Solid Gypsum	950	0.39	-
5	Hollow Leka	1200	0.39	1000
6	Hollow Red Brick	1790	0.6	840
7	Solid Red Brick	1950	1.00	829
8	Solid Cement Brick	1800	1.25	880
9	Hollow Cement Brick	1140	1.6	880
10	Solid Cement Brick	2000	1.4	840
11	Lime stone	985	0.33	850
12	Sand Brick	1800	1.59	835
13	Hollow Sand Brick	1500	1.39	811

Sound and thermal insulation materials are widely used in the construction sector to reach indoor comfort for occupants especially for commercial and public areas. Different types of insulations are used in different buildings functions. There are many types of thermal insulations that are used in Egypt in many forms (Arcelormittal, 2009). Figure 19 represents the main types and forms that are available in the market for thermal insulation. Fiber glass, mineral wool and foams are the most common types that are used in Egypt.

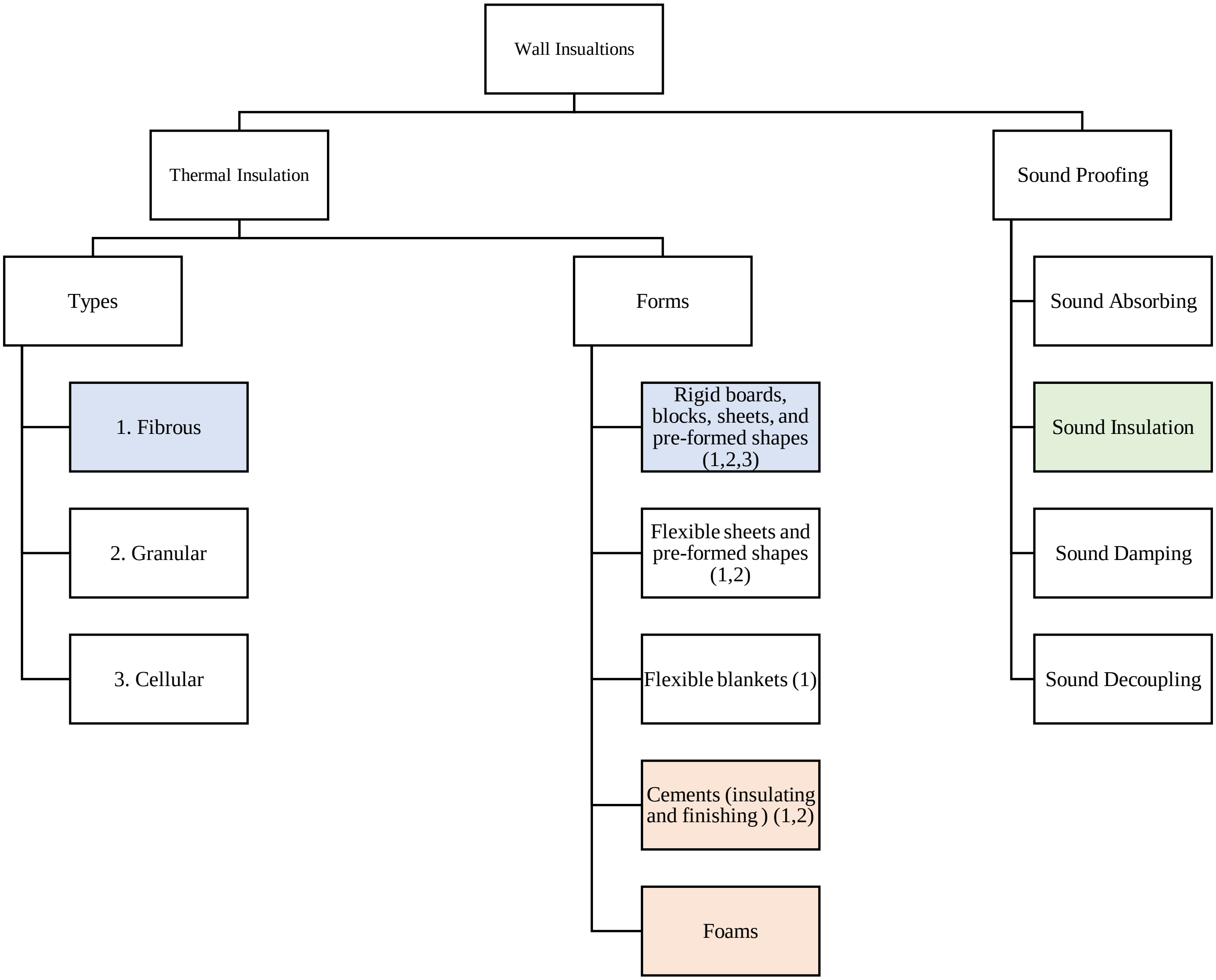


Figure 19: Thermal and sound insulation types and forms (Author)

2.8 Building Materials and sustainable environment

The concept of sustainability is widely focused on by the researchers especially in the architectural context and its literature. To understand the term sustainability, there is a clear definition that illustrates it. This definition stats that “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (El-Kabbany, 2013).There are many different aspects that affect the concept of sustainability in the architectural and urban design context. The concept of sustainable green buildings influences the need for higher quality of life. In a world where there are some significant problems related to global warming, economical risks and resources shortages, new parameters are being taken to fulfil a better living environment. Thus, the concept of sustainable green buildings is becoming more of a requirement. These buildings consume less resources and less waste which ensures the safety for the future generations (Alatawneh, 2017).

2.8.1 Sustainable Green Buildings

Green buildings are becoming more and more the new philosophy of building. Sustainable development aims to reduce the energy crisis as well as the environmental pollutions and this could be tracked back to the 1970s (Umar, 2012). Therefore, the need for energy efficient and environmentally friendly buildings are more desired. Moreover, there are many different aspects that affect the concept of sustainability in the architectural and urban design context. These principles could be applied to move towards green buildings. Some of these principles are related to design efficiency, energy efficiency, efficient use of materials, efficient use of insulative materials, improving indoor air quality using more bio-based products and greener ones, reduction of toxics and waste as well as operation and maintenance techniques (Alatawneh, 2017).

One of the significant aspects of sustainable buildings is the choice of building materials. This is due to the fact that the effect of the building materials is huge on the environment not only in the starting phase, but also during the end of life. Meaning that, the life cycle of the building materials is important and has a huge impact on the environment (El-Kabbany, 2013). Moreover, there are some parameters that indicate the impact of a material on the environment. In the past, the only two guiding indicators for a sustainable building material were the environmental and ecological impacts; however, the definition of a sustainable building material indicates that there are some other analysis parameters that should be taken in consideration. The definition of sustainable materials was stated by Edwards in 2004 to be "Sustainable products are those products that provide environmental, social and economic benefits while protecting public health and environment over their whole life cycle, from the extraction of raw materials until the final disposal" (El-Kabbany, 2013). In addition, the soci-economic indicator is another parameter that should be taken in consideration while choosing a building material. To consider a material as sustainable there are some factors that a material should fulfils either with some or any. Some of these are related to:

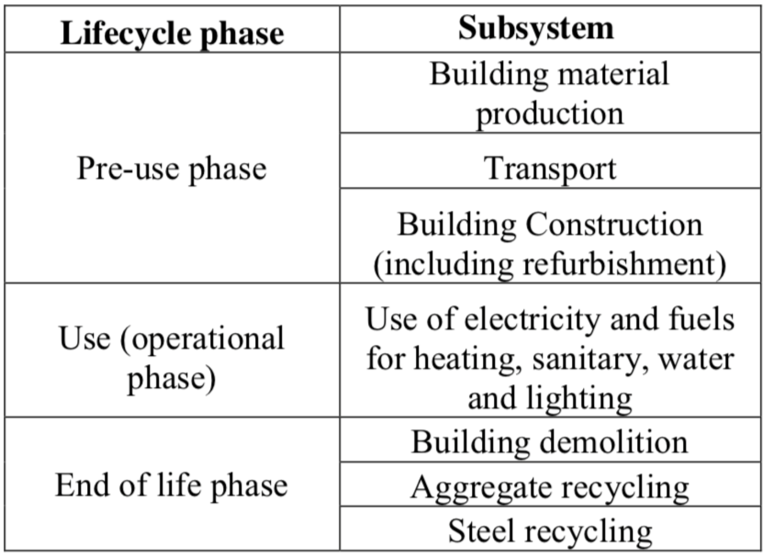
- Reduce energy consumption
- Reduce waste generation during manufacturing
- Existence of recyclable content
- Clean manufacturing meaning no pollution during the process
- Contains natural materials
- At end of life, reduces construction waste
- Ability for being reusable

One of the main purposes of using sustainable materials is to improve the quality of living for the individuals. To illustrate that, the criteria for sustainable buildings is defined as the criteria that have to they have to “Improve quality of life, be comfortable and aesthetically pleasant, improve access to homeownership for the dispossessed and poorest members of society, use materials that are safe to work with, have minimal impact on the environment, be easily recycled at the end of its life, support biodiversity, be resilient to changing environmental and social conditions, be locally built, maintained, fixed and disposed of safely, promote community-building process, be energy and material efficient, be reusable or recyclable, be soft, fun, safe and healthful, build assets, be socially equitable and empowering” (El-Kabbany, 2013). Therefore, the production process of sustainable building materials should be taken in consideration while assessing a building material. To sum up, the two main categories that are in relation with the building materials being sustainable and has a great effect on the Egyptian context are the environmental and the socio-economic analysis.

I. Environmental Analysis

The environmental analysis of a building material is evaluated according to two main aspects. First, the ecological impacts which is related to the manufacturing, construction processes and second is the Indoor Environmental Quality (IEQ) of the material which can be indicated by the humidity levels and the temperature of the indoor space Any building goes through three main life cycle stages as shown in Table 12 (El-Kabbany, 2013).

Table 12: Life cycle stages of buildings (EL-Kabbany, 2013)



Lifecycle phase	Subsystem
Pre-use phase	Building material production
	Transport
	Building Construction (including refurbishment)
Use (operational phase)	Use of electricity and fuels for heating, sanitary, water and lighting
End of life phase	Building demolition
	Aggregate recycling
	Steel recycling

Life cycle assessment (LCA) can be illustrated as a tool that helps in assessing the impacts that occur from a product, material, process, or service on the environment (Keane, 2009). This assessment is a systematic analysis of its ecological impacts which cover the impacts from the production phase till the disposal phase or end of life phase. In addition, the LCA over the years has changed to move more towards Cradle to Cradle instead of Cradle to Grave. This means that, the end of life treatment for the waste especially the solid building materials from the waste goes from disposal to other forms of treatments to be reused or recycled and this can be seen in Figure 20 which shows the Cradle to Cradle concept (Silvestre, 2010). Furthermore, the construction sector consumes huge amounts of raw materials which accompanies with large amount of energy usage during the production process. Moreover, the structure of a building in the construction industry proven to consume more than 50% of the energy used for the entire building. For this reason, some efforts are being implemented to use other alternatives such as concrete hollow blocks, fly ash and the use of other wall bearing techniques are being introduced instead of using reinforced concrete (El-Kabbany, 2013). Also, for the masonry works, the use of other brick types is being implemented such as straw bale, hollow blocks, AAC, and others.

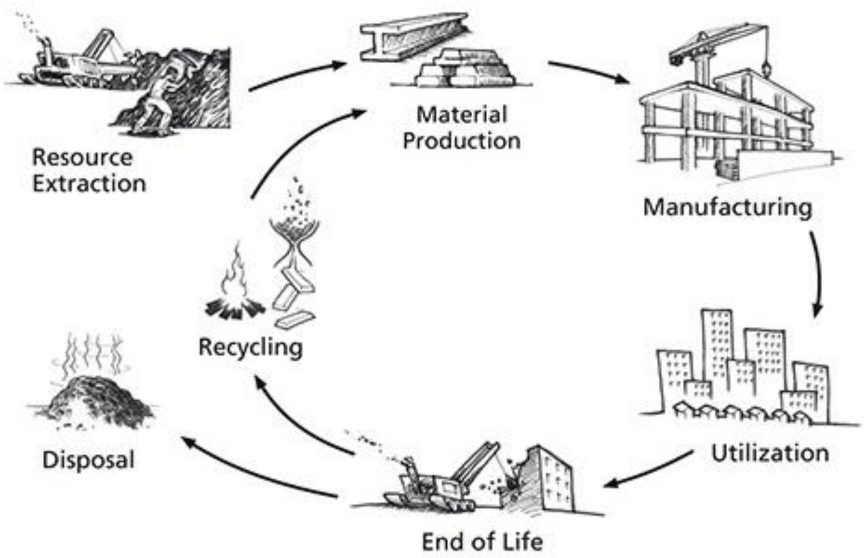


Figure 20: Cradle to cradle approach (Silvester, 2010)

The evaluation of building materials is analyzed, especially, the life cycle assessment of concrete and bricks. These materials consume huge amounts of energy and water during their production as proven and they also contribute to the CO_2 emissions globally. As a result of the proven fail of these materials and their harm to the environment, the use of other materials should be focused on (El-Kabbany, 2013). Moreover, studies regarding the LCA of different building materials and finishing materials of walls shows that a traditional red brick of 1800 kg/m3 demands

3.56 MJ as a primary energy and 0.721 kg of CO_2 emissions is produced and its thermal conductivity is 0.95 W/mk. Also, for a standard ceramic tile of 2000 kg/m^3 produces 0.857 kg of CO_2 emissions, thermal conductivity of 1 and its water demand is 14.453 l/kg. Table 13 shows the LCA of different building materials (El-Kabbany, 2013).

Table 13: LCA of different building materials (El-Kabbany,2013)

Building Product	Density (Kg/m^3)	Thermal Conductivity (W/mk)	Primary energy demand (MJ-Eq/kg)	Global Warming potential (kg CO_2-Eq/kg)
Ordinary brick	1800	0.95	3.562	0.271
Light clay brick	1020	0.29	6.265	-0.004
Sand lime brick	1530	0.7	2.182	0.12
Ceramic tile	2000	1	15.649	0.857
Quarry tile	2100	1.5	2.2	0.29
Ceramic roof tile	2000	1	4.59	0.406
Concrete roof tile	2380	1.65	2.659	0.27
Fiber cement roof slate	1800	0.5	11.543	1.392

For the LCA of cement as one of the major building materials, it can be seen from Table 14 that cement primary energy demand is 4.235 and its CO_2 emissions is 0.818 kg as well as the water demand is 3.937 l/kg. These numbers are by far the highest amounts while comparing to cement mortar, reinforced concrete and concrete (El-Kabbany, 2013).

Table 14: LCA of Cement and Concrete (El-Kabbany,2013)

Building Product	Density (Kg/m^3)	Thermal Conductivity (W/mk)	Primary energy demand (MJ-Eq/kg)	Global Warming potential (kg CO_2-Eq/kg)	Water demand (l/kg)
Cement	3150	1.4	4.235	0.819	3.937
Cement mortar	1525	0.7	2.171	0.241	3.329
Reinforced concrete	2546	2.3	1.802	0.179	2.768
Concrete	2380	1.65	1.105	0.137	2.045

II. Socio-economic Analysis

This analysis is more into the aspects of a building material that are related to the production process, delivery time and the associated cost, also the technology used in this process and its handling, easy to use and transfer, creation of jobs for the locals, social acceptance, as well as the cost of the building material (El-Kabbany, 2013).

A. Sustainable Wall Finishing movement

The green home concept varies globally. The main parts that satisfy this concept are not agreed on. Generally, green homes can be defined as “a type of house that is built or remodeled in order to conserve energy or water; improve indoor air quality; use sustainable, recycled or used materials; and produce less waste in the process" (Alatawneh, 2017). Wall finishing can be described as the finishing that is given to a wall either interior or exterior to enhance its look and performance (Adekunle, 2018). Focusing on Green wall finishing mean and its definition. According to a book entitled “Green from the ground up: Sustainable, healthy, and energy efficient home construction” by Scott Gibson, stated that green wall finishing can be defined as “reusing salvaged materials or choosing products that have been made with recycled material means fewer resources have to be committed to making something new” . In this book, the author also illustrated that the choice of interior finishing materials affects the indoor air quality and thus the health (Gibson, 2008).

More than 90% of our time is spent in the indoors which makes the indoor environment to affect our physiological and physical health. Sick building syndrome (SBS) and Building Related Illness (BRI) are terms that related to building health problems (Feltes, 2007). SBS is a term which used to “describe health complaints such as nasal congestion, headache, irritated eyes, lethargy and tiredness". These symptoms are hard to diagnose medically. These symptoms occur when a person is inside a building and they disappear when a person is not in the building. SBS affects around 30% the inhibitors of new buildings and this number has certainly grown during the last decade (Cain, 2007). On the other hand, BRI is a specific diagnosis of illness that can be related to a specific indoor air quality (Feltes, 2007).

It is more general to use the term indoor environmental quality (IEQ) rather than indoor air quality when talking about the health-related aspects of the indoor spaces. IEQ is a term that can be described as "the physical quality of the indoor environment as opposed to its aesthetic quality". As mentioned, IEQ is the general term underneath there are some other parts. IEQ includes some elements such as Indoor Air quality (IAQ), Humidity level, Acoustics, Light quality and intensity, and Movement of air in the indoor space (Feltes, 2007).

Many of the commercial products contain hazardous chemicals and materials. Choosing environmentally friendly wall finishing materials help decreasing the problem. There are some considerations that should be fulfilled when thinking of a finishing material. Some of these are related to toxicity, durability, resources efficiency, and the sustainability of the material(Gibson, 2008). This concept may include using certain building and finishing materials that are bio-based or can keep heated and cold air inside a building. The choice of the right finishing materials with low VOC emissions will dramatically improve the indoor air quality. In addition, most finishing materials emit gasses that are toxic such as formaldehyde and these gasses affect the health of the inhibitors as well as their productivity and comfort (Alatawneh, 2017).

Most of the common finishing products has some common sources of VOC that are emitted into the indoor air such as: paints, coatings, finishing and building materials, adhesives, some wood products, wall panels, and urea-formaldehyde. Consequently, when specifying finishing materials and products with zero or low VOC, the IAQ improves. Allergy Foundation of America recommended the use of some products that are bio-based to improve the indoor air quality. Over the past couple of years, the need for eco-friendly indoor environment has encouraged producers to focus on more environmentally friendly products. As a result, there are some green paints introduced in the market (El-Nadi, 2016). Figure 21 represents the IEQ and the IAQ factors and comparing them to the standards available (Wagdi, 2015).

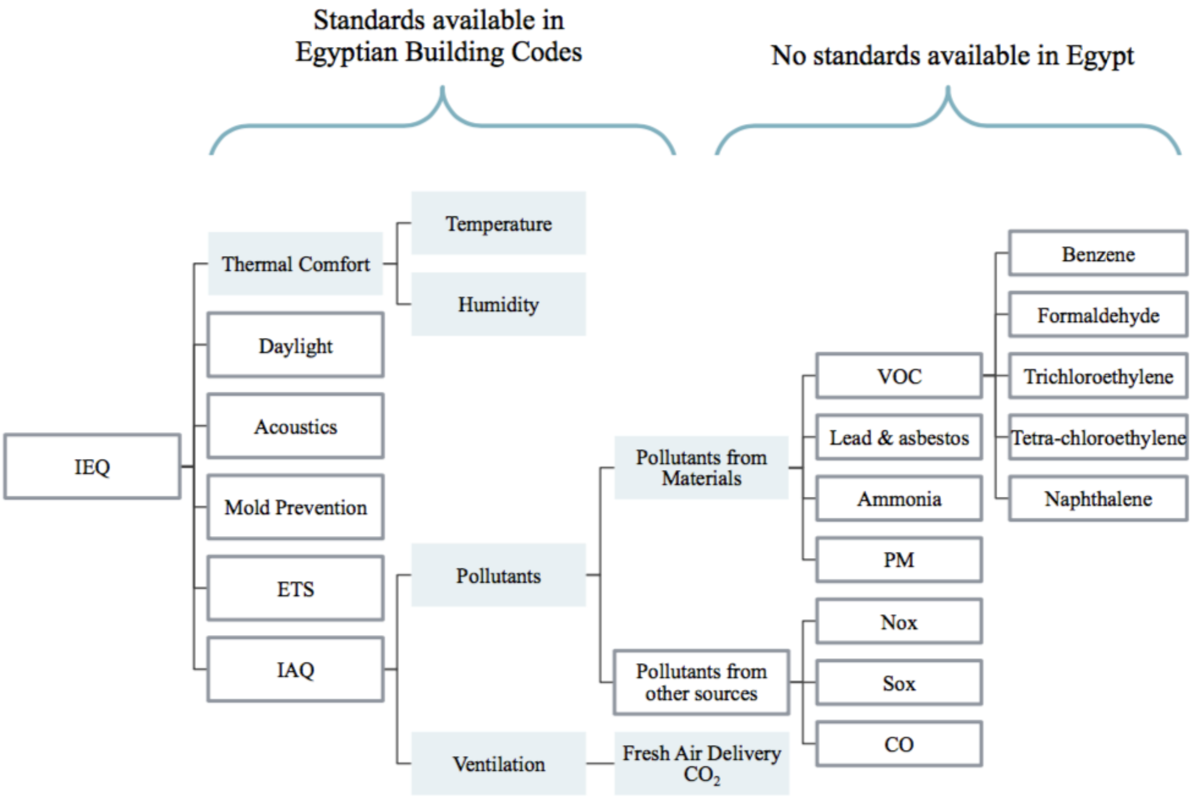


Figure 21: IEQ and IAQ factors (Wagdi, 2015)

2.9 Materials Review and Green Alternative

In Egypt, buildings are influenced by the western ones not like our traditional buildings. A typical building in Egypt consists of a multi-story building of concrete skeleton, masonry walls, flat roofs and aluminum glassed windows and sometimes curtain walls are used as well as some finishing materials for the exterior and the interior. This is a typical description of a building system in Egypt and it is constructed disregarding the main architectural aspects for orientation, climate changes, geography and others. Instead of using earth materials and simple finishing techniques, the use of concrete, bricks, and steel are used widely (Fernandes, 2010).

There are some green alternatives for the common construction materials that could be used to protect the environment and reduce waste. However, the available green products in the market are conditionally green since they should have some of the following characteristics to be considered green (CSD, 2009):

- Renewable: materials that are derived from biological sources such as straw-based products and trees.
- Provide good indoor air quality
- Durable materials
- Low embodied energy
- Recycled materials and recyclable
- Locally obtained and manufactured

There are alternatives for the common building materials such as Concrete, cement, finishing materials and wall systems. Masonry which is a wall structure consists of brick units bonded together using mortar. The common materials used are either bricks or concrete blocks. There are other types of masonry units but are not very common such as light weight concrete blocks. Bricks are durable; however, bricks durability depends on some factors such as workmanship, nature of the material, mortar quality, and patterns of laying. In Egypt, the use of masonry walls is dominating the construction industry and it is either a finished aesthetic material or needs finishing (Thovichit, 2007).

2.9.1 Existing Wall System in Egypt

I. Fired Clay Bricks

It is one of the oldest, most commonly used type of masonry in the world. The widespread use of clay bricks is due to the extensive availability of clay. Bricks are very durable, and they are used in structure of both load bearing and non-load bearings (Castro, 2010). Moreover, bricks are considered the most agreed on traditional wall system in Egypt for the interior and exterior walls (Thovichit, 2007). Due to the need for improving the mud brick specification, burning bricks was developed. The factories which produces clay bricks were of a great number and centered around the Nile bank to use the mud which is the raw material for making bricks from the Nile valley (El-Kabbany, 2013).The number of factories that produce traditional clay bricks are around 3000 and they are located in different cities in Egypt. These factories employ around 320,000 employees and around 2 million indirect labors. However, the traditional fired brick industry is with low quality which needs some skilled manpower and management to enhance their quality (Thovichit, 2007). Figure 22 shows common rural houses in Egypt built with fired clay bricks (El-Kabbany, 2013).

Figure 22: Modern rural houses in Egypt (El-Kabbany, 2013)

On the other hand, In the 70s six factories were opened to produce clay bricks. These factories are fully automated depend on machines and low number of workers. These machines improved the quality of bricks and raises the prices as well. Large projects and buildings use these types of bricks not the traditional ones. Figure 23 represents a factory of clay bricks (El-Kabbany, 2013) and Figure 24 represents the finishing process (Thovichit, 2007). Figure 25 demonstrates the LCA of clay bricks (Ali, 2008).

Figure 23: Fired clay brick factory (EL-Kabbany, 2013)

Figure 24: Plastering of brick walls (Thovichit, 2007)

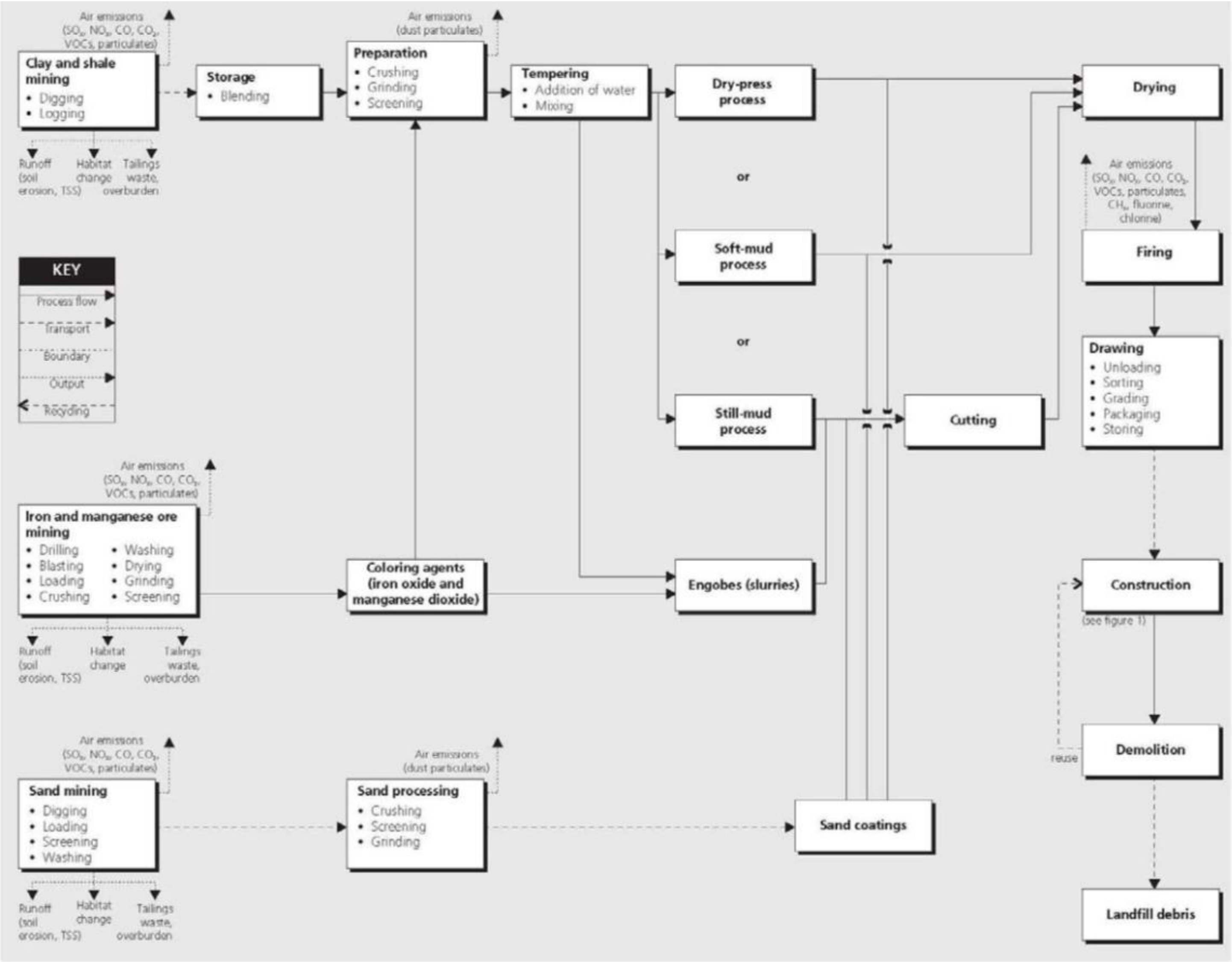


Figure 25: LCA of clay bricks (Ali, 2008)

Consequently, the literature shows that process of manufacturing of fired clay bricks has taken some efforts from the researchers to try to find alternative solutions to prevent the environmental hazards from this type of bricks. Nevertheless, it is indicated that the manufacturing techniques of fired clay bricks have not been adjusted since centuries (Ali, 2008). To sum up, masonry units in Egypt are either produced by heating such as red bricks or using chemicals such as light weight concrete. Furthermore, the concept of green traditional buildings is not very common in Egypt. The practice using different building material are not common and need to be promoted for expansion. The awareness of using innovative materials in the construction industry is needed to reduce the environmental damages as well as the economic losses. Moreover, the use of new materials such as AAC faces some technical difficulties which reduces their use in Egypt.

2.9.2 Overview of the Alternative wall system materials

I. Light Weight concrete (LWC)

The history behind LWC starts with the Romans in the second century. The properties of LWC is that it has low thermal conductivity as well as low density. The LWC is 23% to 87% lighter than the normal concrete blocks which decreases the dead load of a building dramatic. The LWC gain a lot of popularity especially in UK, Sweden and USA. There are many buildings that have been constructed using LWC one of these is the Pantheon in Roma from the 18 century and is still existing till today. There are three types of LWC which are (Somi, 2011):

A. No-Fines concrete

This is a type of concrete is obtained by eliminating the fine aggregates sand material and the single sized coarse aggregates are surrounded by two layers, top and bottom, of cement which gives it its strength. The light weight is achieved by creating Voids which are distributed homogeneously during production as seen in Figure 26. This type of concrete is useful for any type of wall, load bearing and non-load bearing (Patil, 2017).

Figure 26: No-Fine concrete (Patil, 2017)

B. Lightweight Aggregate Concrete

The manufacturing process of this type of concrete include lightweight aggregates with porous surfaces. There are two types of aggregates used for LW aggregate concrete which involve natural source of aggregates and volcanic source of aggregates such as slag. According to the compaction level, light weight aggregate concrete has two main types. The first is the partially compacted and the second type is the fully compacted. Each one of these has different uses than the other. For instance, the partially compacted is used for precast concrete blocks and the fully compacted is used for reinforcement (Somi, 2011).

C. Aerated Concrete

The production process of this type of LWC is excluding the coarse aggregates in its mixture. It can be aerated using gas injection as well as using air entraining agents. In addition, the types of fine aggregates that are being used in the mix are one of silica sand, quartzite sand, Lime and fly ash. The use of the air entraining agents is more practical than the gas injection. There are two types of aerated concrete which differs by the way of curing. The first is the Autoclaved aerated concrete and the second is the Non-Autoclaved aerated concrete as seen in Figure 27. The curing process is significant because it affects the mechanical properties of the blocks as well as the physical properties (Somi, 2011).

Figure 27: Aerated concrete (Somi, 2011)

II. Autoclaves Aerated Concrete (AAC)

The use of burnet clay bricks, as mentioned, is dominating the construction industry; however, it is not an environmentally friendly material. Therefore, the focus nowadays is to find alternatives for this building material for a greener environment. AAC is one of these building materials that this research is going to focus on as an environmentally friendly alternative. AAC which is known also as Autoclaved lightweight concrete (ALC), porous concrete and others is a lightweight foamed precast concrete building block. It was invented in the 1920s and its use has been dominated by Asia and Europe. In the United Kingdom the use of AAC accounts for 40% of all constructions, in Germany 60% and India 16% (Rathore, 2018).

Figure 28 demonstrates a case study for measuring the thermal conductivity through two different wall systems, AAC blocks and Red bricks. The left one is the Red brick and the right one is the AAC block wall system. It can be seen that the AAC block under the infrared is almost green and blue in color which indicates energy saving wall system. However, the Red brick wall system is reddish and yellowish in color which indicated strong to increased energy losses (Plena, 2018).

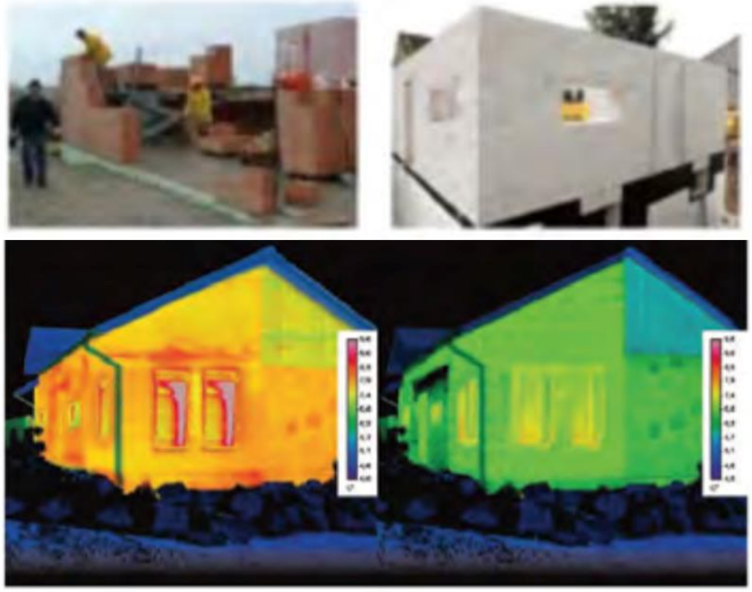


Figure 28: thermal conductivity Simulation (Plena, 2018)

Figure 29 represents a fire simulation case study that is done using two different wall systems. Building 1 is a steel wall system and building 2 is an AAC wall system. Figure 30 and Figure 31 shows the exterior and interior of both buildings. The simulation revealed that AAC blocks maintained a much lower indoor temperatures after burn than the steel (Plena, 2018).

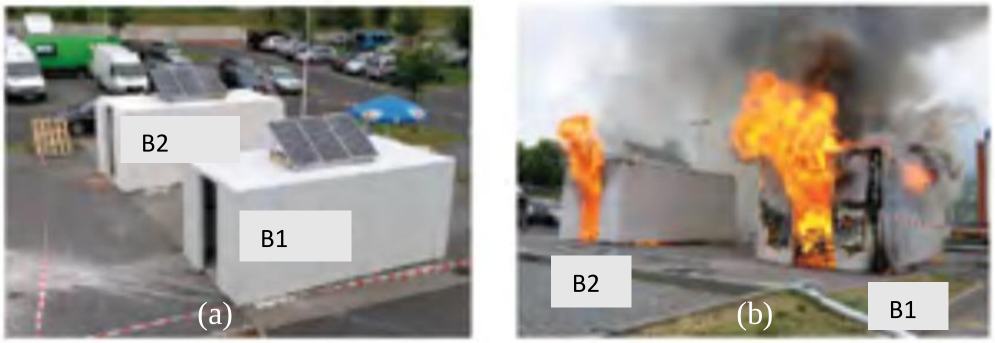


Figure 29: Fire simulation case study (Plena, 2018)

Figure 30: Building 1 exterior and interior with extremely high temperature after burning (Plena, 2018)

Figure 31: Building 2 exterior and interior with low temperature after burning (Plena, 2018)

AAC projects in Egypt are spreading including Four Seasons Nile Plaza Hotel, 57375 hospital, International medical center, Cairo American college, Mars Factory and others. In addition, some other applications for AAC blocks include hollow blocks slab system as seen in Figure 33, load bearing wall systems as seen in Figure 32, internal walls as seen in Figure 35, and external walls as seen in Figure 34 (Plena, 2018). Table 15 represents a comparison between AAC blocks and clay bricks where it shows the differences in thermal and mechanical properties of both.

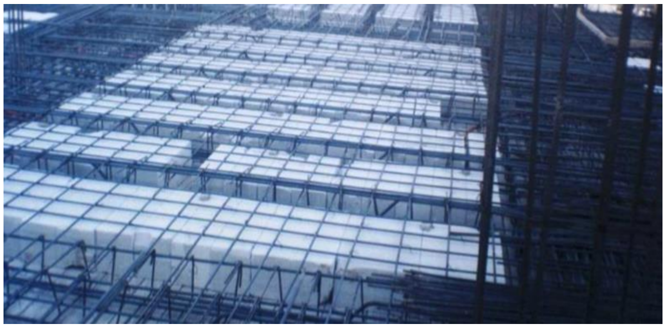


Figure 33: Hollow blocks Slab system (Plena, 2018)

Figure 32: Load bearing walls (Plena, 2018)

Figure 35: Internal walls (Plena, 2018)

Figure 34: External Walls (Plena, 2018)

Table 15: Comparison between clay bricks and AAC blocks (Author)

	Properties	Clay Bricks	AAC Blocks
Sizes and composition	**Composition**	sand grains (Silica), lime, iron, manganese, Sulphur, iron, alumina and phosphate	$2Al + 3Ca(OH)_2 + 6H_2O_3$ $CaO\ Al_2O_3 + 3H_2$ Aluminum powder + Hydrated lime Tricalcium hydrate + Hydrogen. (Water, cement quicklime, aluminum powder, and sand) 0.6-0.65%, 10-20%, 20%, 8%, 3%, 69%
	Variations	According to nature of soil used either earth crust or topsoil	AAC blocks, roof and wall panels and lintels
	Dimensions	25X12X6.5	60X20X10 60X20X12 60X20X15 60X20X20 60X20X25 60X20X30 60X20X40
	No. of bricks in 1 m3	481 Brick	83.33 69.4 55.6 41.7 33.3 27.8 20.8
	No. of bricks in 1 m2	58 Brick	10 8.3 6.67 5 4 3.34 2.5
Mechanical Properties	**Water absorption**	by volume 20 %	45%
	modules of elasticity	1-18 GPa	1.76-2.64 KN/mm2
	Compressive strength	2.5-3N/mm2	3-4 N/mm2 (as mentioned IS 2185)
	Tensile Strength	Neglected	Varies
	Porosity	27 vol. %	35%
	Dry Density	1800-2000 kg/m3	600-800 kg/m3

Thermal Performance	**Thermal resistance**	0.796- thickness 25 cm	1.667 W/m2°C - thickness 15cm 2.325 W/m2°C - thickness 25cm
	Thermal transmittance	0.52-0.76	0.60 W/m2°C - thickness 15cm 0.43 W/m2°C - thickness 25cm
	Thermal conductivity	0.314-0.81 W/m°C	0.132 W/m°C
	Production Process	○ Extraction and storage ○ Mixing and molding ○ Drying ○ Firing	○ Mixing of raw materials ○ Adding the expansive agent ○ Pre-curing and cutting ○ Autoclave curing process ○ Packing and transporting
Aesthetics	**Finishing martials and appearance**	○ laid in different patterns and shapes, done with several shades, sizes, and textures ○ can be used as a finishing material or overlaid with mortar	○ Large size which reduces the number of joints material for finishing is less ○ laid together with the traditional mortar paste traditional mortar of thickness 2 cm or with special mortars with thicknesses two 5mm
Environmental Aspects	**Materials depilation**	○ The consumption of the raw material such as clay and sand in the production process causes resource depilation and environmental damages. ○ Production method is done through the removal of the topsoil causes waste to the virgin clay raw material.	○ Minimal environmental negative impacts. ○ Raw materials that are used in the production process of AAC are available in nature. ○ They don't contain toxic gases, radioactive substances, or allergic materials ○ reduces the construction waste
	Fuel consumption	8 kg of coal is consumed for every 1 sq. ft of carpet area of clay bricks	1 kg of coal is consumed for every 1 sq. ft of carpet area of AAC blocks
	Soil Consumption	1 sq. ft of clay brick consumes 25.5 kg of topsoil	uses waste from power plants (fly ash)
	CO_2 emissions	12 kg of CO_2 is emitted for every 1 sq. ft of carpet area of clay bricks	1.5 kg of CO_2 is emitted for every 1 sq. ft of carpet area of AAC blocks
	Embodied Energy	900-1000 Kwh/m3- High	50-100 Kwh/m-Low
	Green verification	NO	YES-LEED certified

Advantages and Disadvantages	**Advantages**	The availability of raw materials • Relatively low maintenance and highly durable • Can be manufactured in different sizes and textures • Has good compressive strength • It has high fire resistance up to 2 hours • It has good sound insulation due to the density of the wall systems	• Lightweight which reduces the dead load of the structure • Environmentally friendly building material due to less use of cement • Available in large and various sizes • Thermal insulation which keeps interior in summer and winter in moderate temperatures • Sound proofing • Fire resistance • Long-term savings of construction costs • Easy installation, AAC blocks are easy to handle and cut on site • Less steel is used due to low density • Time-saving in construction
	Disadvantages	• The construction process of red bricks consumes time • The manufacturing process consumes energy • Depilation of raw materials will occur due to the extensive use of red bricks • Red bricks absorb water faster • The deadload of the structure increases due to the heavy weight of the bricks • Waste of bricks are not treated at their end of life	• The production cost is higher than the traditional bricks • The surface of AAC blocks is smooth, thus the mortar might not stick
	Sound insulation	>50 dB- thickness 25 cm	37 dB –thickness 10 cm 48 dB- thickness 20 cm
	Fire Rate	120 min for 25 cm thick	240 min for 10 cm thick blocks 420 mins for 25 cm block
	Safety	--	Repositories of Class I codes, the European Waste List (EWC)17 01 01
	Technical approval	--	DIN4165 Egyptian standard 1401/2008
	Durability	varies	uniform

2.10 Literature Summary

This chapter reviews the current situation of the thermal performance of the buildings regarding the indoor environmental quality and its effect on the energy consumption and the running cost of the buildings. Also, the effect of using different building materials on the construction initial cost. Building materials selection in general has several effects on the occupants and their experience regarding the indoor quality of living. The selection of building materials starts from the design stage till the operational level. The common building envelops selection in Egypt is mainly consists of clay bricks as a part of building materials; however, there are other building materials that are available but the lack of awareness to their effect on the construction initial cost and the running cost due to the reduction in energy consumption is not well studies. The increase thermal discomfort due to the climatic changes during the last decade forced occupants to relay more on-air condition to stabilize the indoor environmental quality and thermal comfort zones. This led to an increase in energy consumption, hence the electricity bills are increasing which as well make people unsatisfied and discomfort.

Researchers have worked on testing the building materials and their effect on the IAQ more than their effect on IEQ. Previous studies have investigated some aspects of each of the AAC blocks and red bricks on the level of mechanical performance and the possibility of enhancing the AAC blocks. Most of the studies were more concerned with residential buildings and not the public and commercial ones. The financial analysis in the literature was more into the savings in the initial cost not towards the savings in the operational costs. For instance, a study was carried out on three different residential buildings to see the impact of AAC blocks on the building performance when using different glass sections than what is being used; however, this impact was more into the initial construction cost of both the AAC blocks and the fenestrations. Also, it focused on the effect of glass and shading on the thermal performance of the building (Mahdy, 2015). Few studies were considered about the thermal performance of the building while using AAC blocks and the difference in performance between both AAC and red bricks. Therefore, the effects of different building envelopes as a change to the modern constructions should be taken in consideration as a key to reduce energy consumption, hence reduce electricity bills and minimize the effects of the traditional materials on the IEQ. The LC of each material should be assessed based on the LCA techniques to be able to evaluate the building performance not only from the construction cost part, but also from the overall operational and environmental costs.

CHAPTER 3: SIMULATION WORK

3.1 Overview

This chapter demonstrates the experimental work that has been conducted to evaluate the different wall systems and their environmental impacts as well as cost analysis for each. The perception that the climate doesn’t change, and the building thermal comfort remains the same over the years till the end of its lifetime is no longer valid according to the International Panel on Climate change (IPCC, 2018). In addition, the day time is longer where the sunshine direct and diffused radiations cause increase in the cooling capacity, consequently increasing the energy consumption. Hence, minimize the energy consumption due to the overheating of the buildings is needed.

The studies were done on two buildings in the New Cairo Capital one in the fifth residential area “R5” and the other one is a mall in the commercial hub. This analysis is done using a computer software that is adjusted to simulate different thermal conditions. This analysis was done by simulating the weather conditions of Egypt over a range of a year from 1st of January to 31st of December.

The aim of this simulation is to evaluate the use of new construction methods as AAC wall systems in comparison with the traditional clay bricks wall systems under the current climate conditions while using mechanical air conditioning systems. The simulation focused on the thermal performance of each building which took place in Cairo climatic zone according to the EREC (EREC, 2008). The outputs of these simulations records two main parameters which are the monthly energy consumption (Kwh) and the indoor air temperature (^{o}C). Moreover, the excessive environmental analysis on each building regarding carbon emissions, thermal comfort, humidity, cooling and heating designs, were studies as well. In addition, a comparative cost analysis was conducted to demonstrate the difference in initial construction and finishing costs of each wall system. These studies were conducted through studying two main components which are:

A. Wall systems
   - External Walls
   - External and Internal Finishing materials

B. Fenestrations

3.2 Model Framework

Figure 36 represents the model framework that was used to work on the simulations till the analysis stage. The framework consists of four main stages modeling, specifications, simulation, and analysis. The first stage is the modeling phase, this stage consists of three sub-stages which are acquiring the model inputs/data, building the models, and preparing simulation data.

The second stage is the specifications which consists of two main sub-stages which are adjusting the parameters and the tests needed for the models. The third stage is the simulation stage which consists of four sub-stages, starting from model data verification which decides if the model work or not, if it works, proceeds with the three sub-stages which are simulation setup, run simulation, and data outputs. If it doesn’t work, will go back to the adjusting parameters phase to check the inputs to the model.

The final stage is the analysis phase which consist of three sub-stages which are data validation to make sure the output data are valid according to other tests that have been done by the to the Housing and Building Research Center (HBRC), the recommendations from the

Egyptian Code for Improving the Efficiency of Energy Use in Buildings which is referred to as EREC, the Building Physics and Environmental Institute (BPI) and the Center of Planning and Architectural Studies (CPAS). Then moving to categorizing the analysis to form the final reports and charts needed.

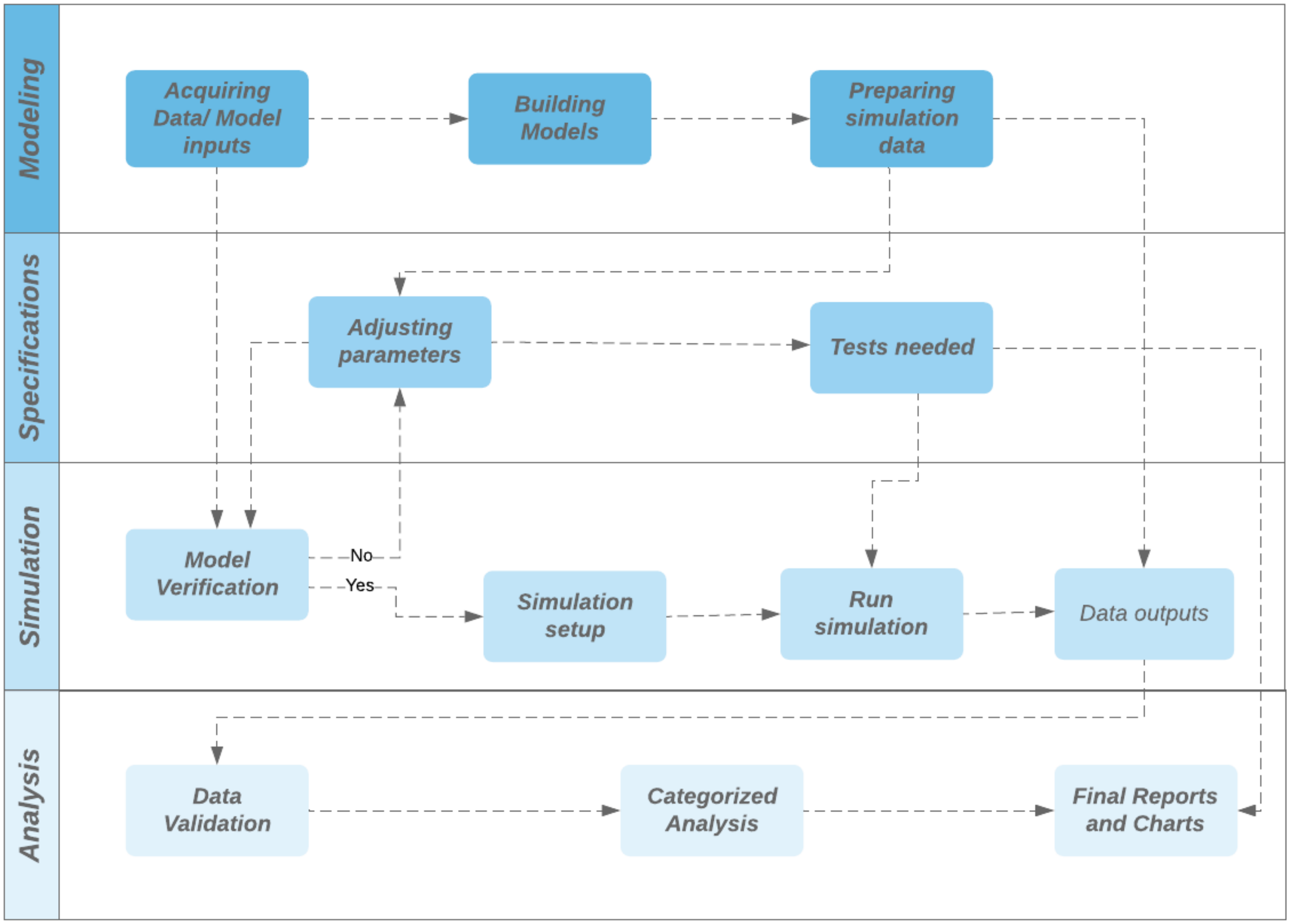


Figure 36: Block Diagram of the simulation Framework

3.3 Financial Analysis

3.3.1 Construction Materials cost

Detailed area calculations for each building that has been used in the simulation were conducted. These calculations included the initial costs of each building material such as bricks, mortar, paint, concrete, and steel. The cost estimation of each building, residential and commercial, was divided into two main segments. The first section included the structural cost of each wall system (Red brick and AAC). This section contained the concrete and steel construction costs for the footings, columns, beams, slabs and cores. The difference in cost between each wall system is due to the lightweight of the AAC blocks which decreases the dead loads on the buildings. The second section is the construction initial costs of each brick itself and the finishing materials as well from mortar and paint.

Each building was divided into zones, then calculating the total area of each zone and the wall parameter to get the wall areas added to them a percentage of waste. After summing all the areas up of each building using the plans, sections and elevations, costs of each item are calculated to provide a total cost of each building using a specific wall system. Then, the total cost of each building was subtracted to get the difference between each wall system initial construction cost. This comparative cost analysis gives the percentage of savings in each item’s initial cost as well as the percentages of savings in the total cost of the buildings.

The unit prices of each item in the New Cairo Capital are demonstrated in Table 16 (Ministry of Housing, 2019). The estimated costs were based on interviews with the project engineers in the New Cairo Capital. According to the Engineering Authority Indicative Guide, the Ministry of Housing, the interviews with Eng. Mostafa Atia, the project engineer for the residential area (R2), Eng. Khalid Adawi, Jotun sales engineer, Eng. Essam Samy, Delta Block Egypt sales engineer, and some contractors from site the estimation of the unit prices are as follows.

Table 16: Prices of Building Materials (Ministry of Housing, 2019)

Type	Item	Unit	Price (LE)	Unit Price (M^2)	Notes
	AAC Blocks	M^3	1032	15-30	25 cm, Including Taxes and transportation
	Red Brick	M^3	750	25-28	25 cm, Including Taxes, and transportation
Construction	Cement	Ton	950	--	--
	Steel	Ton	12500	--	--
	Concrete	M^3	--	320	The Military provides the cement, water and labor cost
	Mortar (Exterior)	M^2	--	45	--
	Mortar (Interior)	M^2	--	22	--
Finishing	Paint (Economic Matt, Interior)	Gallon	115	25.5	2-3 coats, Jotun
	Paint (Fenomastic, Matt, Interior)	Gallon	240	25.5	2-3 coats, Jotun
	Primers (Economic)	10 Liters	150	19.5	2 coats, Jotun
	Primers	10 Liter	180	18.5	Fenomastic
	Base	15 Kilo	90	6	3 coats, Jotun prefix
Fenestration	Glass 1	M^2	--	200	Single clear
	Glass 2	M^2	--	500	Double Reflective

3.3.2 Energy Consumption Cost

The second part of the financial study, which is referred to as the operational cost, includes the cost of energy consumption (Kwh) for each building per month and annually. Using the electricity tariff, for both the residential and commercial rates as shown in Table 17 and Table 18 respectively, revealed by the Ministry of Electricity and Renewable Energy annual report, the annual electricity cost was calculated and adding to it the customer service charge to get the total electricity bill per month, hence the annual one is obtained (MEHC, 2018). Adding the initial cost to the operational cost gives a clear idea about the saving in each wall system annually which predicts the long-term savings as well.

Table 17: Residential Electricity Tariffs (MEHC, 2018)

Electricity selling Price		Customer Service	
Sliced consumption (Kwh/m)	P/KW.h	sliced consumption (Kwh/m)	customer service charge pound/cons/m
0-50	22	0-50	1
51-100	30	51-100	2
0-200	36	0-200	6
201-350	70	201-350	11
351-650	90	351-650	15
651-1000	135	651-1000	25
0-More than 1000	145	More than 1000	40
		Zero Read	9

Table 18: Commercial Electricity Tariffs (MEHC, 2018)

Electricity selling Price		Customer Service	
Sliced consumption (Kwh/m)	P/KW.h	sliced consumption (Kwh/m)	customer service charge pound/cons/m
0-100	55	0-100	5
0-250	100	101-250	15
601-1000	115	601-1000	25
0-More than 1000	150	More than 1000	40
		Zero Read	9

3.4 Models Definition

Two different buildings with different functions were used in the simulation, one residential and the other is commercial according to the avaliable plans. The masterplan of each building zones is presented in the next section. Simulation models are adjusted according to these masterplans using detailed architectural plans, elevations and sections. HVAC systems, orientations, window to wall ration (WWR) were selected for each building and applied for both the traditional and the unconventional building envelope.

3.4.1 Building 1- Residential Model

The first site location is in the R5 area which a residential complex. The masterplan of this area is divided into four main parts as shown in the Figure 37. The highlighted part is the one that was used in the simulation and it is about 1225 m^2 per floor. This building is a multistory residential complex where each floor has seven apartments with three different area and prototypes.

Figure 37: Site location 1 Masterplan

The first prototype (P1) is a three-bedroom apartment which is approximately 140m^2 and each floor has four flats of this area. The areas of each zone of this prototype are demonstrated in the Table 19.

Table 19: Prototype 1 Areas

Typical Building Zones (P1)	Floor areas (M^2)	Wall perimeter (ML)	Wall Areas (M^2)
Reception	35.4	25.7	70.675
Kitchen	12.35	13.4	36.85
Guest toilet	3	5	13.75
Bedroom1	22.26	13.7	37.675
Master bedroom	21.73	16.7	45.925
Master bathroom	4.86	4.5	12.375
Dressing room	5.67	9.6	26.4
Bedroom2	16.4	12.1	33.275
Lobby space	12.1	--	--
Bathroom	7.37	4.4	12.1

The second prototype (P2) is a two-bedroom flat which is 97m^2 approximately and each floor has two flats of this area. The areas of each zone of this prototype are demonstrated in Table 20.

Table 20: Prototype 2 Areas

Typical Building Zones (P2)	Floor areas (M^2)	Wall perimeter (ML)	Wall Areas (M^2)
Reception	30.75	19.1	52.525
Kitchen	10.15	11	30.25
Bedroom1	16.3	14.3	39.325
Master bedroom	18.4	13.9	38.225
Lobby 1	3.6	7.6	20.9
Balcony 1	3.12	4.6	5.045
Balcony 2	2.66	1.9	1.52
Lobby 2	6.3	--	--
Bathroom	6.6	7.3	20.075

The third prototype (P3) is a three-bedroom flat with unique design which is 130m^2 approximately and each floor has two flats of this area. Each flat takes an average of five occupants. The areas of each zone of this prototype are demonstrated in Table 21.

Table 21: Prototype 3 Areas

Typical Building Zones (P3)	Floor areas (M^2)	Wall perimeter (ML)	Wall Areas (M^2)
Reception	30	19.6	53.9
Kitchen	9.6	9.35	25.7125
Guest toilet	2.125	2.95	8.1125
Lobby 1	13.52	15.6	42.9
Bedroom1	14	8.7	23.925
Master bedroom	22.6	15.1	41.525
Master bathroom	4.8	6.8	18.7
Dressing room	5	2	5.5
Bedroom2	18.5	14.2	39.05
Lobby 2	5.7	--	--
Bathroom	4.9	6.4	17.6

Figure 38 shows the typical floor plan of one apartment and Figure 39 represents the simulated model of the residential building

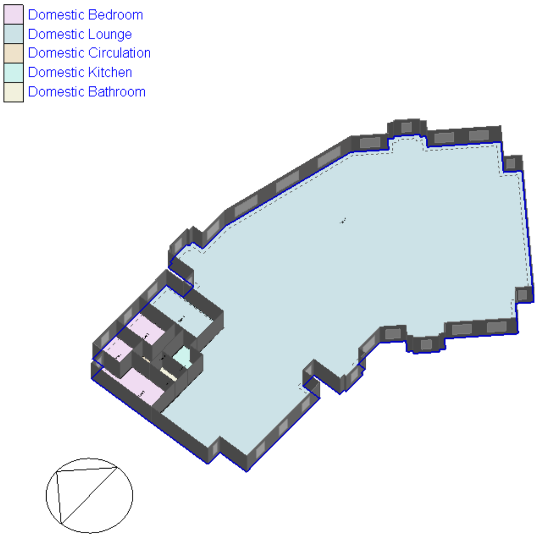


Figure 38: Typical Residential Floor Plan

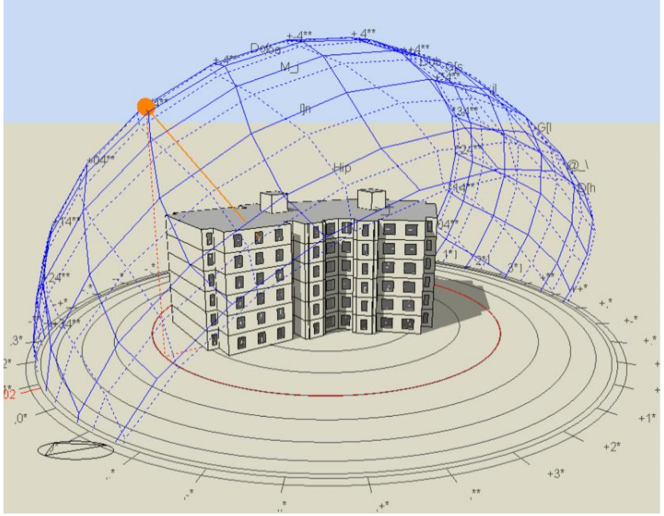


Figure 39: Simulated Residential Model

3.4.2 Building 2- Commercial Model

The second site location is in the commercial hub area which consists of cinema complex, mall complex, hyper markets, car agencies and banks which is around 82100 m2. The masterplan of this area is shown in Figure 40. The highlighted part is the Mall that was used in the simulation and it is around 3990 m2 per floor. This building is a two-story building consists of different commercial spaces and uses.

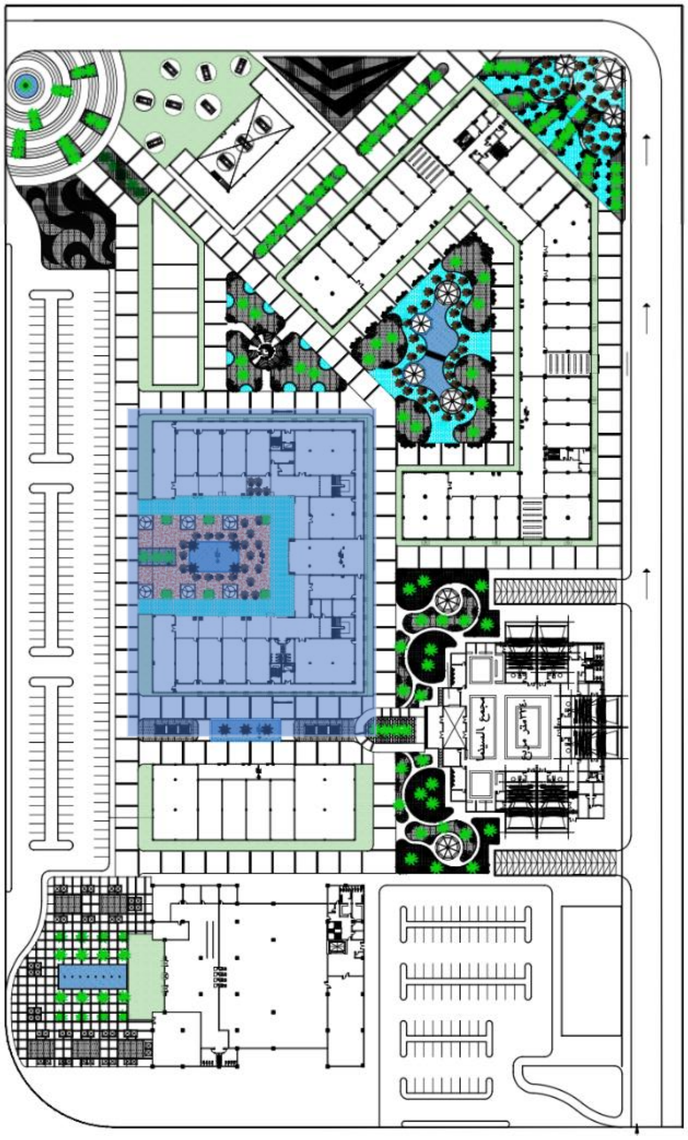


Figure 40: Site Location 2 master plan

Table 22 demonstrates the main zones of the commercial model with the floor areas and wall areas associated to them.

Table 22: Commercial building area

Building Zones per floor	Floor areas (M^2)	Wall perimeter (ML)	Wall Areas (M^2)
Commercial zones	3000	462.4	2775
Storage room	80.94	39.8	238.8
Toilets	124	55	330
Services/food preparation	85	41.2	247
Circulation/corridor	505.89	361.5	2169
Cores	196	84	504
Internal walls	--	188	1128
Partitions	--	300	1800
Extra partitions	--	121	726

Figure 41 represents the simulated model of the commercial building and Figure 42 shows the typical floor plan of one apartment.

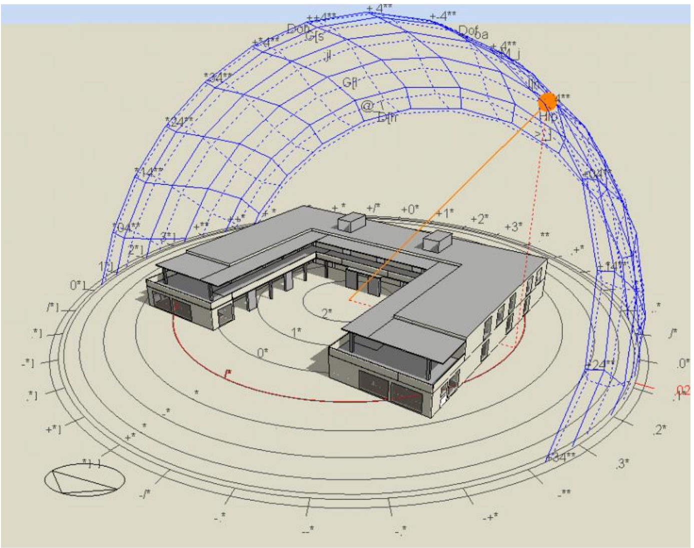


Figure 42: Simulated Model for Commercial Building

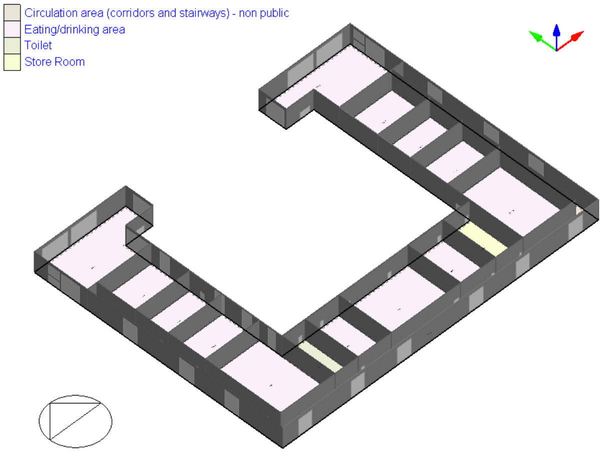


Figure 41: Floor plan for commercial building

3.5 Simulation Specifications

This section demonstrates all the specifications that has been adjusted to form the models and simulate it to obtain the thermal performance data of each wall system in both the residential and commercial building.

3.5.1 Computer software programs

A user-friendly architectural interface was used to simulate each building using “DesignBuilder” version 6.0.1.019 software and its thermal performance tool “EnergyPlus” version 8.9.0. The current needed weather data file for simulating the present weather conditions was downloaded from the department of energy (USDOE) website (DEO, 2019). DesignBuilder is a simulation software that simulates the weather conditions of the required area and takes in consideration different parameters such as heat transfer coefficient, indoor air quality, and indoor thermal comfort taking into account the effect of solar radiation, air ventilation and others on the simulated buildings (Pawar, 2018).

The weather simulation tool “EnergyPlus” installs all the needed weather data files. It contains the .STAT (Energy-Plus weather data statistics), and .EPW (Energy-Plus weather file) files needed for the simulations as shown in Table 23 (Pawar, 2018). It also translates the Weather Year for Energy Calculations (WYEC), and the new International Weather for Energy Calculations (IWEC) format from ASHRAE (Pawar, 2018). The weather data file for Cairo, 2002 which covers from 2012 till 2025 (14 years).

Table 23: Weather data files- EnergyPlus

City	Climate Data files	
Cairo International Airport (ETMY)	.EPW	.STAT
Cairo (IWEC)	.EPW	.STAT

3.5.2 Thermal Comfort

According to the HBRC, the thermal comfort of each person differences than the other which supports the theory of Adaptive Comfort (AC) mentioned by Givoni (Mahdy, 2017). Additionally, there are two factors that play a role in people's thermal comfort which are related to the surrounding environmental climate from humidity, temperatures, and wind speed also the personal comfort. People who already lives in hot regions would be adaptive with high temperatures and vice versa (Mahdy, 2017).

Consequently, in the simulation a modification to the thermal comfort zones that are mentioned by the EREC and HBRC has been done to adapt with the climatic zone of Cairo in 2019 where higher temperatures are being tolerated. The original thermal comfort zones mentioned by EREC were in the cold zones 22.2 ^{o}C- 25.6 ^{o}C and in the hot zones 25.6 ^{o}C -34.5 ^{o}C. The modified thermal comfort zones were applied using Givoni method through including the mean values of both the hot and cold thermal comfort zone values (Mahdy, 2017). The modified thermal comfort zone that has been used is 20 ^{o}C-28 ^{o}C.

The Energy-Plus thermal infiltration rates for both the AAC blocks and red brick were identified and adjusted in the modeling process based on the ASTM-C1363 infiltration tests (ASTM, 2014) and other recent studies (Šadauskienė, 2014). To illustrate, recent studies on the air permeability of building envelops shows that clay bricks air tightness is way less than AAC blocks. The values for red brick in comparison to AAC blocks are 73.6 $m^3/h.m^2$ and 1.2 $m^3/h.m^2$ respectively (Šadauskienė, 2014). Based on the Building for Environmental and Economic Sustainability (BEES) by the National Institute of Standards and Technology (NIST) report (NIST,

2012) and the ASHRAE 90.1(ASHRAE, 2017a), and ASHRAE 62.2 (ASHRAE, 2017b), the total buildings infiltration rates were adjusted.

3.5.3 Building Components specifications

In this section all the building components from external and internal walls, flooring, and roofs will be discussed. In general, two building wall systems were tested and compared to the original two wall systems obtained from the sections shop drawings (Appendix 1). The original wall systems (Case 1) and the alternative wall systems (Case 2) for the residential and the commercial building which were chosen based on the thermal recommendations of the EREC (EREC, 2008) and the Egyptian Specifications for Thermal Insulation Work Items are as follows:

- Traditional wall systems of traditional red bricks with ordinary fenestration (Case 1)
- Alternative wall systems of AAC block with selected type of fenestration (Case 2)

The traditional wall systems of red bricks are the most commonly used wall systems in Egypt due to several reasons such as low market price, availability and most commonly known for labor. However, the chosen wall system is not commonly used in Egypt, but according to a number of tests that have been carried by the HBRC and Center of Planning and Architectural Studies (CPAS), and regarding the recommendations of the EREC for building and glass specifications, AAC wall systems were selected and different glass types were used.

These materials were used to achieve the long-term financial gains from indoor thermal comfort, energy consumption, to recovering the initial cost; however, they might not be the cheapest alternatives but most effective. Table 24 illustrates the difference between each wall system as per the recommended parameters.

Table 24: Building systems compositions

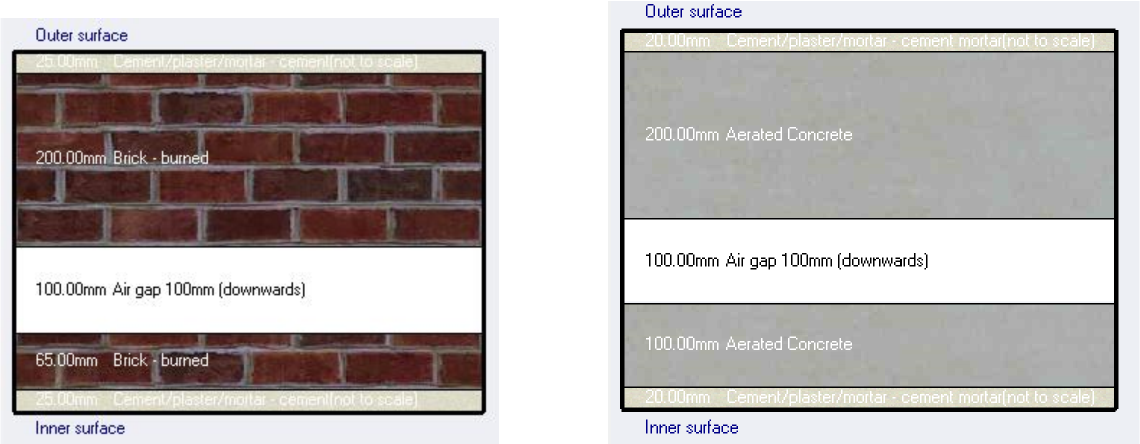
Building Envelope	Type	Description	Thickness (mm)
Traditional wall system	External walls	Mortar (Dense)	25
		red brick wall	250
		Mortar (Dense)	25
	Internal walls	Mortar (Lightweight)	25
		Red brick wall	120
		Mortar (Lightweight)	25
	Fenestrations	Single clear glass and 20% WWR	6
Chosen wall system	External walls	Mortar (Dense)	20
		AAC blocks	250
		Mortar (Dense)	20
	Internal walls	Mortar (Lightweight)	20
		AAC block	100
		Mortar (Lightweight)	20
	Fenestrations	Double reflective clear glass	12.4
		Single clear glass	6.4
Slabs		Cement Plaster (Dense)	25
		Concrete Slab	150
		Cement Plaster (Dense)	25
Flooring		Earth gravel/ Sand	80
		Mortar (Lightweight)	20
		Ceramic Tiles	20

Table 25 represents the main components of each wall system that was used for replacing the traditional wall systems. Figure 43 and Figure 44 exhibits the wall sections that were used in simulating the models. Each building has two wall sections, the original and the selected.

Table 25: Used wall sections compositions

Type	Category	External wall Sections	Thickness (mm)
Residential	Original- Wall Construction Type #1	Double wall of red brick with air cavity	365
	Selected - Wall Construction Type #2	Double wall of AAC block with air cavity	400
Commercial	Original- Wall Construction Type #3	Single layer of red brick with plaster	250
	Selected- Wall Construction Type #4	Single layer of AAC block with plaster	250

- Residential wall section used for simulation in DesignBuilder:

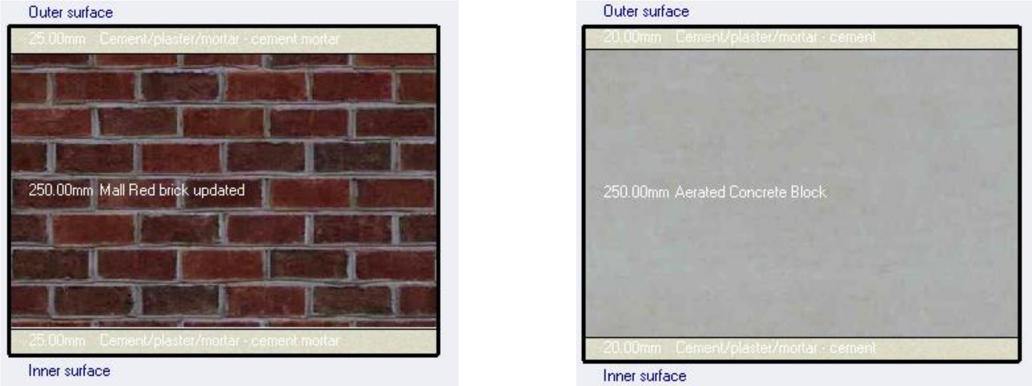


(a)

(b)

Figure 43: Residential Wall Constructions a) Type #1, b) Type #2

- Commercial wall section used for simulation in DesignBuilder:



(a) (b)

Figure 44: Wall Construction a) Type# 3, b) Type#4

3.5.4 Glass specifications

In Egypt, commonly four glass types are used, and they are specified by the EREC which are: Single glass, Single reflective glass, Double glass, and Double Reflective glass. According to recent studies on the fenestrations, the most commonly used type of glass in Egypt is the single glass (Mahdy, 2014).

Table *26* represents the type of glass used in both models and the parameters of each glass type such as the Light Transmission (LT) values, the Solar Heat Gain Coefficient (SHGC), and the U-values according to the recommendations of the HBRC and the EREC.

Table 26: The used glass specifications

Glass type	Category	LT	SHGC	U-Value(W/m^{2}K)
Single glass	Clear 6.4mm	0.66	0.49	3.17
Double reflective glass (Stainless Steel Cover 8%)	Clear Reflective 6.4mm/6mm air	0.05	0.13	2.66

3.6 Thermal Performance Parameters

The thermal performance of buildings depends on some parameters that have been addressed in both models. These parameters include the type of shading devices, Window to Wall Ration (WWR), the Orientation of the building, the Roof Solar Reflective Index (SRI), and the SHGC.

3.6.1 Shading Parameters

The original shading devices for each model kept as presented in the shop drawings. For the alternative models, first the shading systems that were used for the needed facades are based on the recommendations of the EREC in the Annex A-3 (EREC, 2008). Vertical and Horizontal shading devices were used in each model according to the orientation of each façade.

3.6.2 Window to Wall Ratio (WWR) and SHGC

The WWR for each façade is identified based on the shop drawings. WWR is the ratio between the areas of the total façade to the areas of the openings in each façade (Nikolopoulou, 2013). The original Elevations and plans were used to identify the area of each façade and the area of the openings in each façade as well. In addition, no modifications were done to the facades or the WWR in the simulations.

For low-rise buildings, the SHGC for ≤ 20% WWR should be 0.4 max and the SHGC for ≥ 20% WWR should be 0.25 max (Wagdi, 2018). For high-rise buildings more than 4 stories, the SHGC for ≤ 40% WWR should be 0.35 max, SHGC for WWR between 40-60% should be 0.3 max, and the SHGC for ≥ 60% WWR should be 0.22 max (Wagdi, 2018). EREC recommendations was used for verification (EREC, 2008). Table 27 and Table 28 demonstrates the WWR in each elevation for the residential and commercial building.

Table 27: WWR and SHGC for the residential building

Elevation	Total area (m^2)	Windows (m^2)	WWR %	SHGC
North	1564.9	236.6	15.1	Max 0.35
South	1076.1	218.4	20.3	Max 0.35
East	640.1	--	--	--
West	640.1	--	--	--

Table 28: WWR and SHGC for the commercial building

Elevation	Total area (m^2)	Windows (m^2)	WWR %	SHGC
North	1083	360	33.2	Max 0.25
South	1083	240	22.2	Max 0.25
East	843	220	26.1	Max 0.25
West	843	220	26.1	Max 0.25

3.7 Activities, Occupancy and HVAC

For the simulation, some schedules were adjusted to the models in Design Builder according to the CAPMAS latest population census data and the HBRC latest analysis (CAPMAS, 2019b). These data helped in modifying the occupancy timings, activities, lighting, office equipment, and HVAC systems. Based on a recent study that was conducted after surveying over 1500 apartments in Cairo, the normal lifestyle of the Egyptians such as working hours, weekends, and holidays were taken in consideration for preparing the schedules (Attia, 2012). Also, most of the apartments used gas heaters for the Domestic Hot Water (DHW). Fixed schedules as per the recommendations were used as shown in Table 29 and Table 30 for both buildings.

Table 29: Operating schedule, occupancy and working profile- Residential building

Typical Residential building zones	Occupancy Schedule (Hour)	Activity	Clo value (m^2 0C/W)		Working profile (days in week)	DHW
			Winter Cloth	Summer Cloth		
Reception	14:00-23:00 8:00-23:00 (For weekends)	Office Activity	1	0.5	7	OFF
Kitchen	8:00-18:00	Light manual work	1	0.5	7	ON
Bedroom	23:00-9:00	Bedroom	1	0.5	7	OFF
Bathroom	8:00-23:00	Bathroom	1	0.5	7	ON
Lobby	8:00-23:00	Standing/Walking	1	0.5	7	OFF

Table 30: Operating schedule, occupancy and working profile - Commercial Building

Commercial Building Zones	Occupancy Schedule (Hour)	Activity	Clo value (m^2 0C/W)		Working profile (days in week)	DHW
			Winter Cloth	Summer Cloth		
Commercial zones	9:00-23:00	Eating/Drinking	1	0.5	7	OFF
Storage Room	9:00-23:00	Office Activity	1	0.5	5	OFF
Toilets	9:00-23:00	Bathroom	1	0.5	7	ON
Services/Electricity Room	9:00-23:00	Light manual work	1	0.5	7	ON
Circulation/Lobby	9:00-23:00	Standing/Walking	1	0.5	7	OFF
Cores	9:00-23:00	Standing/Walking	1	0.5	7	OFF

For the HVAC systems, mixed modes where used where natural and mechanical ventilations are allowed. This makes use of the passive cooling and use the mechanical systems as efficient as possible (Mahdy, 2017). In addition, the heating and cooling set points were adjusted according to the summer and winter common temperatures. The setting conditions of the HVAC systems were kept fixed for the simulations and according to the HBRC and the EREC recommendations where the cooling set-point for the summer season was adjusted to 20 ^{o}C and the heating set-point for the winter season was adjusted to 22 ^{o}C. The heating and cooling set-points were kept fixed for all the simulations. Moreover, setting the heating and cooling setbacks to 12 and 28 respectively according to the recommendations of the HBRC (HBRC, 2013).

For the residential model, simple split air condition system was used, which is commonly used in Egypt for domestic uses, for heating and cooling of the zones. The cooling Coefficient of Performance (COP) used for this air condition system is 1.83. For the commercial building, a different HVAC system was used which is the Variable Air Volume (VAV) with air-cooled chillers and dual ducts to provide the needed amount of air to every space according to the volume, capacity and use. This facilitates the heating and cooling process in large spaces (Attia et al., 2012).

For validation of the simulation results, monthly electricity bills were collected to calculate the energy consumption per month for a residential building in New Cairo and for the commercial building, a utility and service building at Zewel science city was used to estimate the percentages of saving in electricity bill from previous studies done by the HBRC (HBRC, 2016).

3.8 Materials Thermal Characteristics

The variables used to analyze the thermal performance of each wall system are according to the ISO 6946:2017 (CEN, 2017), the EREC and the HBRC recommendations to verify these performance parameters used and the acceptable ranges. Table 31 specifies the settings used for thermal calculations. Table 32 demonstrates the parameters used for calculating the U-value of the buildings wall sections according to the specifications by the HRBC (HBRC, 2016).

Table 31: Performance parameters verification (HBRC, 2016)

Parameter	Coefficient	Verification		Range
Simulation Period	24-hours	--	--	--
Internal surface resistance	0.13 m^2K/W	ISO 6946:2017 & HBRC	Yes	0.1 to 0.2
External surface resistance	0.04 m^2K/W	ISO 6946:2017 & HBRC	Yes	0.04 to 0.05

Table 32: Materials characteristics (HBRC, 2016)

Material characteristics				Thermal Properties		
Layer	Thickness (mm)	Density (Kg/m^3)	Specific heat (J/kg/K)	Decrement Factor	Areal Heat Capacity (KJ/m^2K)	Time Lag (hrs)
Mortar (Dense)	25	1300	840	--	--	--
Red Bricks	250	950	732.2	0.41	53	8hrs, 38 min
Red Bricks	120	950	732.2	0.79	49	4hrs, 09 min
AAC Blocks	250	450	1000	0.34	43	10hrs,28 min
AAC Blocks	100	450	1000	0.77	45	4hrs,55 min

3.8.1 U-value Calculations

The U-value calculation for each wall system was done through calculating the thermal resistance of each material component used in each wall section based on the ISO 6946:2017(CEN, 2017). Some equations that are provided by the ISO 6946 were used in the calculations and are shown in Equation 1 and Equation . According to the HBRC tests on the AAC blocks, the thermal conductivity for the AAC blocks is 0.132 W/m.K.

$$R = \sum_{j=1}^{n} R_j = R_{so} + R_1 + R_2 + \ldots\ldots + R_n + R_{si}$$

$$R = \frac{1}{h_{so}} + \frac{L_1}{k_1} + \frac{L_2}{k_2} + \ldots\ldots\ldots + \frac{L_n}{k_n} + \frac{1}{h_{si}}$$

Equation 1: Total thermal resistance equation

Where

○ h_{so} & h_{is}	External and internal surfaces heat coefficient	(W/m^2.K)
○ L	Thickness	(m)
○ K	Thermal conductivity	(W/m.K)

$$R = D/\lambda$$

Equation 2: Thermal resistance equation for each item

Where

○ d	the thickness of the material layer in the component	(m)
○ λ	the design thermal conductivity of each material	(W/m·K)

To compute the Average Weighted U-Value of each wall system the process in Figure 45 was used.

Step 1

Identify all wall section components including the thicknesses and building materials

Step 2

Calculate the Thermal Resistance, U-value and Average Weighted U-value as per the recommendation of the HRBS as follows:

Thermal conductivity of each material is provided by the HRBS
Thermal Resistance ‘R’ = (Thickness (mm)/1000)/Thermal Conductivity
U-value = 1/sum of R

Step 3

Calculate the area of each elevation to get the areas of each wall system
Then compute the Average Weighted U-value= Sum (Area*U-Value)/Sum of areas

Figure 45: U-Value Calculation Process

For the residential model, the original wall system's U-value and average weighted U-value were calculated as shown in Table 33. In addition, two other walls systems of AAC blocks were evaluated to find the best wall section with the best U-value and thermal properties.

I. Wall Construction type # 1 (Residential)

Step 1: Calculating the U-Value.

Table 33: U-Value calculations- Type #1

Original Residential Wall Construction Type #1				
No	Building Material	Thickness (mm)	Thermal conducitvity 'K' (W/mK)	Thermal resistance 'R' (K.m^2/W)
1	Internal Surface Resistance			0.13
2	Interior Finish- Paster (Dense)	25	0.57	0.044
3	Construction Wall type #1 -Red Bricks	200	0.314	0.637
4	Air Gap	100	1.06	0.094
5	Exterior Finsih- Plaster (Dense)	65	0.314	0.207
6	Construction Wall type #1 -Red Bricks	25	0.57	0.044
7	External Surface Resistance			0.04
Total R of Wall Construction Type #1				1.196
U-Value (1/R)				**0.836**

Step 2: Table 34 below represents the detailed calcuations of each elevation to get the average weigthed U-Value For wall construction type #1.

Table 34: Elevations calculations- Type #1

Elevation 1 (Front)				
No	Wall type	Area(A)	U-Value	A*U
1	Brick work-Type #1	1233.925	0.836	1031.7
2	Concrete	234.115	0.67	156.86

Elevation 2 (Left)				
No	Wall type	Area(A)	U-Value	A*U
1	Brick work-Type #1	569.8	0.836	476.42
2	Concrete	108.815	0.67	72.91

Elevation 3 (Back)				
No	Wall type	Area(A)	U-Value	A*U
1	Brick work- Type #1	879.725	0.836	735.55
2	Concrete	162.155	0.67	108.64

Elevation 4 (Right)				
No	Wall type	Area(A)	U-Value	A*U
1	Brick work- Type #1	569.8	0.836	476.42
2	Concrete	108.815	0.67	72.91

Step 3: Calculating the Average Weighted U-Value of wall type # 1 and judging the over all perfomance of this wall system as shown in Table 35.

Table 35: Average weighted U-Value- Type #1

Average Weighted U-Value Wall Type # 1				
No.	Type	Total Area (m^2)	U-Value (W/m^2. K)	A*U-Value
1	Wall Type #1- Brick work	3253.25	0.836	2720.09
2	Concrete	613.9	0.67	411.31
Total		3867.15		3131.40
Average Weighted U-value			**Poor**	**0.810**

II. Wall Construction Type #2 (Residential)

Step 1: Calculating the U-Value as shown in Table 36.

Table 36: U-Value Calculations- Type #2

AAC Residential Wall Construction type # 2				
No.	Building Material	Thickness (mm)	Thermal conducitvity 'K' (W/mK)	Thermal resistance 'R' ($K.m^2/W$)
1	Internal Surface Resistance			0.14
2	Interior Finish-Plaster (Dense)	20	0.57	0.035
3	Construction Wall type #2- AAC Block	250	0.132	1.894
4	Air Gap	100	1.06	0.094
5	Construction Wall type #2- AAC Block	100	0.312	0.321
6	Exterior Finish- Plaster (Dense)	20	0.57	0.035
7	External Surface resistance			0.04
Total R of Wall Construction Type # 2				2.559
U-Value (1/R)				**0.391**

Step 2: Table 37 below represents the detailed calcuations of each elevation to get the average weigthed U-Value For wall construction type #2.

Table 37: Elevations Calculations- Type #2

Elevation 1 (Front)				
No	Wall type	Area(A)	U-Value	A*U
1	Wall Type #2- AAC block	1233.925	0.391	482.20
2	Concrete	234.115	0.67	156.86

Elevation 2 (Left)				
No	Wall type	Area(A)	U-Value	A*U
1	Wall Type #2- AAC block	569.8	0.391	222.67
2	Concrete	108.815	0.67	72.91

Elevation 3 (Back)				
No	Wall type	Area(A)	U-Value	A*U
1	Wall Type #2- AAC block	879.725	0.391	343.78
2	Concrete	162.155	0.67	108.64

Table 37: continued

Elevation 4 (Right)				
No	Wall type	Area(A)	U-Value	A*U
1	Wall Type #2- AAC block	569.8	0.391	222.67
2	Concrete	108.815	0.67	72.91

Step 3: Calculating the Average Weighted U-Value of wall type # 2 and judging the over all perfomance of this wall system as shown in Table 38**.**

Table 38: Average weighted U-Value- Type #2

Average Weighted U-value Wall type #2				
No	Type	Total Area (m^2)	U-Value (W/m^2. K)	A*U-Value
1	Wall Type #2- AAC block	3253.25	0.391	1271.31
2	Concrete	613.9	0.67	411.31
Total		3867.15		1682.63
Average Weighted U-value			**Very Good**	**0.435**

III. Wall Construction Type #3 (Commercial)

Step 1: Calculating the U-Value as shown in Table 39.

Table 39: U-value calculations- Type #3

Original Commercial Wall Construction type # 4				
No	Building Material	Thickness (mm)	Thermal conducitvity 'K' (W/mK)	Thermal resistance 'R' (K.m^2/W)
1	Internal Surface Resistance			0.13
2	Interior Finish-Plaster	25	0.57	0.044
3	Construction Wall type #3 - Red Brick	250	0.314	0.796
4	Exterior Finish- Plaster	25	0.57	0.044
5	External Surface resistance			0.04
Total R of Wall Construction Type # 3				1.054
U-Value (1/R)				**0.949**

Step 2: Table 40 below represents the detailed calcuations of each elevation to get the average weigthed U-Value For wall construction type # 3.

Table 40: Elevations calculations- Type #3

Elevation (Front)				
No	Wall type	Area(A)	U-Value	A*U
1	Wall Type #3- Red Brick	1083.00	0.949	1027.61
2	Concrete	279.1	0.67	187.00

Elevations (Left)				
No	Wall type	Area(A)	U-Value	A*U
1	Wall Type #3- Red Brick	843.00	0.949	799.89
2	Concrete	271.1	0.67	181.64

Elevations (Back)				
No	Wall type	Area(A)	U-Value	A*U
1	Wall Type #3- Red Brick	1083.00	0.949	1027.61
2	Concrete	279.1	0.67	187.00

Table 40: continued

Elevations (Right)				
No	Wall type	Area(A)	U-Value	A*U
1	Wall Type #3- Red Brick	843.00	0.949	799.89
2	Concrete	271.1	0.67	181.64

Step 3: Calculating the Average Weighted U-Value of wall type # 3 and judging the over all perfomance of this wall system as shown in Table 41**.**

Table 41: Average weighted U-value- Type #3

Average Weighted U-value Wall type #3				
No	Type	Total Area (m^2)	U-Value (W/m^2. K)	A*U-Value
1	Wall Type #3- Red Brick	3852.0	0.949	3655.0
2	Concrete	1100.4	0.67	737.27
Total		4952.4		4392.27
Average Weighted U-value			**Poor**	**0.887**

IV. Wall Construction Type #4 (Commercial)

Step 1: Calculating the U-Value as shown in Table 42.

Table 42: Average weighted U-Value- Type #4

Original Commercial Wall Construction type # 4				
No	Building Material	Thickness (mm)	Thermal conducitvity 'K' (W/mK)	Thermal resistance 'R' ($K.m^2/W$)
1	Internal Surface Resistance			0.13
2	Interior Finish-Plaster	25	0.57	0.035
3	Construction Wall type #4 -AAC Block	250	0.132	1.894
4	Exterior Finish- Plaster	25	0.57	0.035
5	External Surface resistance			0.04
Total R of Wall Construction Type # 4				2.134
U-Value (1/R)				**0.469**

Step 2: Table 43 represents the detailed calcuations of each elevation to get the average weigthed U-Value For wall construction type #4.

Table 43: Elevations calculations- Type #4

Elevation (Front)				
No	Wall type	Area(A)	U-Value	A*U
1	Wall Type #4- AAC Block	1083.00	0.469	1027.61
2	Concrete	279.1	0.67	187.00

Elevations (Left)				
No	Wall type	Area(A)	U-Value	A*U
1	Wall Type #4- AAC Block	843.00	0.469	799.89
2	Concrete	271.1	0.67	181.64

Elevations (Back)				
No	Wall type	Area(A)	U-Value	A*U
1	Wall Type #4- AAC Block	1083.00	0.469	1027.61
2	Concrete	279.1	0.67	187.00

Elevations (Right)				
No	Wall type	Area(A)	U-Value	A*U
1	Wall Type #4- AAC Block	843.00	0.469	799.89
2	Concrete	271.1	0.67	181.64

Step 3: Calculating the Average Weighted U-Value of wall type # 4 and judging the over all perfomance of this wall system as shown in Table 44.

Table 44: Average weighted U-Value- type #4

Average Weighted U-Value				
No	Type	Total Area (m^2)	U-Value ($W/m^2.K$)	A*U-value
1	Wall Type #4- AAC Block	3852.00	0.469	1804.96
2	Concrete	1100.4	0.67	737.27
Total		4952.40		2542.23
Average Weighted U-value			**Very Good**	**0.513**

3.9 Chapter Summary

Calculations were carried out on two different buildings in the New Egyptian Adminstative Capital, a residential and a commercial building. The study was done on different wall systems. The original wall system that is built on site and the alternative wall systems that was selected using AAC wall sections. These calculations include a finiacial study as well as a thermal performace analysis of each model to evaluate the environmental impact of each brick. The finiacial study was done based on the materials price list given by the Minsistry of Housing and the interviews with the site engineers, sales engineers in Jotun and Delta block Egypt as well as some contratcors from site. Simulation of each model was done on a computer software "DesignBuilder" and the thermal performance was carried out with the Energy-Plus tool.

In order to simulate the models, the original wall systems were adjusted based on the plans, elevations, and sections of each building. After carrying out the original wall systems simulations, they were observed and analysized showing thermal discomfort, therfore, some modifications were done to each wall system using different alternative wall sections for each model to evaluate the difference in thermal comfort and indoor quality of each:

Alternative 1: this alternative composed of double AAC block wall with air cavity of 100mm which is the same as the original case but using different masonry material which was used for the residential model.

Alternative 2: this alternative composed of a single AAC block of 250mm which was used as an alternative for both the reisidential and the commercial models.

The second stage included the schedules, walling materials, activities, HVAC systems as well as lighting. These paramters were adjusted according to the recommecdations of the EREC, HBRC, BPI, CPAS and some recent studies. In addition, the simulation was done by calculating the WWR and SHGC of each façade.

The final stage included all claculations to be adjusted to the simulated models. the U-Value and the average weighted U-Values were computed to each wall system to be adjusted to each model. Simulation paramerters were adjusted to the DesignBuilder models and simulations were run. The calculations were based on a framework that facilitates organizing and calculated each wall system in a systematic way as shown in Figure 46 and for further detailed framework see section 3.7.

Step 1	Identify all walling components
Step 2	Calculate the Thermal resistance for each component and the U-Value for the wall section
Step 3	Calculating the overall average weighted U-Value

Figure 46: U-Value calculations Framework

CHAPTER 4: RESULTS AND ANALYSIS

4.1 Overview

This chapter represents the finidings and results of each wall system after carrying oyr each simulation. It is divided into three sections as follows:

i. Finaincial study of each building (residential and commercial) using the two building systems (Red Brick and AAC Blocks) and a comparison of the results.

ii. Simulation results from the original building wall systems and the alternative wall systems from two sities

iii. Energy comsumption of each wall system includes comparison of data from simulation

The results are the indicators of 10 simulations that were conducted on both buildings in the New Egyptian Adminstarive Capital. The results of each simulation is represented in tables and graphs. These tables include the constant loads from each building and the monthly total heating and cooling loads. The graphs include the monthly energy consumption, the total energy consumption cost , and the indoor thermal comfort zones of each building. In addition, a comparison beteween the wall systems is done.

The studies done on each wall sytem simulations revealed that one of the main building components that leaks heat is the wall system. Also, the fenestrations were indicated as one of the reasons for the increase in energy consumption due to the leakage of heat flow fron the outdoors to indoors. The total energy consumption of the original wall systems, Red brick wall systems, is higher than the alternative wall systems, AAC blocks. This difference in energy consumption is around 23.6% for the residential model and 24.6% for the commercial model. This energy consumption is mainly from the heating and cooling process of the buildings which was translated into electricity bills using the electricty tariffs from the minsirty of electricty.

The second part is the financial analysis which includs the initial construction cost of each wall system and the percentages of savings as well as the long-run savings over a period of 14 years. The relation between the intial cost and the energy consumption cost which is the operational cost was addressed from the prespective of the savings that would occur on the long-term to the investors.

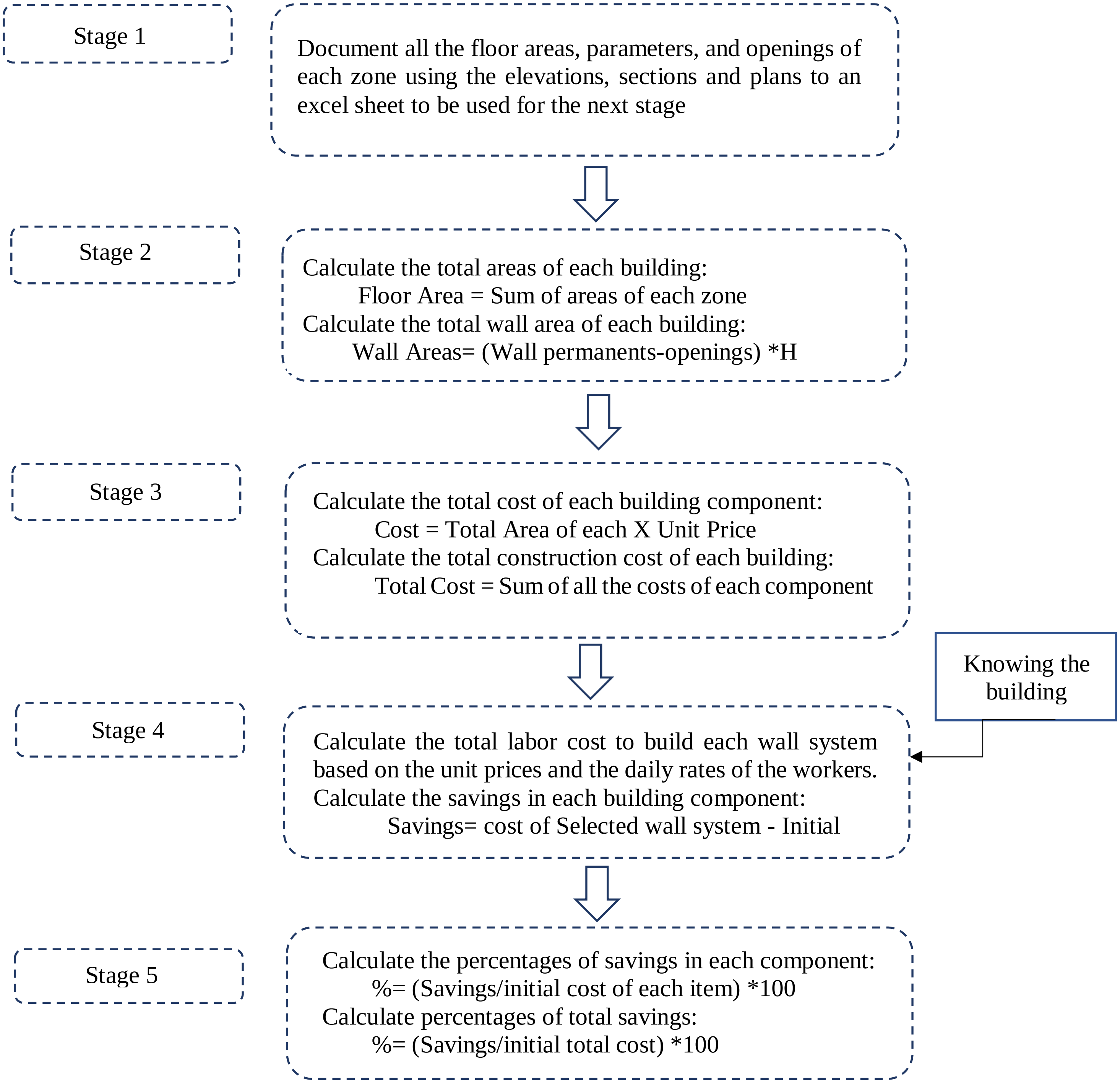
4.2 Financial Analysis

For the financial analsysis part, some equqations were used based on the Net Present value (NPV). The process is illustarted in Figure 47. The cost of the wall systems used in simulation were compared to the long-term investments over a period of 14 years (see section 3.4.1). The interest rate which is 15.57% as well as the electricity tariff were assumned to be fixed over this period of analysis (CBE, 2019). The benefits of this analysis is to show the difference between investing a small amount of money as an intial cost which in this case the Red brick wall systems and investing a larger amount of money which is in this case the AAC blocks but gianing on the long run. The equations used to calcuate the long-term investement in the four wall systems are as follows (Mahdy, 2016):

$$S_1 = D_1 \times (1 + i)^{N} \qquad \& \qquad S_2 = (1 + i)^{N-1} / (i \times D2) \qquad (3)$$

Where

S_1 & S_2	Money after N amount of time	LE
D_1 &D_2	Difference between the costs	LE
N	Number of investment years in bank	Number
I	Interest Rate of the bank	%



Stage 1

Document all the floor areas, parameters, and openings of each zone using the elevations, sections and plans to an excel sheet to be used for the next stage

Stage 2

Calculate the total areas of each building:
Floor Area = Sum of areas of each zone
Calculate the total wall area of each building:
Wall Areas= (Wall permanents-openings) *H

Stage 3

Calculate the total cost of each building component:
Cost = Total Area of each X Unit Price
Calculate the total construction cost of each building:
Total Cost = Sum of all the costs of each component

Stage 4

Knowing the building

Calculate the total labor cost to build each wall system based on the unit prices and the daily rates of the workers.
Calculate the savings in each building component:
Savings= cost of Selected wall system - Initial

Stage 5

Calculate the percentages of savings in each component:
%= (Savings/initial cost of each item) *100
Calculate percentages of total savings:
%= (Savings/initial total cost) *100

Figure 47: Financial Analysis Framework

4.2.1 Savings in Steel and Concrete

Steel and concrete are two of the main components in any building skeleton. The savings in steel and concrete reduces the over all initial construction costs as mentioned in Table 45 and Table 46.

Table 45: Total savings in concrete and steel- Residential building

Item	**Red Bricks**		**AAC Blocks**	
	Concrete (m3)	**Steel (ton)**	**Concrete (m3)**	**Steel (ton)**
Footings	16,405.9	1,105.3	13,696.7	922.8
Columns	3,520.8	527.4	3,044.5	456.0
Cores	265.7	51.6	265.7	51.6
Slabs	398.5	49.4	398.0	49.3
Total Concrete (m3)	20,590.9	--	17,404.9	--
Cost of Concrete	900			
Total Concrete (LE)	18,531,771	--	15,664,365	--
% of savings in concrete	---	--	**15.5**	--
Total Steel (ton)	--	1,733.7	--	1,479.8
Cost of Steel	12,500			
Cost Steel (LE)	--	21,671,250	--	18,497,061.3
% of savings in steel	--	--	--	**14.6**

Table 46: Total savings in Concrete and steel- Commercial building

Item	**Red Bricks**		**AAC Blocks**	
	Concrete (m3)	**Steel (ton)**	**Concrete (m3)**	**Steel (ton)**
Footings	1,088.1	73.3	908.4	63.5
Columns	583.2	87.4	504.3	78.0
Slabs	1,466.5	181.7	1,460.0	148.7
Total Concrete (m3)	3,137.8		2,872.7	
Cost of Concrete	900			
Total Concrete (LE)	2,824,002	--	2,585,430	--
% of savings in concrete	---	--	**8.4**	--
Total Steel (ton)	--	342.4		290.3
Cost of Steel	12,500			
Cost Steel (LE)	--	4,279,713.8	--	3,628,620.5
% of savings in steel	--	--	--	**15.2**

4.2.2 Saving in Mortar

The second step is to calculate the savings in the cement content. AAC blocks consumes less cement in mortar than the Red bricks. This is due to the less number of joints between the AAC blocks and the less thickness of the mortar needed to build a wall of AAC blocks. Table 47 and Table 48 demonstrate the total savings of cement in mortar in the Residential and Construction Commercial buildings.

Table 47: Cement in mortar savings- Residential building

Item	Unit	Red Bricks Type #1	AAC Block Type #2
Area of Brick Walls (12 cm)	M^2	2247.4	2247.4
Volume of Brick Walls (25 cm)	M^3	871.3	871.3
Mortar ratio (12 cm)	ton /m2	0.009	0.004
Mortar ratio (25 cm)	Ton/m^3	0.11	0.063
Total Cement in Mortar	Ton	116.04	64
Cost of cement	Ton	900	
Total cost of Cement in Mortar	LE	104,436	57,416
Total saved Cement	Ton	52.04	
Total cost of cement saved	LE	46,836	
% of savings in Cement in Mortar	**%**	**45%**	

Table 48: Cement in mortar savings- Commercial building

Item	Unit	Red Bricks Type #3	AAC Blocks Type #4
Area of Brick Walls (12 cm)	M^2	8933.04	8933.04
Volume of Brick Walls (25 cm)	M^3	963	963
Mortar ratio (12 cm)	ton /m2	0.009	0.004
Mortar ratio (25 cm)	Ton/m^3	0.11	0.063
Total Cement in Mortar	Ton	186.3	96.4
Cost of cement	Ton	900	
Total cost of Cement in Mortar	LE	167,695	86,761
Total saved Cement	Ton	90	
Total cost of cement saved	LE	80,934	
% of savings in Cement in Mortar	**%**	**48.26%**	

4.2.3 Savings in Brick Cost

The third step to find the total initial savings is to claculate the initial cost of each brick and compare it to the original state of each building. Table 49 and Table 50 demonstrates the extra intial cost of using AAC blocks in the residential and commercial buildings respectivly.

Table 49: Extra cost of brick- Residential building

Item	Unit	Red Bricks Type #1	AAC Block Type #2
Volume of Brick Walls (12 cm)	M^3	269.69	269.69
Volume of Brick Walls (25 cm)	M^3	871.36	871.36
Cost of Brick walls	LE	750	1032
Total cost of Brick	LE	855,788	1,177,565
Extra Cost to Brick	LE	321,776.5	
% of Extra Cost	**%**	**37.6 %**	

Table 50: Extra cost of bricks- Commercial building

Item	Unit	Red Bricks Type #3	AAC Blocks Type #4
Volume of Brick Walls (12 cm)	M^3	1,071.96	1,071.96
Volume of Brick Walls (25 cm)	M^3	963	963
Cost of Brick walls	LE	750	1,032
Total cost of Brick walls	LE	1,526,223	2,100,083
Extra Cost to Brick walls	LE	573,860	
% of Extra Cost	**%**	**37.6 %**	

4.2.4 Savings in Labor Cost

The fourth step is to calculate the total labour cost for building both type of walls through knowig the building rates of each brick type, the cost of 1 m^2 and the areas of each building. The cost of 1 m^2 of both bricks is the avaerage of the max and min unit price. Table 51and Table 52 demonstrate the extra building cost of using AAC blocks in both the residential and commercial building.

Table 51: Savings in labor cost- Residential buildings

Item	Unit	Red Bricks Type #1	AAC Block Type #2
Area of Brick Walls (12 cm)	M2	18728.5	18728.5
Area of Brick Walls (25 cm)	M2	3485.4	3485.4
Cost of Red Brick	LE	26	--
Cost of AAC Block	LE	--	22
Building Rate	--	21.1	8.9
Total Cost of Brick work	LE	577,561	488,705
Savings in cost of Brick work	LE	88,856	
% of savings in Brick work	**%**	**15.4 %**	

Table 52: Savings in labor cost- Commercial building

Item	Unit	Red Bricks Type #3	AAC Blocks Type #4
Area of Brick Walls (12 cm)	M2	8933.04	8933.04
Area of Brick Walls (25 cm)	M2	3852	3852
Cost of Red Brick	LE	26	--
Cost of AAC Block	LE	--	22
Building Rate	--	21.1	8.9
Total Cost of Brick work	LE	332,411	281,270
Savings in cost of Brick work	LE	51,140	
% of savings in Brick work	**%**	**15.4 %**	

4.2.5 Fenestration Cost

In order to be able to achieve the indoor thermal comfort, for each building different types of fenestrations was used. The fenestartion cost is also taken in consideration to calculate the total materials cost of each building. Each construction wall type initial cost is computed and the adjasent fenestration cost (see section 3.3.1) as well to get the total cost of each building without the construction cost. Table 53 represents the total intial components cost of each brick wall system which is computed by adding the intial cost of each brick to the fenestration cost. Construction wall type #1 has the least fenestration cost, yet the least performance. The total initial cost of wall type #1 is the least followed by wall type #3; however, the running cost of these two wall constructions are not taken in consideration in this comparisison which would make a difference in the evalutaion of each wall system.

Table 53: Fenestration cost and total materials cost

Building	Wall Construction	Initial Brick Cost	Fenestration Cost	Total Materials Cost
Residential	Type #1	855,788	72,800	928,589
	Type #2	1,177,565	182,000	1,359,565
Commercial	Type #3	1,526,223	208,000	1,734,224
	Type #4	2,100,083	520,000	2,620,084

4.2.6 Savings in Total Cost

The savings in each item total construction cost and building cost of each building is then computed by adding all the elemnts togther from concrete, steel, bricks, mortar, and paint cost. The percentages of savings are calcuated by dividing the savings in each item by the total cost of this item of Red bricks then summing all the items together to get the total svings in the initial cost. The total savings in the residential building is computued to be 14.3%. Table 54 and Table 55 represent a summary of all the total savings in each item and the percentage of savings in the total cost of the residential and comeercial builidng of around 14.3% and 9.4% respectivly.

Table 54: Total construction savings- Residential building

	Extra cost of AAC block	Savings in Concrete	Savings in Steel	Savings in Mortar	Savings in Paint	Savings in Labor	**Total savings**
Savings (L.E.)	-321,776.5	2,867,406	3,174,189	46,836	157,688	88,856	6,013,198.2
% savings in Item's Total cost	-37.6%	15.5%	14.6%	45%	56.6%	15.4%	--
% savings in Total cost	-0.76%	6.84%	7.57%	0.11%	0.38%	0.21%	**14.3 %**

Table 55: Total construction savings- Commercial building

	Extra cost of AAC block	Savings in Concrete	Savings in Steel	Savings in Mortar	Savings in Paint	Savings in Labor	**Total savings**
Savings (L.E.)	-573,860	238,572	651,093	80,934	769,629	51,140	1,217,508
% savings in Item's Total cost	-37.6%	8.4%	15.2%	48.26%	20%	15.4%	
% savings in Total cost	-4.4%	1.84%	5.02%	0.6%	5.9%	0.39%	**9.4%**

Figure 48 shows the total cost of each item in Red brick wall systems in comparision with the total cost of each item in AAC blocks wall systems in the Residential building.

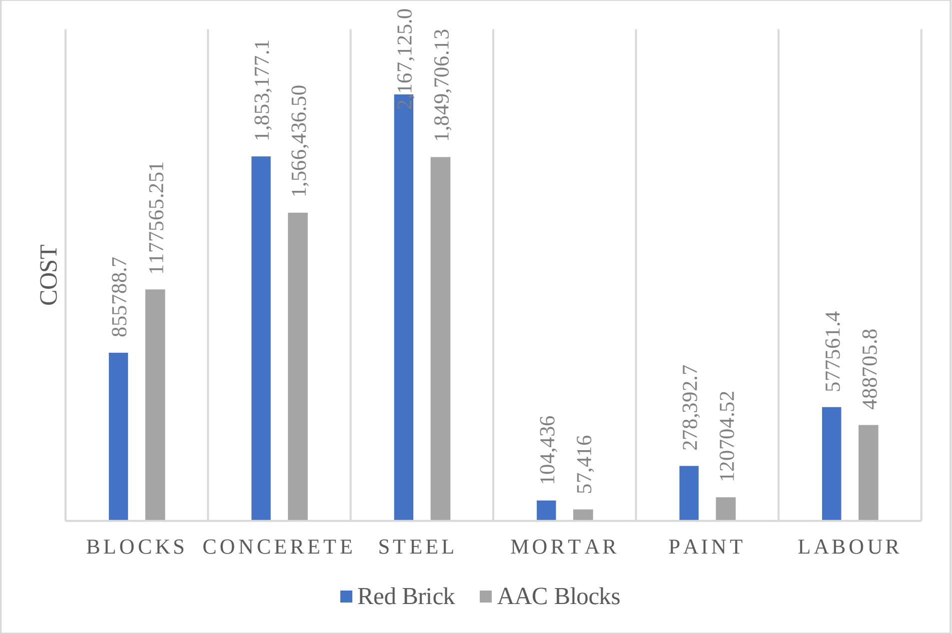


Figure 48: Total cost of each building component in residential building

Figure 49 shows the savings in each construction item with respect to the total cost of the project as a whole for the residential builidng.

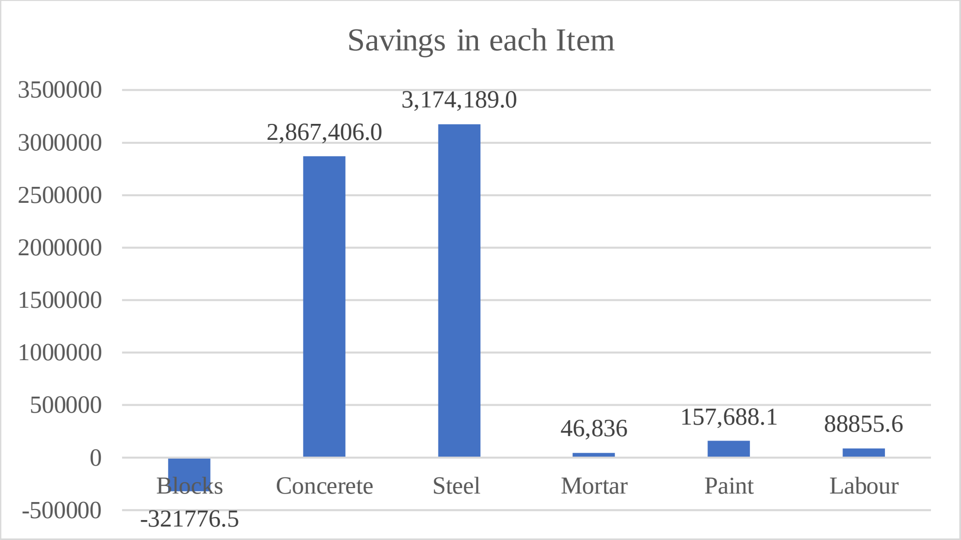


Figure 49: Total savings in each component in residential building

Figure 50 shows the total cost of each item in Red brick in comparision with the total cost of each item in AAC blocks in the commercial building.

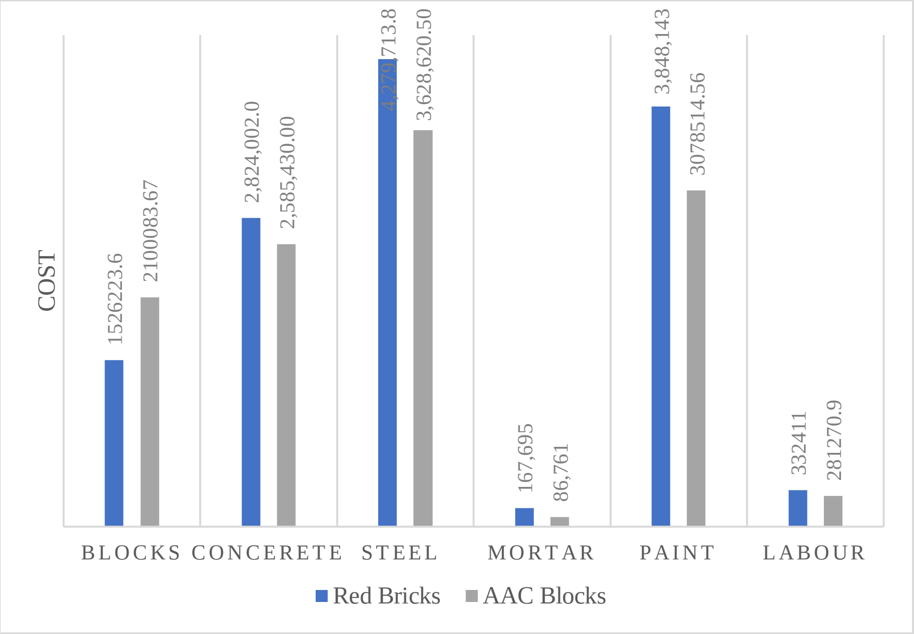


Figure 50: Total Cost of each building component in commercial building

Figure 51 shows the savings in each construction item with respect to the total cost of the project as a whole for the commercial builidng.

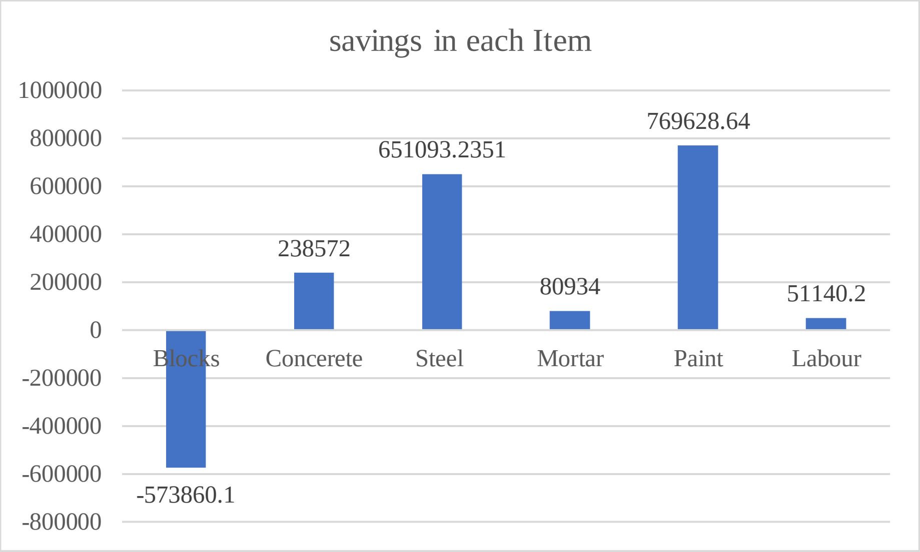


Figure 51: Total Savings in each component in commercial building

4.2.7 Cost Analysis Benefits

The relation between the U-value and the cost of each wall system is shown in Figure 52. The recommended U-Value is 0.3 W/m^2. K which gives excellent thermal performance for the buildings. The U-Value that is required by the EREC and the HBRC is 0.75 W/m^2. K (HBRC, 2013). The graph analyze the relation between the U-Value and the cost for visualizing the effect of each wall system on the cost. All the wall construction types are above 0.3; however, wall construction type # 2 and type #4 are the best U-Values in relation to cost. They are within the acceptable range between 0.3 W/m^2.K and 0.75 W/m^2.K.

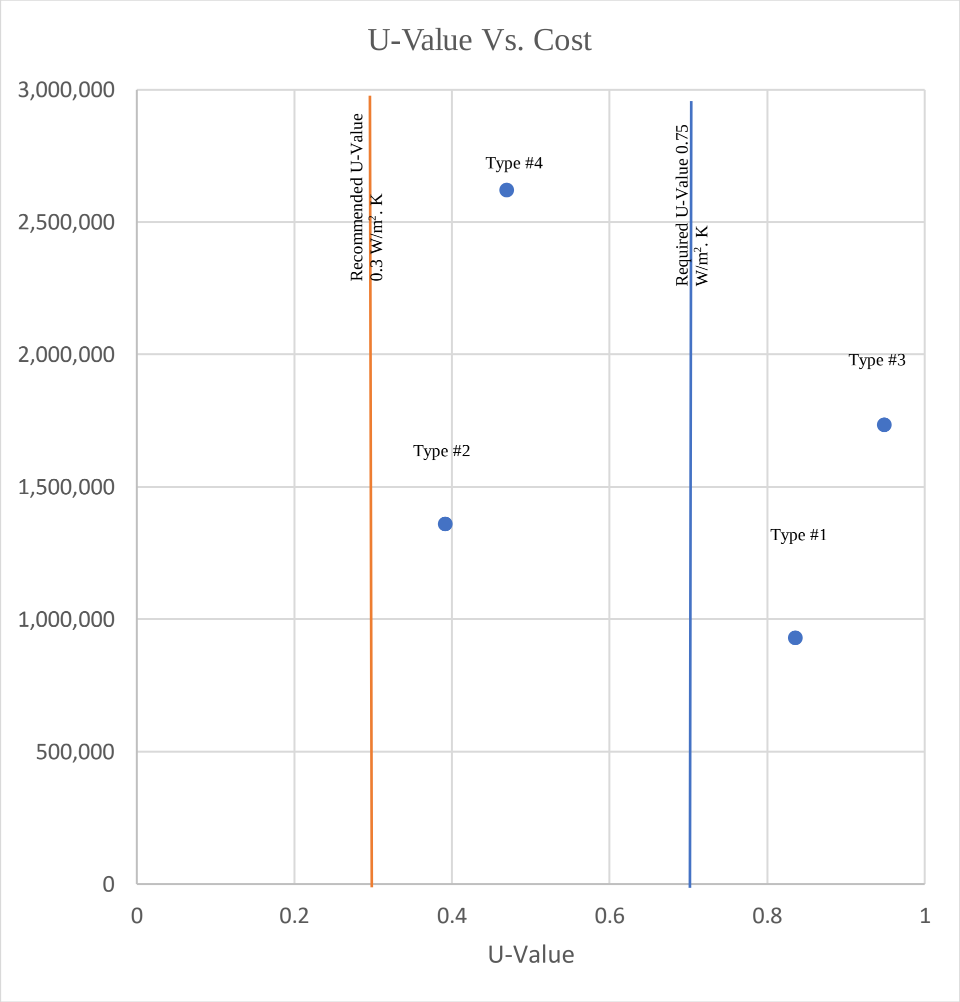


Figure 52: Wall Types Cost VS. U-Value

4.3 Thermal Performance Analysis

The thermal analysis of each building was carried out through the simulation process on DesignBuilder to evaluate the best building envelope and to compare the original state to the selected wall systems. After the simulation, calculations of the total energy consumption were carried and the indoor thermal comfort zones of each building. Moreover, the constant loads of each building (residential and commercial) were taken from the thermal analysis simulations of the building to get the total Kwh of each building which consequently by having the electricity tariff translated into cost per month and annually as well. After that, the cooling and heating loads of each building with a specific wall system was calculated as well to get the total consumption of energy per month and annually.

The construction walls type #2 and type #4 recorded to achieve the best thermal performance, hence the best energy consumption and total energy cost. The results of the simulation regarding different building envelops are illustrated in detail in this section. The simulation results showed that the natural ventilation mood for the two buildings are not in the comfort zone for the occupants' starts from April and increase from May till October. This means an increase in demand on the HVAC systems during this period. To achieve the target of calculating the total energy savings in each building, a framework was used to visualize the process as shown in Figure 53.

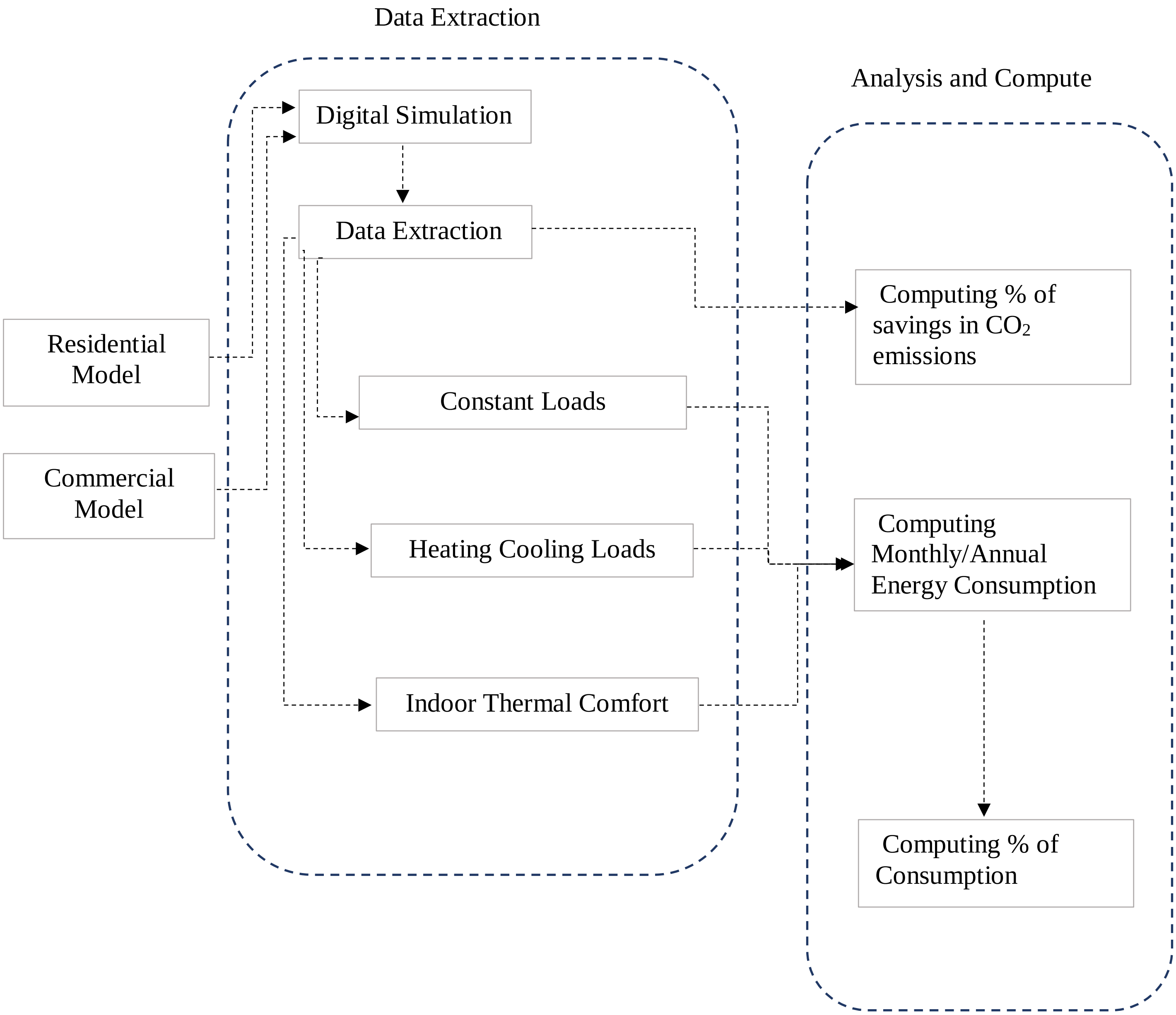


Figure 53: Energy Consumption Computation Flow Chart

4.3.1 Constant Loads

The constant loads on both building due to the lighting and appliances are demonstrated in Table 56 and Table 57. This total load is the constant energy consumption (Kwh) of this building and the corresponding cost (LE) (see section 3.2.2).

Table 56: Constant loads of the residential building

Monthly usage of Resources			
Months	**Lighting (Kwh)**	**Appliances (Kwh)**	**Total (Kwh)**
Jan	5437.17	8101.34	13538.51
Feb	4910.82	7285.6	12196.42
Mar	5438.48	8347.34	13785.82
Apr	5263.47	8157.42	13420.89
May	5435.85	7855.35	13291.2
Jun	5263.47	8157.42	13420.89
Jul	5435.85	7855.35	13291.2
Aug	5437.17	8101.34	13538.51
Sep	5262.16	7911.43	13173.59
Oct	5435.85	7855.35	13291.2
Nov	5262.16	7911.43	13173.59
Dec	5439.8	8593.33	14033.13
--	--	--	--
Total (Kwh)	64022.25	96132.7	**160154.95**
--	--	--	--
Cost (EGP)	92,832.2	139,392.4	--
Customer service (LE)	40		
Total Cost (EGP)	92,872.2	139,432.4	**232,305**

Table 57: constant loads of the commercial building

Monthly usage of Resources				
Months	**Lighting (Mwh)**	**Appliances (Mwh)**	**Total (Mwh)**	**Total (Kwh)**
Jan	13.07	69.97	83.04	83040
Feb	11.66	63.20	74.86	74860
Mar	12.75	69.97	82.72	82720
Apr	12.19	67.71	79.9	79900
May	12.31	69.97	82.28	82280
Jun	11.86	67.71	79.57	79570
Jul	12.26	69.97	82.23	82230
Aug	12.31	69.97	82.28	82280
Sep	12.12	67.71	79.83	79830
Oct	12.84	69.97	82.81	82810
Nov	12.66	67.71	80.37	80370
Dec	13.21	69.97	83.18	83180
--	--	--	--	--
Total (Mwh)	149.24	823.83	973.07	**--**
Total (Kwh)	149240	823830	--	**973070**
Cost (EGP)	223,860	1,235,745	--	--
Customer service (LE)	40			
Total Cost (EGP)	223,900	1,235,785	--	**1,459,685**

4.3.2 Annual Fuel Breakdown

Figure 54 and Figure 55 show the annual breakdowns of the fuel consumption of the residential and the commercial buildings respectively, as a comparison between the two types of bricks used for the residential building. This breaks down the building energy into lighting, appliances and room electricity, heating and cooling. The figure shows that the cooling process due to using mechanical ventilation consumes the most amount of energy (Kwh). It shows that AAC blocks saves energy in all the items except for the constant loads of the building.

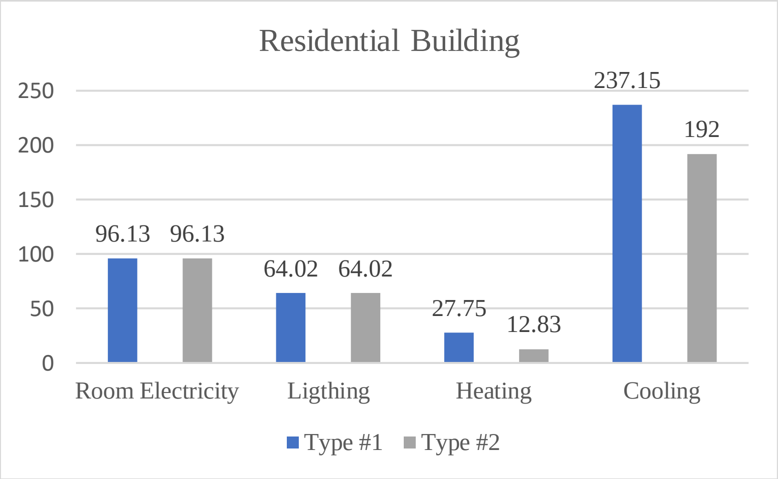


Figure 54: Fuel Breakdown comparison- Residential building

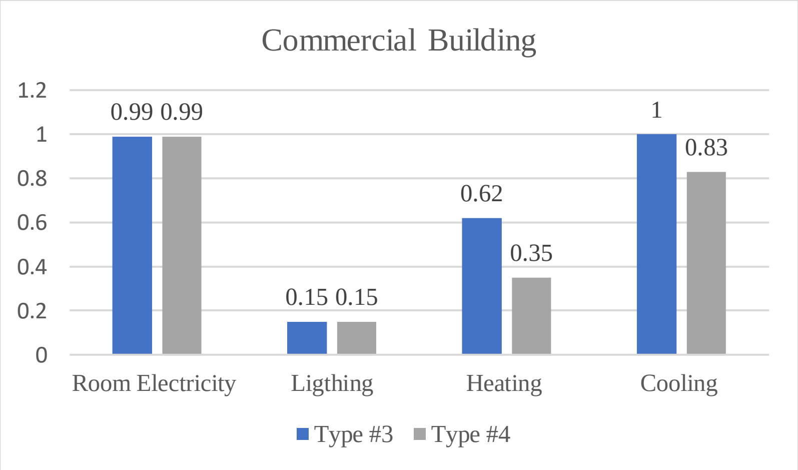


Figure 55: Fuel Breakdown comparison- Commercial building

4.3.3 Annual System Loads

The residential and the commercial buildings use mixed mood ventilation systems. For the heating and cooling loads of the building, the simulation results for the original case which is wall construction type# 1and type #3 has the highest consumption of energy. Figure 56 and Figure 57 show the annual energy consumption of the residential and the commercial buildings respectively. These figures show that the total energy consumption of using double red brick walls in residential building in the New Egyptian Administrative Capital and single red brick. This is by assuming that the other elements regarding energy consumption are neglected such as fans, boilers, chargers and others likewise. This is to evaluate the actual thermal performance of the building envelope only on the heating and cooling loads and the energy consumption.

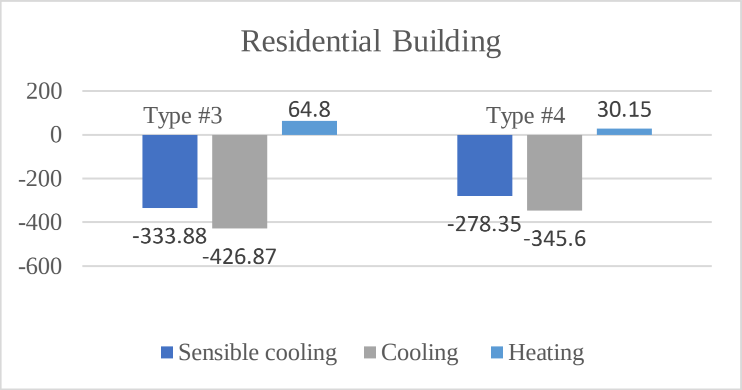


Figure 56: Annual system loads

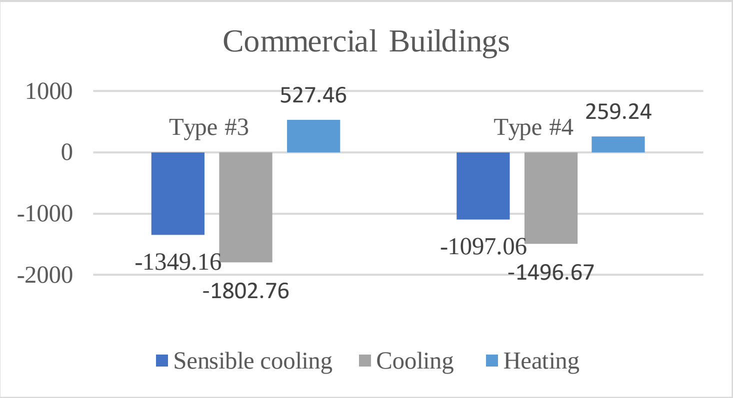


Figure 57: Annual System Load

4.3.4 Indoor Thermal Comfort

Figure 58 and Figure 59 show the annual indoor thermal comfort of the buildings and the total percentage of relative humidity for each wall construction type. The peak months are from May to October where the air temperature increases as well as the humidity. It shows that the highest percentage of indoor thermal discomfort is by the construction wall type # 1 and wall type #3 and that of the relative humidity is also construction wall type #1 and type #3.

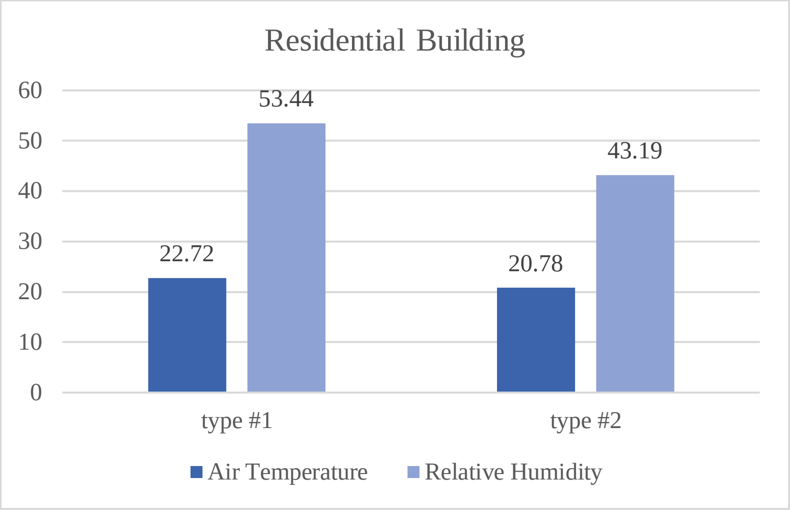


Figure 58: Annual indoor thermal comfort

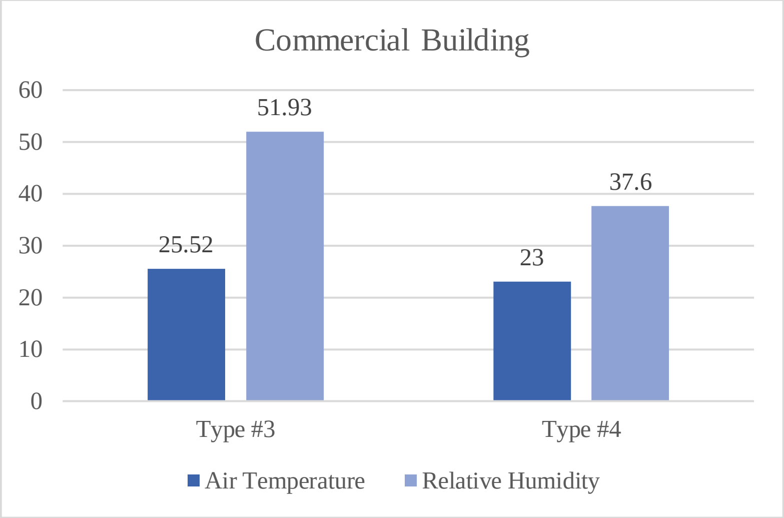


Figure 59: Annual indoor thermal comfort

A comparison between the four wall systems regarding the indoor thermal comfort was conducted as shown in Figure 60. The shaded part is the indoor thermal comfort zone. According to the ASHRAE 55 standard, EN 15251and the ISO 7730 standard, the indoor thermal comfort is achieved by occurring in the comfort thermal zone which is between 20 ^{o}C and 29 ^{o}C. Wall type #2 and wall type #4 are achieving the best thermal comfort. For wall type #2 in the winter season the temperature is around 19 ^{o}C where the outside temperature is around 13.75 ^{o}C, while in the summer season where the outside temperature is around 29 ^{o}C, the indoor temperature is around 26 ^{o}C. For wall type #4, in the winter season the temperature is around 13.75 ^{o}C where the indoor temperature is around 21.8 ^{o}C, while in the summer season where the outside temperature is around 29 ^{o}C, the indoor temperature is around 27 ^{o}C. These two wall systems are the best performance when it comes to indoor thermal comfort.

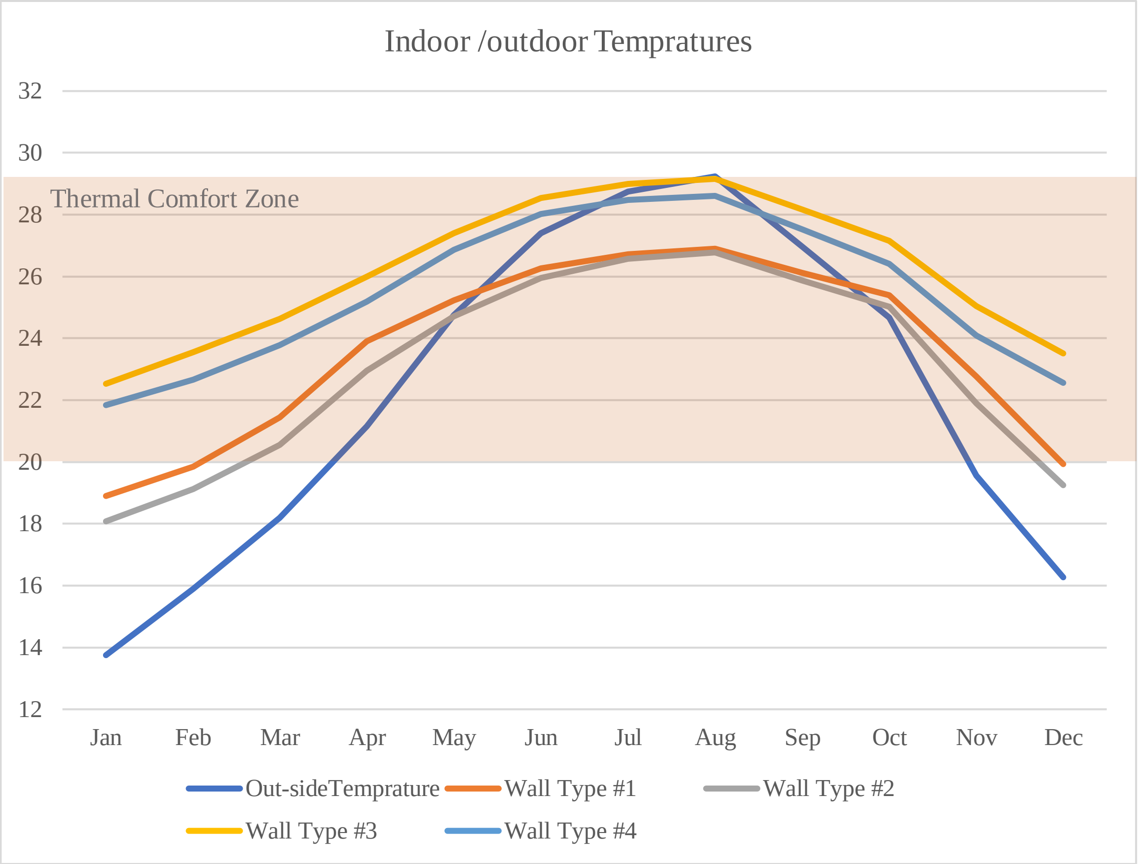


Figure 60: Comparison between the four wall systems

Figure 61 demonstrated a comparison between the four wall systems regarding the relative humidity (RH) which affects the thermal comfort of occupants. The shaded part shows the acceptable ranges of relative humidity which is from 20% to 50% (Wagdi, 2015). Wall type #2 and wall type #4 are achieving the best annual relative humidity percentages while wall type #1 and wall type #3 are above the comfort zone.

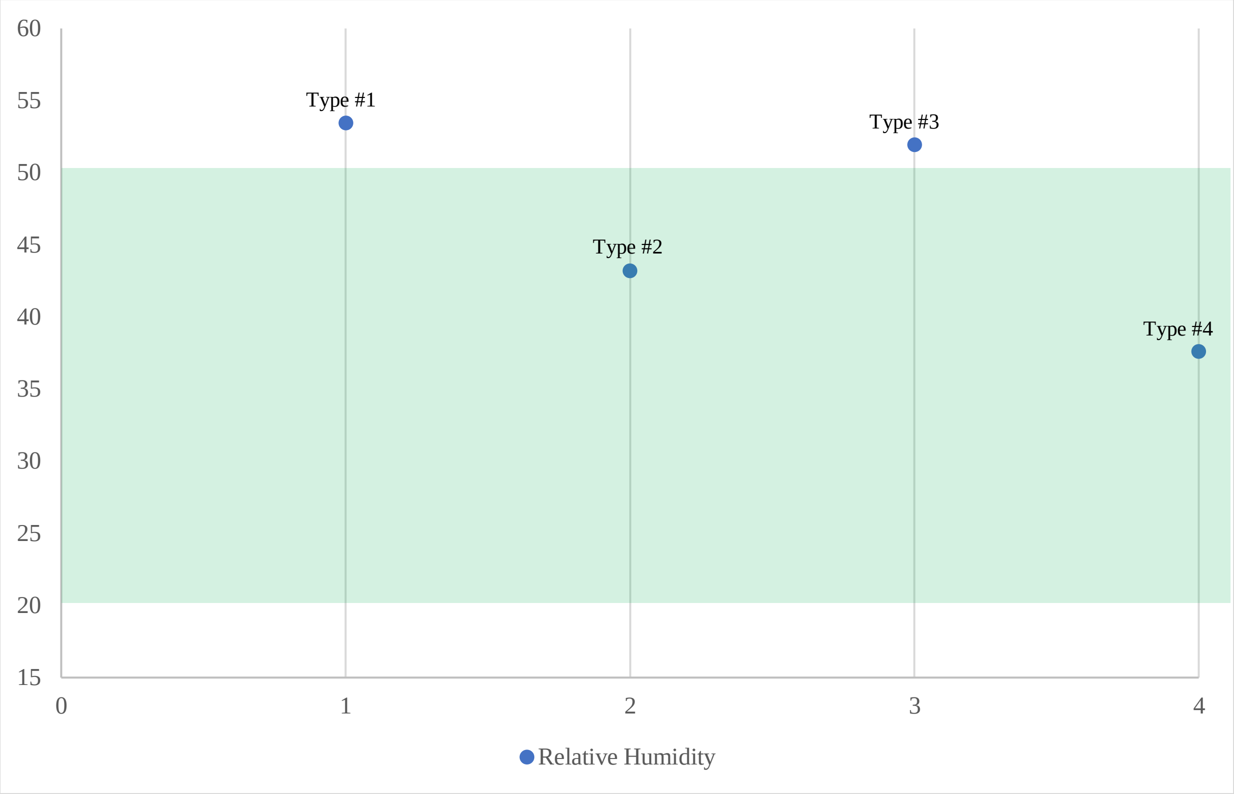


Figure 61: Annual Relative Humidity comparison

4.3.5 Fabric Heat Gains/Loss

Regarding the heat loss of the building, Figure 62 and Figure 63 represents the different building components and the maximum heat loss in each building and in each wall construction type. The analysis revealed that the major contributors to heat loss are the walls and the glazing. From the analysis of the wall systems of the residential model type #1 is the least effective and has the maximum heat gain through the walls and the glazing as well. Also, the building infiltration of type #1 is the highest. The best performance of the two wall systems is type #2 which has the least heat loss building envelope. In addition, wall type #3 is the least effective in the commercial building.

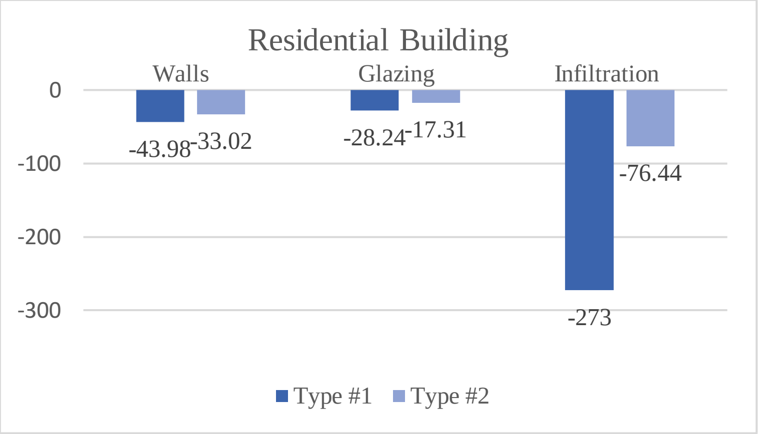


Figure 62: Heat loss of building components

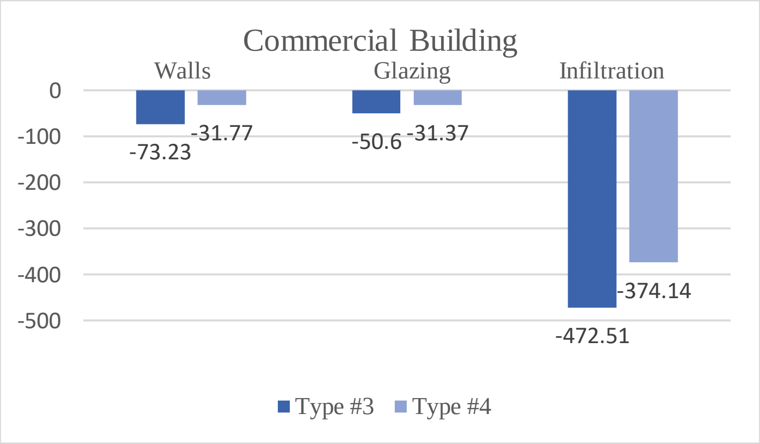


Figure 63: Heat loss of building components

4.3.6 CO_2 Emissions

The overall CO_2 emissions of AAC blocks are recorded to be less than the red bricks. Meaning that, AAC blocks are green building materials with less environmental impacts. Figure 64 and Figure 65 show the annual consumption of CO_2 emissions by each construction wall type.

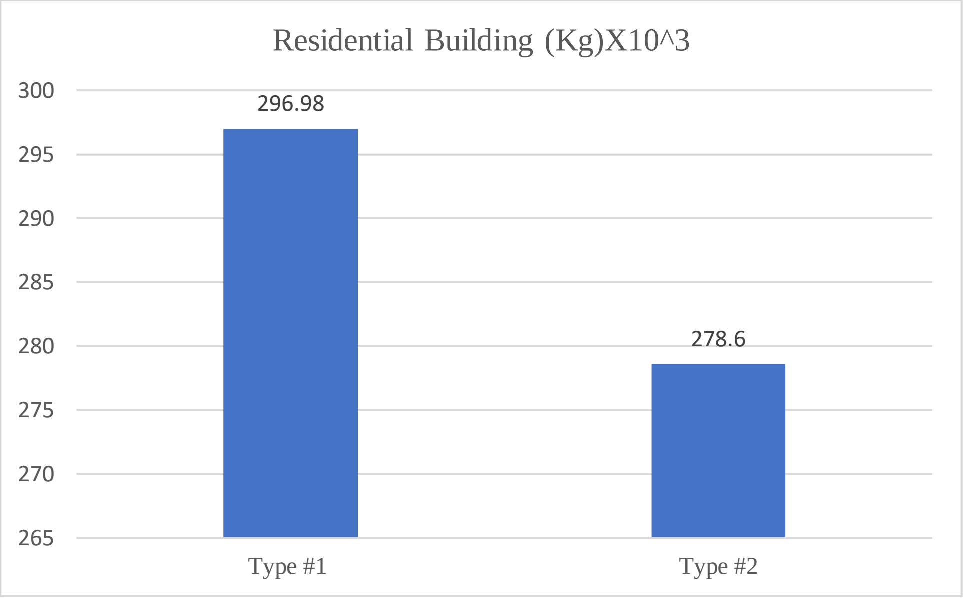


Figure 64: Annual CO_2 consumption

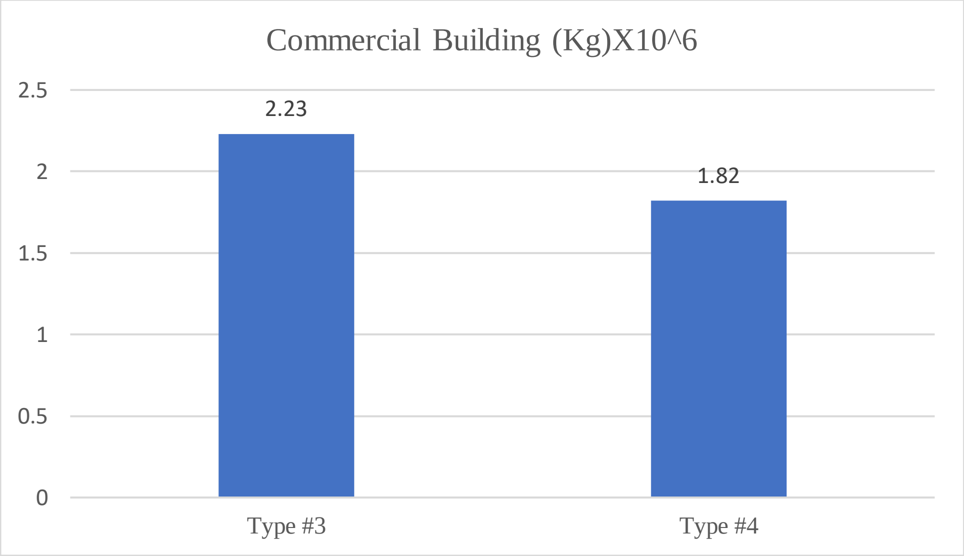


Figure 65: Annual CO_2 consumption

4.4 Electricity Demand Analysis

This section illustrates the process of computing the energy consumption and the accompanied electricity bill for each construction wall type of both building (Residential and commercial).

4.4.1 Residential Building

After simulating both wall systems, the results of the heating and cooling loads of each month are shown as in Table 58 for wall type #1. Since electricity is the only source of energy for both, a monthly electricity consumption was analyzed.

Table 58: Monthly heating and cooling loads- Type #1

Construction Wall Type #1					
Monthly Heating and Cooling Loads					
Months	**Heating (MWH)**	**Cooling (MWH)**	**Total (Mwh)**	**Total (Kwh)**	**Cost (LE)**
Jan	32.32	0	32.32	32320	46864
Feb	11.7	-0.01	11.71	11710	16979.5
Mar	3.23	-2.18	5.41	5410	7844.5
Apr	0.08	-10.94	11.02	11020	15979
May	0	-36.78	36.78	36780	53331
Jun	0	-68.43	68.43	68430	99223.5
Jul	0	-93.99	93.99	93990	136285.5
Aug	0	-104.41	104.41	104410	151394.5
Sep	0	-68.13	68.13	68130	98788.5
Oct	0	-36.99	36.99	36990	53635.5
Nov	3.56	-5.01	8.57	8570	12426.5
Dec	13.91	0	13.91	13910	20169.5
Total (Wh)	64.8	-426.87	491.67	**491670**	--
Cost (LE)	--	--	--	--	712,921.5
Customer service (LE)	40				
Total Cost (LE)	--	--	--	--	**712,961.5**

According to Figure 66 the needed cooling energy for the peak months is high due to lack of insulation for this wall type and the lack of effective building envelope. The Total energy consumption of this wall type is 491670 Kwh.

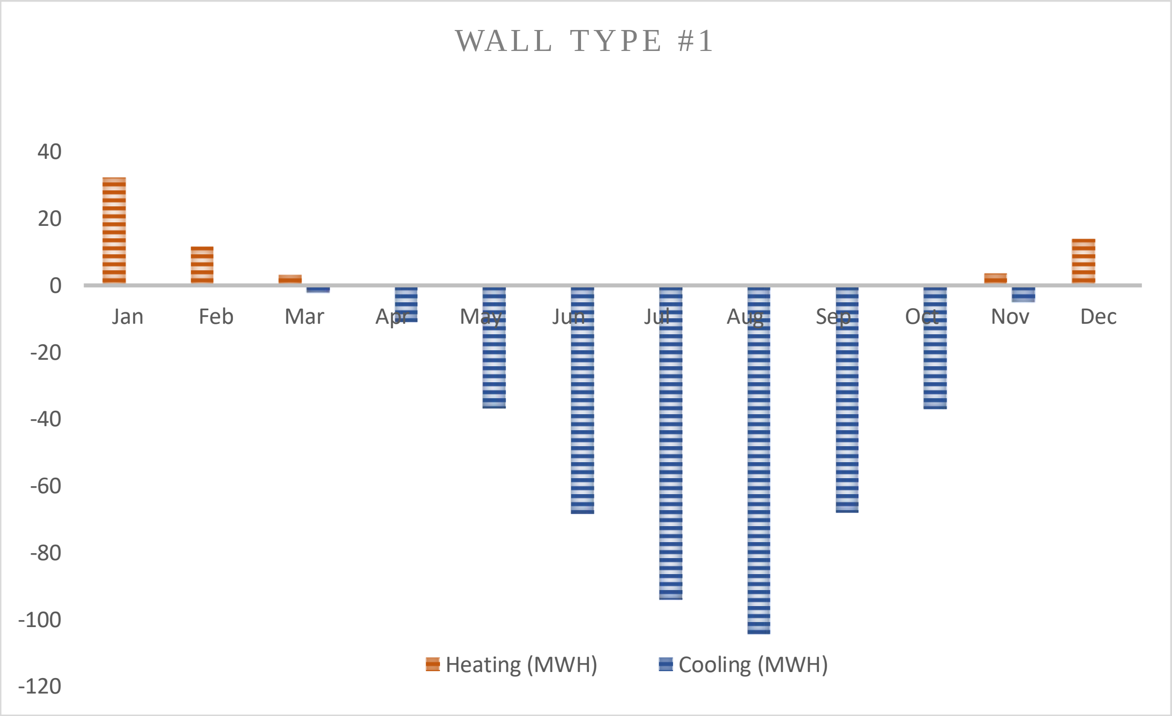


Figure 66: Monthly heating and cooling loads

Table 59 demonstrates the monthly electricity demands for construction wall type #2. The total energy demand for this type is 375749.79 Kwh. The maximum heating loads is in January and the maximum cooling loads is in August. The electricity bill of this construction wall type is 544,877.2 LE annually. This show that the energy demand decreased when used an environmentally friendly building material (AAC blocks). This block increased the insulation to the building preventing heat gain from the building envelope to the indoors which decreases the heating and loading loads, consequently, decreased the total demand to the electricity and decreases the electricity bill as a whole.

Table 59: Monthly heating and cooling loads- Type #2

Construction Wall Type #2				
Monthly Heating and Cooling Loads				
Months	**Heating (Kwh)**	**Cooling (Kwh)**	**Total (Kwh)**	**Cost (LE)**
Jan	17584.43	0	17584.43	25497.424
Feb	4230.44	-3.67	4234.11	6139.4595
Mar	746.3	-1977.43	2723.73	3949.4085
Apr	0	-9939.9	9939.9	14412.855
May	0	-31456.79	31456.79	45612.346
Jun	0	-55617.47	55617.47	80645.332
Jul	0	-73727.7	73727.7	106905.17
Aug	0	-80695.66	80695.66	117008.71
Sep	0	-54777.64	54777.64	79427.578
Oct	0	-32305.64	32305.64	46843.178
Nov	1371.25	-5095.98	6467.23	9377.4835
Dec	6218.37	-1.12	6219.49	9018.2605
Total (Wh)	30150.79	-345599	**375749.79**	--
Cost (LE)	--	--	--	544,837.2
Customer service (LE)	40			
Total Cost (LE)	--	--	--	**544,877.2**

According to Figure 67 the needed energy for cooling and heating decreased due to using a better wall system with higher thermal performance and insulation. The Total energy consumption of this wall type is 375749.79 Kwh

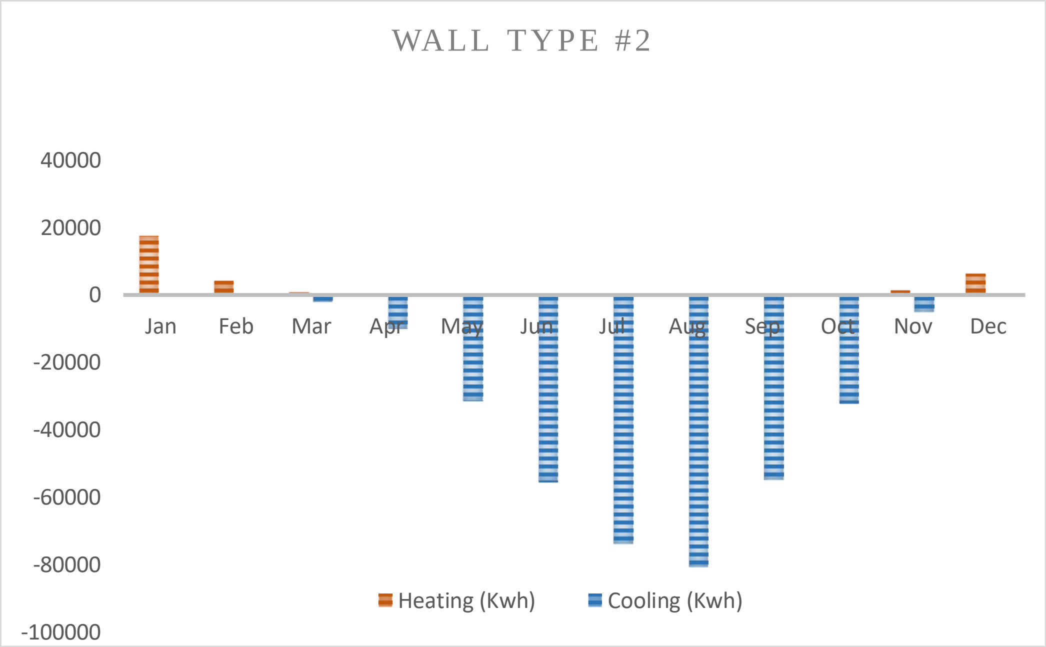


Figure 67: Monthly heating and cooling loads

Figure 68 visualizes the difference between type #1 and Type #2 energy consumption. It is a comparison between these two types of the residential building during a whole year which expresses the energy savings from using type #2 wall system.

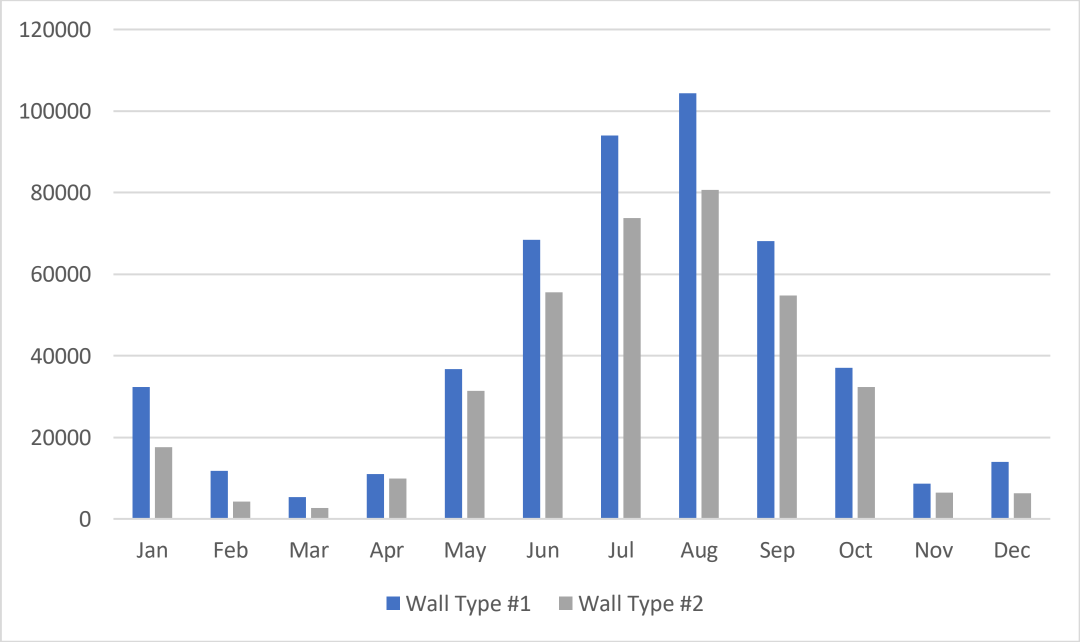


Figure 68: Monthly energy consumption comparison

4.4.2 Commercial building

After simulating both wall systems on DesignBuilder, the results of the heating and cooling loads of each month are shown as in Table 60 for wall type #3.

Table 60: Monthly heating and cooling loads- Type #3

Construction Wall Type #3					
Monthly Heating and Cooling Loads					
Months	**Heating (Mwh)**	**Cooling (Mwh)**	**Total (Mwh)**	**Total (Kwh)**	**Cost (LE)**
Jan	185.68	-0.08	185.76	185760	278640
Feb	98.69	-2.79	101.48	101480	152220
Mar	59.1	-22.35	81.45	81450	122175
Apr	24.5	-63.29	87.79	87790	131685
May	4.99	-161.98	166.97	166970	250455
Jun	0.03	-265.8	265.83	265830	398745
Jul	0	-377.43	377.43	377430	566145
Aug	0	-429.46	429.46	429460	644190
Sep	0.06	-278.59	278.65	278650	417975
Oct	3.54	-167.45	170.99	170990	256485
Nov	41.77	-31.63	73.4	73400	110100
Dec	109.1	-1.92	111.02	111020	166530
Total (Wh)	527.46	-1802.77	2330.23	**2330230**	--
Cost (LE)	--	--	--	--	3,495,345
Customer service (LE)	40				
Total Cost (LE)	--	--	--	--	**3,495,385**

According to Figure 69 the needed energy for cooling and heating of type #3 wall system is high due to lack of thermal insulation and air leakage to the building through the building envelope. The Total energy consumption of this wall type is 2330230 Kwh.

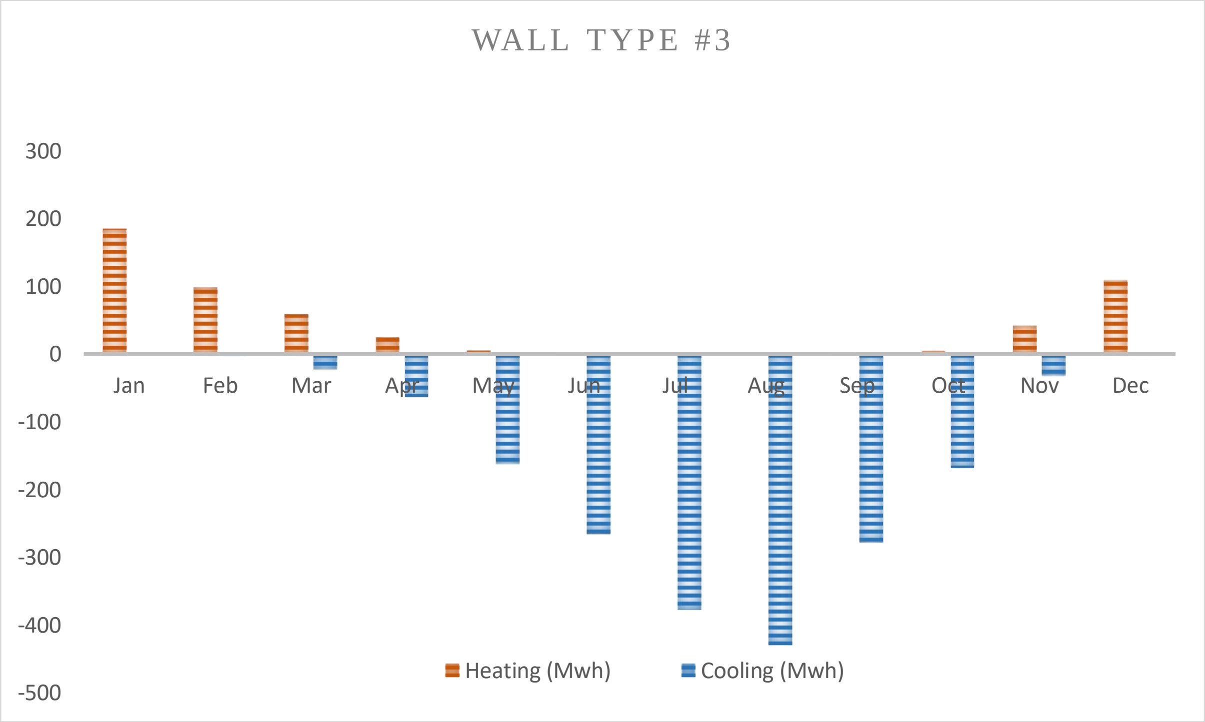


Figure 69: Monthly heating and cooling loads

Table 61 demonstrates the monthly electricity demands for construction wall type #4. The total energy demand for this type is Kwh. The maximum heating loads is in January and the maximum cooling loads is in August. The electricity bill of this construction wall type is 2,633,850 LE annually. In comparison between this wall system and the original wall system, the performance of AAC block for the commercial building is better gives better energy consumption, hence better electricity cost and better indoor thermal comfort.

Table 61: Monthly heating and cooling loads- Type #4

Construction Wall Type #4					
Monthly Heating and Cooling Loads					
Months	**Heating (Mwh)**	**Cooling (Mwh)**	**Total (Mwh)**	**Total (Kwh)**	**Cost (LE)**
Jan	108.66	-0.73	109.39	109390	164085
Feb	54.99	-3.4	58.39	58390	87585
Mar	32.84	-20.15	52.99	52990	79485
Apr	12.91	-53.49	66.4	66400	99600
May	3	-130.43	133.43	133430	200145
Jun	0.05	-213.94	213.99	213990	320985
Jul	0	-311.36	311.36	311360	467040
Aug	0	-315.98	315.98	315980	473970
Sep	0.03	-231.44	231.47	231470	347205
Oct	2	-144.48	146.48	146480	219720
Nov	21.88	-32	53.88	53880	80820
Dec	58.87	-3.27	62.14	62140	93210
Total (Wh)	295.23	-1460.67	1755.9	**1755900**	--
Cost (LE)	--	--	--	---	2633850
Customer service (LE)	40				
Total Cost (LE)	--	--	--	---	**2,633,890**

According to Figure 70 the needed energy for cooling and heating of type #4 wall system is less than that of type #3. The Total energy consumption of this wall type is 1755900 Kwh.

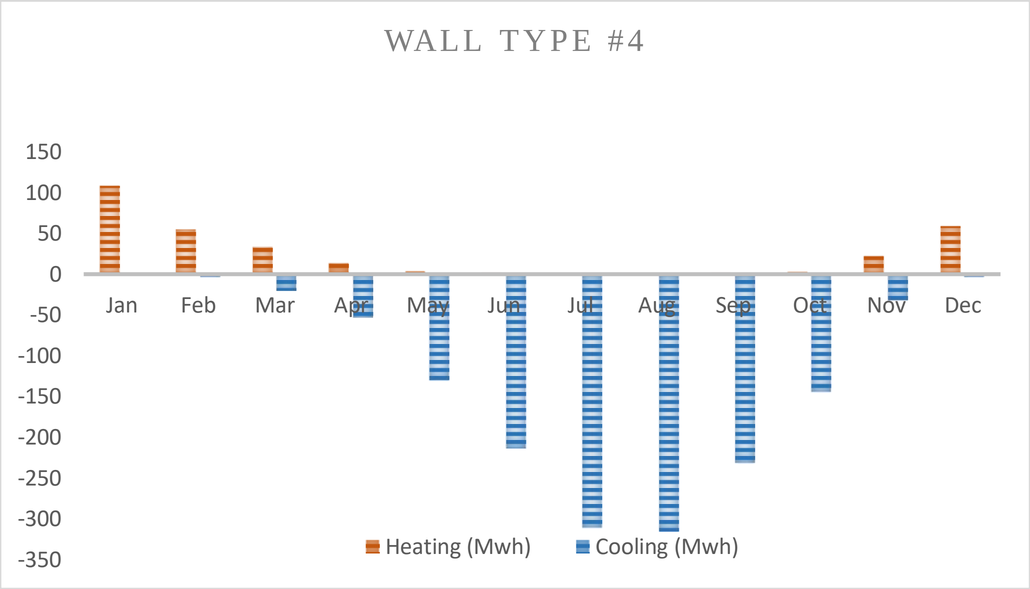


Figure 70: Monthly heating and cooling loads

Figure 71 visualizes the difference between type #3 and Type #4 energy consumption. It is a comparison between these two types of the commercial building during a whole year which expresses the energy savings from using type #4 wall system.

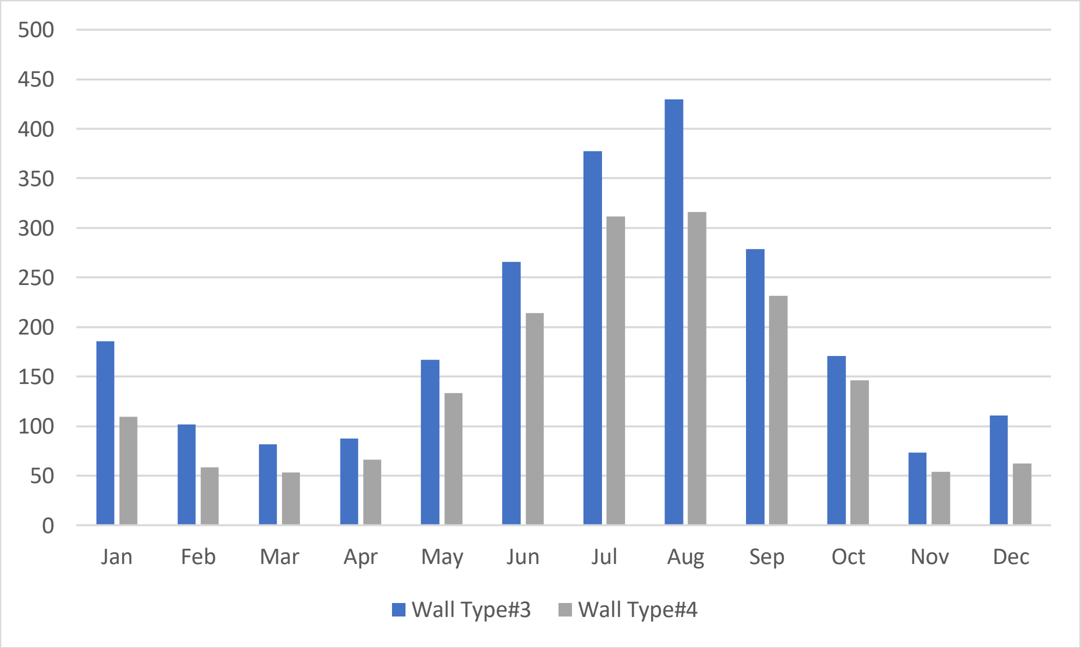


Figure 71: Monthly energy consumption comparison

4.4.3 Comparison between Energy Consumption & Cost

From all the previous thermal performance analysis on both buildings and the four wall systems, it is shown that the total energy consumption of the residential building construction wall type#1 using red bricks is 491670 Kwh and type #2 using AAC blocks is 375749.79 Kwh. These calculations based on the assumption that other sources of energy are neglected such as fans, boilers and others likewise. This is to evaluate the effect of the different building envelopes on the energy consumption, internal loads and the indoor thermal comfort. Figure 72 shows the difference in energy consumption per month between the four wall systems and the highlighted area is the maximum hot period of the year.

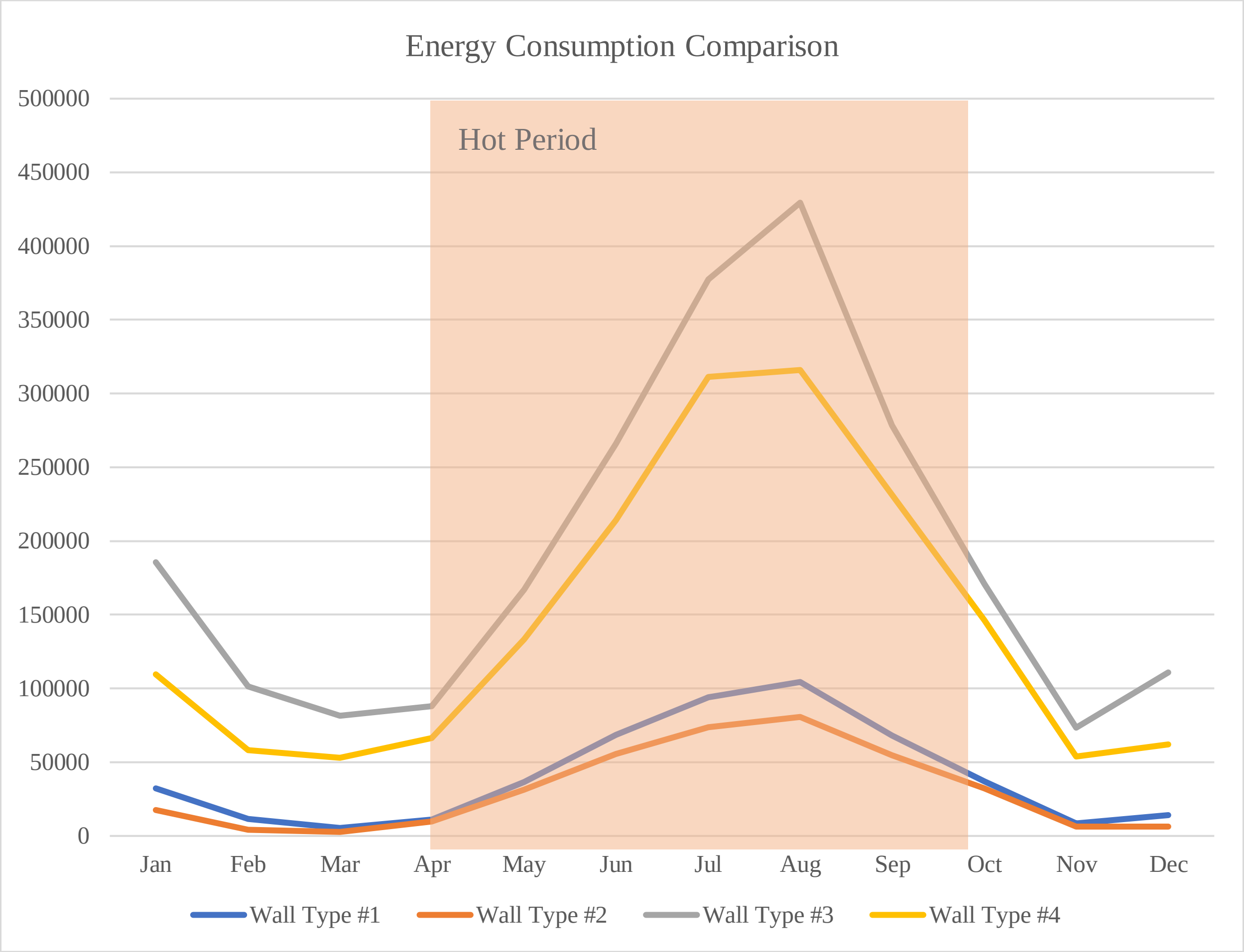


Figure 72: Monthly energy consumption for the four wall systems

Table 62 and Figure 73 demonstrate a comparison between the four wall systems regarding the total energy consumption (Kwh) and the total annual cost.

Table 62: Annual energy consumption Vs. annual cost

Wall Type / **Item**	Residential		Commercial	
	Wall Type #1	Wall Type #2	Wall Type #3	Wall Type #4
Annual Energy Consumption (Kwh)	491670	375749.79	2330230	1755900
Annual Energy Cost (LE)	712,961.5	544,877.2	3,495,385	2,633,890

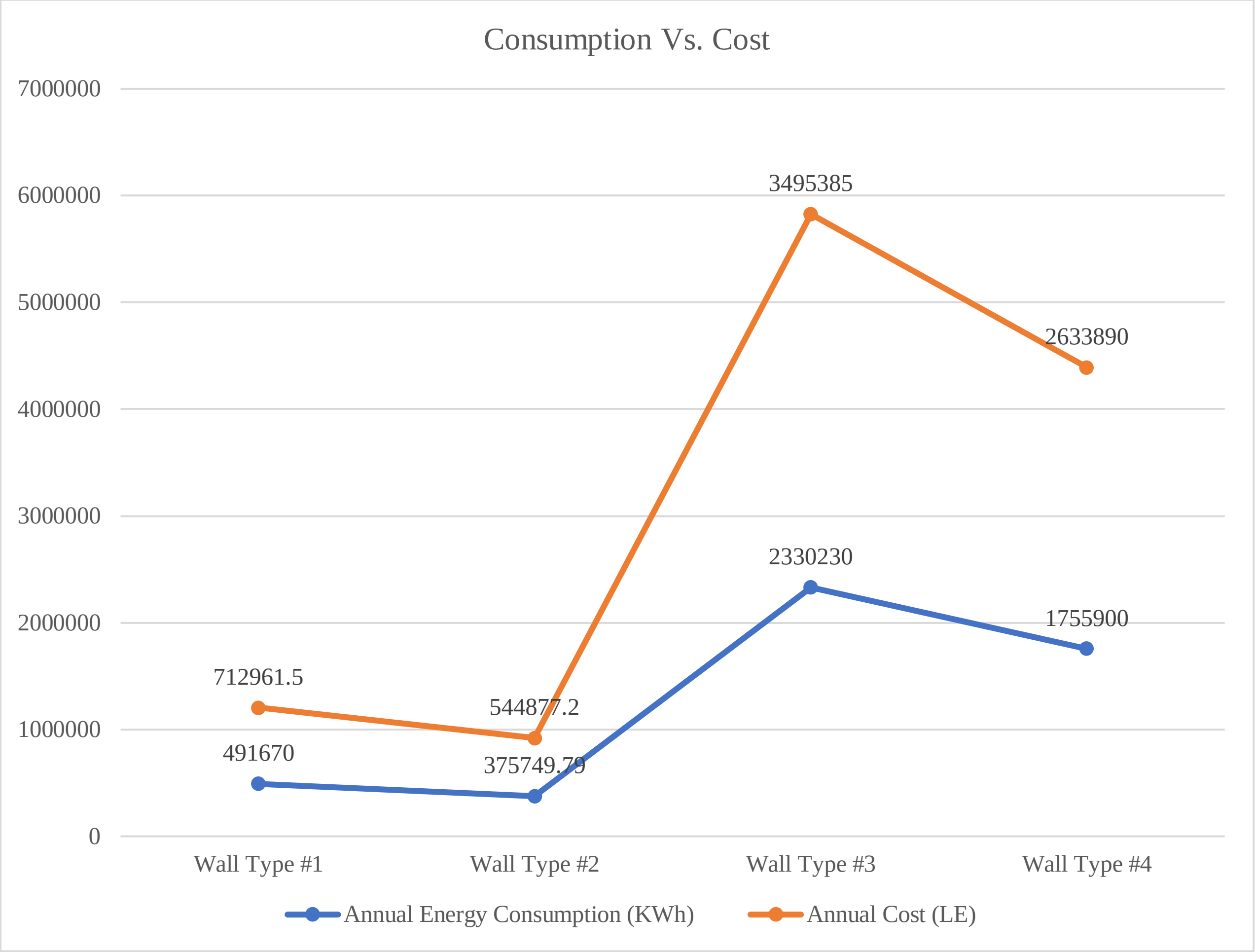


Figure 73: Annual consumption Vs. Annual cost

4.4.4 Computing Percentages of Energy Savings

To calculate the percentage of savings in the energy consumption of each building, the calculations were computed according to the Ministry of Electricity tariffs (see section 3.2.2). Also, an equation used according to the HBRC and the BPI which is (HBRC, 2013):

$$\text{\% of Savings} = \frac{\text{original case consumption} - \text{alternative case consumption}}{\text{Original case consumption}}$$

Table 63 demonstrates the total savings in each building after adding the operational cost and the construction costs. The total percentage of saving in the residential building is 40.5 % and in the commercial building is 34.1%.

Table 63: Total percentages of savings

Building	**Operational Cost**			**Construction Cost**		**Total**
	Original Consumption	**Alternative Consumption**	**% of Consumption savings**	**Construction Savings**	**% of construction savings**	**% of total Savings**
Residential	712,961.5	544,877.2	**23.6%**	6,013,198	**14.3%**	**37.9%**
Commercial	3,495,385	2,633,890	**24.6%**	1,217,508	**9.4%**	**34.1%**

4.5 Summary of the Thermal Performance

This section summaries the performance of each construction wall type of both the residential and commercial buildings. This analysis covers the construction cost of each wall type, thermal potential U-Value, embodied energy, life cycle cost, durability, supply chain and constructability of the building as a whole using the average weighted U-Value. Table 64 summarizes the U-value and cost of each wall type including fenestartion cost as well.

Table 64: Comparison between the four wall systems

Construction Wall	U-Value	Operational Cost
Type #1	0.810	712,961.5
Type #2	0.435	544,877.2
Type #3	0.887	3,495,385
Type #4	0.513	2,633,890

Each wall system is evaluated according to a scale of colors where green means the least environmental impacts and red means the most environmental impacts. Table 65 is the rating key that is used to evaluate each wall system is represented over the tables. The U-value was evaluated based on the recommended values (see section). Table 66 demonstrates the overall thermal performance of each wall type.

Table 65: Thermal Performance Rating Key

Unacceptable	poor	Acceptable	Good	Very Good	Excellent
🟥	🟧	🟧	🟨	🟩	🟩

Table 66: Thermal Performance Assessment of each wall system

Wall construction	Composition	U-Value	Embodied Energy & CO2	Life cycle cost	Constructability	Cost	Durability
Type #1	Double Red Brick	🟥	🟫	🟫	🟧	🟨	🟧

Wall construction	Composition	U-Value	Embodied Energy & CO2	Life cycle cost	Constructability	Cost	Durability
Type #2	Double AAC Block	🟩	🟩	🟩	🟩	🟧	🟩

Wall construction	Composition	U-Value	Embodied Energy & CO2	Life cycle cost	Constructability	Cost	Durability
Type #3	Single Red Brick	🟥	🟫	🟫	🟨	🟩	🟧

Wall construction	Composition	U-Value	Embodied Energy & CO2	Life cycle cost	Constructability	Cost	Durability
Type #4	Single AAC Block	🟩	🟩	🟩	🟩	🟩	🟩

4.6 Financial Analysis Summary

The financial analysis was done for each of the four wall systems to evaluate the best wall system regarding the initial cost as well as the running cost. The objective from this analysis is to figure out the best cost-effective wall system from them as a comparison to the original wall system that is being used in the New Egyptian Administrative Capital.

Assume that two companies invested in the New Egyptian Administrative Capital, one invested in the original cases (Type #1 and Type #3) and one invested in the selected cases (Type #2 and Type #4). The difference in wall initial and building running cost between each wall system will be invested in the bank over a period of 14 years (see section 3.4.1) with the common interest rates in Egypt 2019. These calculations were based on the assumption that the interest rates will not change and will remain constant, also neglecting the inflation if happened in the future. Table 67 represents that detailed Calculations for each wall system in comparison with the original wall system of each building and the total gains that the investors would gain after 14 years.

Table 67: Total investment savings over 14 years

	Initial	**Annually**	**Difference**	**Over 14 Years**	**Annually**	**Over 14 Years**	
Construction Wall	**Initial wall Cost**	**Annual Running Cost**	**Initial cost difference**	**Accumulated Initial cost**	**Running Cost difference**	**Accumulation of running cost**	**Initial Savings Vs. Running Savings**
Type #1	1,506,150	712,962	-	-	-	-	-
Type #2	1,848,271	544,877	342,120	2,594,242	168,084	1,274,555	3,868,798
Type #3	2,066,635	3,495,385	-	-	-	-	-
Type #4	2,901,355	2,633,890	834,720	6,329,543	861,495	6,532,574	12,862,117

4.7 Chapter Summary

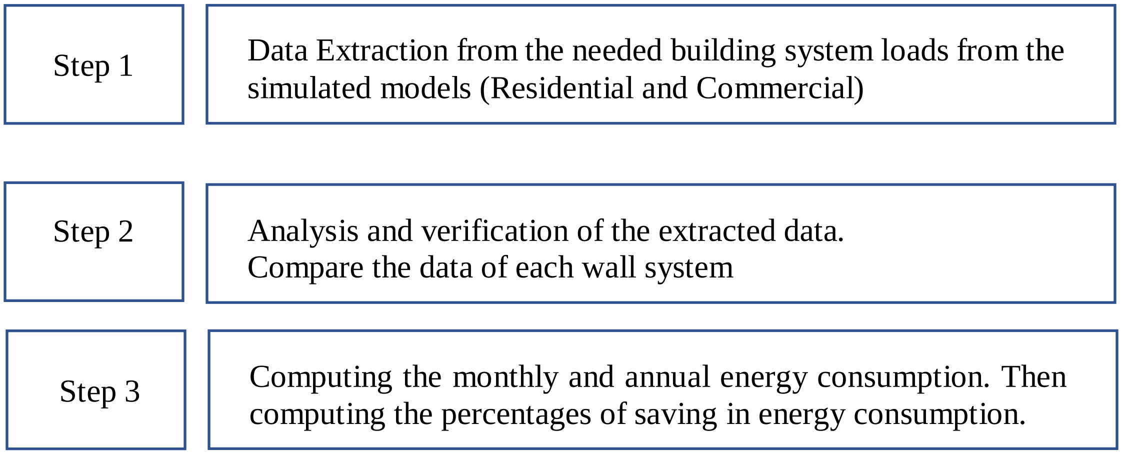
In this chapter, analysis for two buildings in the New Egyptian Administrative Capital was carried out. This analysis included a financial and energy efficiency analysis. First, the financial analysis was done based on a framework that facilitated the methodology behind the computation the construction initial cost savings regarding the four wall systems. Figure 74 shows the framework that was used to compute the financial gains. The detailed framework can be referred to in section 4.2.

Stage 1&2	Document all the floor areas, parameters, and openings of each zone using the elevations, sections and plans. Calculate the total quantities of concrete and steel that are used in each building form the structural plans.
Stage 3&4	Calculate the total: areas of each building Wall area of each building Cost of each building component Construction cost of each building
Stage 5	Calculate the total labor cost to build each wall system Calculate the savings in each building component:

Figure 74: Financial Analysis framework

This framework manages to calculate each building component cost to be able to calculate the total cost of each building, hence the total savings percentages of each building. By knowing the unit prices and labor cost of each building component, the total cost of each item was computed and then the percentages were done. The savings in cement in mortar, concrete, steel, bricks, paint and labor were all calculated. Construction wall system type #1 and type #3 were the least cost-effective which are the original cases; however, construction wall type # 2 and type #4 were the best cost-effective wall systems regarding the initial construction costs. The savings in the construction total cost of the residential and commercial buildings are computed to be 14.3% and 9.4% respectively. This concludes that the initial construction cost of AAC wall system buildings are less than that of red bricks. The initial cost of the brick itself is higher but the saving in the other building components causes the overall savings of the building.

Second, the energy consumption analysis was performed using DesignBuilder software with the EnergyPlus thermal performance simulation tool. The analysis was based on a framework. Figure 75 is the framework that the analysis was based on for further details on this framework see section 4.3.


Step 1

Data Extraction from the needed building system loads from the simulated models (Residential and Commercial)

Step 2

Analysis and verification of the extracted data.
Compare the data of each wall system

Step 3

Computing the monthly and annual energy consumption. Then computing the percentages of saving in energy consumption.

Figure 75: Energy consumption calculations framework

Based on the framework, the data extracted from the simulated buildings and were analyzed to evaluate each wall system thermal performance in comparison with the initial wall system that is used on site. The analysis also included the monthly CO_2 emissions of each wall system which is a significant factor to the evaluation of each wall system environmental impacts and thermal performance. In addition, the thermal performed of each building regarding the thermal comfort zones were plotted using the monthly temperatures. Also, the constant loads of each building were extracted from the simulation analysis and then the energy consumption due to these loads were calculates. The monthly and annually cooling and heating systems loads were extracted as well and the energy consumption due to these parameters were calculates. The percentages of savings in the residential and commercial building are 23.6% and 24.6% respectively. Moreover, the overall percentages of savings in both the residential and commercial building were computed as well and came to be a total of 40.5% and 34.1% respectively. The performance of each wall system was evaluated based on references and in comparison, to the original wall system. A ranking key was developed to facilitate the evaluation as seen in Table 68 and Table 69.

Table 68: Summary of thermal performance components of each wall type

Parameter	**Breakdown**	**Residential Building**		**Commercial Building**	
		Wall Type #1	**Wall Type #2**	**Wall Type #3**	**Wall Type #4**
Fuel Breakdown	Room Electricity	96.13	96.13	0.99	0.99
	Lighting	64.02	64.02	0.15	0.15
	Heating	27.75	12.83	0.62	0.35
	Cooling	237.15	192	1	0.83
Annual System Loads	Sensible Heating	-333.88	-278.35	-1349.16	-1097.06
	Cooling	-426.87	-345.6	-1802.76	-1496.67
	Heating	64.8	30.15	527.46	259.24
Indoor Thermal Comfort	Air Temp.	22.72	20.3	25.52	21.2
	RH	53.44	45.2	51.93	49.6
Heat Gain/Loss	Walls	-43.98	-33.02	-73.23	-31.77
	Glazing	-28.24	-17.31	-50.6	-31.37
	Infiltration	-273	-76.44	-472.51	-374.14
CO_2 emissions	CO_2	296.98*10^3	278.6*10^3	2.23*10^6	1.82*10^6
Overall Performance		🟦	🟩	⬛	🟩

Table 69: Key for overall performance

Needs Improvement	Poor	Very Good	Cross the acceptable limits

4.8 Comparison and Verification of the Analysis with Previous Studies

Previous researches have been conducted on the thermal and financial performance of AAC blocks in comparison to red bricks. According to a financial study conducted by the CPAS, the savings in concrete can reach 8%-14%, the savings in steel can reach 5% -22% according to the cost of the steel and the specifications. In addition, the savings in the cement in mortar is around 43%-46%. According to the same source, the average extra cost due to the use of AAC blocks is around 27.32%-55% and the average savings in the total initial cost of a building is around 8.65-10.7% in a small two story building according to the density of the block and the used systems the percentages change (CPAS, 2016).

According to a study, in general the saving in concrete can reach 20% and the savings in steel ranges from 17.08%-18.5% (Rathi, 2015). The savings in the cement in mortar can reach 47.07% (Khandve, 2016). In addition, the initial savings in the brick cost is around 10.45%-19.96% (Rathi, 2015). Also, the total cost savings in a one-story building can reach 10.97% and it can reach 43.88% for more than 2 floors buildings (Khandve, 2016).

According to other research and a study on the residential buildings, the savings in steel can reach 17.9% and the savings in concrete can reach 43.27%. On average, the savings of cement in mortar can reach 50% since AAC blocks need less thickness of plaster than the red bricks. The saving in the block itself can reach 14.78% for different building types. The total savings in for using AAC on average accounts for 14.5%-20.99% (Rathi, 2015).

Other study on commercial and public buildings revealed that, the savings in cement in mortar for public buildings is around 41.7%-56.13% where the commercial buildings can reach up to 56.13% savings in cement in mortar (Rathi, 2015). Additionally, the savings in steel for public buildings is around 7.86%-19.5% where the commercial buildings savings in steel can reach 14.63% and the savings in the block cost itself is around 15.3%. Moreover, the total savings in the initial cost varies from 10.45%-46.3% according to the building type. The commercial buildings savings in initial cost for using AAC blocks can reach 17.35% (Rathi, 2015).

For the energy consumption analysis, the annual energy consumption according to the HBRC and the BPI is around 23.2% and can reach 43.3% according to the density of the block, the used HVAC system and the function of the building (HBRC, 2013). According to other studies, the energy consumption of AAC blocks can reduce the energy consumption due to heating and cooling by 30% (Rathi, 2015). Table 70 is a comparison between the simulation results and the benchmarks for each component.

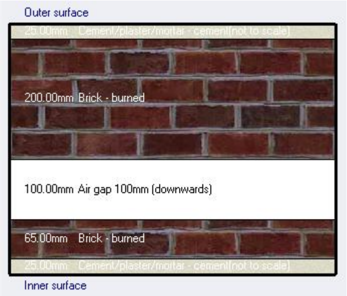
Table 70: Financial and thermal analysis verifications

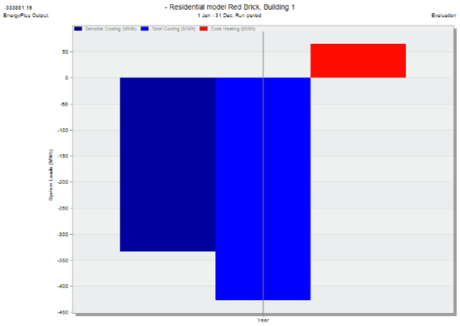
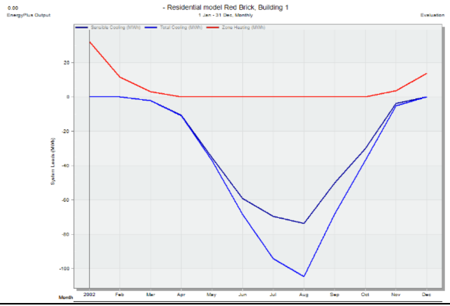
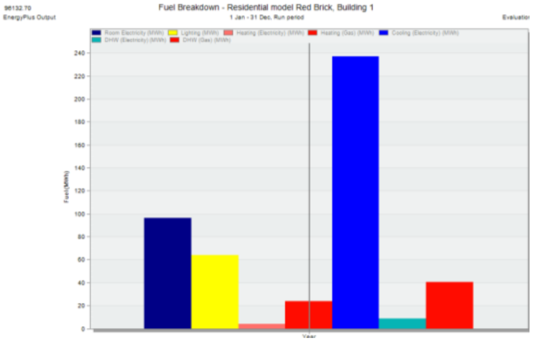
Financial Analysis					
Building Components	Simulation % of Savings	% of Savings Verification			
		CAPS	Other Studies		
			Residential	Commercial	General
Steel	14.6%-15.2%	5% -22%	17.9%	14.63%	17.08%-18.5%
Concrete	8.4%-15.5%	8%-14%	43.27%	7.01%	20%
Cement in Mortar	45%-48.26%	43%-46%	50%	41.7%-56.13%	47.07%
Bricks Extra Cost	37.6%	27.32%-55%	14.78%	12.72%-15.3%	10.45%-19.96%
% of construction savings	9.4%-14.3%	8.65-10.7%	14.5%-20.99%	17.35%-46.3%	10.97%-43.88%
Thermal Analysis					
Energy Consumption	Simulation % of Savings	% of Savings Verification			
		HBRC and BPI		Other Studies	
	23.6%-24.6%	23.2%-43.3%		30%-40%	

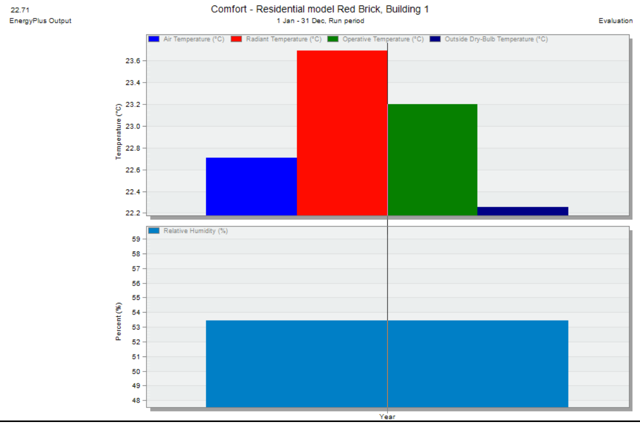
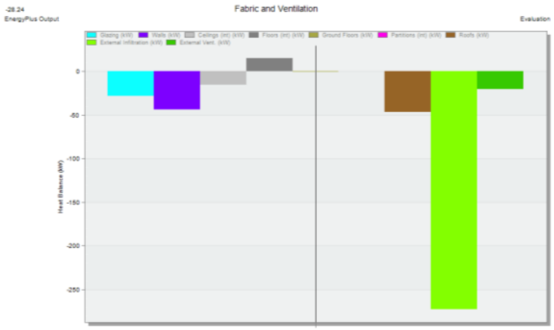
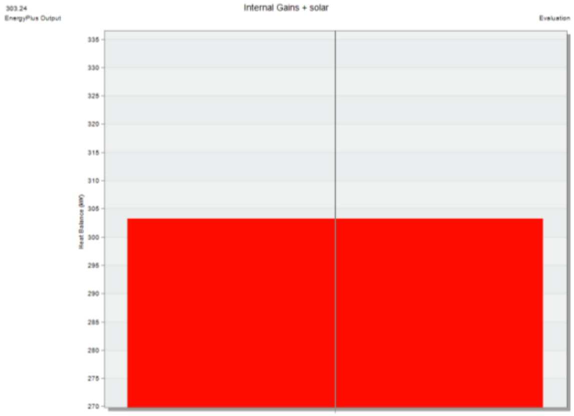
Red: cross the benchmarks

4.9 Simulation Results

In this section all the data from the simulation models will be presented in a table formate with the actual data figures from the simulation tool. The overall performance of each wall type is evlauted as well. The residential wall types #1 and #2 are presented first then moving to the commercial wall stytems wall types #3 and #4.

Wall Type #1		Wall Section
Volume of Bricks	1141.1 m^3	
Materials	Double wall red Brick with air cavity	
Thermal Performance	[✓ Needs Improvement] Poor Very Good Cross the acceptable limits	

Wall Type #1		
Parameters	**Simulation Results**	**Readings**
1.System loads ○ Sensible cooling ○ Total cooling ○ Zone heating	 	-333.88 -426.87 64.8
2. Fuel Breakdown ○ Room Electricity ○ Lighting ○ Heating ○ Cooling		96.13 64.02 27.75 237.15

<table>
<tr>
<td>3. Thermal Comfort
○ Air Temperature ^{O}C
○ Humidity %</td>
<td>
</td>
<td>22.72
53.44</td>
</tr>
<tr>
<td>4. Fabric heat Gain/loss
○ Walls
○ Glazing
○ Infiltration</td>
<td>
</td>
<td>-43.98
-28.24
-273.0</td>
</tr>
<tr>
<td>5. Zone sensible heating</td>
<td>
</td>
<td>303.23</td>
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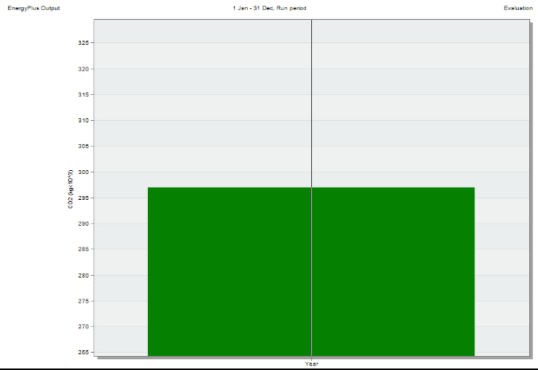
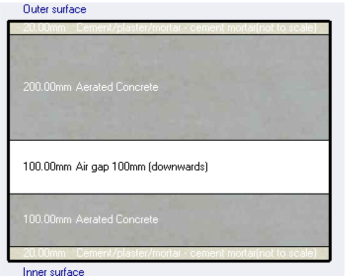
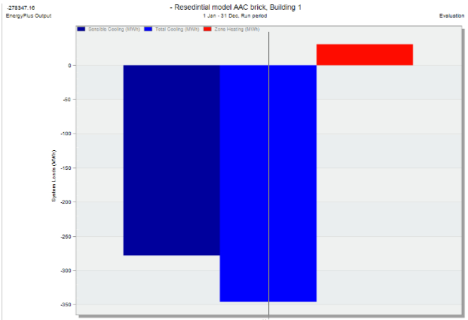
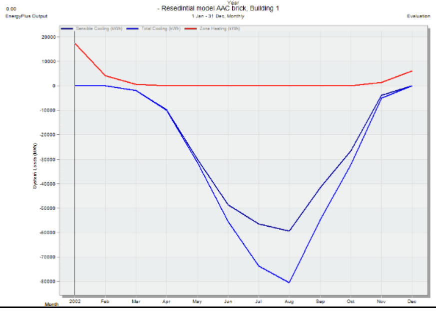
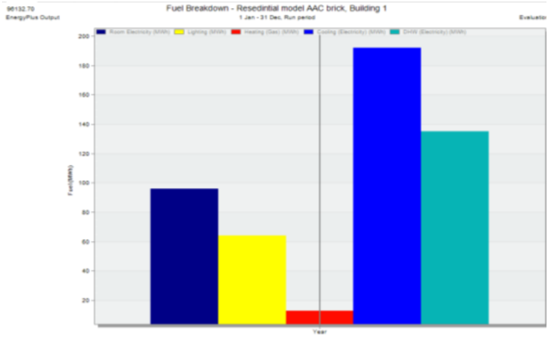
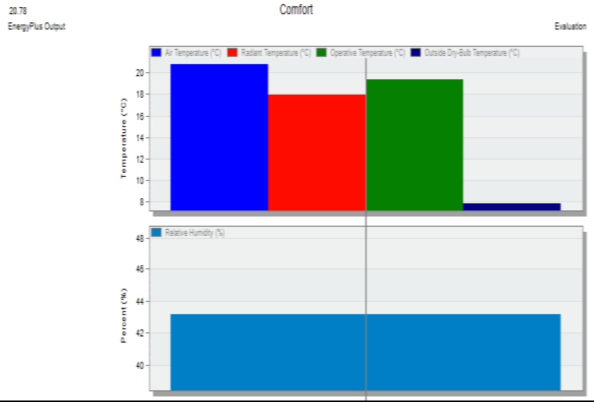
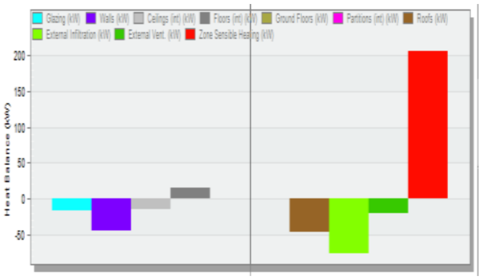
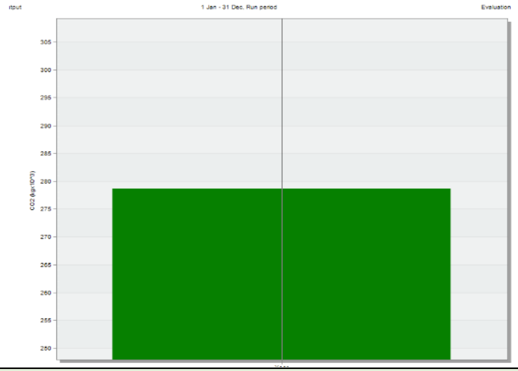
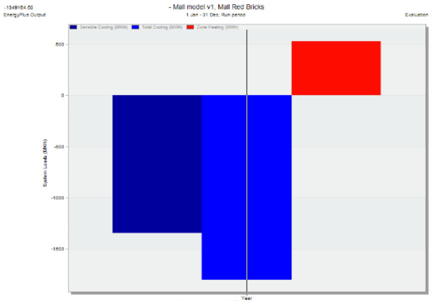
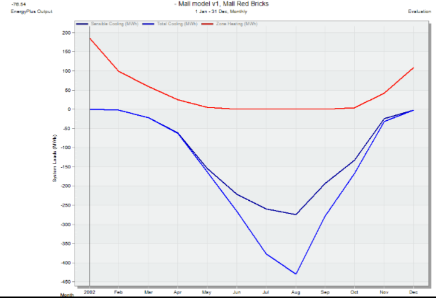
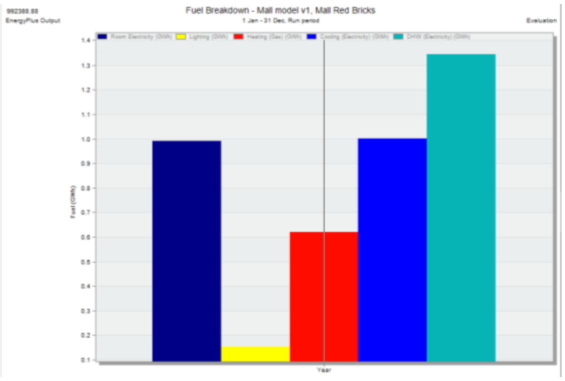
<tr>
<td>6. CO_2 emissions</td>
<td>
</td>
<td>296.98 X10^3</td>
</tr>
<tr>
<td>7. Performance Acceptability</td>
<td colspan="2">Need Improvements</td>
</tr>
</table>

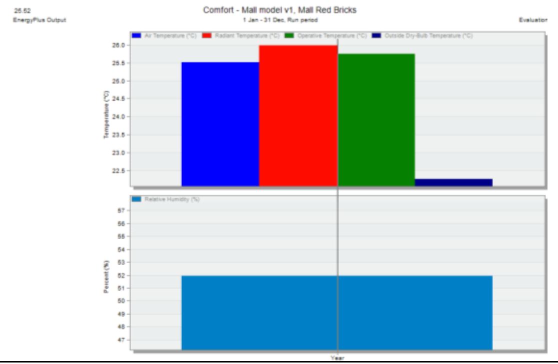
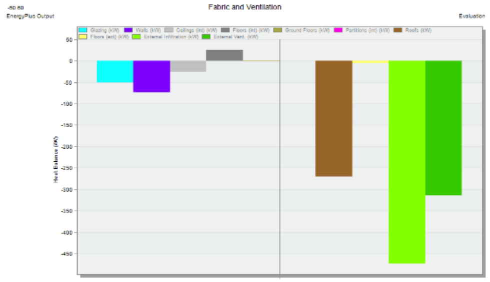
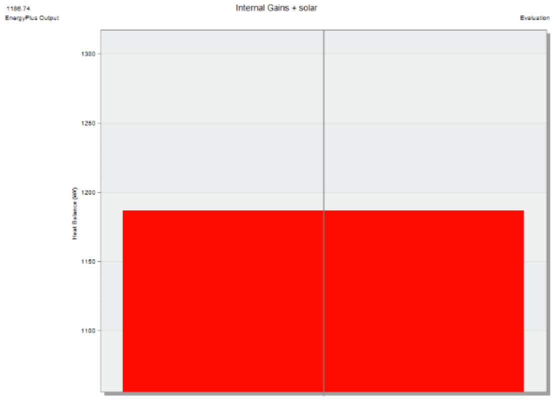
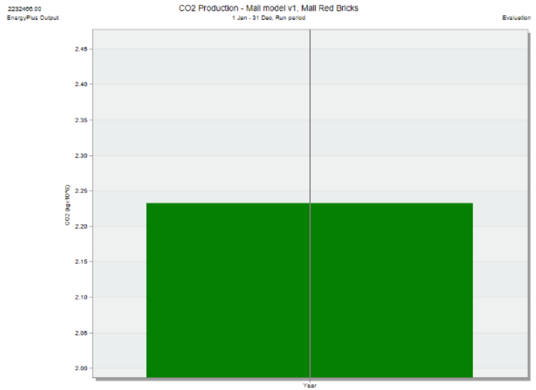
Wall Type #2		Wall Section
Volume of Bricks	1141.1 m^3	
Materials	Double wall of AAC blocks with air cavity	
Thermal Performance	Needs Improvement | Poor | [✓ Very Good] | Cross the acceptable limits	

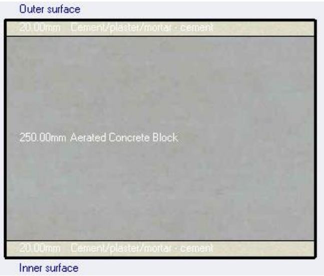
Wall Type #2		
Parameters	Simulation Results	Readings
1.System loads ○ Sensible cooling ○ Total cooling ○ Zone heating	 	-278.35 -345.6 30.15
2. Fuel Breakdown ○ Room Electricity ○ Lighting ○ Heating ○ Cooling		96.13 64.02 27.75 237.15

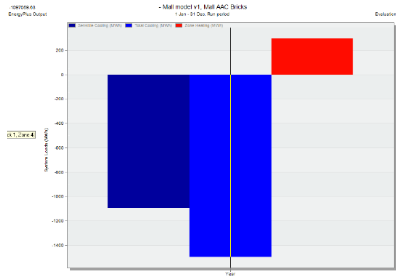
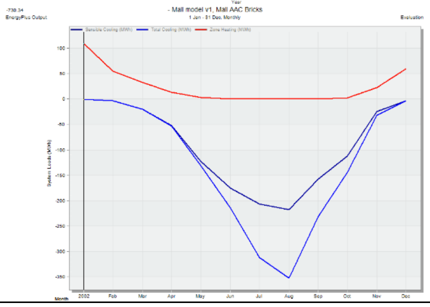
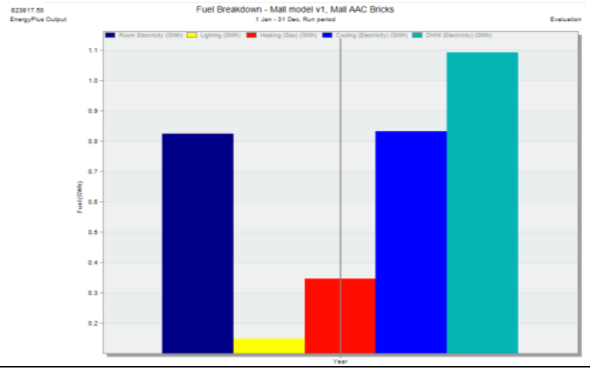
3. Thermal Comfort ○ Air Temperature ^{O}C ○ Humidity %		20.3 45.2
4. Fabric heat Gain/loss ○ Walls ○ Glazing ○ Infiltration		-33.02 -17.31 -76.44
5. Zone sensible heating		205.85
6. CO2 emissions		278.6X10^3
7. Performance Acceptability	Very Good	

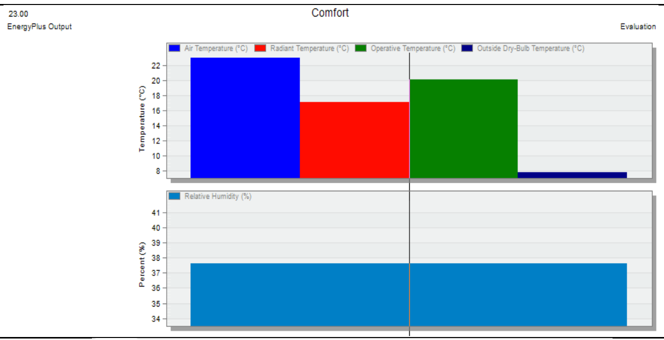
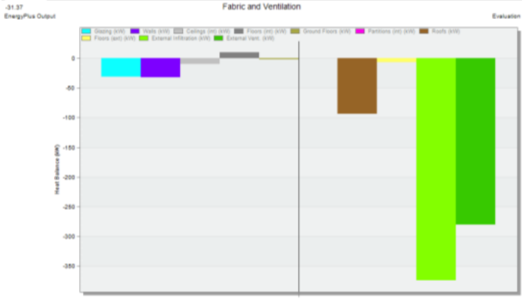
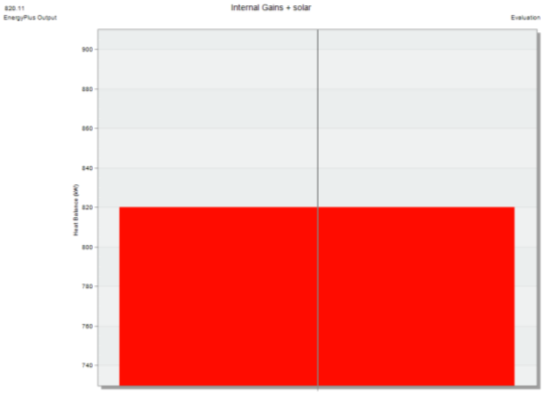
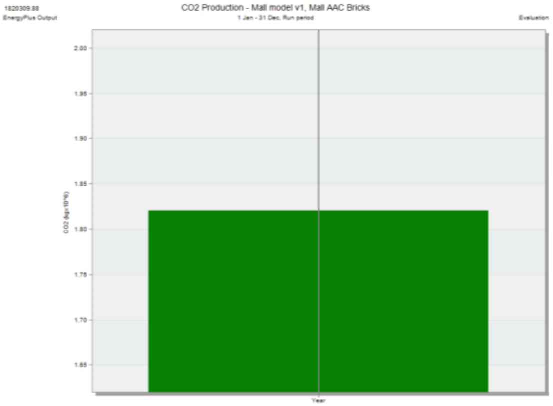
Wall Type #3		Wall Section
Volume of Bricks	2035 m^3	
Materials	Double wall of AAC blocks with air cavity	
Thermal Performance	Needs Improvement [✓ Poor] Very Good Cross the acceptable limits	

Wall Type #3		
Parameters	Simulation Results	Readings
1.System loads ○ Sensible cooling ○ Total cooling ○ Zone heating	 	-1349.16 -1802.76 527.46
2. Fuel Breakdown ○ Room Electricity ○ Lighting ○ Heating ○ Cooling		0.99 0.15 0.62 1

3. Thermal Comfort ○ Air Temperature ^{O}C ○ Humidity %		25.52 51.93
4. Fabric heat Gain/loss ○ Walls ○ Glazing ○ Infiltration		-73.23 -50.6 -472.51
5. Zone sensible heating		1186.74
6. CO_2 emissions		2.23X10^6
7. Performance Acceptability	Poor	

Wall Type #4		Wall Section
Volume of Bricks	2035 m^3	
Materials	Double wall of AAC blocks with air cavity	
Thermal Performance	Needs Improvement Poor [✓ Very Good] Cross the acceptable limits	

Wall Type #4		
Parameters	Simulation Results	Readings
1.System loads ○ Sensible cooling ○ Total cooling ○ Zone heating	 	-1097.06 -1496.67 259.24
2. Fuel Breakdown ○ Room Electricity ○ Lighting ○ Heating ○ Cooling		0.99 0.15 0.35 0.83

3. Thermal Comfort ○ Air Temperature ^{O}C ○ Humidity %		23 37.6
4. Fabric heat Gain/loss ○ Walls ○ Glazing ○ Infiltration		-31.77 -31.37 -374.14
5. Zone sensible heating		820.11
6. CO_2 emissions		1.82X10^6
7. Performance Acceptability	Very Good	

CHAPTER 5: CONCULSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study has conducted an analysis of the effect of different wall systems and fenestrations on the indoor environmental quality. A comparison between the traditional clay brick and AAC wall systems was conducted to evaluate their performance to the standards. In the simulation four different wall systems were used, two of the original wall systems in two buildings in the New Egyptian Administrative Capital and two alternatives. The simulation was done based on the recommendations of the EREC taking into account the WWR, shading, glass types and SHGC. Also, a financial analysis was conducted to evaluate each of the four simulated wall systems and determine the most cost-effective wall system regarding the initial cost and the running cost. Based on the building envelops used, the environmental conditions and weather data files, building finishing materials, and other simulation parameters taken in consideration in this study, a summary of all the findings with conclusions can be stated and categorized into two categories.

A. Conclusions of the construction phase

1. The New Egyptian Administrative Capital is a mega project that targets energy conservation through different techniques. There are some initiatives that are taking place in the New Egyptian Administrative Capital for using more sustainable building materials; however, lack of awareness and high initial construction cost are two causes to the limitation of addressing more effective techniques.
2. AAC blocks takes less mortar due to fewer number of joints because of the size of the block is larger. AAC blocks are much durable than the clay brick and less time consuming.

3. The study revealed that the savings in the construction components such as cement in mortar, concrete, steel, labor, and finishing materials compensate for the extra cost of the AAC blocks.
4. AAC blocks initial construction cost is less than that of red bricks.

B. Conclusions of the thermal performance

1. Energy consumption is increasing in the residential and commercial sectors in Egypt due to the increase in thermal discomfort in the indoor building environment.
2. The rates of energy consumption are increasing due to the unfunctional use of the resources of energy which led to depilation of renewable energy.
3. The residential and the commercial sectors are responsible for more than 48% of the electricity consumption in Egypt.
4. The application of the traditional wall systems using the common practice in Egypt, doesn't satisfy the occupants and causes thermal discomfort. This doesn't fulfil the requirements of the EREC.
5. Wall systems are the main source of indoor thermal discomfort.
6. Heating and cooling loads due to the use of AAC blocks are much less, thus reduce the electricity bills.
7. The main sources of air leakage in buildings are the windows and the walls for around 47% of the leakages.
8. CO_2 emissions worldwide is increasing steadily in the past two decades; Egypt's CO_2 emissions has increased in the last couple of years. Also, the residential and commercial buildings are taking more than 8% of the CO_2 emissions in Egypt.

9. Sustainable buildings require green building materials as an application to the building envelopes, which addresses some specifications for reduction in energy consumption in buildings.
10. AAC blocks are one of the green building materials than should be used as an alternative for clay brick as a building wall system and they are LEED certified where cement is minimally used in the production process and in sometimes mixed with fly ash. Also, AAC blocks performance thermally is much better than clay bricks and AAC blocks insulates sound and fire more than clay bricks.
11. Simulation of a residential and a commercial building in the New Administrative capital revealed differences in the performance of each wall system. Generally, the thermal performance of the clay bricks that are used is less effective than that of the AAC blocks.
12. The results revealed that the use of double AAC blocks with air gap and double reflective glass is the best solution of the four regarding cost-effectiveness and energy consumption. Using double reflective glass has shown an improvement in the indoor environmental quality. The savings in energy consumption goes up to 23.6% and 24.6% for the residential and commercial buildings respectively.
13. The initial cost of AAC blocks, according to the financial study, is greater than that of clay bricks; however, the running cost is much less. The savings in the initial construction cost goes up to 14.3 % and 9.4 % for the residential and commercial buildings respectively. In addition, the thermal performance of the AAC blocks is much better than the clay bricks due to low thermal conductivity and high thermal resistance which leads to less energy consumption.

14. The key for the overall performance of AAC blocks, financially and environmentally, is much better than the clay bricks and reduce the damages that happen to the environment due to using unsustainable building materials. the overall savings in both the residential and commercial buildings are 37.9% and 34.1% respectively.
15. The use of double wall of AAC blocks is recommended for the residential buildings; however, the use of single AAC block with double reflective glass is recommended in the commercial buildings.

5.2 Recommendations for Future Work and the Industry

5.2.1 Future Work

This section summarized some recommendations and potentials for future work. The simulation results showed some differences in the level of emissions using different wall systems; however, there are some limitations in the simulations of the results. There are some recommendations to overcome these limitations in the future:

- Some other parameters should be adjusted in the simulation process to give clearer data such as detailed schedules for lighting in relation with occupancy.
- Using different lighting control units, level of luminance, and dimming controllers in relation with the natural light amount and energy consumption.
- The effect of fenestrations coatings and orientation on the energy efficiency and the effect of double reflective glazing on red bricks performance.
- The effect of different fenestration types on the performance of the red brick with respect to the AAC blocks.

- The effect of using a single brick with insulation materials on the cost and the thermal performance of the building.
- The calculations of the energy consumption may be conducted to include the level of each flat instead of the building as a whole.
- The interaction between the building envelopes and indoor air quality should be taken in consideration in the simulations.
- Enhancing the simulation programs to include life cycle cost analysis and to include more exchange in data between different tools. This would provide the user with a tool to evaluate different aspects in different phases.
- The effect of protective coatings on the thermal performance is recommended in future work.
- Thermal parameters regarding the moisture content and relative humidity should be studied more. Study the effect of coatings on humidity.
- The effect of using different HVAC systems on the thermal performance is recommended.
- The effect of other types of plastering on the thermal performance of AAC blocks needs to be studied especially the use of ready mix plastering on the durability of the blocks.
- The acoustic and thermal performance of AAC blocks for different zones such as building close to airports should be conducted.
- Further testing on the energy efficiency of AAC blocks on real buildings in Egypt should be encourages.
- Further testing on the effect of reducing the aluminum powder and cement content on the AAC blocks and their mechanical properties.
- Most of the sectors are considering sustainability; however, new building wall systems are not that popular.

5.2.2 Recommendations for the Industry and Policy Makers

The availability of sustainable building materials data base and classification standards is significant. This requires a firm process that starts from monitoring the production phase till the installation phase to ensure the level of green of each building material. This process is significant to ensure the evaluation of each building material and reduce the use of unsustainable ones. Some recommendations to the construction industry are as follows:

1. The awareness level of the individuals, contractors, investors and developers is encouraged to be raised to see the effect of sustainable building materials and their impacts financially, environmentally, and for the interest of the nation.
2. It is recommended to keep updating the data and approaches of sustainable materials and work on creating data base for sustainable building materials.
3. Evaluation of systems for building materials should be applied which defines the acceptable ranges and standards for the climate of Egypt.
4. Alternative solutions for building envelopes should be promoted between the government and the construction sector.
5. Having regulations regarding the minimum energy conservation for each building is needed in the construction industry.
6. Promote new building wall systems by using the cost analysis recovery plan to see the payback period of each material.

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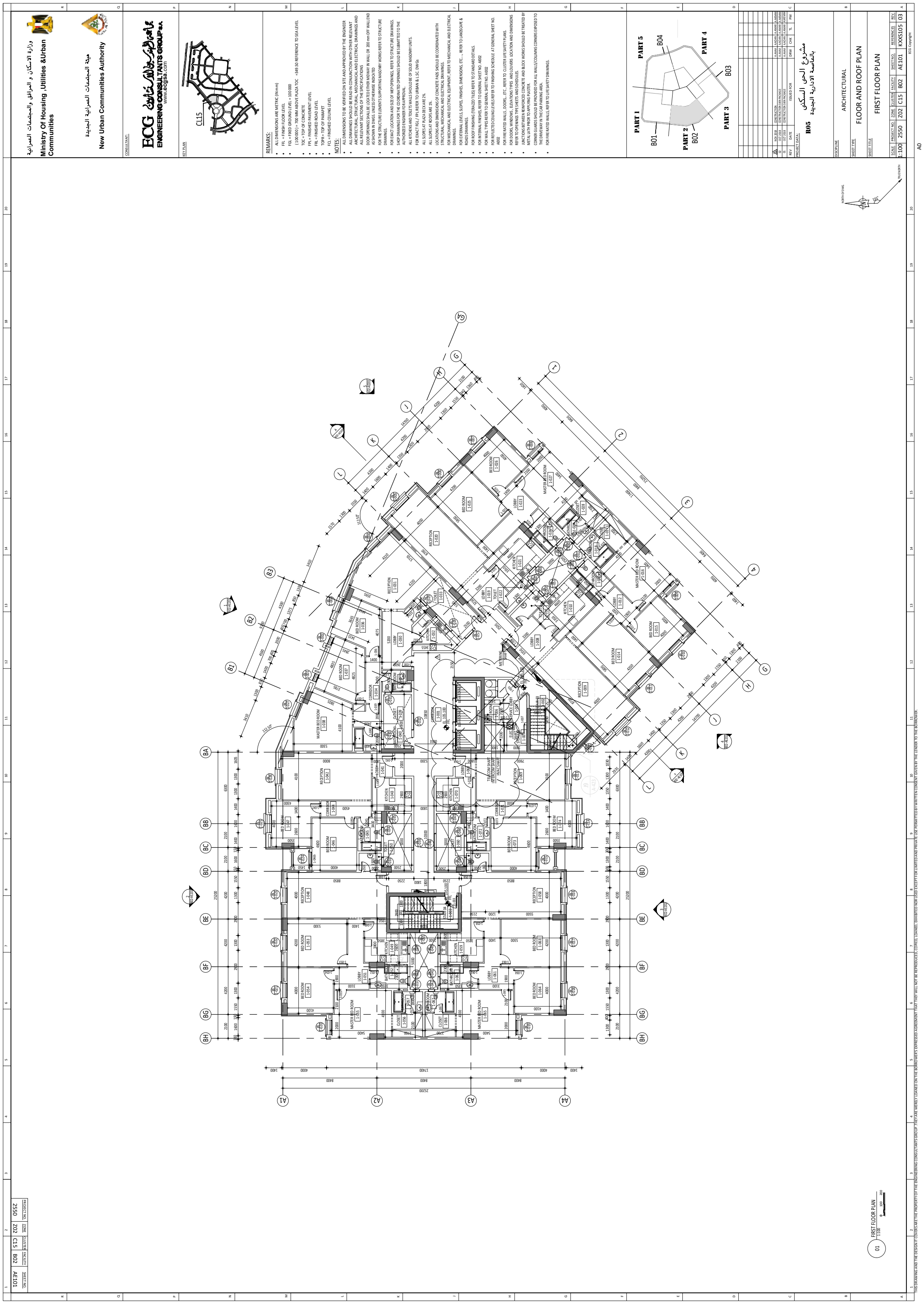
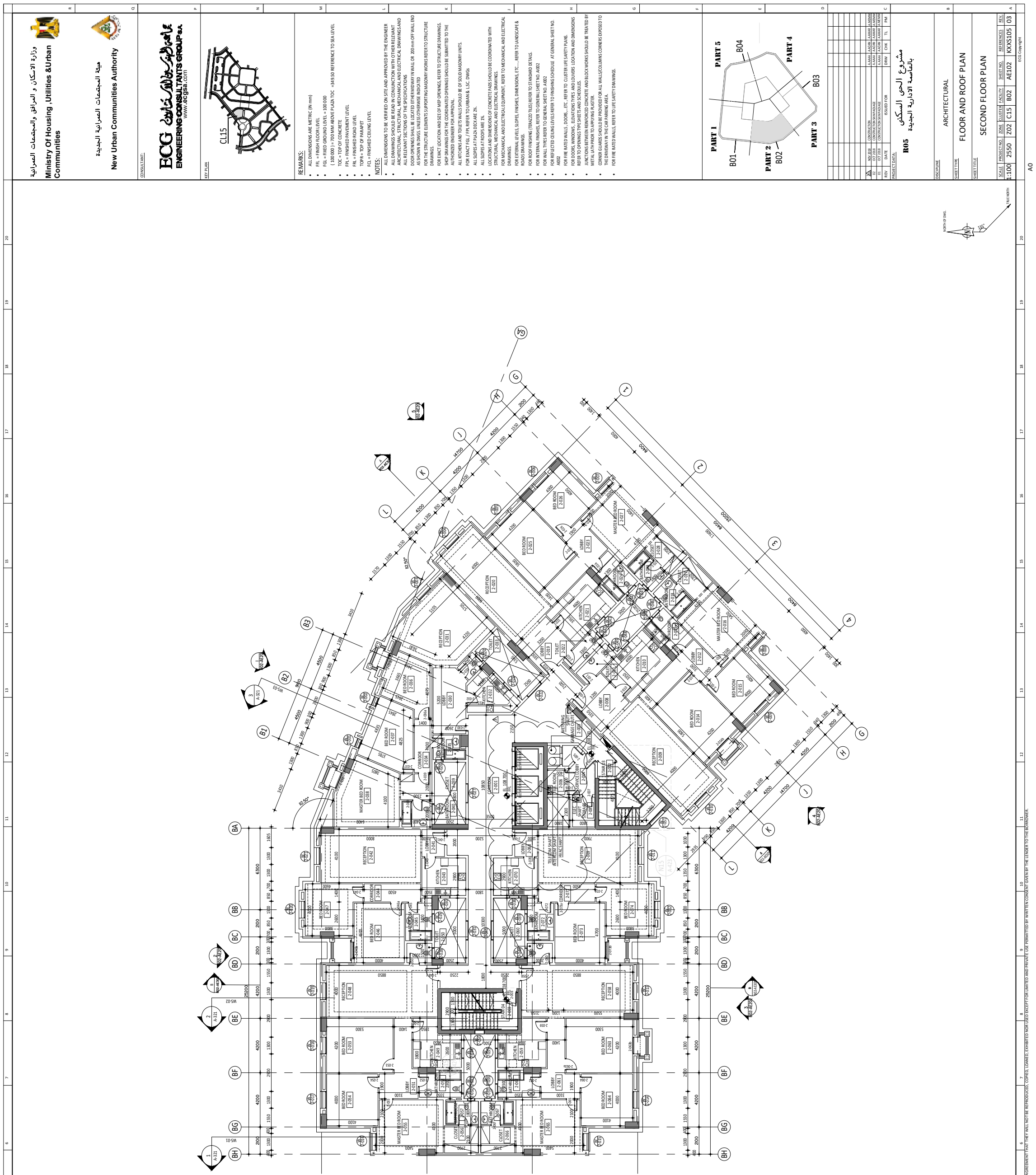
Appendix 1

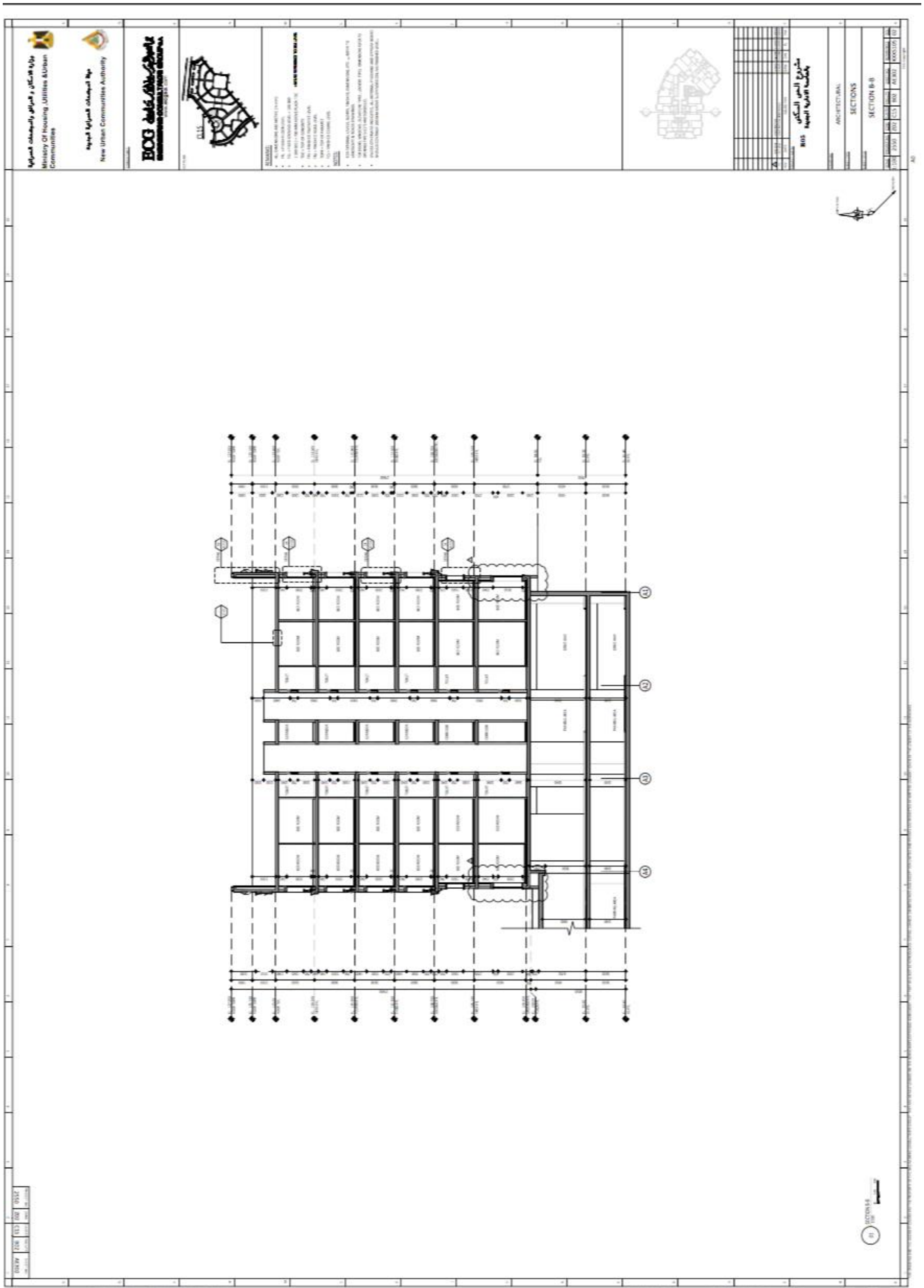
Floor Plans, Sections, and Elevations of Simulated Models



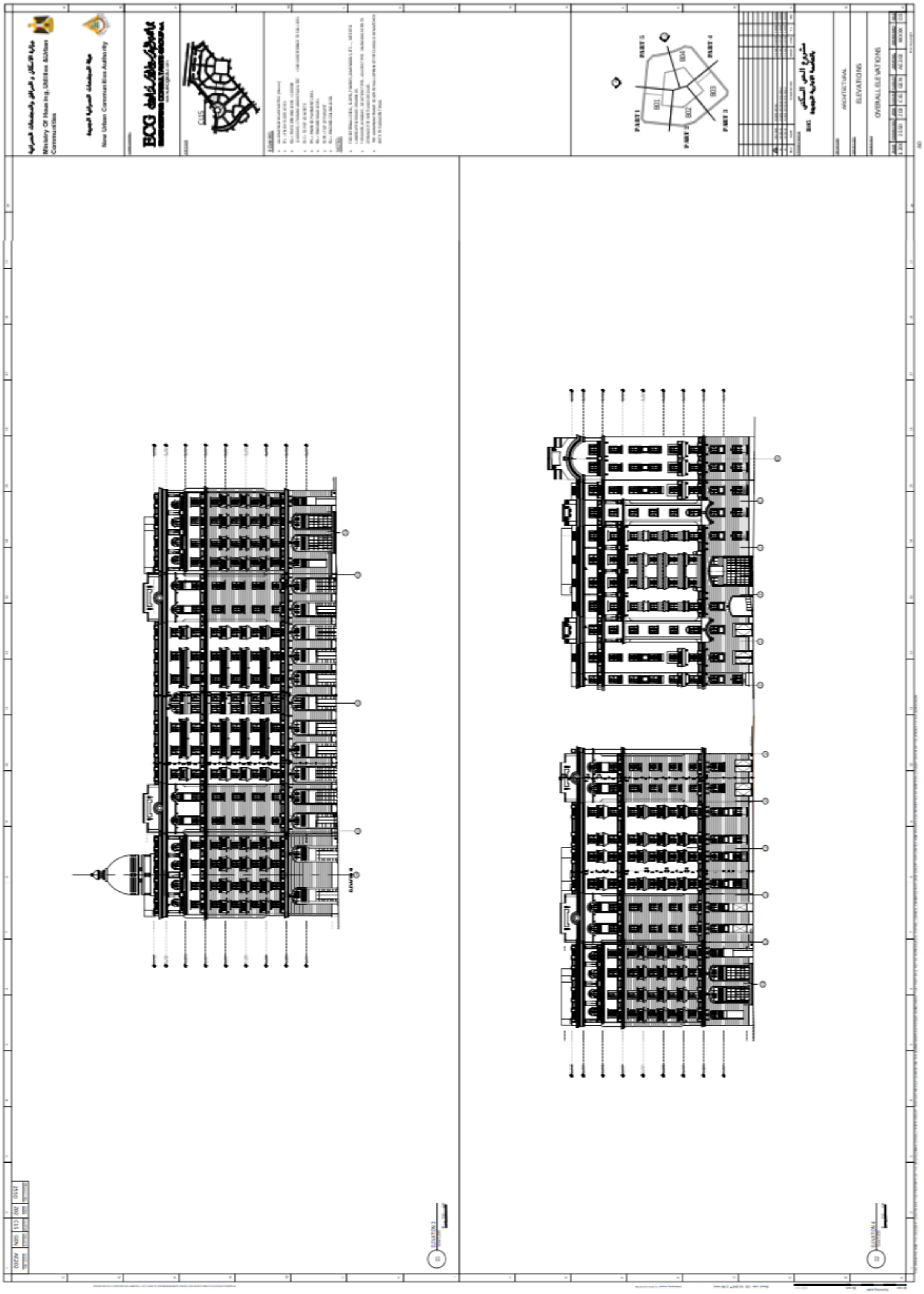
Ground Floor Plan



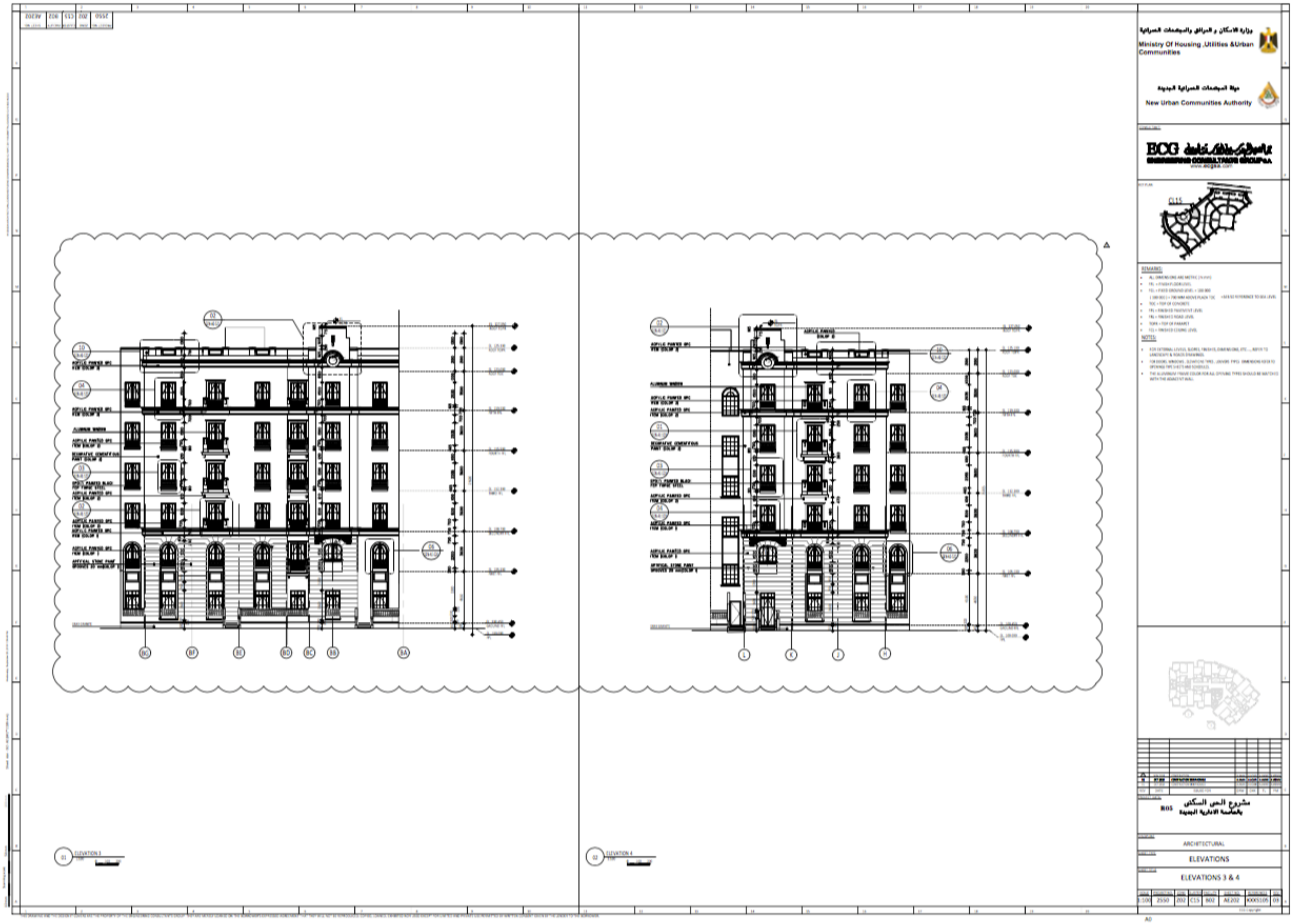
Repeated Floor Plan



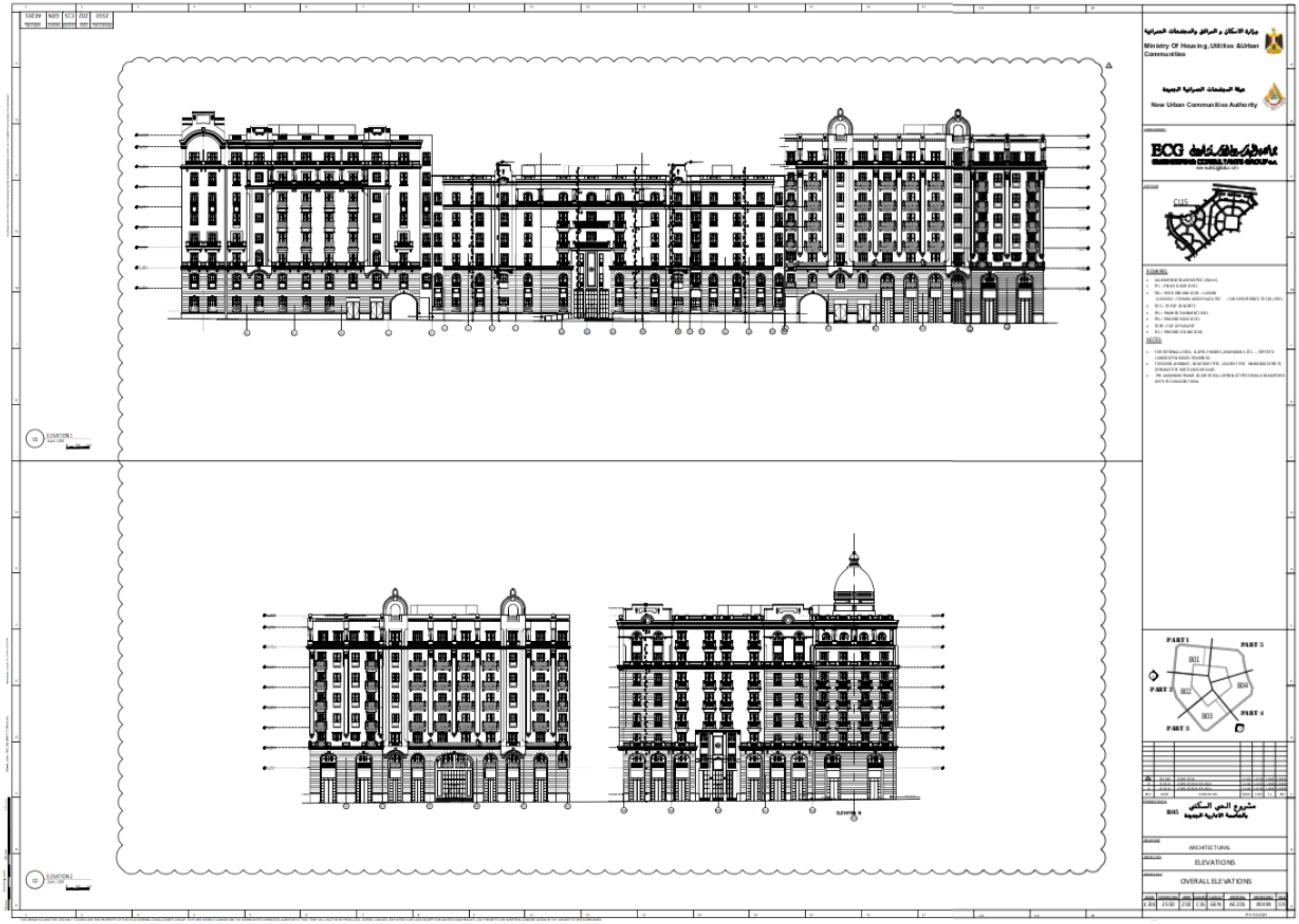
R5 Building Section



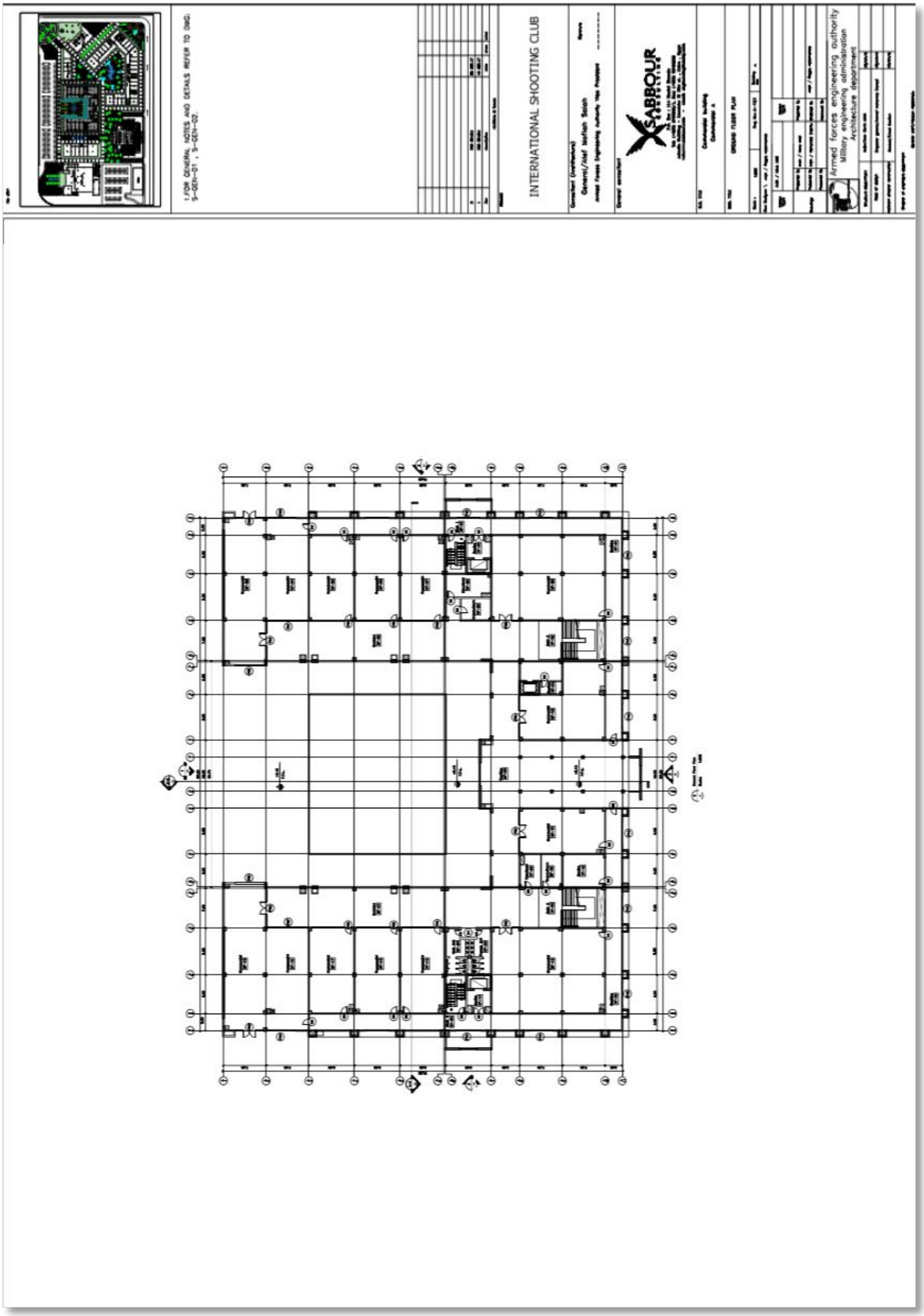
R5 Collaborative Elevations



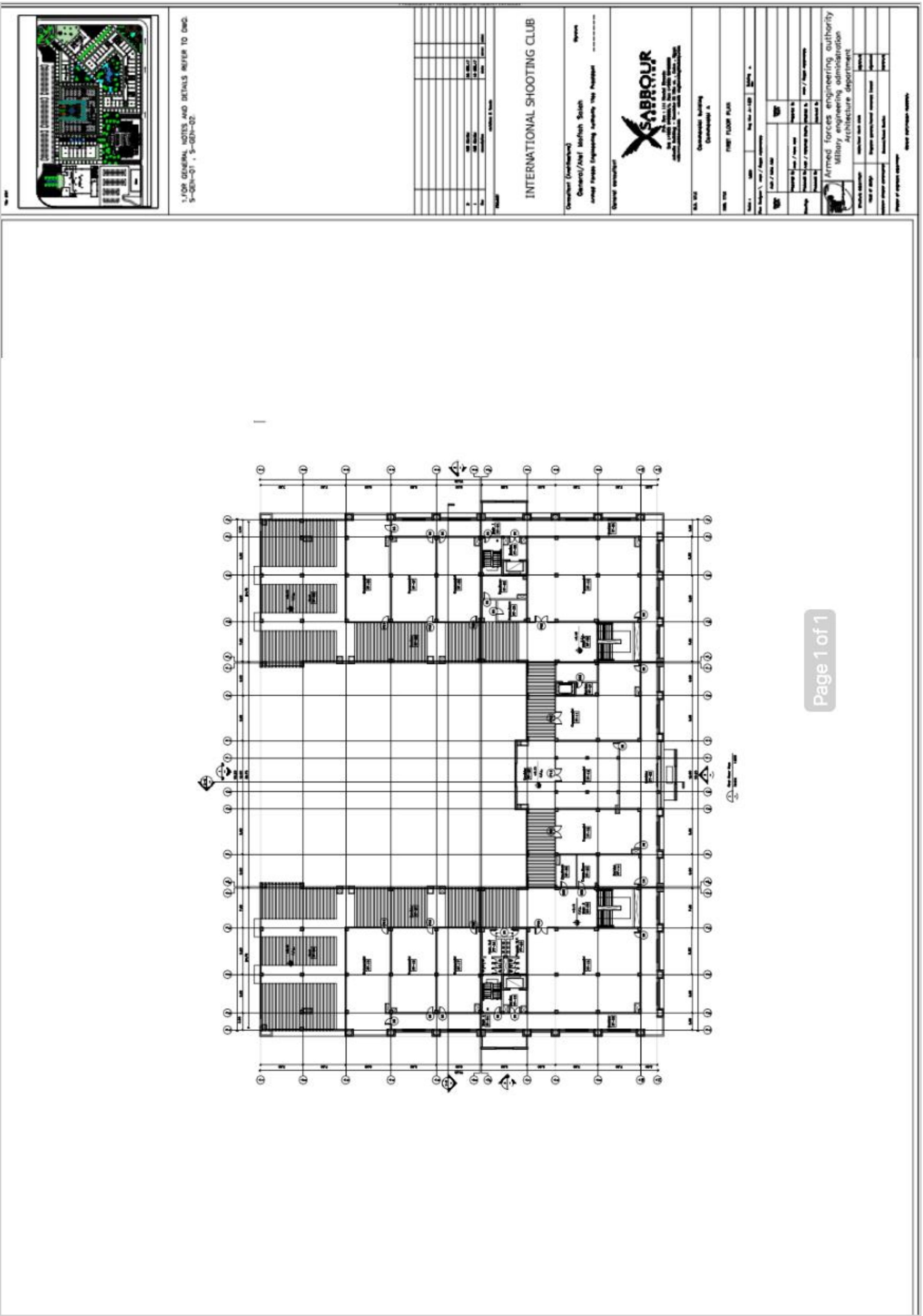
R5 Partial Elevations



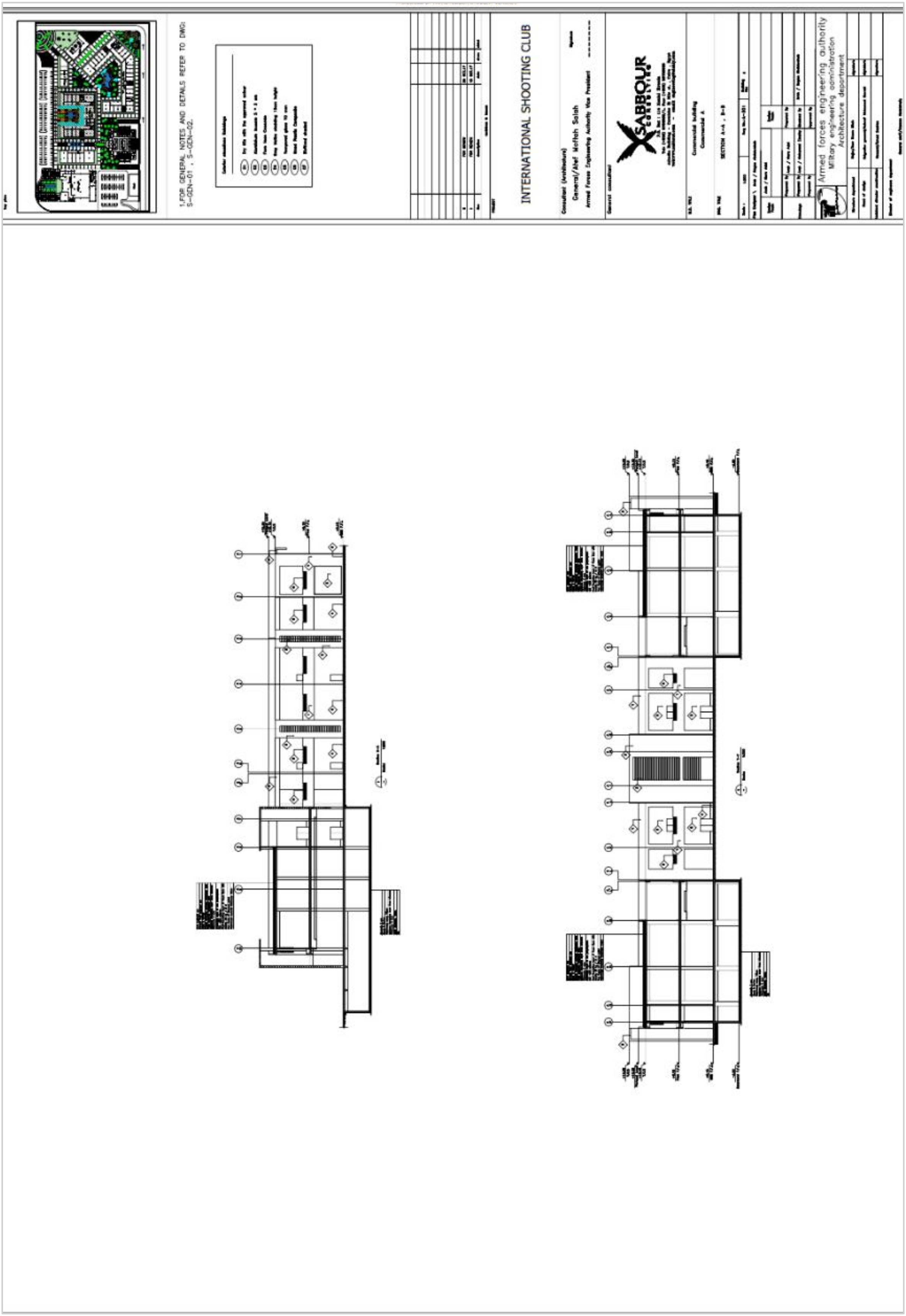
R5 Collaborative Elevations



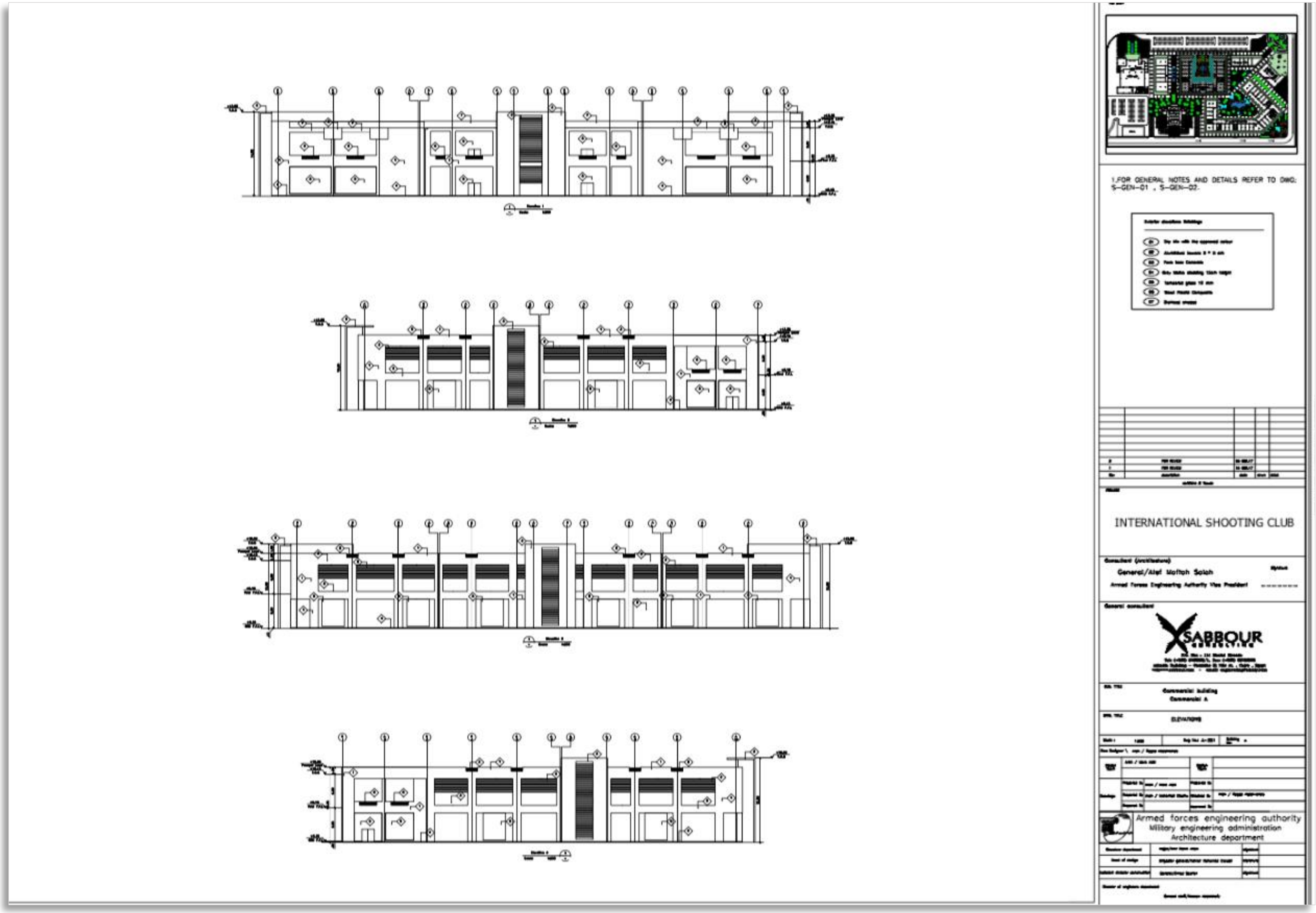
Commercial Building- Ground Floor Plan



Commercial Building- First Floor Plan



Commercial Building- Sections



Commercial Building- Elevations