Palestine Polytechnic University

Deanship of Graduate Studies and Scientific Research

Master of Architecture – Sustainable Design

Simulation Based - Early Design (SBED) Tool for Apartment Buildings

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The undersigned hereby certify that they have read, examined and recommended to the Deanship of Graduate Studies and Scientific Research at Palestine Polytechnic University:

Simulation Based – Early Design Tool for Apartment Buildings

Lisa Jalal Muallem

In partial fulfillment of the requirements for the degree of Master in Renewable Energy & Sustainability.

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Simulation Based – Early Design Tool for Apartment Buildings

Lisa Jalal Muallem

ABSTRACT

Building Envelope design functions as one of the most effective passive design strategies in controlling thermal performance and energy consumption in buildings. A properly designed envelope should contribute to better building performance with minimum energy demand, and so carefully simulating different envelope configurations and assessing their effect on indoor air quality and energy consumption is very essential and is highly needed to be tested while designing buildings which is rarely done within the building design process in Palestine. This thesis presents a parametric simulation algorithm to apartment buildings in Mediterranean climate. The most common envelope designs and construction materials available in Palestine and specifically in the highlands of Nablus, Jerusalem, Bethlehem, Ramallah and Hebron were carefully identified and selected for the purpose of the parametric simulation. The variables design parameters were carefully identified: apartment layout, orientation, floor level, insulation thickness, glazing type, site density and topography. Their influence was tested and evaluated in terms of their effect on indoor air temperatures and on energy consumption using Design Builder simulation program. A simplified tool was developed to help architects and designers to check different envelope parameters and their effect on building performance as well as on energy consumption. The tool's objective is to alert designers to carefully select building envelopes components and to facilitate the integration of building simulation within building design process so as to achieve energy efficient buildings. The results proved that such tools can help in assessing the effect of building envelope parameters on building performance and on energy consumption and so in improving thermal performance while minimizing energy consumption. As well as, pointing out the importance of treating each living space as a separate structure and assessing design decisions carefully to help in achieving best indoor atmosphere. Energy consumption of living spaces in residential buildings can be minimized by 40 - 45% if designers define and test envelope related parameters at early design stages.

أداة قائمة على أساس المحاكاة لتعزيز عملية تصميم المباني السكنية

ليزا جلال معلم

ملخص

يعمل تصميم غلاف المبنى كواحد من أكثر العوامل الفعالة في التحكم في الأداء الحراري للمبنى وكمية استهلاكه الطاقة. يساهم غلاف المبنى المصمم بشكل صحيح في تحسين أداء المبنى مع الحد من عملية استهلاك الطاقة اللازمة للتدفئة والتبريد، وبالتالي فإن عملية تجربة وخوض محاكاة لتكوينات مختلفة لغلاف المبنى وتقييم تأثيرها على جودة الهواء الداخلي وعلى كمية استهلاك الطاقة مفيد من أجل معرفة تأثير تصميم الغلاف على الأداء الحراري. مع التأكيد على أن هناك حاجة شديدة لاختبار كفاءة الغلاف المصمم أثناء عملية تصميم المباني للمساهمة في تصميم وبناء مباني موفرة للطاقة. ان عملية دراسة أداء المبنى الحراري عملية تعتمد على برامج مختصة وهي عملية تستغرق وقت وجهد كبير وبحاجة لمختصين لتنفيذ هذا النوع من الأعمال ولذلك فهي نادراً ما يتم اختبارها جنبا الي جنب مع عملية تصميم المباني في فلسطين. تقدم هذه الدراسة اداة _مصممة بالاعتماد على المحاكاة_ متعددة المعايير تختص بالمباني السكنية المتعددة الطوابق التي تقع ضمن مناخ البحر الأبيض المتوسط. تم تحديد مكونات وتصميمات غلاف المبنى المعتمد بدقة وبالاعتماد على مواد البناء الأكثر شيوعًا والمتوفرة في فلسطين _تحديداً في مرتفعات نابلس، القدس، رام الله، الخليل وبيت لحم_ واختيارها لغرض المحاكاة المتعددة المعايير. تم تحديد العوامل المتغيرة الممكن التحكم بتغيرها من خلال هذه الأداة بعناية وتشمل: تخطيط المبنى السكني (عدد الشقق السكنية بالطابق الواحد)، توجيه غرفة المعيشة، الطابق، سمك العزل المستخدم بالجدران، نوع الزجاج وخصائصه، كثافة البناء المجاور والتضاريس. تم اختبار وتقييم تأثير كل هذه العوامل على أداء المبنى وعلى كمية استهلاك الطاقة باستخدام برنامج محاكاة (DesignDuilder). تقدم هذه الدراسة أداة لمساعدة المهندسين المعماريين والمصممين على اختبار تأثير مكونات الغلاف المصمم على الأداء الحراري وكمية استهلاك المبنى للطاقة. بالإضافة لتسهيل دمج عملية المحاكاة في مرحلة تصميم المبنى بهدف تصميم مباني موفرة للطاقة. أثبتت النتائج أن مثل هذه الأدوات ان وجدت تساعد في تقييم تأثير تصميم غلاف المبنى على أداء المبنى وعلى استهلاك الطاقة وبالتالي في تحسين الأداء الحراري وبالتالي تقليل كمية استهلاك الطاقة اللازمة للتدفئة والتبريد بغرف المعيشة بنسبة 40 - 45%.

DECLARATION

I declare that the Master Thesis entitled" Simulation Based – Early Design Tool (SBED) for Apartment Buildings" is my own original work, and herby certify that unless stated, all work contained within this thesis is my own independent research and has not been submitted for the award of any other degree at any institution, except where due acknowledgement is made in the text.

Student Name: Lisa Jalal Muallem

Signature:——————————— Date:——————————

DEDICATION

To my Husband, Daughter and Son, for all your support, encouragement and unconditional love

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I would like to express my appreciation and my thanks to my supervisor Dr. Shireen Al Qadi for her guidance, support, advice, effort and continuous encouragement throughout the whole research.

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Thank You.

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Chapter One

Introduction

1.1 Introduction

Building design is a complex process. It is a combination of art and science. The complexity of building design process results from all the systems that has to be integrated in the design process, such as: structural, mechanical and electrical systems which require experts to integrate all systems to achieve the required objective. Environmental systems and energy issues are essential parts of this complex process as well. Architects need to be aware of all systems to produce successful lifetime buildings. They need to integrate space design, building shape with structural loads, mechanical and electrical systems as well as building performance simulation which might be a time consuming, expensive and complex process. This has led designers to concentrate on meeting the building regulation in terms of building function as well as aesthetic with minimal consideration for the building performance. There is a great need for tools and for ready to use applications that are simple to use and can help architects to control all design processes with less time, minimum effort and less expenses and that are familiar with local building materials, construction techniques, typical building designs and the climatic conditions in Palestine. This study presents simulation-based tool that accommodates the Palestinian context and that provides information to facilitate design decisions at early design stages while guiding the designers toward thermal performance and energy efficient buildings.

1.2 Background

Housing is one of the basic needs for humans. Because of the “Israeli” colonization activities in the occupied Palestine that has led to shortage of land ((arij), 2008) and was the reason toward the fact that the Palestinian cities are becoming high dense cities since the horizontal urban sprawl is restricted, there has been an increase in the construction of residential buildings (apartments). Residential buildings account for 60.9% of buildings in Palestine (PCBS, 2017). Residential buildings are divided into separate house units, apartments and villas. During 2017, residential apartments forms 62% of the residential buildings in Palestine. Separate houses form 35% and villas form 1.1% based on the PCBS 2017 buildings survey (Park et al., 2016) (PCBS, 2017).

The twentieth century had witnessed a change in the type of residential buildings prototypes (Itma, 2014). It was noticed that there has been a shift from single family units to apartment buildings and nowadays to high dense apartment buildings. There has been a shift toward compact cities to afford housing for the future generations. This prototype is usually composed of one or more independent apartment building per land area. Each building consists of a central staircase with 2, 3 or 4 apartments in each floor. High prices of land pushed the investors to usually build on the fully acceptable built area per land. No space considered for outdoor social interaction (Itma, 2014). This has raised a dramatic issue in terms that the building height, floor area and number of apartment units per floor caused the failure to provide adequate ventilation, indoor air quality and natural sunlight to penetrate into the apartment floor plan. Moreover, investors usually try to build these buildings with minimum cost and so 3cm stone cladding and air gap thermal insulation is usually used to form the building (Park et al., 2016) (PCBS, 2017).

Thermal characteristics of building envelope components greatly influence building performance and energy consumption (Al-Saadi, 2006). Envelope characteristics are highly affected by the construction material characteristics itself, such as the material's ability to gain, store and transmit heat (Fazio et al., 1997). When selecting any construction material, it is very important for the designer to be fully aware for the material density, its conductivity and its specific heat since such information highly affect thermal performance and energy consumption. The complex design process and the limited average household income in Palestine has contributed to designing and constructing without hiring environmental specialists, which was the reason to produce buildings that are not compatible with the local climate (Enshassi, 2000). Construction materials are seldom selected with proper consideration to environmental issues and to thermal performance. Climate was rarely given attention as a design factor. As a result, this have contributed to poor thermal performance of residential buildings in Palestine.

Residential and commercial buildings in Palestine consume 70% of the total energy sources. More specifically, Residential sector consumes up to 60% of the total electrical energy (PCBS, 2017). The energy sector in the Palestinian territories faces significant challenges, basically from the complete dependence on the external sources (mainly from the occupying sources (Israel) for the supply of electricity, gas, and fuel), from the high financial costs to import these energy sources and finally from the environmental risks arising from the use of traditional sources of energy. Rapid industrialization and technological developments, change in standards of living, and the increased population density have caused a raise in energy consumption in Palestine, and so has increased the interests to search for renewable energy resources. There is also a great need to search for methods and techniques to lower such consumption rates and so to save the environment.

These facts impose challenges in front of the Palestinian decision-makers as well as on architects and home owner to search for methods to lower energy consumption resulted from the residential sector and from buildings and to propose some standards and regulations related to average acceptable energy consumption in buildings, and to encourage relying on renewable energy resources if needed.

1.3 Research Problem

Energy consumption in Palestine and specifically in residential buildings has shown great increase over the last few years (PCBS, 2018). Energy consumption mainly depends on nonrenewable sources as well as Palestine depends on Israel for about 80% of their energy demand (Ismail et al., 2013) (Ouda, 2010). 99.6% of the Palestinian households need and do heat their houses during winter (Al Qadi et al., 2018). Up to one fifth of household's monthly income _worst case scenario tested on elderly people_ is consumed on heating energy, which is a great amount when compared to the average heated area of the Palestinian houses which is only 9.2% of the total house area during the winter day which equals 12.1m^2/day (Al Qadi et al., 2018).

Building envelopes are responsible for about 40% of this consumption (Hassan, 2016). There is a great need to improve building envelopes design in order to enhance building performance and to minimize energy consumption. In order to perform the previously mentioned objectives, architects need to analyze and compare different envelope designs by the use of buildings performance simulation tools in order to identify the main parameters that can enhance building performance. Simulation tools needs expertise to use. They are time consuming and this action is costly. There is a great need to find simplified methods to help integrate simulation into the buildings design process since such methods if available can enhance the design process and may lead to the design and execution of energy efficient buildings.

1.4 Research Question

The previous description of the problem generated the following research question:

How can parametric design approach tool (specifically concentrated on building envelope) help architects in investigating thermal performance of indoor environment and so designing energy efficient buildings?

This main question proposed more elaborated questions:

1. **How** does building envelope affect energy consumption and building performance?

2. **How** can parametric design tools help architects to generate, explore and evaluate different alternatives to achieve the desired objective?

3. **What** are the effective strategies and alternatives to enhance thermal performance and to reduce energy consumption in residential buildings in Palestine?

1.5 Research Scope and Limitation

The scope of the study as shown in figure 1 will be limited to:

1. A single family residential apartment with its walls, windows, floors and roofs systems that are in common use in the Palestinian residential construction context. The size and number of occupancies will be defined.

2. The forth climatic Zone in Palestine: it includes sub-humid regions which is also characterized by the Mediterranean climate: Warm sub-humid summer, cold winter. It presents the highlands of Nablus, Bethlehem, Ramallah and Hebron.

3. Three porotypes of five floors residential apartment buildings with fixed window to wall ratios will be defined in chapter three.

4. The building performance under two cases:

4.1 unheated and uncooled space to investigate the influence of thermal characteristics of building envelope on the indoor air temperature behavior.

4.2 A heated and cooled case to quantify the amount of energy needed to achieve the best thermal performance.

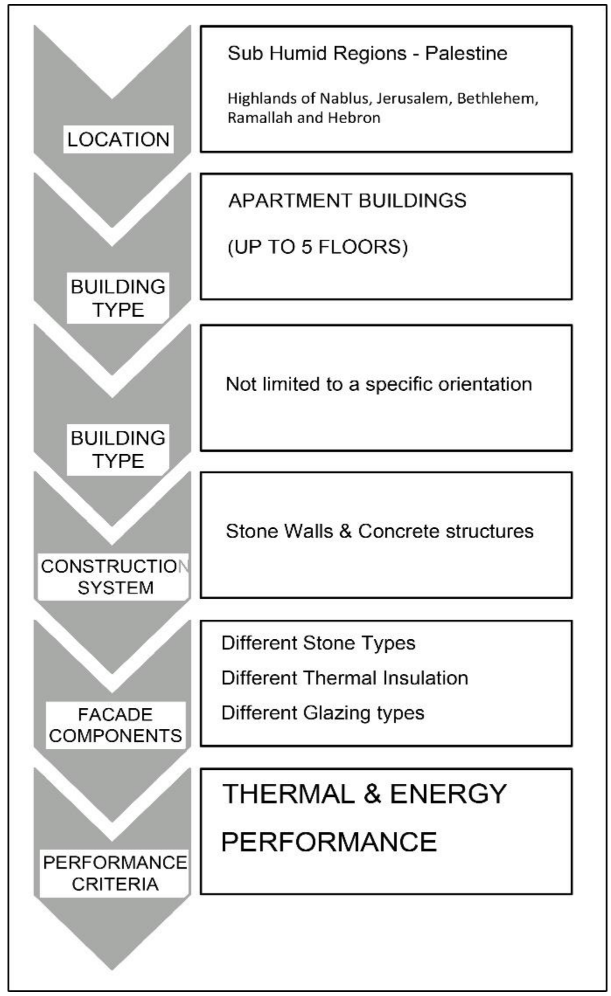


Figure 1: Thesis Scope of Work

Source: By the Researcher

1.6 Research Objective

The **main objective** of this research is to develop a simulation-based tool to enhance the design process for residential buildings (apartment buildings) in Palestine. It aims to propose a parametric-based optimization method that could help architects in finding the best combination of envelop parameters to enhance thermal performance and to minimize energy consumption.

In order to achieve the main objective, group of goals will be achieved too, such as:

● To ***enhance*** thermal performance of apartment buildings in Palestine.

● To ***investigate and define*** the impact of different parameters related to envelope design on the indoor air temperature for a typical residential apartment in Palestine and on energy consumption.

● to ***Guide*** the designer in the early design phases toward designing energy efficient buildings.

● to ***Lower*** the barriers _ that might be financial or has resulted from limited knowledge on the use of simulation programs_ of integrating building performance simulation during early phases of building design.

1.7 Research Significance

In Palestine, there is a great need to solve the problem of high energy consumption in residential buildings, which is mostly related to poor thermal performance of building envelopes. This research investigates the thermal performance of building envelope in a specified climate zone to achieve better building performance and lower energy consumption. A guiding tool based on thermal simulation will be proposed to help architects and designers investigate different parameters related to thermal performance and energy consumption and compare their effect on heating and cooling loads. This study is beneficial to architects, designers and home owners since it gives an indication of building performance without actually performing simulation.

Very few guiding tools are available worldwide and in Palestine as well. ZEBO is an example on such guiding tools. It is an energy simulation guiding tool designed and developed by (Attia et al., 2012) to help architects design zero energy buildings and compare through sensitivity analysis the outcomes of different design parameters and their effect on building energy performance in a high urban Egyptian context and in hot humid Egyptian climate. The user gets to define different inputs such as: the weather file, building Rotation, building height, building dimensions in terms of north south length versus east west length, window type, window size, shading devices if available, wall type, roof type, insulation type and insulation thickness. After defining the input data, the tool gives the user monthly consumption indication graphs as well as energy break down. The output is visualized in the form of graphs. The tool gives the user the option to compare alternatives by changing input parameters and check their effect on energy consumption.

BV²-arch is energy simulation tool that is based on energy analysis program named BV². It allows the user to select already defined parameters such as project location while still allows to modify some inputs such as building shape, glazing ratios and solar panels. The tool calculates energy balance per unit area for day, night and maximum consumption balance (Li, 2017). IP-Energy is a software that calculates energy performance. It imports building geometries from ArchiCAD and can define inputs such as climatic data, construction types, schedules and ventilation. It can be used for all building types and it displays energy balance comparison and cost (Li, 2017).

In Palestine, Eng. Muna Elayan has developed a software program to estimate optimal insulation thickness for residential buildings in different climatic regions considering life cycle cost analysis (Elayan, 2019). The software is valid for all residential building types since building program is what matters and in seven different climatic zones. The user gets to define the location, the desired cost and the building materials as input data in order to get the best insulation thickness with the minimum cost and the payback period. However, Eng. Muna's developed software won't give the user quantitative data regarding heating and cooling consumption resulted from the suggested optimum insulation thickness. It won't show effects of insulation on indoor air temperatures and on building performance. It won't allow the designer to test different alternatives while comparing percentages of savings with payback period.

This research will develop a more specified tool in a very specified building type and in a specific climatic zone so as to achieve detailed information related to monthly heating and cooling energies, indoor air temperature versus outdoor air temperature, annual energy consumption, indication on solar gain related to occupancy, lighting, windows, heating and cooling systems. It gives the user the option to compare different parameters effect on heating and cooling energies as well as on building performance and annual energy savings in New Israeli shekels (NIS). It will precisely show the user the needed payback period since it considers the cost of construction materials used to improve building performance and energy consumption. Not only it will explore percentages of saving in annual energy consumption as a result of different parameters, but also, it'll record saving quantities in the form of energy as well as in the form of money savings. The tool's approach in testing parameters as well as in comparing savings with payback period made it very important to enhance the design process and to design energy efficient buildings.

1.8 Research Methodology

As mentioned in the previous section, this research aims to create early design tool to enhance the design process for residential buildings (Apartment Buildings). It guides the designer in early design phases to design energy efficient buildings and so to enhance thermal performance of residential buildings. Five main phases are found necessary and will be carried out to form the research methodology as shown in the flow chart in Figure 2.

1. Literature review: this phase includes a detailed review for **main envelope parameters** that affect **energy consumption** and **indoor thermal environment** while identifying local and international standards related to human comfort. This phase also includes a comprehensive review for previous studies that are related to building envelope design for thermal comfort as well as guiding tools that are available for architects and home owners to predict building performance and energy consumption:

- Main envelope parameters that affect energy consumption and indoor thermal environment.

- International standards related to human thermal comfort.

- Previous Studies that are related to building envelope designs for thermal comfort.

- Existing guiding tools and simplified methods that helps predicts building performance at early design stage.

2. Identifying practices of building envelope design through surveys and interviews: this phase includes **collecting information** regarding **local construction practices** in the study context in the form of survey questionnaires and interviews with professionals and local manufacturers to identify typical construction materials and to develop a base case residential building based on what is common in the study context:

- Identifying typical construction materials in the study context.

- Developing a base case residential building

- Identifying base case envelope parameters

- Identifying variable parameters

- Identifying confounding variable

- Identifying weather file and simulation program (DesignBuilder)

3. Simulation: this phase gives **quantitative results** showing **indoor air temperatures**, **heating and cooling loads** as well as **money savings**. It includes:

- Simulating the base case scenario

- Validating base case simulation results

- Parametric simulation using the indoor air temperature as comfort performance indicator.

- Parametric simulation to quantify energy consumption.

-Proposing Parametric simulation algorithm structure

4. Results, conclusion and recommendation: this phase include analyzing and discussing the results.

- Exploring the effect of the different parameters on energy consumption and building performance

- Comparing parametric simulation results

- Analyzing findings

- Evaluating the proposed parametric algorithm structure and the evaluation criteria used in the choosing optimum results

- Exploring the effect of the availability of such tool on enhancing the design process

- Conclusion and recommendation

5. Tool Design: this phase includes the development of the tool.

- Tool design which includes tool interface as well as tool output information that can be categorized into four categories: building performance output, Energy consumption output in the form of monthly and annual consumptions, saving output in the form of saving percentage as well as detailed energy saving in Kilowatt hour form and in money form (New Israeli Shekels Form) and payback period which includes detailed analysis to the cost of construction materials used in comparison to base case typical construction materials. Moreover, it gives an indication toward full apartment energy consumption.

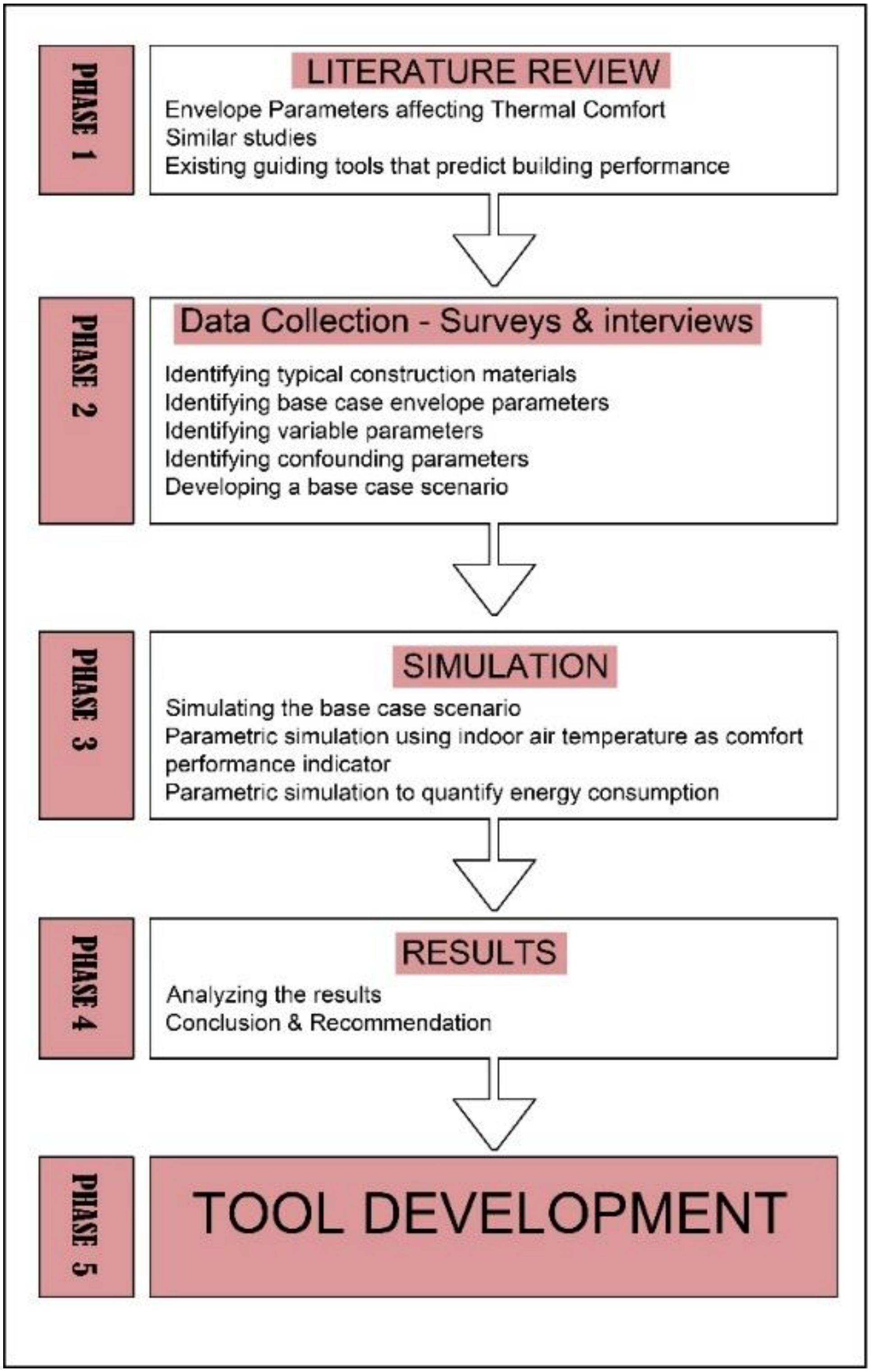


Figure 2: Flow Chart of Research Methodology

Source: The Researcher

1.9 Research Structure:

The overall structure of the study takes the form of six chapters including this introductory chapter.

Chapter two includes the literature review. It defines the impact of different envelope related parameters on thermal performance and on energy consumption. It also discussed energy consumption in buildings as well as energy consumption due to building envelopes worldwide and specifically in Palestine. It studied the general building practices in residential buildings in Palestine as well as the common available construction materials in the local market and their thermal properties. It finally discussed solutions proposed worldwide to minimize energy consumption in buildings. It focused on the effect of parametric simulation on enhancing building performance and energy consumption.

Chapter three began with a brief overview of common residential buildings designs in Palestine which has led to the development of the base case residential typologies that are used throughout this study. It then proposed and tested all envelope related parameters and checked their effect on building performance and on energy consumption. The parameter that showed great effect was taken into consideration while ignoring the ones that showed very little influence. This chapter has defined which parameters will be taken into consideration in the proposed tool. It categorized parameters used in the proposed tool into variable parameters, constant parameters as well confounding parameters.

Chapter four addressed the impact of envelope design on building performance and on energy consumption. It focused on the great advantages of parametric simulation to test different designs so as to choose the best solution.

Chapter five described the proposed tool. It described its interface, input and output data.

Chapter six gives a brief summary and discussion of the results and the main findings. At the end of the research, recommendations and suggested further researches were identified.

Chapter Two

Literature Review

2.1 Introduction

Buildings are physical structures that are composed of different elements and systems in which building envelope is a main element (Sadineni et al., 2011) and the different systems integrated in the design of buildings are passive and active systems. Passive systems are those systems that perform their intended job by the use of their own elements and materials. Active systems are those systems that perform their intended job with the help of electrical and mechanical systems. Building envelope can be defined as the barrier that separates the indoor spaces from the outdoor environment. It is “a three dimensional transition space where the interaction between the outdoor forces and indoor conditions occur under the command of materials and geometries” (Cleveland and Morris, 2005), and is composed of different components such as walls, roofs, floors, foundation, doors and windows. It can be responsible for controlling energy consumption and occupant’s comfort in indoor environments.

Energy consumption in buildings can be affected to a great extent by different parameters such as: climate, building construction techniques, building architectural features and inhabitants (Pettersen, 1994) (Bichiou and Krarti, 2011) (Pérez-Lombard et al., 2008). Climate in terms of the weather conditions in a certain geographic location as well as the climatic variations from one year to another due to global warming. Building construction in terms of building size, envelope U-values, thermal properties of construction materials and levels of infiltration. As well as inhabitants in terms of households’ habits and way of using the space as well as inhabitants age, number of family members and income.

Similar parameters influence building performance as well. They might be summarized again by: the geographic location and climate (air temperature and humidity), building shape and orientation, construction materials, thermal insulation, Envelope U value, type and size of glazing as well as topography and geographical context. The previously mentioned parameters can be also categorized into different categories such as: environmental parameters, social and cultural related parameters, technology, economy and functional factors (Oral et al., 2004) however, they are all interlocked and related and one category can't be separated from another. (Monna, 2012) (Muhaisen and Dabboor, 2013) (Cicelsky and Meir, 2014) have tested the influence of different parameters on the performance of building envelope and have found that such factors can be very critical and can affect the performance of the building envelope itself while also affecting the indoor energy consumption and user's comfort. Better indoor environments will have better effects on people's health and wellbeing as well as on user's productivity and comfort.

Energy Consumption worldwide has shown great increase recently with an annual average of 1.8% to 2% between the years of 1984 to 2004 (Pérez-Lombard et al., 2008). Buildings account for about 40% of the global energy consumption in which a great percentage of such energy is consumed so as to achieve thermal comfort in buildings (Khatib, 2011). The energy sector in Palestine faces many significant challenges due to the lack of primary energy resources and due to the fact that energy is usually imported from Israel which has resulted in financial and political problems. The Residential sector account for about 60% of the total electrical energy consumed in Palestine (Njore, 2016). Special attention is needed to minimize energy consumed in buildings and a special concentration is needed to point out the reasons behind such consumption. Buildings today should be energy efficient and environmentally friendly. Rethinking and improving building envelopes can contribute to a more energy efficient buildings and to a higher comfort level. Introducing codes related to building envelopes is necessary however is not common in Palestine.

Careful selection of construction materials involved in envelope components (walls, roofs, windows, foundations, …etc.) is highly recommended since these materials can be combined carefully to achieve specific function such as thermal comfort, acoustic comfort, natural daylight harvesting and energy efficiency. Construction materials can be combined or arranged in different ways to introduce different types of building envelopes. In walls for instance, the materials can be arranged in different orders and with different thicknesses. Different insulation materials can be used. Insulation materials can be applied to the inner part or the outer part of the wall. Different envelope orientations should be treated differently. In many countries such as Palestine where there are no building regulations related to building envelope selection and consideration, common walls, roofs and floors are rarely insulated. Table 1 explores the most common envelope components arrangements in Palestine.

Table 1: Most Common Envelope Components and their Material Arrangement in Palestine (Ministry of Local Government, 2004) – See Appendix 3

Layers	**Density Kg/m^3**	**Specific heat J/kg .K**	**Thermal conductivity W/m. K**	**Thickness m**	**U value**
Walls					
Stone	2250	1000	1.70	0.05	3.2
Concrete	2300	1000	1.75	0.20	
Roofs					
Plaster	2000	1000	1.20	0.03	2.8
Reinforced Concrete Layer	2500	1000	1.75	0.26	
Inclined concrete layer	2300	1000	1.75	0.07	
Rain water insulation	2300	1000	1.10	0.03	
Floors					
Porcelain Tiles	1900	1000	1.05	0.02	1.17
Sand	1750	1000	0.42	0.15	
Reinforced concrete	2500	1000	1.75	0.26	
Plaster	2000	1000	1.20	0.02	

- Density, specific heat and thermal conductivity values are based on values provided by the ministry of local government in the published guidelines for energy efficient buildings design – 2004.

Many factors are influencing the selection of construction materials. The most common factor is the availability of construction materials in the desired building context by means of available resources. Another is related to design considerations such as building type, social and cultural values as well as common construction practices. Moreover, existing codes and regulations followed such as seismic codes, firefighting codes as well as structural loads can be a major influencing factor as well. Cost, financial issues and maintenance considerations are also important.

Public awareness in the form of energy regulations and energy education plays a great role in facing this trend (Ibrik and Mahmoud, 2005). Energy regulation should be imposed on energy consumption by means of building code and building management as well as energy education in the form of new courses and conferences regarding the introduction of renewable energy resources.

2.2 Thermal Performance in Residential Buildings

Thermal performance is the performance of the space due to heat flow between internal space and the outdoor environment. Building envelope components such as: walls, windows, roofs and their type of construction as well as construction materials are responsible for the previously mentioned flow. Designers should aim to design a thermally comfortable environments with minimum energy demand which is an important goal worldwide since the whole world is facing energy crisis, environmental pollution and climate change that is caused by human's great demand on energy.

2.3 Heat Transfer in Buildings

Heat transfer in buildings occurs as a result of the differences of temperature between indoor and outdoor environments as well as the result of solar energy radiation on envelope surfaces. Not only heat gain and loss occurs due to conduction, convection and radiation. Buildings have internal heat gains resulting from any sensible and latent heat emitted within the space such as number of occupants, their activities, lighting fixtures as well as home appliances used and their working schedule. Infiltration as well as ventilation can also contribute to a great extent to heat transfer in buildings (Younes et al., 2012) (Feijó-Muñoz et al., 2019).

Solar radiation toward building envelopes for a long period of time may cause external envelope surfaces to absorb heat and so to transfer heat into the internal environment causing a raise in the cooling loads. Some ministries worldwide propose energy efficiency regulations to minimize energy consumption in buildings. For instance, the Dubai Green Building Regulations mandates that external buildings envelopes in the United Arab Emirates should use finish materials with 45% light reflecting value as well as 70 % solar reflectance (Salama and AlSaber, 2013). Green Roofs are highly rewarded by other ministries (Friess and Rakhshan, 2017). Phase change envelope materials are emerging in Europe (Kenisarin and Mahkamov, 2016). Climate conscious architecture is highly recommended. Ministries should start imposing regulations on buildings so as to encourage energy efficient buildings since the world is suffering from climate change and

Global Warning. Climatic conscious design as well as energy efficient buildings can be defined as designs and buildings that consume minimum energy for heating and cooling due to their conscious design (Johansson et al., 2009). In other words, due to the fact that the building overall design including its orientation, integrated vegetation, choice of building insulation, size and shape of window, …etc. help maximizing solar gain during winter while minimizing solar gain during summer.

2.4 Impact of Thermal Performance on Energy Consumption

Thermal Performance have a direct relation with energy consumption (Park et al., 2016). The less heat transfer (heat gain and loss) through the building envelope, the less energy demand needed to reach thermal comfort and vice versa. Thermal Comfort is the main source for buildings energy consumption (Ozel, 2011). Thermal comfort is people's satisfaction with the thermal environment (Andersson et al., 1985) which makes it to a great extent the driver for energy consumption. If people are not satisfied with the thermal environment, they will consume energy to reach comfort. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has developed and used two main factors to evaluate thermal comfort. Those are the predicted mean vote (PMV) and the predicted percentage of people dissatisfied (PPD). PMV can be predicted by six variables: air temperature, relative air velocity, mean radiant temperature, mean air humidity, clothing and metabolic rate. Those variables highly effect thermal comfort. PPD is the proportion of inhabitants that are uncomfortable with their thermal environments. The more the percentage of people dissatisfied means that the thermal performance of the environment is not satisfying and so, energy is needed to reach thermal comfort.

2.5 Impact of Different Parameters on Building Thermal Performance and on Energy consumption

There has become a great awareness recently toward energy consumption and sustainability. 73% of heat gain and heat loss in buildings occurs through its building envelope (DoE, 2011). The main methods of heat transfer (gain and loss) in buildings is through conduction with the building envelope itself as well as radiation through windows and infiltration through envelope components (Sabouri, 2012). Controlling heat gain and heat loss through building envelope may be an action toward more energy efficient buildings. Different parameters related to envelope design has been proposed and tested to enhance comfort and energy consumption. They are related _but not limited to_ building shape and size, building orientation, site context and weather data, different window to wall ratios, different glazing types, different thermal insulating materials, shading devices and ventilation strategies and can be categorized as described in Figure 3.

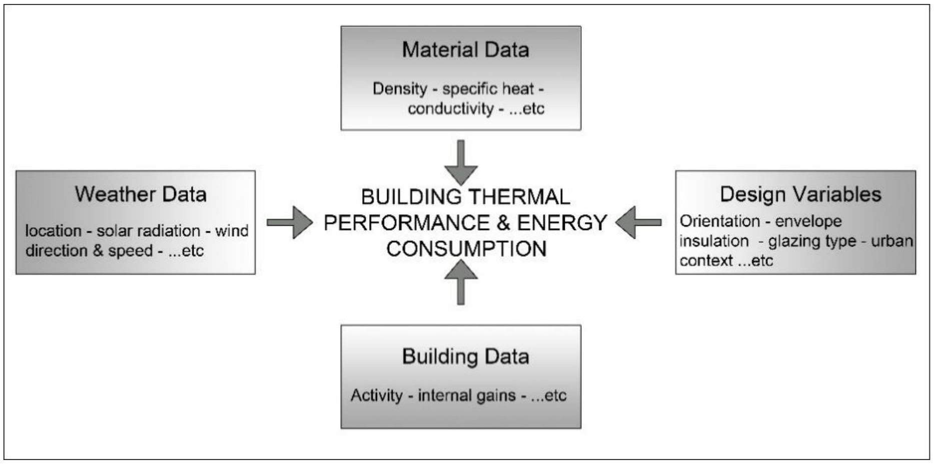


Figure 3: categorized Parameters Related to Thermal Performance and Energy Consumption

Source: by the researcher

2.5.1 Effect of Different Design Decisions

- Building Form and Dimension

Thermal comfort is affected to a great extent by the physical characteristics of a building such as: building shape, building dimensions and floor height. Natural daylight and natural ventilation are highly affected by building shape (AlAnzi et al., 2009). Deep plans reach the degree of thermal comfort harder than shallow plans since deep plans lack good effects of natural ventilation (St. Clair and Hyde, 2009). Building height and natural ventilation are directly connection, the higher the building, the better the effect of natural ventilation. Courtyard buildings proved better thermal performance than regular buildings (Mirrahimi et al., 2016).

Different studies have investigated the optimum building ratio (building length to width) that achieves the best comfort. 1:1.7 and 1:3 were considered optimum ratios for buildings in hot and humid climates (Olgyay, 2015).

- Building Orientation

Building orientation refers to the way building is situated on a specific site taking into consideration the position of windows. It is an important factor to consider when dominant wind air is needed or rejected to enhance comfort as well as when great amount of natural daylight is needed at a specific time frame during the day or the season to minimize energy consumption. In some climatic zones, dominant wind direction and speed are highly needed in buildings and so orientation can play a great role in achieving thermal comfort. For instant, night ventilation is extremely needed during summer in Mediterranean climates (Ascione et al., 2016). It is also important when studying building orientation to relate building rotation to the closeness to neighboring building and to any elements that cause shading such as topography or trees (Abanda and Byers, 2016) (Siddhartha, 2015) (Friess and Rakhshan, 2017).

Choosing the best orientation can affect heating and cooling loads in buildings (Al-Tamimi et al., 2011). For moderate as well as hot and humid climates, it was observed that buildings consume less energy annually if oriented north. However, in hot and humid climates, west orientation was observed to have the less annual energy consumption (Siddhartha, 2015). Not only building orientation differs, but also heat gain through different window orientations makes big difference. In cold climates, south oriented openings are the best. In hot climates, north orientation is the most favorable. In moderate climates, the lowest total loads are usually acheived when spaces are oriented toward the south (Andersson et al., 1985).

Shading devices play an important role in parallel with orientation. They have great impact on controlling heat gain and the amount of natural day light penetrating through the space in rooms that suffers from orientation problems in a specific season. Solar gains are sometimes essential, however, in some cases excessive solar gains affect the thermal and visual comfort especially in terms of daylight, views and temperature. And so, an adaptable shading device can manage to completely block sunrays, or to completely block direct sunrays while allowing the reflected sunrays to penetrate to the interior. As well as, they might work as a reflective light shelve that can reflect needed sunlight into the interior. Shading device whether external or internal are necessary to deal with different window to wall ratios (Ascione et al., 2016).

- Thermal Insulation

One of the most effective passive envelope parameters for energy efficient buildings is thermal insulation. Insulation materials can be found in different forms, shapes and dimensions. They might be in the form of rigid panels or loose material. Some are spray type. Others are reflective. Air space medium can also be considered an insulating material. They can be combined with other building materials or integrated within different envelope configuration to improve their thermal resistance.

The optimum insulation thickness is defined to be what caused the lowest heating and cooling energies at minimum total cost which includes initial cost, running cost and final cost (Alsayed and Tayeh, 2019). Applying thermal insulation to walls and roofs can help reduce occupants discomfort by 17% annually in a Palestine - Gaza (Asfour and Kandeel, 2016). (Eskin and Türkmen, 2008) have tested the effect of different thicknesses of Extruded polystyrene thermal insulation on a base case office space in four different climates in Turkey. Antalya represents Mediterranean climate, Istanbul represents mild climate, Ankara represents hot summer and cold winter and Izmir represents hot summer and warm winter. By applying 75mm thick insulation on the inner side of the wall, 29.2% reduction in heating and cooling energies was achieved in Antalya, 25.43% in Izmir, 18% in Istanbul and 19.02% in Ankara.

- Glazing

Another effective passive envelope parameter related to energy efficient buildings is window size and type. Many aspects need to be taken into consideration when choosing a window type such as: glass thickness and color, solar control, its architectural appearance, day light control, safety, visual contact, sound control, thermal losses and shading devices(Hassouneh et al., 2010). Choosing an appropriate window design will definitely reduce the energy consumption (Muhaisen and Dabboor, 2013). South windows are not favored in hot climate of Gaza. Low U value glazing is also preferred to reduce energy consumption. Triple windows are better than double windows in both hot and cold climates (Bülow-Hübe, 1998). However glazing properties differs. In hot climates, triple reflecting glass is encouraged. In cold climates triple clear glass is recommended.

- Effect of urban context

Urban context can be a source of sun shading (Samuelson et al., 2016). Urban context has greater effects on cooling energies rather than heating energies. It might decrease the annual cooling energies from 11 – 18% annually (Samuelson et al., 2016).

2.5.2 Effect of Material Data

Building thermal performance is an important factor to successful building designs. Building thermal performance can be defined as the ability of building components to transfer heat between the indoor and the outdoor environment. When getting to select walls, roofs and floors construction materials, there are different thing to consider (Jatav et al., 2014). One is material thermal mass, which is the ability of the material itself to absorb and store heat. Another is material U value and R value, which is its ability to transfer heat or resist heat. The thermal performance of a building envelope depends largely on how the thermal characteristics and material thicknesses are selected and arranged within the envelope (Al-Saadi, 2006) (Said and Alsamamra, 2019).

2.5.2.1 Common Construction Materials in the Study Context

- Stone: Stone is a very popular cladding material in Palestine. It is highly available in the Palestinian market as well as it is very hard and durable which made it a preferable material. Stone passes through different stages until it’s ready to be used as a cladding material. From finding and extracting suitable rocks to cutting the stone into the needed size and shaping and giving it its final textures. It is usually produced in standard dimensions of rectangular pieces with thicknesses range from 2 to 7cm and length ranges from 25-80cm and height mainly 25 or 50cm.

Different types of stone are available in the Palestinian market. Its type and properties differ according to the geographic location where it’s been extracted and so stone is classified and named after its extracting location. For example: Yata stone and Bani Naim Stone are named after the extracting origin. It might be classified also based on its final texture as well.

Table 2: Thermal Properties of the Most Popular Stone in the Study Context

Source: (Hadid, 2002b)

Stone Type	**Source**	**Density kg / m³**	**Thermal Conductivity (W/m.c°)**	**Price dollar per m²**
Injasah	Hebron – Bini Na’em	2200	1.53	22
Qabatya	Jenin	2580	2.23	
Asserah & Jameen	Nablus & Ramallah	2650	2.6	21
Samouh	Hebron	2500	2.2	17
Tafouh	Hebron	2000	1.4	17

- Concrete: concrete is a mixture of Portland cement, aggregate and water. Chemical reaction resulted from this mixture called hydration which helps the mixture to harden and form the desired concrete material. The properties of concrete depend on the proportion of ingredients mixed in the concrete making process. Typically, the mixture consists of 10 to 15 percent cement, 60 to 75 percent aggregate with 15 to 20 percent water. The type and size of aggregate used or needed depend on the thickness and the purpose of the desired mixture. When mixing cement and water, a paste material resulted and help in the mixing with aggregate while this entire paste hardens and gains strength through the hydration process. This mixture should be poured in the desired location before it become very hard.

Concrete is used to a great extent in walls, roofs and floors. There are different forms of concrete. Ready mixed concrete which is the most common form. Concrete get mixed at plant factory and then delivered to construction sites. This form is used in floors (slabs) and ceilings. Precast concrete is another form, however is not very common in the study context. Concrete masonry blocks are another form and are widely used in residential buildings for internals walls and partitions. Concrete might be also mixed on site depending on the quantities and size of pouring, this is a very common method in residential buildings for backup concrete behind stone in external walls. Thermal properties of ready-mix concrete as well as masonry blocks are shown in table 3 and 4. They mainly depend on the mixture density as well as different block sizes and weight.

Table 3: Thermal Properties of Ready-Mix Concrete.

Source: : (Hadid, 2002b)

Density (Kg/m³)	Thermal Conductivity (W/m.C°)	Specific Heat Capacity (Kj/Kg/C)
800	0.39	0.97
900	0.44	0.97
1000	0.49	0.97
1100	0.55	0.97
1200	0.62	0.97
1300	0.70	0.97
1400	0.79	0.97
1500	0.89	0.97
1600	1.00	0.97
1800	1.30	0.97
2000	1.60	0.97
2300	1.75	0.97
2500	1.75	0.97

High densities such as 2300 and 2500 kg/m³ are usually used in reinforced slabs and backup concrete behind stone walls for apartment buildings. High densities are required since apartment buildings have high structural loads, large areas and large overall building height.

Table 4: Thermal Properties of Ready-Mix Concrete.

Source: : (Hadid, 2002b)

Block Dimensions (cm) (Width X Length X Thickness)	Weight (KG)	Density Kg/m³	Thermal Conductivity (W/m.c°)
40 x 20 x 20	18	1125	0.38
40 x 20 x 20	21	1350	0.32
40 x 20 x 20	14	875	0.43
40 x 20 x 15	16	667	0.33
40 x 20 x 10	11	1375	0.15
40 x 20 x 7	8	1428	0.10
40 x 20 x 7	9	1607	0.09

- Insulations: there are few types of insulation available in the construction market. Polyurethane foam and polystyrene sheets whether expanded or extruded are insulating products that are manufactured in Palestine. Rock wool Panels are available in the Palestinian market but are imported from Jordan.

Polystyrene is available in the form of rigid board in different thicknesses 12.7, 19.05, 25.4, 38.1, 50.8, 76.2, 101.6 mm. Extruded polystyrene insulation (XPS) and Expanded Polystyrene Insulation (EPS) differs in their manufacturing process. The XPS manufacturing process involves melting all ingredients together. The liquid formed for this process is then extruded through a die and expands during the cooling process. The Expanded polystyrene insulation (EPS) is manufactured through a mold. Heat is then applied to the mold which cause the small beads to expand and fuse together (WEB). The previously mentioned types as well as the polyurethane foam has very similar thermal properties as shown in Table 5.

Figure 4: Expanded Polystyrene

Source: https://www.indiamart.com/proddetail/xps-extruded-polystyrene-insulation-9457949688.html

Figure 5: Extruded Polystyrene

Source: https://www.styroboard.com/eps

Figure 6: Polyurethane foam

Source: https://www.ufcsprayfoam.com/about-spray-foam.html

Rock Wool Panels are available in the form of rigid and semi rigid panels with different thicknesses that ranged from 30 – 100 mm. Semi Rigid Panels are usually used in buildings. Different facing materials can be applied on top of those rigid panels (Hadid, 2002b).

Table 5: Thermal Properties of Different Insulating Materials

Source: (Hadid, 2002b)

Type	Density (Kg/m³)	Conductivity (W/mK)
Extruded Polystyrene	27	0.025
Expanded Polystyrene	27 – 40	0.022
Foam Polyurethane	30	0.026
Rock Wool	40 – 80	0.032

Insulation materials in the Palestinian construction sector are used in a very typical way without any thermal calculation. For example, different houses with different areas and different orientation share similar construction materials, similar wall sections and similar type and thickness of insulation.

- Fenestration: In Palestine and specifically in residential buildings, double clear glazing is the most used glass in windows with regular aluminum frame. Aluminum shutters are the basic and common shading devices. The average window to floor ratio in reference to the researcher observations done to the real estate market is 29 – 30 % in living space (Living room + kitchen).

Different glazing types as shown in Table 6 as well as thermal break aluminum is available in the Palestinian market. Those types differ in their Solar Heat Gain Coefficient (SHGC) and in their visible transmittance (VT). SHGC is the ration of solar heat gain through a glazing surface resulting for the solar radiation touching that surface at a specific angle which is usually perpendicular to the glazing surface and at a considerable environmental condition (outdoor temperatures and wind speed (Rathi, 2012). VT is the ratio of natural daylight penetrating through the glazing surface.

Tinted and reflected glass are used to reduce the amount of solar energy transmitted through the space. Tinted glass absorbs little amount of solar heat while blocking daylight. It helps in reducing glare. Reflected glass reflect solar heat. And so, both tinted and reflected glass are great solutions to minimize cooling energies. Low energy coating glass whether double low energy or triple low energy are designed with low U values but are intended to allow maximum solar heat to penetrate through their surface.

Table 6: Physical Characteristics of Windows Available in the Palestinian Market

Source: (Hadid, 2002b)

Type	**Visible Transmittance**	**Solar Heat Gain Coefficient (SHGC)**	**U-Value**
Clear – double glass	81 %	76%	2.73
Tinted – double glass	61%	63%	2.70
Reflective – double glass	8%	63%	2.73
Double – High Solar Gain - Low E Glass	78%	26%	1.99
Double – Low Solar Gain - Low E Glass	64%	26%	1.7
Triple – High Solar Gain - Low E Glass	69%	55%	1.42
Triple – Low Solar Gain - Low E Glass	63%	38%	1.02

2.6 Energy Loss through building envelopes

The building envelope is the critical part (layer) that can control the quality of indoor environments. The indoor space energy demand is highly connected to the efficiency of the building envelope. 20 – 50% of heating and cooling demand is produced from the design and properties of the building envelope only (Yu et al., 2015) (González et al., 2011). There are many different ways to improve the performance of building envelopes. Method one _which is the focal method in this research_ is by the use of high-performance building materials such as employing insulating materials, high quality glazing as well as good quality thermal aluminum to eliminate air leakage and heat gain and loss through building envelopes. The second method is by using advanced and sustainable building materials such as: phase change materials, unfired clay bricks, aerated concrete blocks, …etc (Goodhew and Griffiths, 2005) (Wijesuriya et al., 2018). The third method is by using sustainable techniques in constructing building envelopes such as: the tromb wall, the ventilated double skin façade, wall based solar chimney, solar walls and integrated greenery walls (Zhang et al., 2016). All are methods that have been studied and elaborated recently as a result of the recent increase interest in environmentally friendly and energy efficient buildings.

Heating energies needed due to envelope components is highly affected by the envelope component U Value. It can be calculated by multiplying envelope U values (walls, glass and roofs U values) with its area and with the difference in temperature between the desired indoor temperature and the average outdoor air temperature (Handbook, 2017). Material U values _which is defined as the rate of heat transfer through the material itself_ is an important characteristic in minimizing heating and cooling energies. The lower the U value, the less energy required for heating and cooling energies and vice versa.

2.7 Energy Consumption in Palestine

Electricity accounts for 34% of the energy consumption in Palestine while diesel, Gasoline, LPG and wood accounts for 26%, 11%, 11% and 10% of the energy consumption respectively (Njore, 2016) as shown in Figure 7 which is considered a general consumption for all aspects of life sectors (buildings, industry, transportation and manufacture…etc.). While such consumption was classified more specifically according to building sectors as shown in Figure 8. Residential sector accounts for 62% of the energy consumption (Njore, 2016)

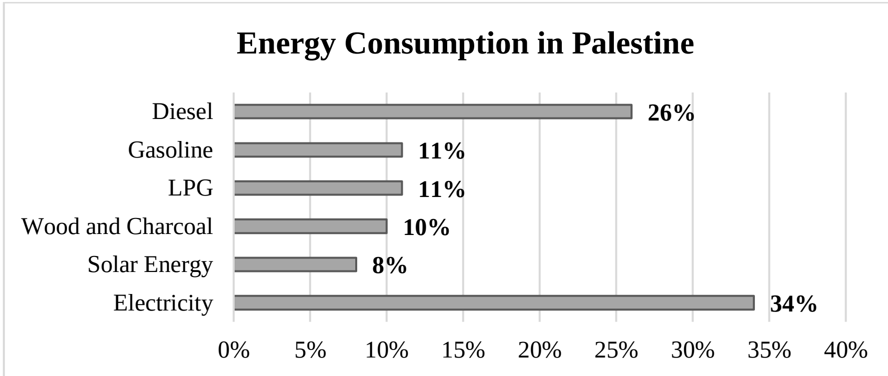


Figure 7: Summary of Total Energy Consumption in Palestine Including all Aspects of Life Sectors

Source: (Njore, 2016)

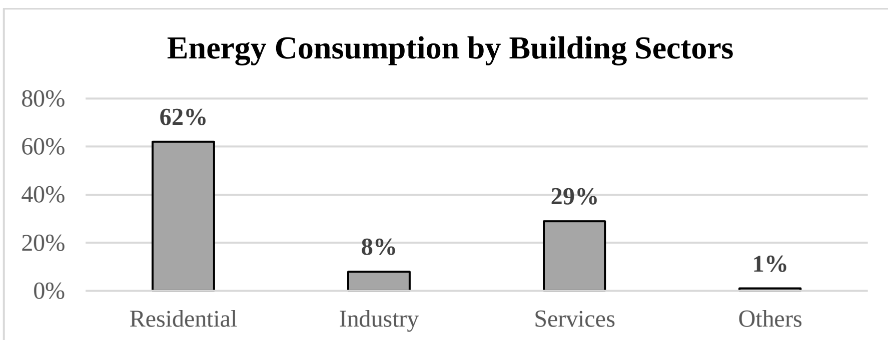


Figure 8: Classification of Energy Consumption per Building Sector in Palestine

Source: (Njore, 2016)

2.8 Electricity Consumption in Residential Buildings in Palestine

Residential buildings account for 60.9% of buildings in Palestine (PCBS, 2017). 99.6% of households in Palestine are connected to the main electrical network as reported by the central Bureau of Statistics in the year 2006. The electricity in Palestine is mainly imported from other countries, 87% from the occupying entity “Israel”, 1% from Jordan, 3% from Egypt and 9% from Palestinian electric company (Hamed et al., 2012)

Since electricity accounts for the largest energy consumption, monthly electrical consumption records were gathered by the researcher from the Jerusalem District Electrical Company (JDECO) however, the electrical consumption in Palestine is not classified by building sectors and so Figure 9 presents general electricity consumption in Palestine in all building sectors. The JDECO company covers the Bethlehem, Jericho, Ramallah and the Jerusalem governate only. Figure 6 summarizes the total consumption annually in Gigawatt Hour. The records show that between 2007 to 2019 the electrical consumption has increased (doubled), which means that electrical consumption is rising at a great rate. Since buildings account for 60% of such consumption, designers, architects, engineers and decision makers should mandate and propose the design and construction of energy efficient buildings. Building simulation should become an integral part of the building design process. It should be given greater attention so as to save the environment and the depletion of natural resources.

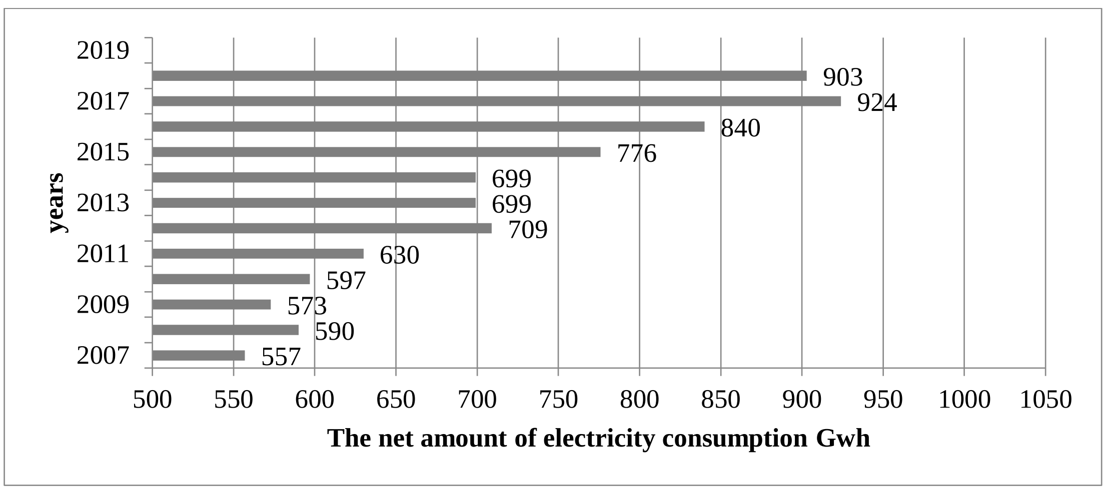


Figure 9: Total Annual Electricity Consumption in Giga Watt hour (GWH) in all aspects of life sectors

Source: (JDECO, 2019)

2.9 Strategies to Minimizing Energy Consumption in Buildings

Strategies to minimize energy consumption in buildings can be divided into two levels. Level one is at decision making levels (regional level) which includes imposing new strategies and new regulations that helps minimizing energy consumption in buildings. The second is at design level which includes accurate energy modeling of buildings.

Level one of strategies can be achieved by mandatory imposing regulations on buildings. Such regulation can propose for example _while it is not limited to_ mandatory self-generate electricity to cover a certain percentage of its own consumption. This can be achieved by adding rooftop PV systems to self-generate electricity. In addition to mandatory imposing regulations on the percentage of integrated greenery per built area, since greenery has great effect on surrounding air quality, it may be a good shading device which will enhance building performance.

The second level of strategies can be achieved by accurately modeling building performance and energy consumption in Buildings during the design of any building to check the effect of design on building performance. Building environmental simulation engines are highly needed at this level. Designers need to be familiar with the use of simulation programs.

Computational simulation is one of the most powerful building performance analysis tools. Building simulation programs are highly needed to accurately model environmental aspects. DesignBuilder is a comprehensive interface for EnergyPlus and has been used throughout this research. It provides specific material templates that includes wide range of materials and parameters and can be effective for different countries and regions. It may also allow the user to introduce and modify parameters and material characteristics to its already defined library. It performs simulations of energy, CFD and daylighting despite the fact that it is a slow and complicated process unless someone is very familiar with the use of such software.

2.9.1 Parametric Simulation Process

Parametric simulation is one kind of building simulation. Parametric is derived from the word parameter. It may be defined by measurable and quantifiable feature (Gero, 1990) (Hudson, 2010)(Hudson, 2010). Such definitions have led to its methodology used throughout this thesis, parametric simulation will be treated as measurable factor that led to optimum solutions (Hudson, 2010).

It helps in testing different design decisions. It can be very effective in predicting the best building design related performance. Parametric simulation can be an optimization strategy toward better building performance. It can be a supporting decision making method that is very effective during design phases (Østergård et al., 2016). Parametric design is an approach to generate and explore a wide range of design alternatives (Lapinskiene and Martinaitis, 2013). It allows testing unlimited variables while evaluating and comparing what best suits the specific design condition. However, if done by a computational simulation engine, it might take lots of time and effort which makes simplified tools highly recommended.

A parametric design is usually a presentation of a design with constant and variable parameters. The designer can manage to change the variable parameters to achieve different solutions to the problem associated with the designed parametric model. It is a method based on relationship thinking and testing the effect of such relationships on the designed model. The parametric design process starts by defining the variable parameters that need to be tested, identifying the relationship between the different parameters, clearly identifying the design conditions in order to create variations and to test the results (Ozel, 2011).

Parametric design method has unlimited advantages. It considers all relevant parameters that may affect the design. It leads to determining and choosing the best parameter while understanding its effect on the design. This study proposes a simulation-based tool to help designers test different envelope related parameters and their effect on building performance and on energy consumption through parametric simulation and sensitivity analysis. It is simple to use and is usable throughout the design process. It graphically presents its results by graphs and charts.

2.10 Conclusion

This chapter has focused on discussing all envelope related parameters that affect thermal performance and energy consumption. Those parameters were categorized into four different categories. One is related to the building design such as: its orientation, its envelope insulation properties, its glazing type, the urban context …etc. Another is related to construction materials and their thermal properties. Another is related to building internal loads and activity and finally parameters related to building location and weather data. It has analyzed energy consumption in buildings and the available construction materials in Palestine. This intensive literature review has guided this research through testing all the previously mentioned parameters to assess their effect on building performance and on energy consumption in the defined prototype as well as in the defined weather data used throughout this research, as will be elaborated and discussed in details in the next chapter.

Chapter Three

Simulation Methodology and Proposed Tool Preset factors

3.1 Introduction

Thermal performance of residential buildings can be affected by many factors as studied in detail throughout the literature review. It is affected by the building design, its geometry, its function, its layout and height, in addition to the construction materials used in its envelope (Monna, 2012) (Muhaisen and Dabboor, 2013) (Cicelsky and Meir, 2014). Dominant building laws and regulation influenced to a great extent the design of residential buildings and so influenced the building performance as well, in addition to the available construction materials and construction techniques in the building context, as well as the social and cultural values that can’t be ignored while proposing optimization strategies to enhance the overall building performance.

This chapter will study and test the factors and parameters affecting building performance as well as it will identify and describe general practices for residential buildings in Palestine such as: the characteristics of residential buildings in Palestine, the construction techniques used in apartment buildings and the common construction materials used for such types of buildings.

3.2 Documenting common designs of apartment buildings in Palestine

A survey was carried out for the residential buildings in Palestine in order to collect data related to the most common design used in such buildings by means of floor plan layout, windows ratios, areas, number of floors, number of residential units per floor and envelope configuration in order to develop a typological base case model based on the followings:

1. Floor plan layout: includes spaces and standard related to window to floor ratios.

2. Building size: includes floor area and height.

3. Building envelope: includes floors, walls and roofs construction materials.

An online questionnaire was emailed to 30 selected experienced engineers from Bethlehem, Ramallah, Nablus and Hebron with the help of the local engineering syndicate _ that helped in forwarding the survey to selected engineers with experiences greater than 10 years in the working field _ in order to develop a general idea on the most common model for residential apartments in the study context. The questionnaire as shown in APPENDIX-1 & 2 is divided into three sections. The first section includes general information about the respondent such as region or city of work as well as years of experience in the field of designing and supervising the construction of residential buildings and specifically apartment buildings. The second section includes general characteristics usually found in apartment buildings such as the number of residential units per floor, the average apartment areas and number of floors. The third section covered the envelope insulation materials by means of the most common type of insulation used in the generic wall design as well as the type and color of glazing used in the generic windows. The last section also concentrated on whether local people and investors care to add insulation to the building envelope and what part of the building envelope is usually insulated.

The questionnaire was designed using google form and was then analyzed. The number of residential units per floor has been divided based on the responses into three categories: two units per floor, three units per floor and four units per floor. Figure 10 shows that the result differed from one governate to another. For example, two residential units per floor is very common in Ramallah, while three units and four are more dominant in Nablus. While In terms of the usual average apartment area, the majority voted for 140 – 150m² as shown in Figure 11. Which was in accordance with the buildings statistics done by the Palestinian Central Bureau of Statistics who stated that the average apartment areas for apartment buildings in Palestine is about 144m² (PCBS, 2017).

The questionnaire showed that great percentage (78% of the responses) of local people and investors are aware of the importance of insulation. However, it is not common to add insulation to floors and roofs in Palestine. External walls are the only membrane that is usually insulated in buildings, either by the use of thermal air gap or by the use of expanded polystyrene insulating sheets. Double and clear glazing is widely used in windows. Refer to figures 12, 13, 14, 15 and 16.

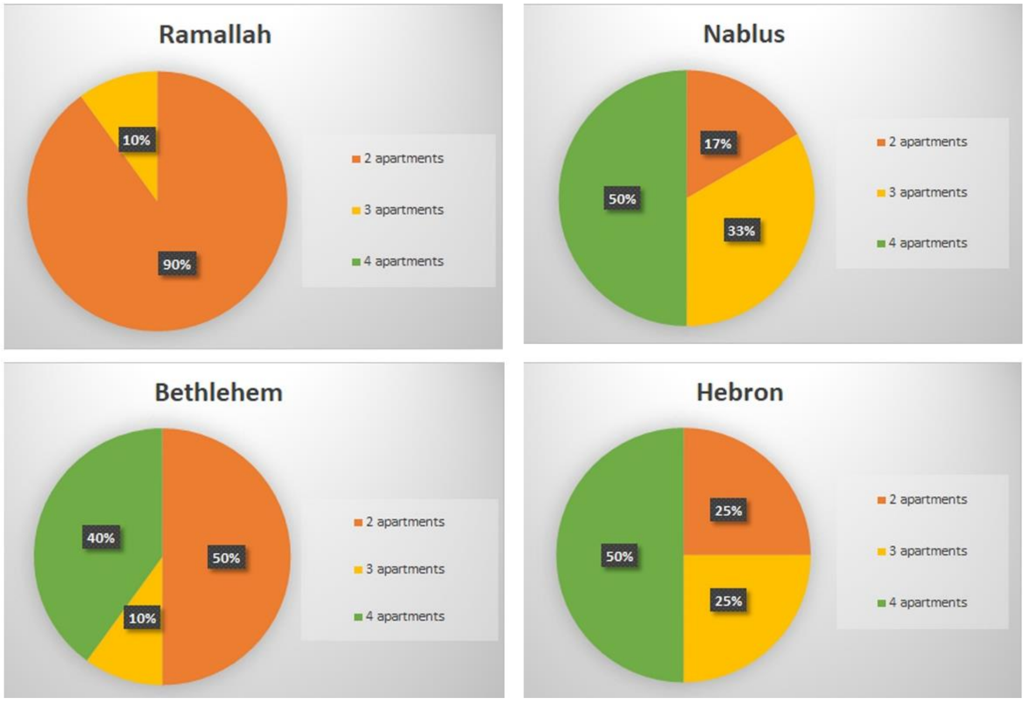


Figure 10: Common Residential Units Per Floor According to Governate

Source: Questionnaire designed, distributed and evaluated by the researcher

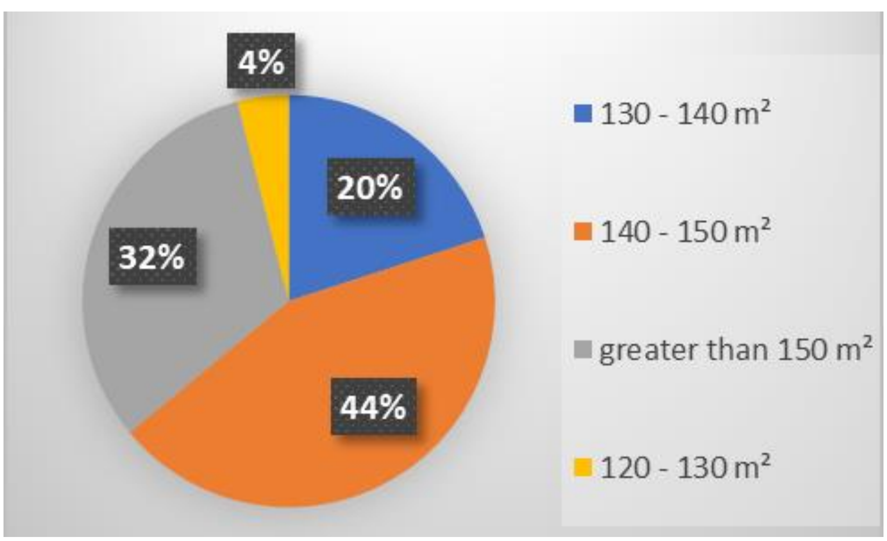


Figure 11: Common Apartment Areas

Source: Questionnaire designed, distributed and evaluated by the researcher

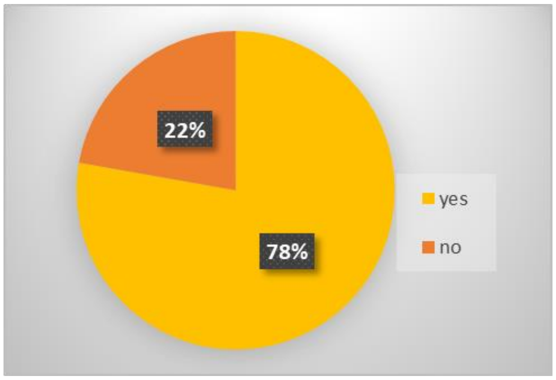


Figure 12: Awareness of the Importance of Insulation in the study context

Source: Questionnaire designed, distributed and evaluated by the researcher

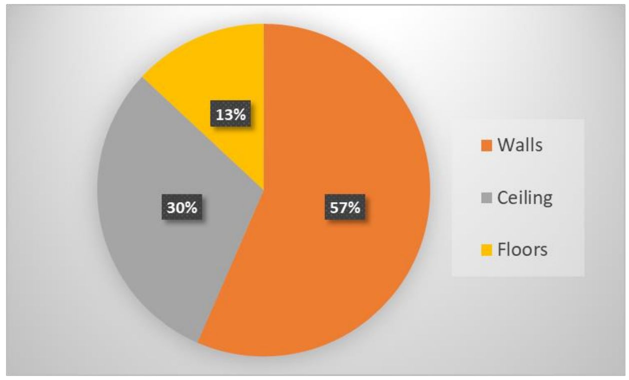


Figure 13: location of Insulation Within typical Building Envelope (Walls, Floors, Roofs)

Source: Questionnaire designed, distributed and evaluated by the researcher

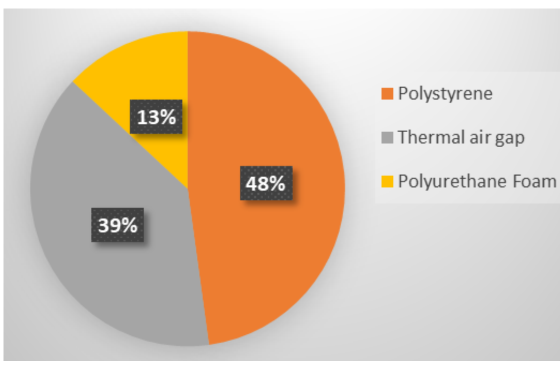


Figure 14: The Most Common Insulating Materials Used in Buildings

Source: Questionnaire designed, distributed and evaluated by the researcher

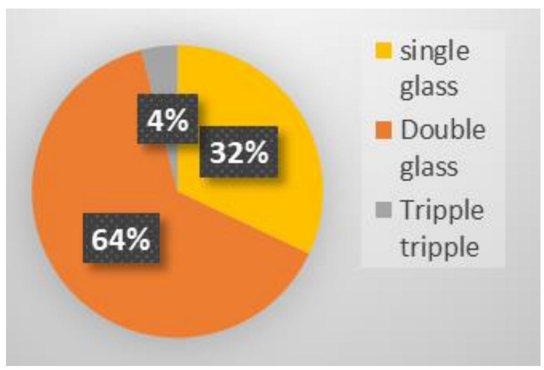


Figure 15: The Most Common Type of Glazing Used in Buildings

Source: Questionnaire designed, distributed and evaluated by the researcher

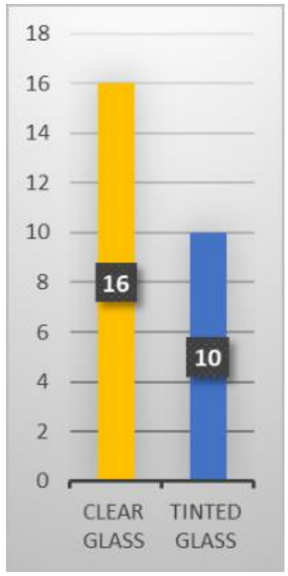


Figure 16: The Most Common Fenestration Color Used in Buildings

Source: Questionnaire designed, distributed and evaluated by the researcher

Residential buildings designs fails if it doesn't consider the occupants (Ardda et al., 2018). This is very true when observing residential buildings in Palestine. Socio cultural values are never ignored in this type of buildings. Visual privacy is highly needed. Large Window to wall ratios or completely glazing facades are never found or accepted. Apartments compositions in terms of accessibility as well as access to view need to be private. Social values are given greater attention in residential buildings than environmental or economic values. For instance, so as to give the social values a great priority, apartment owners might accept to have guests' rooms with poor access to daylight and natural ventilation or even with no available access at all.

Two interviews were done with professionals in the design of residential buildings from Bethlehem to get a more elaborated image toward the most common designs used for apartment buildings in the study area. They both agreed on many facts. One is that the previously mentioned type of buildings uses local construction techniques and local construction materials in their construction. In other words, such type of buildings is characterized by its stone walls and reinforced concrete structure. Second is that the design concept should respect the social and cultural values in terms of space configuration and openings sizes. It should provide privacy. Moreover, its area should be sufficient to accommodate the average number of the Palestinian family members (Dieck, 2020) (AlAraj, 2020).

Observing the real estate market and analyzing many recently built apartment buildings was also done to the study context. The major observations outcomes were summarized by:

- There is a demand for open living space areas in recent apartment buildings (open kitchen and living space).

- The guest room is an important space and is never ignored in the study area.

- All spaces have windows which is an important factor and without its availability building permits won't be approved.

- Windows sizes are very similar in almost all observed cases. Their height ranged between 1.3 to 1.56 meters, while their width range between 0.90 to 1.20 meters.

The previous methods were all used in the development of the base case residential prototype developed for the use of this thesis and for the development of the simulation-based tool.

3.3 Documenting Construction Techniques and Construction Materials Used in Residential Buildings in Palestine

- Wall Systems: Stone walls are widely spread in the Palestinian cities and in some villages. It is very common in the construction of residential buildings. Figure 17 shows the most common wall type that is usually used in apartment buildings in Palestine and especially in the study area. Stone thickness varies from 3 – 5cm. However, since the majority of these buildings are constructed to be sold by investors to home owners, stone thickness was minimized to 3cm thick stone to save money in construction.

The external walls are constructed from 3 cm stone cladding material, 25 cm concrete layer and 1.5cm thick layer of plaster is usually applied to the 25cm concrete layer.

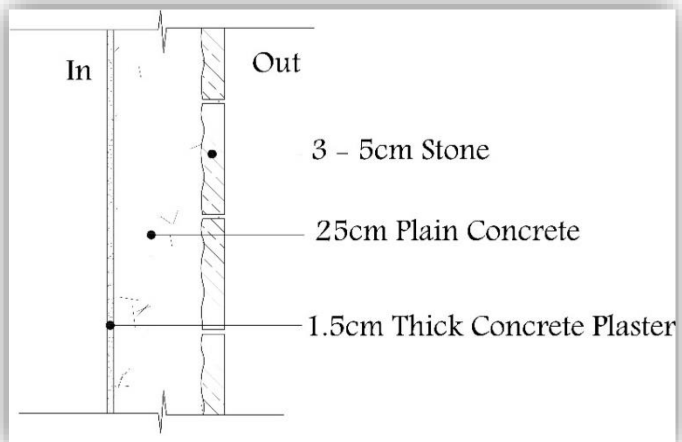


Figure 17: Vertical Section in Typical Stone wall

Source: (Salameh, 2012)

- ***Roof Systems***: reinforced concrete slabs are found to be widely used for roofs in residential buildings with water treatment membrane on top. Inclined concrete layer covered with asphalt layer are the most common water treatment membrane. Concrete slabs are rarely insulated.

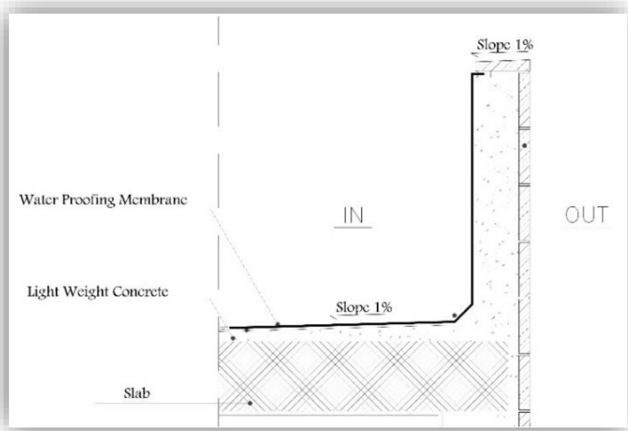


Figure 18: Horizontal section in a typical Roof

- Floor Systems: floors consist of 26cm reinforced concrete slabs, 15cm sand and cement mortar to separate the concrete slab from the porcelain tile (the finish material) as shown in figure 18. Sand thickness varies depending on the amount needed to cover all electrical and mechanical pipes installations.

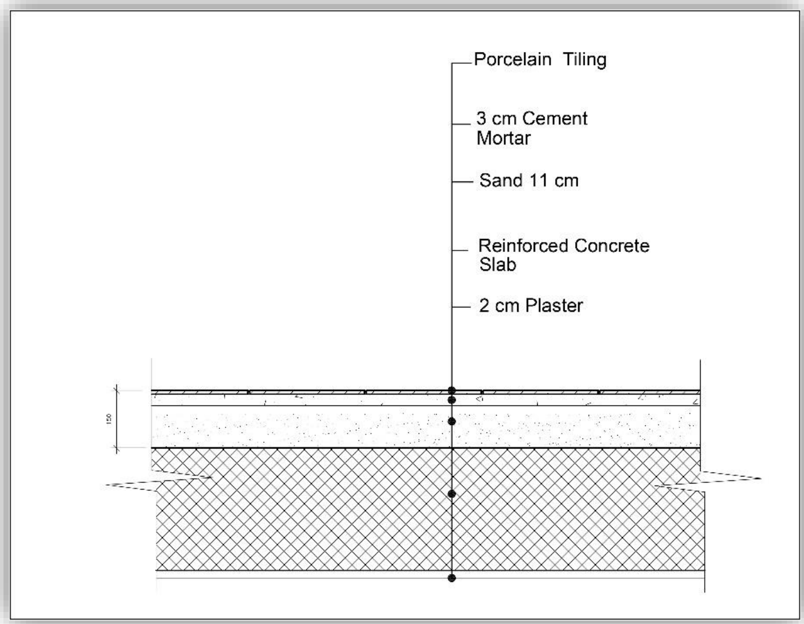


Figure 19: Horizontal Section in Typical Floor

Source: (Salameh, 2012)

The energy losses in buildings and specifically in the residential sector reaches 25% resulting from the external walls only (The World Bank Group, 2016).

3.4 Development of the Base Case Residential Building:

Based on the data collected in the form of survey, interviews and observation. It is found that the architectural design of residential buildings in Palestine are affected to a very high extent by social and cultural values. In another words, residential units should provide privacy in terms of spaces distribution as well as openings sizes and layouts. In addition to provide sufficient area to accommodate the average number of Palestinian family members.

In terms of construction techniques and as mentioned before, local construction techniques are local construction materials are used in such type of buildings. Buildings are of stone facades and concrete structures.

Three apartment typologies have been taken as base case studies. The three typologies shown in figures 20, 21 and 22 were found to be representative models for residential buildings in the study context depending on the number of residential units per floor. Typology one as shown in figure 20 represents two residential units per floor building. The average area of one apartment is 150 m² with a net heated and cooled area of 40m2 representing the common living space area. The second typology as shown in figure 21 represents three residential units per floor building. The average area of each apartment is 155m² with a net heated and cooled area of 40m² also representing the living space zone. The third typology represents four residential units per floor building. All three typologies are of five story building blocks based on the Palestinian Local Buildings Regulations.

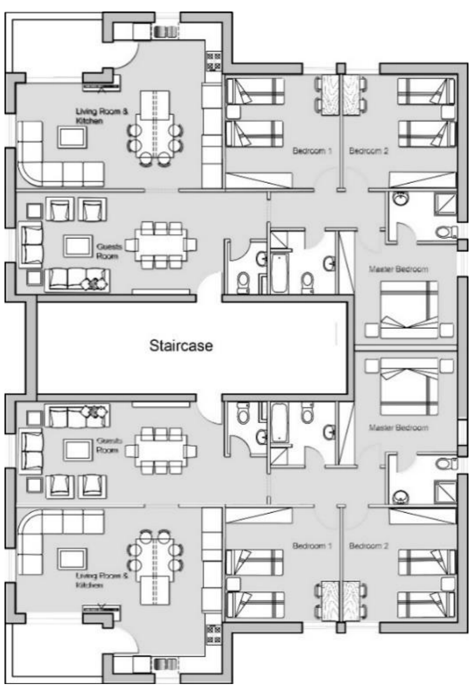


Figure 20: Base Case Model – Typology 1

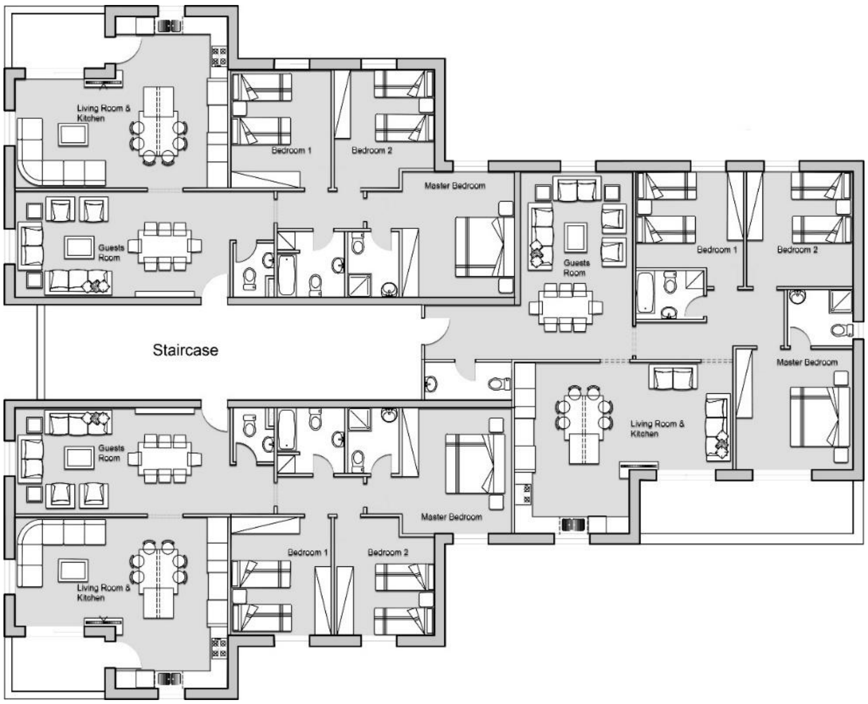


Figure21: Base Case Model – Typology 2

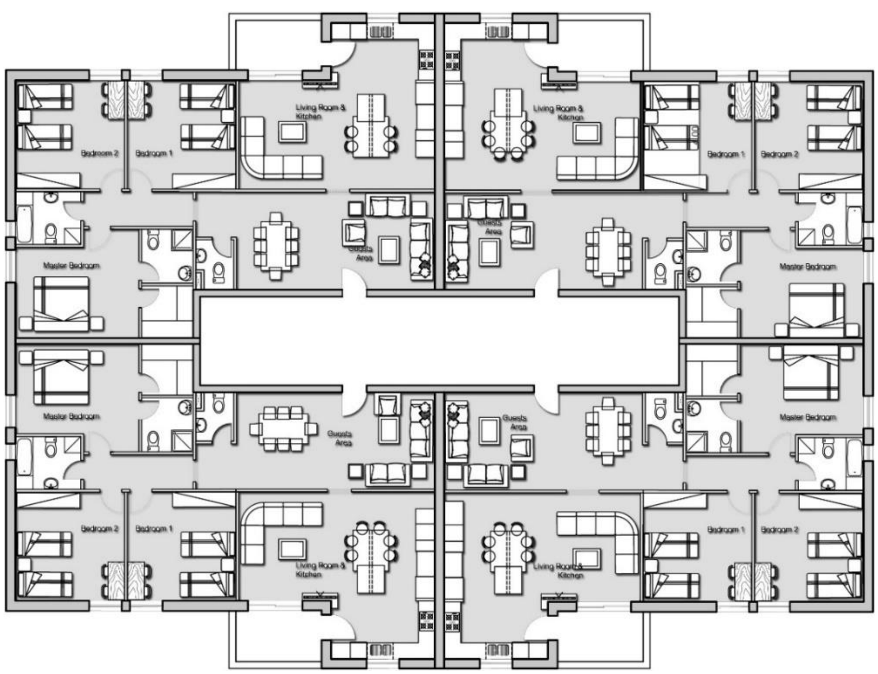


Figure 22: base Case Model – Typology 3

The basic building construction for all typologies is a reinforced concrete structure with 3cm thick stone walls. Thermal air gap is used for insulation. Windows are clear double glazed with 81% visible transmittance and 76% Solar Heat Gain Coefficient. Table 7 describes the physical characteristics of Typical Residential buildings (Apartments) in the study context.

Table 7: Physical Characteristics of Residential Buildings (Apartments) in Palestine

Physical Characteristics		
1.	Floor Layout	- 2 apartments per floor - 3 apartments per floor - 4 apartments per floor
2.	Apartment Area (m²)	145 – 160 m²
3.	Glazing ratio (window to floor ratio)	- 27 to 30 % in living zone - 11% in Bedrooms
4.	Shape of the plan	- Rectangular in 2 apartment buildings - Square in 3 and 4 apartment buildings
5.	Floor Height	- 3.00 meter
6.	Number of floors	- 5 floors
Construction method		
5.	Stone wall consists of: - 3cm stone - 20 cm backup concrete - 1.5cm plaster	
6	Roof Construction method - 26 cm Concrete slab - Asphalt layer	
7	Floor Construction: - 26cm reinforced concrete - 15cm Sand and cement mortar - 2-3 cm thick Tile	
Finishing Materials		
8	Internal Partitions	Painted 10cm Block
9	Floors	Porcelain tiles

To address the different variable parameters and the way the proposed tool deals with such variable. Different parameters were identified and investigated to check their effect on building performance and energy consumption. They will be tested in section 3.6 under a fixed set of conditions to check their effect on thermal performance and on energy consumption. The testing outcomes will determine how the tool will be dealing with such parameters.

3.5 Development of the Design Conditions

The case study was chosen to be located in the fourth climatic zone of Palestine. Palestine is characterized by the Mediterranean climate. It has long, hot and dry summers and short, cool and rainy winters. Palestine has been divided into seven climatic zones: five climatic zones in the west bank and two in Gaza (Juaidi et al., 2016) (see Figure 23). This division depended on variety of criteria such as: rainfall, temperature, humidity and vegetation (Hadid, 2002a). The forth climatic zone includes sub-humid regions (Mediterranean climate), warm sub-humid summer and cold winters. It lies in the central highlands such as Nablus, Jerusalem, Bethlehem, Ramallah and Hebron. It covers about 23.2% from the area of Palestine excluding Gaza (1314.6 km²). The population in this area is approximately 1.2 million people in comparison with 2.99 million people in Palestine (excluding the population of Gaza). It represents 47% of the total population in Palestine excluding Gaza. The average mean annual temperature is 17.7°C which is in reference to 11.1°C in January and 25.6°C in August. The prevailing wind speed is 4.7 km/h and is directed to the west and north west direction.

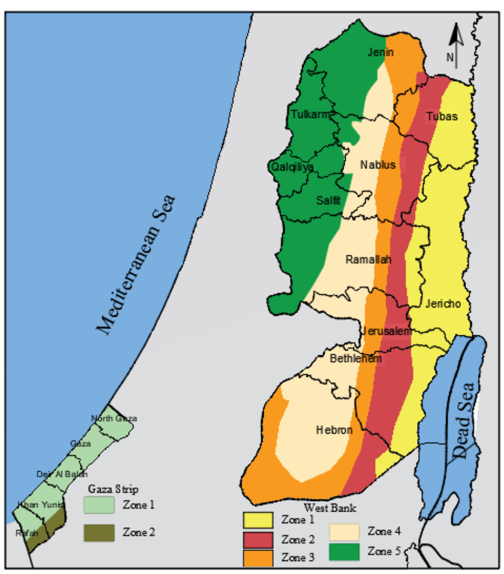


Figure 23: Climatic Zones in Palestine

Source: ((ARIJ), 2003)

The base case model presents a base case apartment building model with a special emphasis on the living space. The living space presents an open living space with a kitchen area of 35.00 m² facing different orientations (north, south, east, west, north west, south west, north east and south east… etc.). It is assumed that the building is in a low urban context and that its envelope is composed of 3cm stone, 20cm backup concrete as well as 2cm plaster and paint which is the typical scenario in the study context. Glazing is double clear glazing as well as aluminum is normal aluminum frames. Window to floor ratio ranges between 26 to 29.5% depending on the building prototype (see figure 20, 21 and 22) which is in accordance to most green building regulations that tend to restrict glazing ratio that is below 25% to the total floor area (Communities and Government, 2010). The thermal properties and the availability of the construction materials were assigned based on different interviews with manufacturers as well as with reference to the Energy Codes For buildings and their publication "Construction Techniques Survey In Palestinian Territories" (Khammash, 2002).

The residential space is considered to be occupied daily. The base case models are equipped with HVAC system. The operation time is 8:00AM to 10:00PM. The living space is the only space that is equipped with heating and cooling system. The set point of room temperature is 25°C for cooling and 21°C for heating. The occupancy density equals to 0.0215 people/m². The lighting target was set to 300 Lux in the simulation program. The minimum fresh air for one person equals 2.36 l/s-person.

Different Parameters such as insulation thicknesses and different glazing characteristics …etc. available in the local Palestinian market will be evaluated against the previously described base case to check their effect on building performance and energy consumption as shown in section 3.6.

3.6 Testing and Identifying Design Parameters and Input Values

To determine the main variables that affect thermal performance and energy consumption. Different simulations were conducted and sensitivity analysis techniques _changing only one variable at a time while keeping others constant_ was used to check the effect of building layout (number of residential units per floor), orientation, floor level, types of stones available in the study context, insulation, glass type and topography on the previously mentioned sustainable factors (building performance and energy consumption). This will help in classifying parameters depending on their effect on energy consumption.

3.6.1 Building Layout:

Building Layout in terms of building design and the number of residential units planned per floor is very important. Not only, building layout highly affect the apartment's envelope area that is exposed to the outdoor environment and so might to a great extent affect energy consumption, it also presents typical residential prototypes available in Palestine and specifically in the study context that needs to be taken into consideration as reference base cases in the design of the proposed tool.

3.6.2 Orientation

To check the effect of orientation on building performance and on heating and cooling energies, a reference case was estimated and then the same case was simulated every 15° degree starting from 0 to 360 as shown in figure 24. It has been observed that orientation has great effect on energy consumption and that it is an important factor to consider when studying building performance and energy consumption.

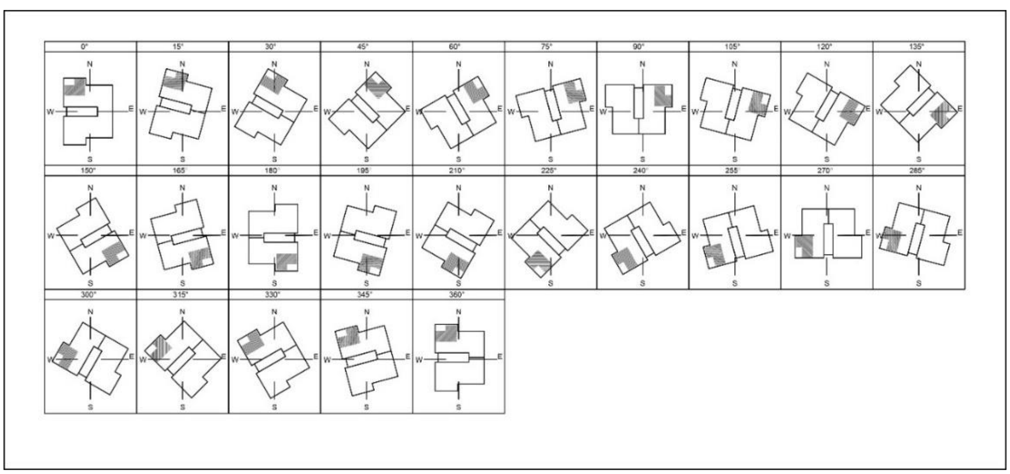


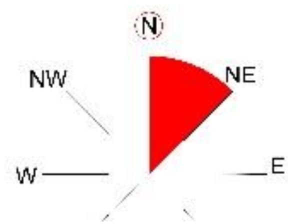
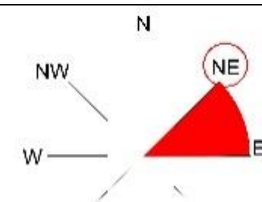
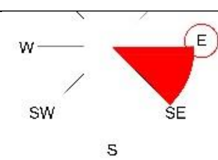
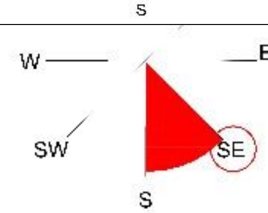
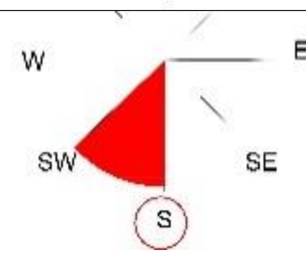
Figure 24: Orientation

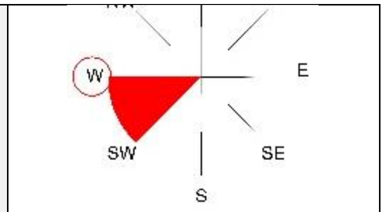
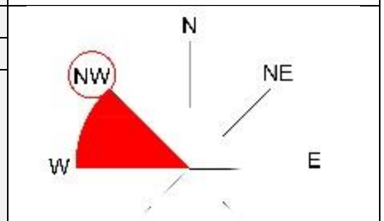
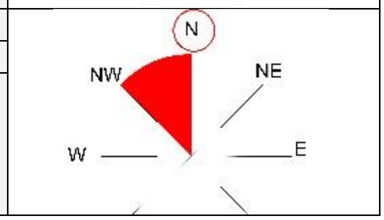
Table 8: Effect of Orientation on Annual Heating and Cooling Loads (Jerusalem Weather Data)

Reference case	Orientation	Annual Heating (KWh)	Annual Cooling (KWh)
- 2 residential units per floor - Roof Floor - Orientation: north west - Low urban density - Envelope: 3cm stone 20cm backup concrete 3cm thermal air gap 7cm masonry blocks 1.5 cm plaster	0	3,904.0	1,590.0
	15	3,974.0	1,538.0
	30	4,032.0	1,488.0
	45	4,054.0	1,482.0
	60	4,028.0	1,508.0
	75	3,951.0	1,528.0
	90	3,833.0	1,548.0
	105	3,688.0	1,594.0
	120	3,548.0	1,658.0
	135	3,422.0	1,713.0
	150	3,306.0	1,741.0
	165	3,199.0	1,752.0
	180	3,118.0	1.758.0
	195	3,045.0	1,779.0
	210	3,064.0	1,798.0
	225	3,001.0	1,830.0
	240	3,033.0	1,862.0
	255	3090.0	1,872.0
	270	3,181.0	1,844.0
	285	3,295.0	1,826.0
	300	3,485.0	1,810.0
	315	3,631.0	1,786.0
	330	3,760.0	1,728.0
	345	3,864. 0	1,654.0
	360	3,950.0	1,587.0

For the pupose of this study, some actions (decisions) need to be taken so to get the best outcomes from the designed tool. For instant: 15° and 30° orientations will be identified as 0° orientation following the worst consumption scenario…etc.

Table 9: Actions and Considerations to be Taken into Account When Defining Orientation

Degree	Annual energy consumption (KWH) (heating and cooling)	Compared to	Difference in consumption annualy (KWH)	Action
15°	5,419.0	0°	+ 68.0	
30°	5,134.0	45°	-28.0	
		0°	+112.0	
60°	5,489.0	45°	-1.0	
75°	5,075.0	90 °	+ 93.0	
105°	5,161.0	150°	+ 145.0	
120°	5,018.0	90	-288.0	
		150	+320.0	
135°	4,857.0	150	+ 170.0	
165°	4,524.0	150	-174.0	
		180	+140.0	
195°	4,260.00	180	-124.0	
		225	+62.0	
210°	4,188.0	225	-10.0	
		180	+ 196.0	
240°	4,284.0	225	+86.0	

255°	4,388.0	255	+190.0	
285°	4,636.0	270	+139.0	
300°	4,817.0	270	+319.0	
		315	-178.0	
330°	5,136.0	315	+141.0	
345°	5,247.0	315	+252.0	
		360	-103.0	

3.6.3 Floor Level

To check the effect of building height on building performance and on heating and cooling energies, a reference case was estimated and then the same case was simulated at each floor level as shown in table 8. The results prove that building height has great effects on energy consumption and it's an important parameter and need special actions to be taken into consideration when trying to achieve low energy buildings.

Each floor should be treated differently depending on its location (Height) as well as orientation which is not common in the construction practices in Palestine. The purpose of this study as well as this tool is to propose such differences and its effects on energy consumption so as to facilitate decision making at the very early design stages while dealing with such parameters.

Table 10: Effect of Building Height on Energy Consumption

Reference case		Ground Floor	First Floor on top of a parking	Mid Floor – Third Floor	Roof – Fourth floor
- 2 residential units per floor - Orientation: north west - Low urban density - Base case envelope (3cm stone, 20cm concrete, 3cm air gap, 7 cm block, 1.5 plaster)	Annual Heating (KWh):	2,672.0	3,370.0	3,416.0	3,919.0
	Annual Cooling: (KWh):	1,283.0	1,578.0	1,263.0	1,587.0
	Total Energy Consumption (KWh):	3,955.0	4,948.0	4,679.0	5,506.0

3.6.4 Type & Thickness of Stone

To check the effect of different types of stone with different thicknesses on building performance and on heating and cooling energies, a reference case was estimated and then the same case was simulated using different stone characteristics and different thicknesses as shown in table 11 and 12. The results shows that the varying stone characteristics has little effects on energy consumption and the worst stone type can be generalized for the purpose of this study.

Table 11: Effect of 3cm Thick Stone on Energy consumption

Reference case		Stone Type 1 (Injasah)	Stone Type 2 (Qabatya)	Stone Type 3 (Aseerah & Jamaeen)	Stone Type 4 (Samou')	Stone Type 5 (Tafooh)
2 residential units per floor - Roof Floor - Orientation: north west - Low urban density - Base case envelope (3cm stone, 20cm concrete, 3cm air gap, 7 cm block, 1.5 plaster)	Annual Heating (KWh):	3,937.0	3,949.0	3,950.0	3,947.0	3,934.0
	Annual Cooling: (KWh):	1,591.0	1,588.0	1,587.0	1,587.0	1,591.0

Table 12: Effect of 5cm Thick Stone on Energy Consumption

Reference case		Stone Type 1 (Injasah)	Stone Type 2 (Qabatya)	Stone Type 3 (Aseerah & Jamaeen)	Stone Type 4 (Samou')	Stone Type 5 (Tafooh)
- 2 residential units per floor - Roof Floor - Orientation: north west - Low urban density - Envelope (5cm stone, 20cm concrete, 3cm air gap, 7 cm block, 1.5 plaster)	Annual Heating (KWh):	3,898.0	3,914.0	3,919.0	3,914.0	3,894.0
	Annual Cooling: (KWh):	1,592. 0	1,588.0	1,587.0	1,588.0	1,592.0

3.6.5 Type of Insulation

To assess the effect of insulation on heating and cooling energies, a reference case was estimated and then the same case was simulated using different insulation materials as well as with different locations within envelope to assess insulation effect on energy consumption in buildings.

The results as shown in table 13 showed that insulation is a very important parameter and has major effects on energy consumption however, the different types of insulation shows little difference in their effect on energy consumption. Its location as well as thickness is what actually matters when concentrating on energy consumption in buildings. Table 14 and 15 assess different thicknesses of insulating materials as well as different locations.

All insulating materials are designed to have low thermal conductivity and so are great materials to resist heat gain and heat loss. Not only, the use of insulation within envelop configuration is important, their thickness as well as their location within envelope is what matters the best. As shown in table 14, using 76.2mm expanded polystyrene insulating sheets help minimizing 231.23 KW annually in 40.0m² net heated area, while raising the cooling energy by 57.95 KW annually. Moreover, complete envelope insulation help minimizing heating and cooling energies by 29.54%, 15.98 % annually.

For the purpose of this study insulation type is ignored however, insulation thickness and different locations within envelope will be clearly considered and identified.

Table 13: Effects of Thermal Insulation on Heating and Cooling Energies

Reference case		**No Insulation (Base Case)**	**Thermal air Gap**	**3cm extruded Polystyrene**	**Medium Density expanded Polystyrene**	**Polyurethane Foam**	**Rock Wool**
2 residential units per floor - Roof Floor - Orientation: north west - Low urban density - Base case envelope	Annual Heating (KWh):	4,503.0	3,950.0	3,268.0	3,237.0	3,278.0	3,332.0
	Annual Cooling: (KWh):	1,508.0	1,587.0	1,808.0	1,819. 0	1,804.0	1,785.0

Table 14: Effects of Different Polystyrene Thickness on Heating and Cooling Energies

Reference case		Expanded polystyrene			
		25.4 mm	38.1 mm	50.8 mm	76.2 mm
2 residential units per floor - Roof Floor - Orientation: north west - Low urban density - Envelope (3cm stone, 20cm concrete, thermal insulation, 7 cm block, 1.5 plaster)	Annual Heating (KWh):	3,279.0	3,180. 0	3,120.0	3,048.0
	Annual Cooling: (KWh):	1,806.0	1,835.0	1,850.0	1,864.0

Table 15: Effect of Expanded Polystyrene in Different Locations

Reference case		No Insulation	38.1 mm Expanded polystyrene	
			On walls only	On walls and roof
2 residential units per floor - Roof Floor - Orientation: north west - Low urban density - Envelope (3cm stone, 20cm concrete, thermal insulation, 7 cm block, 1.5 plaster)	Annual Heating (KWh):	4,503.0	3,180. 0	2,335.0
	Annual Cooling: (KWh):	1,508.0	1,835.0	1,523.0

3.6.6 Type of Glass

Similarly, different types of glazing available in the local market were assessed against a reference base case. However, glazing properties (U Value, Visible light transmittance (VT) and Solar Heat Gain Coefficient (SHGC)) can’t alone give a clear view to the impact on heating and cooling energies since window orientation and exterior shadings are considered major factors when dealing with energy efficient windows (Hassouneh et al., 2010).

Double tinted glass as well as double reflected glass have great impact on cooling energies, however, reflecting and blocking direct sunrays from entering the indoor environment have raised heating energies. Low energy glazing has great impact on heating and cooling energies in specific orientations. Triple glazing has high heating energies when oriented south and south east while it positively affects heating energies in north and north west orientations.

For the purpose of this study, and since glazing is considered the major source for heat gain and heat loss (Hassouneh, 2012), and since it is affected by different factors and can't be generalized to a specific case (Rathi, 2012), all five fenestration types will be taken into consideration.

Table 16: Effect of Glazing on Heating and Cooling Energies

Reference case		**Urban context (Shading)**	**Orientation**	**Clear Double Glass**	**Tinted Double Glass**	**Reflected Double Glass**
2 residential units per floor - Roof Floor - Low urban density - Base case envelope (3cm stone, 20cm concrete, 3cm air gap, 7 cm block, 1.5 plaster)	Annual Heating (KWh):	Ignored	North west	3,932.0	4,073.0	4,072.0
	Annual Cooling: (KWh):			1,577.0	1,338.0	1,389.0
	Annual Heating (KWh):	Ignored	South West	3,155.0	3,397.0	3,377.0
	Annual Cooling: (KWh):			1,873.0	1,651.0	1,671.0
	Annual Heating (KWh):	Ignored	North East	4,072.0	4,121.0	4,175.0
	Annual Cooling: (KWh):			1,529.0	1,474.0	1,409.0
	Annual Heating (KWh):	Ignored	South East	3158.0	3,253.0	3,418.0
	Annual Cooling: (KWh):			1,743.0	1669. 0	1,521.0

Table 17: Effect of Glazing on Heating and Cooling Energies

Reference case		**Urban context (Shading)**	**Orientation**	**Low Energy Double Glass**	**Low Energy Triple Glass**
2 residential units per floor - Roof Floor - Low urban density - Base case envelope (3cm stone, 20cm concrete, 3cm air gap, 7 cm block, 1.5 plaster)	Annual Heating (KWh):	Ignored	North west	3,914.0	3,899.0
	Annual Cooling: (KWh):			1,508.0	1,469.0
	Annual Heating (KWh):	Ignored	South West	3,337.0	2,588.0
	Annual Cooling: (KWh):			1,701.0	1,686.0
	Annual Heating (KWh):	Ignored	North East	4,147.0	4,150.0
	Annual Cooling: (KWh):			1,429.0	1,420.0
	Annual Heating (KWh):	Ignored	South East	3,205.0	3,235.0
	Annual Cooling: (KWh):			1,654.0	1,597.0

3.6.7 Topography and Urban Context:

The relationship between buildings and their surrounding is a very important factor when trying to study energy consumption of buildings (Yaşar et al.). Topography as well as the surrounding environment highly affect the building exposure to solar energy and to natural ventilation. The effect of topography and urban context can’t be ignored since it is a source of shading which have great effect on heating and cooling energies.

- Topography Scenarios: within the scope of this study and based on the researcher observations to the study context which represents the highlands of Nablus, Jerusalem, Ramallah, Bethlehem and Hebron. The topography was categorized into 4 scenarios as shown in figure 25, 26, 27 and 28. Scenario one represents sites with minimum effect of clips on building sites.

Scenario 2 represents sites facing cliffs from one side. Scenario 3 and 4 represents sloped sites with the effect of cliffs from two sides.

- Urban Context scenario: Table 18 describes the urban context scenarios highly presented in the study context. Low urban context represents low density sites where there is minimum 5 meters distance away between surrounding buildings that are of maximum 2 floors height. Medium Urban context represents sites where neighboring buildings are closer to each other (minimum 3 meters distance) however their height does not exceed three floors high. High urban context represents sites where neighboring buildings have great height which equals15meters (5 floors).

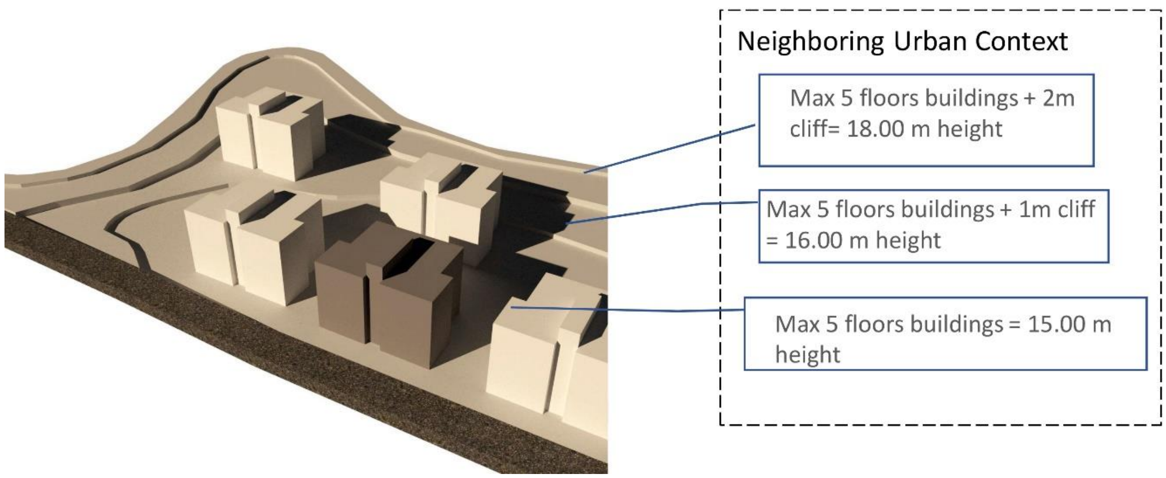


Figure 25: Topography Scenario 1

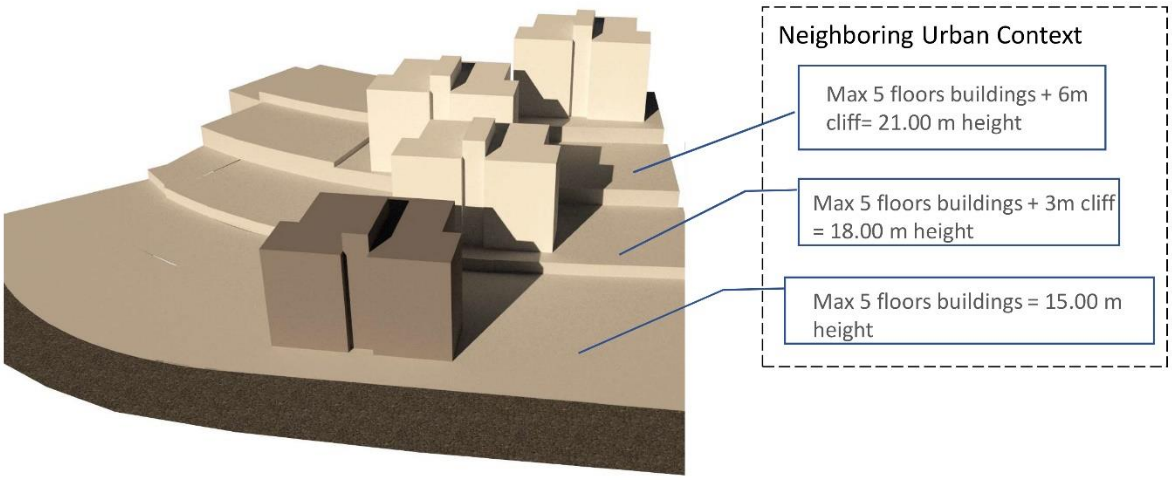


Figure 26: Topography Scenario 2

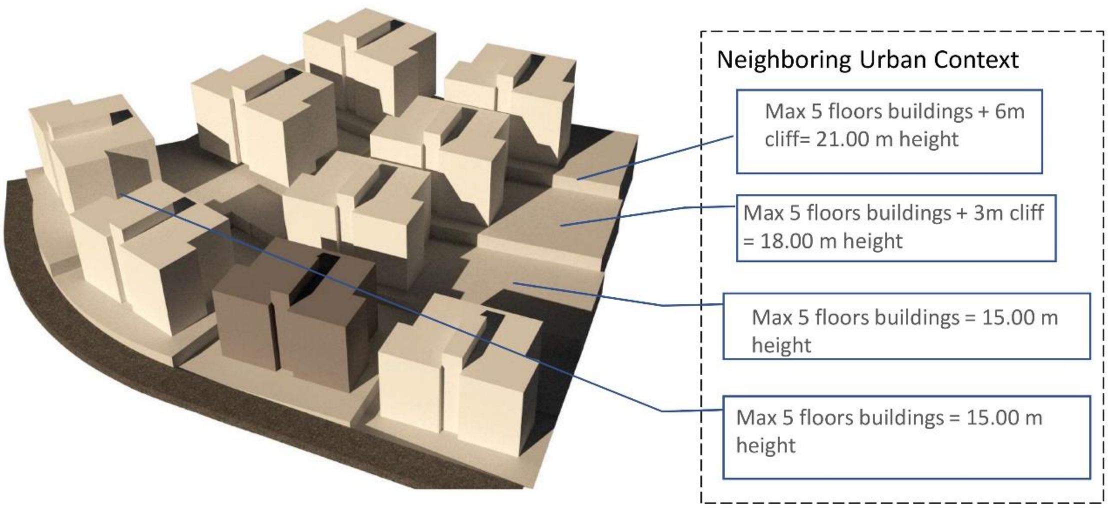


Figure 27: Topography Scenario 3

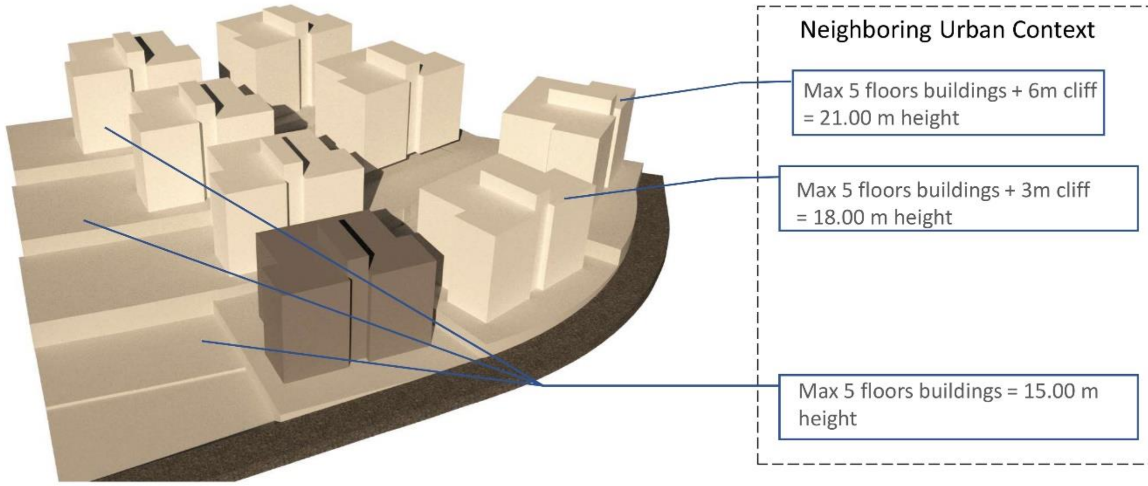


Figure 28: Topography Scenario 4

Topography combined with urban context have minimum effects in some cases which is due to the fact that living spaces are oriented opposing to the topography that is forming a shading source. However, such cases can't be ignored since when assessing the overall heating and cooling loads per apartment unit, the topography will have greater effects on other rooms and so will affect the overall apartment energy consumption. For the purpose of this study, the parametric simulation target living spaces in apartment building, however, the tool will give the user a percentage to be added to the consumption per prototype and per context so as to give a hint of overall occupied rooms energy needed for heating and cooling in buildings.

Table 18: Urban Context Scenario

Low Urban Context	Medium Urban Context	High Urban Context
- Topography scenario 1 - Surrounding buildings have side setbacks more than 5 meters between buildings - Surrounding buildings are two floors high maximum	- Topography scenario 2 - Surrounding buildings side setbacks don't exceed 3 meters between buildings - Surrounding buildings are of maximum two to three floor high	- Topography scenario 2, 3, 4 - Surrounding buildings side setbacks don't exceed 3 meters between buildings - Surrounding buildings are of five floors high

For the purpose of this study, and to assess the effect of urban context on heating and cooling energy, a reference case was assessed within the three urban context scenarios to check the effect of the surrounding environment on heating and cooling loads. The results showed that apartment buildings with 2 residential units per floor, their living spaces are less affected by topography and urban context if oriented opposing to the cliff as shown in table 19. However, three residential units apartments as well as Four residential units apartments are highly affected. Moreover, while analyzing whole apartment topography as well as urban context have shown great effect on energy consumption to all building's prototypes.

Table 19: The Effect of Urban Context on Heating and Cooling Energies – Apartment Orientation Opposite to the Cliff

Reference case			Low Urban context	Medium Urban Context	High Urban Context
- 3 residential units per floor - Orientation: north west ***(opposing the cliffs)*** - Base case envelope (3cm stone, 20cm concrete, 3cm air gap, 7 cm block, 1.5 plaster)	Ground Floor	Annual Heating (KWh)	3,197.0	3,209.0	3,207.0
		Annual Cooling (KWh)	1,000.0	1,012.0	1,008.0
	First Floor on top of a parking level	Annual Heating (KWh)	3,307.0	3,309.0	3,305.0
		Annual Cooling (KWh)	1,566.0	1,542.0	1,535.0

	Mid Floor (Third Floor)	Annual Heating (KWh)	3,041.0	3,042.0	3,050.0
		Annual Cooling (KWh)	1,273.0	1,273.0	1,249.0
	Roof Floor (Fourth Floor)	Annual Heating (KWh)	3,551.0	3,553.0	3,554.0
		Annual Cooling (KWh)	1,563.0	1,563.0	1,560.0

Table 20: The Effect of Urban Context on Heating and Cooling Energies – Apartment Orientation Facing the Cliff

Reference case			**Low Urban context**	**Medium Urban Context**	**High Urban Context**
- 3 residential units per floor - Orientation: south oriented - Base case envelope (3cm stone, 20cm concrete, 3cm air gap, 7 cm block, 1.5 plaster)	Ground Floor	Annual Heating (KWh)	2,369.0	2,682.0	2,844.0
		Annual Cooling (KWh)	873.0	882.0	845.0
	First Floor on top of a parking level	Annual Heating (KWh)	2,352.0	2,399.0	2,753.0
		Annual Cooling (KWh)	1,380.0	1,323.0	1,287.0
	Mid Floor (Third Floor)	Annual Heating (KWh)	2,163.0	2,165.0	2,229.0
		Annual Cooling (KWh)	1,181.0	1,181.0	1,089.0

Roof Floor (Fourth Floor)	Annual Heating (KWh)	2,734.0	2,734.0	2,752.0
	Annual Cooling (KWh)	1,513.0	1,512.0	1,489.0

3.6.8 Internal Loads

Internal Loads are loads gained from occupancy, lighting and home appliances… For the purpose of this study, all internal loads such as: number of occupants, their schedules and activities, lighting, home appliances and their operation schedule will be fixed throughout the entire parametric simulations.

Internal Loads also includes loads (whether heat gain or heat loss) resulted from the use of HVAC in one zone rather than the use of HVAC in the entire apartment. Such load will be analyzed and taken into consideration for the purpose of this study.

3.7 Categorizing Parameters

All the previously discussed parameters and values whether investigated in section 3.3 or pointed out in the literature review in chapter two were categorized into three categories for the purpose of this study. Those categories are the design parameters (variables), constant parameters and confounding variables. Design Parameters are the elements that are allowed to vary during the assessment process while constant parameters related to common design practices that were summarized in section 3.2. Confounding variables are factors that can't be controlled by the user but may still influence the building performance such as occupancy, lighting, buildings schedule and residential appliances…etc.

Table 21: Categorizing Parameters

Design variables (Input Parameters)	**Constant Parameters**	**Confounding Variables**
- Building layout (Residential units per floor) - Orientation - Floor Level - Insulation thickness - Glazing type and color - Aluminum type (normal aluminum or thermal break aluminum) - Urban context - Topography	- Wall configuration - Window to floor ratio - Insulation Type	- Occupancy - Lighting - Appliances

Figure 29 shows a simplified scheme of the overall cases that will be part of the developed tool. Part of these cases will be defined as base cases. For building Prototype 2, 15 base cases are developed. For building prototype 3 and 4, another 16 and 15 based cases are developed respectively. The tool will be designed to give the user the ability to compare base cases with cases that propose the use of newly defined parameters to check their influence on energy consumption as well as on building performance. Moreover, the tool will give the user a hint of annual savings in the amount of Israeli Shekels that may be saved based on the chosen envelope parameters design in comparison to the base case scenario. All cases will be simulated using Design Builder simulation software and in a fixed weather data.

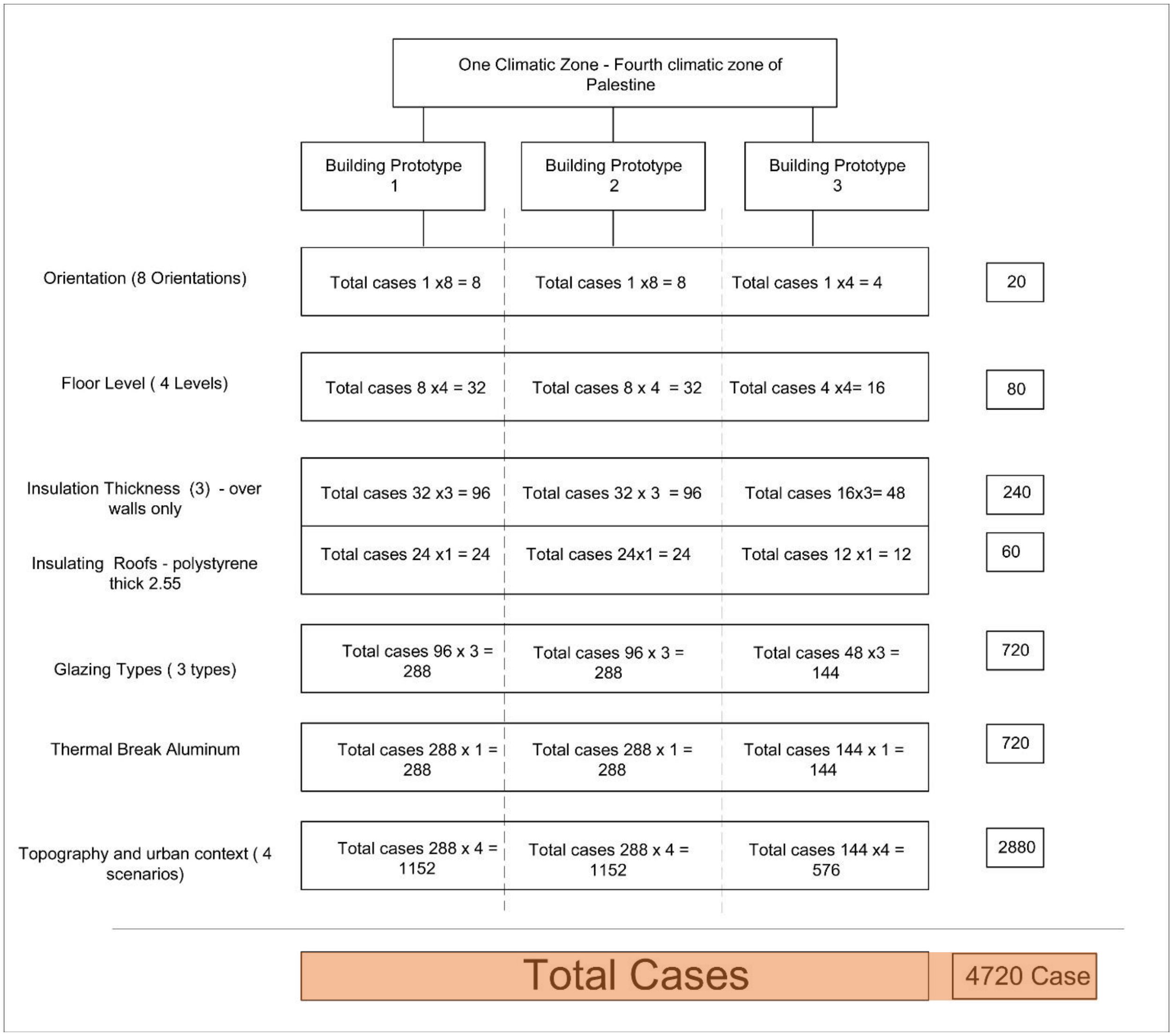


Figure 29: Overall Scheme of the Parametric Study for the Development of the Tool

3.8 Conclusion

This chapter has clearly defined the building prototype used in this tool as well as the base case envelope materials that represent the most common residential buildings envelopes in the study context. It has also defined precisely all parameters taken into consideration in the proposed tools. It informed the user of which parameters are considered variable parameters and which are considered constant parameters. This was done based on a through testing that is presented in details in this chapter. This chapter is the basic foundation to the tool interface and criteria. It led to the next chapter which include the parametric simulation and the testing procedures.

Chapter Four

Impact of Envelope Design on Building Performance and on Energy Consumption

4.1 Introduction

Indoor air temperature is used for measuring building performance. A comfortable indoor environment has been what humans always try to achieve in their buildings. A comfortable environment and a good building performance can be achieved by the use of proper envelope materials. The lack of simplified simulation tools has caused the absence of testing building performance during the design phase as well as testing the effect of different envelope configurations on building performance and so have contributed to designing poor envelopes which greatly rely on mechanical means to achieve a comfortable indoor environment. It is very important to evaluate the behavior of different envelope configurations and so to properly select the best combination that provides better indoor air temperatures and minimum energy consumption. For instance: north oriented envelopes have different effect on building performance than south or east oriented envelopes. Envelopes in a very dense urban sites react different that envelopes in a low-density urban site, ground floor level vs. roof floor is subject to different measures …etc.

4.2 Parametric Simulation

Parametric design is an approach to generate and explore a wide range of design alternatives (Lapinskiene and Martinaitis, 2013). Any parametric design should start by a set of input values (parameters) which will be subject to specific testing in order to test their outcomes. This process will allow the user to test unlimited parameters under different design conditions and to evaluate and respond to performed outcomes. This process depends on algorithm structure. The algorithm structure for this research is shown in figure 30 and has been used throughout this study to assess both building performance as well as energy consumption. Table 22 summarize the parameters being adjusted throughout the parametric design process. Such parameters were carefully selected and tested as was described in chapter three.

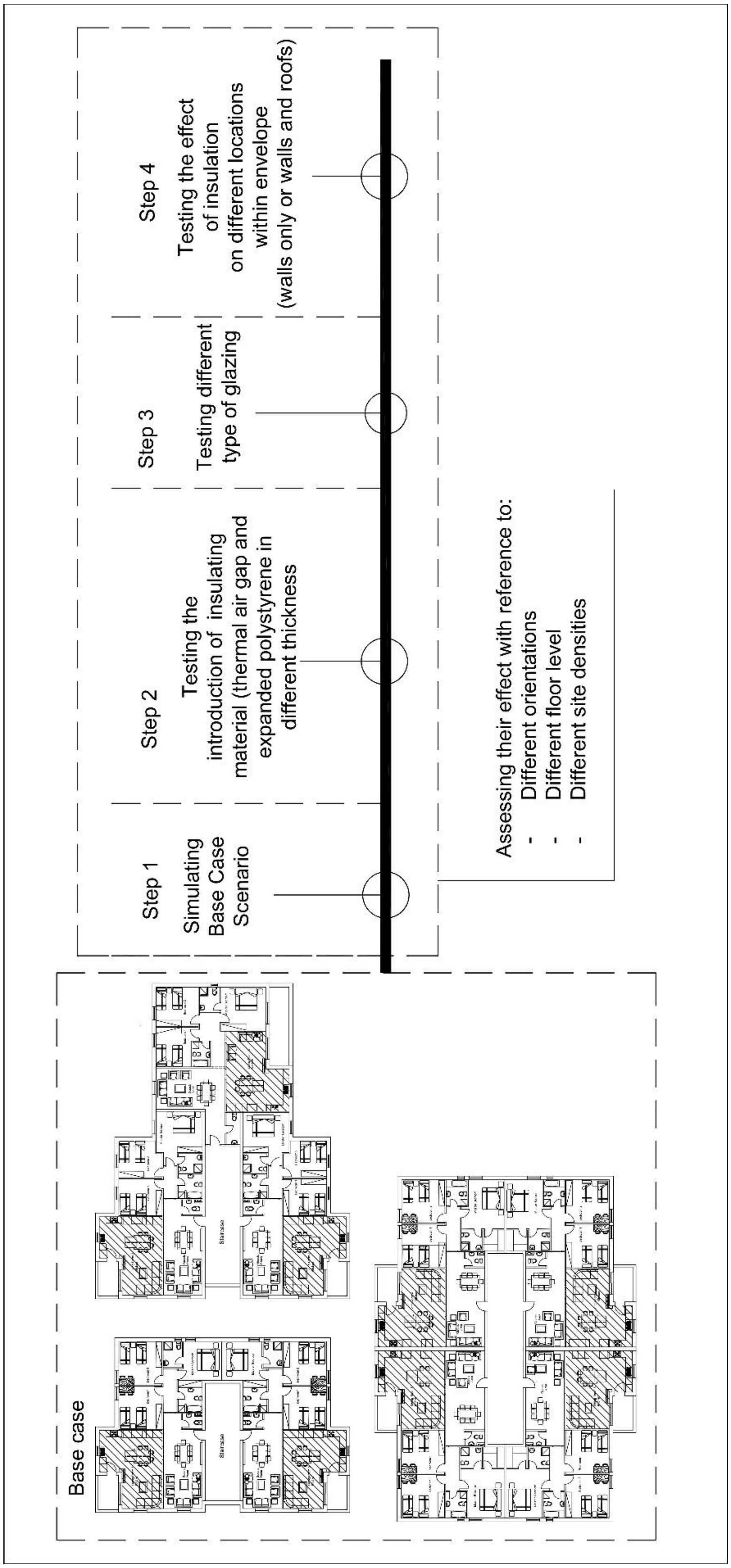


Figure 30: The Algorithm Structure for Evaluating Building Performance and Energy Consumption

Usually in early design phases, designers challenge many different concepts and alternatives to reach final design. Parametric design is highly needed to face challenges and to come up with the best design alternative. When it comes to residential buildings, each residential unit, its location, its orientation, its context as well as envelope materials need to run through different parametric simulations to figure out the best design that provides best indoor environment performance as well as minimum energy consumption. This research presents a platform where the designer can evaluate different envelope related parameters and test their effect on thermal performance and energy consumption in a simplified and fast method.

Table 22: Building and Design Parameters Adjusted During the Parametric Design Process

Parameters	**Attributes**	**No. of Values**
Insulation thickness	Variety of thickness	3
Insulation Material location	Variety of location within envelope	2
Glazing Materials	Variety of glazing properties	4
Aluminum	Variety of two types	2
Building design	Variety of number of apartments per floor	3
Building orientation	Variety of orientations	8
Floor Level	Variety of levels	4
Site densities & Topography	Varieties of urban densities combined with topography	4
Total Number of variables Parameters		22

4.3 Parametric Design Algorithm

Based on the proposed algorithm structure, different envelope configurations can be tested as shown in section 4.6. They will be tested against a fixed orientation, a fixed floor level and an estimated urban context scenario. This study is a simulation-based study that integrates simulation techniques with parametric approach optimization process in order to achieve best thermal performance and energy efficient buildings. The main objective of this study is to evaluate different envelope alternatives that could enhance thermal performance and minimize energy consumption. The base case envelope has followed the following series of parametric commands under certain variables and precisely defined constants as per the following:

1. Simulating the base case scenario (a)

2. Simulating the effect of adding thermal air gap insulation as well as block 7cm to base case wall (b)

2. Replacing thermal air gap by an insulating material (Expanded Polystyrene) (c)

3. Checking the effect of different insulation thicknesses on building performance (d)

4. Applying different glazing properties to the different insulation thicknesses to check their effect on buildings performance (e)

5. Adding Insulating layer to roofs (f)

6. Using thermal break aluminum with the best envelope configuration found (g)

For accurate results, the different parametric commands were applied to the whole building despite the fact that this study focus on the performance of the living space specifically.

4.4 Evaluation Criteria

There is no specific value used to evaluate thermal performance and energy consumption. The evaluation followed relied on a comparison approach between base case and the proposed envelope commands. The command that gives better performance and less energy consumption will be favored and recommended.

Both building performance and energy consumption are of direct relation and that's the reason why they're evaluated within the same evaluation criterial. The difference in temperature between the indoor air temperature and human comfort temperature directly affect the amount of energy needed in source of heating and cooling to reach the comfort temperature. The average comfort temperature presented in the proposed tool as well as the comfort range shown in section 4.6 is calculated based on the adaptive comfort Standard presented in ASHREA 55-2010 which use the following equation to calculate the comfort temperature: $T_{comfort} = 17.8 + 0.31*T_{outdoor}$ (De Dear, 2011)

Such evaluation criteria have strengthened the need for a simplified tool to assess building performance and energy consumption so as to give the user a chance to test and evaluate in a time-consuming process different commands so as to choose the best alternative.

4.5 Parametric Simulation Results

Random cases were selected to present the parametric simulation framework and to generalize the comparison approach in the decision-making process. As well as to prove the great demand for a ready to use applications and simplified tools to assist designers and home owners to predict thermal performance and energy consumption which is the main objective of this research.

Parametric simulation results will provide the user with complete set of options and alternatives so as to decide which option might best fit the desired objective which in some cases might not be the case that produced the minimum energy consumption. This what's make this evaluation criteria highly important and needed.

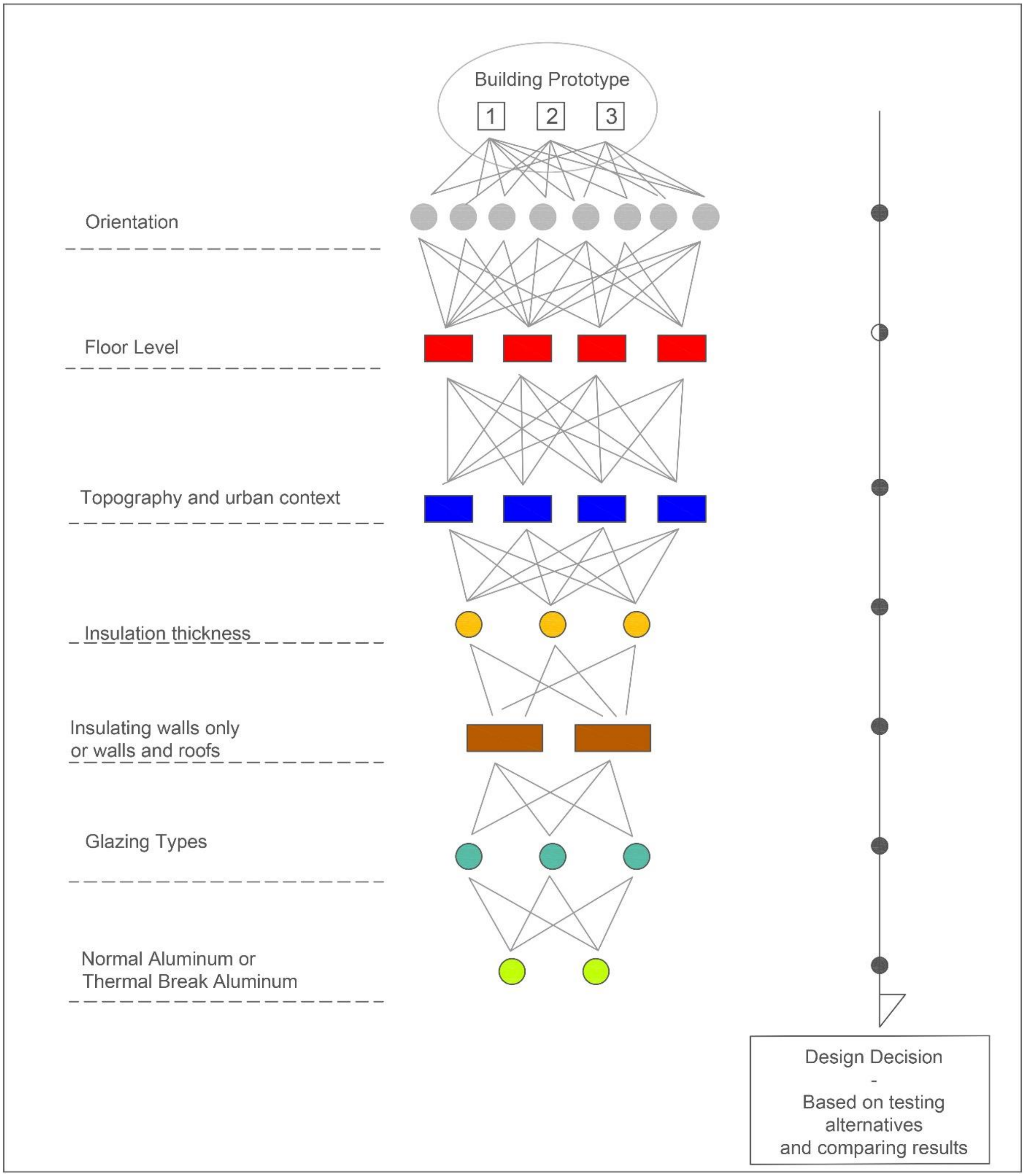


Figure 31: Parametric Testing Process to Formulate Results

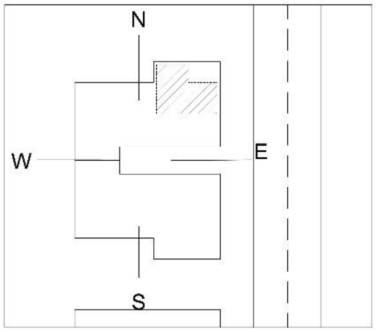
4.5.1 Building Typology 1

4.5.1.1 Base Case Simulation

The generic wall typically used in the study context (stone and concrete wall) in the following randomly selected living space which is a ground floor, north east oriented living space and located in a low urban context defined by topography scenario 1 has shown extremely poor building performance in winter and poor building performance which has led to 4,106.0 KWh annual heating energy consumption and 1,401.0 KWh annual cooling energy consumption.

A very common practice in the study context to add thermal air gap insulation was assessed to check this effect on heating and cooling loads in comparison to the base case scenario. This action has led to the need for 3,475.0 KWh and 1,405.00 KWh energy annually to heat and cool this space respectively which means that by adding air gap thermal insulation to the north east envelope, 631.00KWh can be saved in the form of heating energies.

Testing different envelope related parameters_ in this case adding insulation with different thicknesses as well as changing the glazing properties is highly needed.

<table>
<tr><td colspan="3">Command A: (Base Case Scenario) <u>(1)</u></td></tr>
<tr><td rowspan="2">- North East Oriented Apartment


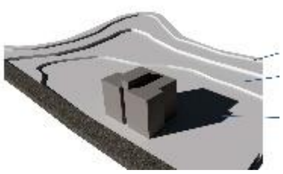
- Ground Floor Level
- Air gap thermal insulation in generic wall
- Double Glass Windows
- Topography scenario 1 - Low urban context
-
</td><td colspan="2">

Figure 32: North East Base Case Scenario – Building Thermal Performance</td></tr>
<tr><td>Total Loads

Annual Heating Loads: 3,475.0 KWh

Annual Cooling Loads: 1,406.0 KWh</td><td>Percentage of saving when compared to base case scenario

15.4%

0.004%</td></tr>
</table>

4.5.1.2 Validation of a Common Case Simulation Results

The intent of this tool is to give the designer indication toward the best envelope that will lead to the best building performance. The tool has carefully defined the base case building prototype that was used for the design of the tool. The base case model had defined clearly the window to floor ratio in the living spaces which is 30 – 33% for 40 – 44m² living space. In order to achieve the tool's goal, the key issue was to determine a set of parameters that affect thermal performance and to actually link and combine parameters to test their impact on building performance and so on energy consumption.

The approach is to allow designers to test the relative effect of different parameters on thermal performance at early design phases when the designer is facing multi design variants without the need to manually calculate loads for each case as well as without the need to do building performance simulation for each design alternative. The proposed tool was based on the scenario-by-scenario approach to evaluate envelope related alternatives to make design decision.

Calculation of heating and cooling demands to estimate total energy consumption is usually affected by unlimited factors. The building activity, the number of residents and their age (Shariah et al., 1998), residents activity and behavior as well as the total occupancy hours (Yezioro et al., 2008) (Gasparella et al., 2011), individual metabolic rate (Shariah et al., 1997), envelope insulation (Ozel, 2011), glazing type, window to wall ratio, building orientation etc.… Computer simulation models are programed based on thermodynamic principles and have proven to be very important in building simulation and in testing building performance (Yezioro et al., 2008). However, their use requires a set of assumptions. For the purpose of this study, it was assumed that HVAC system is used in the living space with set point winter temperature equals to 21°C and set point summer temperature equals to 25°C with time frame 12 hours per day. Occupancy density as well as activity factor and clothing schedule definitions were set as fixed values in the simulation program. Any changes in the previously mentioned factors, in simulation program set point temperature will affect heating and cooling loads and so getting actual measurements from existing buildings in the study context was not considered. Setting the simulation program to accommodate all common practical applications can't be ecological that's why the intent of this tool is to give percentages of saving in comparison with building performance while taking all the pre-defined parameters into account.

A Rule of Thumb Method developed for Heating and cooling Loads calculations especially for Palestine (Othman and Abughalion, 2017) was used as the main method to validate simulation results. A rule of thumb as defined by the authors is an easy and simplified method to calculate approximate loads while preserving high level of accuracy. This method was developed depending on fundamentals of heat transfer and was used though this study to validate simulation results. General heat transfer equation used was $q=UA(Ti-To)$. Table 23 defines all heat transfer equations through construction materials as well as caused by ventilation.

Table 23: Heat Loss Equations as Developed by the Rule of Thumb Available for Palestine

Source: (Othman and Abughalion, 2017)

Heat Loss through construction material	
Heat Loss Through Boundary Walls	Qwall=UwAw(Ti-To)
Heat Loss through partitions	Qpartition=UpAp(Ti-Tun)
Heat loss through glass	Qglass=UgAg(Ti-To)
Heat loss through floor	Qfloor=UfAf(Ti-Tg)
Heat loss through roof	Qroof=UrAr(Ti-To)
Heat loss through ceilings	Qceiling=UcAc(Ti-To)
Heat Loss through Doors	Qdoor=UdAd(Ti-To)
Heat Loss by Ventilation	
Heat loss by sensible ventilation	1.2×V×(To-Ti) V= volumetric outdoor air flow rate introduced to the space (L/S)
Heat loss by latent ventilation	3×V×(wo-wi) Wo = outside air humidity ration Wi = inside air humidity ratio
Heat gain from occupants and lighting	
Heat gain from occupants	Qocc=n(Qsens(CLF)occ+Qlatent)
Heat gain from lighting	Qlight=A×light intensity × DF
Total Heating Loads	
Total Heating Loads	QHL = ∑ Qloss

- Design Conditions:

  Table 24 describes the design conditions valid in this research which presents the specific climate zone chosen for the purpose of this study

Table 24: Design Conditions in the Study Context

Item	**Heating**	**Cooling**	**Notes**
Latitude	------	------	31.87
Elevation	------	------	795
Indoor Temperature	21°C	25°C	------
Indoor Relative Humidity	N/A	50%	------
Average Outdoor Temperature	10°C	23.5°C	------

Wind Speed	8 m/s	6 m/s	------
Design Δt	11°C	2°C	------

Table 25: Base Case Component Quantities

Component	**Quantity**
Ceiling	147.50 m²
Windows	17.3 m²
Walls (exposed) Gross	202.0 m²
Walls (Exposed) Net	185.0 m²
Floor Area	111.00 m²
Floor Perimeter	55.6 m
Volume	6,172.0 m³

Table 26: Design temperature in winter

Temperature	Dry bulb (C°)
Ti	T indoor
To (min)	0.5(Ti-To)
Tun	0.5(Ti-To)
Tg	To+10

Table 27: Design temperature in winter

	RH%		w(kg/kg dry air)	
	Winter	summer	winter	summer
inside	50	50	9.37	10.91
outside	-	-	1.61	30.6

4.5.1.3 Heating Design Calculations:

Table 28: Winter Design Conditions of Living Space

Ti	**T0**	**Tg**	**Tu**	**Tavg**
21	0.7	10.7	10.15	8.95

Table 29: Heating Gain from Internal Elements of Living Space

Item	AT	U Value	UA	T	AT* T	Q
Floor	34.6	1.047	36.226	10.7	370.22	373.1278
Ceiling	34.6	1.047	36.226	21	726.6	0
North window	1.17	3.226	3.77	0.7	0.819	76.531
West window	1.872	3.226	6.04	0.7	1.31	122.612
North Door	4.85	3.226	15.65	10.15	49.23	169.8025
West Door	2.18	3.226	7.03	10.15	22.13	76.2755
Partitions	35.0	2.579	90.30	10.15	355.25	979.755
Walls	34.7	1.973	68.52	0.7	24.29	1390.956
Total						3189.06

- Heating gain due to sensible and latent ventilation:

Q ventilation sensible = 1.2 X V X (t0 – Ti)

= 1.2 X 2.36 X -20.3 = -57.49

Q Ventilation latent = 3 x V X (Wo – Wi)

= 3 * 2.36 * -19.87 = -140.67

- Total heating loads = heating gain from envelope components + heating gain from ventilation

= 3189.06 + 57.49 + 140.67

= 3387.22 KWh

4.5.1.4 Cooling Design Calculations:

Table 30: Summer Design Conditions

Ti	T0	Tg	Tadj	Tun	To,m	Tmax	Tmin	Tavg
24	35	25	6.66	30	27.25	35	19.5	22.11

	RH%		W(kg/kg dry air	
	Winter	Summer	winter	Summer
Inside	50	50	9.37	10.91
Outside			1.61	30.6

Table 31: Condition Heat Transfer from Unexposed Internals of Space

Item	A	U value	T	Q
Floor	34.6	1.047	25	0
Ceiling	34.6	1.047	25	0
Partitions	35.0	2.579	6.67	602.07
Total				602.07

Table 32: Heat Gain from Sunlit Walls

Item	A	U Value	T	CLTD	LM	K	25.5-Ti	CLTDcorr	Q
North Wall	19.26	1.973	35	6	-0.5	0.83	0.5	2.915	110.77
West Wall	21.31	1.973	35	13	-0.5	0.83	0.5	8.725	366.84
Total									477.61

Table 33: Heat Gain from Sunlit Windows

Item	A	U Value	T	CLTD	LM	K	25.5-Ti	CLTDcorr	Q
North Window	1.17	3.226	35	7	-1.1	0.65	0.5	2.185	8.25
North Door	4.85	3.226	35	7	-1.1	0.65	0.5	2.185	34.187
West window	1.872	3.226	35	7	0	0.65	0.5	2.9	17.51
West Door	2.18	3.226	35	7	0	0.65	0.5	2.9	20.39
Total									80.337

Heat gain through occupants: Q sensible + Q latent

Q sensible = heat gain sensible x No. of people x diversity factor

= 70 * 4 * 0.84 * 0.6

= 141.12 KWh

Q latent = heat gain latent X no. of people * diversity factor

= 44 * 4 * 0.06 = 10.56 KW

Heat gain through lighting = light intensity x A x clf x diversity factor

= 30 x 34.5 x 0.07 x 0.95 x 0.3

= 21.74

Total cooling Load= 602.07+477.61+80.337 + 141.12 + 10.56 + 21.74 = 1,333.437 KW

4.5.1.5 Summary of Validation Results:

The validation was done to a common practice case in the study context which is adding thermal air gap insulation to the generic stone and concrete wall.

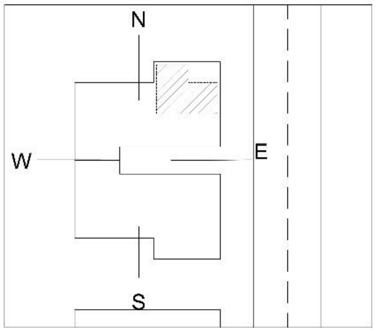
Table 34: Comparison Between Simulation Results and Manual Calculation Results

	Average Simulation Results between different floors	Manual Calculations	Difference ratio
Heating Load	3,460.00 KWh	3387.22 KWh	3.0 %
Cooling Load	1,450.0 KWh	1,333.437 KWh	8.0 %

4.5.1.6 Limitation for Manual Calculations

Manual calculation didn't consider floor level effects during the manual calculations which has shown great effect during the simulation. For the purpose of comparing between simulation results and manual calculation results total average heating and average cooling for all floor in the same validated orientation has been used. Moreover, the rule of thumb method has ignored the effect of appliances when calculating the cooling loads which might have caused the 8.0% variation between simulation results and manual calculations.

4.5.2 Building Typology 1- Parametric Simulation

<table>
<tr><td colspan="3">Command (B): Assessing the effect of replacing the thermal air gap insulation with 2.54 thermal insulation <u>(3)</u></td></tr>
<tr><td rowspan="3">- North East Oriented Apartment


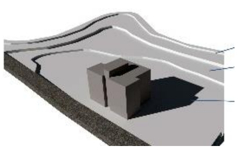
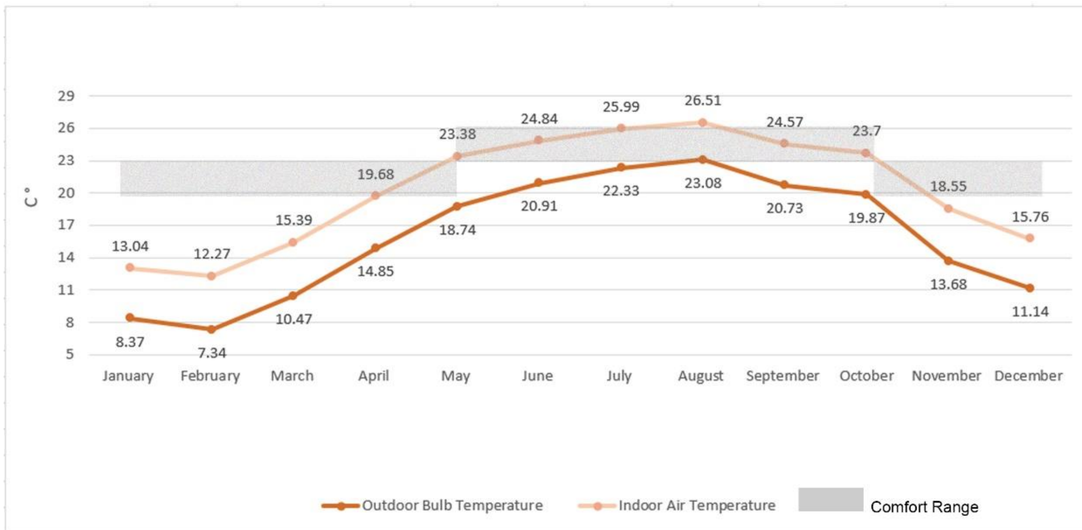
- Ground Floor Level
- 2.54cm Thick Expanded Polystyrene
- Double Glass Windows
- Topography scenario 1 - Low urban context
</td><td colspan="2">

Figure 33: Effect of adding 2.54cm thick Expanded Polystyrene to North East Base Case Scenario</td></tr>
<tr><td>Total Loads</td><td>Percentage of Saving when compared to base case</td></tr>
<tr><td>Annual Heating Loads: 2,736.0 KWh

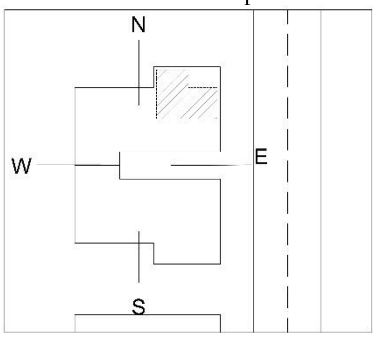
Annual Cooling Loads: 1,504.0 KWh</td><td>33.4 %

-7.4 %</td></tr>
</table>

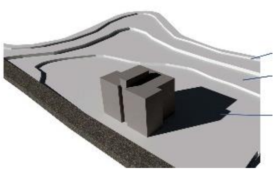
The user (designer or homeowner) will get the chance to evaluate the objective which is to minimize energy consumption by replacing the thermal air gap with 2.54cm Expanded Polystyrene in this specific living space. For the selected case and referring to the identified assumptions, heating and cooling loads may be minimized by a percentage of 23.0%. The proposed tool may also give the user the option to run sensitivity analysis such as to check the effect of either using 3.81cm thick insulation layer or to examine different glazing properties such as Low-Energy double glass or even Low-Energy triple glass. He might also check the effect of using thermal break aluminum rather than normal aluminum and to evaluate the results during the building design process.

Command (C): Assessing the effect of using 3.81cm or 5.08cm thermal insulation instead of 2.54cm (4 & 5)

- North East Oriented Apartment



- Ground Floor Level
- 3.81cm or 5.08cm Thick Expanded Polystyrene
- Double Glass Windows
- Topography scenario 1 - Low urban context



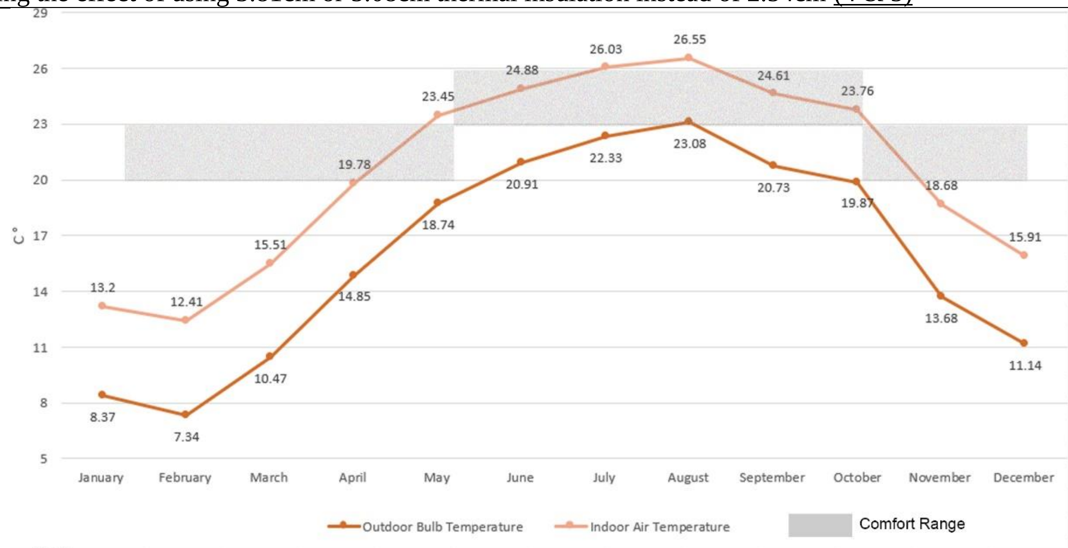


Figure 34: Effect of Adding 3.81cm Thick Expanded Polystyrene to North East Base Case Scenario

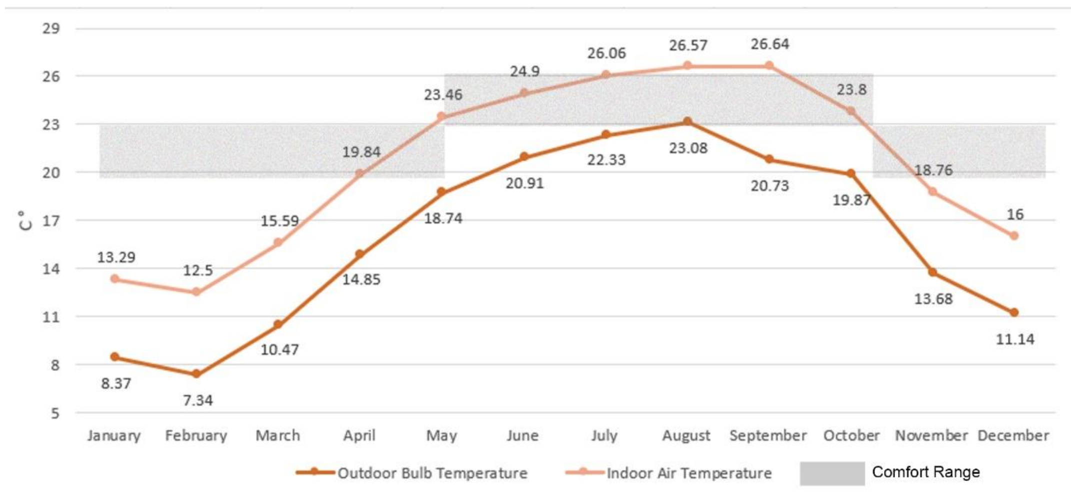
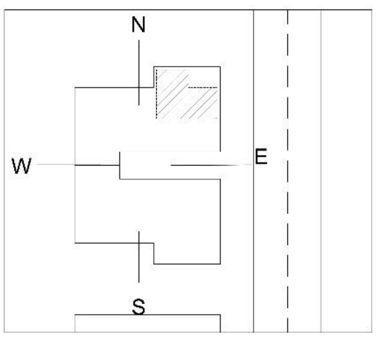


Figure 35: Effect of Adding 5.08cm Thick Expanded Polystyrene to North East base Case Scenario

For 3.81cm expanded polystyrene	For 5.08 cm expanded polystyrene
Annual Heating Loads: 2,586.0 KWh Annual Cooling Loads: 1,523.0 KWh	Annual Heating Loads: 2,513.0 KWh Annual Cooling Loads: 1,527.0 KWh
Percentage of Savings when compared to base case	
37.0 % -8.7 %	38.8 % -9.0 %

This gives the user an idea about the ability of thermal mass to reduce heating and cooling loads based on the living space orientation, floor level, site description... etc. Using different insulation thicknesses is likely to affect the load savings due to the envelope thermal mass (Byrne and Ritschard, 1985). The parametric simulation has proved that by replacing the thermal air gap with 2.45cm, 3.81cm or 5.08cm thick Expanded Polystyrene in a north east oriented ground floor apartment, the heating loads was minimized by 33.4%, 37.0% and 38.8% respectively. However, the cooling loads was raised by 7.4%, 8.7% and 9.0% respectively. The user will then evaluate such outcomes in term of savings or raise in consumption and will choose whether to test different alternatives such as the effect of different glazing properties with and without the installation of thicker insulation layer as shown in figure 36, 37, 38 & 39.

<table>
<tr><td colspan="2">Command (D): Assessing the effect of using adding Low Energy Double Glass and Low Energy Triple Glass to envelopes with 3.81cm thermal insulation instead (6 & 7)</td></tr>
<tr><td>- North East Oriented Apartment



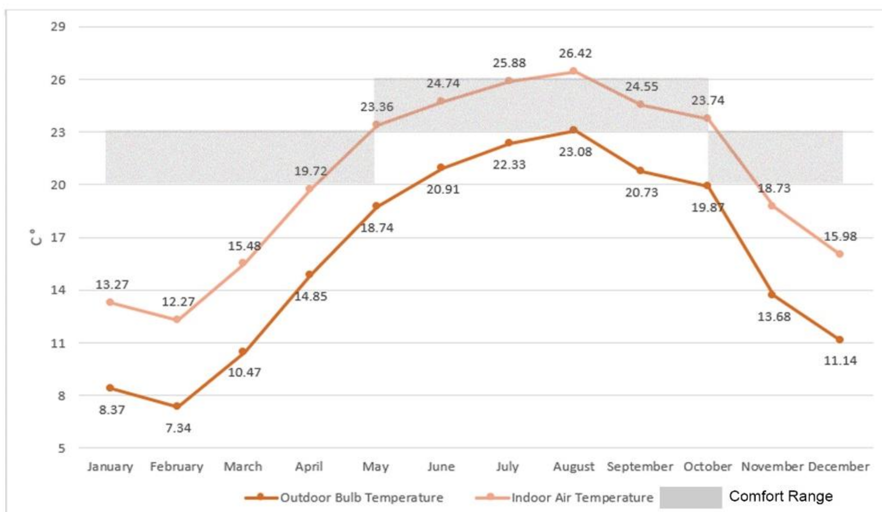
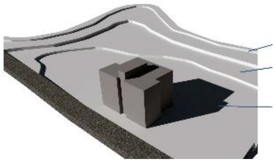
- Ground Floor Level
- 3.81cm Thick Expanded Polystyrene
- Low Energy double and Low Energy Triple Glass Windows
- Topography scenario 1 - Low urban context</td>
<td>

Figure 36: Effect of Using Low Energy Double Glass with 3.81cm Thick Expanded Polystyrene to North East Base Case Scenario</td></tr>
</table>



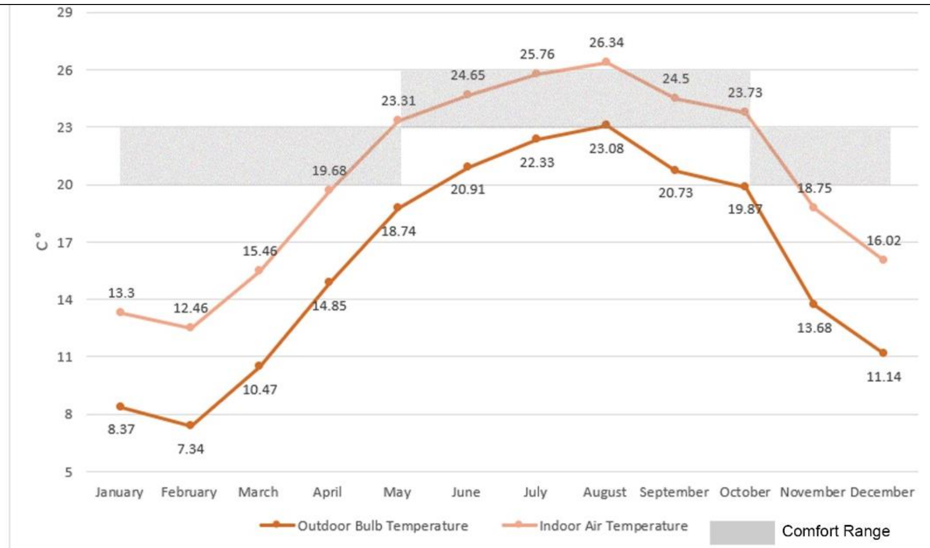


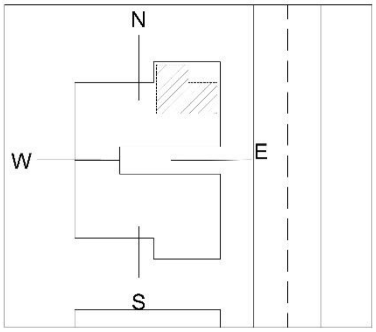
Figure 37: Effect of Using Low Energy Triple Glass with 3.81cm Thick Expanded Polystyrene to North East Base Case Scenario

For 3.81cm expanded polystyrene with Low Energy Double Glass Window Annual Heating Loads: 2,529.0 KWh Annual Cooling Loads: 1,391.0 KWh	For 3.81cm expanded polystyrene with Low Energy Triple Glass Window Annual Heating Loads: 2,505.0 KWh Annual Cooling Loads: 1,320.0 KWh
Percentage of Savings when compared to base case	
38.4 % 0.7 %	39.0 % 5.8 %

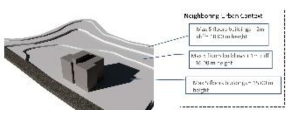
Adding insulation has minimized heating energies while it has caused a raise in cooling loads, however, when insulation was combined with high quality glazing such as Low Energy Double Glass and Low Energy Triple Glass, cooling loads were lowered. Resulting in 38.4% saving in heating loads as well as 0.70% saving in cooling loads when combining 3.81cm Expanded Polystyrene with Low Energy Double Glazing. Whereas combing 3.81cm expanded polystyrene with low energy triple glazing has resulted in saving 39.0% in heating loads and 5.8% in cooling loads. Similarly combing 5.08cm insulation with Low Energy Double Glass has lowered both heating and cooling loads by 40.2% and 0.60% respectively while combing with Low Energy Triple Glass has lowered both heating and cooling loads by 40.8% and 5.6% respectively.

Command (D) : Assessing the effect of adding Low Energy Double Glass and Low Energy Triple Glass to envelopes with 5.08 cm thermal insulation instead (8 & 9)

- North East Oriented Apartment



- Ground Floor Level
- 5.08cm Thick Expanded Polystyrene
- Low Energy double and Low Energy Triple Glass Windows
- Topography scenario 1 - Low urban context



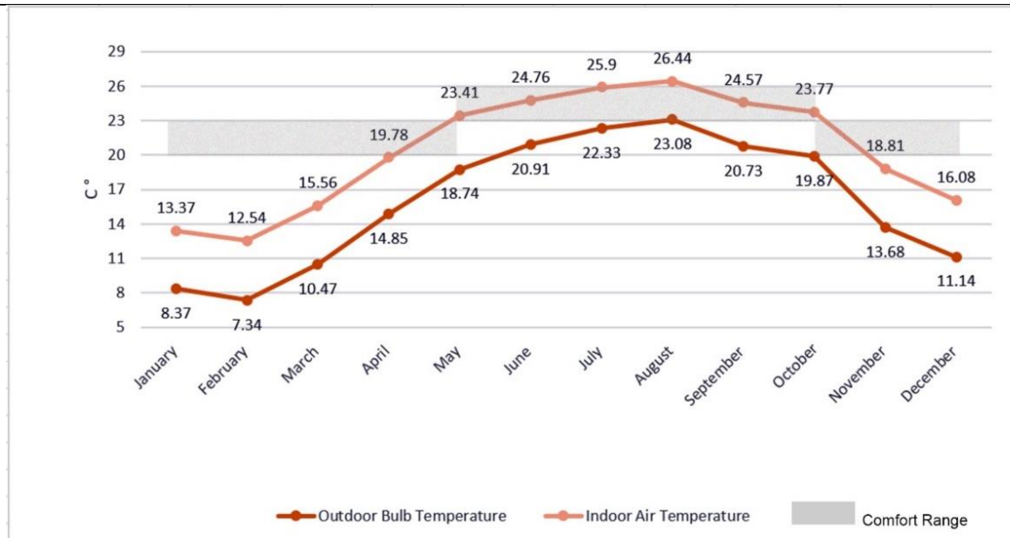


Figure 38: Effect of Using Low Energy Double Glass with 5.08cm Thick Expanded Polystyrene to North East Base Case Scenario

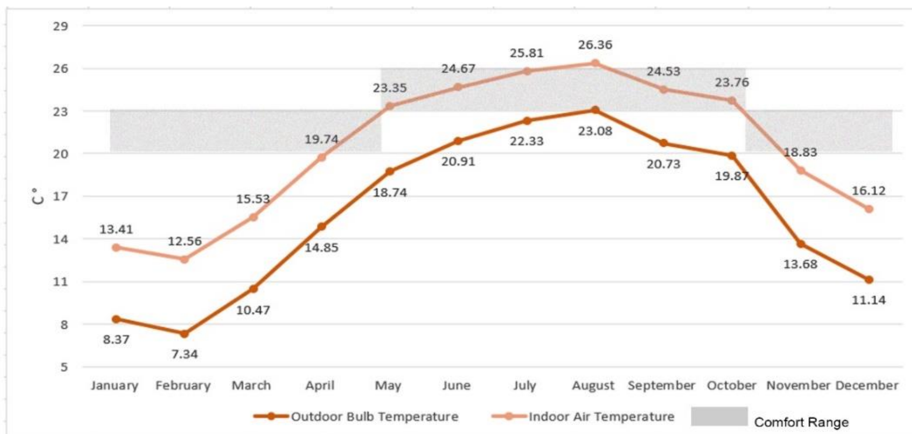


Figure 39: Effect of Using Low Energy Triple Glass with 5.08cm Thick Expanded Polystyrene to North East Base Case Scenario

For 5.08 cm expanded polystyrene with Low Energy double glass Annual Heating Loads: 2,454.0 KWh Annual Cooling Loads: 1,393.0 KWh	For 5.08 cm expanded polystyrene with Low Energy triple glass Annual Heating Loads: 2,430.0 KWh Annual Cooling Loads: 1,322.0 KWh
Percentage of Savings when compared to base case	
40.2 % 0.6 %	40.8% 5.6 %

By comparing the results, the designer will be able to determine the more energy efficient envelope for specific defined parameters. Table 35 summarize all envelopes previously tested for a north east oriented – ground floor living space.

Table 35: Summary of all envelope Configuration already tested in section 4.6.2

North east oriented living roof – low urban context – ground floor – two residential units per floor	Envelope Designs	Type of insulation & thickness	Location of insulation	Type of glass
	Base case (1)	No insulation	_____________	Clear double glass
	2	3cm thermal air gap	On walls only	Clear double glass
	3	2.54 Expanded Polystyrene	On walls only	Clear double glass
	4	3.81 Expanded Polystyrene	On walls only	Clear double glass
	5	5.08 Expanded Polystyrene	On walls only	Clear double glass
	6	3.81 Expanded Polystyrene	On walls only	Low Energy Double Glass
	7	3.81 Expanded Polystyrene	On walls only	Low Energy Triple Glass
	8	5.08 Expanded Polystyrene	On walls only	Low Energy Double Glass
	9	5.08 Expanded Polystyrene	On walls only	Low Energy Triple Glass

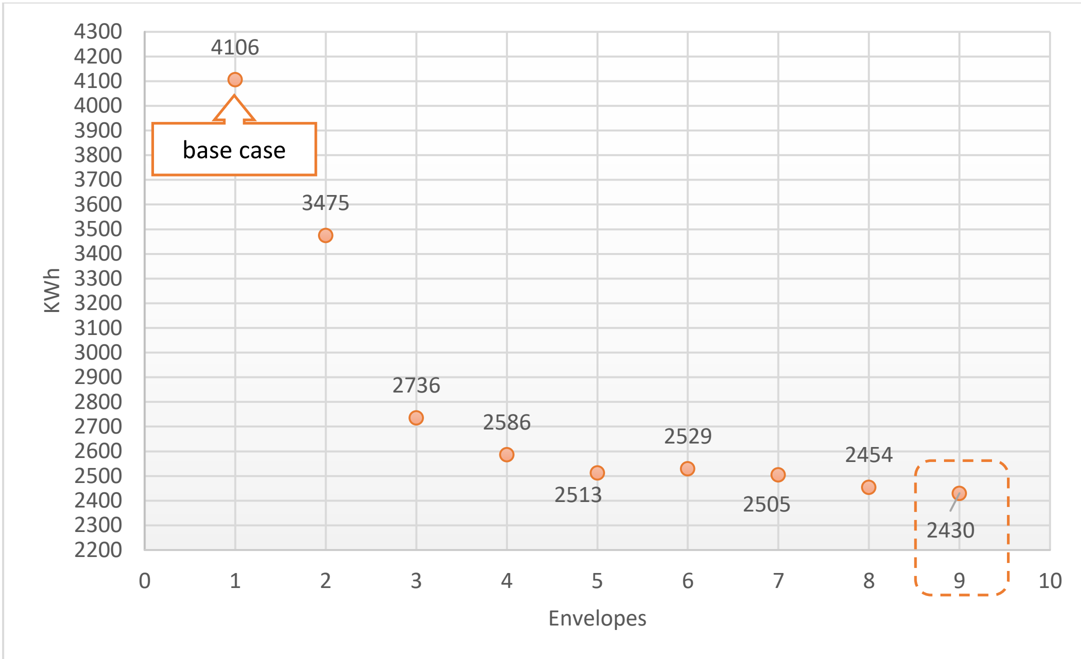


Figure 40: Comparison of Heating Energies Consumed Based on Envelope Designs Summarized in Table 35

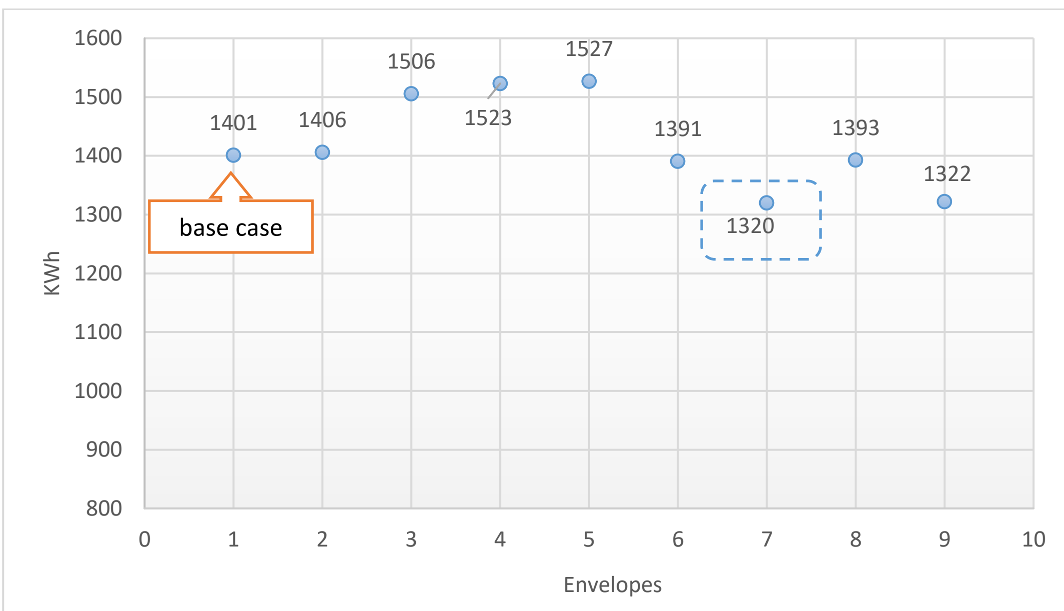
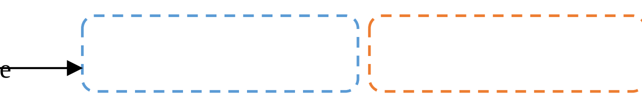


Figure 41: Comparison of Cooling Energies Consumed Based on Envelope Designs Summarized in Table 35

Shapes Representing the Optimum Envelope



Based on the previous results, the user will choose the best envelope design and can also test three more commands to check their effect on heating and cooling energies. One is to test the effect of insulating the apartment roof. The other is to test the effect of thermal break aluminum. Finally, to combine both roof insulation and thermal break aluminum and check their effect on heating and cooling energies.

The results show that when applying insulation to inner ceiling at roof floor, ground floor level will be affected. This has added 0.45% additional savings over the total consumption at ground floor level apartment. Moreover, thermal break aluminum added a percentage of 0.48% savings to the overall consumption.

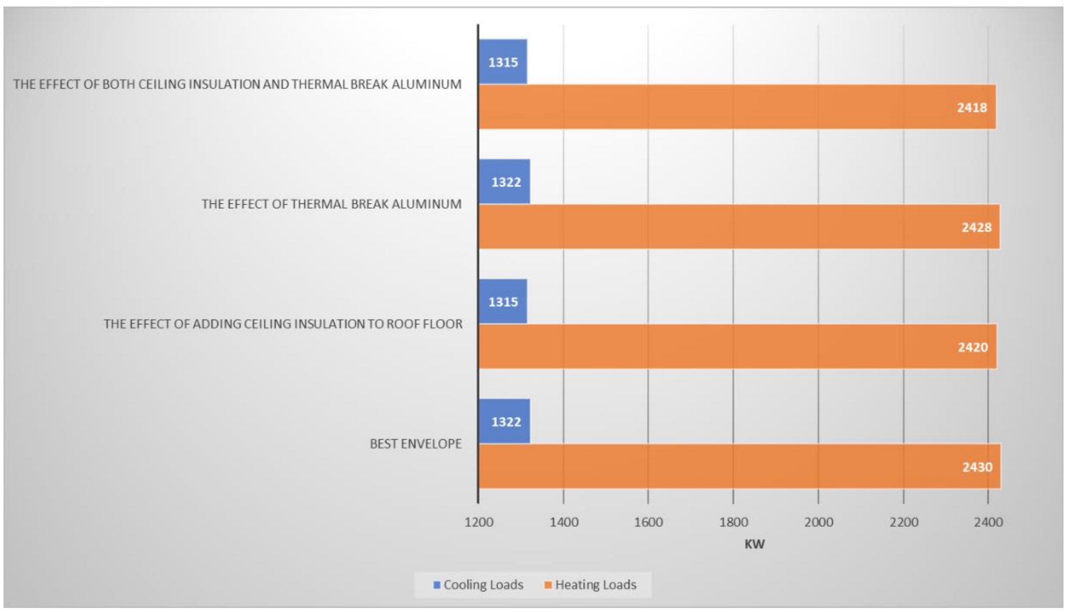


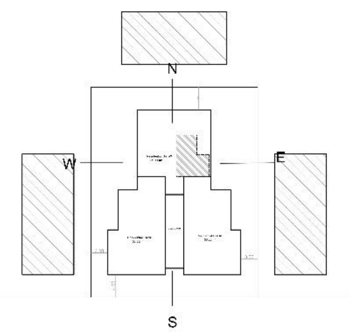
Figure 42: Examining the Effect of Roof Insulation and Thermal Break Aluminum on Heating and Cooling Energies

4.5.3 Building Typology 2 - Parametric Simulation

The generic wall typically used in the study context in the following randomly selected living space which is a mid-floor, east oriented living space and located in a high urban context defined by topography scenario 3 has shown extremely poor building performance in winter and summer. This leads to the need for 3157.0 KWh and 1246.0 KWh energy annually to heat and cool this space respectively.

Command A: adding 3cm Air Gap Layer (2)

- East Oriented Apartment



- Mid Floor Level
- Air gap thermal insulation in generic wall
- Double Glass Windows
- Topography scenario 3 – high urban context

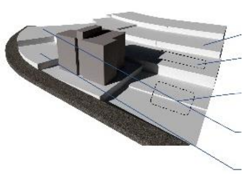
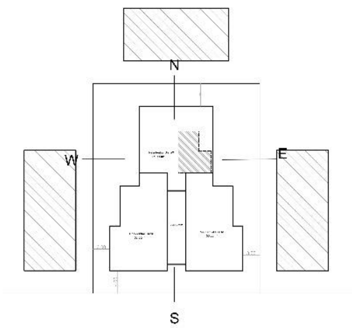


Figure 43: East Oriented Scenario – Building Thermal Performance

Energy Loads:	Percentage of savings in comparison with base case scenario
Annual Heating Loads: 2,814.0 KWh	10.9 %
Annual Cooling Loads: 1,266.0 KWh	-1.6 %

<table>
<tr><td colspan="3">Command (B): Assessing the effect of replacing the thermal air gap insulation with 2.54 thermal insulation (3)</td></tr>
<tr><td rowspan="3">- East Oriented Apartment


- Mid Floor Level
- 2.54 cm thick thermal insulation
- Double Glass Windows
- Topography scenario 3 – high urban context
</td><td colspan="2">

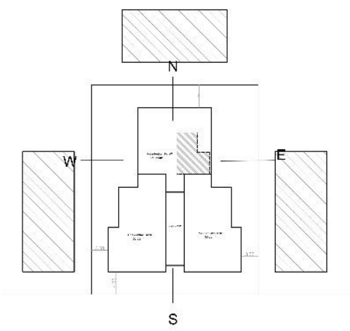
Figure 44: Effect of Adding 2.54 cm Thick Expanded Polystyrene to East Oriented Scenario</td></tr>
<tr><td>Total Loads</td><td>Percentage of savings when compared to base case scenario</td></tr>
<tr><td>Annual Heating Loads: 2,263.0 KW

Annual Cooling Loads: 1,405.0 KW</td><td>28.3 %

-12.8 %</td></tr>
</table>

In dense urban sites _ as elaborated in the literature review _ when the spaces are shaded as a result of the neighboring buildings and the surrounding topography, here will exist a contradiction between the building performance in winter versus summer. Cooling loads will be the minimum in comparison to heating loads which will be the maximum resulting from the blocking and the interruption of solar energy. Adding 2.54cm expanded polystyrene has negatively affected the cooling loads in comparison with the based case scenario. It has raised the cooling loads by 12.8% while it has lowered the heating loads by 28.3%. Parametric simulation is highly needed to check whether better building performance can be achieved by only enhancing the glazing properties, or by using better quality insulation or by combining both. As well as, comparing costs of construction materials in comparison with savings to check its feasibility.

<table>
<tr><td colspan="3">Command (C): Assessing the effect of using 3.81cm or 5.08cm thermal insulation instead of 2.54cm <u>(4 &5)</u></td></tr>
<tr><td rowspan="5">- East Oriented Apartment



- Mid Floor Level
- 3.81 cm, 5.08 cm thick thermal insulating material
- Double Glass Windows
- Topography scenario 3 – high urban context

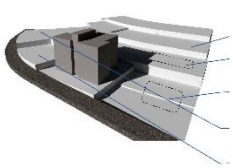
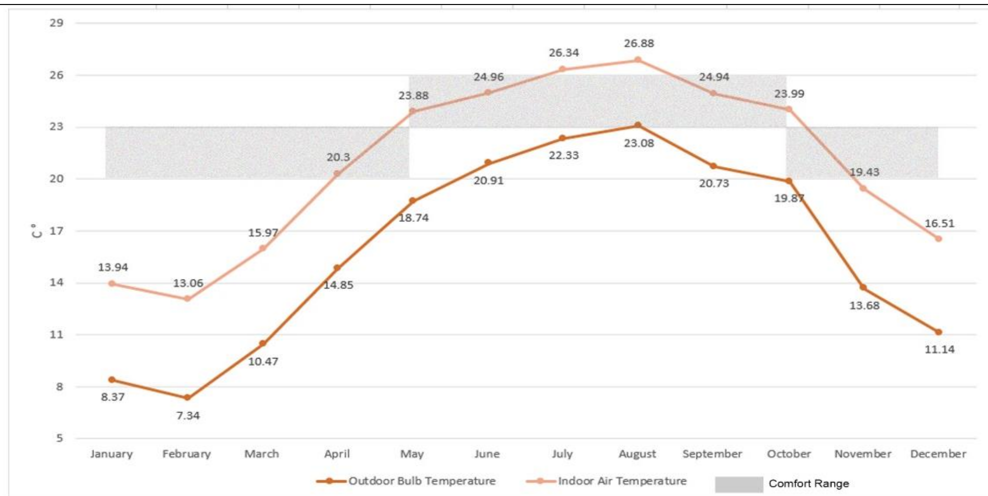
</td>
<td colspan="2">

Figure 45: effect of adding 3.81 cm thick expanded polystyrene to east oriented scenario

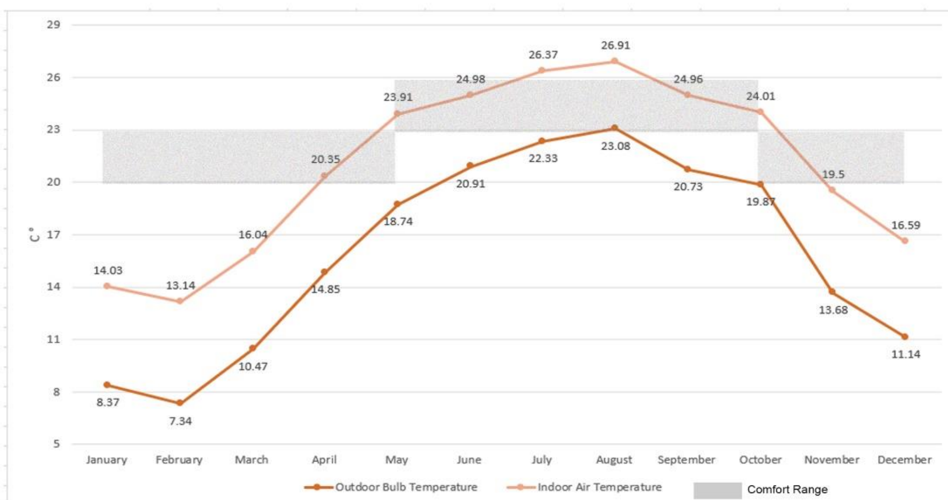
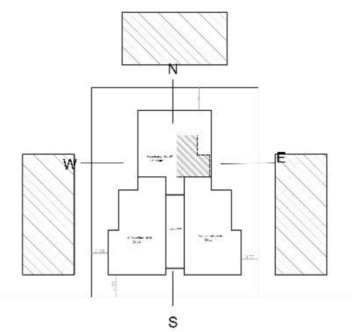


Figure 46: Effect of Adding 5.08 cm Thick Expanded Polystyrene to East Oriented Scenario</td></tr>
<tr><td>For 3.81cm expanded polystyrene
Annual Heating Loads: 2,177.0 KWh
Annual Cooling Loads: 1,421.0 KWh</td><td>For 5.08 cm expanded polystyrene
Annual Heating Loads: 2,126.0 KWh
Annual Cooling Loads: 1,429.0 KWh</td></tr>
<tr><td colspan="2">Percentage of Savings when compared to base case scenario</td></tr>
<tr><td>31.0 %
-14.0 %</td><td>32.7 %
-15.0%</td></tr>
</table>

Adding wider insulation to the base case envelope is enhancing the heating energies, however, it's not affecting the cooling energies anymore. This has seen obvious in figure 45 and

46 where the cooling loads has raised by an average of 20KW and 8KW annually when applying 3.081cm and 5.08 cm expanded polystyrene respectively. However, this action has minimized the heating energies by 31.0% and 32.7% when applying 3.81cm and 5.08 cm expanded polystyrene respectively.

<table>
<tr><td colspan="2">Command (D): Assessing the effect of using adding Low Energy Double Glass and Low Energy Triple Glass to envelopes with 3.81cm thermal insulation instead (6 & 7)</td></tr>
<tr><td>- East Oriented Apartment


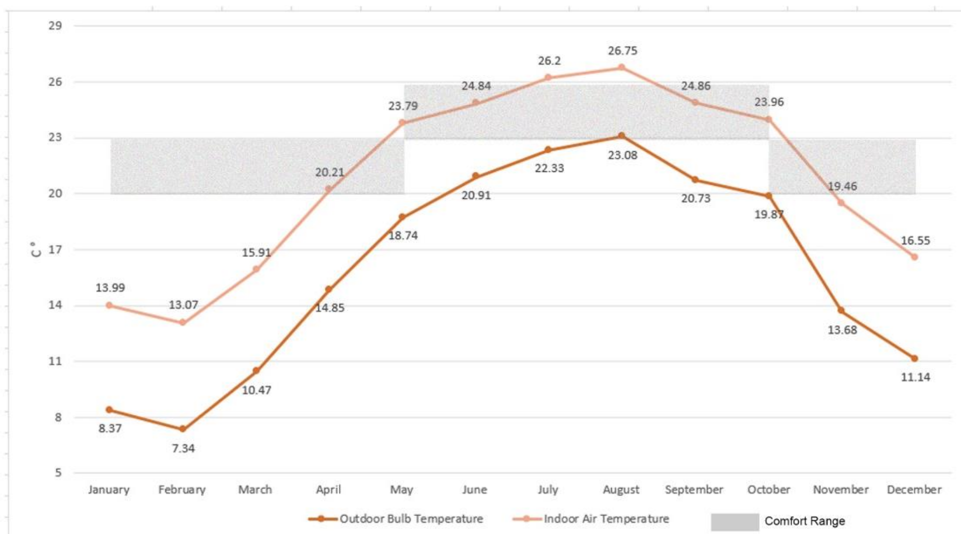
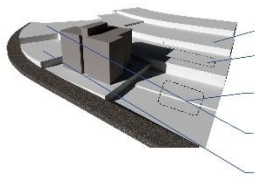
- Mid Floor Level
- Air gap thermal insulation in generic wall
- Double Glass Windows
- Topography scenario 3 – high urban context</td><td>

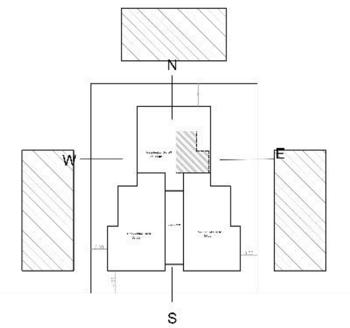
Figure 47: Effect of Using Low Energy Double Glass with 3.81 cm Thick Expanded Polystyrene to East Oriented Scenario</td></tr>
</table>

	 Figure 48: Effect of Using Low Energy Triple Glass with 3.81 cm Thick Expanded Polystyrene to East oriented Scenario	
	For 3.81cm expanded polystyrene with Low Energy Double Glass Window Annual Heating Loads: 2,163.0 KWh Annual Cooling Loads: 1,325.0 KWhh	For 3.81cm expanded polystyrene with Low Energy Triple Glass Window Annual Heating Loads: 2,155.0 KW Annual Cooling Loads: 1,258.0 KWh
	Percentage of savings when compared to the base case scenario	
	31.5 % -6.3 %	31.7 % -1.0 %

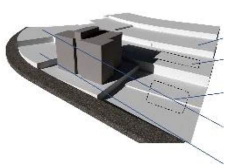
In high dense sites, insulation is not enough to affect thermal performance and energy consumption. However, when combined with high resisting glazing, it shows better results. Best heating loads were achieved with 5.08 cm Expanded Polystyrene and best thermal resisting glass (triple glass). On the other hand, best cooling loads were achieved when using 3.81 cm Expanded Polystyrene with triple glass windows. In this case the user may refer to annual consumption so as to decide what will be the most energy efficient option as well as analyzing the cost of construction materials as described in table38, 39 and 40 versus the payback period in order to come up with final decision.

Command (D) : Assessing the effect of adding Low Energy Double Glass and Low Energy Triple Glass to envelopes with 5.08 cm thermal insulation instead (8 & 9)

- East Oriented Apartment



- Mid Floor Level
- Air gap thermal insulation in generic wall
- Double Glass Windows
- Topography scenario 3 – high urban context



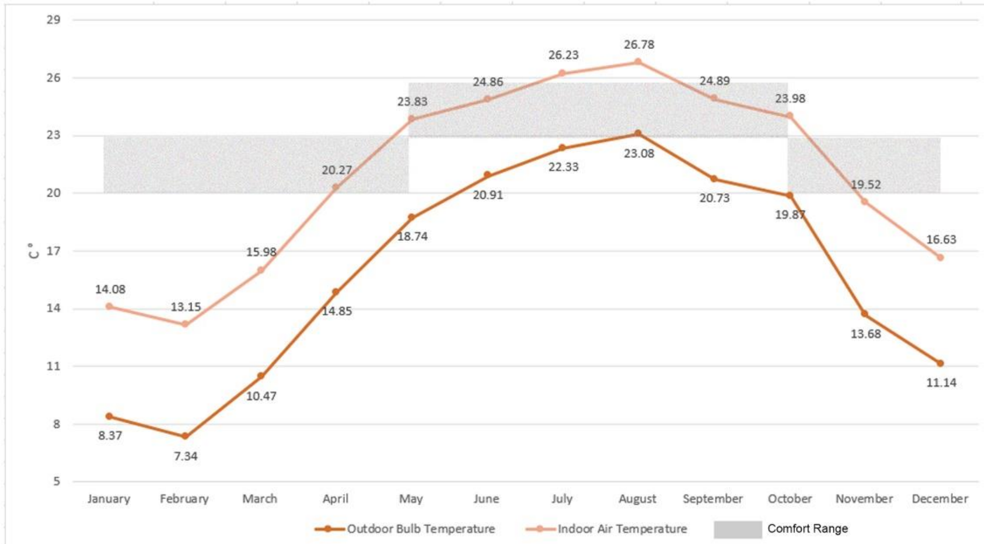


Figure 49: Effect of Using Low Energy Double Glass with 5.08 cm Thick Expanded Polystyrene to East Oriented Scenario

Figure 50: Effect of Using Low Energy Triple Glass with 5.08 cm Thick Expanded Polystyrene to East Oriented Scenario

For 5.08cm expanded polystyrene with Low Energy double glass	For 5.08 cm expanded polystyrene with Low Energy triple glass
Annual Heating Loads: 2,110.0 KWh	Annual Heating Loads: 2,102.0 KWh
Annual Cooling Loads: 1,333.0 KWh	Annual Cooling Loads: 1,264.0 KWh
Percentage of savings when compared to base case scenario	
33.2 %	33.4 %
-7.0 %	-1.4 %

By comparing the results, the designer will be able to determine the more energy efficient envelope for specific defined parameters. Table 36 summarize all envelopes previously tested for east oriented – middle floor living space.

Table 36: Summary of all envelope Configuration already tested in section 4.6.3

East oriented living roof – topography scenario 3 (high urban context) – middle floor – three residential units per floor	Envelope Designs	Type of insulation & thickness	Location of insulation	Type of glass
	1 (Base Case)	No Insulation	________	Clear double glass
	1	3cm thermal air gap	On walls only	Clear double glass
	2	2.54 Expanded Polystyrene	On walls only	Clear double glass
	3	3.81 Expanded Polystyrene	On walls only	Clear double glass
	4	5.08 Expanded Polystyrene	On walls only	Clear double glass
	5	3.81 Expanded Polystyrene	On walls only	Low Energy Double Glass
	6	3.81 Expanded Polystyrene	On walls only	Low Energy Triple Glass
	7	5.08 Expanded Polystyrene	On walls only	Low Energy Double Glass
	8	5.08 Expanded Polystyrene	On walls only	Low Energy Triple Glass

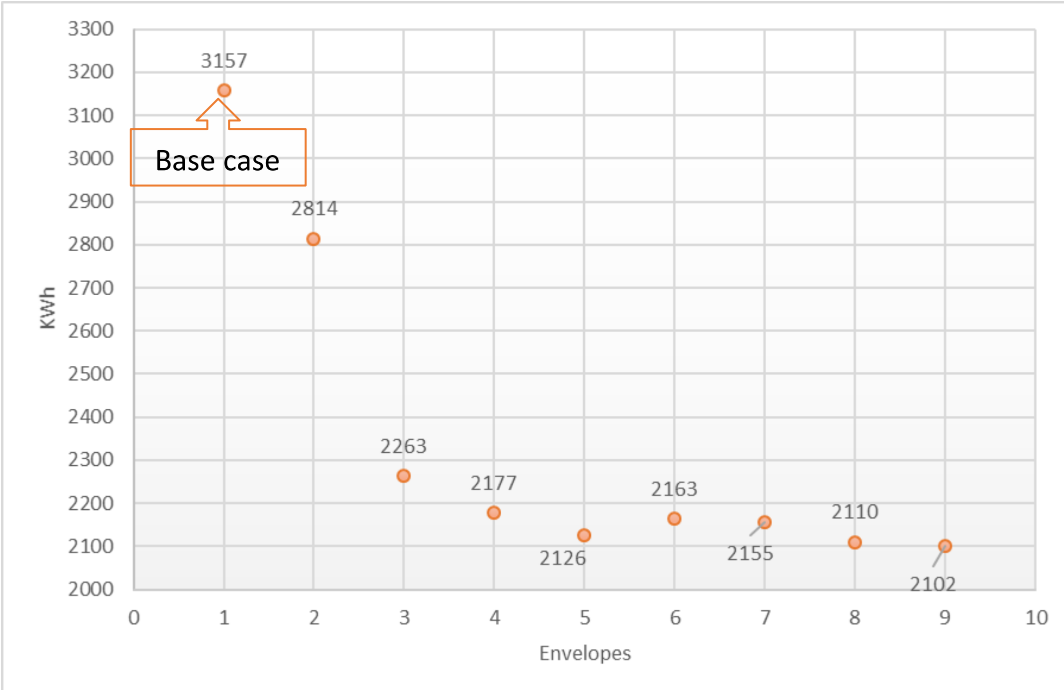


Figure 51: Comparison of Heating Energies Consumed Based on Envelope Designs Summarized in Table 36

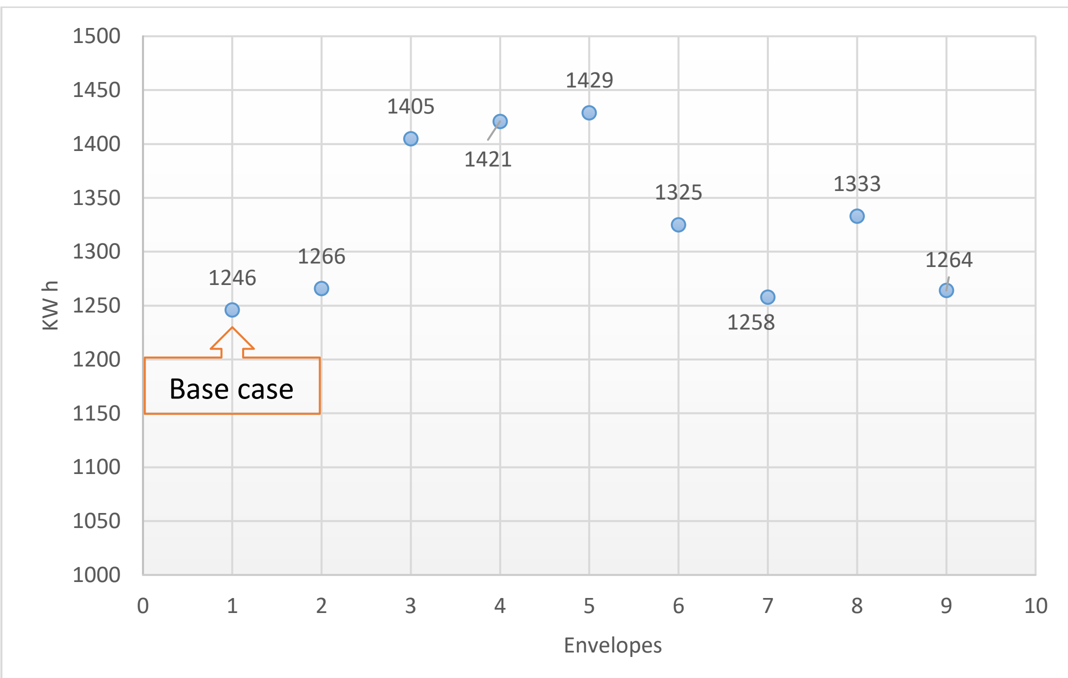


Figure 52: Comparison of Cooling Energies Consumed Based on Envelope Designs Summarized in Table 36

When the user gets very close heating and cooling energies consumption assumptions between different envelopes designs, the proposed tool provides monthly consumption that helps to compare results and choose the best option as well as it compares implementing cost in comparison with energy saving costs so as to help in choosing the best and the most efficient envelope option. Figure 53and 54 present monthly consumption break down for Elevation 6 and Elevation 8.

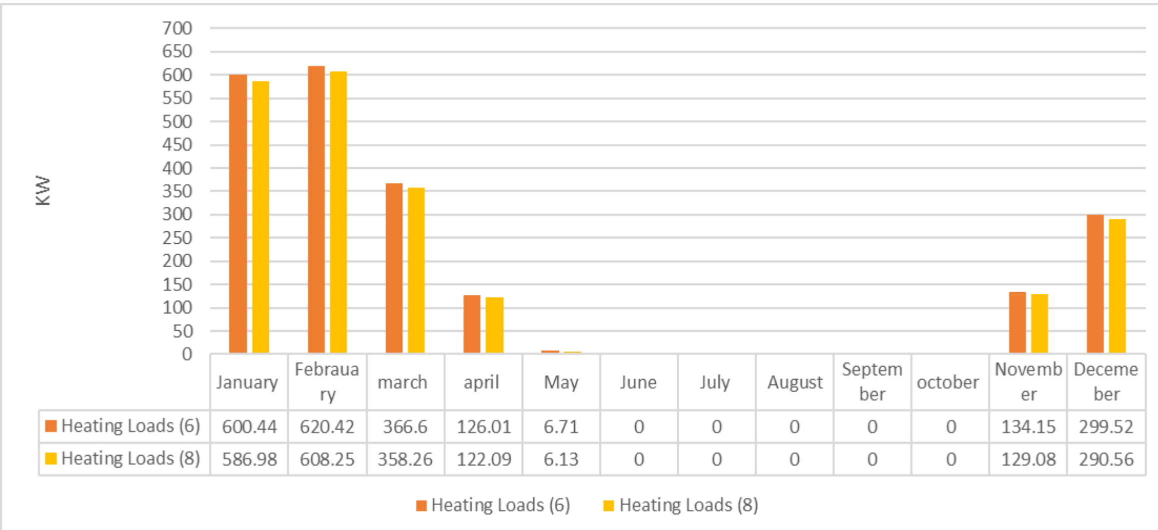


Figure 53: Monthly Heating Loads for Envelope 6 & 8

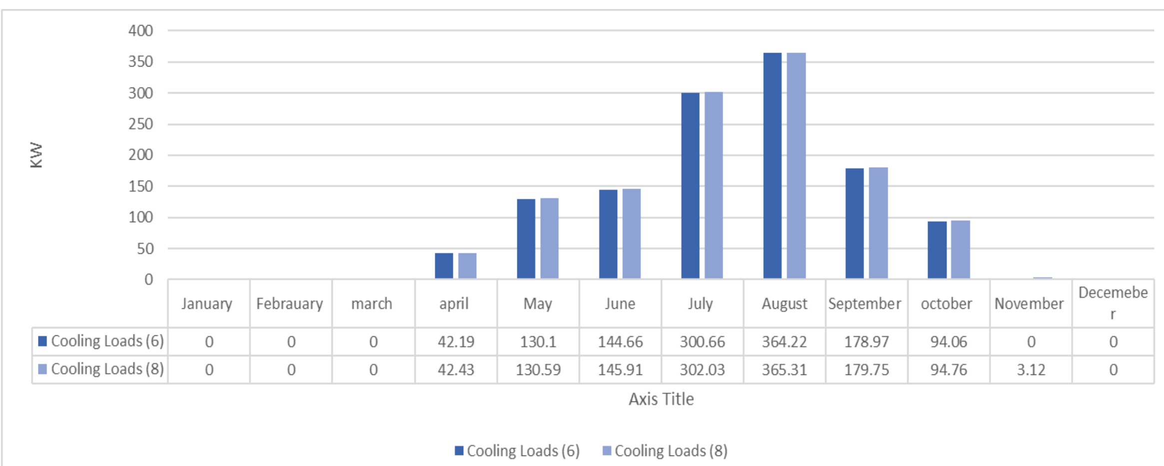


Figure 54: Monthly Cooling Loads for Envelope 6 & 8

Parametric design combined with the tool design and its structure gives the designer complete energy related information for a specific design. For instance, if the designer decided in the previous selected case that it is acceptable to ignore the few differences in heating loads and to approve envelope 6 rather than spending too much money in purchasing 5.08cm width expanded polystyrene which won't have any payback period since the savings are not compatible. He can still check whether thermal break aluminum can enhance energy consumption or not while comparing thermal break aluminum cost in comparison to insulating material cost and energy cost so as to approve with great evidence his or her selection.

4.5.4 Building Typology 3 - Parametric Simulation

Building typology 3 includes four living units per floor. The random selected case presents a comparison between two roof living spaces (A & B) and one ground living space (C). (A) is oriented East and the (B) is oriented West. The west oriented living space (B) is affected by the rear cliff (topography scenario 2). In addition to living space (C) which is a ground floor living space that is oriented to the east and that is not affected much by the urban context and topography scenario since it is located opposing to the cliff.

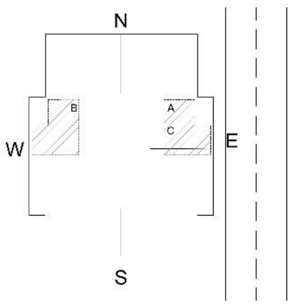
Parametric simulation Proves that each living space need to be treated differently. Since Orientation, floor level, topography and urban context have great effect on building performance and so on energy consumption.

Living space (A) and Living space (B) are in the same floor level however have opposite orientations. When designed with the generic construction envelope they both performed differently. Living space (B) consumes 4% more heating energy annually and 12.0% less cooling energies than living space (A). On the other hand, living space (C) consumes 20.0% and 37.3% less heating and less cooling energies respectively when compared to living space (A) that has the same orientation but at different floor level. When applying 3cm air gap insulation both living space A and B reacted the same in minimizing heating energies, however adding 2.54cm expanded polystyrene insulation has caused cooling energy to rise 25% more in living space B that is oriented west and that is affected by the rear topography than living space A that is oriented east. While when replacing the air gap insulation with 2.54cm expanded polystyrene, heating energy were minimized by 20.4% and 16.63% for living space C and A respectively. While cooling loads were maximized by 1.0% at living space C and 8.5% at living space A.

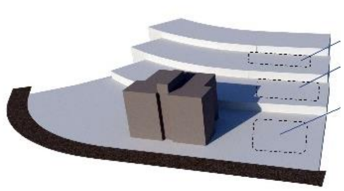
East oriented living space whether at ground or roof floor level showed better performance and improvement in energy consumption when applying 2.54cm expanded polystyrene to walls than west oriented living space.

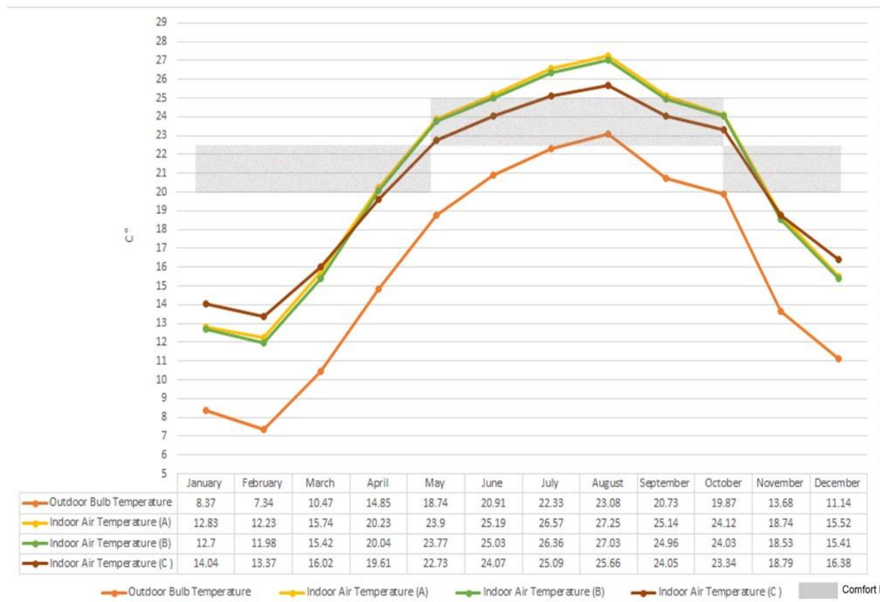
Command A: Applying 3cm air gap insulation (2)

living - East vs. West Oriented Apartment



- Roof Floor Level & Ground Floor Level
- Air gap thermal insulation in generic wall
- Double Glass Windows
- Topography scenario 2





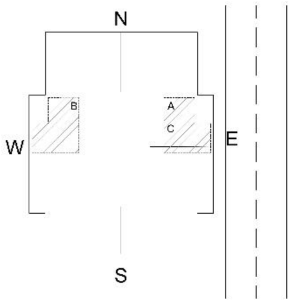
	January	February	March	April	May	June	July	August	September	October	November	December
Outdoor Bulb Temperature	8.37	7.34	10.47	14.85	18.74	20.91	22.33	23.08	20.73	19.87	13.68	11.14
Indoor Air Temperature (A)	12.83	12.23	15.74	20.23	23.9	25.19	26.57	27.25	25.14	24.12	18.74	15.52
Indoor Air Temperature (B)	12.7	11.98	15.42	20.04	23.77	25.03	26.36	27.03	24.96	24.03	18.53	15.41
Indoor Air Temperature (C)	14.04	13.37	16.02	19.61	22.73	24.07	25.09	25.66	24.05	23.34	18.79	16.38

Figure 55: East vs. West Base Case Scenario at Roof Floor vs. East Base Case Scenario at Ground Floor – Building Thermal Performance

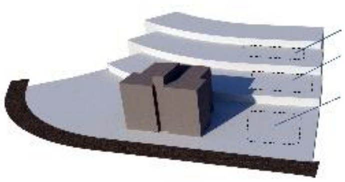
Living Space (A)	Living Space (B)	Living Space (C)
Annual Heating Loads:	Annual Heating Loads:	Annual Heating Loads:
3,061.0 KWh	3,184.0 KWh	2,421.0 KWh
Annual Cooling Loads:	Annual Cooling Loads:	Annual Cooling Loads:
1,650.0 KWh	1,474.0 KWh	999.0KWh
Percentage of saving when compared to base case scenario		
2.9 % -2.2 %	6.7 % -3.4%	7.8% 1.2%

Command B: Assessing the effect of replacing the thermal air gap insulation with 2.54 thermal insulation (3)

- East vs. West Oriented Apartment



- Roof & Ground Floor Level
- 2.54cm expanded polystyrene
- Double Glass Windows
- Topography scenario 2



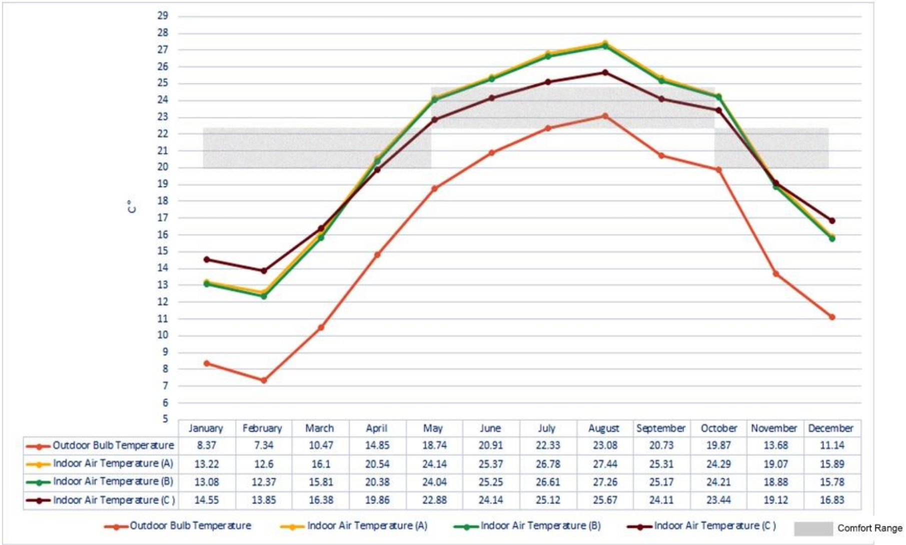


Figure 56: East vs. West Envelope at Roof Level vs. East Envelope at Ground Floor Level – Building Thermal Performance

Living Space (A)	Living Space (B)	Living Space (C)
Annual Heating Loads: 2,728.0 KWh	Annual Heating Loads: 2,828.0 KWh	Annual Heating Loads: 2,089.0 KW
Annual Cooling Loads: 1,751.0 KWh	Annual Cooling Loads: 1,596.0 KWh	Annual Cooling Loads: 1,001.0 KW
Percentage of savings when compared to the base case scenario		
17.2 %	17.1%	20.5%
-8.5 %	-12.3%	1.0 %

The three living spaces that have different orientations and that are at different floor levels showed different percentages of savings or over consumption as a result of replacing thermal air gap with 2.54, 3.81 and 5.08cm insulating material. When applying 2.54 cm, heating energies were minimized by 17.2% at living (A), 17.1% at Living Space (B) and 20.5% at living Space (C). However cooling energies were raised by 8.5% at living space (A), 12.3% at living space (B) but minimized by 1.0% at living space (C).

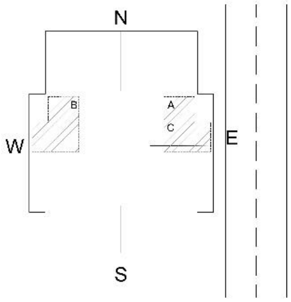
When applying 3.81cm, heating energies were minimized by 18.1%, 18.6%, 22.0% at living space A, B and C respectively however, the cooling energies were raised by 9.2% and 13.3% at living space A and B respectively and was minimized by 1.3% at living space C.

When applying 5.08cm, heating energies were minimized by 19.0%, 19.6%, 23.0% at living space A, B and C respectively however, the cooling energies were raised by 9.5% and 13.8% at living space A and B while living space C hasn’t shown any changes.

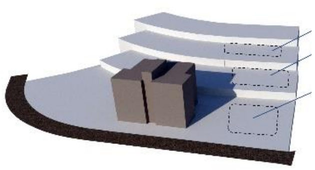
(Shariah et al., 1997) in a detailed study on heating and cooling loads in residential buildings in Jordan has tested and analyzed the effect of insulation on buildings in comparison with non-insulated envelope. (Shariah et al., 1997) results have shown great intersection with the results and conclusions got in the parametric testing introduced in this study. (Shariah et al., 1997) concluded that wall insulation only has great impact on heating loads but negative impacts on cooling loads.

Command C: Assessing the effect of 3.81cm thermal insulation (4)

- East vs. West Oriented Apartment



- Roof & Ground Floor Level
- 3.81cm expanded polystyrene
- Double Glass Windows
- Topography scenario 2



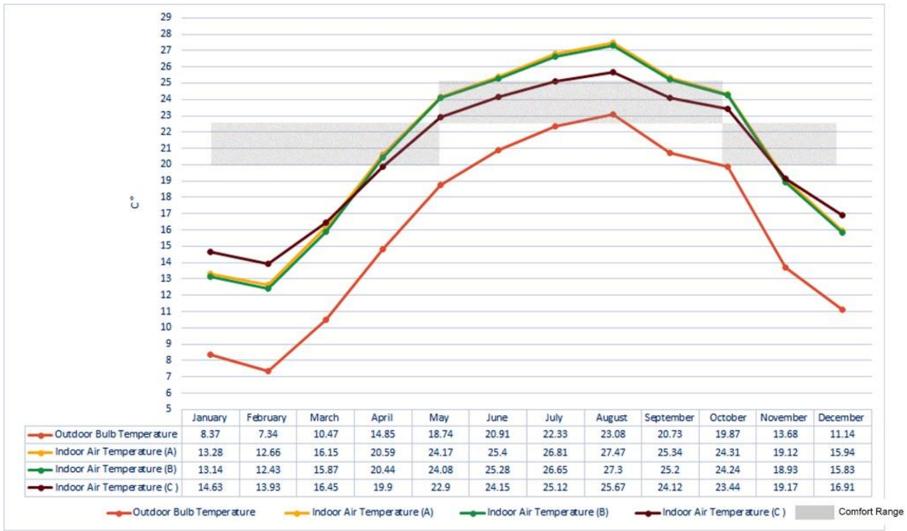


Figure 57: East vs. West Envelope at Roof Level vs. East Envelope at Ground Floor Level – Building Thermal Performance

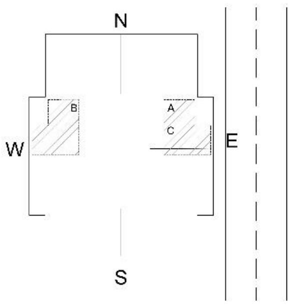
Living Space (A)	Living Space (B)	Living Space (C)
Annual Heating Loads: 2,679.0 KWh	Annual Heating Loads: 2,776.0 KWh	Annual Heating Loads: 2,049.0 KW
Annual Cooling Loads: 1,762.0 KWh	Annual Cooling Loads: 1,610.0 KWh	Annual Cooling Loads: 998.0 KWh

Percentage of savings when compared to the base case scenario

Living Space (A)	Living Space (B)	Living Space (C)
18.1%	18.6 %	22.0 %
-9.2%	-13.3 %	1.3 %

Command D: Assessing the effect of 5.08cm thermal insulation <u>(5)</u>

- East vs. West Oriented Apartment



- Roof & Ground Floor Level
- 5.08cm expanded polystyrene
- Double Glass Windows
- Topography scenario 2

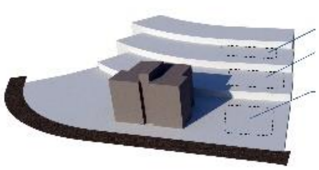


Figure 58: East vs. West Envelope at Roof Level vs. East Envelope at Ground Floor Level – Building Thermal Performance

Living Space (A)	Living Space (B)	Living Space (C)
Annual Heating Loads: 2,650.0 KWh	Annual Heating Loads: 2,745.0 KWh	Annual Heating Loads: 2,019.0 KWh
Annual Cooling Loads: 1,768.0 KWh	Annual Cooling Loads: 1,617.0 KWh	Annual Cooling Loads: 1,011.0 KWh

Percentage of savings when compared to the base case scenario

Living Space (A)	Living Space (B)	Living Space (C)
19.0%	19.6%	23.1%
-9.5%	-13.8%	0.0 %

Cooling energies at Ground floor level were not negatively affected by raising the thermal mass of the envelope due to the installation of thermal insulation in comparison with living spaces at roof level. As well as, it achieved the best saving with maximum insulation thickness and with the lowest glazing U value (triple glass). Living Space C when combining triple glazing with 5.08cm insulation, heating and cooling energies were minimized by 24.5% and 12.5% respectively.

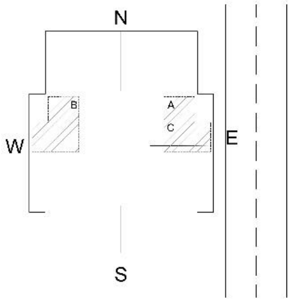
Roof floors reached a dew point when building performance has stopped to record any improvement in performance resulting from the insulation of thicker insulation material. for example: living space (A) when tested with 3.81cm insulation material and with double glass and compared with 5.08cm insulation material and with double glass, an average of 30.0 KW energy was saved annually for heating energy, however, an average of 6KW energy was raised annually for cooling energy.

However, when applying high glazing properties such as Low Energy double glass and low energy triple glass to walls insulated with 3.81cm thick and 5.08cm thick, building performance showed better performance but still the cooling energies were raised with an average percentage of 5.1% and 10.9% at living Space A and B respectively and raised to an average percentage of 2.7% and 9.6% respectively with 5.08 insulation and triple glazing. Which is in accordance with (Gasparella et al., 2011) detailed study on windows and glazing systems that proved that low thermal resistant windows are effective in winter.

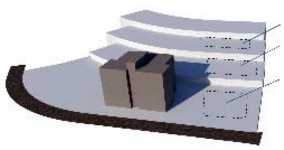
Careful designing is highly needed so as to achieve both comfort and energy conservation. The choice of glazing is very important (Manz and Menti, 2012). It varies according to orientation, to window size as well the amount of shadings affected the opaque surfaces. Glazing with high solar resistance is highly needed in summer while the opposite is needed in winter. However, in Mediterranean climate, glazing with high U value and low g value is favorable (Tsikaloudaki et al., 2015), which proved to be right throughout this study. Low energy glazing has shown great effects on heating and cooling energies when combined with high level of envelope insulation. The proposed tool had shown great advantages since it guides the user toward testing the best alternative in comparison to real design conditions such as site, orientation, floor level …etc.

Command E: Assessing the effect of combing 3.81cm thermal insulation with Low Energy Double Glass (6)

- East vs. West Oriented Apartment



- Roof & Ground Floor Level
- 3.81cm expanded polystyrene
- Low Energy Double Glass Windows
- Topography scenario 2



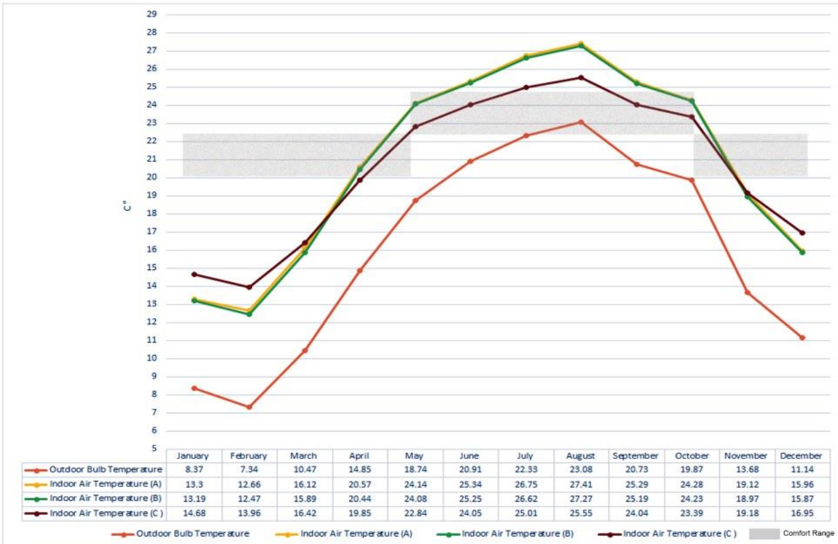


Figure 59: East vs. West Envelope at Roof Level vs. East Envelope at Ground Floor Level – Building Thermal Performance

Living Space (A)	Living Space (B)	Living Space (C)
Annual Heating Loads: 2,661.0 KWh	Annual Heating Loads: 2,730.0 KWh	Annual Heating Loads: 2,021.0 KWh
Annual Cooling Loads: 1,690.0 KWh	Annual Cooling Loads: 1,570.0 KWh	Annual Cooling Loads: 927.0 KWh

Percentage of Savings when compared to base case scenario

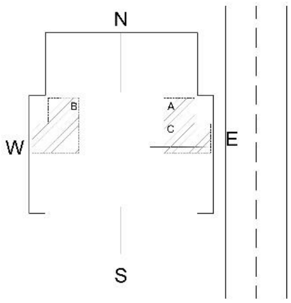
Living Space (A)	Living Space (B)	Living Space (C)
18.6%	20.0%	23.1%
-4.7%	-9.5%	8.3%

East oriented living spaces A & C responded better to envelope insulation and glazing in cooling energies than west oriented living space B.

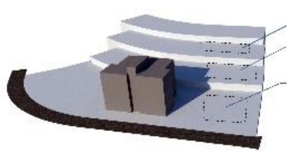
Roof insulation was tested since the previous results have shown that there isn't much improvement on building performance which might be due to heat gain and loss through another important envelope membrane which is the roof.

Command F: Assessing the effect of combing 3.81cm thermal insulation with Low Energy Triple Glass (7)

- East vs. West Oriented Apartment



- Roof & Ground Floor Level
- 3.81cm expanded polystyrene
- Low Energy Triple Glass Windows
- Topography scenario 2



	January	February	March	April	May	June	July	August	September	October	November	December
Outdoor Bulb Temperature	8.37	7.34	10.47	14.85	18.74	20.91	22.33	23.08	20.73	19.87	13.68	11.14
Indoor Air Temperature (A)	13.3	12.65	16.1	20.55	24.13	25.31	26.71	27.37	25.27	24.27	19.12	15.96
Indoor Air Temperature (B)	13.21	12.49	15.9	20.44	24.07	25.23	26.6	27.25	25.18	24.22	18.99	15.88
Indoor Air Temperature (C)	14.7	13.97	16.39	19.81	22.8	24	24.95	25.48	24	23.36	19.17	16.96

Figure 60: East vs. West Envelope at Roof Level vs. East Envelope at Ground Floor Level – Building Thermal Performance

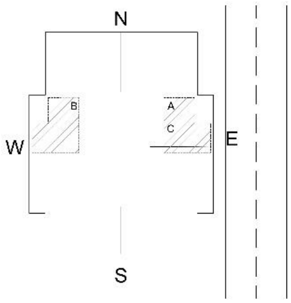
Living Space (A)	Living Space (B)	Living Space (C)
Annual Heating Loads: 2,655.0 KWh	Annual Heating Loads: 2,710.0 KWh	Annual Heating Loads: 2,017.0 KWh
Annual Cooling Loads: 1,652.0 KWh	Annual Cooling Loads: 1,551.0 KWh	Annual Cooling Loads: 889.0 KWh

Percentage of Savings when compared to base case scenario

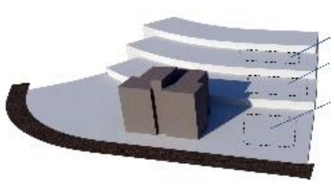
Living Space (A)	Living Space (B)	Living Space (C)
18.8%	20.6%	23.2%
-2.35%	-9.1%	12.1%

Command G: Assessing the effect of combing 5.08 thermal insulation with Low Energy Double Glass (9)

- East vs. West Oriented Apartment



- Roof & ground Floor Level
- 50.08cm expanded polystyrene
- Low Energy Double Glass Windows
- Topography scenario 2



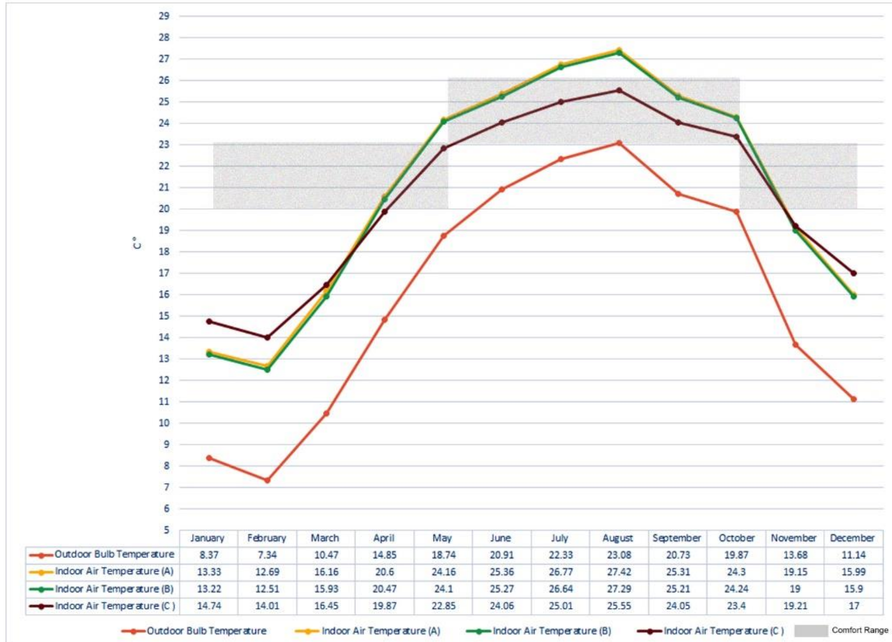


Figure 61: East vs. West Envelope at Roof Level vs. East Envelope at Ground Floor Level – Building Thermal Performance

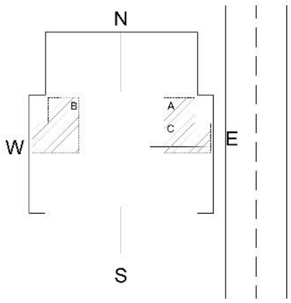
Living Space (A)	Living Space (B)	Living Space (C)
Annual Heating Loads: 2,6310.0 KWh	Annual Heating Loads: 2,699.0 KWh	Annual Heating Loads: 1,990.0 KWh
Annual Cooling Loads: 1,696.0 KWh	Annual Cooling Loads: 1,577.0 KWh	Annual Cooling Loads: 938.0 KWh

Percentage of savings when compared to base case scenario

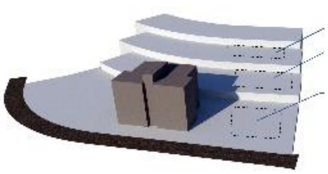
Living Space (A)	Living Space (B)	Living Space (C)
19.6%	20.9%	24.2%
-5.1%	-10.9%	7.2%

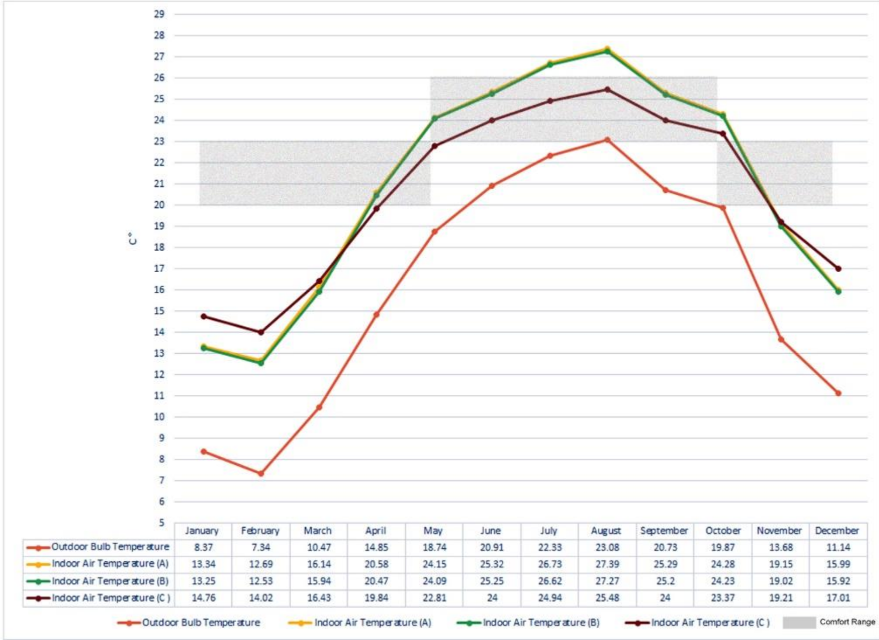
Command H: Assessing the effect of combing 5.08 thermal insulation with Low Energy triple Glass (10)

- East vs. West Oriented Apartment



- Roof & Ground Floor Level
- 50.08cm expanded polystyrene
- Low Energy Triple Glass Windows
- Topography scenario 2





	January	February	March	April	May	June	July	August	September	October	November	December
Outdoor Bulb Temperature	8.37	7.34	10.47	14.85	18.74	20.91	22.33	23.08	20.73	19.87	13.68	11.14
Indoor Air Temperature (A)	13.34	12.69	16.14	20.58	24.15	25.32	26.73	27.39	25.29	24.28	19.15	15.99
Indoor Air Temperature (B)	13.25	12.53	15.94	20.47	24.09	25.25	26.62	27.27	25.2	24.23	19.02	15.92
Indoor Air Temperature (C)	14.76	14.02	16.43	19.84	22.81	24	24.94	25.48	24	23.37	19.21	17.01

Figure 62: East vs. West Envelope at Roof Level vs. East Envelope at Ground Floor Level – Building Thermal Performance

Living Space (A)	Living Space (B)	Living Space (C)
Annual Heating Loads: 2,625.0 KWh	Annual Heating Loads: 2,679.0 KWh	Annual Heating Loads: 1,983.0 KWh
Annual Cooling Loads: 1,657.0 KWh	Annual Cooling Loads: 1,557.0 KWh	Annual Cooling Loads: 885.00 KWh
Percentage of savings when compared to the base case scenario		
19.7%	21.5%	24.5%
-2.7%	-9.6%	12.5%

Roof insulation have shown a remarkable improvement in building performance and in energy savings. Combining roof insulation with envelopes insulated by 3.81cm thick expanded polystyrene and Low energy Double Glass has improved heating energies by a percentage of 45.7%, 45.3%, 16.53% at living space A, living space B and living space C respectively when compared to the generic wall. As well as, has improved cooling energies by a percentage of 13.05%, 12.01% and 7.28% at living space A, B and C respectively.

Moreover, combining roof insulation with envelopes insulated by 5.08cm thick expanded polystyrene and Low energy Double Glass has improved heating energies by a percentage of 43.15%, 45.3%, 23.1% at living space A, living space B and living space C respectively when compared to the generic wall. As well as, has improved cooling energies by a percentage of 11.0%, 8.7% and 8.3% at living space A, B and C respectively. Similarly (Shariah et al., 1997)when assessing the effect of insulation on energy consumption, when ceiling only was insulated, both heating and cooling loads were reduced. While with both wall and ceiling insulation the total energy consumption can be reduced by about 40%.

<table>
<tr><td colspan="4">Command I: Assessing the effect of proposing roof insulation to 3.81 thermal insulation with Low Energy double Glass <u>(11)</u></td></tr>
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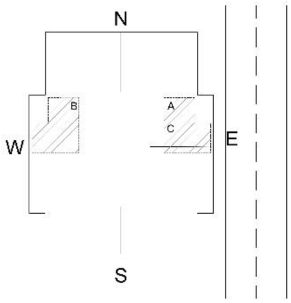
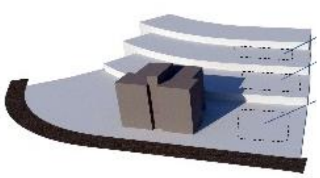

- Roof & Ground Floor Level
- 3.81 cm expanded polystyrene
- Low Energy Double Glass Windows
- 2.54 cm roof Insulation
- Topography scenario 2
</td><td colspan="3">
Figure 63: East vs. West Envelope at Roof Level vs. East Envelope at Ground Floor Level – Building Thermal Performance</td></tr>
<tr><td>Living Space (A)

Annual Heating Loads: 1,776.0 KWh

Annual Cooling Loads: 1,435.0 KWh</td><td>Living Space (B)

Annual Heating Loads: 1,867.0 KWh

Annual Cooling Loads: 1,297.0 KWh</td><td>Living Space (C)

Annual Heating Loads: 2,021.0 KWhh

Annual Cooling Loads: 927.0 KW</td></tr>
<tr><td></td><td colspan="3">Percentage of Savings when compared to the base case scenario</td></tr>
<tr><td></td><td>45.7%

11.0%</td><td>45.3%

8.7%</td><td>23.1%

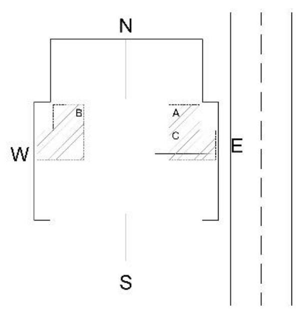
8.3%</td></tr>
</table>

Similarly, roof insulation has shown different reactions in building performance and in energy savings when combining roof insulation with envelopes insulated by 5.08cm o3 3.81cm thick expanded polystyrene and Low energy Double or Triple Glass. Double Glazing with 3.81cm insulating thicknesses when combined with roof insulation has shown better building performance in summer than winter. In comparison with triple glazing with 5.08cm insulating thicknesses when combined with roof insulation has shown better building performance in winter than summer.

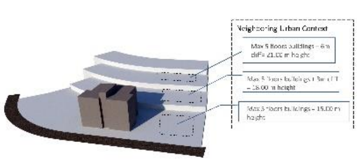
(Shariah et al., 1998) in his referenced study in Jordan has proved that the absorptance of the flat roofs has a very big effect on heating and cooling loads and if treated well with insulation and light color finish material, a remarkable saving in the total load can be achieved.

Command J: Assessing the effect of proposing roof insulation to 3.81 thermal insulation with Low Energy triple Glass (12)

- East vs. West Oriented Apartment



- Roof & ground Floor Level
- 3.81 cm expanded polystyrene
- Low Energy Triple Glass Windows
- 2.54 cm roof Insulation
- Topography scenario 2



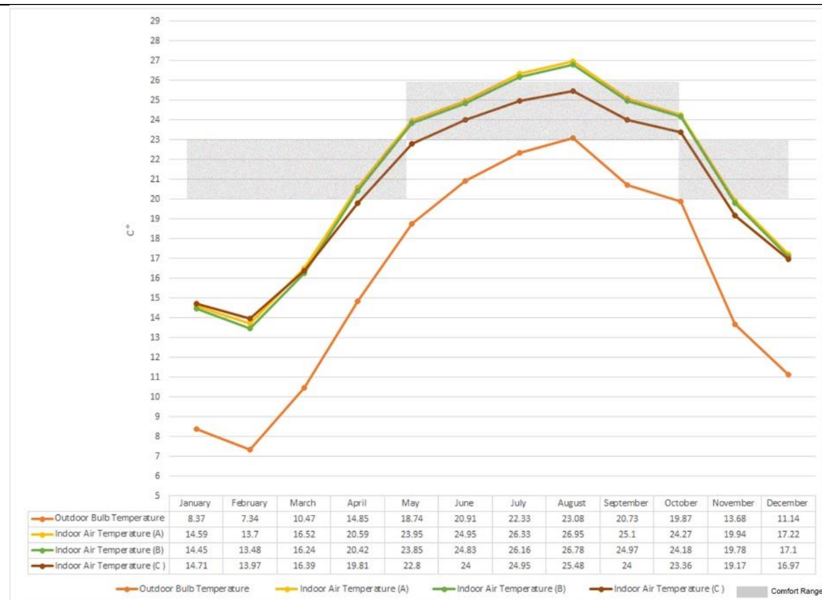


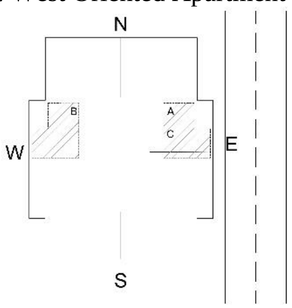
Figure 64: East vs. West Envelope at Roof Level vs. East Envelope at Ground Floor Level – Building Thermal Performance

Living Space (A)	Living Space (B)	Living Space (C)
Annual Heating Loads: 1,766.0 KWh	Annual Heating Loads: 1,842.0 KWh	Annual Heating Loads: 2,013.0 KWh
Annual Cooling Loads: 1,386.0 KWh	Annual Cooling Loads: 1,271.0 KWh	Annual Cooling Loads: 889.0 KWh
Percentage of savings when compared to the base case scenario		
46.0% 14%	46.0% 10.6%	23.4% 12.1%

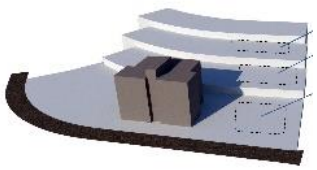
The results show that when combining roof insulation with envelopes insulated by 3.81cm thick expanded polystyrene and Low energy triple Glass, heating energies has improved by a percentage of 46.0% at living space A and B and 23.4% at living space C when compared to the generic wall. As well as, has improved cooling energies by a percentage of 14.0%, 10.6% and 12.1% at living space A, B and C respectively.

Command K: Assessing the effect of proposing roof insulation to 5.08 thermal insulation with Low Energy double Glass (13)

- East vs. West Oriented Apartment



- Roof & Ground Floor Level
- 5.08 cm expanded polystyrene
- Low Energy Double Glass Windows
- 2.54 cm roof Insulation
- Topography scenario 2



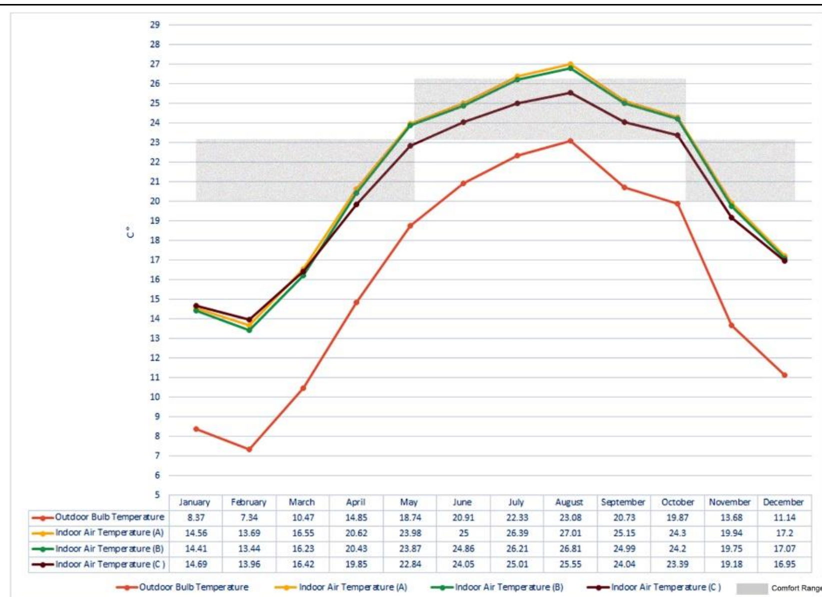


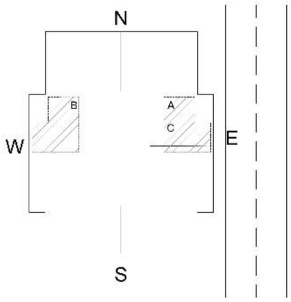
Figure 65: East vs. West Envelope at Roof Level vs. East Envelope at Ground Floor Level – Building Thermal Performance

Living Space (A)	Living Space (B)	Living Space (C)
Annual Heating Loads: 1,740.0 KWh	Annual Heating Loads: 1,829.0 KWh	Annual Heating Loads: 1,990.0 KWh
Annual Cooling Loads: 1,439.0 KWh	Annual Cooling Loads: 1,302.0 KWh	Annual Cooling Loads: 938.0 KW h
Percentage of savings when compared to the base case scenario		
46.8%	46.4%	24.3%
11%	8.4%	7.2%

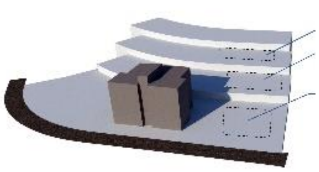
Similarly, the simulation results show that when combining roof insulation with envelopes insulated by 5.08cm thick expanded polystyrene and Low energy triple Glass, heating energies has improved by a percentage of 51.1%, 47.5%, 25.7% at living space A, living space B and living space C respectively when compared to the generic wall. As well as, has improved cooling energies by a percentage of 9.4%, 6.8% and 6.0% at living space A, B and C respectively.

Command L: Assessing the effect of proposing roof insulation to 5.08 thermal insulation with Low Energy triple Glass (14)

- East vs. West Oriented Apartment



- Roof & Ground Floor Level
- 5.08 cm expanded polystyrene
- Low Energy Triple Glass Windows
- 2.54 cm roof Insulation
- Topography scenario 2



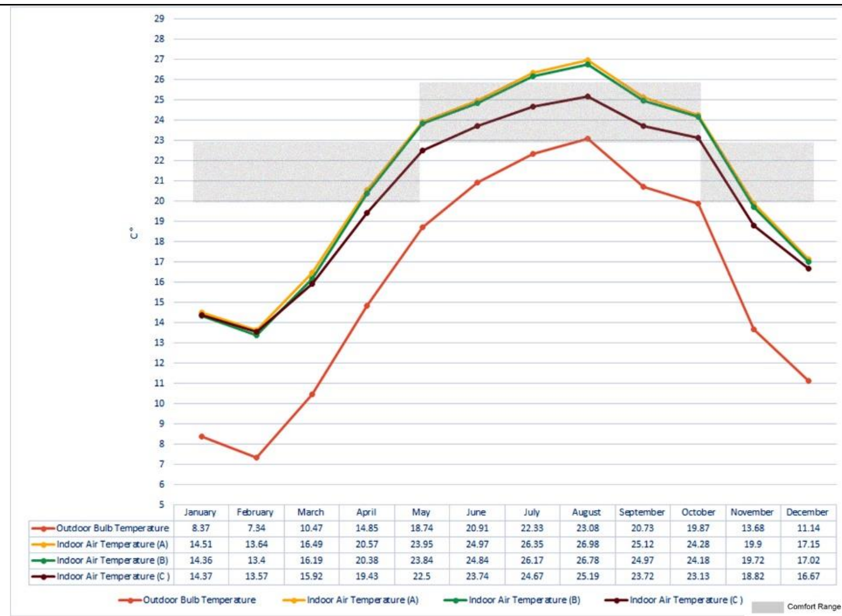


Figure 66: East vs. West Envelope at Roof Level vs. East Envelope at Ground Floor Level – Building Thermal Performance

Living Space (A)	Living Space (B)	Living Space (C)
Annual Heating Loads: 1,600.0 KWh	Annual Heating Loads: 1,792.0 KWh	Annual Heating Loads: 1,951.0 KWh
Annual Cooling Loads: 1,462.0 KWh	Annual Cooling Loads: 1,324. 0 KWh	Annual Cooling Loads: 950.0 KWh
Percentage of savings when compared to the base case scenario		
51.1%	47.5%	25.7%
9.4%	6.8%	6.0%

By comparing the results, the designer will be able to determine the more energy efficient envelope for specific defined parameters.

Table 37: Summary of Different Envelope Configurations to be Used in the Comparison Process

East and west oriented living room – Topography scenario #2 – ground & Roof floor – Four residential units per floor	Envelope Designs	Type of insulation & thickness	Location of insulation	Type of glass
	1 (BASE CASE)	No insulation	______	Clear double glass
	1	3cm thermal air gap	On walls only	Clear double glass
	2	2.54 Expanded Polystyrene	On walls only	Clear double glass
	3	3.81 Expanded Polystyrene	On walls only	Clear double glass
	4	5.08 Expanded Polystyrene	On walls only	Clear double glass
	5	3.81 Expanded Polystyrene	On walls only	Low Energy Double Glass
	6	3.81 Expanded Polystyrene	On walls only	Low Energy Triple Glass
	7	5.08 Expanded Polystyrene	On walls only	Low Energy Double Glass
	8	5.08 Expanded Polystyrene	On walls only	Low Energy Triple Glass
	9	3.81 Expanded Polystyrene	On walls only and ceiling	Low Energy Double Glass
	10	3.81 Expanded Polystyrene	On walls only and ceiling	Low Energy Triple Glass
	11	5.08 Expanded Polystyrene	On walls only and ceiling	Low Energy Double Glass
	12	5.08 Expanded Polystyrene	On walls only and ceiling	Low Energy Triple Glass

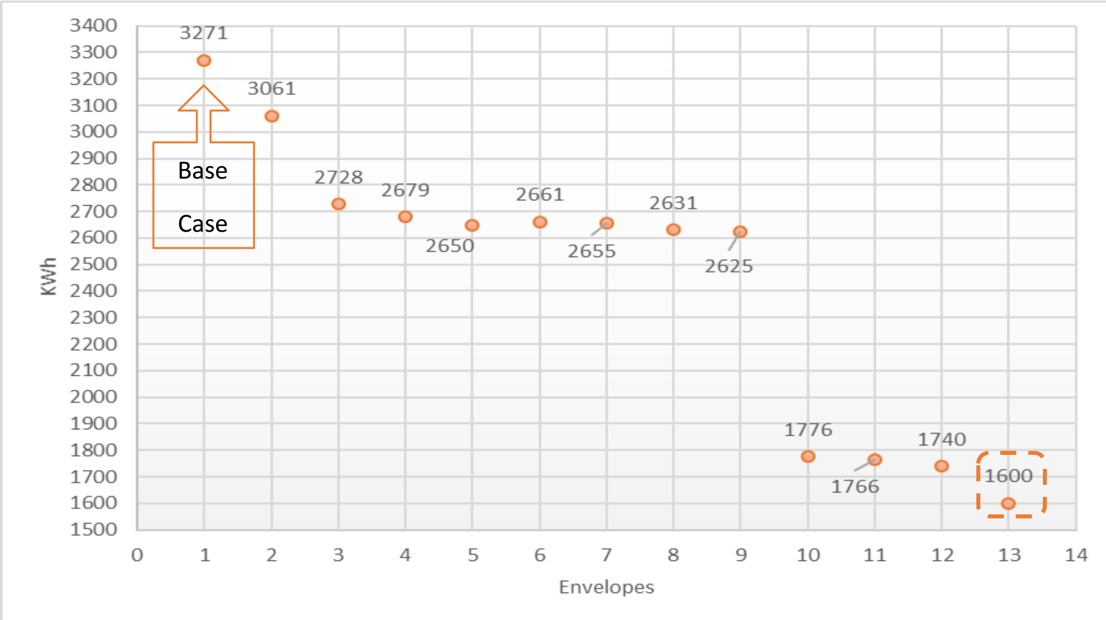


Figure 67: Comparison of Heating Energies Consumed Based on Envelope Designs Summarized in Table 37 for Living Space A

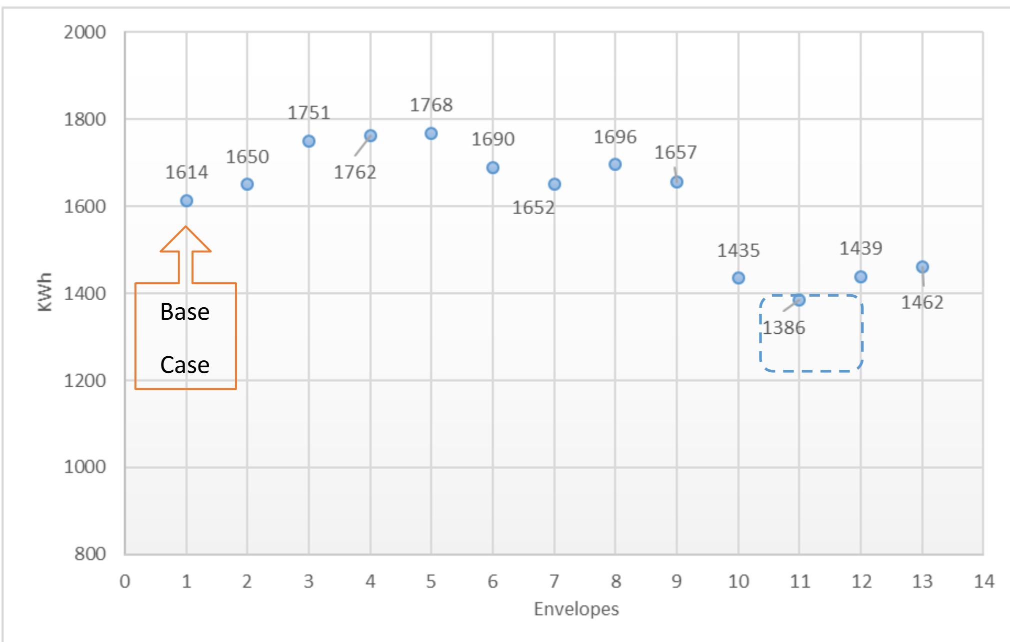


Figure 68: Comparison of Cooling Energies Consumed Based on Envelope Designs Summarized in Table 37 for Living Space A

Shapes presenting the best envelopes

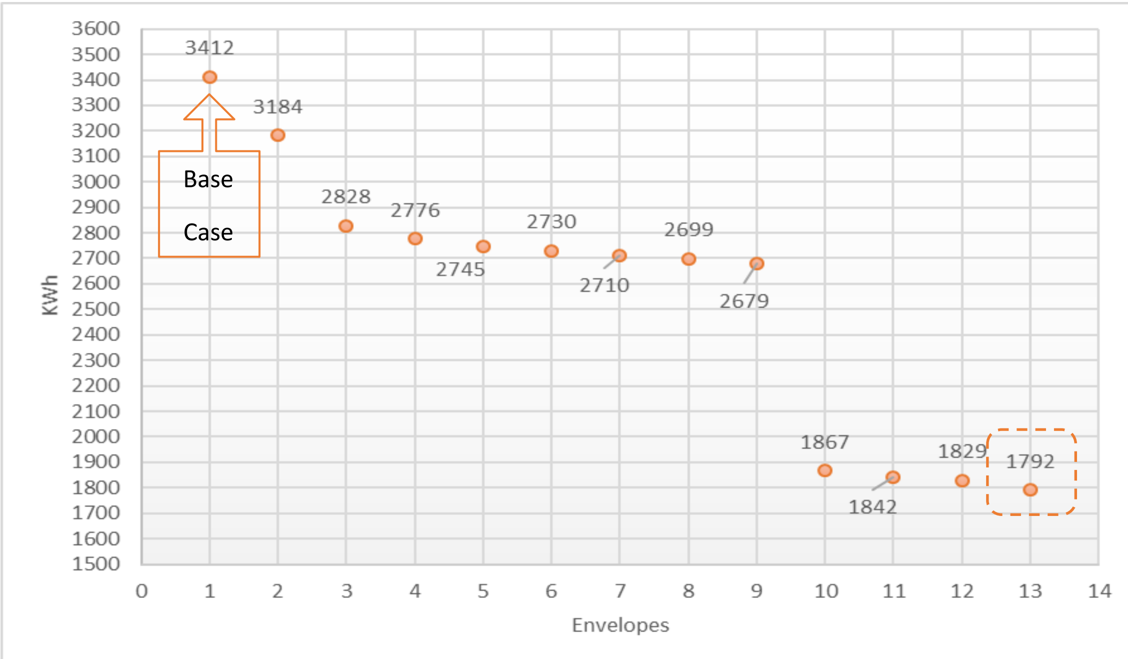


Figure 69: Comparison of Heating Energies Consumed Based on Envelope Designs Summarized in Table 37 for Living Space B

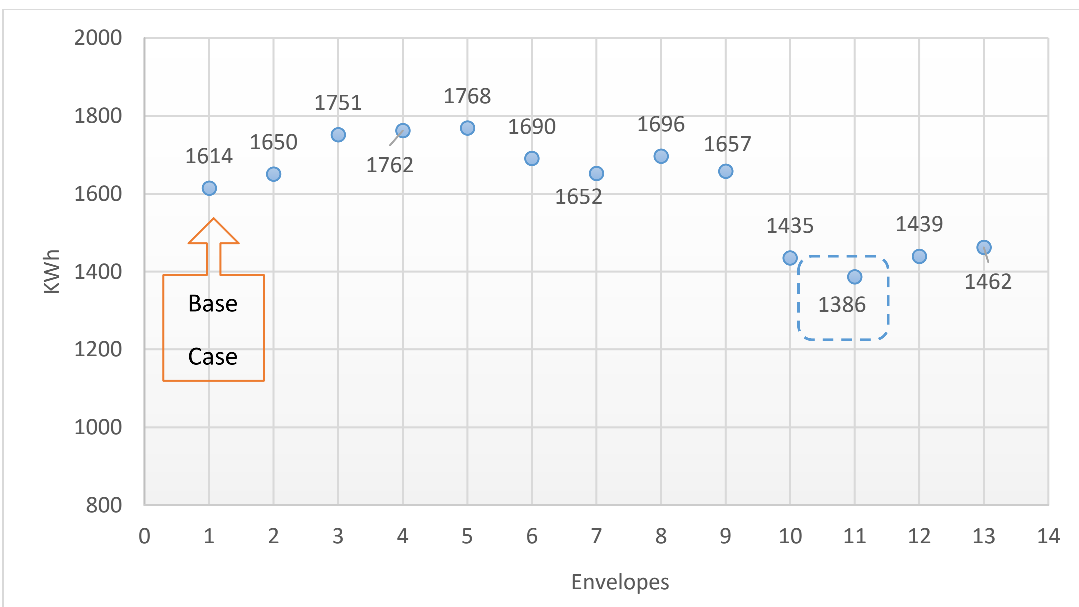


Figure 70: Comparison of Cooling Energies Consumed Based on Envelope Designs Summarized in Table 37 for Living Space B

Shapes presenting the best envelope

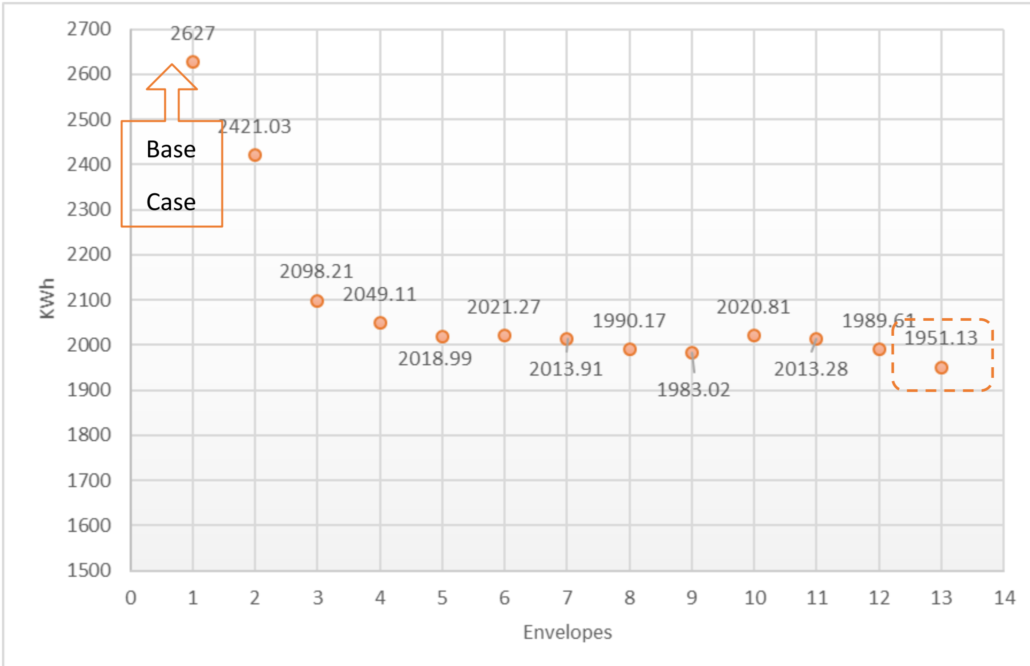


Figure 71: Comparison of Heating Energies Consumed Based on Envelope Designs Summarized in Table 37 for Living Space C

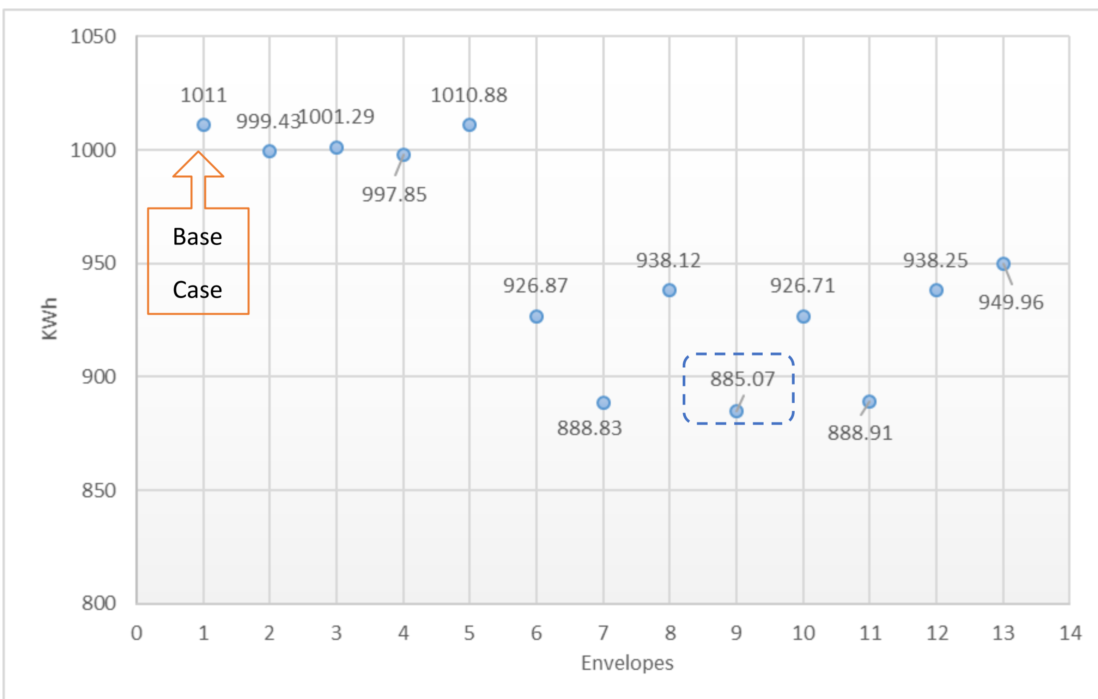


Figure 72: Comparison of Cooling Energies Consumed Based on Envelope Designs Summarized in Table 37 for Living Space C

Shapes presenting the best envelope →

Base on the previous results and when different envelope configuration between summer and winter are recommended for the same space, the designer should do cost analysis vs. saving analysis to choose the best option. Table 38 summarize the costs of insulation in the study context as well as table 39 summarize the costs of glazing in the study context.

Table 38: Cost of Insulation Material

Source: interview with local manufacturers

	Material	Cost / m² in Shekel
1	2.54 Insulation material	5.75 shekel / m²
2	3.81 Insulation material	7 shekel / m²
3	5.08 Insulation material	12 shekel / m²

- Prices are based on the year 2020 market price

Table 39: Cost of glazing

Source: interview with local manufacturers

	Material	Cost / m² in Shekel
1	Double Glass	90 shekel / m²
2	Low Energy Double Glass	150 shekel / m²
3	Low Energy Triple Glass	190 Shekel / m²

- Prices are based on the year 2020 market price

Table 40: Cost of Aluminum

Source: interview with local manufactures

	Material	Cost / m² in Shekel
1	Normal Aluminum	900 shekel / m²
2	Thermal Break aluminum	1300 shekel / m²

- Prices are based on the year 2020 market price

4.6 Conclusion

This chapter has presented random simulation results and has proved that the parametric simulation is highly recommended to compare different design alternatives. It’s a method to compare and evaluate different simulation results so as to choose the optimized solution. The previously discussed results as well as the proposed parametric methodology has proved the need to develop a simplified tool _ which is elaborated in the next chapter _ so as to test all alternatives in a fast and easy way and to help in designing energy efficient building.

Chapter Five

Tool Description

5.1 Introduction

In response to the research problem and to the great need that was described in chapter one for a simplified tools and methods to test building performance and energy consumption during the design phase of buildings, a simulation-based early design tool was developed. The tool is a simulation-based tool that aims to address envelope design related parameters and test their ability to enhance building performance and to minimize energy consumption through building envelope design. The tool allows for parametric analysis as well as sensitivity analysis for different envelope related design parameters. Such analysis can be easily done during the early design phases of buildings and is valid in the precisely defined climatic zone (the fourth climatic zone of Palestine). The tool is an experimental tool and has been developed by the use of a base case model that highly presents the Palestinian residential buildings and by the use of local construction materials and the local construction techniques.

This tool targets architects and interior designers with little experience in building simulation programs. It can be a method to lower the barriers of studying building performance during the design phase of buildings. It can be also a method toward designing and constructing energy efficient residential buildings. During building design phase, usually architects produce many designs and many different design alternatives, in which such tool are highly needed and can be applied to test the energy consumption of each design alternative so as to help in choosing the best design. Similarly, interior designer can test different envelope insulating alternatives and different window glazing thermal properties to choose the combination that produce the best building performance and the lowest energy consumption.

There was a great need to use a representative model in order to develop this tool. The model was chosen based on a complex study to find representative base case that presents the local Palestinian residential buildings. The base case model represents different apartment buildings configurations: two residential units per floor, three residential units per floor or four residential units per floor as shown in figures 20,21 and 22, in eight different orientations and in four different floor levels and are assumed to be located in four different topography scenarios that represents the study context. The simulation results were validated using the rule of thumb method developed for Palestine.

The base case model was described earlier in chapter three and the input parameters were briefly tested and identified in chapter three as well. The outputs of this tool can be divided into four output categories. The first output is a building performance indicator in the form of a graph that indicates indoor air temperatures versus outdoor dry bulb temperature, and in comparison, with the comfort level range. The second output is energy consumption summary represented by monthly heating and cooling loads, as well as annual consumptions. The third output is a saving indicator describing how much energy can be saved as a result of the selected parameters in the form of Kilo watts energy and in the form of money savings (Israeli Shekels) as well as an indicator of how much money the home owner needs to purchase the selected parameters (construction materials) in comparison with the generic wall design. The fourth output gives an indication of how much energy needed to heat and cool the entire apartment in comparison to only heating the living space. In addition to a construction material library that is defined and described in this tool including: insulation, glazing and aluminum.

The use of parametric simulation is very important and is the main goal of this tool in order to analyze and compare results before taking design decisions. This tool allows to test unlimited options in building envelope parameters and has proved that such methodology can positively affect building performance and energy consumption.

5.2 Interface, input and output data

To address the tool objective, its interface presents a variety of drop-down menu icons related to building envelope passive design strategies. Upon executing the tool file, the main page that represents its interface appears as shown in Figure 73. Input data will be found at the left edge of the tool interface as shown in Figure 74. Output categories previously defined can be shown in Figure 75.

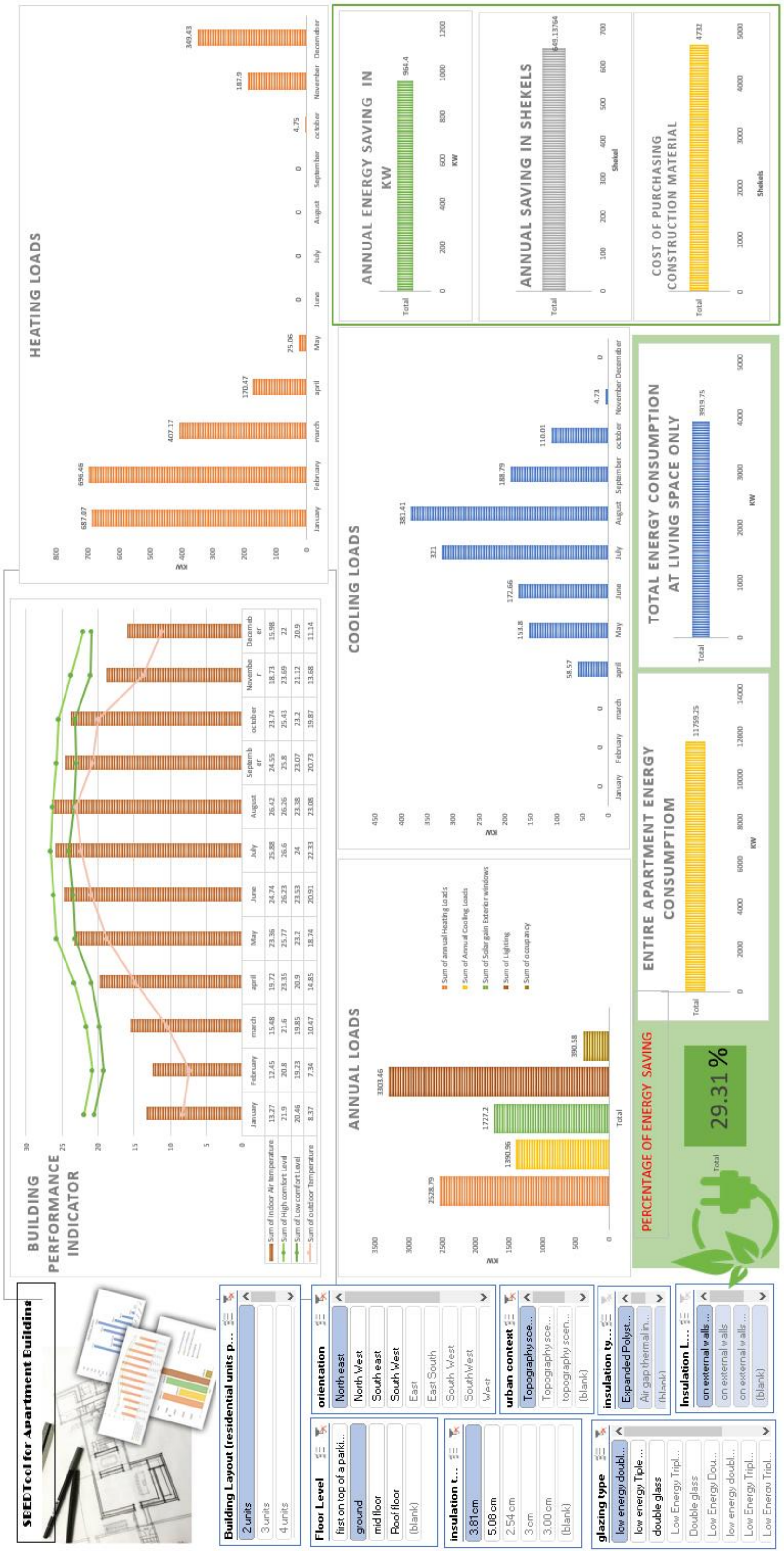


Figure 73: Tool Interface

The tool can accept the following input data. Input data is the data that the user can select by clicking on an option in the shown drop down menu:

Figure 74: Tool Input Data

The user can choose first a building prototype

- The user can choose a floor level as well as living space orientation. Living Space orientation need to be precisely chosen following the tool identified rules related to orientation as shown in chapter 3 in table 9

- Topography scenario including urban context which are also precisely defined in chapter 3 in figures 24, 25, 26 and 27

- The user can ten test the effect of

1. Different Insulation thicknesses

2. Different Glazing properties

3. Combined effect of insulation and glazing

4. The effect of thermal break aluminum

5. The effect of adding insulation to another envelope component (roof)

The tool presents its outputs graphically. The user is allowed to change the input parameters that are already defined which automatically change the output graphs and results. For each different input parameters, the tool will display the different results and will give the user a chance to compare and test different alternatives in an easy, simple and time-consuming method.

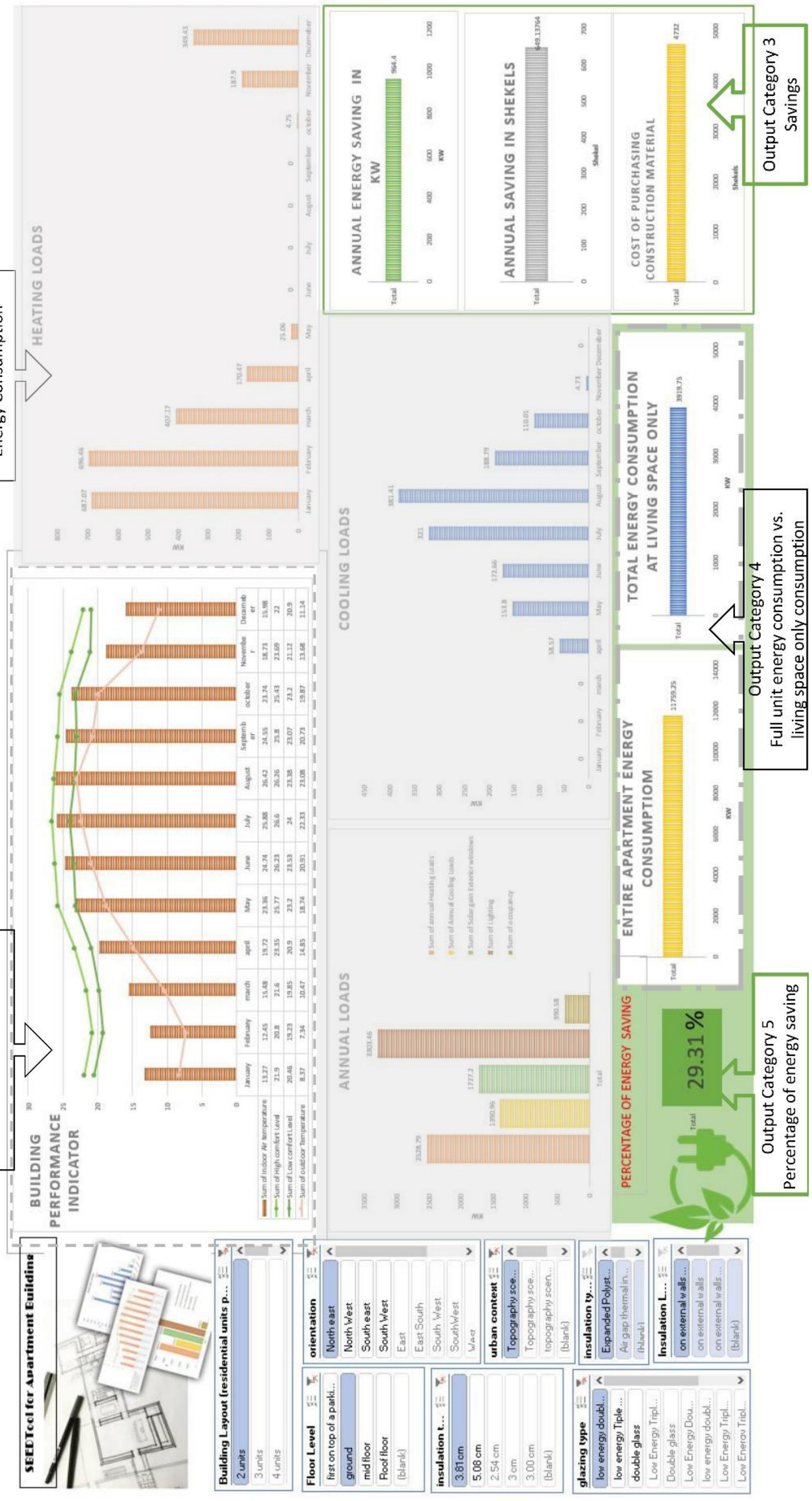


Figure 75: Tool Output categories

The first step is to test a base case scenario. While testing a base case scenario, the user can have a detailed description of performance as well as detailed analysis of monthly loads. The second step is to start a sensitivity analysis (a parametric analysis) which allows the user to start selecting different parameters to test their effects on building performance and on energy consumption. Even if the user missed to test a base case, the tool in its third output category will give a hint of savings based on a self-defined base case scenario which represents the typical generic envelope usually used in the study context. However, testing a base case scenario is very important so as to check its related performance and energy consumption in details which will make the comparison and evaluation process more successful.

The second step helps introducing the user to the impact of different parameters that can affect building performance and energy consumption during and in parallel with the design process. Such approach gives the tool its importance, specialty and feasibility since it performs opposite to the classical approach when simulation is usually performed after the building's design is completed. It prevents the designer from redesigning if the simulation results were not satisfying.

5.3 Detailed Tool Output Description

5.3.1 Building Performance Output

Depending on the input parameters selected by the user, a building performance graph will be displayed. This graph presented in figure 76 will plot average indoor air temperatures in comparison with outdoor bulb temperature as well as the comfort range that were carefully identified as shown in table 42 and 43. Comfort range has been calculated using the equation "Tcomfort = 17.8 + 0.31*Toutdoor".

Table 42: Monthly Outdoor Air Temperature in the Study Context from 2010 - 2020

Source: Palestinian Meteorological Department Ramallah – Hebron Weather Station (See Appendix 4)

	January	February	March	April	May	June	July	August	September	October	November	December
Average Mean Maximum Temp. C°	11.7	13.6	16.8	21.1	25.7	27.5	29.4	29.4	28.4	24.9	19.3	14.0
Average Mean Minimum Temp. C°	5.4	6.7	8.8	11.9	16.0	17.8	19.5	19.5	18.1	15.6	11.7	7.4
Average Temp. C°	8.55	10.15	12.8	16.5	20.8	22.7	24.5	24.45	23.25	20.25	15.5	10.5
Temp. Range	6.3	6.9	8	9.2	9.7	9.7	9.9	9.9	10.3	9.3	7.6	6.6

- Average temperatures were given to the researcher by the Palestinian Meteorological Department. All data is based on hourly plotted temperatures to come up with averages as shown in Appendix 4 from year 2010 to 2020

Table 43: Calculated Monthly Comfort Temperatures in the Study Context from 2010 - 2020

Source: calculated by the researcher

	January	February	March	April	May	June	July	August	September	October	November	December
Highest comfort Temp. C°	21.4	25.0	23.0	24.3	25.8	26.3	26.9	26.9	26.6	25.5	23.8	22.14
Lowest Comfort Temp. C°	19.5	19.9	20.5	21.5	22.8	23.3	23.8	23.8	23.4	22.6	21.4	20.1
Average comfort Temp. C°	20.45	22.45	21.75	22.9	24.3	24.8	25.3	25.35	25.0	24.0	22.6	21.12
Comfort Range	1.9	5.1	2.5	2.8	3	3	3.1	3.1	3.2	2.9	2.4	2.04

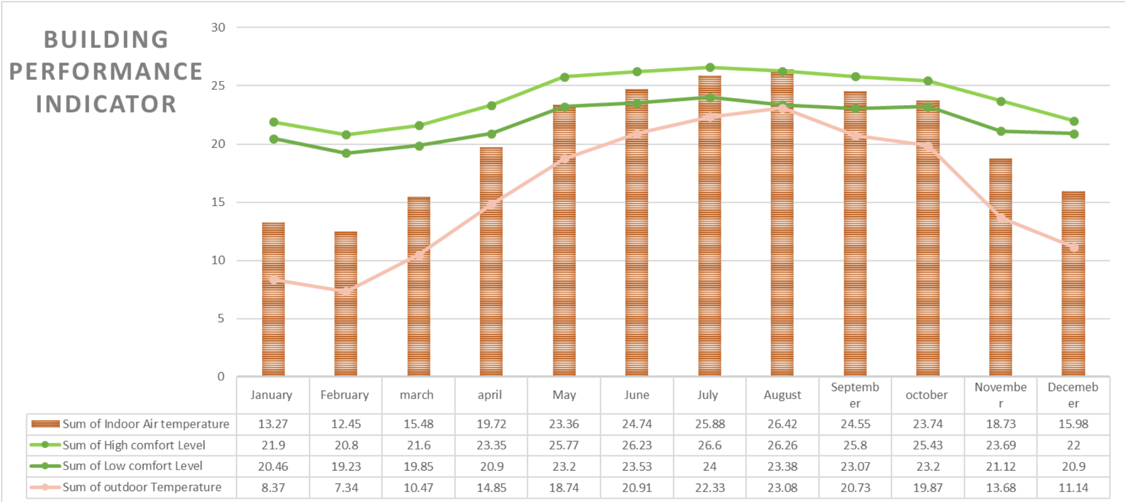


Figure 76: Building Performance Graph as Displayed in the Proposed Tool

5.3.2 Energy Consumption Output

Energy Consumption is represented through monthly heating and cooling load graphs as shown in figure 77 and 78, as well as, annual heating and cooling consumption. Within Annual heating and cooling loads graph, the tool also plots the effect of occupants, lighting fixture, and solar heat gain through exterior windows on load calculation as shown in figure 79.

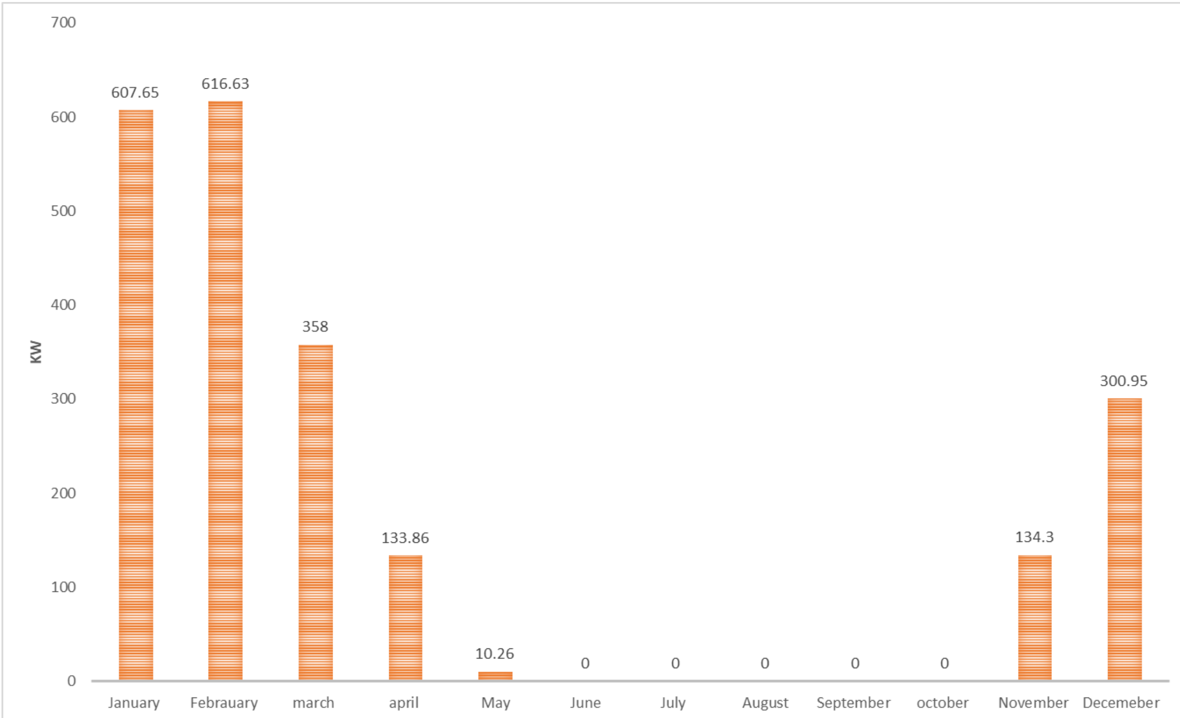


Figure 77: Monthly Heating Loads as Presented in the Proposed Tool

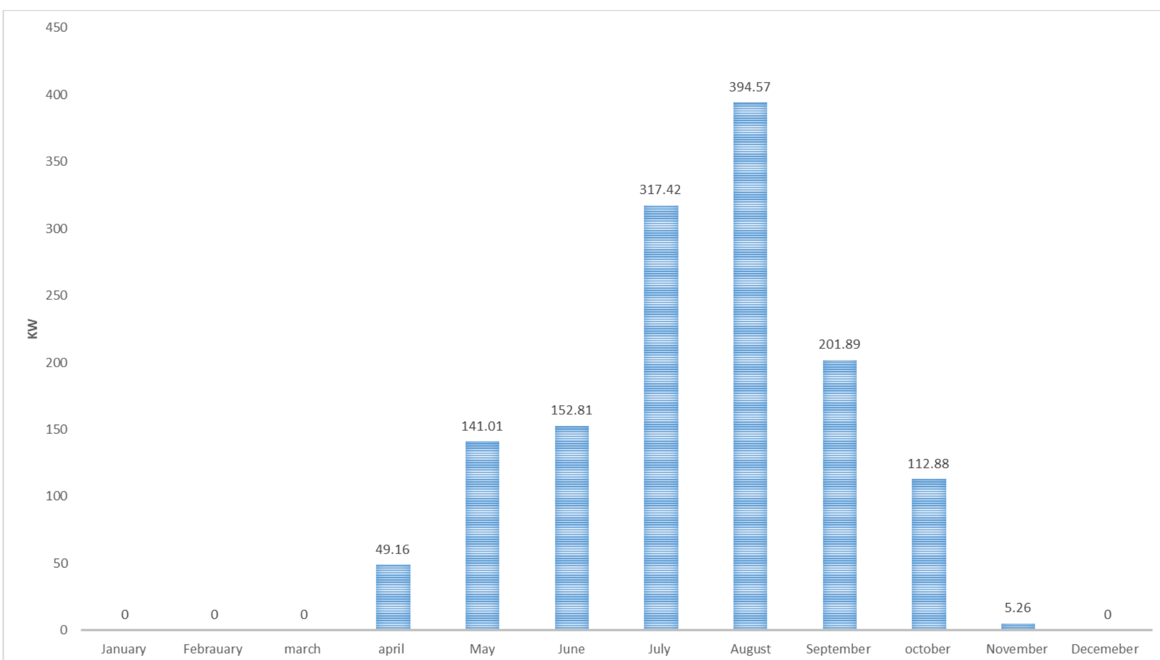


Figure 78: Monthly Cooling Loads as Presented in the Proposed Tool

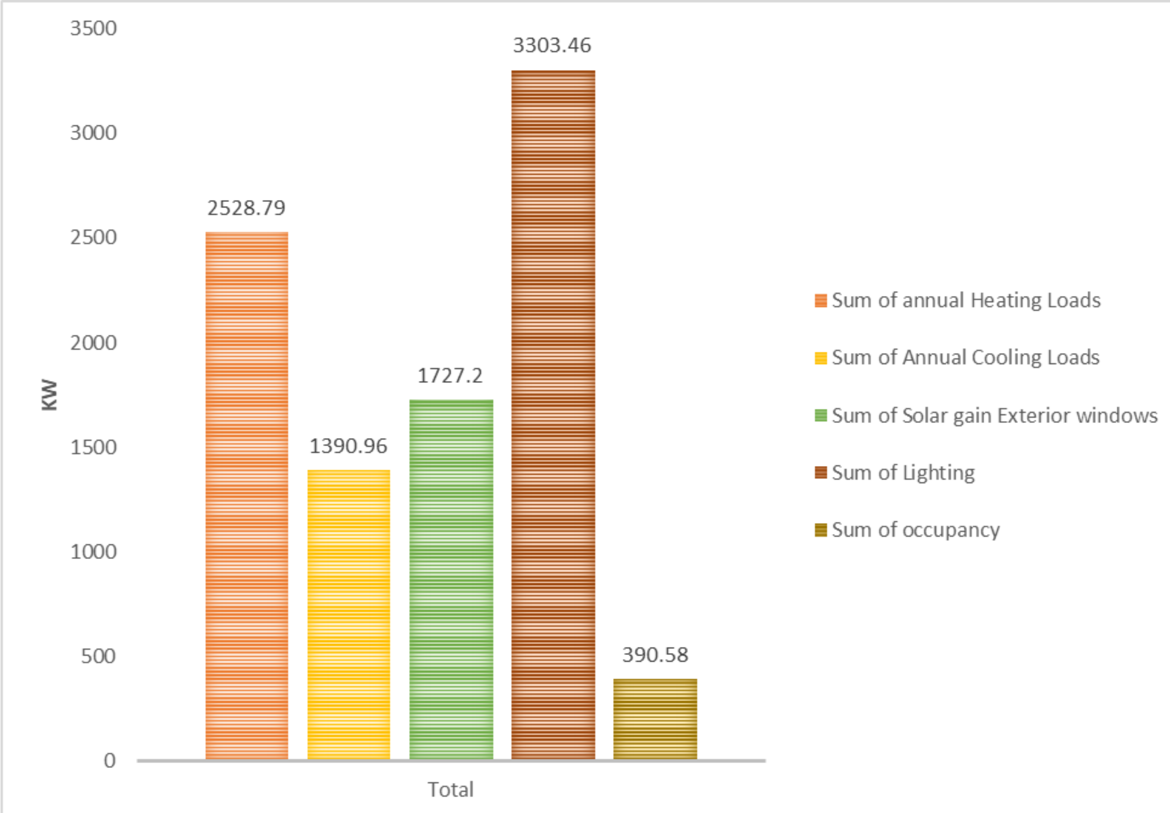


Figure79:Annual Consumption as Presented in the Proposed Tool

5.3.3 Energy Saving Output

Depending on the input parameters selected by the user, the tool plots annual energy savings in the form of Kilowatt Energy as well as in the form of money saving. Savings will be calculated in comparison with the base case typical envelope identified in chapter three. Money savings were calculated based on the price of Kilowatt electricity in the study context which is equals to 0.6731 ILS / KWh (referring to 2020 price of KWh electicity).

The tool gives the user a chance to calculate energy savings which is very important so as to plot savings achieved based on the selected input parameters. It also gives an indication of how much money the home owner needs in order to purchase construction materials as per the selected inputs. Which is also important so as to know the difference between the purchasing cost versus the pay back saving period.

Construction material cost was calculated referring to tables 38, 39 and 40 that has summarized actual prices of local construction materials as per interviews done with local manufacturers. The cost of material plotted in the tool records the additional cost applied to the generic wall. For example, if the designer has selected to insulate walls with 3.82cm thick expanded polystyrene, the cost of material will equal the square meters needed to insulate the entire residential unit walls since thermal air gap insulation is what's characterized in the local generic wall. However, if the designer has selected to use low energy double glazing, the cost will equal the difference in price between low energy double glazing and the generic double glazing usually used in the generic envelope so as to give the home owner an indication of how much money it'll cost to improve the envelope based on the chosen input parameters. The cost will be then compared with the annual savings so that the user will decide whether what was selected may be considered feasible or not. In addition to the fact that some input parameters may cost a lot when compared to their effect on energy performance, and so it will be more feasible to choose different input value. Moreover, in some situations, different combination of input parameters gives minimal difference in annual energy consumption_ which was noticed in chapter four in the simulation results of the randomly selected case_ and so cost analysis will help in choosing the most feasible combination. The tool also gives percentages of energy savings when compared to base case envelope scenario.

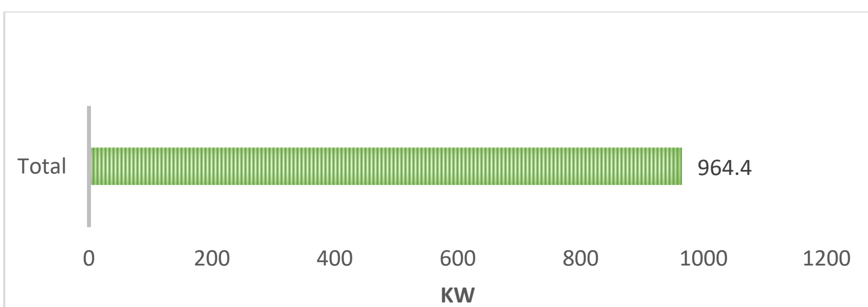


Figure 80: Annual Energy Saving in KWh as presented in the Proposed Tool

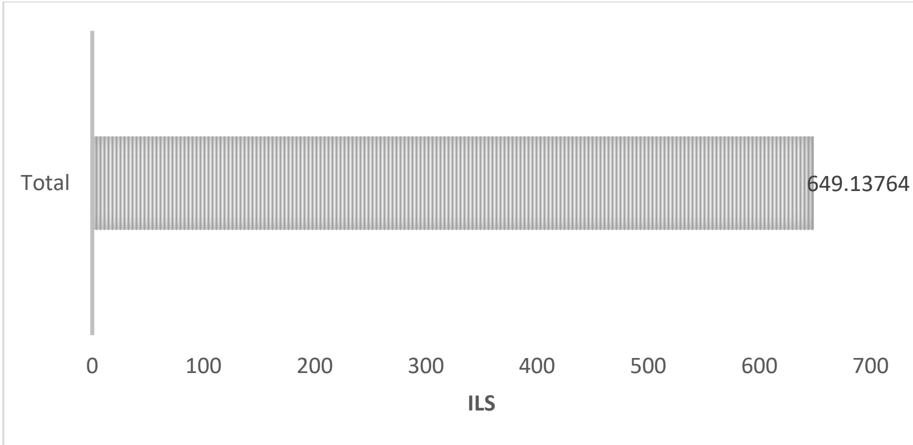


Figure 81: Annual Consumption Saving in ILS as Presented in the Proposed Tool

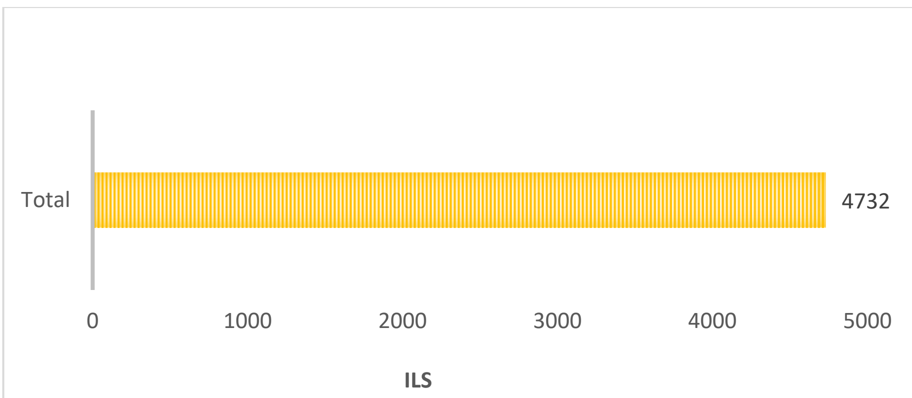


Figure 82: Cost of Purchasing Construction Materials as Presented in the Proposed Tool

Calculating the cost of the needed construction materials is essential to allow the designer to calculate the payback period for the savings achieved per design decision, which may be calculated by dividing the total construction material cost by the annual savings as the following:

$$\text{Payback period} = \text{Total Costs} / \text{Annual Savings}$$

5.3.4 Full Residential Unit Loads Output

This research has given special concentration on living spaces due to the study context social attitudes toward the daily use of living spaces and toward the fact that living spaces are usually the spaces operated by heating and cooling systems in the study context. However, the proposed tool plots an estimate toward the energy needed to heat and cool the entire apartment.

Large number of simulations were done to find a relationship between the energy needed for heating and cooling living spaces versus the energy needed to heat and cool the entire apartment. The following table summarize the percentages figured out based on series of simulation conducted and was used for the purpose of calculating energy consumption throughout the entire apartment.

Table 44: Percentages of load calculation differences between full apartment and living spaces only

Building Prototype	Floor Level	Heating and Cooling Loads
Prototype 1 (2 residential units per floor)	Ground Floor Level	Apartment heating and cooling loads = 2.97 X loads at living space only
	Mid Floor Level	Apartment heating and cooling loads = 3.12 X loads at living space only
	Roof Floor Level	Apartment heating and cooling loads = 3.00 X loads at living space only
Prototype 2 (3 residential units per floor)	Ground Floor Level	Apartment heating and cooling loads = 3.22 X loads at living space only
	Mid Floor Level	Apartment heating and cooling loads = 3.19 X loads at living space only
	Roof Floor Level	Apartment heating and cooling loads = 3.20 X loads at living space only
Prototype 3 (4 residential units per floor)	Ground Floor Level	Apartment heating and cooling loads = 2.80 X loads at living space only
	Mid Floor Level	Apartment heating and cooling loads = 2.78 X loads at living space only
	Roof Floor Level	Apartment heating and cooling loads = 3.00 X loads at living space only

5.4 Conclusion

This chapter has covered the tool design. The tool was developed using Microsoft Excel software. It is an interactive dashboard with graphic interactive charts that the user can through its interface select the parameters that best fit his design situation and get the requested outcomes in building performance, energy consumption, annual energy savings, money savings, cost of construction materials. This tool is specialized in living spaces however, it gives the user an indication toward full apartment unit heating and cooling loads if desired. It is based on simulation using Designbuilder software.

The tool is valid for apartment buildings only and in the fourth climatic zone of Palestine. It uses available local construction materials in the local context. Such tool was found very important since it enlightens decision making at early design phases. It increased the knowledge about the effect of building envelope design on heating and cooling loads. The tool specialty is achieved in its capacity to inform design prior to decision making through its methodology of testing and evaluating. It is fast and easy to use. It provides the designer with a comparative format base and a sensitivity analysis platform. The scope of the tool can be extended further as will be discussed in the following chapter.

Chapter Six

Conclusion and Recommendations

6.1 Introduction

Parametric thinking in design is a very successful design method. It is efficient, flexible and of high capability especially when trying to solve prolonged problem in practice. The complexity of the design at the conceptual design phases (Abdullah and Kamara, 2013) discussed in chapter one that includes generating the possibility of different design solutions and different design alternatives for the same model. Incorporating parametric design can be very essential. The proposed tool solves the limitation of programming knowledge as well as complex parametric modelling and allows the designer to generate and explore different solutions so as to choose the optimum.

6.2 Conclusion

The responsibility toward designing energy efficient buildings is increasing with the growing awareness and concerns of the preservation of natural resources. Simulation programs are seen very important tools to help designers evaluate the impact of their design decisions on building performance and on energy consumption. However, since such programs are time consuming and need expertise to use, evaluating building performance has rarely been integrated in the building design process. This study focuses on the great need to integrate building simulation in the building design process by proposing and developing a simplified tool that helps in facilitating such need and objective.

In response to the research goal and objective, this study evaluates and test the need for a simplified tools or ready to use applications to assess building performance and energy consumption in residential buildings and to check whether the availability of such tool can enhance building performance and can minimize energy consumption through the introduction of parametric simulation that was found successful in testing and comparing different envelope related parameters and finally through developing a tool to help testing building performance during the building design phases.

The tool was found helpful in guiding designers at early design phases as well as in helping architects with little experience in building simulation programs in testing the performance of their intended design in a fast and simple way. It also increased the knowledge and awareness toward designing envelopes that can be characterized as reduced energy envelopes for residential buildings in Palestine that accounts for the vast majority of energy consumption in building sectors.

Parametric Design is based on a step by step approach to test unlimited variety of options so as to choose the optimum. This research presented a platform for parametric design approach. The simulation was conducted on three different residential buildings typology, in different floor levels and different orientations as well as in different topography scenarios. The parametric evaluation process was finished after 4888 simulation alternatives. The results in chapter four illustrate random case and random results for all simulation alternatives of the commands that formed the parametric analysis process. The tools efficiency is in its concept in being a platform of information for users so as to give the user the option to test and evaluate unlimited options so as to choose optimum solution.

Through the development and use of this proposed tool as well as resulting from the large simulation options conducted, the user can notice that:

- Parametric simulation has shown great advantage in improving the thermal performance of buildings which leads to minimizing energy consumption. Testing building performance during early design phases can save 40 - 45% of total energy consumption in living spaces as well as in minimizing 15 – 17% of building total consumption which is a great percentage since building envelopes accounts for 40% of the energy consumption in buildings as has been clearly identified in the literature review.

- Building envelope should never be treated as one same structure, however, each level and each orientation needs to be simulated, tested and evaluated separately. Surrounding urban fabric highly effect building performance.

- The tool may allow the user to conduct cost-benefit analysis.

- It was found that optimal envelope configurations with highest energy savings can be found by the use of maximum insulation thicknesses as well as the lowest glazing U value. Insulation recorded great advantages on heating loads however, it has sometimes raised the cooling loads. But when combined with high quality glazing, the optimum energy consumption and best building performance was achieved. In some cases, when spaces were highly shaded by the surrounding urban fabric that has caused low cooling loads especially at ground floor plan, it's recommended to use medium insulation thickness with very high-quality glazing.

- The use of high-performance building materials _which is the focal method of the proposed tool_ has proven to have great effects on minimizing energy consumption in winter, while it has minimal effects in summer. Natural ventilation was considered in the design of this tool however with schedules similar to occupant's schedule and according to simulation program set points and pre-defined hours the program specified to open and close windows depending on the chosen HVAC system which didn't show any remarkable effects on cooling energies. Moreover, the design of the common residential buildings by means of low window to floor ratio as well as the design of two, three and four residential units per floor by means that the space will be connected to the outdoor atmosphere from only two sides and in its best condition three sides with very few opposing windows has caused the failure of the effect of natural ventilation during occupancy schedule described in section 3.6.8 as well as section 3.7 to minimize the cooling energies. In the case of summer, passive techniques need to be introduced such as forced ventilation as well as night ventilation. The proposed tool gives the designer an indication of how the neighboring topography scenarios, orientation, construction materials and floor level are affecting the cooling loads. However, it is highly recommended and can be part of future development of the tool to study the effect of forced natural ventilation as well as night ventilation and its impact on energy consumption, to prove that natural ventilation can be a supporting factor and can add more savings along with the proposed methodology used in the design of this tool.

- Roof Floors consumes the largest amount of energy for heating and cooling in comparison with ground floors and mid floor levels. Roof insulation is highly recommended at roof floor, it can help in minimizing 50% of living space energy consumption.

- High urban contexts as well as natural cliffs and topographies has helped in minimizing cooling loads in residential units since they've provided shading, however, this has led to maximizing heating loads. In such cases average envelope insulation is recommended with low glazing U Value since thermal mass will negatively affect cooling loads.

- Economic evaluation of the building envelope design in comparison with the energy saving achieved by the implementation of the selected envelope design is very essential. Analyzing and comparing results are the best evaluation process in choosing energy saving envelope.

The proposed assessment tool is intended to be used as guidelines during the design process as well as environmental assessment methodology rather than only a tool to evaluate building performance. Since the results have confirmed the importance of integrating building energy performance in the early architectural design decision. When aiming to design energy efficient buildings, it is very helpful to have some guidance toward which parameter that can make a large impact on energy performance.

6.3 Research Limitation:

Simulation tools had proven to be powerful tools for studying the environmental performance of the building and the amount of energy consumed to achieve the best performance. However, simulation tools are based on scenario by scenario approach in modeling and in evaluating all alternatives in order to make design decisions. Early design guiding tools are highly important as discussed and elaborated in this research despite their limitation.

SBED Tool designed in this research proved to be very important and can save 10 – 15% energy consumption if used at early design stages. However, some limitations are bound to the proposed tool such as:

- SBED tool depends mainly on preset factors. The designer needs to carefully choose the factors that are very similar or similar enough to his/her design case. He won't be able to change the building outline, nor adding any construction material or wall configuration that is not already defined to the tool interface. It doesn't have any graphic interface or a modeling option. There are several other tools that allow the user to model or import their designs however all are time consuming. SBED tool still gives the user an indication of the amount of energy saving even if the design differs from what was already defined.

- SBED tool used the available weather data on the design builder simulation program which is Jerusalem weather file. The results can be valid for similar climatic conditions like Nablus, Hebron, Ramallah and Bethlehem with minimum variation depending on the microclimate. However, the user can't define or introduce new or different weather files.

- SBED tool calculates the cost of construction materials based on a preset price (2020 market). The user can't change materials prices nor introduce new prices as per market changes.

6.4 Future Work

The research can be extended in several ways such as:

● Implementing additional types of buildings not only apartment buildings. The tool can be extended to allow the designer not only to test the performance of apartment buildings but also to test other types of buildings such as office buildings, commercial building, villas, single family housing, etc.

● Implementing more climatic zones. Rather than only giving the user information related to one climatic zone, the tool can be extended toward adding and defining more climatic zones.

- Exploring the effect of advanced and sustainable building construction material. It might also include materials such as phase change materials, different options of insulating materials as well as more glazing options such as photovoltaic integrated glass panels, etc.

- Exploring the effect of sustainable construction techniques in building envelopes. It might be elaborated to introduce the designer to the effect of forced natural ventilation, double skin facades as well as trombe and green walls, roof gardens, etc.

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Appendix 1

استبيان لجمع معلومات حول النموذج الأكثر شيوعا في تصميم الشقق السكنية في فلسطين - لتلبية احتياجات تعليمية خاصة برسائل ماجستير

عزيزي (عزيزتي) المهندس / ة المحترم / ة

تسعى الطالبة ليزا معلم الى جمع معلومات حول النموذج الأكثر شيوعا في تصميم الشقق السكنية في فلسطين ذلك لتلبية احتياجات تعليمية ولدعم رسائل ماجستير في الهندسة المعمارية - العمارة المستدامة في جامعة بوليتكنك فلسطين. ونظرالما سيكون لنتائج هذا الاستبيان الأثر الكبير لتوجيه الدراستين فاننا نأمل منكم إعطاء المعلومات بكل دقة و موضوعية و ذلك من خلال قراءة أسئلة الاستبيان بدقة و عناية. نود أن نؤكد أن المعلومات ستكون خاصة وللأغراض الأكاديمية وسيراعى فيها الخصوصية الشخصية.
مع الاحترام.

1. اسم المنطقة (المدينة) التي يتبع لها المكتب الهندسي

____

2. تصنيف المكتب الهندسي

( ) استشاري
( ) هندسة أولى
( ) هندسة ثانية
( ) هندسة ثالثة

3. ما هو عدد الشقق السكنية الموجودة في كل طابق بالنسبة لأغلبية المباني السكنية (الاسكانات) الموجودة في فلسطين والتي تم تصميمها وتنفيذها في منطقتكم؟

( ) شقة واحدة
( ) شقتين
( ) ثلاث شقق
( ) أربع شقق
( ) أكثر من اربع شقق

4. كم تبلغ المساحة الكلية لأغلبية الشقق السكنية ؟

( ) أقل من 120 متر مربع
( ) 120 – 130 متر مربع
( ) 130 – 140 متر مربع
( ) 140 – 150 متر مربع
( ) أكثر من 150 متر مربع

5. ما هي مواد البناء المستخدمة في غلاف المبنى الخارجي(الجدران الخارجية) مع توضيح سماكات المواد وترتيبها ان امكن :

---

6. ما هي مواد البناء المستخدمة في الجدران الداخلية (القواطع الداخلية) مع توضيح سماكات المواد وترتيبها ان امكن:

---

7. من ناحية عزل الجدران - هل تم عزل الجدران في أغلبية مشاريع المباني السكنية؟

( ) نعم، تم عزل كافة الجدران

( ) تم عزل جزء من الجدران

( ) لم يتم عزل اي جدار

( ) غير ذلك : ____

8. في حال تم عزل جزء من الجدران، ما الجدران التي تم عزلها (مثال: الجدران الشمالية أو الشمالية الشرقية وهكذا)؟

---

9. ما نوع مادة العزل المستخدمة في غالبية المشاريع ومتوفرة في السوق المحلي؟

( ) الواح البوليسترين

( ) الصوف الصخري

( ) فراغ هواء

( ) غير ذلك : ____________________.

10. في حال تم استخدام مادة عزل لم يتم إدراجها ضمن الخيارات السابقة، ما نوع مادة العزل المستخدمة؟

---

11. هل تم عزل أجزاء أخرى من المبنى غير الجدران؟

( ) نعم تم غزل الاسقف

( ) نعم تم عزل الأرضيات

( ) تم عزل القواطع الداخلية

( ) لا

12. ما هو نوع الزجاج المستخدم في الشبابيك؟

(   ) زجاج واحد (Single Glass)

(   ) زجاج مزدوج (Double Glass)

(   ) زجاج ثلاثي (Trippel Glass)

13. ما هو لون الزجاج المستخدم في أغلب المشاريع السكنية؟

(   ) شفاف

(   ) مظلل

Appendix 2

This questionnaire aims to collect information about the most common designs of residential buildings (apartments) in Palestine.

Dear respected engineers:

1. Region (city) to which the engineering office is affiliated?

____

2. Classification of the engineering office?

( ) Advisor

( ) Classification 1st degree engineering

( ) Classification 2nd degree engineering

( ) Classification 3rd degree engineering

3. What is the common number of apartments per floor for the majority of residential buildings (housing) in Palestine? that is usually designed and constructed in your area?

( ) One apartment per floor

( ) Two apartments per floor

( ) Three apartments per floor

( ) Four apartments per floor

( ) More than four apartments per floor

4. What is the average approximate area of the majority of apartments?

( ) Less than 120 square meters

( ) 120 - 130 sqm

( ) 130 – 140 sqm

( ) 140 – 150 sqm

( ) More than 150 square meters

5. What are the common construction materials used in the building's exterior envelope (external walls), with an explanation of the material thickness and arrangement if possible?

____

____

6. What are the common construction materials used in the internal walls (internal partitions) with an explanation of the thicknesses of the materials and their arrangement if possible?

____

____

7. In terms of wall insulation - have walls been insulated in most residential building projects?

( ) Yes, all walls are insulated

( ) Part of the walls are isolated

( ) The walls are not insulated

( ) Other :______________________________.

8. In the case that part of the walls is isolated, what are the walls that are isolated (example: the north or north-east walls, and so on)?

____

____

9. What type of insulation material is used in the majority of projects and is available in the local market?

( ) Polystyrene sheets

( ) Rock wool

( ) Thermal Air Gap

( ) Other : ___________________________.

10. If an insulation material is used that was not listed among the previous options, what type of insulation material is used?

____

____

11. what parts of the building _other than the external walls_ isolated?

( ) floors

( ) roofs

( ) No.

12. What is the type of glass used in windows?

( ) Single Glass

( ) Double Glass

( ) Trippel Glass

13. What is the color of glazing usually used in most residential projects?

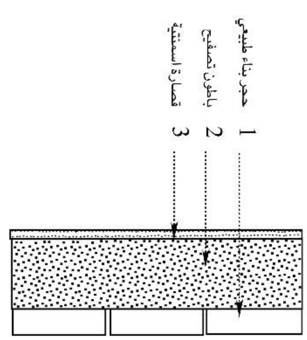
( ) Clear and transparent

( ) Tinted

Appendix 3

Thermal Properties for Construction Materials

Source: Guidelines for Energy Efficient Building Design (Chapter 6) – Ministry of Local Government (Ministry of Local Government, 2004)



جدول رقم: (1-5/6)
مقطع جدار حجري غير معزول

الطبقة	الكثافة ρ (kg/m³)	السعة الحرارية C (J/kg.K)	الموصلية الحرارية k (W/m.K)	السماكة d (m)
1	2250	1000	1.70	0.07
2	2300	1000	1.75	0.20
3	2000	1000	1.20	0.03
الانتقالية الحرارية (U) W/m.K		منطقة محمية		2.63
		منطقة معتدلة التعرض		2.77
		منطقة شديدة التعرض		3.03
التخلف الزمني (ϕ) ساعة				7.97
معامل النقص (μ)				0.26

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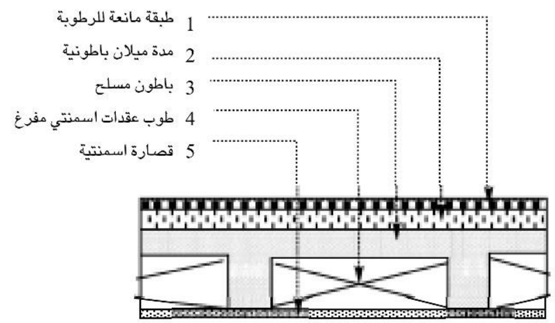
السماكة d (m)	الموصلية الحرارية k (W/m.K)	السعة الحرارية C (J/kg.K)	الكثافة ρ (kg/m^3)	الطبقة
0.02	1.10	1000	2300	1
0.08	1.75	1000	2300	2
0.07	1.75	1000	2500	3
0.18	1.10	1000	1620	4
0.02	1.20	1000	2000	5
2.20	منطقة محمية		الانتقالية الحرارية (U) W/m.K	
2.36	منطقة معتدلة التعرض			
2.47	منطقة شديدة التعرض			
10.50	التخلف الزمني (ϕ) ساعة			
0.15	معامل النقص (μ)			

القطـــاع الإنشائي



جدول رقم: (13-5/6)
مقطع سقف باطوني مسلح ذو أعصاب غير معزول

Appendix 4

Weather data

Source: Palestinian Meteorological Department – Eng. Isam Isa (Director of Applied Meteorological studies)

Monthly Data Report

Station: BET00007 Bethlehe Lat. 31.70 N Long. 35.20 E Elv. 771 Element: Daliy Minimum Temp. (C)

Month / Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Avg	Min	Max
2010	9.4	9.1	10.8	12.4	16.0						0	9.9	9.7	0	16.0
2011	7.4	7.3	8.5	11.1	14.3	17.5	21.0	19.6	18.7	15.2	8.8	7.1	13.0	7.1	21.0
2012	5.3	5.0	6.8	13.3	16.8	20.2	22.2	21.6	19.0	17.9	13.7	8.5	14.2	5.0	22.2
2013	6.4	7.9	10	12.4	17.6	19.2	19.3	20.5	18.5	15.5	14.4	6.3	14.0	6.3	20.5
2014	8.0	8.2	11.1	14.3	16.7	18.9	20.0	20.8	18.5	15.5	8.9	10.4	14.3	8.0	20.8
2015	6.2	7.0	10.4	11.2	17.0	17.3	21.0	22.2	21.9	17.4	13.2	7.3	14.3	6.2	22.2
2016	5.7	9.7	10.8	16.3	16.1	21.5	21.1	20.4	19.0	18.2			15.9	5.7	21.5
Avg	6.9	7.7	9.8	13.0	16.4	19.1	20.8	20.9	19.3	16.6	9.8	8.3	13.8		
Min	5.3	5.0	6.8	11.1	14.3	17.3	19.3	19.6	18.5	15.2	0	6.3	0		
Max	9.4	9.7	11.1	16.3	17.6	21.5	22.2	22.2	21.9	18.2	14.4	10.4	22.2		

Monthly Data Report

Station: BET00007 Bethlehe Lat. 31.70 N Long. 35.20 E Elv. 771 Element: Daily Maximum Temp. (C)

Month / Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Avg	Min	Max
2010	16.0	16.1	19.7	22.8	24.7							17.2	19.4	16.0	24.7
2011	13.0	13.5	16.8	20.1	24.4	27.2	31.6	29.7	28.2	24.1	15.7	14.3	21.5	13.0	31.6
2012	10.3	11.6	14.4	23.3	25.9	30.2	31.5	30.7	29.8	26.7	20.4	14.6	22.5	10.3	31.5
2013	12.6	15.0	19.9	20.7	27.3	28.5	29.2	30.3	27.9	23.8	21.1	12.1	22.4	12.1	30.3
2014	14.2	15.2	18.7	24.2	25.6	28.5	29.1	30.4	27.3	23.9	14.0	16.1	22.3	14.0	30.4
2015	12.0	13.3	18.1	20.2	26.3	26.5	30.8	32.3	31.1	26.0	18.9	13.3	22.4	12.0	32.3
2016	10.8	16.1	18.1	25.1	25.6	31.3	30.3	30.5	28.6	27.3	20.9	13.2	23.1	10.8	31.3
2017	10.8	13.0	17.7	23.0	26.8	29.6	33.1	30.1	29.3	23.5	18.6	16.7	22.7	10.8	33.1
2018	11.3	16.3	20.9	21.6	26.9	28.0	28.7	28.6	29.1	24.8	18.6	12.9	22.3	11.3	29.1
2019	11.9	12.6	14.5	19.1	28.9	28.7	30.1	29.9	28.8	25.9	21.3	14.1	22.1	11.9	30.1
2020	10.0	12.3	16.4	20.5	27.0	27.8	30.9	30.1	32.8	28.5	19.2		23.2	10.0	32.8
Avg	12.1	14.1	17.7	21.9	26.3	28.6	30.5	30.3	29.3	25.4	18.9	14.4	22.3		
Min	10.0	11.6	14.4	19.1	24.4	26.5	28.7	28.6	27.3	23.5	14.0	12.1	10.0		
Max	16.0	16.3	20.9	25.1	28.9	31.3	33.1	32.3	32.8	28.5	21.3	17.2	33.1		

Appendix 4

Monthly Data Report

Station: HEB00008 Hebron Lat. 31.53 N Long. 35.10 E Elv. 891 Element: Daliy Minimum Temp. (C)

Month / Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Avg	Min	Max
2010	8.4	8.5	11.1	12.2	15.8	18.8	18.9	22.6	18.8	18.2	15.7	9.6	14.9	8.4	22.6
2011	6.3	6.5	7.8	10.9	13.8	16.1	20.3	19.0	17.8	14.3	8.4	6.9	12.3	6.3	20.3
2012	3.9	4.6	6.1	12.5	15.5	19.1	20.6	20.5	18.1	17.1	13.1	7.8	13.3	3.9	20.6
2013	5.9	7.4	9.7	10.9	16.4	17.5	17.3	18.7	16.5	13.6	12.5	5.3	12.6	5.3	18.7
2014	6.6	7.0	9.5	12.7	14.5	16.7	17.7	18.6	15.7	13.7	9.8	8.5	12.6	6.6	18.6
2015	5.2	5.7	8.8	10.1	15.2	15.1	19.3	20.4	19.7	16.2	10.6	5.6	12.7	5.2	20.4
2016	4.2	8.4	9.1	14.2	13.9	19.7	19.0	18.1	16.9	15.8	10.8	4.8	12.9	4.2	19.7
2017	4.6	5.0	8.3	11.7	15.3	18.2	21.2	19.0	18.2	13.7	10.6	9.5	12.9	4.6	21.2
2018	5.6	9.7	11.6	13.0	17.7	17.7	18.9	18.2	18.6	15.2	11.0	7.0	13.7	5.6	18.9
2019	5.2	5.6	6.9	10.7	18.1	19.1	19.5	19.4	17.3	16.1	12.6	7.5	13.2	5.2	19.5
2020	4.0	5.7	8.0		20.1	17.6	21.7	19.5	21.7	17.7	11.1	8.9	14.2	4.0	21.7
Avg	5.4	6.7	8.8	11.9	16.0	17.8	19.5	19.5	18.1	15.6	11.5	7.4	13.2		
Min	3.9	4.6	6.1	10.1	13.8	15.1	17.3	18.1	15.7	13.6	8.4	4.8	3.9		
Max	8.4	9.7	11.6	14.2	20.1	19.7	21.7	22.6	21.7	18.2	15.7	9.6	22.6		

Monthly Data Report

Station: HEB00008 Hebron Lat. 31.53 N Long. 35.10 E Elv. 891 Element: Daily Maximum Temp. (C)

Month / Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Avg	Min	Max
2010	14.9	15.4	19.0	22.1	25.3	27.9	28.9	31.6	28.4	26.8	24.1	16.7	23.4	14.9	31.6
2011	12.4	12.4	15.8	19.3	23.2	25.7	30.0	28.1	26.9	22.9	15.3	14.4	20.5	12.4	30.0
2012	9.2	11.0	13.3	22.8	24.9	29.1	30.3	29.4	28.4	26.0	19.8	13.7	21.5	9.2	30.3
2013	12.5	14.4	19.1	19.7	25.7	27.5	27.8	28.8	26.7	22.8	20.8	11.9	21.5	11.9	28.8
2014	14.8	15.2	18.0	22.9	24.3	26.8	27.9	29	26.2	23.3	17.4	16.2	21.8	14.8	29
2015	11.7	12.9	17.1	18.8	25.0	25.0	29.2	31.6	30.7	25.3	18.1	13.0	21.5	11.7	31.6
2016	10.2	15.9	17.4	24.4	25.1	29.9	29.2	28.9	27.5	26.2	19.6	11.5	22.2	10.2	29.9
2017	11.3	12.6	16.9	21.4	26.1	28.2	31.4	29.8	28.8	23.3	19.2	15.1	22.0	11.3	31.4
2018	10.9	16.6	20.2	21.6	26.4	27.1	28.4	28.0	28.7	24.2	18.5	12.5	21.9	10.9	28.7
2019	11.7	11.9	13.8	18.2	27.6	28.2	29	29.1	27.8	25.5	20.9	13.8	21.5	11.7	29.1
2020	9.5	11.8	14.6		28.8	26.8	31.2	28.9	32.3	27.9	18.4	15.3	22.3	9.5	32.3
Avg	11.7	13.6	16.8	21.1	25.7	27.5	29.4	29.4	28.4	24.9	19.3	14.0	21.8		
Min	9.2	11.0	13.3	18.2	23.2	25.0	27.8	28.0	26.2	22.8	15.3	11.5	9.2		
Max	14.9	16.6	20.2	24.4	28.8	29.9	31.4	31.6	32.3	27.9	24.1	16.7	32.3		

Appendix 4

Monthly Data Report

Station: NAB00003 Nablus Lat. 32 . 13 N Long. 35 . 15 E Elv. 73 Element: Daliy Minimum Temp. (C)

Month / Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Avg	Min	Max
2010	9.5	9.8	12.0	13.1	16.3	19.4	20.6	22.6	20.7	19.1	15.8	10.8	15.8	9.5	22.6
2011	8.1	8.3	9.3	12.2	15.4	17.8	20.5	20.3	19.3	16.0	9.0	10.8	13.9	8.1	20.5
2012	6.0	6.3	7.7	13.3	16.2	18.8	21.8	21.6	19.9	18.2	14.0	9.2	14.4	6.0	21.8
2013	7.4	9.4	11.6	13.0	17.4	18.8	19.7	20.5	19.0	15.6	14.3	6.6	14.4	6.6	20.5
2014	7.8	8.4	10.6	13.6	15.8	18.5	20.0	20.8	19.2	15.7	11.7	9.8	14.3	7.8	20.8
2015	6.4	7.8	11.0	11.6	16.0	17.5	20.1	22.3	21.5	17.5	13.1	6.8	14.3	6.4	22.3
2016	6.0	9.5	11.0	15.2	15.8	20.5	20.8	20.8	19.1	17.4	12.3	7.0	14.6	6.0	20.8
2017	6.4	6.8	9.9	12.6	16.0	18.8	21.4	20.7	19.9	16.0	12.1	10.4	14.3	6.4	21.4
2018	7.4	9.7	12.2	13.5	18.7	19.3	20.8	21.0	20.0	17.9	12.8	9.7	15.3	7.4	21.0
2019	6.6	7.8	8.9	11.9	17.7	20.1	21.0	21.6	20.1	18.0	14.9	9.8	14.9	6.6	21.6
2020	7.3	8.2	10.8		22.0	18.5	22.1	21.6	22.3	19.9	13.6	10.3	16.1	7.3	22.3
Avg	7.2	8.4	10.4	13.0	17.0	18.9	20.8	21.2	20.1	17.4	13.1	9.2	14.7		
Min	6.0	6.3	7.7	11.6	15.4	17.5	19.7	20.3	19.0	15.6	9.0	6.6	6.0		
Max	9.5	9.8	12.2	15.2	22.0	20.5	22.1	22.6	22.3	19.9	15.8	10.8	22.6		

Monthly Data Report

Station: NAB00003 Nablus Lat. 32 . 13 N Long. 35 . 15 E Elv. 73 Element: Daily Maximum Temp. (C)

Month / Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Avg	Min	Max
2010	16.8	17.3	21.0	23.5	27.1	29.9	30.8	33.5	30.6	29.2	26.7	18.9	25.4	16.8	33.5
2011	15.6	15.5	19.2	21.9	25.5	28.5	32.5	30.6	29.1	25.7	17.7	15.9	23.2	15.5	32.5
2012	12.5	13.3	16.0	25.1	27.3	31.2	33.4	33.0	31.0	27.9	22.1	16.6	24.1	12.5	33.4
2013	14.4	17.0	21.3	21.4	28.7	29.6	30.6	32.0	29.7	25.5	22.4	13.3	23.8	13.3	32.0
2014	15.9	16.7	19.6	25.2	26.6	29.5	31.1	32.0	29.0	25.9	20.0	17.4	24.1	15.9	32.0
2015	13.4	15.1	20.0	22.4	28.2	28.4	32.0	33.6	32.6	27.3	20.6	14.6	24.0	13.4	33.6
2016	12.8	18.3	20.3	26.5	28.1	33.2	31.0	31.9	30.8	28.8	21.1	13.5	24.7	12.8	33.2
2017	13.4	15.3	19.3	24.8	29.1	31.3	34.5	32.5	31.2	26.8	21.5	18.8	24.9	13.4	34.5
2018	14.2	18.9	23.5	25.4	29.5	30.9	32.4	31.7	31.5	27.2	21.4	15.4	25.2	14.2	32.4
2019	14.5	14.9	16.5	22.0	31.6	32.1	33.5	33.0	31.2	28.2	23.6	16.3	24.8	14.5	33.5
2020	12.6	14.3	17.4		31.9	28.9	30.3	30.4	33.4	29.2	20.8	17.1	24.2	12.6	33.4
Avg	14.2	16.1	19.5	23.8	28.5	30.3	32.0	32.2	30.9	27.4	21.6	16.2	24.4		
Min	12.5	13.3	16.0	21.4	25.5	28.4	30.3	30.4	29.0	25.5	17.7	13.3	12.5		
Max	16.8	18.9	23.5	26.5	31.9	33.2	34.5	33.6	33.4	29.2	26.7	18.9	34.5		

Appendix 4

Monthly Data Report

Station: RAM00004 Ramallah Lat. 31.90 N Long. 35.22 E Elv. 809 Element: Daliy Minimum Temp. (C)

Year \ Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Avg	Min	Max
2010	9.6	9.5	11.9	12.9	16.2	18.4	18.6	22.0	19.5	18.8	16.4	10.7	15.4	9.5	22.0
2011	7.6	7.6	9.0	11.8	14.4	16.8	20.6	19.2	18.4	15.6	16.4	8.2	13.8	7.6	20.6
2012	5.3	5.9	7.3	12.9	16.0	18.9	20.7	21.0	18.7	18.1	14.4		14.5	5.3	21.0
2013	8.0	8.9	10.6	12.4	17.0	18.1	18.1	19.3	17.8	15.1	13.9	6.9	13.9	6.9	19.3
2014	8.2	8.3	10.3	13.7	15.7	17.7	18.7	20.0	17.8	15.6	11.5	10.4	14.0	8.2	20.0
2015	6.3	7.0	10.2	10.9	16.3	16.2	19.8	21.0	21.3	17.7	12.9	7.3	13.9	6.3	21.3
2016	5.8	10.0	10.2	16.3	15.4	20.5	19.9	19.5	18.4	17.7	12.6	6.1	14.4	5.8	20.5
2017	5.7	6.6	9.4	12.7	15.7	18.5	21.6	19.6	19.0	15.5	12.1	10.9	13.9	5.7	21.6
2018	6.7	10.5	12.2	13.9	18.2	18.0	19.2	19.2	19.2	16.8	12.3	8.5	14.5	6.7	19.2
2019	6.1	6.8	8.0	11.1	18.6	19.4	19.7	19.9	18.1	17.1	14.1	8.5	14.0	6.1	19.9
2020	5.5	7.0	8.8		12.6	17.6	19.7	20	22.1	18.9	12.4	9.9	14.0	5.5	22.1
Avg	6.8	8.0	9.8	12.9	16.0	18.2	19.7	20.1	19.1	17.0	13.5	8.7	14.2		
Min	5.3	5.9	7.3	10.9	12.6	16.2	18.1	19.2	17.8	15.1	11.5	6.1	5.3		
Max	9.6	10.5	12.2	16.3	18.6	20.5	21.6	22.0	22.1	18.9	16.4	10.9	22.1		

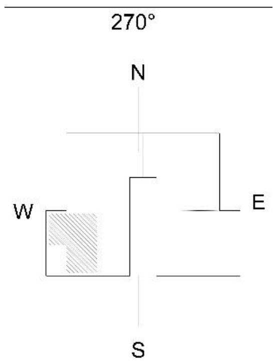
Monthly Data Report

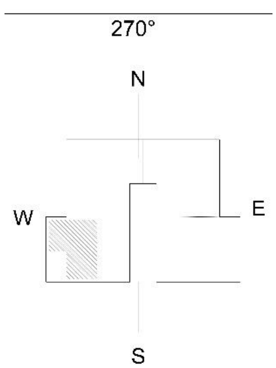
Station: RAM00004 Ramallah Lat. 31.90 N Long. 35.22 E Elv. 809 Element: Daily Maximum Temp. (C)

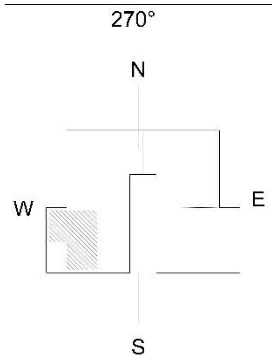
Year \ Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Avg	Min	Max
2010	15.0	15.2	19.0	21.4	24.9	27.4	28.3	31.0	28.3	26.5	23.9	16.3	23.1	15.0	31.0
2011	12.5	12.5	13.3	18.8	22.9	24.6	29.3	27.7	26.5	22.8	15.1	13.7	20.0	12.5	29.3
2012	9.7	11.0	13.3	21.8	24.0	28.3	29.6	28.7	27.8	25.5			22.0	9.7	29.6
2013	12.9	14.0	18.5	19.3	25.4	26.2	26.6	27.9	25.7	22.3	20.1	11.5	20.9	11.5	27.9
2014	13.7	14.4	17.6	22.1	23.4	25.9	26.8	28.4	25.3	22.8	17.2	15.4	21.1	13.7	28.4
2015	11.0	12.6	16.9	18.6	24.4	24.3	28.4	30.2	29.4	24.7	17.8	12.5	20.9	11.0	30.2
2016	10.3	15.4	16.8	23.6	23.8	29.0	28.0	27.9	26.2	25.2	18.8	11.0	21.3	10.3	29.0
2017	10.5	12.1	15.7	21.3	24.7	27.0	30.3	28.7	27.3	22.7	18.0	16.2	21.2	10.5	30.3
2018	11.0	16.1	19.8	21.4	26.0	26.4	28.0	27.4	27.6	23.7	18.0	12.6	21.5	11.0	28.0
2019	11.3	11.9	13.6	17.1	27.5	27.4	28.2	28.3	26.7	25.0	20.5	13.1	20.9	11.3	28.3
2020	9.1	11.8	14.8		20.4	25.3	26.6	28.7	31.2	27.3	17.9	14.7	20.7	9.1	31.2
Avg	11.5	13.4	16.3	20.5	24.3	26.5	28.2	28.6	27.5	24.4	18.7	13.7	21.2		
Min	9.1	11.0	13.3	17.1	20.4	24.3	26.6	27.4	25.3	22.3	15.1	11.0	9.1		
Max	15.0	16.1	19.8	23.6	27.5	29.0	30.3	31.0	31.2	27.3	23.9	16.3	31.2		

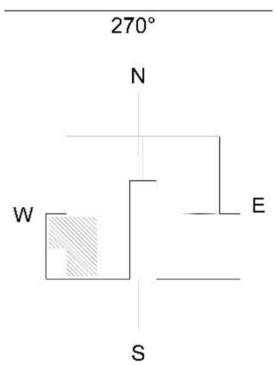
Appendix 5

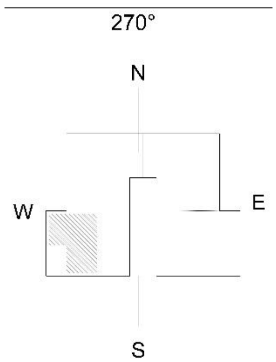
Additional Simulation Results

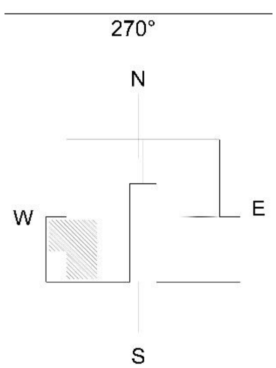
Model	Envelope Description		Percentage of saving when compared to base case scenarios
- South West living space  -Urban Scenario 1 - Ground Floor	Base Case Scenario: - air gap insulation + double glazing window + normal aluminum		
	Loads (KWh)		
	Heating Loads	2,409.0	Not Applicable
	Cooling Loads	2,096.0	
	Total	4,505.0	

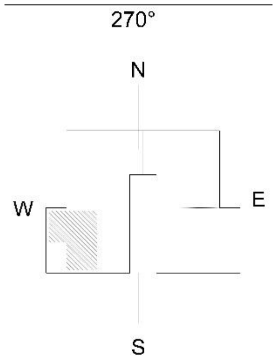
Model	Envelope Description		Percentage of saving when compared to base case scenarios
- South West living space  -Urban Scenario 1 - Ground Floor	Base Case Scenario: - 2.54 cm expanded polystyrene + double glazing window + normal aluminum		
	Loads (KWh)		
	Heating Loads	1,880.0	22%
	Cooling Loads	2,192.0	-4.6%
	Total	4,072.0	10 %

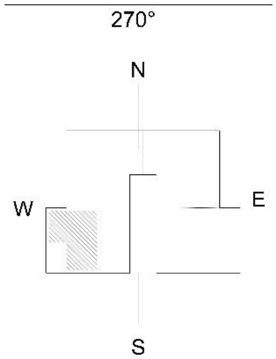
Model	Envelope Description		Percentage of saving when compared to base case scenarios
- South West living space  -Urban Scenario 1 - Ground Floor	Base Case Scenario: - 3.81 cm expanded polystyrene + double glazing window + normal aluminum		
	Loads (KWh)		
	Heating Loads	1,797.0	25.4%
	Cooling Loads	2,199.0	-4.6%
	Total	3,996.0	11.3%

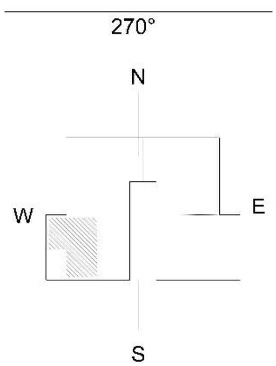
Model	Envelope Description		Percentage of saving when compared to base case scenarios
- South West living space  -Urban Scenario 1 - Ground Floor	Base Case Scenario: - 5.08 cm expanded polystyrene + double glazing window + normal aluminum		
	Loads (KWh)		
	Heating Loads	1,746.0	27.5%
	Cooling Loads	2,201.0	-5.0%
	Total	3,947.0	14%

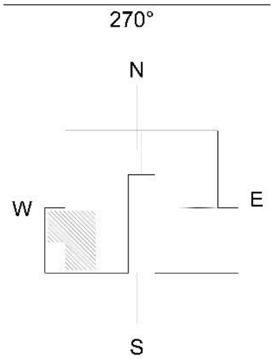
Model	Envelope Description		Percentage of saving when compared to base case scenarios
- South West living space  -Urban Scenario 1 - Ground Floor	Base Case Scenario: - 2.54 cm expanded polystyrene + Low Energy double glazing window + normal aluminum		
	Loads (KWh)		
	Heating Loads	1,972.0	18.14%
	Cooling Loads	1,868.0	10.8%
	Total	3,840.0	15%

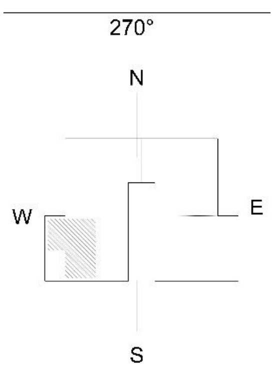
Model	Envelope Description		Percentage of saving when compared to base case scenarios
- South West living space  -Urban Scenario 1 - Ground Floor	Base Case Scenario: - 3.80 cm expanded polystyrene + Low Energy double glazing window + normal aluminum		
	Loads (KWh)		
	Heating Loads	1,887.0	21.7%
	Cooling Loads	1,869.0	10.83%
	Total	3,756.0	16.6%

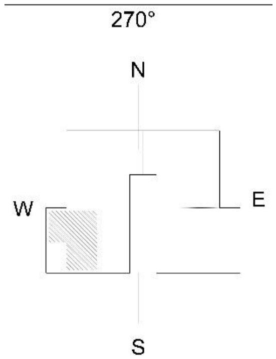
Model	Envelope Description		Percentage of saving when compared to base case scenarios
- South West living space  -Urban Scenario 1 - Ground Floor	Base Case Scenario: - 5.08 cm expanded polystyrene + Low Energy double glazing window + normal aluminum		
	Loads (KWh)		
	Heating Loads	1,919.0	20.3%
	Cooling Loads	1,732.0	17.4%
	Total	3,651.0	19%

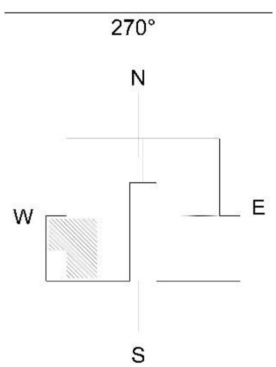
Model	Envelope Description		Percentage of saving when compared to base case scenarios
- South West living space  -Urban Scenario 1 - Mid Floor	Base Case Scenario: - air gap insulation + double glazing window + normal aluminum		
	Loads (KWh)		
	Heating Loads	2,326.0	Not Applicable
	Cooling Loads	1,573.0	
	Total	3,899.0	

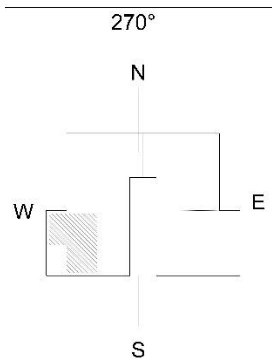
Model	Envelope Description		Percentage of saving when compared to base case scenarios
- South West living space  -Urban Scenario 1 - Mid Floor	Base Case Scenario: - 2.54 cm expanded polystyrene + double glazing window + normal aluminum		
	Loads (KWh)		
	Heating Loads	1,731.0	25.6%
	Cooling Loads	1,749.0	-11.2%
	Total	3,480.0	10.7 %

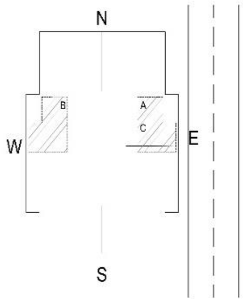
Model	Envelope Description		Percentage of saving when compared to base case scenarios
- South West living space  -Urban Scenario 1 - Mid Floor	Base Case Scenario: - 3.81 cm expanded polystyrene + double glazing window + normal aluminum		
	Loads (KWh)		
	Heating Loads	1,644.0	29.3%
	Cooling Loads	1,771.0	-12.6%
	Total	3,415.0	12.4%

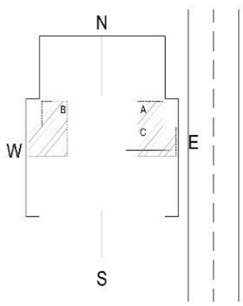
Model	Envelope Description		Percentage of saving when compared to base case scenarios
- South West living space  -Urban Scenario 1 - Mid Floor	Base Case Scenario: - 5.08 cm expanded polystyrene + double glazing window + normal aluminum		
	Loads (KWh)		
	Heating Loads	1,591.0	31.6%
	Cooling Loads	1,782.0	-13.3%
	Total	3,373.0	13.5%

Model	Envelope Description		Percentage of saving when compared to base case scenarios
- South West living space  -Urban Scenario 1 - Mid Floor	Base Case Scenario: - 2.54 cm expanded polystyrene + Low Energy double glazing window + normal aluminum		
	Loads (KWh)		
	Heating Loads	1,796.0	22.8%
	Cooling Loads	1,565.0	0.5%
	Total	3,361.0	14%

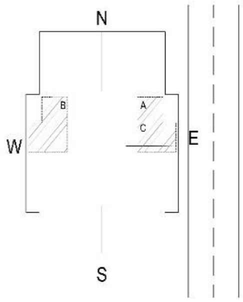
Model	Envelope Description		Percentage of saving when compared to base case scenarios
- South West living space  -Urban Scenario 1 - Mid Floor	Base Case Scenario: - 3.80 cm expanded polystyrene + Low Energy double glazing window + normal aluminum		
	Loads (KWh)		
	Heating Loads	1,708.0	26.6%
	Cooling Loads	1,581.0	-0.5%
	Total	3,289.0	15.6%

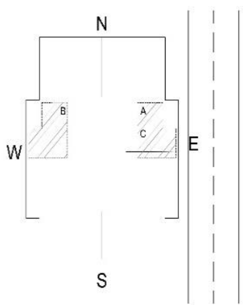
Model	Envelope Description		Percentage of saving when compared to base case scenarios
- South West living space  -Urban Scenario 1 - Mid Floor	Base Case Scenario: - 5.08 cm expanded polystyrene + Low Energy double glazing window + normal aluminum		
	Loads (KWh)		
	Heating Loads	1,704.0	26.7%
	Cooling Loads	1,614.0	-2.6%
	Total	3,318.0	14.9%

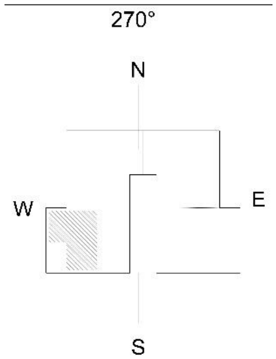
Model	Envelope Description		Percentage of saving when compared to base case scenarios
- West living space  -Urban Scenario 2 - Mid Floor	Base Case Scenario: - air gap insulation + double glazing window + normal aluminum		
	Loads (KWh)		
	Heating Loads	2,392.0	Not Applicable
	Cooling Loads	1,089.0	
	Total	3,481.0	

Model	Envelope Description		Percentage of saving when compared to base case scenarios
- West living space  -Urban Scenario 2 - Mid Floor	Base Case Scenario: - 3.82 cm expanded polystyrene + low double glazing window + normal aluminum		
	Loads (KWh)		
	Heating Loads	1,838.0	23.2%
	Cooling Loads	1,164.0	-6.9%
	Total	3,002.0	13.8%

Appendix 5

Model	Envelope Description		Percentage of saving when compared to base case scenarios
- West living space  -Urban Scenario 2 - Mid Floor	Base Case Scenario: - 5.08 cm expanded polystyrene + Low energy double glazing window + normal aluminum		
	Loads (KWh)		
	Heating Loads	1,710.0	28.5%
	Cooling Loads	1,134.0	-4.1%
	Total	2,844.0	18.3%

Model	Envelope Description		Percentage of saving when compared to base case scenarios
- South West living space  -Urban Scenario 2 - Mid Floor	Base Case Scenario: - 3.82 cm expanded polystyrene + low energy triple glazing window + normal aluminum		
	Loads (KWh)		
	Heating Loads	1,808.0	24.4%
	Cooling Loads	1,145.0	-5.14%
	Total	2,953.0	15.2%

<table>
<tr><th>Model</th><th colspan="2">Envelope Description</th><th rowspan="3">Percentage of saving when compared to base case scenarios</th></tr>
<tr><td rowspan="5">- South West living space


-Urban Scenario 3
- Mid Floor</td><td colspan="2">Base Case Scenario: - 5.08 cm expanded polystyrene + Low Energy triple glazing window + normal aluminum</td></tr>
<tr><td colspan="2">Loads (KWh)</td></tr>
<tr><td>Heating Loads</td><td>1,770.0</td><td>26%</td></tr>
<tr><td>Cooling Loads</td><td>1,150.0</td><td>-5.6%</td></tr>
<tr><td>Total</td><td>2,920.0</td><td>16.11%</td></tr>
</table>