Integration between Building Information Modeling (BIM) and Energy Performance Modeling to Analyze the Effects of Building Shape and Orientation on Energy Consumption

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ABSTRACT

Beneficial influences of Building Information Modeling (BIM) and energy performance modeling in construction projects have been separately recognized and proved. Furthermore, modern methods of construction necessitate a concurrent approach to improve the efficiency and effectiveness of decision making procedure in very beginning of design stage. Hence, integration between BIM tools and energy simulation software can result in a significant saving in energy and cost.

Due to the fact that many attempts have been made to develop sustainable and cost-effective design, analyzing and optimizing shape factor and building orientation as two highly effective design parameters can contribute to addressing such issues. These two factors are feasible and inexpensive to be considered in early design phase when there are lots of alternatives to choose.

In this research the considerable impacts of orientation and shape factor on thermal load were elucidated and demonstrated through the integration of BIM and energy analysis tool. During the investigation the appropriate orientation of implementing construction in Cyprus was obtained. Also the optimal proportion of wall area in north-south to east-west was determined.

Keywords: Building Information Modeling (BIM); Thermal Modeling; Building Shape; Orientation

ÖZ

Building Information Modeling (BIM) ve inşaat projelerinde enerji performans modellemelerinin faydalı etkileri ayrı ayrı kabul edilmiş ve ispatlanmıştır. Ayrıca, modern inşaat yöntemleri tasarım aşamasının başındaki karar alma prosedürünün verimliliğini ve etkinliğini artırmak için eşzamanlı bir yaklaşım gerektirmektedir. Bu nedenle,(BIM) araçları ve enerji simülasyon programlarının bütünleşmesi enerji ve maliyet tasarrufunun önemli bir nedeni olabilir.

İki etkili tasarım parametreleri olarak şekil faktörü ve bina yöneliminin analiz ve optimasyonu sürdürülebilir ve uygun maliyetli tasarım geliştirmek için önemli bir katkıda bulunabilir. Seçim için birçok alternatif varken bu iki faktör erken tasarım aşamasında dikkate alınması gerekrlidir.

Bu araştırmada yönelim ve şekil faktörünün termal yük üzerindeki önemli etkileri, BIM ve enerji analizin entegrasyonu aracılığı ile açıklanmıştır . Araştırma sırasında Kıbrıs'taki inşaatlar için uygun oryantasyon elde edildi. Ayrıca doğu-batı, kuzey-güney duvar alanı, optimum oranda tespit edilmiştir.

Anahtar Kelimeler: Building Information Modeling (BIM); enerji simülasyon; şekil faktörü; Oryantasyon

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LIST OF ABBREVIATIONS

AEC	Architecture, Engineering and Construction
ARE	Architectural Registration Examination
BIM	Building Information Modeling
CFD	Computational Fluid Dynamics
CIFE	Center for Integrated Facilities Engineering
EPA	Environmental Protection Agency
ESS	Energy Simulation Software
gbXML	green building Extensible Markup Language
HVAC	Heating, Ventilation, and Air Conditioning
IFC	Industry Foundation Class
OOCAD	Object-Oriented Computer Aided Design
RFI	Requests For Information
TAT	Turn Around Time

Chapter 1

INTRODUCTION

1.1 Background

Lots of attempts have been made recently at energy saving and efficiency to provide environmentally sustainable design. Moreover, an appropriate thermal design can be a significant cost-saving method (Omer, 2008). Hence determining and optimizing design factors which influence thermal load are required to achieve desired results. Due to this fact, shape factor, transparent surface, orientation, thermal-physical properties of building materials, and distance between buildings have been identified by Ekici, et al. (2011) as the effective design parameters on energy demand. Also it is indicated by Wang, et al. (2006) that the best time to adopt sustainable approach and consequently reduction in construction expenditure is the early design phase of construction.

Based on a research carried out by Morrissey, et al. (2011) into designing an efficient passive solar scheme, orientation was known as the most effectual factor in this area. This research also aimed at recognizing the effective parameters of building in energy demand through change in orientation. To obtain the desired results, 81 different residential houses in Australia's climate were modeled by using AccuRate computer program to calculate the total thermal load. They also investigated the relation between orientation and size in building. It was concluded that, modification in orientation of houses with larger size is more effective compared to buildings with smaller size. Also it is stated by Aksoy, et al. (2006) that "by combining the optimization of shape and orientation, it is possible to obtain benefits that can lead to heat energy savings of 36%". In the study, effects of shape factor and orientation – as passive design factors – on heating load of building for a cold climate were examined. Hence "one-dimensional transient heat transfer within the building envelope was solved by using a finite difference approach". In order to optimize received solar radiation in India, optimum orientation of a dwelling with different shapes was obtained by Gupta, et al. (2004) when walls with the highest length were placed in north and south sides. Since reduction in total thermal load was the objective of the investigation, mathematical method was used to obtain optimum orientation and certain ratio of wall dimensions to minimize the received solar radiation in summer and maximize it in winter. Furthermore, a computer program was established in 'C' Language to calculate indoor thermal comfort via approximating the value of solar radiation in various orientations and certain wall dimensions. In accordance with the research done by Florides, et al. (2002) on building orientation and shape factors impacts, minimum amount of energy demand for a square house was measured when "the building facade was directly oriented toward the four cardinal points." It was also concluded that in a four-sided house, smaller area of surface should be exposed to the east to reduce energy requirements. In the study, a conventional detached house was simulated and analyzed in TRNSYS software to investigate the effects of building parameters such as orientation, shape factor, controlled and natural ventilation on thermal load with the aim of decreasing energy consumption. Finally, based on an overview of preceding researches on design parameters that affect energy efficiency, provided by Pacheco, et al. (2012) "building orientation, shape factor, and the ratio between the external building surface and building volume" were known the most effective factors in energy requirements. It was also concluded that energy consumption analysis in early phase of design results in final cost-saving.

1.2 Scope and Objective

Based on conducted investigations into considerable influences of shape factor and building orientation upon energy consumption, this research concentrates on these parameters in conventional Cypriot houses applying Building Information Modeling (BIM) and energy analysis tools in early phase of design. Hence the main objectives of the survey are mentioned as below:

1. To illustrate the positive impacts of integration between BIM and energy simulation tools in the briefing stage of construction projects.
2. To demonstrate the effective role of drawing or selecting an appropriate building plan in reducing energy consumption.
3. To investigate the effects of orientation on total thermal load of dwellings and determining the optimal orientation in Cyprus.
4. To investigate the influence of building walls length and location on energy consumption.
5. To calculate an optimum ratio of total wall length in north- south direction to east-west in order to save energy.

1.3 Works Undertaken

So as to attain the abovementioned goals, three scenarios are considered. Steps followed in these scenarios can be numbered as below in the same chronological orders as the objectives:

1. In the first scenario, 40 various Cypriot building plans in 4 categories with different area are modeled with Autodesk Revit as BIM tool and then analyzed by Autodesk Ecotect as energy analysis tool.

2. Building characteristics such as properties of used materials and weather condition are considered alike in the first scenario, so changes only occur in shape of plans.
3. In the second scenario, a 100 Square Meters – 20m by 5m – building is modeled and analyzed by using Autodesk Ecotect to compare two directions of implementing construction ; one with 20m-walls in north and south sides, the second one with 20m-walls in east and west sides of dwelling.
4. The next step in second scenario is assigning the best and the worst wall materials – in terms of insulation – to respectively, north and south walls with 20m length. Afterwards, building is rotated by 90 degrees, for three times.
5. In the third scenario, a 50 square meters rectangular house with equal length of walls in 4 sides are modeled. In each step length of north wall is increased by 10%, for ten times, while building area kept fixed. The same process is utilized for houses with area of $65m^2$, $75m^2$ and $100m^2$.

1.4 Achievements

In accordance with conducted investigations, achieved results of research can be listed as below with the same chronological order as the objectives and works undertaken:

1. Integration between BIM and energy analysis in early phase of design leads to obtain reliable and detailed information to estimate energy cost and construction expense. Hence this integration provide the accurate information to make a precise comparison between energy consumption of models to find the best building plan in terms of the energy requirements.

2. About 5% difference in total thermal load between the best modeled plan and the worst one was measured in all categories of area.
3. The optimum orientation of implementing construction in Cyprus was when the longest walls faced to the north and south.
4. It was confirmed that each exterior wall has its own unique effect on thermal load due to its location. Hence theoretically in a rectangular Cypriot house, the longest and shortest walls should be respectively placed in north and west side in order to save the energy.
5. It is concluded that in rectangular dwellings, 55% of total walls area should be exposed to north and south, and 45% of them to the east and west to make a reduction in energy consumption.

1.5 Guide to Thesis

The second chapter (literature review) has been divided into five sections. In the first section studies relating to Building Information Modeling (BIM) and its positive role on modern construction are reviewed. Also, advantages and obstacles of performing BIM in construction projects are discussed. In the second section, a survey on capabilities and shortages of Autodesk Revit as a powerful BIM tool is carried out. In the third section of this chapter, major roles and aims of energy performance simulation in recent construction industry are investigated based on conducted researches and reports. General shortages in applying Energy Simulation Software (ESS) and significant role of BIM to address these issues are mentioned in this chapter as well. Autodesk Ecotect as a powerful energy analysis tool is introduced in the fifth section. And finally in the last section of chapter two, integration between BIM and energy simulation software is investigated together with a survey on current state of this integration.

In the third chapter (methodology), firstly a review of obtained results from conducted researches is presented to clarify the objectives of adopted method in this study, and then three scenarios are described in details. In each scenario the process of modeling, exporting, importing, defining properties and analyzing using Revit and Ecotect is explained.

The fourth chapter (results and discussion) shows the achieved results of software and calculations in graphs, tables, and figures. Moreover, additional detailed explanations about analysis outcomes are given.

And finally, major achievements and highlights of the study are presented in the last chapter (conclusion).

Chapter 2

LITERATURE REVIEW

2.1 Introduction

In order to determine the most profitable energy system and also to figure out the level of energy efficiency in a building, energy simulation models are being effectively utilized. Data which is used in the simulation procedure is of great significant in terms of certainty and quality of the simulation model. Precise and careful energy operation models are supposed to simulate the true circumstance of the building and its exact energy operation. Nonetheless, the results of such models are generally consisting of ambiguous and even incorrect presumptions and data respecting the real circumstance of the project. Many of the simulation software give this chance to the designers to put presumed (Seongchan Kim, 2011). Energy performance in a building is changeable between its predicted and exact value approximately 30 percent (Yudelson J. , 2010). The reason is, some users who are using these simulation programs, can make unclear changes on non-existed parameters. These inadequate information and guesses for simulations create a lot of conclusions far away from the target (Seongchan Kim, 2011).

Building Information Modeling (BIM) is becoming an extremely popular model for Architecture, Engineering and Construction (AEC) sector and will become quite commonplace amongst building designers in close future. Regarding to this explanation, it has to include (supposed to have) a huge data about structure's geometric information, space relationships, geographic information, structure fragments, production particulars, construction timeline, fabrication duration etc. By its features and method of operation besides huge databace of information make it an effective instrument (Kumar, 2008).

Meantime, BIM-based simulation models can properly integrate construction project and energy performance settlement at early stage. In addition, with BIM-based energy simulation models which are combined with itemized HVAC information from BIM, the energy performance settlement can be developed efficiently. Since more data has been gathered in this model, BIM can provide more information and also considerable expertise, as needed, in order to manage different sight of structure energy performance (Seongchan Kim, 2011). The model is available for complete structure analysies until the ingredients that create the structure's thermal zones, (such as walls, windows, roofs, floors etc.) are founded. More time is needed for particular designs, but achieved results are not meaningful enough (Autodesk, 2009). According to this, BIM-based energy models can be operated to exchange the energy data with different energy simulation programs to make the analysis function more efficiently (Seongchan Kim, 2011). Enabling information exchange or sharing data between various programs is the principle aim of integration between these software tools (Chuck Eastman, 2011). Certain information and data settlement within BIM that defined by model as ‘’information exchange demands’’ supposed to be assisted by all programs in order to launch together in a precise operation (Bazjanac, 2008).

2.2 Building Information Modeling (BIM)

2.2.1 Introduction

BIM has been described as “a verb or adjective phrase to describe tools, processes and technologies that are facilitated by digital, machine-readable documentation about a building, its performance, its planning, its construction and later its operation.” by BIM handbook (Chuck Eastman, 2011). BIM software devices utilize machine- readable parametric items to collect a virtual model of building which is called ‘building information model’ (Sacks, 2004).

High-quality visualization of the whole project from different outlooks and easier forecasting of the project result by using data analysis before constructing are the primary applications of the 3D model, but it should be mentioned that BIM is greater than a simple 3D model (Bennett, 2009).

In any design and scheming procedure, precise as-built is one of the most significant constituents. Advantages of precise as-built information include:

- Assessment of construction reuse capacity
- Comprehend the original structure
- Appraisal of required structural renovation or seismic retrofit
- Create and visualize model easily and precisely

Precise as-built information can be collected during BIM process even on highly complicated projects (Bennett, 2009) .

McGraw-Hill Smart Market Report considered recently that “71% of contractors report positive results with the use of BIM”. According to the report, between 2007 and 2009, using BIM by constructors was increased from 13% to 50%. It shows the quickest adopting, compared to all other groups in the industry (Young, 2009).

Supported by a research of anticipation in construction industry which have been done by graduates of construction management, it has been realized that the greatest request for applying BIM were in “constructability” and “visualization” of projects. It also has been realized that 4D modeling as a part of BIM process has been utilized in almost half of respondent firms presently. 4D model is produced when time is added to the created 3D model in BIM process to establish a detailed timetable for project crews. Visualizing, designing arrangements, and keeping better contact between crews in construction project are some advantages of 4D modeling as a part of BIM process (Bradley A. Hyatt, 2011).

2.2.2 BIM Applications

BIM has been expressed by (Azhar, 2008) as: “the process that is focused on development and use of computer generated model to stimulate the planning, design, construction and operation of facility.” Virtual constructing a dwelling before implementing in site to overcome the drawbacks and investigate possible influences is initial idea of BIM as a visualization instrument. It improves exchanges of data between architects, engineers and other groups in construction industry (Figure 1) (Smith, 2007).

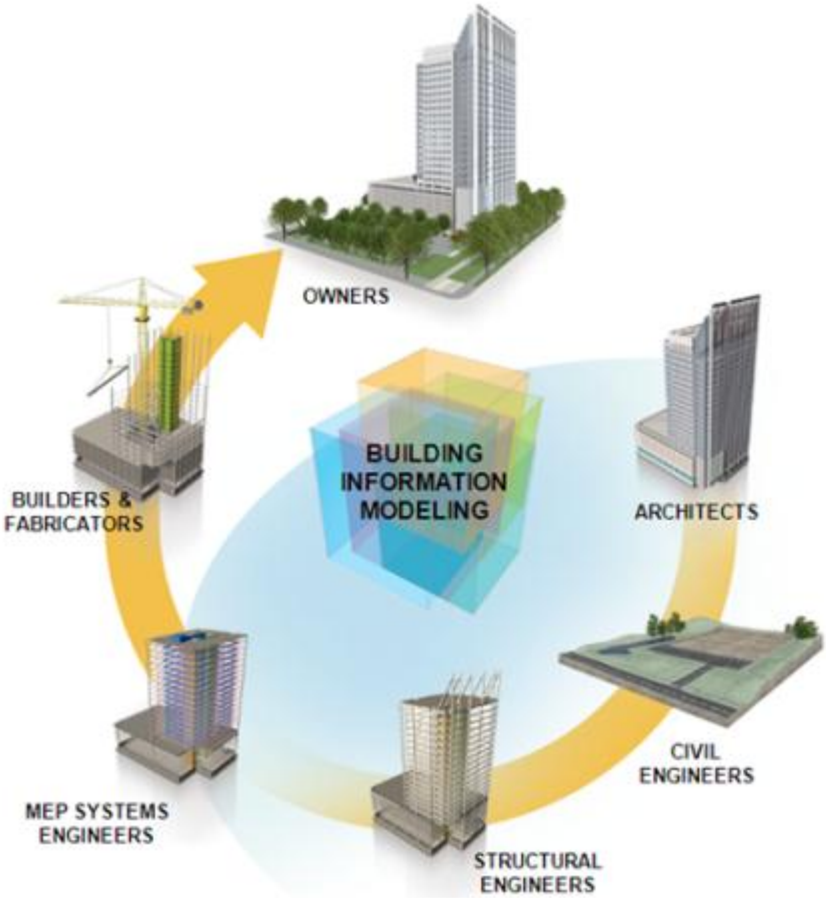


Figure 1: Building Information Modeling Process (Smith, 2007)

Some aims of applying BIM are mentioned below (Lincoln H. Forbes, 2011):

1. Visualization: producing 3-D rendering easily
2. Fabrication/shop drawings: generating shop drawings readily for different construction systems
3. Automated fabrication: BIM exported files are useful inputs for programs which check the fabrication supplies numerically
4. Code reviews: it could be beneficial for fire divisions and others who need to check the construction
5. Forensic analysis: displaying a clear graphic image of possible crashes, leakages etc.

6. Facilities management: BIM can be utilized by facility managers to recondition, organize the area and so on.
7. Cost estimating: calculating cost is an attribute of BIM software
8. Construction sequencing: setting a timetable, making an arrangement to purchase material and fabrication can be done by using building information model.
9. Conflict, interference and clash detection: 3-D models help engineers to check the building for conflicts visually.

Some failures, misunderstanding about crashes in construction projects, and delays are owing to absence of construction documents and data interoperability between different divisions of construction project. These deficiencies are remedied by applying BIM (Lincoln H. Forbes, 2011).

2.2.3 BIM Advantages

Geometrical elements of a building are displayed precisely in an environment with the unified information by BIM that is the main advantage of BIM. Some of other advantages are mentioned below (Innovation, 2007):

1. Increase in speed and efficiency of project procedure
2. Providing more detailed analyses and running quicker simulations that lead to improve design quality
3. Proper understanding of lifecycle costs and environmental data
4. Digital outputs are beneficial to automate the assembly for manufacturing of building systems
5. Precise visualization and better understanding the plan result in improving customer service

6. Facility managers can use lifecycle data to provide required material and other demands

One of the most essential capabilities of building information model is bidirectional associativity. Bidirectional associativity is known as the ability of spreading an occurred change in a view or element of model to all other related views or elements automatically. For instance, by making any alteration in length, material or place of a column, all linked parts with the column like beam frame are changed in all plans, elevations and other details (Figure 2) (Autodesk, 2009). This ability facilitates all construction project divisions to add their own particular changes to only one model and give it to other divisions, which decreases delays, wastes and loss of data in construction projects (Lincoln H. Forbes, 2011).

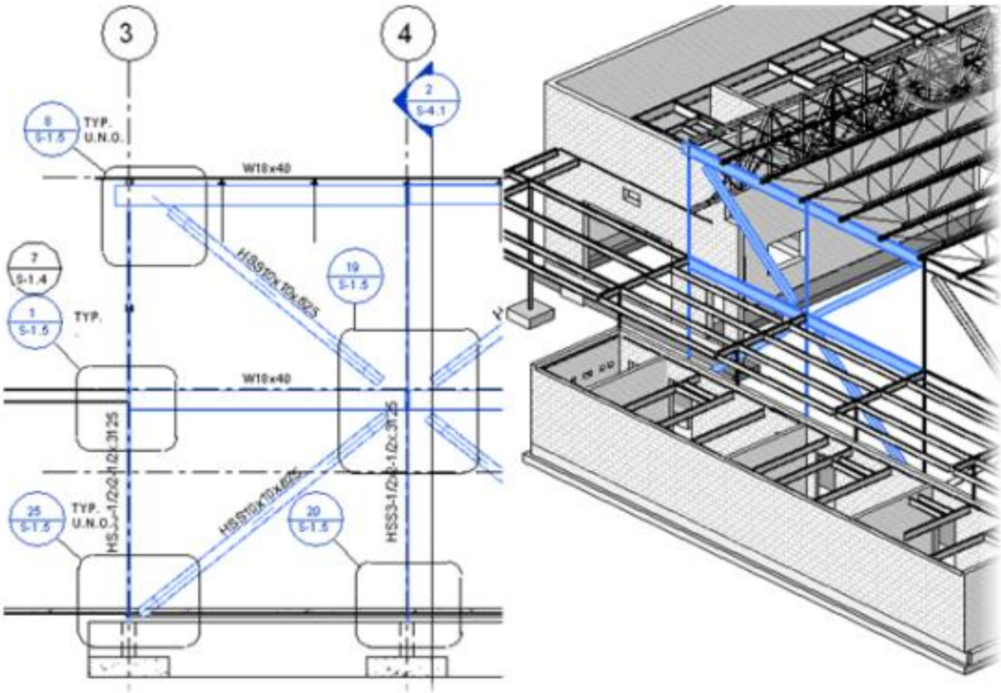


Figure 2: Bidirectional Associativity (Autodesk, 2009)

- BIM advantages in the design stage:

By applying BIM, real time modifications can be carried out easily in the design process which is cost effective and time saving, also all involved stakeholders and construction divisions can access these data. Moreover, a machine-readable form of shop drawings is produced simply by BIM software. It decreases cost and increases preciseness in comparison with traditional method of generating shop drawings (Lincoln H. Forbes, 2011). Although BIM does not produce cost estimation automatically, it increases accuracy of material quantities calculation that leads to estimating costs more precise (Rick Rundell, 2006).

- BIM advantages in the Construction stage:

BIM make integration between work scheming and constructor's timetable to control the operations in accordance with master schedule, and make a reliable cost estimation. It results in detecting clashes and decreasing failures of understanding contract documents before setting up the project (Lincoln H. Forbes, 2011).

- Economic benefits:

Achieved results of an investigation, which has been carried out by Stanford University's Center for Integrated Facilities Engineering (CIFE) on some main projects, shows following savings (Lincoln H. Forbes, 2011):

1. Removing unbudgeted alteration up to 40%
2. 3% increase in precision of forecasting project cost
3. Producing an expense assessment up to 80% quicker
4. Up to 10% savings in contract worth as a consequence of detecting the clashes

5. Decrease in project delays up to 7%

6. Between 20 to 30% growth in field efficiency

7. Decrease in Requests For Information (RFIs) and instructions alteration 10times or more

2.2.4 BIM Disadvantages

The main disadvantages of BIM are (Lincoln H. Forbes, 2011):

- Entitlements of Ownership: It is slightly ambiguous to know the owner of BIM information in project to defend these data regarding copyright and other regulations. Since the project owner pays for drawings, so the project owner can be owner of the information, on the other hand members of that division, who prepare the information, can be the possessor of information to protect them. So determining the data ownership is somewhat complicated.
- Managing the Data Entry: providing updated and precise BIM data are critical and risky for designers who are responsible for liability claims. Also due to the fact that BIM information need to be imputed and revised, more time and subsequently more expense will be added to the project.
- Liability for mistakes: since the integration between construction divisions is one of the main theories of BIM, responsibility level of each division will be unclear. Hence when a design error is identified by owner, each department (architecture, engineering, and so on) looks to other departments to find the responsible of the error.

Other challenges in BIM system can be stated as below (Lincoln H. Forbes, 2011):

1. A BIM schema needs to be designed for each project to determine what draws and when, also who is responsible for drawings.
2. Owners need to be instructed to know about BIM influences because BIM is a tool and a procedure too.
3. Huge files are generated by applying BIM. Larger projects mean larger files.
4. There is an obstacle for distribution a single BIM between several operators because of limitation in hardware capacities.
5. In spite the fact that lots of architectural data are presented by BIM models, there are some shortages in providing the same details on fire safety, energy analysis and so on.
6. A number of specialized or “purpose-driven” software is required to optimize specific aspects of building systems.

2.3 Autodesk Revit

2.3.1 Introduction

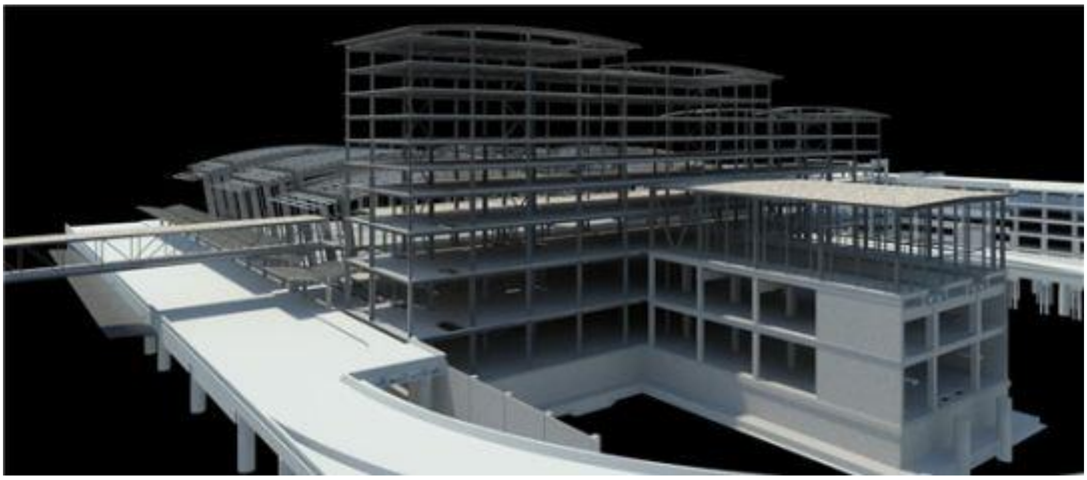


Figure 3: Designed building by Revit (L.A Fuess partner, Inc. (Autodesk, 2009))

“Revit” which represents ‘revise instantly’, is a potent building information modeler for planning, drawing, and documenting. Productivity, organization, and attributes of Revit are highly beneficial for architects, constructors, engineers, and other specialists in construction industry (Autodesk, 2009). In view of the fact that Revit is an object oriented system, acquiring different sections and elevations in building is quite easy (Farah, 2005).

Automation the drafting task was the basic proposition of CAD scheme. CAD system concentrated primarily on characterizing 2D geometry by introducing graphical elements, but these graphical elements do not have meaning, for instance, walls are just showed like two parallel lines. Layering the correlated elements was established to give sense to these graphical elements. Although by layering, drawing files are prepared and plotted, these files are somewhat separate and detailed data such as association between sections are not included. Hence, 3D CAD was provided to make a better visualization and accurate rendering (Ian Howell, 2005).

Lately, 2D symbols have been substituted with building elements by Object-Oriented CAD scheme (OOCAD). These elements behave like conventional building elements and are capable to present in different views. “The inclusion of parametric 3D geometry, with variable dimensions and assigned rules, adds “intelligence” to these objects, permitting the representation of complex geometric and functional relationships between building elements.” (Ian Howell, 2005).

2.3.2 Revit Advantages

- Automatic Renewing the Model (Cumpton, 2010)

  Making an arrangement in process when something changes in model is a basic feature of Revit. By bidirectional associativity feature of Revit, associated elements are found, so any change in a part or element reflects to other linked elements automatically.

- Parametric Change Management

  Parametric change management is an ability to keep updated 2D drawings that is integrated with 3D model to detect clashes throughout the design stage.

- 3D Model

  In contrast with 2D model, 3D model allows user to zoom the desired part to look the details such as join section, with high resolution when there is a conflict in that part.

- Floor Plan Devices

  Generating floor plan as a critical section in a building document is accelerated by Revit.

- Sheets Organization

  Dependent upon viewport’s scale, dimensions of comment tags, text, and hatch shapes are scaled automatically. Moreover, Revit updates plans, sections or elevations numbers and their reference tags at the same time as adding details to them.

- Time and Cost Management

  Precise cost estimating, managing bids, contract supervising, performing field examinations, administrating produced changes in commands, and checking construction process in accordance with keeping to schedule and budget, can be prepared by Revit after gaining Bill of Quantities.

- Parametric Family

  In contrast with AutoCAD wherein related objects are not moved when distance between objects are altered, parametric family in Revit maintains the association between items, thus by changing in dimension value, all connected items to the dimension are shifted.

- Work on a Single File

  Revit provides and saves all information into a single file.

- interoperability in Projects

  In a cooperative design work, all connected parties can operate on the same model and unify their modifications.

- Accessibility to Different Design View

  Any views (plan, elevation, perspective and section) are accessible to work for Revit user.

Other Revit benefits for enhancing performance of building can be numbered as below (Cumpton, 2010):

1. Decreasing time of field cycle by finding ways
2. Improving teamwork and coordination
3. Reducing Turn Around Time (TAT)
4. Reducing waste
5. Enhancing chances of on-site renewable
6. Failures detecting and risks minimizing
7. Improving society's assurance in stewardship
8. Maximizing staff efficiency

2.3.3 Revit Disadvantages

In spite the fact that Revit has many advantages, there are some obstacles to implement it that are mentioned below (Cumpton, 2010):

1. Lack of “Add-on” Feature

   In spite the fact that Revit is highly practical for architects and engineers, owing to lack of “Add-on” feature, it is not very widespread among MEP (Mechanical, Electrical, and Plumbing) contractors. On the other hand, “Add-on” programs can be assigned to AutoCAD that makes models more informative with adding more details.

2. Mistaken belief about Revit

   There are some untruth beliefs about Revit such as:

   - Decrease in efficiency throughout transition
   - Applying to small company is complex
   - It is beneficial just for owners
   - Interference in current process

- Reluctance in employing new method

3. Considerable expenditure and time-consuming

   Considerable expenditure and time-consuming of Revit training and changing platform from AutoCAD to Revit can be the main obstacles for small company to utilize Revit.

2.4 Energy Performance Simulation

2.4.1 Introduction

Based on the Environmental Protection Agency (EPA) report in US, 39 percent energy consumption and also 68 percent of entire produced electricity is being addressed by buildings; that is to say, around half of the annual emission of greenhouse gas (Chung-Suk Cho, 2011).

Building energy simulation models were developed in order to determine the most cost-effective energy system and also to examine the energy performance in buildings. Functionality and efficiency of these models are highly dependent on the given data. Although careful and precise simulation models are supposed to outline the real performance of the operation, the results frequently contain ambiguity and errors. Many of such programs let users set the default values on unavailable simulation factors. Thus, lack of adequate data and also high amount of the assumptions in simulating might be followed by the subsequent flaws and mistakes in the outcomes. Taking everything into account, the difference between estimated and precise energy performance in one building is supposed to be higher than 30 percent (Seongchan Kim, 2011).

Studying about energy performance and thermal comfort among the buildings' life-cycle, programs such as energy performance simulation programs, have been found so potent and constructive. Nowadays, there are various types of such programs which vary in different ways; such as their thermodynamic models, their graphical user interfaces, their purpose of use, their life-cycle applicability, and their ability to exchange data with other software applications (Tobias Maile, 2007).

Graphic interface is one of the most important criteria in practical use of these programs that facilitates the formation of inputs as well as the investigation of the outputs. Besides, they show users how the engine functions (Tobias Maile, 2007).

The energy performance and also the thermal comfort of a certain building can be anticipated by simulation tools. Typically, the programs enhance the comprehension of the building operation based on its specific factors and also facilitate the way to compare various design options. As shown in Figure 4 the inputs predominantly includes of geometry of the building, internal loads, HVAC systems and components, weather data, operating strategies and schedules, and simulation specific parameters. At present, these programs can fairly accurate their anticipations with precise measurements and approaches (Tobias Maile, 2007).

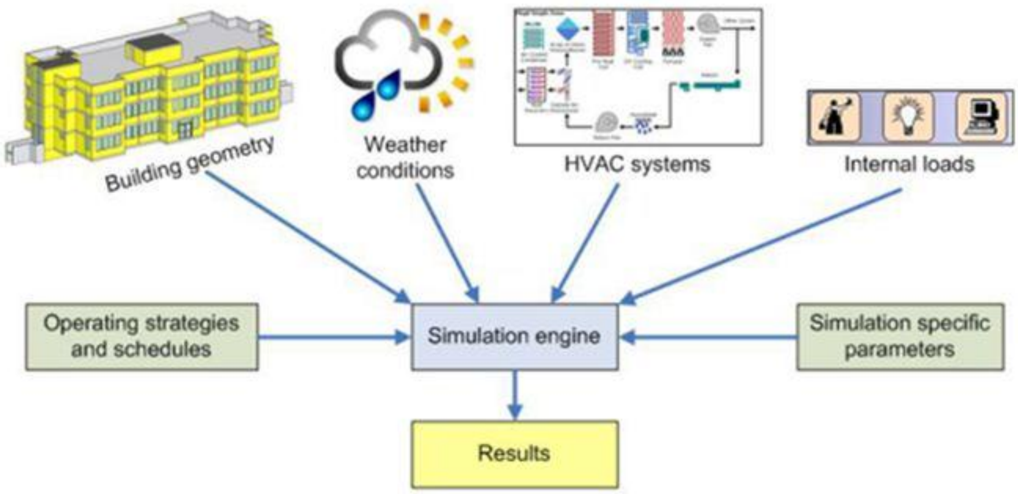


Figure 4: Simulation engines process (Tobias Maile, 2007)

2.4.2 Energy Modeling Procedure

Energy modeling procedure has been simply illustrated in Figure 4. Shape and geometry of the building formulates the primary inputs for simulation. It is vital to know that the required building model for energy simulation is different from the one made by architect. The model for energy simulation majorly concerns the thermal perspective which is a conceptualized view of the building. They vary in a way that architectural spaces can be combined as thermal spaces or even be separated into multiple thermal spaces when the area is quite large. This combination or separation in the building rooms is being made according to thermal considerations; that is to say, the spaces which have same or similar thermal features and controlling design have been aggregated (Tobias Maile, 2007).

In thermal models it is possible to disregard unconnected walls or columns, because there is not any heat transmit between the two sides of them. External slabs and walls that are not connected to a certain building can be dismissed in heat transmit control, but if they play role in shading the building they have to be considered as shading elements. As far as these shading elements can considerably decrease the solar loadings in space, they have great importance in energy models (Tobias Maile, 2007).

In order to obtain necessary data for energy balance in a space, considering both internal and external loads is highly needed. Weather condition and climatic features greatly impact the external loads; hence, gathered information with this respect is used in energy performance simulation. The loads such as occupants, lighting and building equipment which named internal loads, are highly dependent on the practical using of the space (Tobias Maile, 2007).

Building simulation instruments are consisting of two parts, the engine along with the graphical user interface (Figure 5). The input information of a distinct format includes of a formerly depicted data will be applied in simulation engine. The engine runs the simulation and produces the output file(s) by means of the input data. On the other hand, graphical user interfaces normally wrap up this procedure and provides more accessible and friendly user input data; they establish the simulation with the engine and make the output data to be visualized as the final output (Tobias Maile, 2007).

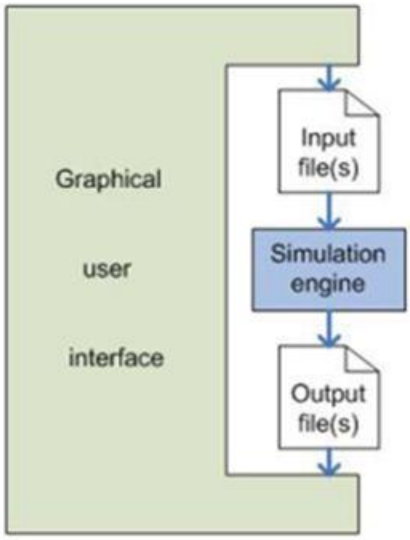


Figure 5: Building simulation instruments manner (Tobias Maile, 2007)

2.4.3 Shortages in Using Energy Performance Simulation

According to a carried out research by (Wong, 2000) using equipment in performance-based simulation in buildings is not that widespread because of some certain reasons:

1. Inherent technical limitation of the software,
2. Emphasis on initial or capital cost by clients,

3. A fragmented building delivery process that does not routinely include quantifiable assessments of design options by the design team, and
4. The prescriptive nature of current building codes and design guidelines do not promote analytical use of these tools.

Also, ARE (The Architectural Registration Examination) makes the candidates to think about the energy and ecological aspects before design phase. The requisites make the architecture designers ready to concern the ecological issues, rather than the methods to evaluate them (Khee Poh Lam, 2004).

- Geometry Semantics: To be able to give an accurate description to design is one of the major difficulties in having a successful energy simulation. It is important to consider the difference between CAD and simulation modeling. Investigations show where these kinds of differences happen and examine the way each energy simulation helps designer to define the true efficiency model.
- Usability: The main concern of the designers is how to apply and use the energy simulation tools. A considerable effort and time is required to examine the possibility of using a specific mean in design process.
- Informational needs: Taking into account the data which designers require, evaluation of each tool's potential has to be carried out to provide applicable information for assessment or finding an alternative design.

2.4.4 BIM and Energy Modeling Interoperability

In order to assure some prerequisites of the building in terms of energy performance and efficiency as well as sustainability in the long run, some programs including Ecotect, IES<VE>, eQuest, Energy Plus, Design Builder, HEED etc. have been traditionally studied and used. Such practices are consisting of simulations, load calculations and thermal, solar, lighting, acoustic, ventilation, computational fluid dynamics (CFD) analysis as well as a host of other functions. Besides, many of these programs support Three Dimensional Modeling, and let the designers and engineers transfer drawings from CAD or other drawing plat forms (Kumar, 2008).

In order to examine energy decisions, such applications are mostly being used late in the process of designing. In general, recreating the models which are used for analysis are quite expensive; one of the most important merits of BIM and interoperability is that there is no need to create the data models from the first, instead they can be simply transferred to the programs (Kumar, 2008).

In order to ensure and improve the interoperability of building information, IFC (Industry Foundation Class) and gbXML (Green Building Extensible Markup Language) were designed; IFC aims to bring a widespread foundation for enhancing the process and data sharing in construction projects as well as management Industry. Whereas, gbXML which is formulated by Green Studio, improves the way for exchanging data amongst BIM and energy analysis programs (Hyeun Jun Moon, 2011).

In XML program which is considered as a computer language program, it has been tried to reduce human interference for communicate information. This method helps designers to be able to concentrate on what is mainly aimed for; such as aesthetic aspects and environmental responsibility of buildings which also requires the project to be cost-effective (Hyeun Jun Moon, 2011).

This interoperability is beneficial in different ways; such as simplifying the transfer data to/from engineering teams and also analyzing means. Moreover, there would be a fine save in time and costs if the exchange of data could be flawless. This backwards and forwards in transferring data would also lead to the more profitable energy decisions from at the start of the design process; moreover, there would be a better cooperation between the design and engineering teams (Kumar, 2008).

Concisely, the ultimate goal of the energy simulation models in buildings is to determine the most profitable and practical energy system and examine performance of the energy in a specific building. The used information in the simulation process can greatly influence the way energy simulation works. Careful and explicit energy simulation models should symbolize the real performance circumstances and also the factual buildings' energy performance. Nevertheless, the final results normally consist of frequent ambiguity, inaccurate stats, and unclear assumption concerning the real buildings' circumstance. Many of the simulation programs provide the chance to use default values evolved from the unclear assumption on the taken simulation guidelines. Inadequacy of data and large number of assumptions in simulation process would inevitably be misleading and result in inaccurate outcomes (Seongchan Kim, 2011). The difference between estimated and real energy performance in a certain building is calculated and recommended to be higher than 30 percent (Soebarto, 2001 and Yudelson, 2010).

2.5 Autodesk Ecotect

2.5.1 Introduction

This tool is considered as an environmental analyzing technique which facilitates the way designers simulate and analyze building performance. It contains a wide range of necessary analysis functions and simulation details from the early beginning of the building design. It represents the analytical results of the design with a highly effective method of three-dimensional visualization as well as energy efficiency tools. Notably, some certain features of it consists of shading design and solar analysis, lighting analysis, acoustic analysis, thermal analysis, ventilation and air flow analysis, building regulations and resource management (Kumar, 2008). More specifically, designers are able to determine thermal properties in Ecotect varying from "HVAC system and its effectiveness, the thermostat range, occupancy, internal gains and infiltration rates" (Kumar, 2008).

One of the considerable merits in Ecotect is the ability to transfer various types of files. They include geometric information; such as AutoCAD drawing files (*.DXF), Lightscape (*.LP,) Lightwave (*.LWO), VRML (*.WRL). In addition to the geometric information, general data files can be directly imported and applied into the Ecotect as well; they include Green Building XML(*.XML), ASCII model files(*.MOD), Energy Plus Input Data files(*.IDF), Weather data files(*.WEA) and Radiance Scene files(*.RAD) (Kumar, 2008).

gbXML, which is the green building expandable markup language, is a nonproprietrary diagram, designed to simplify the transactions of intelligent information. gbXML, nowadays provides a bridge between Building Information Modeling (BIM) and a comprehensive diversity of engineering analysis tools. gbXML file format is esteemed from Autodesk Green Building Studio to transmissions building information safely among DOE-2 (a web-based engine which analyses the energy use and its cost of a building) and design instruments like Autodesk Revit (Autodesk, 2009).

2.5.2 Ecotect Advantages and Disadvantages

The main advantages of Ecotect are (Autodesk Ecotect Analysis, 2010):

- Total energy analysis of building: Hourly, daily, monthly or annual total thermal load and carbon emissions can be measured by Ecotect.

- Carbon dioxide emissions data: Carbon dioxide emissions can be informed about almost all parts of construction such as on-site burnt fuel or produced carbon dioxide from power plant.
- Estimating cost and water use: According to the number of residents in a building or type of structure, water consumption amount is assessed.
- Investigation on solar radiation: Effects of solar radiation on any exteriors of building and differential occurrence solar radiation can be monitored and measured.
- Energy performance: Heating and cooling load quantity, occupancy influences, infiltration impacts, and effects of equipment pieces on energy performance are analyzed.
- Daylighting: Intensity of light in any spot of model and daylight factors is accurately assessed by Ecotect.
- Shades and reflections: Location and track of sun corresponding to the model is demonstrated by Ecotect simulation which shows how sunlight comes into and moves around an area.

Other advantages can be numbered as below (Khee Poh Lam, 2004):

1. Beneficial for early design stage because of quickness in turnaround time
2. Acoustic analysis
3. Easy to learn
4. 3D geometry importing
5. Material archives
6. Comfort analysis
7. Cost estimation

Notwithstanding the mentioned advantages, some disadvantages can be numbered such as (Khee Poh Lam, 2004):

1. Running several projects simultaneously results in unexpected errors
2. After closing one project, program needs to be restarted before opening new project
3. Administering building with complicated geometry is pretty tough
4. Thermal properties of materials are separated from building layers
5. Each area is one zone that explains the Lack of hierarchy of areas and zones
6. Lack of clear explanation for HVAC system
7. Lack of detail on thermal calculations
8. There is a shortage in providing engineering documents to describe the different assumptions
9. Incomplete schedule for post processing
10. Export files have restricted information for post processing
11. Lack of multiple state in undo/redo

Ecotect features in desktop version and web-based version are shown in Figure 6, briefly:

	Desktop Tools Visualize and Simulate Design Performance	Web-based Technology Analyze Multiple Design Alternatives
Whole Building Energy Analysis		x
Carbon-Emissions Estimates		x
Water Use and Cost Estimates		x
ENERGY STAR® Scoring		x
LEED® Daylighting Credit Potential		x
Natural Ventilation	x	x
Wind Energy	x	x
Photovoltaic Collection	x	x
Thermal Performance	x	x
Solar Radiation	x	
Visual Impact	x	
Shadows and Reflections	x	
Daylighting	x	
Shading Design	x	
Acoustic Analysis	x	

Figure 6: Ecotect features in desktop and web-based versions (Autodesk Ecotect Analysis, 2010)

2.6 Integration between Building Information Modeling (BIM) and Energy Simulation Software (ESS)

2.6.1 Introduction

BIM programs are needed to be developed by its interoperability with other energy modeling programs and techniques to provide strong and correct data. Energy performance and design tools must be able to associate the information and be in accordance with the anticipated data in design; moreover it should be able to be updated automatically. This co-operation will assist the users to enhance the performance of energy and improve the construction process (Kumar, 2008).

Energy efficiency can be greatly improved through BIM (helps the constitution of structure models with data attainable in project) and also ESS (allows architects to resolve and proving the energy data of a structure through different simulations) models can be useful. Hence, both models can be helpful in terms of promoting the project performance, and also to assist the users to create projects more consciously accompanying with precise project decisions. Combination of these models bases on direct exchange of information between various programs. This transfer needs a certain model that can be shared by exchanging functions (Haksar, 2010).

Furthermore, to provide the better condition for users to understand the energy demand and to make the changes to reach the data, combining BIM and ESS has proven to be highly significant. Thus, the instruments will let the users to optimize energy performance and user will make the necessary changes at the very beginning stages. It will create a disambiguated, tenderly environmental and energy productive project (Haksar, 2010).

2.6.2 Current State of BIM – ESS Integration from the Viewpoint of Software

Focusing on sustainability in designs shows that architects largely aim to pursue a path to energy efficient design. Architectural design companies have been aware of significance of sustainability considerations and are trying to combine the data from building and energy to make up the required decisions (Haksar, 2010).

Autodesk Revit along with ESS can be utilized via two types of Revit; Autodesk Revit Architecture and Revit MEP. First Autodesk Revit Building, and then Revit Architecture, was straightly connected with the ESS via Green Building Studio (Haksar, 2010). gbXML model with a plugin inside, gives authorize to energy analysis to be created and used within Revit Architecture. Revit Architecture can make this analysis function and can let the users set out different areas within Revit. Before this stage, users also can itemize ingredients of building by this plugin. However lots of data is needed for this simulation of energy which is not needed in the BIM file, this software has to apply specific presumptions to fill in the losses.

Hence, the software is not only practicable at the upper levels but also can be very helpful for the basic stages of the design (Haksar, 2010).

The most functional contributing model which is in an active collaboration is the IFC file. It is also like gbXML because of its noncommercial and free source features. The main difference between them is that the IFC file can provide bidirectional interoperability among the IFC model and any IFC-compliant BIM model. It can also give intangible service such as schedules in addition to representing the physical elements of the design like doors and doors (Haksar, 2010).

2.6.3 Current State of BIM – ESS Integration from the Viewpoint of Construction Companies

Architectural companies have also recognized the benefits of combining BIM-ESS in early design phase like software companies. They understood that this combination can make enormous contribution into the design process (Haksar, 2010). Autodesk Revit Architecture was the BIM tool that utilized in the Sheraton Ulaanbaatar Hotel, Mongolia, and Autodesk Ecotect was the energy simulation software of this project. Autodesk Ecotect has been used to examine sunshield and photovoltaic space on the roof by means of Revit building model. An architect at HOK, Dickson Mak, briefed the advantages of the model by saying ‘’It would be better to made up many design decisions based on examined assumptions before they are being applied. Revit Architecture, Ecotect, and other analysis software, such as IES, help designers and architects to act more confidently in terms of sustainability decision makings” (Haksar, 2010).

In some other architectural engineering companies such as Burt Hill Co, the aforementioned tools and models in green design procedures are being used. For designing the New Literacy Center in Springfield, PA, for BIM and ESS instruments, they used Autodesk Revit Architecture and IES. Research director at Burt Hill, declared that ‘’ We are using the information-rich digital model created with Revit Architecture in combination with sustainability analysis tools very early in the schematic design phase to evaluate specific aspects of a green design” (Haksar, 2010). IFC model as a tool among the BIM and Ecotect also was managed by SOM for their project. To perform the shell of the structure, the original design was extracted as a set of 3D shape. Furthermore, to analyze a glazed section of the building surface, Ecotect model was used to balance the sunshine based on building form and facade. Afterwards, in order to update the improved model of the building, new information were imported to BIM software again. Hence, by using the IFC model, interoperability and two dimensional work flow acquired. Therefore, Ecotect model was operated to analyze the building facade and perform essential changes, the amended building facade and shape consequently turns back into BIM model to be implemented and applied into this tool (Haksar, 2010).

Chapter 3

METHODOLOGY

3.1 Introduction

In order to save the energy costs, precise thermal design is one of the most effective techniques (R. Pacheco, 2012). Optimizing construction factors and design parameters that influence the energy demands will improve the energy efficiency of building (Feng, 2004). These factors are summarized by Ekici and Aksoy (Betul Bektas Ekici, 2011) in Figure 7.

Physical–environmental parameters	Design parameters
Daily outside temperature (°C)	Shape factor
Solar radiation (W/m^2)	Transparent surface
Wind direction and speed (m/s)	Orientation
	Thermal–physical properties of building materials
	Distance between buildings

Figure 7: Effective parameters in energy demand (Betul Bektas Ekici, 2011)

The deep concentration of this study is on orientation and shape of building using BIM and energy simulation tools.

- Effects of building shape

  Due to the building geometry, solar radiation affects total amount of energy requirements. As stated by Elasfouri, et al. (1991) "The radiation hitting a building can increase energy requirements for cooling to up to 25%". Hence, shape of a building can be determined as a "total area of façade and roof that receive solar radiation" as well as "the surface exposed to the outside" that results in energy losses (R. Pacheco, 2012). According to (R. Pacheco, 2012), smaller ratio of external surface to the overall built volume makes model approach to the ideal model, although construction problems make it impossible in most cases.

- Orientation

  Orientation is known as the most effective factor in passive solar scheme (J. Morrissey, 2011). Mingfang states that: "The level of direct solar radiation received on the building façade depends on the azimuth in the wall, and thus, on the orientation angle of the building" (Mingfang, 2002). Moreover, shading, solar encloses performance, and other factors in passive design are affected by orientation. Positive influences of optimizing the building orientation can be stated as below:

1. Decrease in energy requirements
2. Decrease in operating complex passive system
3. Greater efficiency in other sophisticated passive system
4. Greater efficiency in solar collectors
5. Perfectly feasible and inexpensive to use in early design phase
6. Increase in daylight amount, decrease in energy requirements for artificial light and in – house heating load

Eventually, Aksoy, et al. (2006) explains that "by combining the optimization of shape and orientation, it is possible to obtain benefits that can lead to heat energy savings of 36%".

In order to achieve the desired results, this chapter was divided into three scenarios. In the first scenario, impacts of shape factor on energy demand were investigated. For the second scenario, best orientation of implementing Cypriot dwellings was determined. And in the last scenario, an optimum ratio of wall length in north/south side to wall length in east/west side was measured.

3.2 Scenario One

In this scenario, study focused on building-shape influences on total thermal load. Therefore, 40 different conventional buildings were modeled by Autodesk Revit Architecture as BIM tool (see Appendix). The original plans of these 40 models were obtained from available plans of constructed projects in Cyprus. Since area of these single and two-bedroom buildings were generally between $40m^2$ – $100m^2$, four categories of plans with area of $50m^2$, $65m^2$, $75m^2$, and $100m^2$ were modeled to cover the existing range of building areas. During the process of generating similar houses with different areas, it has been tried to adhere as much as possible to the original plan. Subsequently, models were exported to Autodesk Ecotect to perform the thermal analysis. Due to the fact that Revit and Ecotect are both produced by Autodesk, integration between these two tools as a vital factor in this investigation was supposed to be seamless.

With the intention of producing 40 models, 8 single bedroom houses with the area of $50m^2$ were modeled in first step (Appendix, Part A). For all 8 models bedroom area was $18m^2$, bathroom area was $7.5m^2$, and the rest of the house area belonged to lounge and kitchen. Since a comparative approach has been used in this research, it necessitated assigning the same percentage of walls for glazing area, which in this case has been assumed to be 10%. Also the used materials for walls, doors and windows were the same in all models. Properties of applied materials including brick wall, single glazed window, solid core-pine timber door, and concrete slab floor have been illustrated in Figures 8-12. Afterward, 8 more single bedroom plans with the area of $65m^2$ were modeled by Revit in second step (Appendix, Part B). All conditions and properties were assumed similar to the previous models and the extra area was added only to the lounge and kitchen.

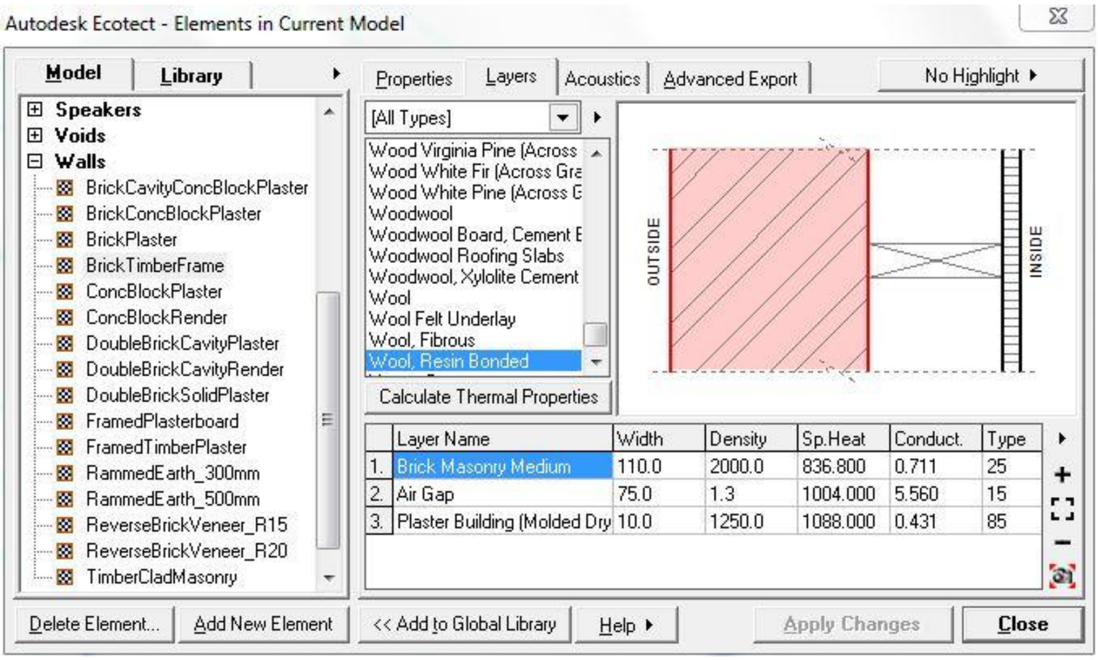


Figure 8: Brick wall properties

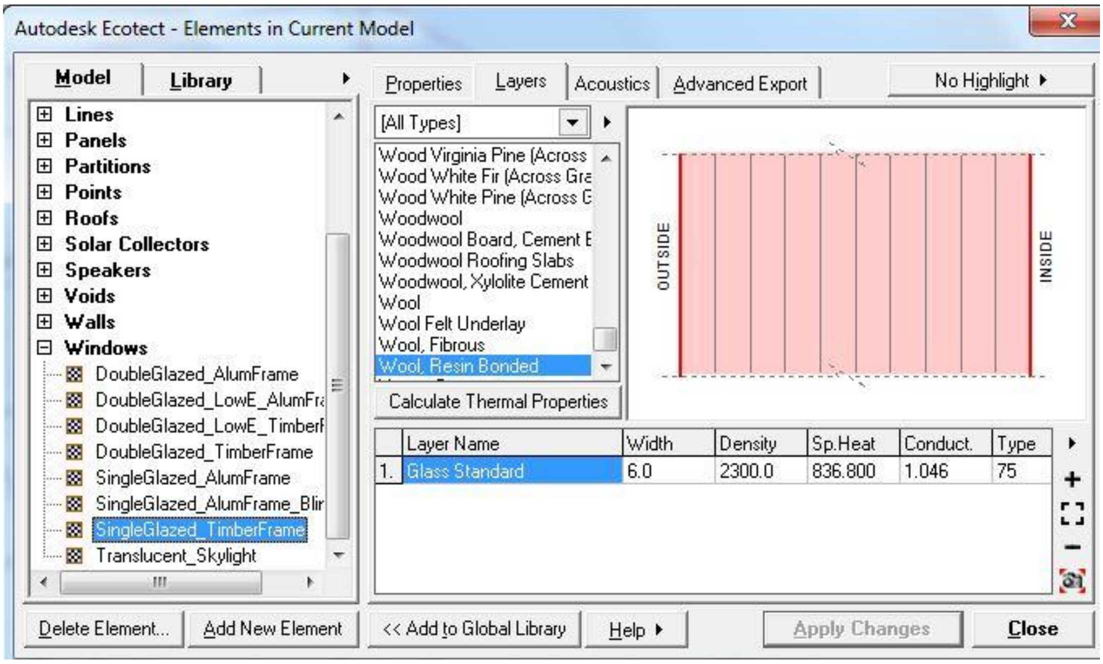


Figure 9: Single glazed window properties

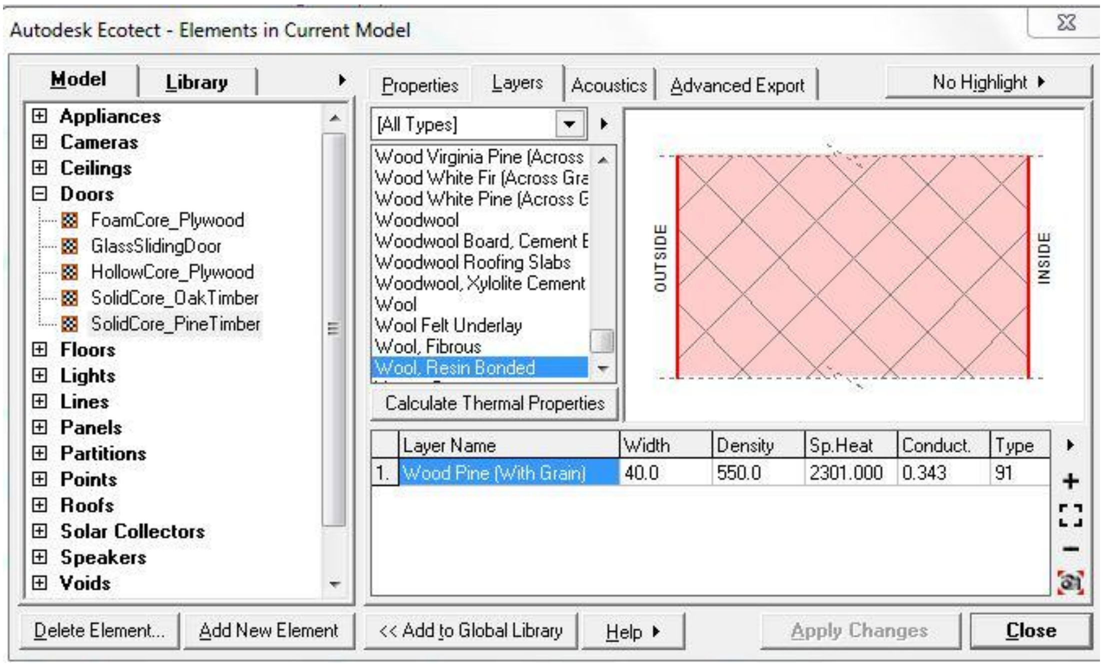


Figure 10: Properties of Solid core-pine timber door

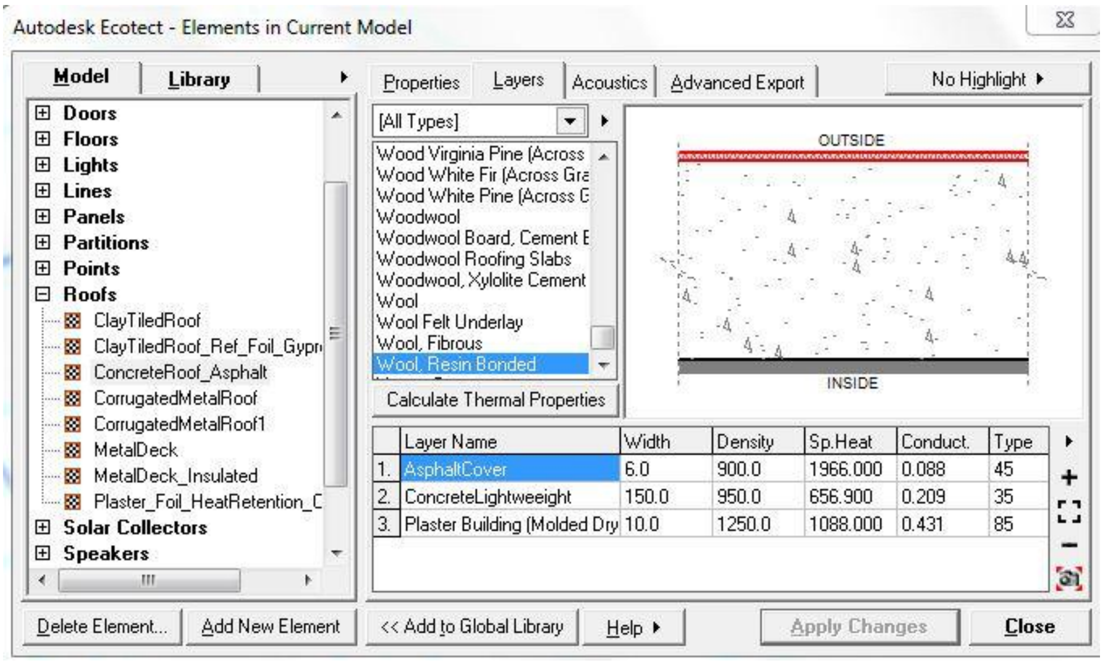


Figure 11: Concrete roof properties

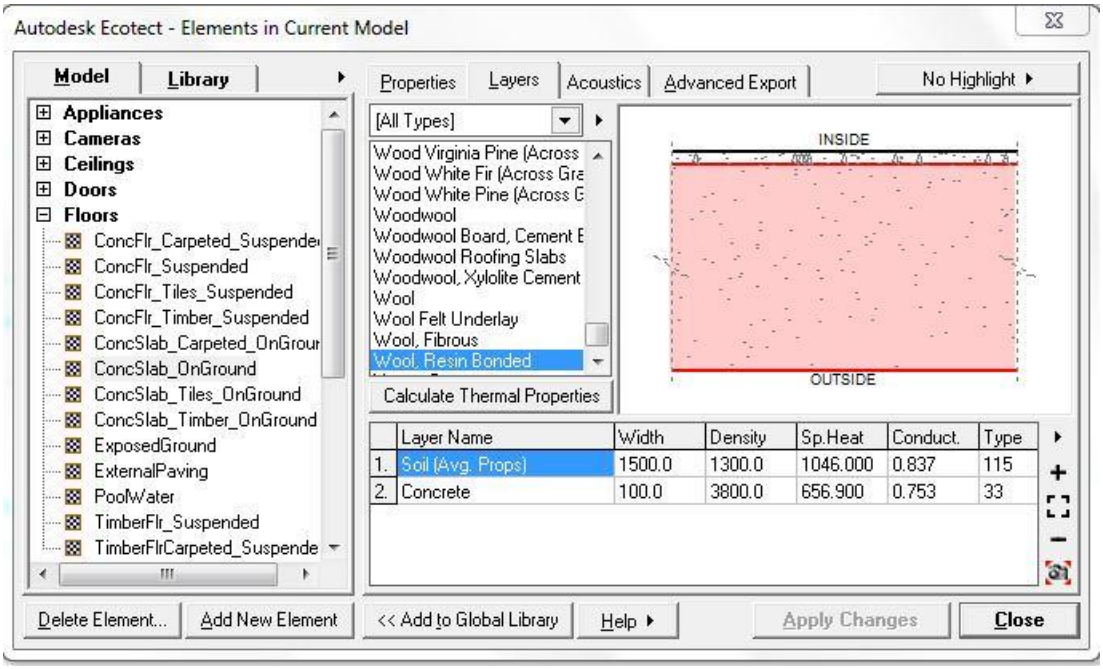


Figure 12: Concrete slab floor properties

In the next step, 12 two-bedroom houses were modeled (Appendix, Part C). Total area for each house was equal to 75m^2, where 28m^2 of the area were assigned to two bedrooms and 8.75m^2 to bathroom. Rest of the area was allocated to the lounge and kitchen. Other conditions such as glazing area and used materials were the same as in the 2 last steps. Finally, 12 two-bedroom plans with the area of 100m^2 were modeled similar to the last step while the additional area was assigned only to lounge and kitchen (Appendix, Part D).

Keeping identical condition for all 4 categories and change in just size and shape of buildings led automatically to concentrate on impacts of shape factor on thermal load. Explained process has been shown in Figures 13 - 16:

Figure 13: Real plan

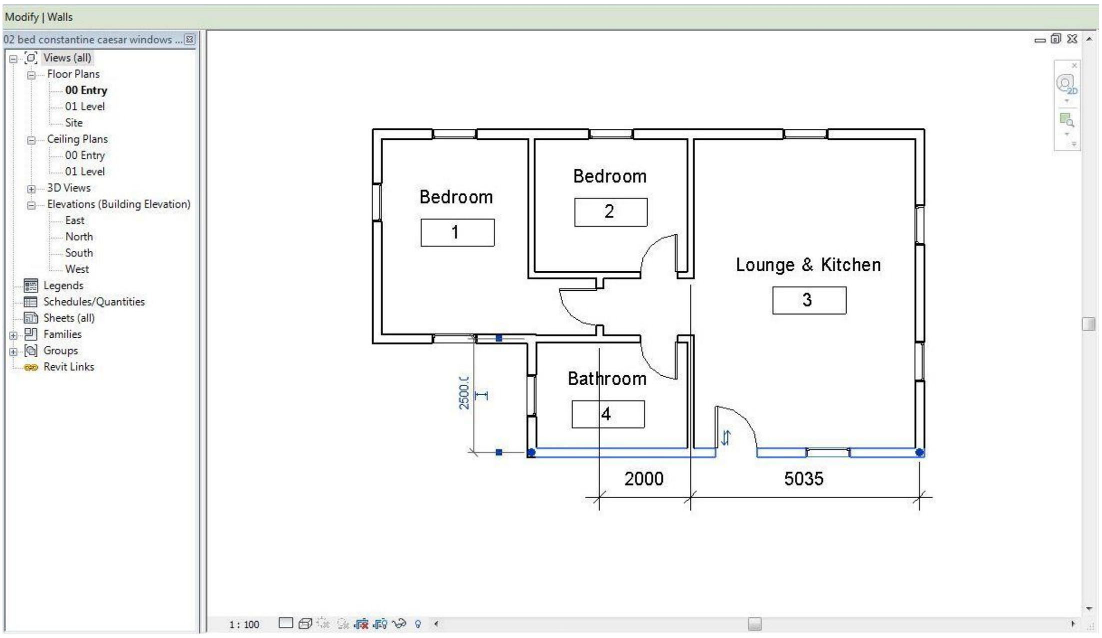


Figure 14: Modeling process by using Revit Architecture

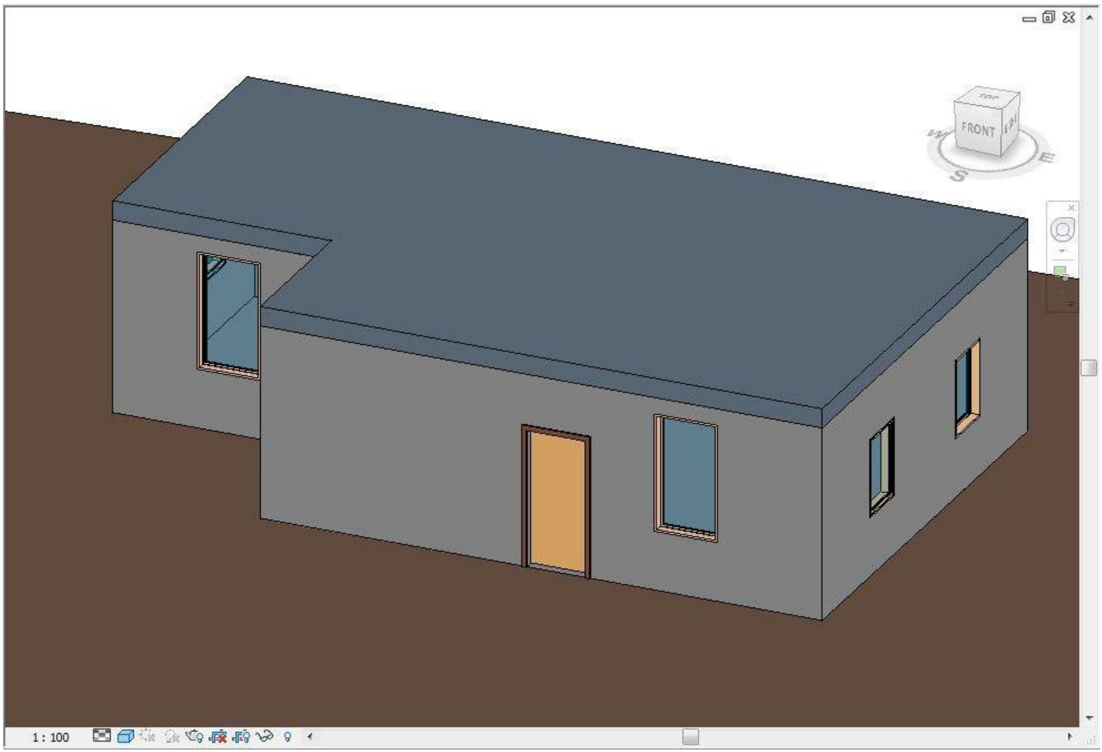


Figure 15: Realistic image of modeled building

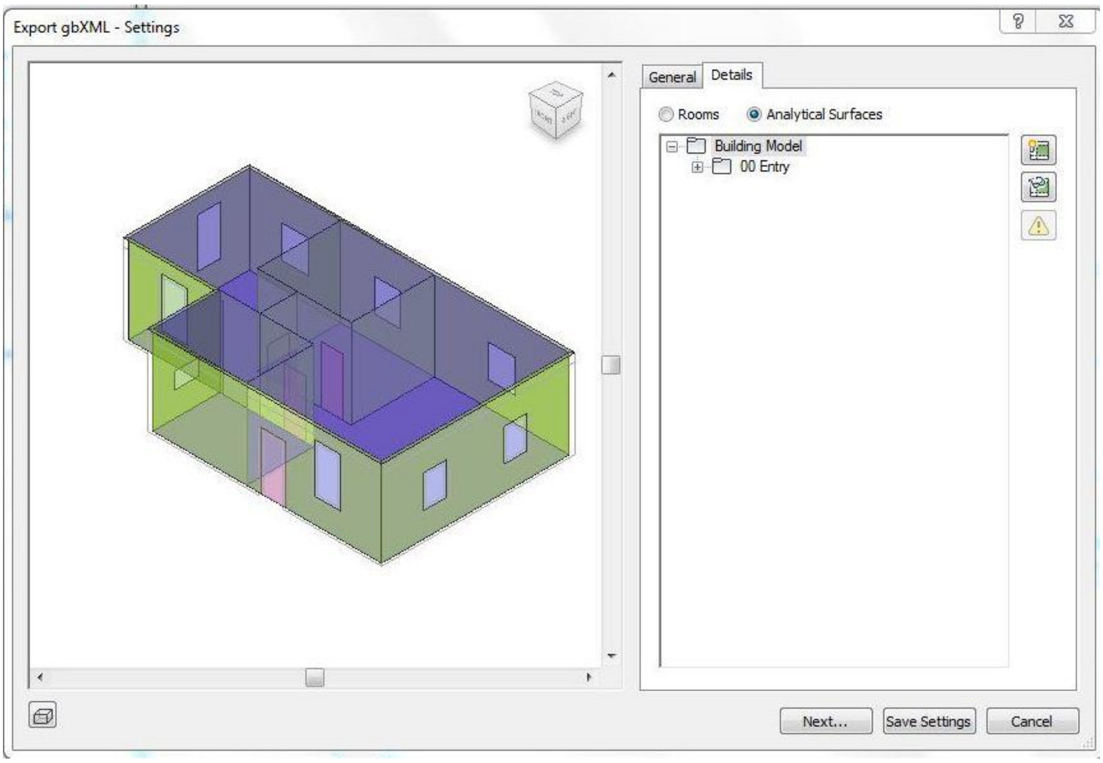


Figure 16: Exporting model from Revit as a gbXML file

Due to the fact that data transmission from 3D building information models to analysis engines such as Ecotect has been simplified by using Green Building XML open schema, all model were exported as gbXML file (Figures 16 and 17). (schema, 2012).

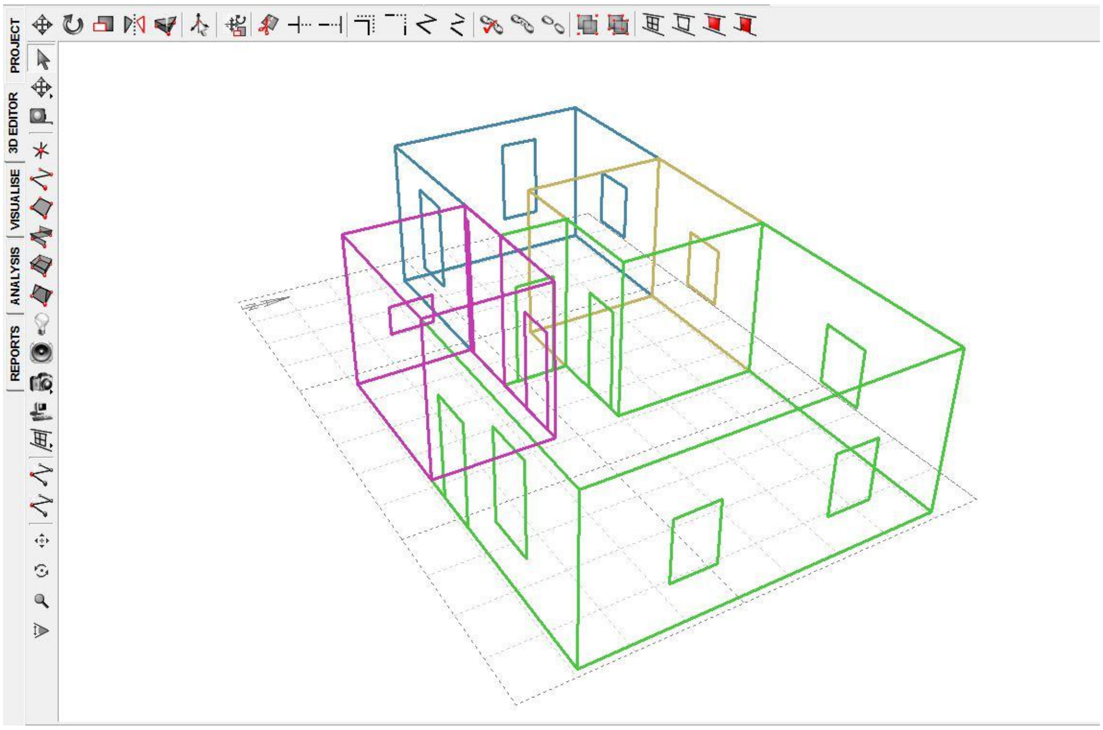


Figure 17: Imported model from Revit to Ecotect

In this stage, the properties of zones were defined after importing files into Ecotect. Due to the proper integration between Revit and Ecotect, all defined boundaries in Revit (bedrooms, bathroom, and lounge & kitchen) were known as zones in Ecotect, so it was not required to define zones.

In order to have an equal condition for comparison, identical properties were considered for all zones in all models. General information about physical-environment parameters such as air speed, air change rate, and wind sensivity for a conventional building – suggested by Ecotect – was entered onto General Setting and

Thermal Properties as two essential parts of zone management. All these assigned data are shown in Figures 18 and 19.

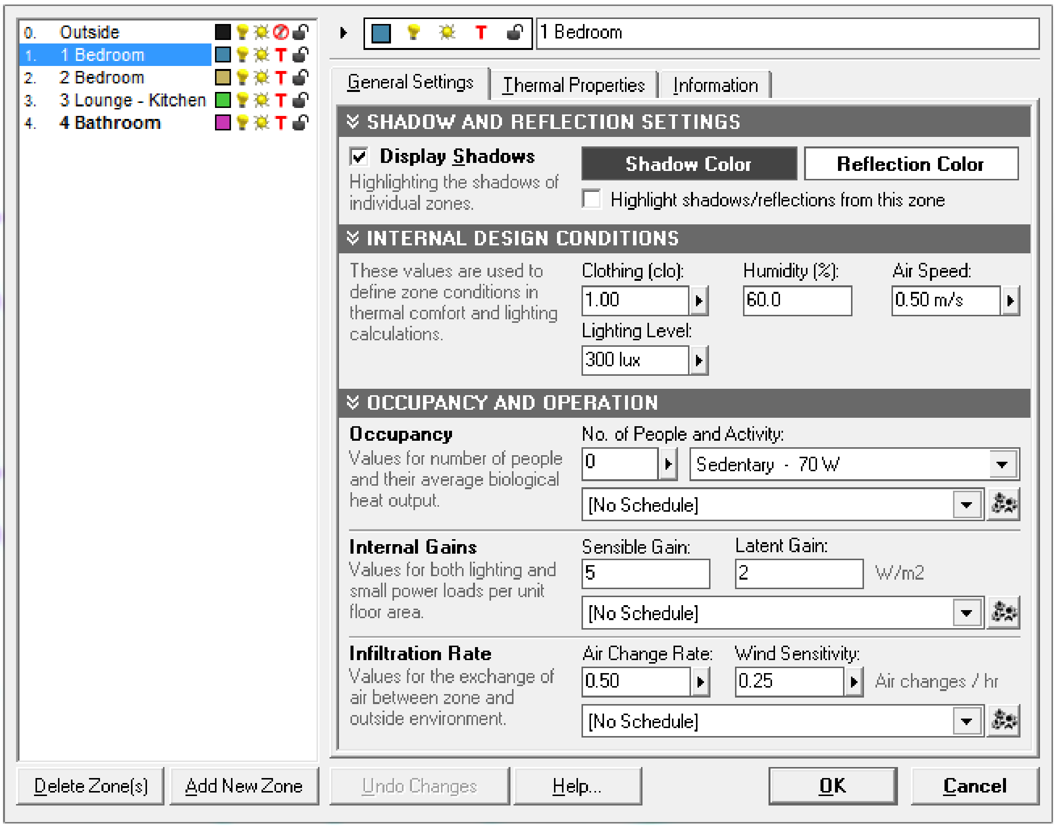


Figure 18: Entered data for General Setting

For General Setting (Figure 18), Air Speed for inside the building was assumed 0.5m/s, which means a pleasant breeze. “Light Level or Illuminance, is the total luminous flux incident on a surface, per unit area” (Recommended Light Levels, 2012). Hence 300 lux lighting level is assumed for conventional house, while according to Ecotect database, the recommended illumination for workshop and office is 400 lux and for waiting area and lift it is equal to 200 lux. Air change rate and wind sensitivity, which determine the value for the exchange of air between zone and outside environment, were considered respectively 0.5 and 0.25 ach. These values represent a well-sealed home with reasonably protected. Higher amount of air change rate and wind sensitivity expresses the higher level of leakage and lack of well protection in a building.

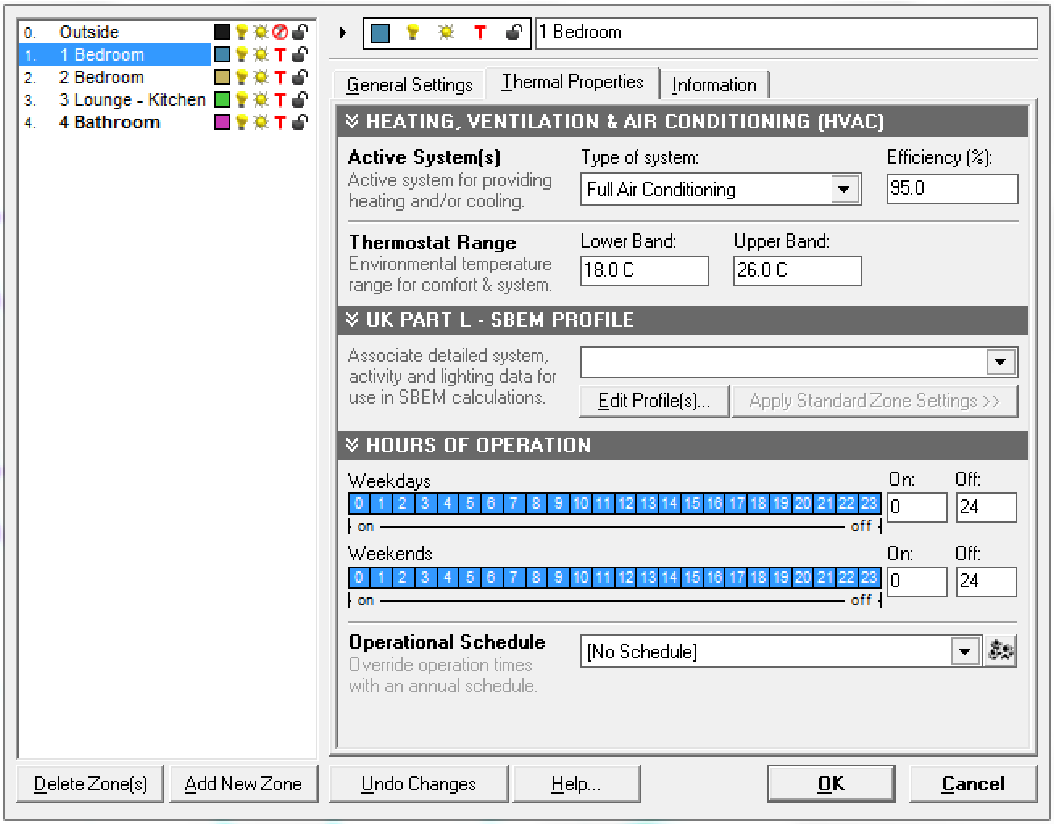


Figure 19: Entered data for Thermal Properties

Figure 19 displays the details of Zone Thermal Properties. In this window, type of system for providing heating and cooling load is determined. Furthermore, environmental temperature range for comfort and system as well as hours of operation are defined here. In this part, 24 hours operation for all 7 days in a week was supposed just to keep the same condition for all models. Given that cost related issues are not encompassed in this research, this assumption does not cause divergence from the main purpose of the study. Comparative nature of the study necessitates consideration of equal values for all cases. Hence such an assumption could be considered a reasonable and acceptable value for the comparison between total thermal loads of designed models in the study. Subsequently, in calculation wizard window (Figure 20) there is some options to select depend on user needs. For instance, Temperatures option displays outside and inside temperatures for thermal zones, also Losses and Gains option shows relative contribution of different heat flow paths. Since the aim of this survey was to calculate the total thermal load, Space Loads option was selected in this window to determine Heating, Ventilation, and Air Conditioning (HVAC) required loads to maintain thermostat temperature.

Because Larnaca's weather data were available in Ecotect data base, Larnaca weather data was loaded as climate data in the last step. In other words, the buildings were assumed to be in Larnaca (Figure 21).

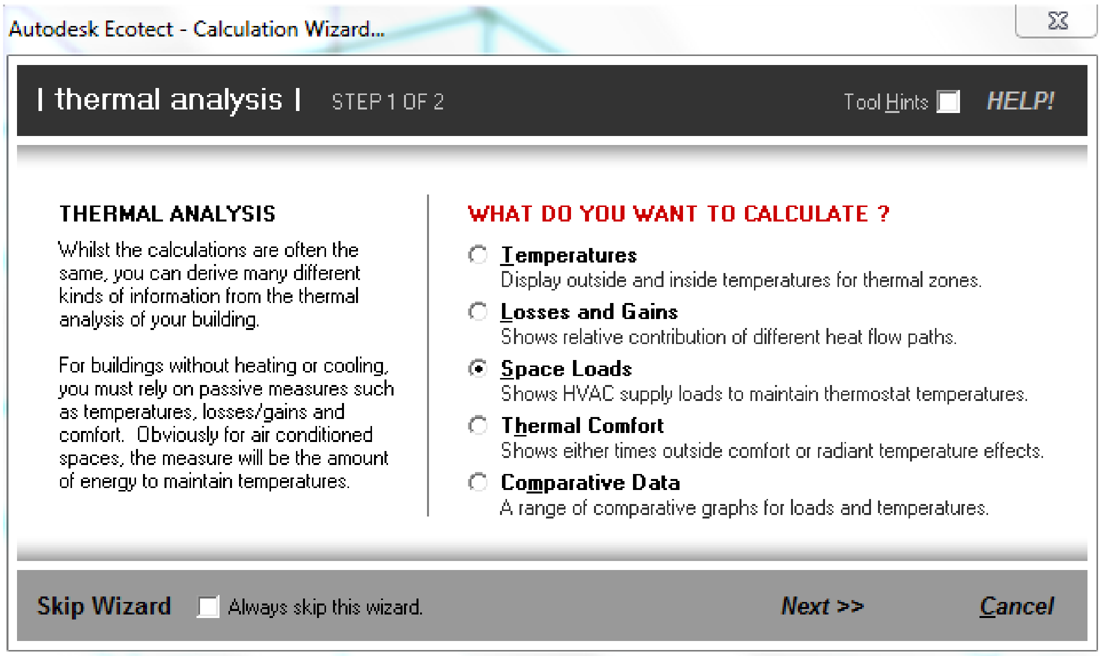


Figure 20: Thermal Analysis window

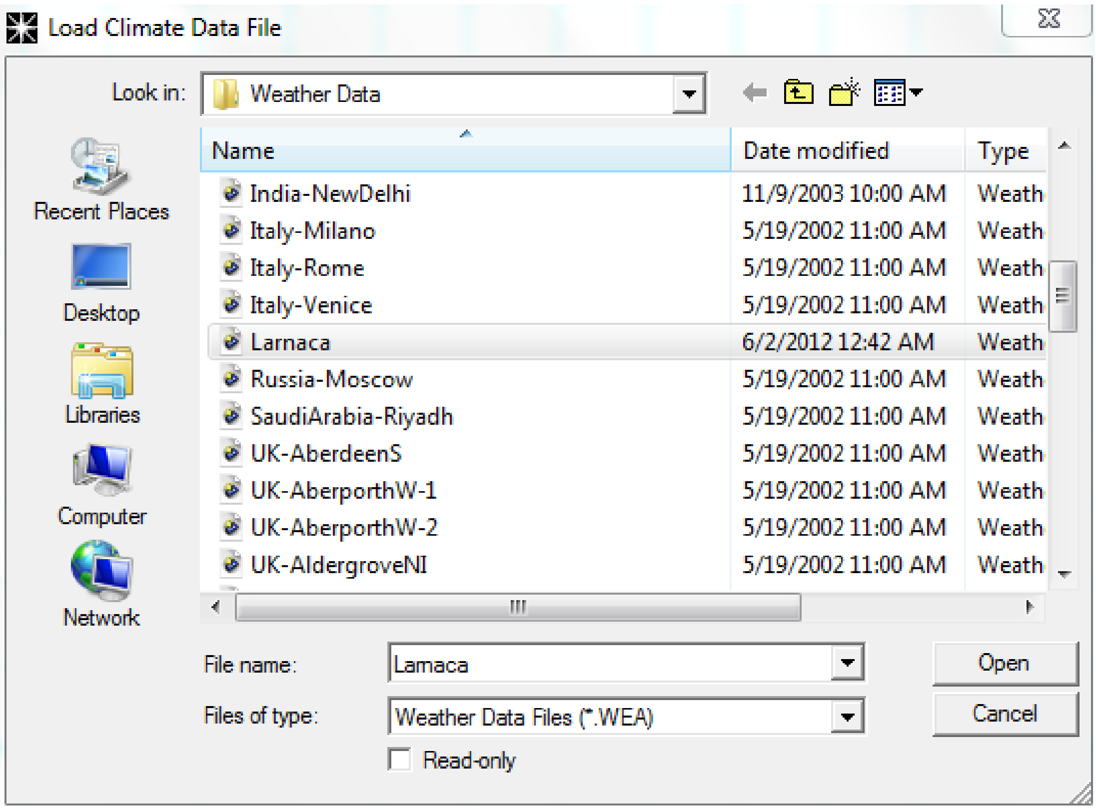


Figure 21: Climate Data window

3.3 Scenario Two

In this scenario focus was on orientation impacts besides the analyzing the role of each side wall on thermal load. As a matter of fact, the hypothesis concerned to realize the best orientation of implementing construction and the most effective side of building in energy load. To obtain these results, a 100 m^2 plan was modeled and analyzed by using Ecotect. One of the special properties of Ecotect is to provide simple tools and design space to produce a basic architectural model. In order to avoid errors induced through exporting models from Revit to Ecotect and also save the time, all architectural modeling and thermal analysis were done by Ecotect.

In order to avoid the decreasing effect of dimensional symmetry, a plan with higher relative ratio (20*5) is assumed. This assumption leads to using a much prevalent form of plan and also made it possible to attribute the measured thermal load to orientation of the longer side of the building.

For the first step in this scenario, 20m- walls were placed in north and south sides of model. After modeling, in zone management window all data for a conventional building were assigned in the same way as what were done in first scenario (Figures 18 and 19). This process was taken place again after rotating model by 90 degrees, in which 20m-walls, located in east and west sides of model. Then total thermal load of these two cases were calculated and compared to each other to find the best orientation of implementing building from the viewpoint of energy demand.

Since there are two walls in each direction and each wall has its own effects on thermal load because of their location, role of each wall was studied separately in second step. For this reason, the best material in terms of insulation with the lowest U-value (Reverse Brick Veneer) was applied to 20m-wall in north side and the worst material from viewpoint of insulation with the highest U-value (Rammed Earth) was used for the opposite side (Figures 22 and 23). For 5m-walls in east and west sides, general material (Brick Frame) were assigned. It should be mentioned that, U-value displays heat transferring capacity of building elements by measuring loss of heat. Hence, U-value with the higher amount shows the lower level of insulation, and vice versa (Brennan, 2011). After assigning material to model, zone properties were defined as it was done before in scenario one (Figures 18&19). Then analysis was performed to calculate the total thermal load (Figures 20&21).

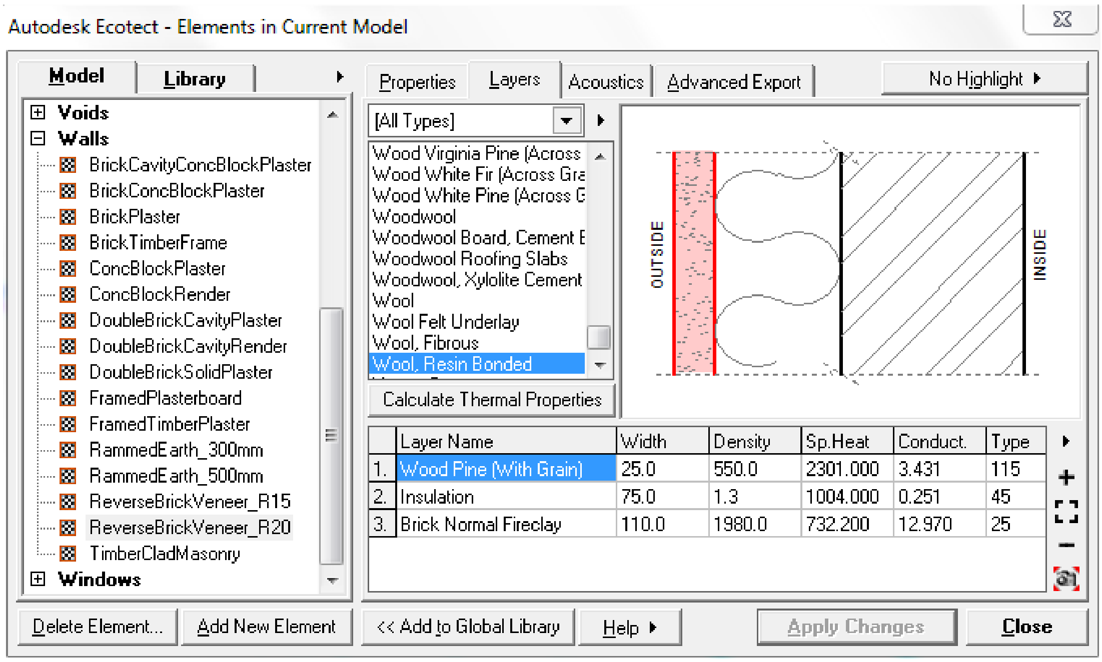


Figure 22: Reverse Brick veneer properties (wall material with lowest U-value)

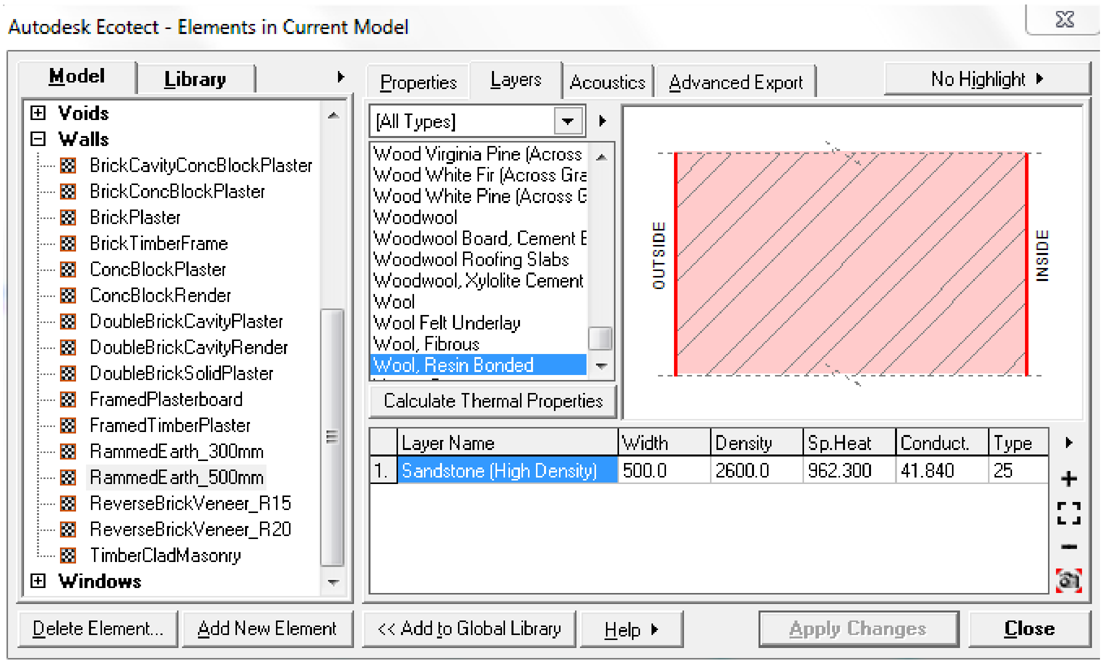


Figure 23: Rammed Earth properties (wall material with the highest U-value)

For the second case, model was rotated by 90 degrees. Therefore, 20m-wall with the best material located in east side and 20m-wall with the worst material placed in west side. Thermal load calculation method was the same as the first case. After that, same process was taken place in the third case where 20m-wall with the best material placed in south side (contrary to the first case) and the 20m-wall with the worst material located in north side because of 90 degrees rotation of second case. And finally for the last case, model was rotated again by 90 degrees. So in the last case in opposition to the second case, 20m-walls with the best and the worst material located respectively in west and east sides of model. Achieved outcomes and comparing total thermal loads of these four cases led to determine the effects of wall location on total energy requirements.

3.4 Scenario Three

It was concluded from previous scenario that implementing construction in north-south direction, which means placing the walls with the highest length in north and south sides, helps to reduce energy demand. Hence the idea of the third scenario was to find the optimum ratio of total length in north-south walls to total length in east-west walls. To do so, for the first case a $50m^2$ model with the equal length of wall in all four sides was modeled using Ecotect. After defining properties of model zone (Figures 18&19), thermal analysis was carried out to calculate the total thermal load (Figure 20&21). For the next case, length of north wall – spontaneously south wall – was increased by 10%. By considering the fixed amount of area ($50m^2$), wall length of east and west sides were measured. Model was produced and analyzed like the first case. Identical process was taken place for 9 more cases by adding 10% to length of north wall in each case (Table 1). Finding the least total load through comparing total thermal load of these 11cases determines the optimum proportion of walls length.

In order to completely fulfill and ensure the obtained results, similar procedure was adopted for models with the area of $65m^2$, $75m^2$, and $100m^2$. Tables 1- 4 show the geometric specifications of all models in each category of area, in which, X represents the wall length in north/south sides, Y indicates the wall length in east/west sides, and perimeter of models are displayed by P.

Table 1: Geometric specifications of models with 50 square meters area

Added length to the north wall (%)	X, Wall length in north/south side (m)	Y, Wall length in east/west side (m)	P, Perimeter (m)	X/Y	X/P
0%	7.071	7.071	28.284	1	0.25
10%	7.778	6.428	28.413	1.21	0.27
20%	8.485	5.893	28.756	1.44	0.3
30%	9.192	5.439	29.263	1.69	0.31
40%	9.899	5.051	29.9	1.96	0.33
50%	10.607	4.714	30.641	2.25	0.35
60%	11.314	4.419	31.466	2.56	0.36
70%	12.021	4.159	32.36	2.89	0.37
80%	12.728	3.928	33.312	3.24	0.38
90%	13.435	3.722	34.313	3.61	0.39
100%	14.142	3.536	35.355	4	0.4

Table 2: Geometric specifications of models with 65 square meters area

Added length to the north wall (%)	X, Wall length in north/south side (m)	Y, Wall length in east/west side (m)	P, Perimeter (m)	X/Y	X/P
0%	8.062	8.062	32.248	1	0.25
10%	8.868	7.33	32.396	1.21	0.27
20%	9.674	6.719	32.786	1.44	0.3
30%	10.481	6.202	33.365	1.69	0.31
40%	11.287	5.759	34.091	1.96	0.33
50%	12.093	5.375	34.936	2.25	0.35
60%	12.899	5.039	35.877	2.56	0.36
70%	13.705	4.743	36.896	2.89	0.37
80%	14.512	4.479	37.982	3.24	0.38
90%	15.318	4.243	39.122	3.61	0.39
100%	16.124	4.031	40.311	4	0.4

Table 3: Geometric specifications of models with 75 square meters area

Added length to the north wall (%)	X, Wall length in north/south side (m)	Y, Wall length in east/west side (m)	P, Perimeter (m)	X/Y	X/P
0	8.66	8.66	34.64	1	0.25
10%	9.526	7.873	34.798	1.21	0.27
20%	10.392	7.217	35.218	1.44	0.3
30%	11.258	6.662	35.84	1.69	0.31
40%	12.124	6.186	36.62	1.96	0.33
50%	12.99	5.774	37.527	2.25	0.35
60%	13.856	5.413	38.538	2.56	0.36
70%	14.722	5.094	39.633	2.89	0.37
80%	15.588	4.811	40.799	3.24	0.38
90%	16.454	4.558	42.024	3.61	0.39
100%	17.32	4.33	43.301	4	0.4

Table 4: Geometric specifications of models with 100 square meters area

Added length to the north wall (%)	X, Wall length in north/south side (m)	Y, Wall length in east/west side (m)	P, Perimeter (m)	X/Y	X/P
0%	10	10	40	1	0.25
10%	11	9.091	40.182	1.21	0.27
20%	12	8.333	40.667	1.44	0.3
30%	13	7.692	41.385	1.69	0.31
40%	14	7.143	42.286	1.96	0.33
50%	15	6.667	43.333	2.25	0.35
60%	16	6.25	44.5	2.56	0.36
70%	17	5.882	45.765	2.89	0.37
80%	18	5.556	47.111	3.24	0.38
90%	19	5.263	48.526	3.61	0.39
100%	20	5	50	4	0.4

Chapter 4

RESULTS AND DISCUSSION

4.1 Introduction

Three scenarios were designed to achieve the different type of results using Autodesk REVIT Architecture as a BIM software, and Autodesk Ecotect as energy simulation software. In the first scenario, different plan types influences in energy load variation of building was investigated by modeling 40 common plans in Cyprus (see Appendix), categorized in four various areas. Also other origins of this variation were found in this stage. In the second scenario, the best orientation of Cypriot buildings was figured out. A 100 square meters building was modeled and rotated three times by 90 degrees to survey the effect of each side wall on thermal load. And finally highly suitable ratio of North-South walls length to East-West walls length was achieved in the third scenario by modeling more than 40 buildings in four classes of area.

4.2 Scenario One: Shape Factor Influences

4.2.1 Category One: 50 Square Meters Area

Table 5: Total thermal load of different perimeters (50 square meters)

A=50 Square Meters		
Plan Types	Perimeter (m)	Total Thermal Load (kWh)
T1.Square	28.56	34436.8
T2.Detached A	31.80	34832.8
T3.Detached B	32.30	35021.4
T4.Detached C	32.31	34541.7
T5.Detached D	32.56	35037.1
T6.Detached E	32.80	34843.4
T7.Detached F	32.80	35082.5
T8.Detached G	35.30	35406.4

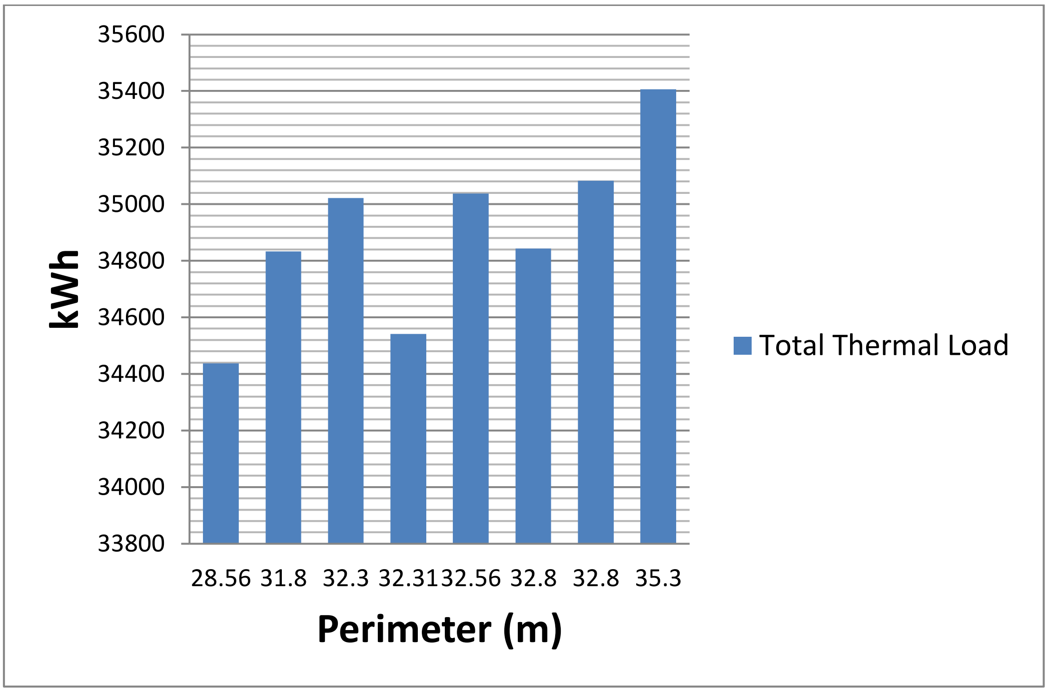


Figure 24: Load variations due to different plan types and perimeters (50 square meters)

In this phase, eight types of conventional building plans in Cyprus that one of them was a square shape building (Appendix, Part A), were modeled and analyzed. Results of these analyses which have been shown in Table 5 and Figure 24 explain that, by keeping the building area fixed but changing in plan shape and perimeter, total thermal load has been altered. At the first, it was supposed to have a steady growth in total thermal load by increasing in perimeter, but outcomes of the Type 4 and Type 6 refuted it. Since all parameters were considered fixed except for building shape and orientation, it can be stated that influences of these two factors have led to deviation from steady growth in total thermal loads.

According to Table 5 and Figure 24, Type 1 (Figure 25) which is a square shape, is known as the best case in terms of energy consuption, and Type 8 (Figure 26) is the worst case. The difference in total thermal load of these two models is about 3%.

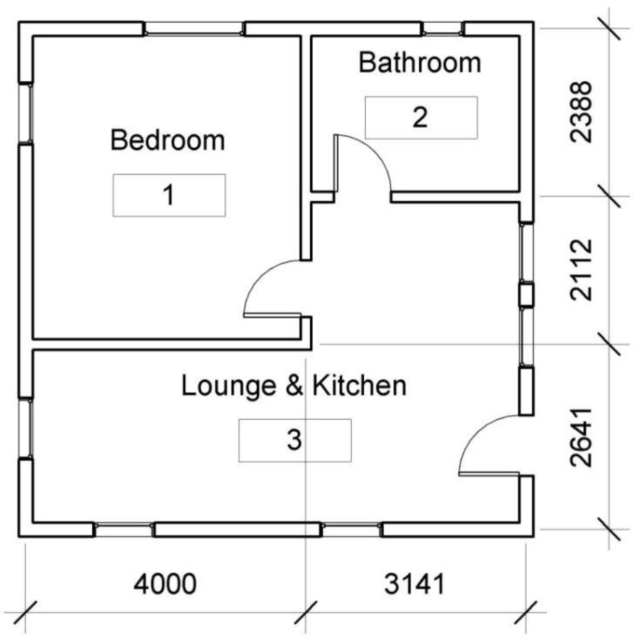


Figure 25: Type 1 the best case (50 square meters)

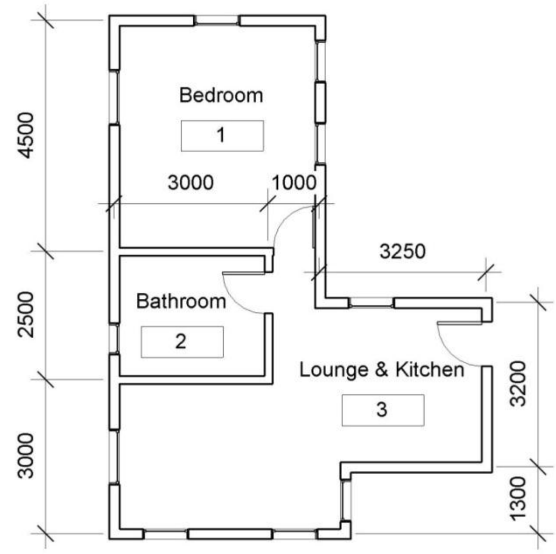


Figure 26: Type 8 the worst case (50 square meters)

4.2.2 Category Two: 65 Square Meters Area

Table 6: Total thermal load of different perimeters (65 square meters)

A= 65 Square Meters		
Plan Types	Perimeter (m)	Total Thermal Load (kWh)
T1.Square	32.25	43686.4
T2.Detached A	35.10	42792.5
T3.Detached B	35.80	43421.2
T4.Detached C	36.80	44238.8
T5.Detached D	36.80	44376.7
T6.Detached E	37.22	44838.6
T7.Detached F	38.80	44628.2
T8.Detached G	39.38	43797.5

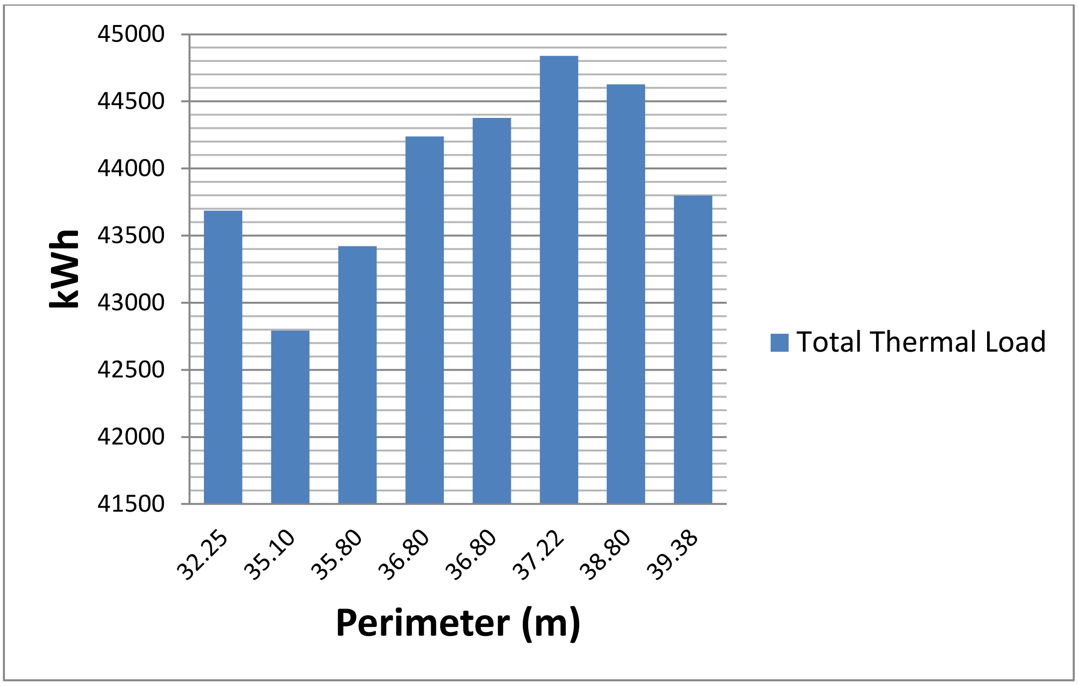


Figure 27: Load variations due to different plan types and different perimeters (65 square meters)

Corresponding to category one, eight different plans with one bedroom were designed and studied (Appendix, Part B). Based on analyses, squared plan – Type one – was not the greatest one in view point of energy consumption (Table 6). It means, although building perimeter is a significant point in energy requirements, it is not the only one. As Figure 27 shows, there is a growth in energy load by increasing in building perimeter from Type 2 to Type 6, but Types one, seven and eight have the dissimilar behavior to other ones. These results corroborate the noticeable effects of building shape and orientation on energy consumption.

Since increase or decrease in energy demand of a building is directly affected by received solar energy, shape as an effective factor in receiving solar radiation is a significant cause for the total thermal load fluctuations. Moreover, the amount of solar energy that directly is received by a building greatly depends on the building location with respect to the sun’s position.

In this category, Type 2 with 42792 kWh total thermal loads (Figure 28) and Type 6 with 44838 kWh total thermal loads (Figure 29) are respectively the best and the worst cases with 4.5% difference in total load.

Figure 28: Type 2 the best case (65 square meters)

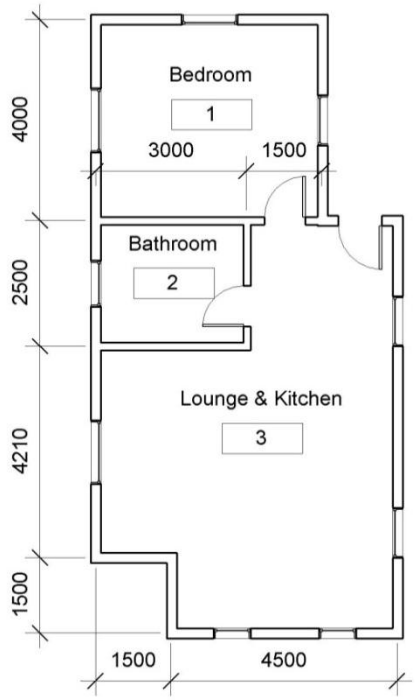


Figure 29: Type 6 the worst case (65 square meters)

4.2.3 Category Three: 75 Square Meters Area

Table 7: Total thermal load of different perimeters (75 square meters)

A= 75 Square Meters		
Plan Types	Total Thermal Load (kWh)	Perimeter (m)
T1.Square	49288.7	34.64
T2.Detached A	49985.3	36.74
T3.Detached B	49863.1	37.10
T4.Detached C	49919.8	37.95
T5.Detached D	48937.9	38.10
T6.Detached E	49719.2	38.44
T7.Detached F	49470.1	38.67
T8.Detached G	50022.1	39.23
T9.Detached H	50195.8	39.90
T10.Detached I	50233.8	40.80
T11.Detached J	50549.7	42.61
T12.Detached K	51131.6	43.70

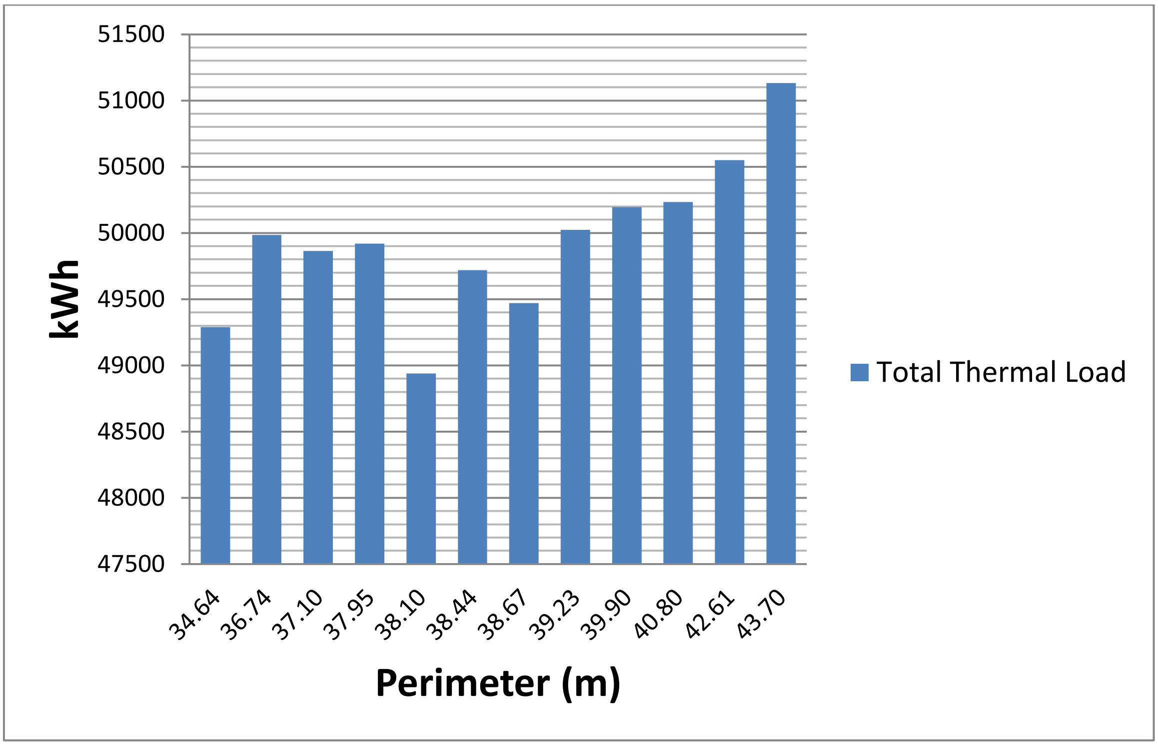


Figure 30: Load variations due to different plan types and different perimeters (75 square meters)

Table 7 and Figure 30 illustrate thermal consumption of 12 types of Cypriot conventional building with two bedrooms (Appendix, Part C). Outcomes demonstrate approximately the same results as two last categories. Since there is an incremental thermal load from Type 7 to Type 12 by increasing perimeter, so total length of the exterior walls have a significant impact on thermal load. Furthermore, the highest energy consumption belongs to Type 12 (Figure 32), which has the maximum perimeter in this category. However according to the total thermal load fluctuations in other dwelling types, perimeter influences are considerable as well as building orientation and shape factor. Total thermal load variation between the best case – Type 5 (Figure 31) – and the worst case – Type 12 (Figure 32) – is about 4.5%.

Figure 31: Type 5 the best case (75 square meters)

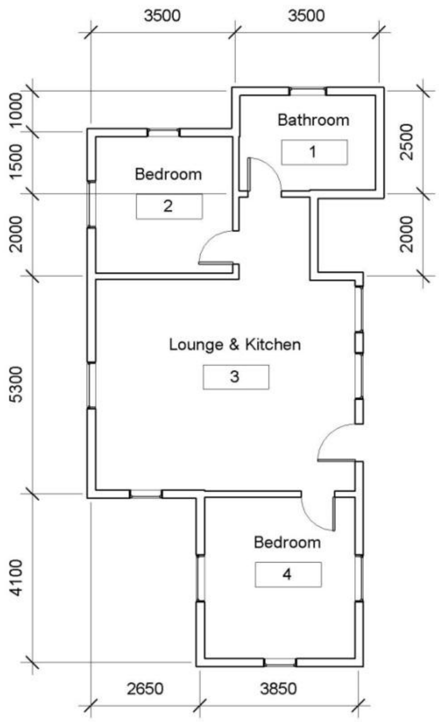


Figure 32: Type 12 the worst case (75 square meters)

4.2.4 Category Four: 100 Square Meters Area

Table 8: Total thermal load of different perimeters (100 square meters)

A= 100 Square Meters		
Plan Types	Total Thermal Load (kWh)	Perimeter(m)
T1.Square	65419.5	40.00
T2.Detached A	66055.5	41.54
T3.Detached B	65830.3	41.68
T4.Detached C	65457.9	42.58
T5.Detached D	64654.4	43.42
T6.Detached E	64496.4	43.70
T7.Detached F	66030.2	44.30
T8.Detached G	65393.5	44.62
T9.Detached H	66566.6	44.72
T10.Detached I	65503.3	45.07
T11.Detached J	67366.1	46.35
T12.Detached K	66707.1	46.76

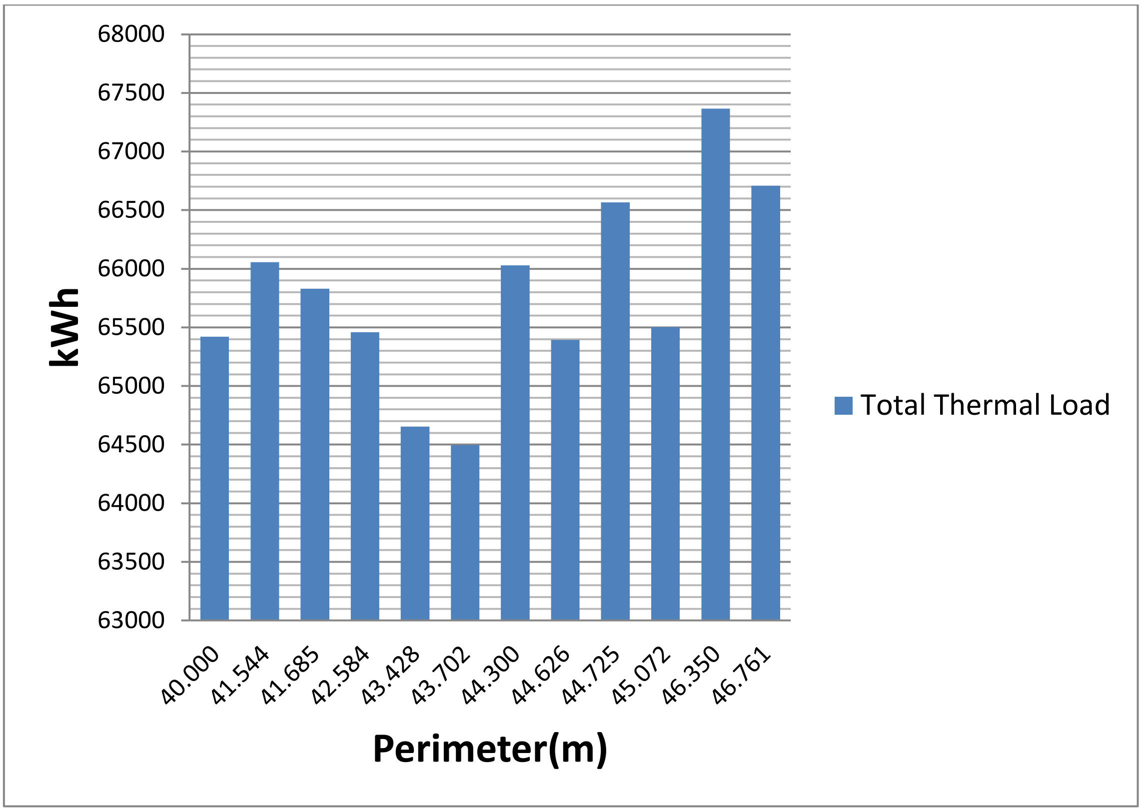


Figure 33: Load variations due to different plan types and different perimeters (100 square meters)

In this step, 12 dwelling types were modeled to emphasize on the effects of building shape on energy consumption of conventional buildings in Cyprus (Appendix, Part D). For instance, there is 2% (1173.132 kWh) difference between type 8 and type 9 while, they had just a variation of 0.099m – less than 10 centimeters – in perimeter.

Based on Table 8 and Figure 33, difference in energy consumption between the best case – Type 6 (Figure 34) – and the worst case – Type 11 (Figure 35) – is about 4.5%.

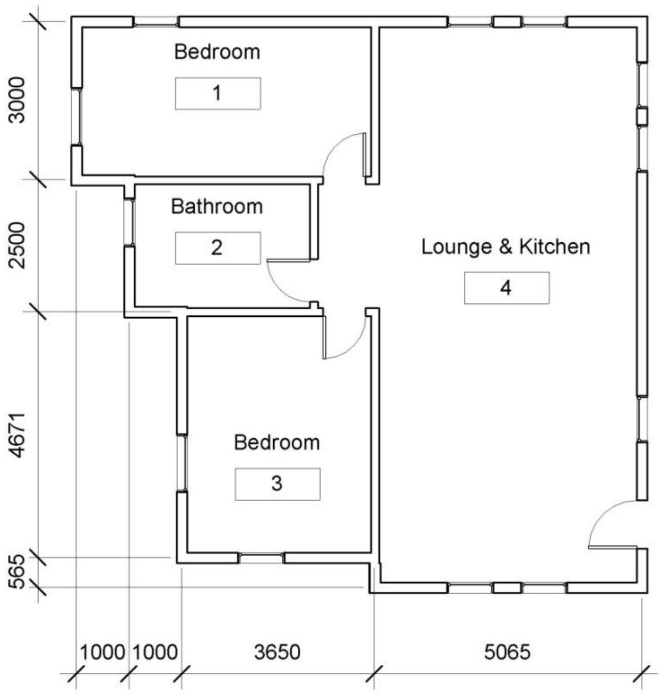


Figure 34: Type 6 the best case (100 square meters)

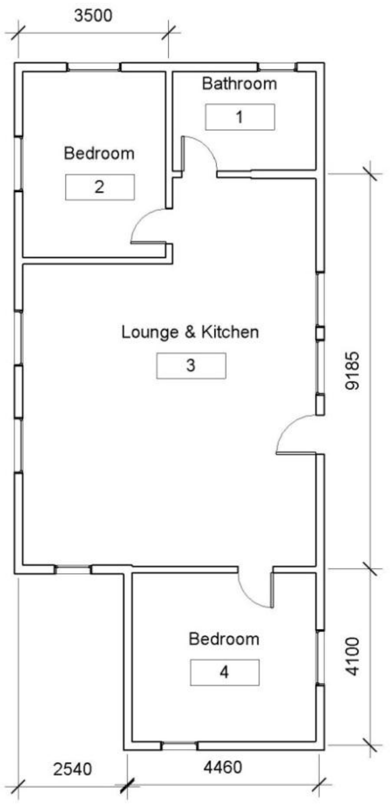


Figure 35: Type 11 the worst case (100 square meters)

Obtained results from scenario one, which had been categorized into four groups according to dwelling area, demonstrated the impacts of two critical factors – total length of exterior walls and shape of the construction – on total thermal load. Outcomes also indicate, there are other effective parameters like building orientation and area of walls exposed to the outside, which should be considered for the investigation. In the next scenarios, these two factors were studied.

4.3 Scenario Two: Dwelling Orientation Impacts

In this part, a 100 Square Meters – 20m by 5m – building has been modeled and analyzed by using Autodesk Ecotect.

Scenario two contained two steps. In the first step, two directions were compared to each other; one with 20m-walls in north and south sides, the second one with 20m-walls in east and west sides of dwelling. Achieved outcomes (Figure 36) led to find the proper direction of implementing construction in Cyprus, considering thermal load. In the second step, the best and the worst wall materials in terms of insulation – available in Ecotect – were assigned to respectively, north and south walls with 20m length. Afterwards, building was rotated by 90 degrees, three times, to find the most effective sides of the building in thermal load demand. Table 9 and Figure 37 show the results of step two.

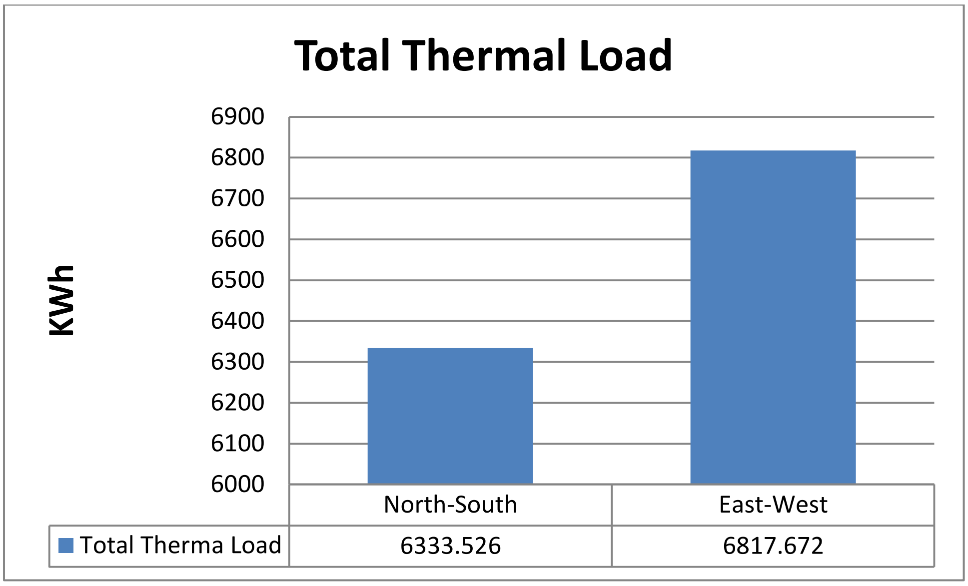


Figure 36: Comparing two directions of implementing construction

According to Figure 36, constructing building in North-South direction aids to save the energy and reduce the total thermal load by 7% compared to East- west direction. In fact results indicate that, walls with more length should be located on the north and south sides of building.

Table 9: Total thermal load of different orientations

Orientation Impacts	
Rotated by (Degree)	Total Thermal Load (kWh)
0	3234.1
90	3318.3
180	3257.2
270	3407.2

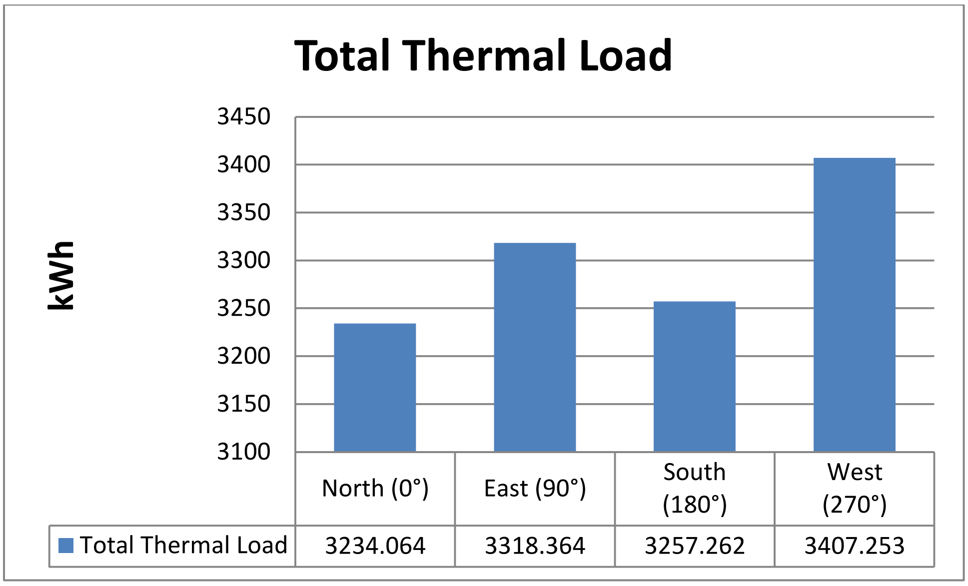


Figure 37: Load variations due to different orientations

Model rotation and changes which occurred because of this rotation in place of wall with the best material and wall with the worst material demonstrated that, the first case, which were modeled with the best material in the north side and the worst material in the south side, had the least energy consumption. In comparison with the worst case – the fourth model with 270 degrees rotation – which the best material were located in the west and the worst material were placed in the east side; there is a 7% difference in total thermal load between these two cases.

According to Figure 37 and Table 9, walls were analyzed separately to find out the impact of each wall on thermal load demand. Results explain that, wall with the highest length should be placed on the north side then respectively on the south, east and finally the shortest length should be located in west side of building. Although achieving this purpose is not feasible, it can be deduced from results that total length of north-south walls should be more than total length of east-west walls to attain the minor total load.

4.4 Scenario Three: Determining the Best Ratio of North-South Walls Length to East-West Walls Length

In the previous scenario, the best direction of implementing a construction was determined, also it was concluded that to obtain the minor thermal load, total length of north-south walls should be more than total length of east-west walls. But the main question is; what is the optimum length of building walls to reach the minimum energy consumption? In this scenario, this question would be answered.

In this stage, a 50 square meters house with equal length of walls in 4 sides were modeled. In each step length of north wall was increased by 10% (as the model is a rectangle, length of south wall expands naturally). By dividing the area ($50m^2$) by this amount, length of walls in other sides was determined. This procedure was taken place nine more times by adding 10% to the north wall length in each step. Thermal load was calculated by Ecotect in every step to find the best proportion (Table 10 and Figure 38). In tables below, X indicates the wall length in north/south side and Y signifies the wall length in east/west side, also perimeter has been shown by P.

Table 10: Measured outcomes under impact of different wall lengths (50 square meters)

Added length to the north wall (%)	Total Thermal Load (kWh)	X, Wall length in north/south side (m)	Y, Wall length in east/west side (m)	P, Perimeter (m)	X/Y	X/P
0%	3591.0	7.071	7.071	28.28	1.00	0.25
10%	3585.5	7.778	6.428	28.41	1.21	0.27
20%	3601.7	8.485	5.893	28.75	1.44	0.30
30%	3637.2	9.192	5.439	29.26	1.69	0.31
40%	3677.7	9.899	5.051	29.90	1.96	0.33
50%	3728.6	10.607	4.714	30.64	2.25	0.35
60%	3797.3	11.314	4.419	31.46	2.56	0.36
70%	3871.1	12.021	4.159	32.36	2.89	0.37
80%	3942.3	12.728	3.928	33.31	3.24	0.38
90%	4029.7	13.435	3.722	34.31	3.61	0.39
100%	4112.0	14.142	3.536	35.35	4.00	0.40

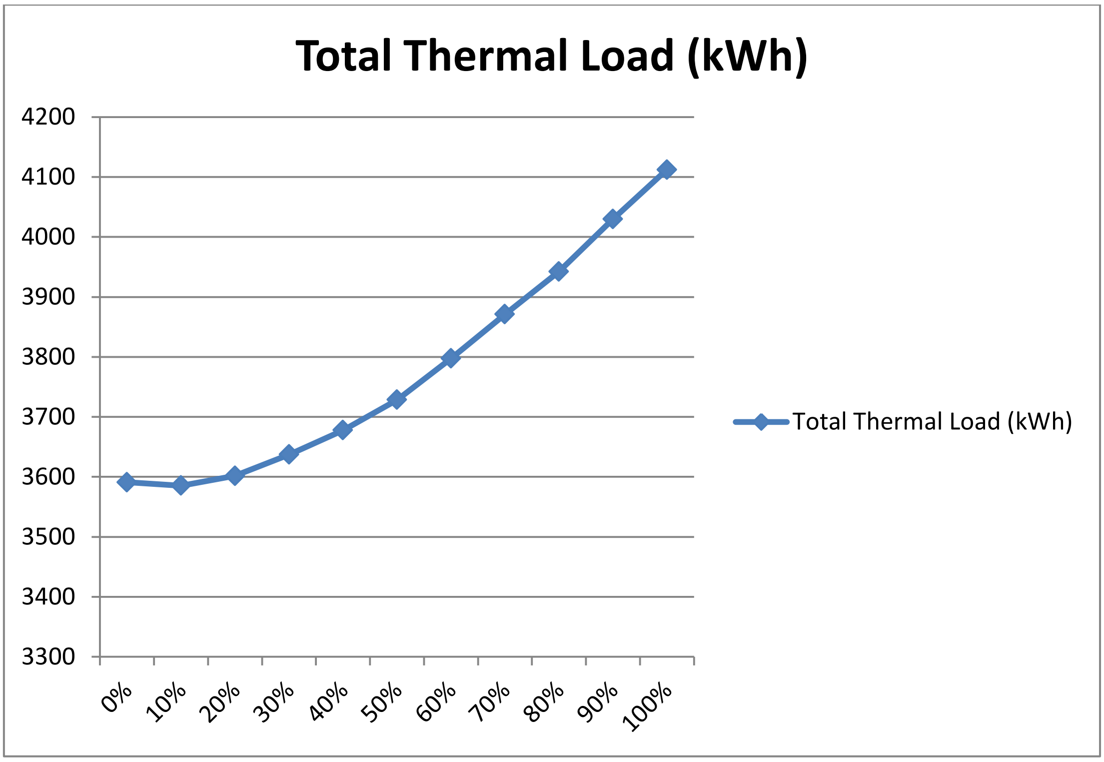


Figure 38: Total thermal load variations by making change in walls length (50 square meters)

Based on Table 10 and Figure 38, the least energy consumption is achieved when the ratio of wall length in north (or south) to wall length in east (or west) is 1.21, i.e. wall area in north/south side should be 1.21 times more than wall area in east/west side. In other words, the best ratio of total walls length in north and south sides to perimeter is equal to 2*0.27= 0.54. As a result, about 55% of total building walls should be facing north-south and 45% of them should be exposed to east and west sides to reach the minimum thermal load. Steady growth in the total load after this point could be as a consequence of increasing in perimeter.

According to Figure 38, in the second case where lengths of north and south walls have been increased by 10%, there is a decrease in total thermal loads. Due to this decline it can be derived that, although the total area of the exterior surface has been enhanced compared to the first case, placing the longest walls in appropriate sides of building – north and south – reduced the energy consumption.

After the minimum point, there is a steady growth in thermal load parallel to increase in perimeter. This steady rise of thermal load represents the effective role of perimeter, and also it can confirm that to minimize the energy losses, ratio of external surface area to the total construction volume should be as small as possible (R. Pacheco, 2012).

For confirming and completing the produced outcomes, the same process was utilized for houses with area of 65m^2, 75m^2 and 100m^2. As it is evident in tables 11-13 and Figures 39-41, results in all models are remarkably similar.

Table 11: Measured outcomes under impact of different wall lengths (65 square meters)

Added length to the north wall (%)	Total Thermal Load (kWh)	X, Wall length in north/south side (m)	Y, Wall length in east/west side (m)	P, Perimeter (m)	X/Y	X/P
0%	4264.2	8.062	8.062	32.24	1.00	0.25
10%	4242.6	8.868	7.330	32.39	1.21	0.27
20%	4258.1	9.674	6.719	32.78	1.44	0.30
30%	4290.6	10.481	6.202	33.36	1.69	0.31
40%	4340.1	11.287	5.759	34.09	1.96	0.33
50%	4400.6	12.093	5.375	34.93	2.25	0.35
60%	4470.7	12.899	5.039	35.87	2.56	0.36
70%	4546.1	13.705	4.743	36.89	2.89	0.37
80%	4642.5	14.512	4.479	37.98	3.24	0.38
90%	4726.7	15.318	4.243	39.12	3.61	0.39
100%	4826.4	16.124	4.031	40.31	4.00	0.40

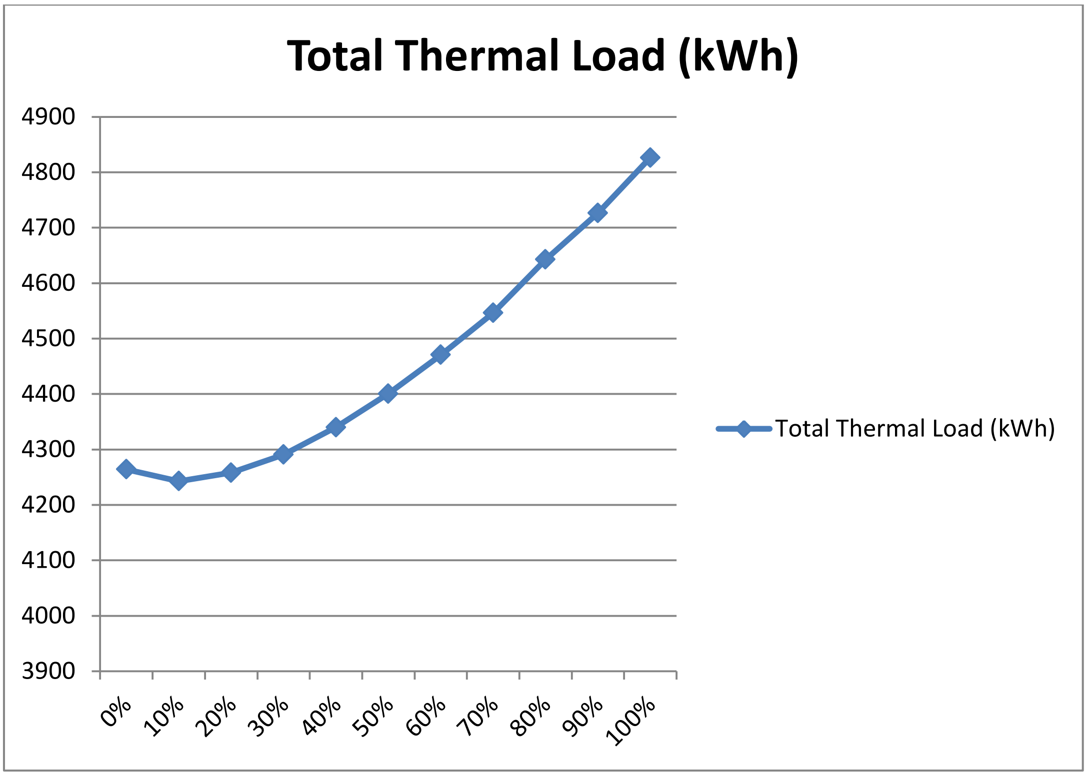


Figure 39: Total thermal load variations by making change in walls length (65 square meters)

Table 12: Measured outcomes under impact of different wall lengths (75 square meters)

Added length to the north wall (%)	Total Thermal Load (kWh)	X, Wall length in north/south side (m)	Y, Wall length in east/west side (m)	P, Perimeter (m)	X/Y	X/P
0	4681.5	8.660	8.660	34.64	1.00	0.25
10%	4662.7	9.526	7.873	34.79	1.21	0.27
20%	4673.5	10.392	7.217	35.21	1.44	0.30
30%	4710.5	11.258	6.662	35.84	1.69	0.31
40%	4762.1	12.124	6.186	36.62	1.96	0.33
50%	4824.1	12.990	5.774	37.52	2.25	0.35
60%	4899.1	13.856	5.413	38.53	2.56	0.36
70%	4984.8	14.722	5.094	39.63	2.89	0.37
80%	5067.8	15.588	4.811	40.79	3.24	0.38
90%	5173.1	16.454	4.558	42.02	3.61	0.39
100%	5277.7	17.320	4.330	43.30	4.00	0.40

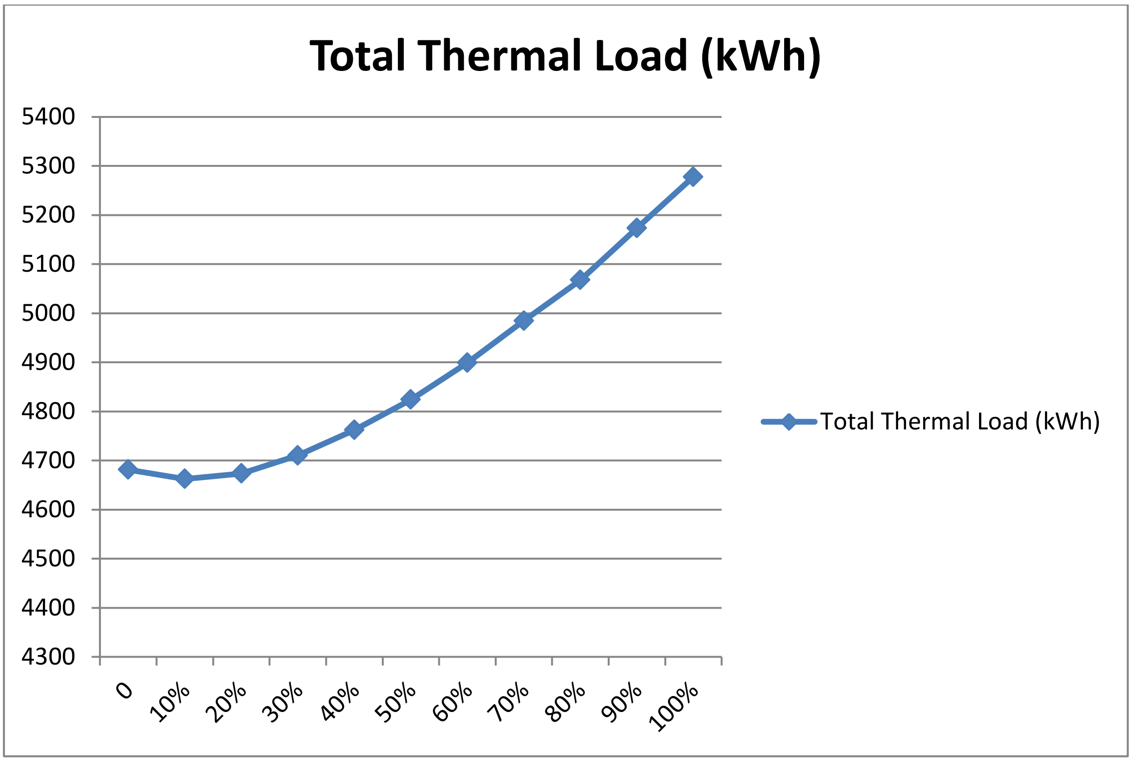


Figure 40: Total thermal load variations by making change in walls length (75 square meters)

Table 13: Measured outcomes under impact of different wall lengths (100 square meters)

Added length to the north wall (%)	Total Thermal Load (kWh)	X, Wall length in north/south side (m)	Y, Wall length in east/west side (m)	P, Perimeter (m)	X/Y	X/P
0%	5664.2	10.000	10.000	40.00	1.00	0.25
10%	5648.9	11.000	9.091	40.18	1.21	0.27
20%	5666.5	12.000	8.333	40.66	1.44	0.30
30%	5703.7	13.000	7.692	41.38	1.69	0.31
40%	5748.2	14.000	7.143	42.28	1.96	0.33
50%	5827.5	15.000	6.667	43.33	2.25	0.35
60%	5911.5	16.000	6.250	44.50	2.56	0.36
70%	6009.3	17.000	5.882	45.76	2.89	0.37
80%	6102.7	18.000	5.556	47.11	3.24	0.38
90%	6219.1	19.000	5.263	48.52	3.61	0.39
100%	6337.1	20.000	5.000	50.00	4.00	0.40

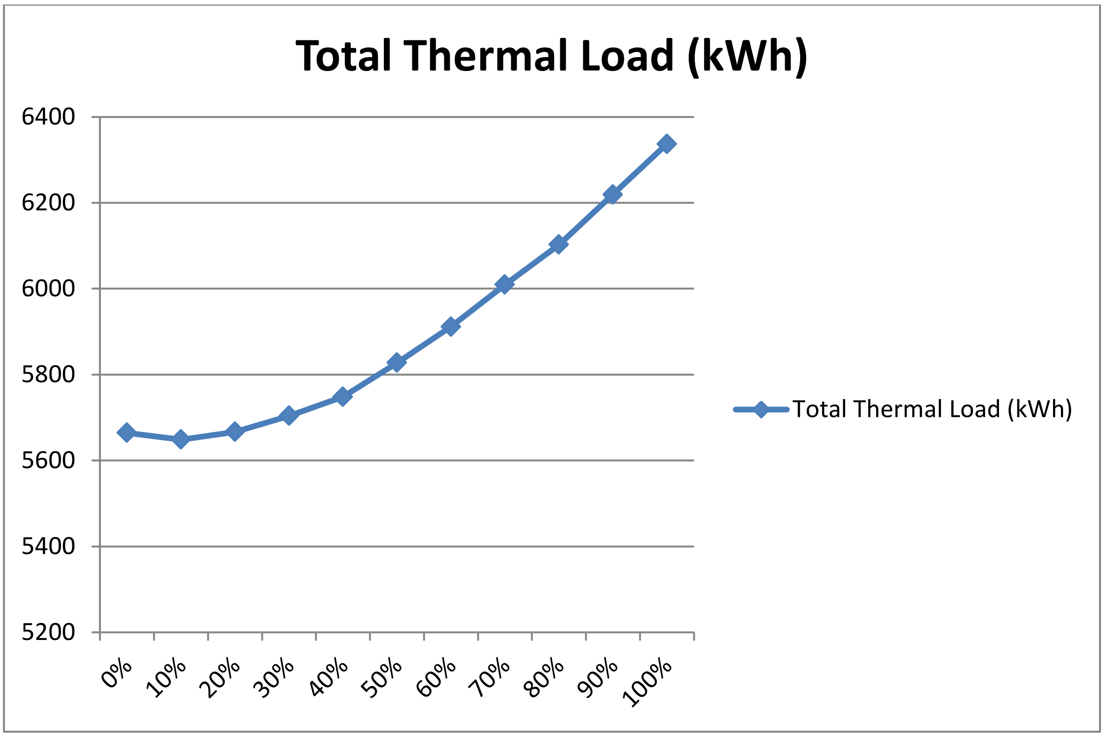


Figure 41: Total thermal load variations by making change in walls length (100 square meters)

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This research aimed at investigating building shape and orientation influences on total energy requirements through integrating BIM tools with energy modeling engine. Main conclusions of this survey can be listed as below:

1. A concurrent approach is necessary to enhance the efficiency and effectiveness of decision making process in early design phase when there are lots of alternatives to choose. Integration between BIM and energy analysis could contribute to address such an issue.
2. According to obtained results, shape factor and orientation can effect on thermal load up to respectively 5 and 7 percent in buildings with the same amount of area.
3. Achieved results are highly considerable because it has not been defrayed extra expense to apply particular material or method in order to save the energy. This amount of energy-saving can be reached just by optimizing the shape and orientation of building in early stage of design. Therefore, it could be stated that, shape factor and orientation are the most effective parameters at the very beginning of the design phase.
4. Besides investigating shape factor and building orientation, two other critical parameters were found and analyzed. According to study on perimeter and walls location it was concluded that wall length in north side

should be the maximum and length of wall in west side should be the minimum amount (although it is not feasible in practice). Also it was measured that, the ratio of wall length in north (or south) to length of wall in west (or east) side should equal to 1.2 to minimize the energy consumption. In fact, 55% of total walls should be placed in north-south direction and 45% of them should be located in east-west direction.

5. As construction designer are not expert in energy analysis and modeling, thus to achieve the accurate outcomes, user-friendliness of software and interoperability between them are two essential factors. Due to this fact, Revit Architecture and Ecotect are in appropriate level of interoperability and user-friendliness.

5.2 Recommendations

The main objective of this research was to explore the impacts of two significant design parameters – building orientation and shape factor – on energy consumption through integration of Building Information Modeling (BIM) and Energy Simulation Software (ESS). Since other parameters were considered fixed, investigation into the effects of other design factors such as distance between dwellings and surface transparency for the future study is recommended.

REFERENCES

A.S Elasfouri, R. M. (1991). Shading Control by Neighbouring Buildings: Application to Buildings in Amman, Jordan. *International Journal of Refrigeration*, 112-116.

Autodesk. (2009). *Autodesk Ecotect Analysis 2010 Questions and Answers.* San Rafael: Autodesk, Inc.

Autodesk. (2010). *Autodesk Ecotect Analysis: Visualize Sustainable Design.* San Rafael: Autodesk, Inc.

Autodesk, I. (2009). *Learning Autodesk Revit Structure 2010.* San Rafael: Autodesk, Inc.

Azhar, S. H. (2008). Building Information Modeling: Benefits, Risks And Challenges. *44th Asc National Conference.* Auburn: Auburn University.

Bazjanac, V. (2008). *IFC BIM-Based Methodology for Semi-Automated Building Energy Performance Simulatio.* Berkeley: Lawrence Berkeley National Laboratory.

Bennett, T. (2009). *BIM and Laser Scanning for As-built and Adaptive Reuse Projects: The Opportunity for Surveyors.* Cheves media.

Betul Bektas Ekici, U. T. (2011). Prediction of Building Energy Needs in Early Stage of Design by Using ANFIS. *Expert Systems with Applications*, 5352-5358.

Bradley A. Hyatt, P. (2011). A Case Study in Integrating Lean, Green, BIM into an Undergraduate Construction Management Scheduling Course . *47th ASC Annual International Conference.* Fresno : Associated Schools of Construction.

Brennan, J. (2011). *U-Values*. Retrieved from Sustainability Hub: http://www.architecture.com

Chuck Eastman, P. T. (2011). *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, Contractors, and Fabricators.* New Jersey: John Wiley & Sons.

Chung-Suk Cho, D. C. (2011). Buildin Information Modeling (BIM)-Based Design of Energy Efficient Building. *International Symposium on Automation and Robotics in Construction (ISARC)* (pp. 1079-1084). Seoul: International Association for Automation and Robotics in Construction (IAA RC).

Cumpton, L. (2010, April 7). *Revitology: The Evolution of Revit over AutoCAD.* Retrieved from Architectural Evangelist: http://www.architecturalevangelist.com

Farah, T. (2005). *Review of Current Estimating Capabilities of the 3D Building Information Model Software to Support Design for Production/Construction.* Worcester : Worcester Polytechnic .

Feng, Y. (2004). Thermal design standards for energy efficiency of residential buildings in hot summer/cold winter zones. *Energy and Buildings*, 1309-1312.

G.A Florides, S. T. (2002). Measures Used to Lower Building Energy Consumption and Their Cost Effectiveness. *Applied Energy*, 299-328.

Gupta R, R. R. (2004). Estimation of Beam Radiation for Optimal Orientation and Shape Decision of Buildings in India. *Architectural Journal of Institution of Engineers*, 27-32.

Haksar, R. (2010). *An Investigation Into a Visual Framework and Workflow Integrating Building Information Modeling and Energy Simulation Software in the Early Design Stage.* Philadelphia: Pennsylvania State University.

Hyeun Jun Moon, M. S. (2011). Case Studies for the Evaluation of Interoperability Between a BIM Based Architectural Model and Building Performance Analysis Programs. *12th Conference of International Building Performance Simulation Association* (pp. 1521-1526). Sydney: Building Simulation 2011.

Hyeun Jun Moon, M. S. (2011). Case Studies for the Evaluation of Interoperability Between a BIM Based Architectural Model and Building Performance

Analysis Programs. *12th Conference of International Building Performance Simulation Association* (pp. 1521-1526). Sydney: Building Simulation 2011.

Ian Howell, B. B. (2005). *Building Information Modeling Two Years Later - Huge Potential, Some Success and Several Limitations.* Manchester: The Laiserin Letter.

Innovation, C. C. (2007). *Adopting BIM for Facilities Management: Solutions for Managing the Sydney Opera House.* Brisbane: Cooperative Research Center for Construction Innovation.

J. Morrissey, T. M. (2011). Affordable Passive Solar Design in a Temperate Climate: An Experiment in Residential Building Orientation. *Renewable Energy*, 568-577.

Khee Poh Lam, Y. C. (2004). *Energy Modeling Tools Assessment For Early Design Phase* . Pittsburgh: Center for Building Performance and Diagnostics School of Architecture Carnegie Mellon University .

Kumar, S. (2008). *Interoperability Between Building Information Models (BIM) and Energy Analysis Programs.* Los Angeles: UNIVERSITY OF SOUTHERN CALIFORNIA.

Lincoln H. Forbes, S. M. (2011). *Modern Construction: Lean Project Delivery and Integrated Practices.* Boca Raton: Taylor and Francis Group.

Mingfang. (2002). Solar control for buildings. *Building and Environment*, 659-664.

Omer, A. M. (2008). Energy, environment and sustainabledevelopment. *Renewable and Sustainable Energy Reviews*, 2265-2300.

R. Pacheco, J. O. (2012). Energy Efficient Design of Building: A Review. *Renewable and Sustainable Energy Reviews*, 3559-3575.

Rick Rundell, A. (2006). *1-2-3 Revit: BIM and Cost Estimating, Part 2.* Longitude Media.

Sacks, R. E. (2004). Parametric 3D Modeling in Building Construction with Examples from Precast Concrete. *Automation in Construction*, 291-312.

schema, T. G. (2012, October 8). *Open Green Building XML Schema: a Building Information Modeling solution for Our Green World*. Retrieved from http://www.gbxml.org/

Seongchan Kim, J.-H. W. (2011). Analysis of the Differences in Energy Simulation Result Between Building Information Modeling (BIM)-Based Simulation Method and the Detailed Simulation Method. *Winter Simulation Conference* (pp. 3545-3556). Phoenix: IEEE.

Smith, D. (2007). AIA: An Introduction To Building Information Modeling (Bim). *Journal Of Building Information Modeling*.

Soebarto, V. I. (2001). Multi-criteria Assessment of Building Performance: Theory and Implementation. *Building and Environment*, 681-690.

Tobias Maile, M. F. (2007). *Building energy performance simulation tools – a life-cycle and interoperable perspective* . Stanford: CIFE (Center for Integrated Facility Engineering) at Stanford University .

U. Teoman Aksoy, M. I. (2006). Impacts of Some Building Passive Design Parameters on Heating Demand for a Cold Region. *Building and Environment*, 1742-1754.

Weimin Wang, H. R. (2006). Floor shape optimization for green building design. *Advanced Engineering Informatics*, 363-378.

Wong, N. H. (2000). The use of performance-based simulation tools for building design and evaluation-a Singapore perspective. *Building and Environment*, 709-736.

Young, N. J. (2009). *The Business Value of BIM: Getting Building Information Modeling to the Bottom Line.*

Yudelson, J. (2010). *Greening Existing Buildings.* New York: Green Source/McGraw-Hill.

Illuminance - Recommended Light Levels. (2012, October). Retrieved from The Engineering ToolBox: http://www.engineeringtoolbox.com

Open Green Building XML Schema: a Building Information Modeling solution for Our Green World. (2012, October 8). Retrieved from http://www.gbxml.org/

APPENDIX

Part A: Plans with the area of 50m^2

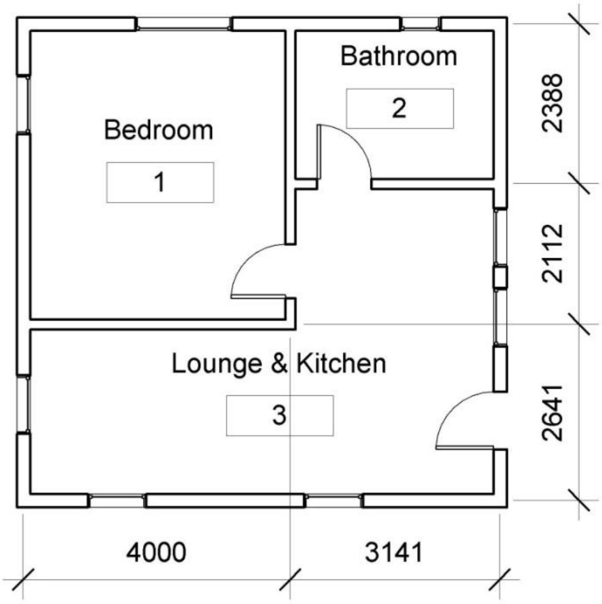


Figure 42: Type 1, Square Model

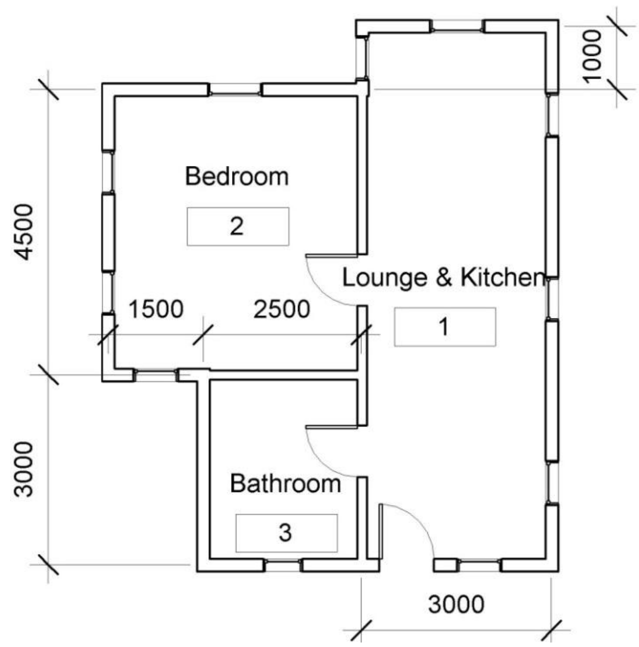


Figure 43: Type 2, Detached A

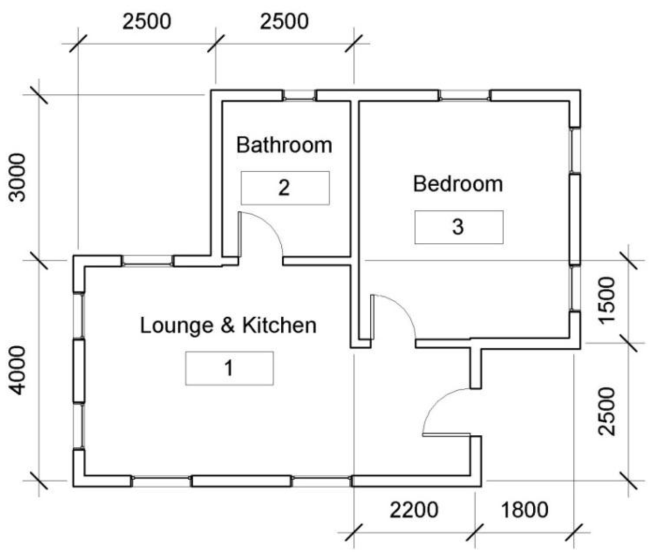


Figure 44: Type 3, Detached B

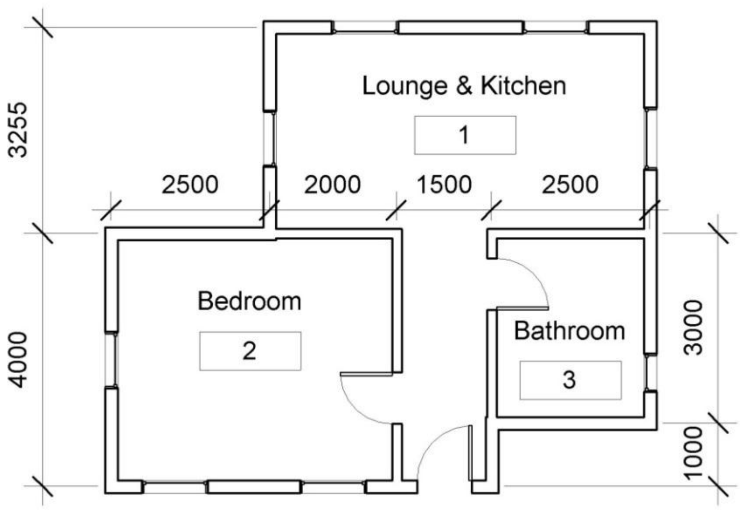


Figure 45: Type 4, Detached C

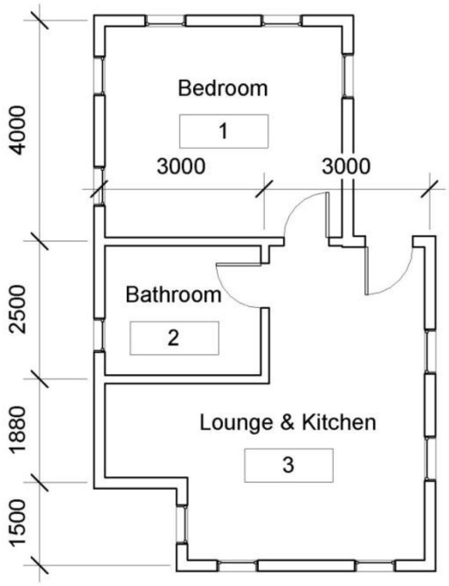


Figure 46: Type 5, Detached D

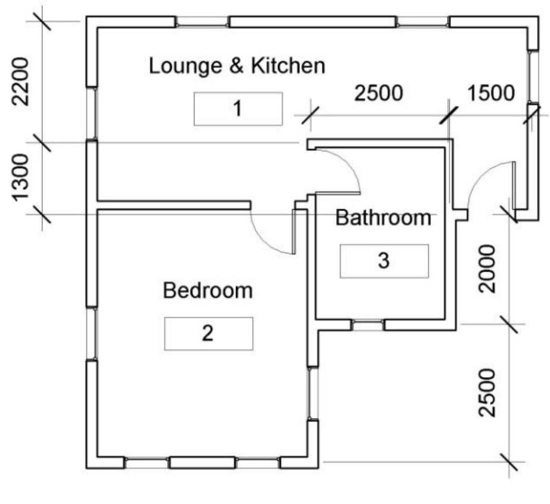


Figure 47: Type 6, Detached E

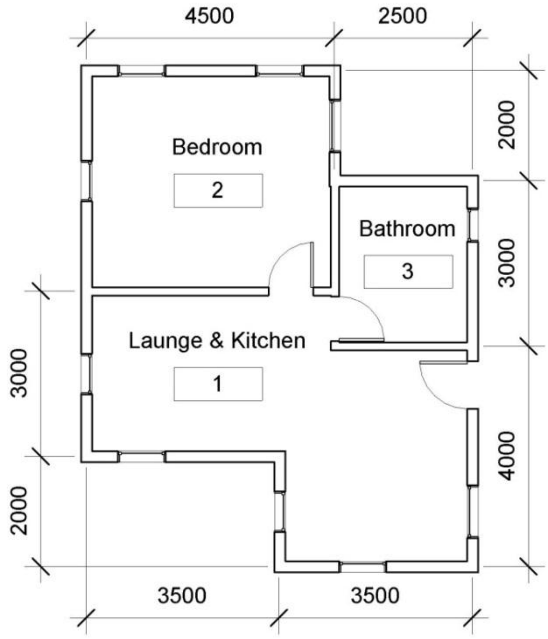


Figure 48: Type 7, Detached F

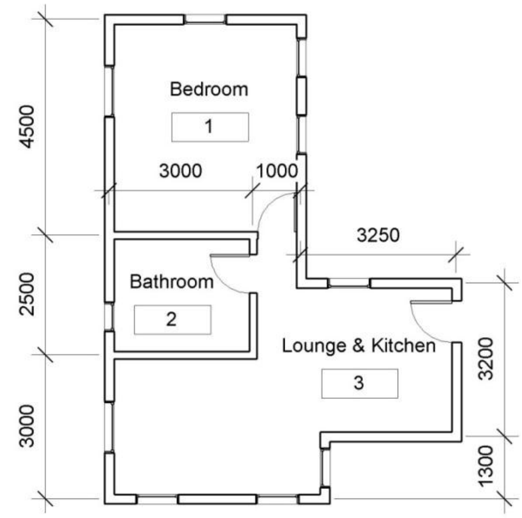


Figure 49: Type 8, Detached G

Part B: Plans with the area of 65m^2

Figure 50: Type 1, Square Model

Figure 51: Type 2, Detached A

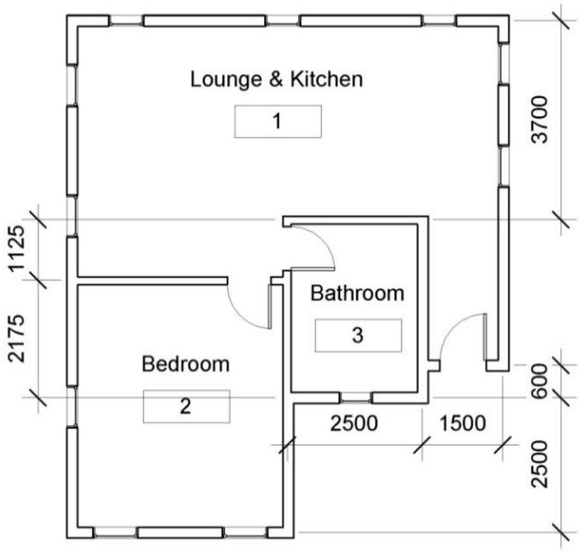


Figure 52: Type 3, Detached B

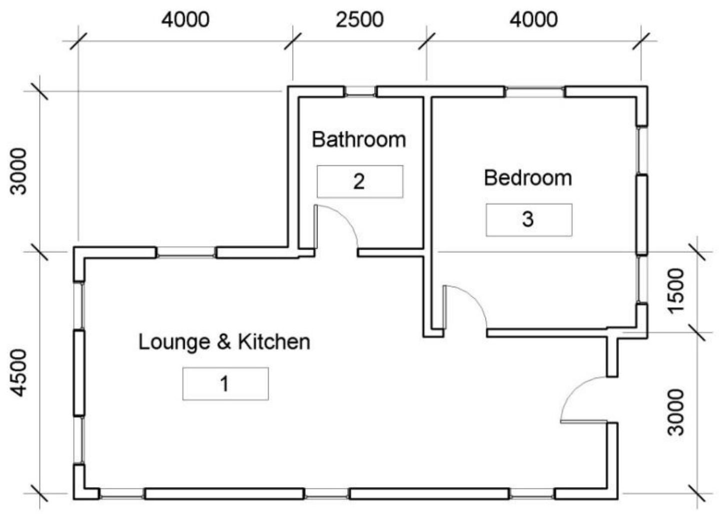


Figure 53:Type 4, Detached C

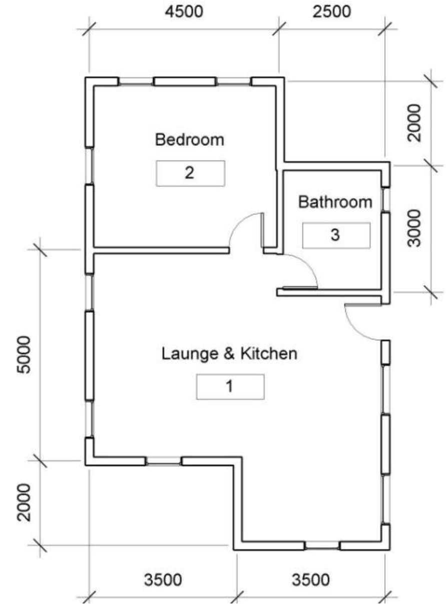


Figure 54: Type 5, Detached D

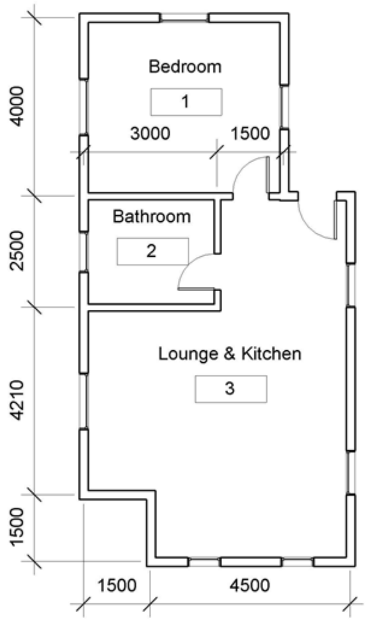
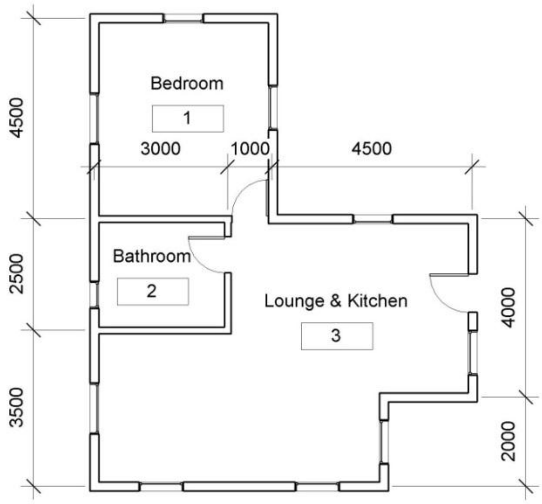


Figure 55: Type 6, Detached E



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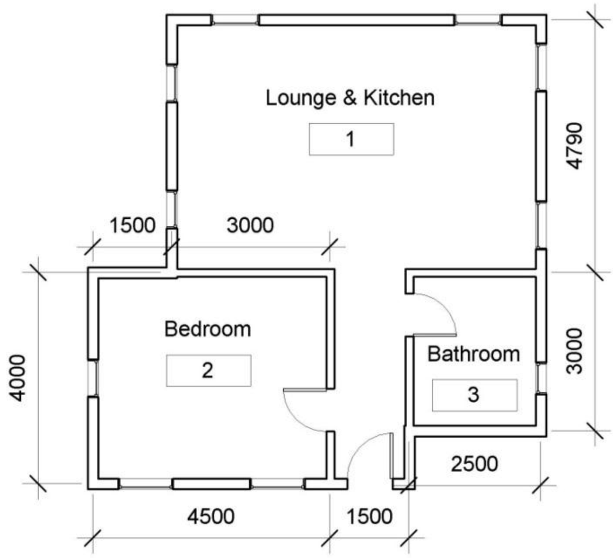

Figure 57: Type 8, Detached G

Part C: Plans with the area of $75m^2$

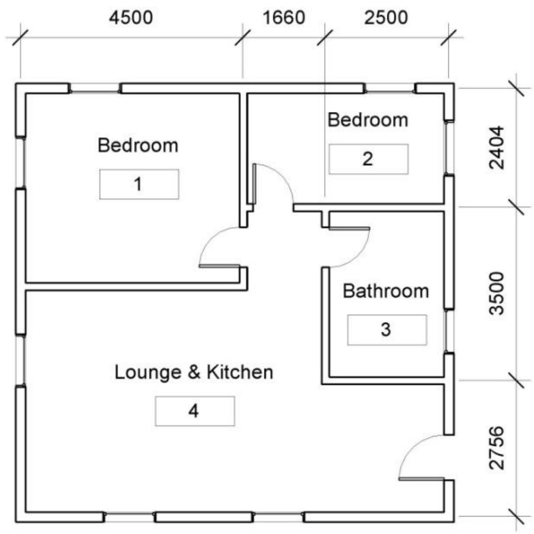

Figure 58: Type 1, Square Model

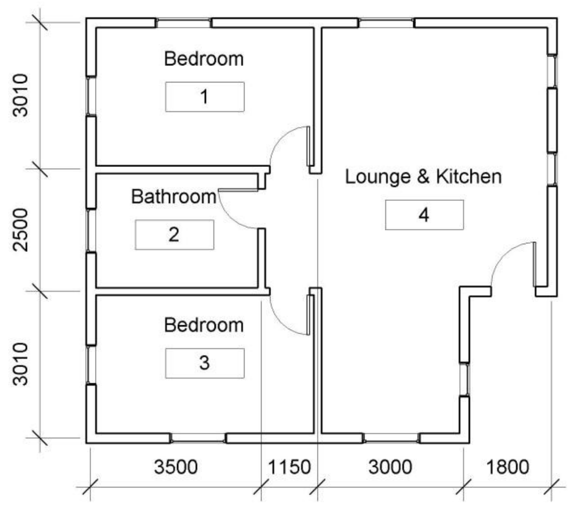

Figure 59: Type 2, Detached A

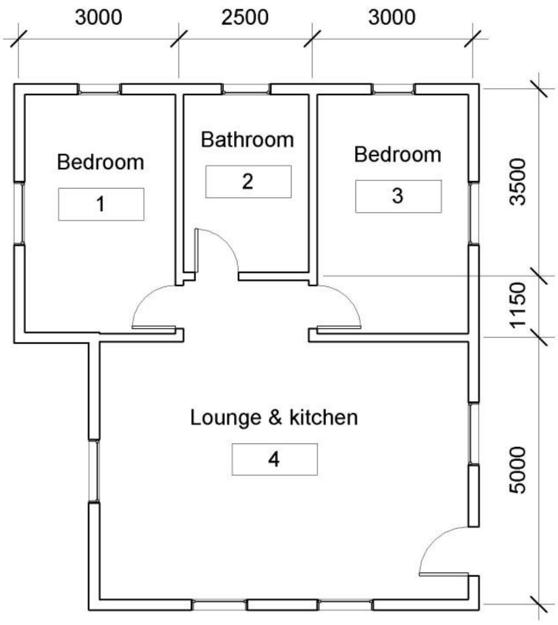

Figure 60: Type 3, Detached B

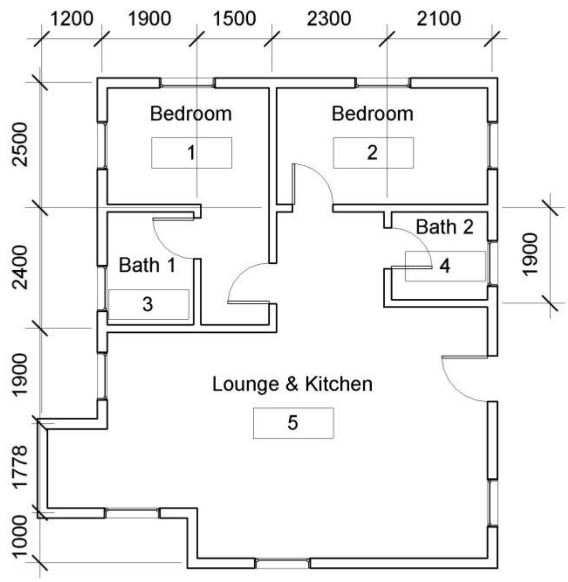

Figure 61: Type 4, Detached C

Figure 62: Type 5, Detached D

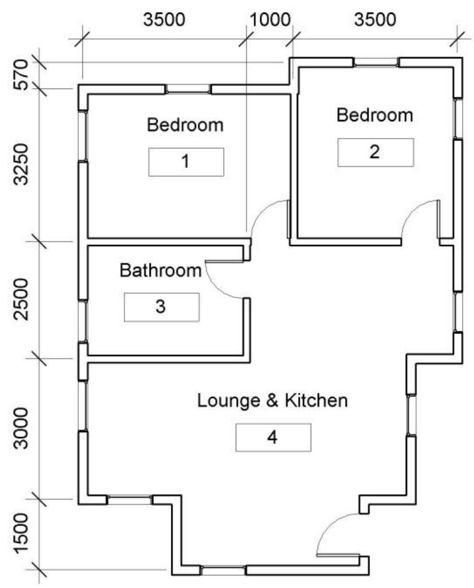

Figure 63: Type 6, Detached E

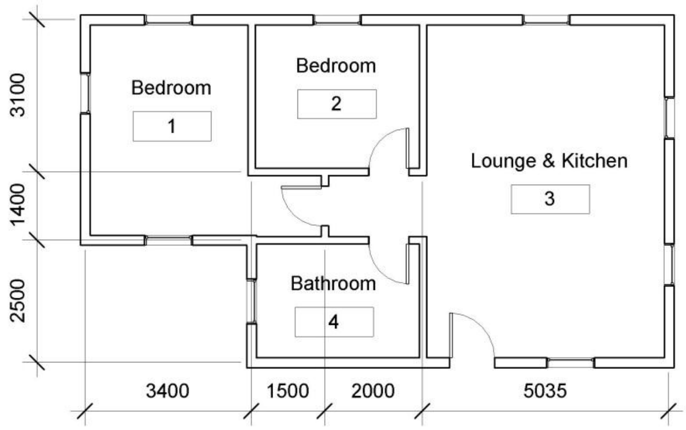

Figure 64: Type 7, Detached F

Figure 65: Type 8, Detached G

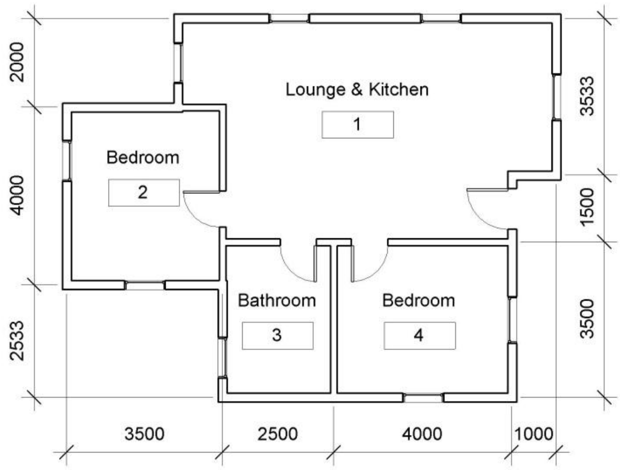

Figure 66: Type 9, Detached H

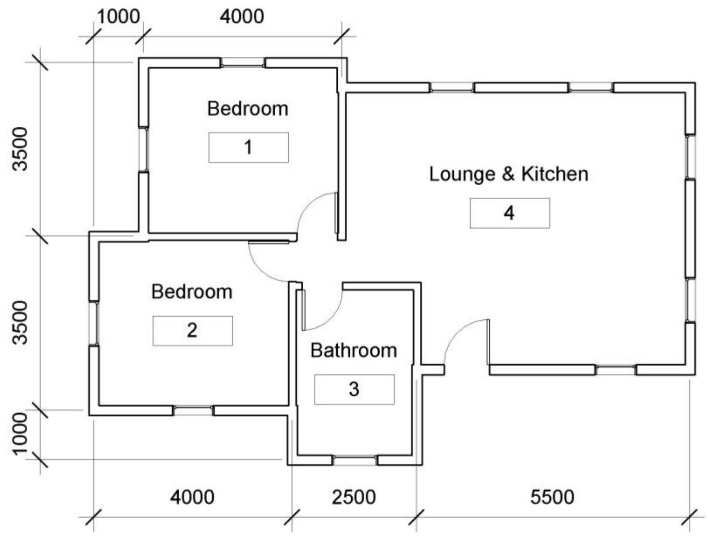

Figure 67: Type 10, Detached I

Figure 68: Type 11, Detached J

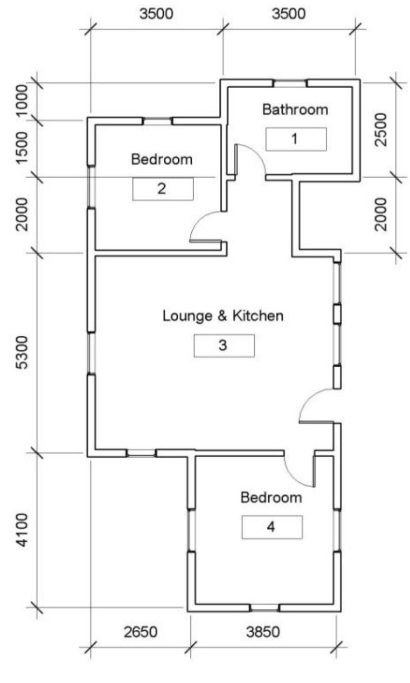

Figure 69: Type 12, Detached K

Part D: Plans with the area of 100m²

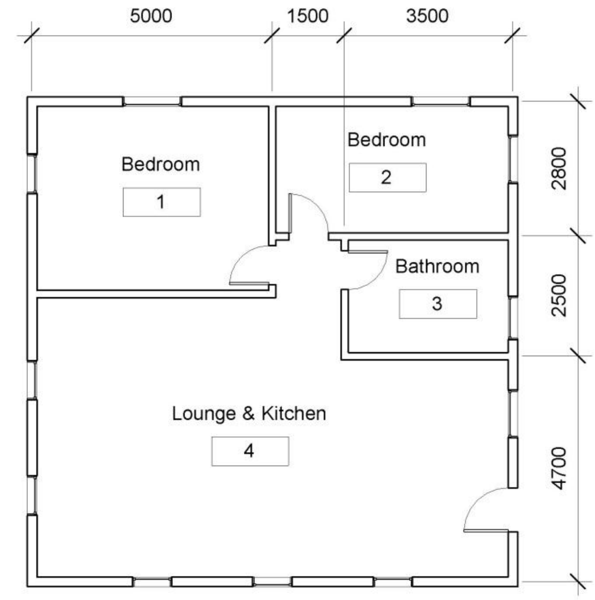

Figure 70: Type 1, Square Model

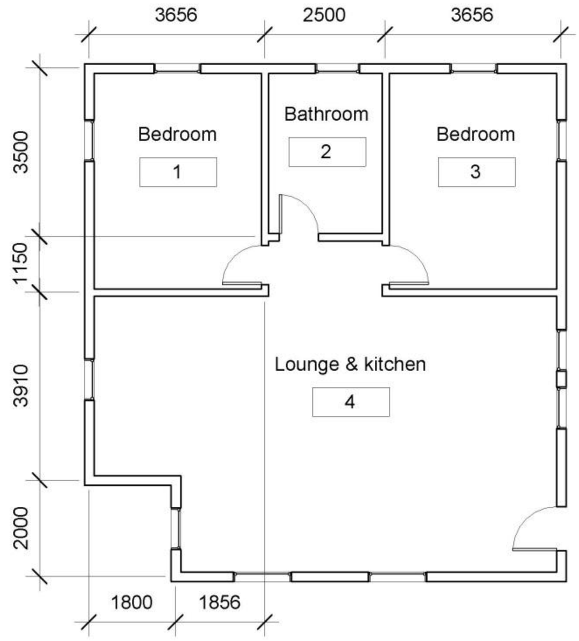

Figure 71: Type 2, Detached A

Figure 72: Type 3, Detached B

Figure 73: Type 4, Detached C

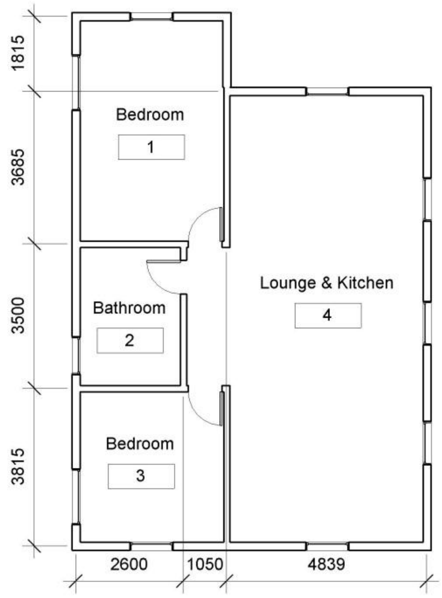

Figure 74: Type 5, Detached D

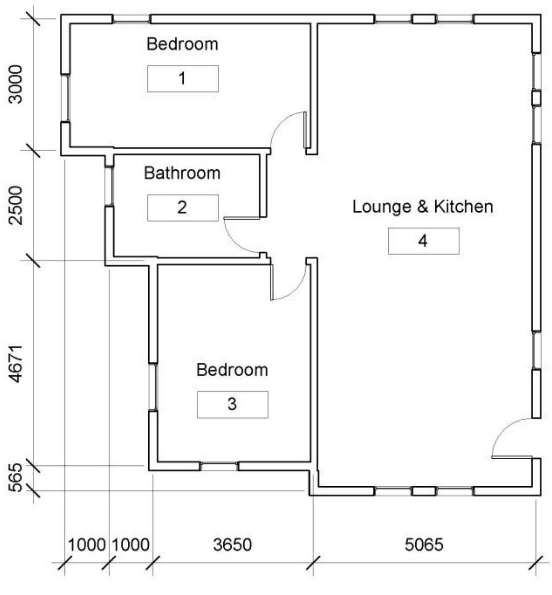

Figure 75: Type 6, Detached E

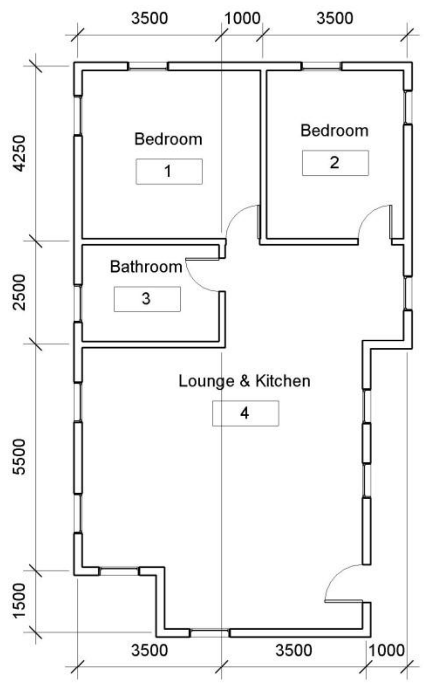

Figure 76: Type 7, Detached F

Figure 77: Type 8, Detached G

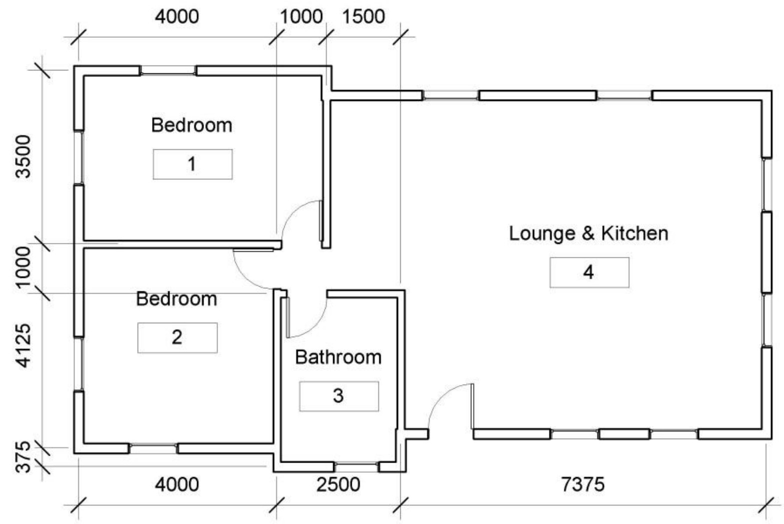

Figure 78: Type 9, Detached H

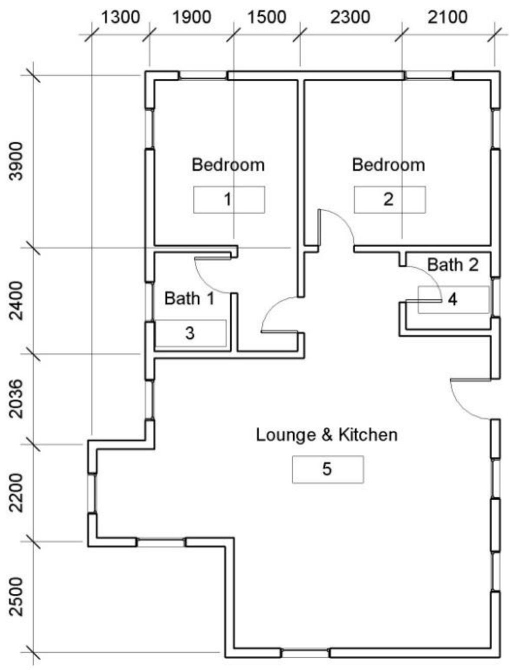

Figure 79: Type 10, Detached I

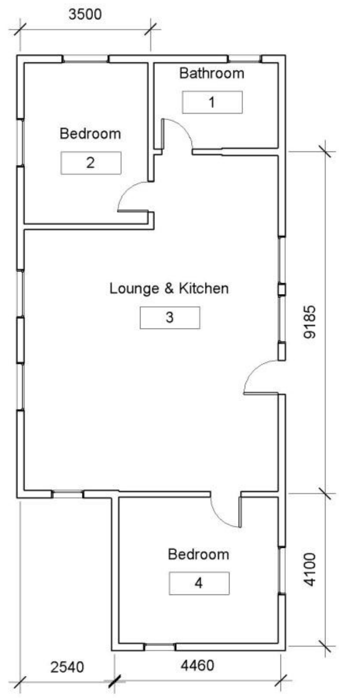

Figure 80: Type 11, Detached J

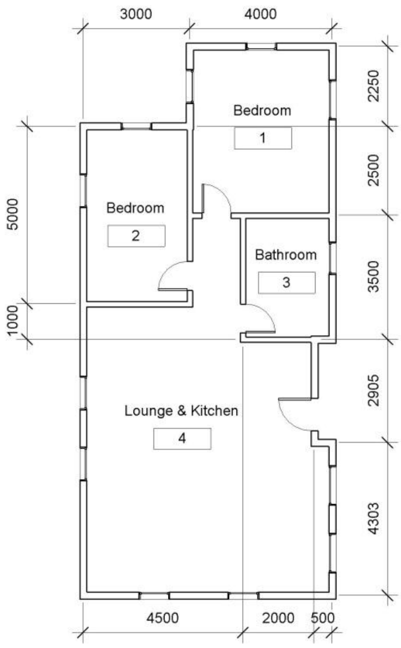

Figure 81: Type 12, Detached K