# BIM and Building Performance Modeling Integration, in Minimizing the Annual Energy Demand of Typical Cypriot Dwellings

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# ABSTRACT

The significance of energy conservation cannot be overstated. Besides, in hot and humid climate conditions annual energy demands is comparatively higher due to air conditioning usage for cooling the living spaces. Total annual energy consumption adds up to nearly 50% of the total energy consumption in Cyprus where thermal insulation is not applied to most dwellings' external envelopes.

In the current study, the integration of Building Information Modeling (BIM) and Building Performance Modeling was carried out in order to identify measures to minimize annual energy consumption in a Cypriot single family detached house. For the modeling process two prominent BIM programs namely, Autodesk Revit and Autodesk Ecotect were used. Furthermore, P1-P2 mathematical method and Net Present Value were used for optimization and comparison purposes.

As a result, the best combination of conventional construction materials used in Cyprus from energy consumption point of view was proposed. Additionally, in order to improve thermal performance of residences, applying 1.6cm high density Rockwool as the outside insulation layer of roof, using double glazed windows and using solid core doors found to be the most effective and economic measures taking which leads to 8654 Turkish Lira saving in 30 years horizon (July 2012 Prices and rates). In addition, by taking the aforementioned measures, thermal comfort will be increased by 41%.

Besides, the sensitivity analysis divulged the intense dependency of net saving as the result of improving thermal performance of dwellings, on the interest rate, material price and electricity tariff changes. A rise in insulation material's price as well as interest rate increased the payback period while the trend was different for electricity tariff.

Additionally, the effect of low quality construction implementation was studied by altering the air change rate in the simulation program. The impact found noticeable, accounting for up to 2300 kWh increase in electricity consumption if the project is poorly implemented.

Similarly, increasing the glazing size led to a surge in annual energy demand, as if the fenestration area enlarged to 60%, neutralizes the effect of improving thermal performance of a 20%-glazed residential unit.

**Keywords:** BIM, building performance modeling, Autodesk Revit, Autodesk Ecotect, Cypriot typical houses, annual energy consumption

# ÖZ

Enerji tasarrufu konusu yeterince önemsenmemektedir. Özellikle sıcak ve nemli hava koşullarında yaşam alanlarında soğutma amaçlı ihtiyaç duyulan enerji miktarı oldukça yüksektir. Kıbrıs'ta yıllık toplam enerji tüketiminin yaklaşık %50'si dış kabukta ısı izolasyonu uygulanmayan evlerde meydana gelmektedir.

Bu çalışmada normal bir Kıbrıs evi ele alınarak yıllık enerji tüketimini en aza indirmek amacı ile Bina Bilgi Modellemesi (BIM) ve Bina Performans Modellemesi tekniği uygulanmıştır. Modelleme işlemi için Autodesk Revit ve Autodesk Ecotect bilgisayar programları kullanılmıştır. Ayrıca, optimizasyon ve karşılaştırmalar yapmak amacı ile P1–P2 matematik metodu ve "bugünkü net değer" hesabı kullanılmıştır.

Yapılan çalışmalar neticesinde enerji tüketimini en aza indirme amacı ile, Kıbrıs'ta ev yapımında kullanılabilecek en uygun yapı malzemeleri önerilmiştir. Ayrıca evlerin ısı izlasyonu performansını artırmak amacı ile çatıda taş yünü kaplaması, pencerelerin çift cam yapılması ve kapıların dolu kapı olması enerji harcamalarında tasarrufa sebep olmasından dolayı 30 yıl içerisinde yaklaşık 8,654 TL tasarruf sağlamaktadır. Ayrıca ısı konforunda %41'lik bir artış sağlamaktadır.

Yapılan "hassasiyet analizi" neticesinde, evlerde ısı izolasyonu performansının en çok malzeme fiyatlarına, para faizine ve elektrik tarifesine bağlı olduğu ortaya çıkmıştır. İzolasyon malzemesi ve faiz oranlarının artması geri ödeme periodunu artırmakta iken elektirk tarifeleri artışında bu eğilim farklıdır.

Ayrıca, hava değişim simulasyonu uygulanarak düşük kaliteli inşaat uygulamalarının elekrik tüketimi üzerindeki etkisi de çalışılmıştır. Bu çalışmaların sonucunda düşük kaliteli proje uygulamalarında yıllık elektrik enerjisi harcamasında 2300 kWH artış gözlemlenmiştir.

Evlerdeki kapı ve pencere açıklıklarının bina enerji performansı üzerine olan etkileri de araştırılmıştır. Elde edilen verilere gore, binalardaki bu tip açıklıklar %20 oranından %60 oranına çıkarılması halinde, binanın enerji tasarrufundaki tüm kazanımları ortadan kalkmaktadır.

**Anahtar kelimeler:** BIM, bina performans modellemesi, Autodesk Revit, Autodesk Ecotect, Kıbrıs'ın geleneksel evleri, yıllık enerji tüketimin

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# Chapter 1

# INTRODUCTION

## 1.1 Background

The significance of energy conservation cannot be overstated. Besides, a considerable share (up to 40%) of total energy demand is consumed by residential sector (Chwieduk 2003). Furthermore, most of the energy consumption in residences is attributed to air conditioning, especially in hot climates (Al-Homoud 2004). On the other hand, the annual heating and cooling load demand can be noticeably decreased by applying thermal insulation materials to building external envelopes.

Cyprus, with more than 21000 annual cooling degree hours is a representative of a hot and humid country in which household energy consumption is responsible for nearly half of the total final, and the share is rising considerably as a result of global warming. However, construction industry in Cyprus does not consider insulation in building external envelopes as thermal performances of residences are comparatively low. Moreover, although an increasing number of literature has studied the effect of improving thermal performance of buildings on the annual energy consumption and consequently money saving in several countries and climate conditions, there are rather little literature published on such effect in Cyprus (Panayi ,2004), (Kalogirou, Florides , & Tassou ,2002), (Florides , Tassou , Kalogirou, & Wrobel ,2001) ,(Florides, Kalogirou, Tassou, & Wrobel ,2000). As a result, the application of insulation materials is conventionally regarded as an action which solely increases the initial costs of a project. Besides, as there is not enough information on the optimum thickness of insulation materials, thicker layers may be added to envelope layers and/or in the wrong place, which reduces the performance, as well as imposing extra initial costs which cannot possibly be compensated in the near future. Thermal comfort on the other hand, has never been mentioned in the current literature about Cyprus, while it is one of the most important non-monetary benefits improving which makes the living space more comfortable whether or not the inside air is conditioned.

Kitsios (2009) reported that 43% of total energy usage is attributed to dwellings and Zachariadis (2010) predicted that the electricity consumption will be three times higher in 2030 in Cyprus. However, after examining 482 dwellings among which most of them were 100-150 m2 and built between mid-80 and 2001, it is concluded by Panayiotou, et al. (2010) that, 80% of total building envelopes do not apply thermal insulation at all.

In the current study first, the most proper types of conventional building envelopes were identified. The most proper combination of them was then insulated with different types of available insulation materials and the most economic one was figured out. Subsequently, optimum insulation thickness was calculated and offered for each type of insulation method. Accordingly, the best insulation material was proposed. Finally, the impact of enlarging fenestration area, rate of air change per hour (ACH) as well as the sensitivity of cash flow on changes in interest rate, material price, and electricity price was also studied.

Is it not to say that monetary benefits attributed to the improvement in thermal performance of the case study, is an additional benefit to non-monetary benefits that contribute to the improvement of living spaces' quality and security as well as providing comparatively healthier environment for living.

As the result, in order to reduce annual energy consumption of residences, replacing normal single-glazed windows with double-glazed aluminum frames, insulating roof with 1.6 centimeter high density polystyrene from outside and, substituting doors with solid core ones are proposed as the most proper measures respectively.

## 1.2 Scope and Objectives

Current investigation principally focuses on detecting measures towards the diminution of annual energy consumption, in conventional single family dwellings of Cyprus. Accordingly, the objectives are presented in chronological order below:

1- To identify the best combination of typical walls, roofs and floors which are normally being used in the residential construction industry of Cyprus, from energy consumption point of view.

2- To calculate the construction cost of each combination and provide a comparison in order to figure out the best one from cost point of view.

3- To come across the available thermal insulation materials in Cyprus.

4- To compute the optimum thickness of each thermal insulation material.

5- To detect the most proper thermal insulation material for Cypriot detached houses.

6- To study the effect of improving thermal performance of residences by replacing doors and windows.

7- To analyze the sensitivity of savings attributed to the aforementioned measures on the variation of thermal insulation material’s cost, interest rate and electricity tariff.

8- To demonstrate the effect of enhancing building's thermal performance on the thermal comfort of inhabitants.

9- To investigate on the effect of construction implementation's quality on the annual electricity consumption.

10- To study the impact of increasing the glazing area on the total energy demand of residences.

## 1.3 Works Undertaken

To achieve the aforesaid objectives, several methods and computer programs where utilized which are listed below in the same chronological order as the objectives:

1- One hundred and twenty possible combination of conventional materials used as external envelopes were generated according to probability formulas and, the thermal performance modeling of each was studied by employing Autodesk Ecotect thermal simulation engine.

2- As each envelope comprises several layers, by calculating the price per square meter of each layer based on the official published unit prices, adding them up and multiplying by total area of each envelope, corresponding construction prices were calculated. Therefore, total construction price of each combination was computed and compared consequently.

3- Types of available thermal insulation materials and corresponding prices could be derived from official unit prices while; more realistic data in this area could be collected from local suppliers. In this case, data including 8 types of insulation materials and their prices was gathered from C.E.E LTD, one of the prominent material suppliers in Cyprus.

4- To calculate the optimum insulation thickness of each thermal insulation materials, which is related to the specifications of the external envelope and insulation material, electricity and insulation material's price, weather condition, interest rate and analysis period, P1-P2 method was employed.

5- The best combination of typical envelopes was insulated with each thermal insulation type and, annual energy demand of each case was computed using Autodesk simulation tool subsequently. Finally, by comparing expenditures at the initial and the operation phase, the most proper insulation material was identified.

6- The most proper case was then revised by substituting windows and doors with more appropriate ones from energy consumption point of view and, the impact of such revisions was investigated by employing Ecotect program.

7- Taking the first 10 year of case study's life span, the sensitivity analysis on changes in the interest rate, insulation material price and electricity price in Cyprus was performed by utilizing Microsoft Excel.

8- Thermal comfort level was studied by using Ecotect software and, a comparison was made between the insulated and uninsulated cases.

9- The effect of construction implementation's quality on the annual electricity consumption was investigated by changing the air change rate per hour - which difference in post construction phase with the designed one in the early design stage is a proper representative for poor construction implementation - in thermal zone properties of Autodesk Ecotect program.

10- Glazing area was increased from 20 to 60% by 20% increments in Autodesk Revit, exported to Ecotect using gbXML schema and, the impact of such alteration was studied by providing a comparison between the estimated annual load demands of each case, computed by Ecotect simulation engine.

## 1.4 Achievements

Results corresponding to each step are presented below in the same chronological order as the objectives and works undertaken.

1- The best combination of envelopes from energy consumption point of view was the combination of floor type 4, roof type 1 and wall type 1 which led to 7864 kWh electricity usage yearly. The difference with the worst case added up to 11526 kWh annually. Envelope types are described in methodology chapter, construction materials' section.

2- Six minimum combinations were derived from 120 cases and the net present value of their incremental cash flow, over 10 years' time was calculated. Consequently, the best case was the combination of floor type 4, roof type 1 and wall type 1. Choosing any other combination imposed a minimum extra expenditure of 3224 Turkish lira to the project in 10 years.

3- Eight thermal insulation materials namely low density expanded polystyrene , high density expanded polystyrene, extruded polystyrene, low density fiberglass, high density fiberglass, low density Rockwool, high density Rockwool and perlite were suggested as available and most popular thermal insulation materials in Cyprus. Technical specifications and prices are provided in the methodology chapter.

4- The least optimum thickness was calculated for high density Rockwool (1.6cm) while, 28.2cm was computed for perlite which was the maximum amongst.

5- The most beneficial material was high density Rockwool, applying 1.6cm of which, along with other measures, pays back in 6 years' time which was the minimum payback period amongst.

6- Replacing windows, in addition to insulating roofs with high density Rockwool, saved 8610 Turkish Lira in 30 years. This amount increased to 8654 Turkish Lira in case of substituting doors, in the same period.

7- Project's net saving was significantly sensitive on the electricity tariff as more than 10200TL was saved, in case of an increase in electricity tariff to 0.8TL/Kwh in 10 years, compared to less than 200TL in the same period for 0.2TL/kWh. Similarly, an increase in high density Rockwool’s price to 15TL/m2 saved as little as 422TL in 10 years while, figures surge to the net saving of 2547TL if the price was reduced to 6TL/m2. Interest rate on the other hand, led to 1406TL net saving in 10 years if raised to 0.06, compared to 2410TL if reduced to 0.02.

8- 41% increase in thermal comfort was observed in case of applying 1.6cm high density Rockwool to the best combination of typical envelopes, based on the degree hour concept and the percentage of time that the temperature of thermal zone was outside the comfort range.

9- As the ACH rate was increased to 2.5, which represents leaky construction, up to 2300 kWh increase in annual load demand was observed comparing to 0.5 ACH for the optimum case.

10- Annual energy consumption surged from 5800kWh to 10219kWh, as the fenestration area enlarged from 20 to 60% for the optimum case.

## 1.5 Limitations of Study

Because of small amount of published literature on the case study of the current investigation and to avoid adding excess detail to the research, some simplifications was considered in number of study’s stages. Indeed, these simplifications led to limitations that are listed below:

1- The only energy source for maintaining the inside air's temperature in the comfort band is considered electricity

2- Air conditioners assumed to be employed 24 hours 7 days a week

3- One study with fixed architectural plan, floor area and height is opted as the representative of typical Cypriot family house

4- Study carried out based on construction and insulation materials which were the conventional and available ones in Summer 2012

## 1.6 Guide to Thesis

In the second chapter - literature review - previous investigations relating to the current research are mentioned and important relevant information and findings are addressed accordingly. Highlighted areas covered optimum thermal insulation material's thickness, computer based thermal performance simulation, energy life cycle costing in residential buildings, the effect of airtightness on building energy demand and studies which considered Cyprus as their case study, from energy profile and energy consumption point of view.

In the third chapter - methodology - data, data collecting methods and building simulation computer programs namely Autodesk Revit and Autodesk Ecotect are presented. Besides, the modeling process and set-factors in simulation engines are also described. Additionally, the process during which the effect of airtightness and enlarging glazing area was carried out is also explained.

In the fourth chapter, optimization methods namely net present value and P1-P2 method are described. The aforementioned methods were utilized to calculate the optimum thickness of insulation materials and to identify the most economic cases.

In the fifth chapter - results and discussion - optimization, calculation, and modeling results is demonstrated using graphs and tables. Furthermore, corresponding additional explanation and discussion is provided were needed.

In the sixth chapter - conclusion - highlights and significant findings of this investigation are mentioned and recommendations for future studies in this area are provided.

# Chapter 2

# LITERATURE REVIEW

## 2.1 Introduction

It is generally believed that, the importance of energy conservation is increasing significantly. Besides, residential sector consumes a large proportion of total energy. In Cyprus, Zachariadis (2010) predicted that the electricity consumption will be three times higher in 2030 which magnifies the need for reducing energy consumption. The electricity consumption of residential sector in mostly as a result of using air conditioner systems to achieve thermal comfort in houses especially in Cyprus since, the water heating is efficiently performed by solar water heating systems which are cheap and their performance is high.

The electricity consumption of dwelling as a result of using air conditioners could be decreased significantly by applying thermal insulation materials which are available in different costs and performances. In the current study, available insulating materials in Cyprus are identified and the impact of applying them to building external envelopes, from annual electricity consumption point of view is investigated.

A considerable amount of investigation has been performed on the effect of insulation materials on energy consumption of buildings using different calculation methods and, the optimum insulation thickness is computed consequently.

In this chapter, a comprehensive background study is carried out on the following subjects and presented in the same order:

1- The optimization of thermal insulating material's thickness, employing degree time concept and dynamic thermal conditions in different parts of the world having diverse construction methods and climate conditions.

2- Insulation materials which have the application feasibility in building external envelopes for thermal insulation purposes.

3- Building performance modeling using computer-based simulation engines focusing on Autodesk Ecotect, EnergyPlus, Equest and, TRNSYS thermal simulation tools. Additionally, less popular computer programs were also mentioned.

4- Life cycle costing of residences from the energy consumption point of view focusing on the embodied energy versus the energy demand in the operational phase and, the effect of applying insulation.

5- The effect of air leakage in building load demand.

6- Investigations in which Cyprus was taken as case study with respect to the energy consumption profile and predictions, construction method and preferences, conventional construction materials and architectural plans and, statistical analysis of the building types and lifestyle.

## 2.2 Insulation Material’s Optimum Thickness

### 2.2.1 Introduction

According to figure 1, by choosing the optimum point for insulation material thickness, life cycle cost of the residence will be lowered as much as possible (Kaynakli, 2012).

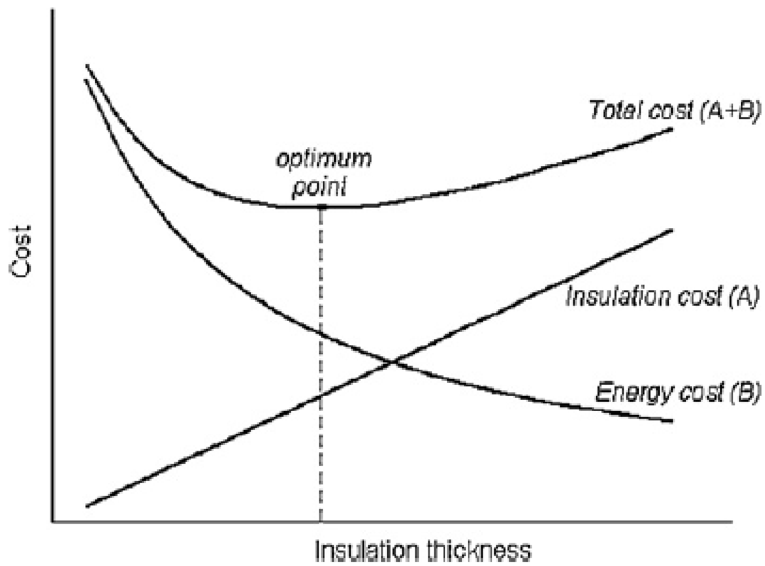


Figure 1: Optimum insulation material thickness, Kaynakli (2012)

The aforementioned thickness indeed, is mainly influenced by the following factors:

1- The type of the energy and its cost (Fuel, Electricity, Gas, Renewable, Etc.)

2- HVAC type and efficiency

3- The cost of the material used for insulation

4- Place of the project which configures a specific weather condition

5- Construction type and materials

6- Building orientation and shape (Al-Homoud, 2005; Ansari, Mokhtar, Abbas, & Adam, 2005; Al-Khawaja, 2004; Yu, Yang, L. Tian, & Liao, 2009).

### 2.2.2 Insulation Thickness Optimization

Calculations based on degree time concept which normally being used for simple modeling and applications, is based on the difference between the desired and defined inside temperature and outside air temperature.

Three cities in the cold regions of Turkey namely Erzincan, Erzurum and Kars were analyzed for 10 years of life-time by Comaklı & Yuksel (2003), and the optimum thickness for the insulation material (stropor in this case) was computed. Ucar and Balo (2009) concluded that under the effect of fuel type and place of the building, insulation thickness differs from 1.06 and 7.64cm which leads to the payback period of 1.8 and 3.7 years respectively, analyzing four different cities in Turkey. In China, considering both cold and hot regions which are represented by Changsha, Shanghai, Chengdu and Shaoguan, analysis was performed on 5 insulation materials comprising foamed polyurethane, foamed polyvinyl chloride, expanded polystyrene, perlite and extruded polystyrene by Yu, Yang, Tian, & Liao (2009), the result was between 0.053 to 0.236m of optimum thickness and the most eminent material was polystyrene due to maximum saving and shortest payback period. Besides, the varieties of orientations and surface colors were taken into account in this study. Using HTB2 simulation software for calculating heat transfer in buildings, the effect of moving the insulating layer's position in a layered wall, based on the cooling load and demand throughout the year was investigated by Bojic, Yik, & Sat (2001) for two high-rises in Hong Kong. A decrease of 6.8% in cooling load and, 7.3% reduction in the demand for cooling load was calculated in this study. Additionally, some increases in cooling load, by increasing the thickness of concrete and insulation was also observed in their research. Another research based on the same city was carried out by Cheung, Fuller, & Luther (2005), that proposed adding 10cm of extruded polystyrene facing indoor to external walls of high-rise apartments which along with some other modification in glass type, wall color and shading led to a reduction of 31.4% in cooling load. Different fuel types for heating were studied by Kaynakli (2008) in Turkey, Bursa and, the optimum insulation thickness was estimated between 0.053 and 0.124m. Al-Khawaja, (2004) concluded that wallmate was the best choice amongst fiberglass, wallmate and polyethylene foam for hot regions like his case study Qatar but since it was a comparatively expensive material, others might have been be preferred. Additionally, instead of air temperature, he used sol-air temperature in his computations. Farhanieh & Sattari (2006) used a rather different method, investigating on Iranian typical buildings in the capital of the country Tehran. Their method called Nodal Network was capable of taking into account "both temperature field and, heat flux from composite external walls which, is not possible with analytical or experimental methods". Accordingly, saving more than 10 cubic meter of gas by insulating external walls was the result of their work. The initial and operating cost of air conditioning systems was studied by Aktacir, Buyukalaca, & Yılmaz (2010). As the result, a reduction of 22% in the initial costs as well as 25% and 33% decrease in the running cots of constant-air-volume system and variable-air-volume system was observed in insulated buildings respectively. Focusing on the position of insulation layer in walls, Kossecka & Kosny (2002) claimed that differences in total energy demand between the configuration ‘‘all insulation inside’’ and, the most effective configuration (from the point of view of energy savings) ‘‘all insulation outside’’ may exceed 11% for a continuously used residential building. Taking Sri Lanka as case study, Halwatura & Jayasinghe (2009) concluded that rooftop vegetation contributes to significant cooling energy saving. Jaber (2002) focused on reducing the combustion of fossil fuels in Jordan and other Arab countries living with similar standards and, demonstrated a 50% diminution of space heating load, by applying insulation to typical buildings of that region where there wasn't any insulation applied to the roofs and very little to the walls (5% of all buildings). Employing RENCON program Al-Sallal (2003) figured out that the payback period in cold regions was comparatively short. He focused on two different states of United States (Texas and Minnesota) and, two different materials for insulation namely fiberglass and polystyrene. Emphasizing on the distribution of insulation layers, Ozel & Pihtili (2007a, 2007b) suggested that three pieces of insulation with equal thicknesses, which are placed in the outer, middle and inner layers of wall and roof, brings out the most desired thermal performance. Kossecka & Kosny (2002) compared six walls with the same R-value and materials, with different placement of insulation and concrete layer, in 6 United States' cities (Miami, Denver, Atlanta, Phoenix, Washington DC and Minneapolis), which represent different climate conditions of US, using DOE-2 modeling software and, showed that if massive layers are placed as internal layers, the most effective thermal performance is achieved. The impact of modifying the glass space of double glazed windows was cogitated by Arıcı & Karabay (2010) and, a 60% net saving attributed to optimum air layer thickness of 12-15mm was observed. Furthermore, the thickness found to be a function of fuel type and climate conditions and, the effect was reported to be less in cold climates. Similar result observed for the city Kars, Turkey, by Aydin (2000). He also computed the space of 15-18mm for Trabzon and Ankara and, 18-21mm for Antalya.

Another factor having noticeable impact on the optimum insulation thickness is the electricity tariff. In addition, choosing a thermal insulation material, the initial cost is obviously one of the main factors that should be considered and, taken into account to perform energy life cycle costing. Running costs of the aforementioned LCC study can be appointed to electricity tariff. This factor was investigated by Gustafsson & Karlsson (1989) and Al-Sanea, Zedan, & Al-Aj (2005). Al-Sanea, Zedan, & Al-Aj (2005) computed the thickness of 4.8-16cm for the average electricity tariff of 0.05 to 0.4 SR/kWh (1 US$ = 3.75 Saudi) for Riyadh, Saudi Arabia, choosing polystyrene as insulation material. The base case was conventional wall in the construction industry of Riyadh which was concrete blocks, that was insulated with fixed 2.5-2.75cm of insulation. Bolatturk (2008) suggested that it is more economical to base the optimization on the cooling load in warm regions since the thickness of polystyrene as thermal insulator calculated less for heating degree hours(HDD) than cooling degree hours(CDD). The same method was employed for the determination of optimum insulation thickness by M. Ozel, K. Pihtili (2008a, 2008b). Considering polystyrene, similar investigation was done by Aytac & Aksoy (2006) and Bolatturk (2006). Concentrating on external walls and ceiling Sisman, Kahya, Aras, & Aras (2007) calculated optimum insulation (Rockwool) thickness for the lifespan of N years for each degree day areas of Turkey, based on Turkish standard BS825. They stated that to improve the comfort quality of residences, providing walls and roofs with insulation is indispensably more economic than other solutions. Building parameters in general, and the effect of their modification on cooling load estimation was also studied by Ansari, Mokhtar, Abbas, & Adam (2005). Rather simple approach – one simplified computer software - was developed in their research, which basically tried to eliminate mathematical complexities. By the way, the software declared to be comprehensive and user-friendly compared to others in market.

There have been several researches on building performance under the effect of multifarious physical conditions, using numerical or computer-aided methods, which consider all aspect of building construction or milieu in detail. Quintessentially, there have always been differences between modeling and real conditions since; numerical methods cannot possibly take into account every detail and, modeling software also cannot simulate human behavior toward energy consumption. The reason behind is that the behavior is directly related to thermal comfort and, the construction itself is not as perfect as software simulates it. However, some studies are carried out on empirical basis. Cabeza, et al. (2010) built 2.4 x 2.4 x 2.4 m cubes with perforated bricks and plasters that represents conventional Mediterranean construction in Lleida, Spain which represents Mediterranean climate conditions. Three insulation materials (polyurethane, mineral wool and polystyrene) were compared and as a result, energy consumption was reduced by 64% in summer and 37% in winter for the cube which had been insulated with polyurethane. In addition, up to 14% difference experienced between theoretical and experimental transmittance value. By the way, some researchers preferred not to calculate the insulation thickness; a case in point is Durmayaz, Kadıoglu, & Sen (2000) and Durmayaz & Kadıoglu (2003) who limited their work to energy requirements and consumption in Turkey's big cities.

Compared to the simple degree time method, quite little researches have been going on based on dynamic thermal conditions. Indeed, calculating the accurate amount of gains and losses by building elements (roofs, walls, floors and ceilings), contributes to more realistic calculations of loads and subsequently, optimizing insulation layers or projecting the thermal performance of a building. Employing this concept, Daouas (2011) discovered the great impact of wall orientation on annual transmission loads with 71.33% of saving in energy and 3.29 years for payback period by south orientations in Tunisian climates, for 30 years’ lifetime. Trying to achieve a desirable combination of wall type and insulation material, Daouas , Hassen, & Aissia (2010) found the most economic choice to be stone/brick sandwich wall, insulated with 5.7cm expanded polystyrene, which led to 58% of saving, applying Complex Finite Fourier Transform method. Kaska, Yumrutas, & Arpa (2009) compared theoretical and experimental findings in Gaziantep Turkey, for 8 conventional layered walls and 2 roofs and found similar results computing decrement factor, time lag and total equivalent temperature difference. Focusing on total equivalent temperature difference solely, Kaska &Yumrutas(2009) carried out similar experimental study and reasoned out that "Meteorological values, absorptivity of surfaces, thermo physical properties and directions of the walls have significant effects on the TETD values". Yumrutas, Unsal, & Kanoglu (2005) and Yumrutas, Kaska, & Yıldırım (2007) developed an analytical method for calculating heat transfer for multi-layer building elements, by employing Complex finite Fourier Transform method, regarding 6 wall types and 2 roofs in Gaziantep, Turkey climate condition. A rather different objective namely achieving thermal comfort, which is represented by Predicted Percentage of Dissatisfied, was followed by Djuric, Novakovic, Holst, & Mitrovic, (2007). Combining EnergyPlus thermal modeling software with the mathematical method, which was used by GenOpt optimizing program, total cost was minimized at 60 degrees centigrade for water supply temperature while, the desired thermal comfort requirement was satisfied for Belgrade, Serbia climate condition. The same modeling computer program was used by Masoso & Grobler (2008) to simulate the thermal performance of a typical office in Botswana. They challenged the common knowledge of ‘‘the lower the u-value the better’’ and discovered an anti-insulation behavior for the aforesaid building, during the process of increasing cooling set point temperature, studying its effect on the fuel consumption throughout a year. As a result, for 6 different set points, the variation of 0 to 160mm of extruded polystyrene was considered and the anti-insulation behavior was observed at 25.72 degrees centigrade and for 80mm of the mentioned material.

Additionally, they reported that the saving happened only for the set points lower than 25.72. Radhi (2009) evaluated envelope thermal insulation codes, which had been proposed by the electricity and water authority in Bahrain. The codes were supposed to diminish the electricity consumption and $CO_2$ emissions by 40% while, results showed at least 15% difference for electricity consumption and almost 33% difference in $CO_2$ emissions simulated by DOE modeling computer program. By using the same program (DOE), in order to conserve energy in a 5 story office building in Dammam, Saudi Arabia, Iqbal & Al-Homoud (2007) recommended replacing HAVC and glazing system as well as lighting equipment in brief.

## 2.3 Thermal Insulation Materials

There are several studies on the properties and performances of thermal insulating building materials. Some researchers tried to make a comparison between thermal properties, benefits and drawbacks of conventional insulating materials while, others focused on an specific one to investigate on its feasibility of becoming a widely used material in construction industry. Although the function and characteristics of every single material may alter due to the context in which the material is installed, a comparison table may narrow the options and lighten the passive building analysis burden. Detailed information on existing thermal insulation building materials was provided by Lyons (2007). Al-Homoud (2005) compared the performance characteristics of five common building insulation materials (Polyurethane/Polyisocyanurate-Foam, Fiber Glass-Rigid Board, Polystyrene-Expanded, Fiber Glass-Blanket, Polyethylene-Blanket and Vermiculite) based on their R-Value for 5cm of thickness, giving concrete block as reference. There were also some recommendations and sketches for the application of materials available in his work. Papadopoulos (2005) demonstrated the increasing trend of insulation thickness, applicable in European countries and provided the anticipated U-values for building external envelopes in the same region. Besides, feature tables, installation procedure's briefings, place and the environmental concerns of insulation materials were also provided. Mahlia, Taufiq, Ismail, & Masjuki (2007) carried out an analytical study over the relation between the insulation material thickness for walls and the corresponding thermal conductivity feature. As a result, a nonlinear function was developed and, fiberglass–urethane was proposed as the most economic material for insulation which saved more than 70 thousand US dollars in Malaysian weather. "Currently, there exist no single insulation material or solution capable of fulfilling all the requirements with respect to the most crucial properties" states Jelle (2011). He has performed one of the most recent and quite comprehensive studies and comparisons on all insulation materials in past, present and future and their characteristics. He took into account specifications such as "thermal conductivity, perforation vulnerability, building site adaptability and cuttability, mechanical strength, fire protection, fume emission during fire, robustness, climate ageing durability, resistance towards freezing/thawing cycles, water resistance, costs and environmental impact". In addition, the future application's feasibility of using some insulation materials such as dynamic insulation materials, nano insulation materials and NanoCon, which is a load-bearing insulation material, was also investigated. In another similar work by Jelle, Gustavsen, & Baetens, (2010) that compared the potential of, present state of the art materials to become future materials, NIM (Nano insulation materials) was suggested as the most feasible one due to its low thermal conductivity. Basically, to develop dynamic materials, which can regulate their thermal conductivity in a wide range, was the objective of their research. The sensitivity of 7 different insulation materials on altering operating temperature was discussed by Abdou & Budaiwi (2005) and polyethylene reported to be highly sensitive among others, while polystyrene was the least sensitive one and the reason behind was considered to be the different density of each subject of the analyzed group. An investigation on the environmental performance of the production process of two insulation materials namely extruded polystyrene and stone wool was done by Papadopoulos & Giama, (2007), using Global Emission Model for Integrated Systems computer program and, corresponding tables were provided based on ISO 14031 standard. Another study by Liang & Ho (2007) focused on the toxicity properties of conventional insulation materials in Taiwan, based on an experimental study according to United Kingdom Naval Engineering standards 713. They computed Toxicity Index for tested materials and concluded that toxicity characteristic index of all tested materials was bigger than untreated wood, polyurethane foam, organic foamy materials and polyethylene, which were not approvable in foreclosing fire in buildings. As a result, to install insulation materials in the middle or outside of the building external envelope and to cover those with fireproof materials were suggested.

## 2.4 Researches Utilizing Computer Programs for Thermal Simulation

### 2.4.1 Introduction

Computer programs for building simulation provide us with cherished knowledge of building performance in several aspects before the project is initiated. The projection indeed is cost effective since, myriads of shortcomings in the life cycle of the project are foreseeable by aforementioned software. Thermal modeling with computer is the most recent approach in construction schemes and there has been a strong tendency to employ them, due to their simplicity, versatility and their result compatibility with reality.

### 2.4.2 Autodesk Ecotect

Kanagaraj & Mahalingam, (2011), developed a framework titled "Integrated Energy-Efficient Building Design Process" which provided guidelines for designers to choose the proper strategy to design energy efficient buildings in commercial sector of New Delhi, India. Thermal performance of their case study was carried out by Ecotect v5.6 simulation program and, it was suggested by them to use Ecotect for site vegetation, open space and activity zoning, building roof form, building fenestration design and building skylight design. Concentrating on high rise buildings, Ling, Ahmad, & Ossen (2007) tried to achieve the optimum shape and orientation for these types of buildings in order to minimize solar radiation that contributes to cooling load demand in hot and humid weather conditions. Accordingly, utilizing ECOTECT V5.2, north-south oriented square shape high-rise with width-length ratio of 1:1, reported to receive the least solar radiation. Taking Fajar Harapan Hostel in the University Science Malaysia as case study, Al-Tamimi & Fadzil (2011) validated the ECOTECT simulation tool in terms of indoor temperature development and concluded that the application of natural ventilation as well as shrinking the glazing area leads to a surge in comfort period. The most effective solution to provide thermal comfort in Chongqing, China was proper natural ventilation, stated Zhao, Gao, & Cheng (2011), and the optimum strategy was improving the heat storage capacity of building along with the aforementioned measure. ECOTECT software was used in their study.

### 2.4.2 EnergyPlus

Crawley, et al. (2001) compared EnergyPlus with DOE-2, IBLAST and BLAST, the older generations of modeling programs, which were supported by United States government and concluded that most of the shortcomings of these programs was met in EnergyPlus. Tian & Love (2009) pointed out the significant role of radiant heating and cooling systems in energy consumption optimization, taking University of Calgary’s ICT Building as case study. They found modeling with EnergyPlus time consuming and not fulfilling, in term of "allocating cooling loads between the air and radiant cooling systems, especially at part load". Furthermore, assessing current building external envelopes, they concluded that a properly designed system would consume 80% less energy than the existing one. EnergyPlus was also used by Guo & Nutter (2010) to simulate k-12 school buildings, to calculate suitable temperature for United States different climate conditions and various types of construction. Accordingly, glazing area and building orientation found to have minor effects on current setup and setback temperatures. Fumo, Mago, & Luck (2010) retrieved some coefficients for calculating energy consumption by "EnergyPlus Benchmark Models simulations" from bills, without the need to generate simulations that needs expertise and time. Their case studies located in Meridian and Atlanta, United states. Errors of this method were investigated in a later study by Smith, Fumo, Luck, & Mago (2011), by testing 72 buildings. It was suggested that the possible applicability of this method for every single user for their corresponding case studies can be assessed based on these error evaluations. Krartia & Ihmb (2009) computed 20% overestimation of annual loads by EnergyPlus for a conventional dwelling, in case of inadequately integration of calculation in the software, simulating heat transfer characteristic of building foundation. EnergyPlus was also used by Djuric, Novakovic, Holst, & Mitrovic, (2007) and Masoso & Grobler (2008), whose work is mentioned in "Insulation thickness optimization" section.

### 2.4.3 eQuest

"Computer-based simulation is a valuable technique to assist facility managers in determining energy conservation solutions" states Zhu (2006). However, he found the modeling and data collection process time and resource consuming. Trying to achieve energy star designation he combined portfolio manager and eQuest program, and figured out the importance of the "combination of resetting heating set points and controlling the fan operation of air handling", that led to the adequate saving. Besides, the drawback to eQuest program mentioned to be incapable of modeling different operation schedules and lack of incorporation capacity with other programs. Medrano, Brouwer, Mauzey, & Samuelsen (2008) employed eQuest to analyze the impact of the combination of three types of different advanced distributed generation technologies in mild climate condition. Using eQuest software, Yu, Yang, & Tian (2008) computed 11.31% and 11.55% of net saving in electricity consumption of air conditioning systems in hot and cold climates of China, for shading and exterior wall insulation respectively. 25.92% of saving was the result of implementing versatile strategies at the same time. One of the latest studies using eQuest by Moon & Han (2011) described thermostat strategies' effect on building energy saving in terms of parameters, in family residences of two different climate conditions of United States, and computed the heating system more sensitive to thermostat strategies than cooling systems. Hester, Li, Schramski, & Crittenden (2012) conducted the most recent research on energy saving measures namely daylight control, glazing area and structural insulated panels, and concluded that the application of these strategies together which led to 6.1% reduction in energy consumption is four times more effective than mitigations in operating phase, for United States dwellings in Phoenix. Lai & Wang (2011) stated that roof construction and window type play the most significant role in energy consumption of residences and, calculated 4.9% decrease in energy demand in Taiwan, by modifying the aforesaid factors in eQuest simulation program. The thermal performance part of the environmental impact assessment of dwelling, based on various wall constructions was done by Kahhat, et al. (2009) using eQuest and, 94% of the whole energy consumption was reported to happen in the operational phase of residential projects.

### 2.4.4 TRNSYS

Al-ajmi & Hanby (2008), trying to propose modifications to future energy conservation codes, which had been originally issued in 1983, simulated 7 case studies in Kuwait with TRNSYS-IISIBAT program, and pointed out the significant effect of infiltration and glazing area and type on energy consumption of Kuwaiti dwellings. Employing TRNSYS simulation tool, Bhaskoro & Haq Gilani (2011) proposed the application of air conditioners with adjustable set points to academic buildings of Malaysia, which led to achieve 27.4% reduction in cooling load, since 50% of the total cooling load was wasted during off peak and peak time. The main contributor to cooling load demand (52.57%) reported to be the heat gain through building external envelopes.

### 2.4.5 Studies Based on Less Popular Programs

In Sweden, glazed office buildings and the effect of adding more glass to the building’s façade was studied by Poirazis, Blomsterberg, & Wall (2008), using IDA ICE 3.0 simulation tool. They studied 30, 60 and 100% glazed buildings and recommended that the construction type must be regarded carefully, since its impact on the energy consumption level was huge. They declared that choosing proper glass from transmittance point of view would add only 15% to energy usage in 100% glazed building compared to 30% one, and increasing window area imposed negligible effect of lighting load due to the disqualifying visual comfort character of extra daylight in office building. Chirarattananon & Taveekun (2004) "utilized DOE-2 simulation program in a series of parametric runs, to develop an overall thermal transfer value formulation each for four types of commercial buildings". Taking a building in Sheffield, England, simulated by Radiance program, Altan, Ward, Mohelnikova, & Vajkay, (2009) assessed the effect of glazed façade on thermal comfort and working conditions. Frank (2005) criticized Switzerland's SIA standard based on which designers neglect climate change, while buildings have a normal lifetime of 50 to 100 years. As a result, up to 1050% surge in cooling load demand for office buildings was predicted using HELIOS simulation program, considering 4.4 degrees centigrade rise in temperature for a 50 years period between 2050 and 2100. The heating load demand in the same sector was projected to fall by almost 60% while, in residential sector it was less than 45%. Gugliermetti, Passerini, & Bisegna (2004) employed Integrated Energy Use Simulation to perform "an analysis of the stochastic component to understand the reliability of reduced data characterized by only the climatic deterministic component, versus more complex series of one year hourly data". Bojit, Milovanovic , & Loveday (1997) computed 20% saving in cooling load, for pitched roof facing north, in case of choosing the right angle, using BRE-ADMIT simulation tool. The saving reported as small as 11% for the same roof facing south. Monthly loads based on heating, ventilation and air conditioning for three case studies in Jeddah, Saudi Arabia was calculated by Al-Rabghi & Douglas (2001), utilizing BLAST simulation tool. Some works using thermal simulation tools were mentioned before in the "Insulation thickness optimization" section namely Bojic, Yik, & Sat (2001) who utilized HTB2, Kossecka

& Kosny (2002) who used DOE tool and Al-Sallal (2003) who performed thermal simulation with RENCON simulation software.

### 2.4.6 Investigations Providing Comparative Analysis of Simulation Tools

A comprehensive comparison between twenty prominent thermal simulation programs was performed by Crawley, Hand, Kummert, & Griffith (2008) and summarized in corresponding tables for each category of research; although, the ability to perform mentioned features was not investigated. Yazoo, Dong, & Leite (2008) used artificial neural network to evaluate building energy performance, and compared the method with results from Green Building Studio web tool, Energy_10, EnergyPlus and eQuest simulation programs. They found 3% and 0.9% error to mathematical method respectively. In a similar research, Neto & Fiorelli (2008) compared ANN with EnergyPlus, taking the Administration Building of the University of Sao Paulo as the case study and, 13% error was recorded for 80% of tryouts while, for ANN the error was 10%. They suggested that human behavior could be a major cause of inaccuracy and complexity of energy modeling. A comparison between EnergyPlus and DOE-2.1e was done by Andolsun, Culp, Haberl, & Witteb (2011), and different results were reported for the "ground coupled heat transfer (GCHT) with basements". "The results revealed that the ground isolated EnergyPlus houses used 3–23% more cooling, 12–29% less heating and 3–7% lower overall HVAC electricity use when compared to the ground isolated DOE-2 houses" (Andolsun, Culp, Haberl, & Witteb, 2011). Tenório & Pedrini (2002) compared Esp-r, PV Design PRRO 4.0, Ecotect and VisualDOE-2.1 in the process of sustainable design of dwellings in Brazil. "Low energy design feature combined with the production of energy through a PV grid connected system installed on top of roof, demonstrated that the energy loads were minimal and close to zero" they reported.

## 2.5 Energy Life Cycle Costing

### 2.5.1 Introduction

Minimizing costs has always been one of the most important challenges for construction engineers and managers, since it plays a significant role in the feasibility analysis of every project. The focus of this area of interest however, was merely on the initial phase historically, before the impact of operating costs was discovered during the 1930's (Dale, 1993).

By definition, "Life Cycle Cost (LCC) analysis provides a framework for specifying the estimated total incremental cost of developing, producing, using, and retiring a particular item"(Asiedu & Gu, 1998). LCC is a propitious tool to compare different projects which function analogously, in term of costs which pertain diverse phases during the life cycle of each project, by calculating net saving of every single case.

Broadly speaking, five categories must be considered in the process of life cycle costing of buildings:

1- Initial

2- Operation

3- Maintenance

4- Replacement

5- Salvage value

### 2.5.2 Energy Life Cycle Costs

A noticeable amount of studies were published on the life cycle costing of residences from the energy consumption point of view. In 2012 Ramesh, Prakash, & Shukla published their research in which they evaluated the energy demand of a dwelling located in Hyderabad, India during its life-time using DesignBuilder as an interface for EnergyPlus simulation engine. Different construction materials with diverse thicknesses and varying climate conditions were investigated in their work. Being dependent on the climate, up to 30% of life cycle energy saving was observed in their study and the humid and warm weather reported the most suitable condition to install insulation, because it led to the maximum energy saving. Insulation layer's thickness' limit was also calculated for walls and roofs taking into account life cycle costs. In Denmark, Marszal & Heiselberg (2011) maintained that the installation of renewable technologies needs more budget than making multi-story residential buildings energy efficient, with 2011 prices and producing electricity with photovoltaic systems. Utama & Gheewala (2008) pointed to single landed dwellings in Indonesia and concluded that the energy performance of cement based building enclosures is low, compared to the typical clay and brick roofs, using Autodesk ECOTECT as thermal modeling engine. Two major energy categories namely "embodied energy" and "energy demand during operational phase" was regarded in their energy life cycle analysis. Gustavsson & Joelsson (2010) investigated on the CO2 emission and energy use of low energy and typical dwellings in Sweden in two different stages, namely operation and construction. Various systems, by which energy was supplied for the aforementioned phases of case studies during their life time, were considered. "The primary energy used and the CO2 emission resulting from production is lower for wood-framed constructions than for concrete-framed constructions" said Gustavsson & Joelsson (2010). Hernandez & Kenny (2010) argued for neglected factors like embodies energy in net-zero residences regulations, which were issued by some countries recently, and defined a methodology which explains both energy during operation phase and embodied energy together, and provided a comprehensive definition of "life cycle zero energy building (LC-ZEB)". Pointing to the varying parameters in the analysis phase of embodied energy, which leads to inaccuracy of energy data and consequently causing these data being unreliable, Dixit, Fernández-Solís, Lavy, & Culp (2010) signalized a standard process, during which data related to embodied energy is being collected. Ramesh, Prakash, & Shukla (2010) mentioned operating and embodied energy as the most important contributors to life cycle energy, with 80-90% and 10-20% contribution respectively; They provided a statistical investigation on 73 case studies (office buildings as well as dwellings) from 13 different developed countries, having rather cold climate conditions. Furthermore, the impact of reducing operating energy regarding a possible rise in the embodied energy reported to be dramatic. Fay, Treloar, & Iyer-Raniga (2000) calculated 12 years energy payback period of an Australian case study, in case of increasing the insulation level in buildings, and reported that the saving of total energy use was minimal in 100 years' horizon. Accordingly, other possible strategies suggested to be studied before increasing the insulation level. A rather different and opposing idea is expressed later in 2011, employing AccuRate thermal simulation tool by Morrissey & Horne (2011), who criticized current requirements of Australian energy codes, and demonstrated that in terms of money it is more economical to refine current code requirements and construct more energy efficient residences, taking Melbourne Victoria as Australian weather representative in 25 & 40 years' time, taking into account the rise in energy price. Shu-hua, Yuan, & Xue (2010) calculated 76.5% total energy usage in the operational phase in urban dwellings in China, and mentioned electricity and specially coal, the major resources for energy supplication. The effect of building orientation and shape on the energy consumption was addressed by Bostancioğlu (2010), and a maximum 26.92% increase in energy demand was computed. Conversely, the effect of building orientation was reported minimal with as little as 0.86% rise in energy usage. Asif, Muneer, & Kelley (2007) calculated the embodied energy for different construction materials like "wood, aluminium, glass, concrete and ceramic tiles" that were used in a semi-detached house in Scotland. Total embodied energy reported to be 227.4 GJ, among which concrete's share was the biggest following by timber and ceramic tiles with 61, 13 and 14% of total respectively. The whole energy consumption of three prefabricated single-unit houses in Sweden was evaluated by Adalberth (1997) who computed 85% and 15% energy usage as operation and embodied energy respectively. The required energy to produce heat insulation materials was then concluded to be equal to two years of energy usage, during the management phase of case studies which, was mainly employed for providing electricity or water and space heating purposes. Sartori & Hestnes (2007) showed a linear relationship between total energy and operating energy, as a result of an investigation on 60 case studies from 9 different countries, comprising both non-residential and residential buildings. Low-energy units reported more economical than conventional ones although, the embodied energy was comparatively higher in the latter. "The embodied energy of buildings along with the transport energy of their users, represent, together, the largest share of the life cycle energy" stated Stephan, Crawford, & de Myttenaere (2011), attributing 23% of the whole life cycle energy to space heating, which added up to 47%, taking into account appliances and water heating. The embodied energy reported significantly high in suburb low-energy residences, due to some factors such as transportation (39.5% higher than urban dwellings).

## 2.6 Airtightness Effect on Building Energy Consumption

A number of investigations have mentioned infiltration as one of the most important contributors to the superfluous energy consumption in the existing buildings. Emmerich & Persily (1998) analyzed United Stated office buildings and found that the infiltration accounts for 13% and 25% of heating load demand in old and recent US buildings respectively while, this share for cooling load demand in both cases was 3%. The impact of unrestrained air change on the "ventilation heating energy" was reported to be significant, causing more than 50% loss in this type of heating energy (Binamu, 2002). Jokisalo (2009) studied the effect of different factors on the infiltration rate, as well as the impact of infiltration rate on total energy demand of detached houses of Finland. It was concluded that 15-30% of energy is consumed as the result of infiltration. They also concluded that airtightness and annual infiltration rate is correlated linearly. More temperature fluctuation as a result of higher leakage rates was reported by Kurnitski (2005), investigating the effect of airtightness on thermal comfort characteristics of buildings. Kalamees (2007) investigated on Estonian buildings and concluded that near 60% of buildings do not meet the airtightness requirements of Estonian construction standards, using infrared cameras and smoke detectors. Chan, Nazaroff, Price, Sohn, & Gadgil (2005) performed a statistical analysis of 70000 leakage areas in residential sector of United States, and mentioned construction date and building areas as the most important factors of air leakage anticipation, in single-family detached dwellings.

## 2.7 Cyprus as Case Study in Literatures

Although there are numerous studies on building thermal performance, thermal insulation materials, effect of different factors on the heating and specially cooling load demand of dwellings and, optimum insulation thickness in the Mediterranean climate, very little research has been performed taking Cyprus, which is located right in the middle of the Mediterranean Sea, as case study.

The electricity consumption profile of service and residential sector, and their relationship to climate condition changes, as well as prices and people's income in Cyprus was studied by Zachariadis & Pashourtidou (2007). They drew a conclusion that climate conditions' changes have noticeable impact on the electricity consumption in short term. Conversely, people's income as well as market prices had little effect on the electricity consumption in the same period while; their effect was reported significant in the long run. Employing econometric analysis, Zachariadis (2010) predicted that the electricity consumption will be three times higher in 2030 in Cyprus. He also took global warming into account, as an effect of which, 1 degree centigrade increase in temperature is expected in the Mediterranean area by 2030, and calculated 2.9% increase in the electricity consumption by the aforementioned time horizon as a result of which, 200 million euros (based on 2007) of welfare loss might be tolerated. Egelioglu, Mohamad, & Guven (2001) found that three important factors are major contributors to electricity consumptions yearly. These factors were "the number of customers, the price of electricity and the number of tourists" (Egelioglu, Mohamad, & Guven 2001). In addition, modeling based on these factors, declared to possess the prediction capability of future energy consumptions.

Koroneos, Fokaidis, & Moussiopoulos (2005) discussed the feasibility of Cyprus to employ renewable energy resources in order to reduce the amount of imported fuel and coal for electricity production purposes. Introduction of building codes, focusing on thermal insulation and developing public transport systems were two major suggestions as a result of their study. "Climatically responsive houses and settlements in Northern Cyprus" was analyzed by Ozay (2005) in different architectural periods. Some elements of buildings like windows and fenestration areas as well as the design were considered in her analysis. Besides, "the impact of socio-economy, technology, culture, politics and building management strategies" was also taken into account. Isik & Tulbentci (2008) provided an investigation on the possible contribution of "gypsum-stabilized earth" which is called "Alker" in the sustainable construction as wall material as it is widely used in Cyprus for construction purposes. They concluded that the possibility is quite high since not only Alker has a comparatively low heat transfer characteristic, but also it provides health advantages. Embodied energy for this construction material on the other hand, is considerably low. Florides, Kalogirou, Tassou, & Wrobel (2002) modeled an "absorption solar cooling system" and determined several factors such as "appropriate type of collector, the optimum size of storage tank, the optimum collector slope and area, and the optimum thermostat setting of the auxiliary boiler" using TRNSYS simulation engine. Panayi (2004) studied the effect of building orientation, applying thermal mass, fenestration type and thermal insulation on the energy (Heating and cooling load) demand of Cypriot houses, using TAS Building Designer software, taking a detached house and an apartment as case studies. Double glazing was suggested as the first measure and 2.5 centimeter wall insulation as the second measure to take for both cases while, applying 0.6 and 0.4 meter of thermal mass was suggested for apartments and detached houses respectively in order to reduce energy consumption. Additionally, the effect of orientation reported to be minimal. "The application of wall insulation and thermal mass leads to an increase of air-conditioning and dehumidification energy" Panayi (2004) concluded. Kalogirou, Florides, & Tassou (2002) emphasized on thermal mass usage for buildings in Cyprus, using TRNSYS software. As a result, nearly 50% reduction in heating load demand was observed. Accordingly, optimum overhang size calculated 1.2 meter and the effect of wall cover, double glazing and altering air gap reported minimal. Besides, the impact of roof insulation found significant and, ventilation by the rate of 3 ACH per hour led to 7.5% reduction in cooling load. The evolution of residential buildings during 20th century in Cyprus, taking into account their energy (heating and cooling load) demand was carried out by Florides, Tassou, Kalogirou, & Wrobel (2001) using TRNSYS thermal simulation tool. Inside temperature of insulated and traditional dwelling was 16-20 degrees centigrade in winter time and, 25-30 degrees for summer. For the same seasons, corresponding temperatures was 11-20 degrees and 33-46 degrees centigrade for flat roof residences. Accordingly, a drop of 5 degrees was observed as a result of imposing ventilation during summer time and they draw a conclusion that construction methods and precautions such as “allowing high ceilings and doors and positioning doors and windows towards the prevailing night winds" provide the same inside temperature as modern, expensive and insulated houses. Panayiotou, et al. (2010) performed a statistical study on energy consumption profile of the residential sector of Cyprus, examining 482 dwellings among which most cases were 100-150 square meter, and build between mid-80's and 2001. 68% of case studies were single house, 80% of total did not apply insulation to building external envelopes, where double glazed windows were installed to more than fifty percent of case studies and, 82% of residences employed solar heating systems for water heating purpose. Finally, the most comprehensive study similar to current research was done by Florides, Kalogirou, Tassou, & Wrobel (2000), during which a typical modern 196 square meter Cypriot dwelling's energy (heating and cooling load) demand was computed in various cases, which differed from each other in construction materials for walls and roofs. For both walls and roofs the typical construction method which does not apply insulation to building external envelopes was regarded. "Hollow bricks made of fired clay" was considered as the conventional construction material. The modeling process was followed by considering 2.5 and 5 centimeter of polystyrene insulation material in different cases, for both roofs and walls. The simulated house was divided into four identical thermal zones to provide the capability of studying diverse factor for each zone. Consequently, cooling and heating load for each, as well as heat losses and gains of all building external enveloped were computed for every case. The effect of natural ventilation, internal shading and inclined roof was also studied. Finally, an economic analysis was performed to calculate savings as a result of insulation in 20 years' time horizon. Results showed that maximum 68.1% reduction in heating at 18 degree centigrade occurs in case of applying 2.5 centimeter roof insulation and, 75.1% in case of 5 centimeter insulation, compared to the non-insulated roof case. Ventilation led to not more than 6.3% reduction in cooling load (to heating load reduction observed) in summer while, 19.9% was computed as a result of using internal shadings. Inclined roof demonstrated a negative effect on the load demand, accounting for up to 13.2% increase; although, if had been constructed for decoration purpose caused 41-55% reduction in cooling load. Considering life cycle costing, wall insulation's payback time was calculated 20 years, while in the same time more than 22 thousand euros could have been saved by insulating the roof (2000 prices and factors). In this investigation, Type 19 of TRNSYS simulation engine was employed. Set values for the most important factors which are normally applied in thermal zone during the process of modeling, are demonstrated in tables 1-3:

Table 1: Parameters used in the modeling process by TRNSYS type 19, Florides, Kalogirou, Tassou, & Wrobel (2000)

Important zone parameters used in the calculations with TRNSYS Type 19

| Parameter | | Description | Set value[a] |
|---|---|---|---|
| 1 | Mode | 1-energy rate control, 2-temperature level control | 1 |
| 2 | $V_a$ | Zone volume of air ($m^3$) | 147 |
| 3 | $K1$ | Constant air change per hour | 0.1 |
| 4 | $K2$ | Proportionality constant for air change due to indoor–outdoor temperature difference ($(°C)^{-1}$) | 0.017 |
| 5 | $K3$ | Proportionality constant for air change due to wind effects ($(m/s)^{-1}$) | 0.049 |
| 6 | Cap | Capacitance of room air and furnishings (kJ/°C) | 500 |
| 7 | $N$ | Number of total surfaces comprising room description | 7 |
| 8 | $T_o$ | Initial room temperature; also used for calculation of inside radiation coefficients (°C) | 15 |
| 9 | $w_o$ | Initial room humidity ratio (kg water/kg dry air) | 0.0075 |
| Mode 1 only | | | |
| 10 | $T_{min}$ | Set point temperature for heating (°C) | 21 |
| 11 | $T_{max}$ | Set point temperature for cooling (°C) | 25 |
| 12 | $w_{min}$ | Set point humidity ratio for humidification (kg water/kg dry air) | 0.005 |
| 13 | $w_{max}$ | Set point humidity ratio for dehumidification (kg water/kg dry air) | 0.008 |
| Input number | | | |
| 1 | $T_a$ | Ambient temperature (°C) | * |
| 2 | $w_a$ | Ambient humidity ratio (kg water/kg dry air) | * |
| 3 | $T_v$ | Temperature of ventilation flow stream (C) | * |
| 4 | $v$ | Mass flow rate of ventilation flow stream (kg/hr) | 0 |
| 5 | $w_v$ | Humidity ratio of ventilation flow stream (kg water/kg dry air) | * |
| 6 | $I$ | Rate of moisture gain (other than people) (kg/hr) | 0 |
| 7 | $N_{people}$ | Number of people in every zone | 1 |
| 8 | $I_{act}$ | Activity level of people | 2 |
| 9 | $Q_{IR}$ | Radiative energy input due to lights, equipment, etc. (kJ/hr) | 750 |
| 10 | $Q_{int}$ | Sum of all other instantaneous heat gain to space (kJ/hr) | 0 |
| 11 | $W$ | Wind-speed (m/s) | * |

[a] *Parameter read from TMY file.

Table 2: Wall parameters used in the modeling process by TRNSYS type 19, Florides, Kalogirou, Tassou, & Wrobel (2000)

Important wall parameters used in the calculations with TRNSYS Type 19

| Parameter | | Description | Set value |
|---|---|---|---|
| 4 | $r$ | Reflectance of inner surface to solar radiation | 0.7 |
| 5 | $\alpha$ | Absorptance of exterior surface to solar radiation | 0.65 |
| 7 | $h_c$ | Inside convection coefficient ($kJ/hr-m^2-C$) | 9.58 |

Table 3: Window parameters used in the modeling process by TRNSYS type 19, Florides, Kalogirou, Tassou, & Wrobel (2000)

Important window parameters used in the calculations with TRNSYS Type 19

| Parameter | | Description | Set value[a] |
|---|---|---|---|
| 5 | $t_d$ | Transmittance for diffuse solar radiation | 0.833 |
| 6 | $h_{c,i}$ | Inside convection coefficient ($kJ/hr-m^2-°C$) | 31.5 |
| 7 | $N_I$ | Number of surfaces on which transmitted beam radiation strikes | 1 |
| 8 | $k$ | First surface number of which beam of radiation strikes | 5 |
| Input number — Window Mode 1 | | | |
| 1 | $I_T$ | Total incident radiation ($kJ/m^2-hr$) | * |
| 2 | $I_{bT}$ | Incident beam radiation ($kJ/m^2-hr$) | * |
| 3 | $t$ | Overall transmittance for solar radiation | 0.833 |
| 4 | $U_g$ | Loss coefficient of window (+ night insulation) not including convection at the inside or outside surface ($kJ/hr-m^2-°C$) | 12.3 |
| 5 | $f_k$ | Fraction of incoming beam radiation that strikes surface $k$ | 1 |

[a] *Parameter calculated by the solar radiation processor.

## 2.8 Non-Monetary Benefits of Improving Thermal Performance

The improvement of building's thermal performance has monetary benefits as well as non-monetary advantages. Intangible benefits regarding this specific characteristic of residences are attributed to the quality of inside air, changing which the quality of the living space and inhabitants' behavior toward their lives in these spaces alters. Besides, according to Harvard health letter, 80-90% of people's lifetime is spent in indoor spaces which highlight the importance of inside air's quality assurance. In addition, Harvard health letter (2002) reported that "A good, strong fan certainly helps, but at around 90º F and at a humidity of 35%, fans don't protect against heat-related illness" that intensifies the need to employ air conditioners.

Some diseases and specially allergies are because of small particles in the air which are mostly a result of industrial processes, power plans and vehicle emissions. Particles are actually quite small for the filters inside the conditioning system but, using such systems requires doors and windows to be closed which contributes to lowering air change rate per hour and consequently decreasing the existing level of such pollution particles in the inside air.

Harvard health letter (2002) reports that "For several years now, researchers have documented that hospital admissions for cardiovascular and lung disease go up when air pollution levels are high". They also mentioned that these particles "May get into the blood, increasing the levels of proteins that cause blood clots; triggering inflammatory responses; constricting blood vessels; or some mix of all three". Additionally, those who suffer from asthma, hayfever which causes constant sneezing and dripping, and allergies to humidity and changes in temperature should find air conditioning a cure to their diseases because of providing even temperature and moisture reduction as well as resulting in less harmful particles in the air. Heat in some residences, specially detached houses, may be provided with natural fire via fireplace or fuel combustion which can fill the house with smoke and fine ash that contribute to allergies and respiratory disease of any kind. In addition, storing wood make an ideal place for insects and snakes, states Shopperholic,(2012).

Another disadvantage of living outside the comfort band is decreased productivity, concentration and intellectual activity. "Recent studies have shown that the ideal temperature to work in is around 20°C. and when the temperature rises by just 4°C to 24°C, productivity drops by as much as 15%" declares cross-group, (2012). An improvement in comfort level and dehydration risk reduction was also highlighted as two important advantages of air conditioning by HelloDailyNews (2012). Climachill (2012) concluded that human body's endeavor to maintain body temperature, can cause extreme fatigue when exposed to too hot or too cold temperatures.

Additionally, an increase in security assurance of dwellings as well as diminishing the level of unnecessary racket are results of keeping doors and windows closed as long as possible, reports apolloair, (2012).

# Chapter 3

# METHODOLOGY

## 3.1 Introduction

A typical single-family Cypriot residential unit is modeled with Autodesk REVIT. The floor area of the case study is approximately 110 square meters, which is a representative for the majority of family houses in Cyprus, based on a statistical investigation carried out by Panayiotou, et al. (2010). The architectural plan is also a typical plan for dwellings in modern architectural period, as a result of a research by Ozay (2005).

Consequently, the model is exported to Autodesk Ecotect in order to perform thermal analysis. For the base run, conventional construction materials of Cyprus, comprising 10 types of wall, 4 types of floor and 3 types of roof, is assigned to the model and, every single possible combination of these envelopes - totally 120 cases - is analyzed from energy consumption point of view. As a result, the best combination that leads to the least annual energy consumption is chosen. This combination is going to be referred as “the best case”. At this stage, no insulation material is considered since it is concluded by Panayiotou, et al. (2010) that normally, buildings are not thermally insulated in Cyprus.

Additionally, required information's for available thermal insulation materials in Cyprus is gathered and, according to heating and cooling degree hours, the optimum insulation thickness for the best case study is calculated, utilizing p1-p2 optimization method.

Then, the best case is insulated with available materials considering each material's optimum thickness, the placement of insulation layer in the envelope and the assignment of doors and windows with better thermal performance characteristics and, annual energy consumption is compared to the best case.

Moreover, an economic analysis is carried out on each case, and based on the net present value of each insulation material, the most proper one for Cyprus' residential sector in figured out. This case is going to be referred as "the optimum case".

Furthermore, the impact of two important factors namely increasing fenestration area and airtightness, on the energy consumption profile of the optimum case are studied.

Finally, a sensitivity analysis is performed to figure out the sensitivity level of the optimum case's payback period, on different factors such as material price, interest and inflation rates fluctuation and electricity tariff.

Detailed information of the integration process of Autodesk Revit and Ecotect, as well as mathematical optimization methods' description and information regarding the economic analysis is provided in this chapter.

## 3.2 Modeling Process

### 3.2.1 Autodesk Revit

The software is specifically created for Building Information Modeling (BIM) and provides engineers and managers with adequate facilities and tools, to model a project at the most detailed level available, in order to preserve consistency in all possible phases of a construction project. Inconsistencies emerge in several stages of design, which are carried out by totally different teams of engineers. For instance, at the architectural design stage, the design is carried out regardless of particularized structural, mechanical, electrical and plumbing consideration. Accordingly, later design stages lead to several modifications of the initially proposed plan. Such problems are minimized by Revit, by networking different engineering teams, in order to combine every possible details of a project and propose one complete flawless series of plans that is consistent with construction and operation phase of a project. This takes place by creating a master copy of the file on a main computer, which all designers have access to. Then, it is possible for each user to work on the file as local file independently, make desired changes and save it again. Besides, Revit prevents the same change by different users and corresponding conflicts as well. Additionally, Revit can carry out "Collision Checking" which prevents one physical space to be occupied by different components that contributes to conflict prevention between the design and construction phases as well.

To start a project in Revit it is possible to choose either architectural, construction, structural or mechanical template (figure 2).

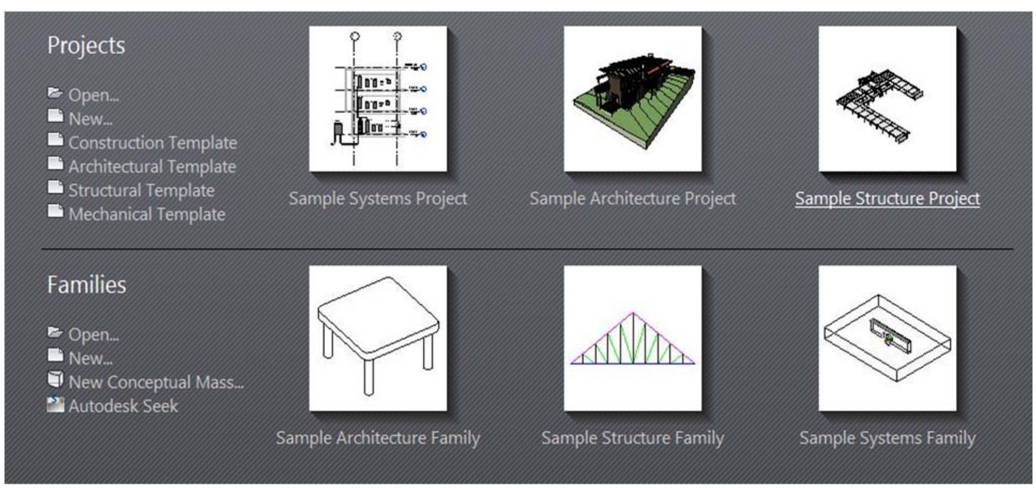



Figure 2: New project template, Revit (2013)

Prior to commence drawing, it is better to revise elevations of the project from project browser menu that is located on the bottom left side of the program by default. Altering the elevation later would cause problems and errors which are rather time consuming to figure out and solve (figure 3).

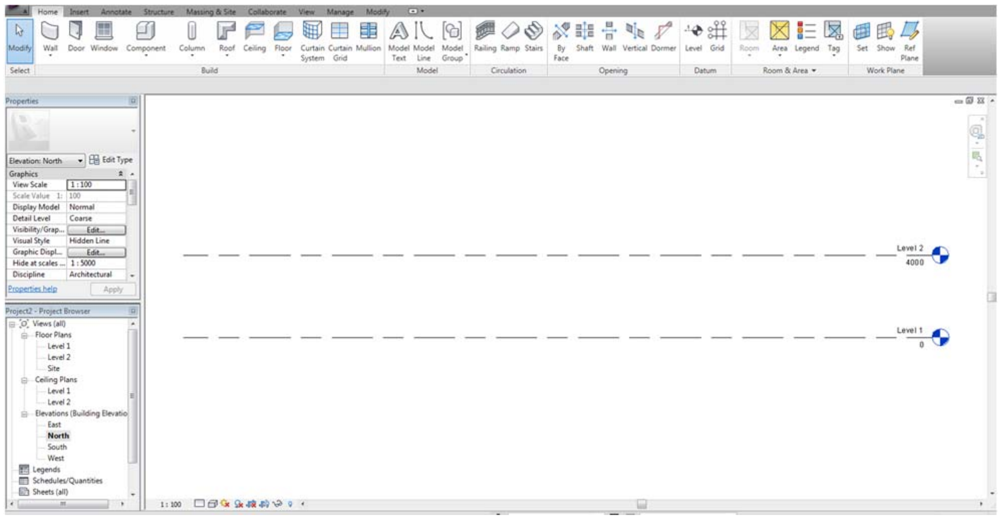


Figure 3: Defining building elevation, Revit (2013)

Going to levels from the same menu, it is possible to draw architectural plans, while envelope types can be assigned. Besides, it is indispensable to set top constraints for vertical elements - walls - to confine them within building's boundaries (figure 4).

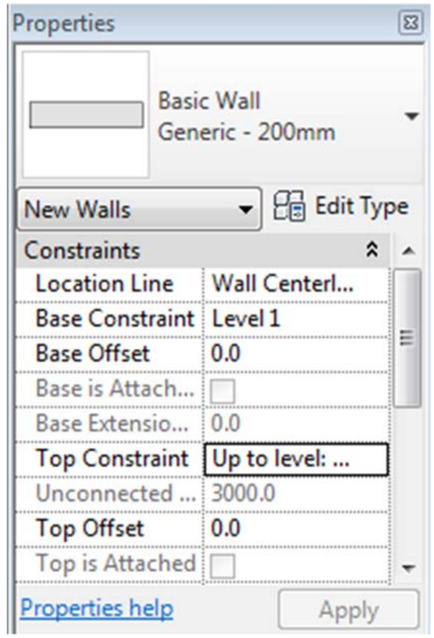


Figure 4: Defining wall constraints, Revit (2013)

Selecting desired types of doors and windows as well, the process of modeling continues (figure 5).

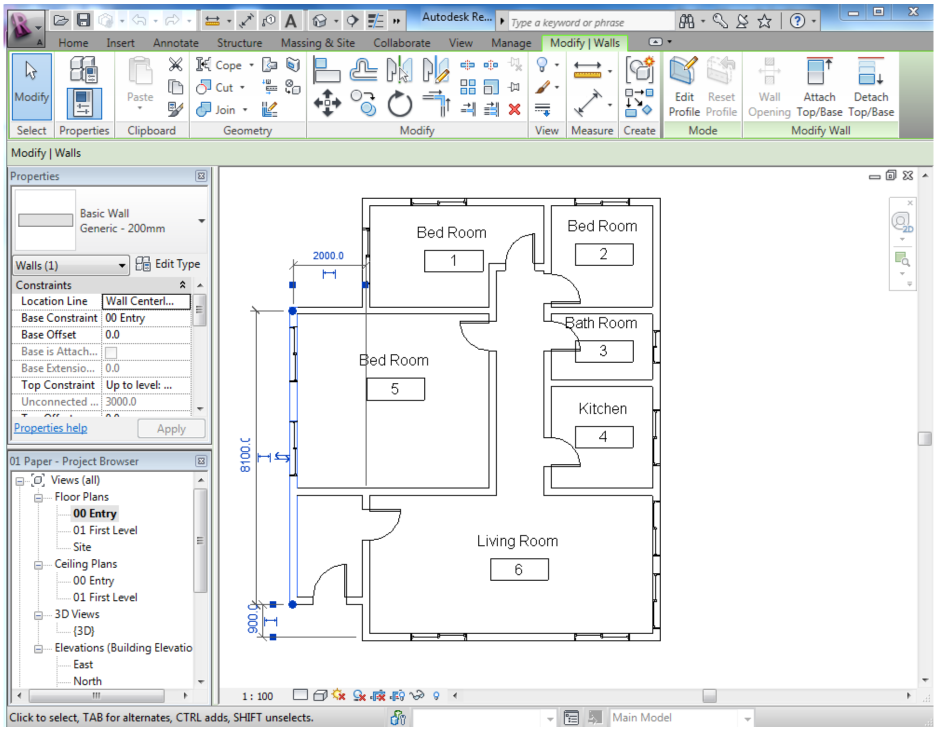



Figure 5: Completed plan drawing, Revit (2013)

One of the most important assignments in Revit is topography definition, which can be accessed from model massing and site menu as "toposurface", while the "site" is chosen from the project browser panel. Additionally, after defining the topography, from the same menu, "building pad" must be chosen, and building boundaries must be defined in order to specify floor for the project. Otherwise, building is considered constructed on the plain ground (figure 6).

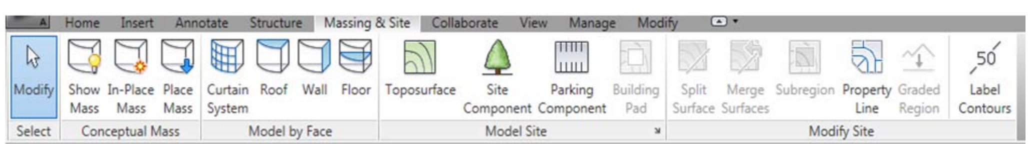



Figure 6: Assigning floor and topography to model, Revit (2013)

There are two important techniques by which errors can be eliminated during the export process to Autodesk Ecotect thermal simulation tool. First, room boundaries must be defined as every wall can be considered as a boundary from the wall properties panel (figure 7 & 8). The action will make every space separate, so during the export and import process to Ecotect, each space is transformed to an individual thermal zone, to which specific factors can be assigned. The aforesaid action can be accessed from the home panel.

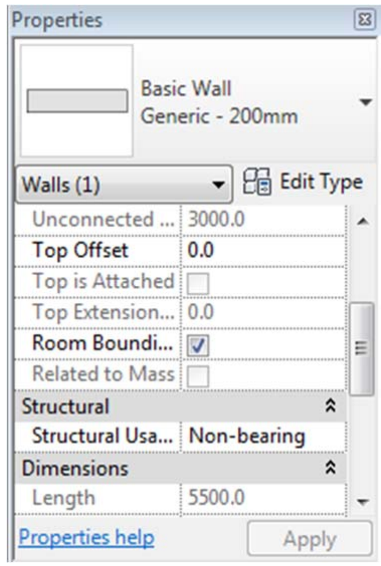


Figure 7: Making room boundaries by walls, Revit (2013)

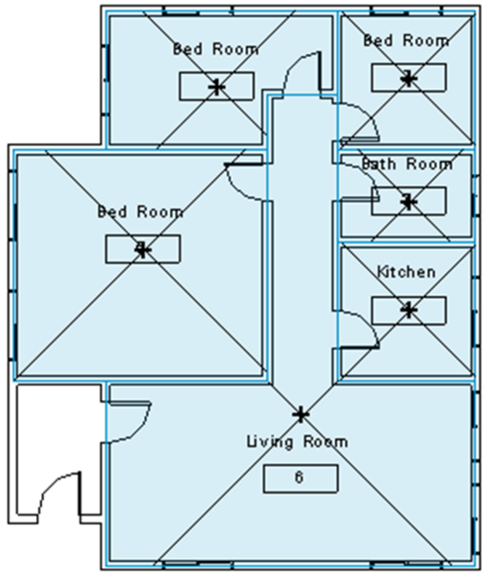



Figure 8: Assigned room boundaries, Revit (2013)

Second, there is area and volume computation function, in which it is possible to define volume and room area computation preferences. To prevent errors and to make the program able to perform the export process, both areas and volumes must be chosen to be computed in Revit software and room area computations must be opted to be computed at wall centers (figure 9).

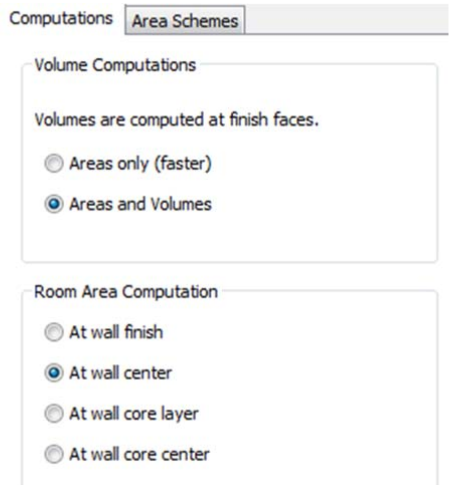



Figure 9: Volume and area calculation preferences, Revit (2013)

Finally, the export can be done by using Green Building XML schema by which all modeling information can be exported to other simulation tools such as Ecotect, in order to carry out performance simulation (figure 10).

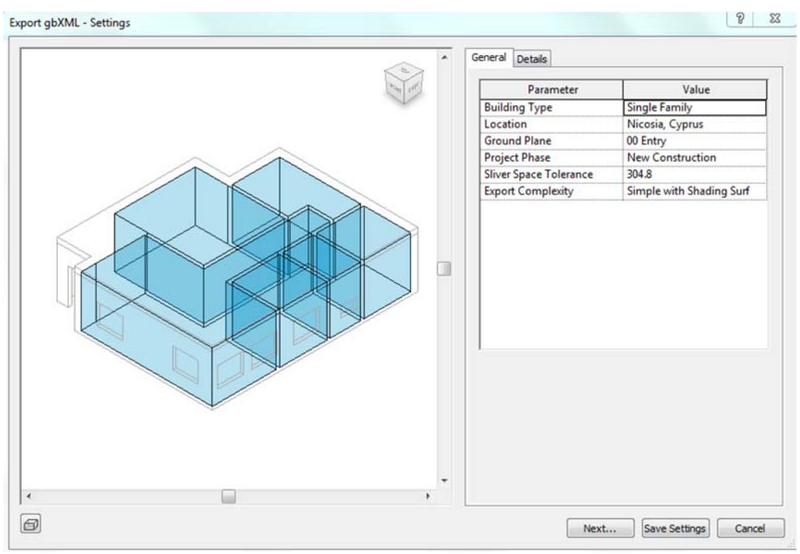



Figure 10: gbXML export from Revit, Revit (2013)

### 3.2.2 Autodesk Ecotect

Autodesk Ecotect is one of the most important simulation engines, which is being universally used for building performance modeling purposes, as it provides engineers the tool to estimate carbon emission, water and energy demand or consumption of a project. Besides, it is also capable of visualizing solar radiation as well as day lighting, shadows and reflections. The specialty of Ecotect is the ability of performance modeling in the early design stage, when simple modifications can cause a surge in the quality of project's performance or energy saving.

The import process is done by using Green Building schema (figure 11) - gbXML - which "facilitates the transfer of building information stored in CAD building information models, enabling integrated interoperability between building design models and a wide variety of engineering analysis tools and models available today"(gbXML, 2012).

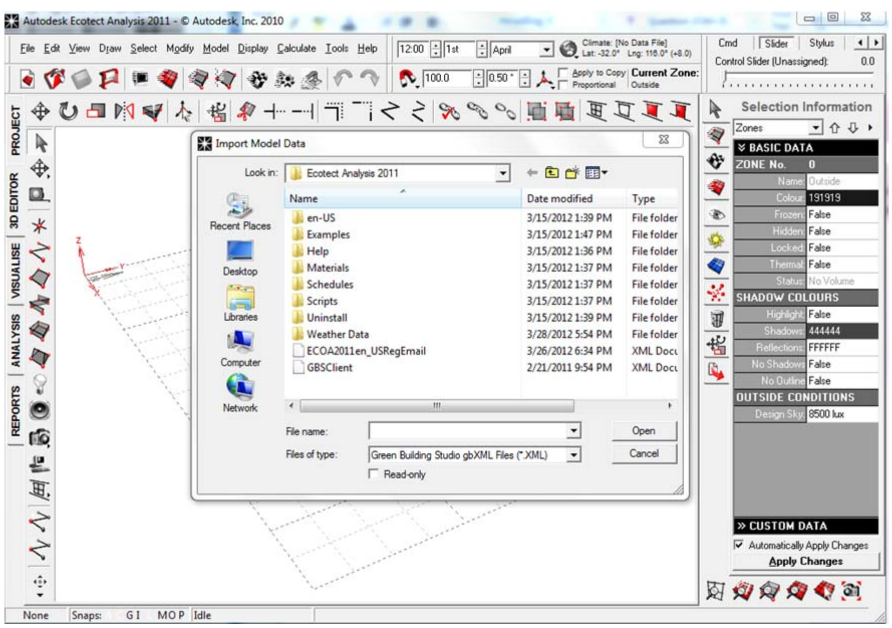


Figure 11: Importing gbXML format from Revit, Ecotect (2011)

After a successful import from Revit, some modifications are indispensable such as, eliminating extra envelopes that are regarded as a separate zone in Ecotect. Normally, the roof is imported as a detached envelope and can be deleted afterwards. Additionally, the entrance of the building - a space that is not designed for living and, has no effect on the performance and the energy consumption of the unit - is considered as an independent thermal zone, and should be eliminated as well. Subsequently, the model is ready for technical assignment and performance analysis procedure (figure 12).

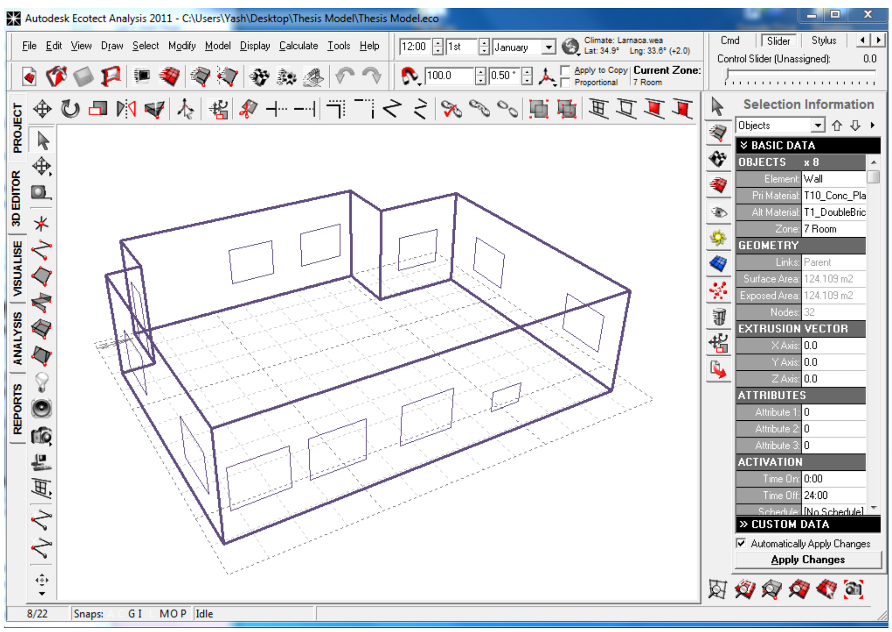


Figure 12: Successfully imported model using gbXML schema, Ecotect (2011)

Whole building is considered as one thermal zone to which a 24 hours a day air conditioning system is assigned.

Obviously, 24 hours a day air conditioning cannot possibly represent the reality of using these systems in dwelling since, it leads to a surge in energy consumption and of course energy costs, which is not an option for families. Besides, as long as the temperature is tolerable in Cyprus, it is widely preferred to use natural ventilation in residences but, in order to be able to make a comparison between different case studies and to demonstrate the impact of using thermal insulation materials, simplification has been done during the analysis process. By the way, different working schedules could be assigned to air conditioning working schedule.

In order to calculate thermal comfort, several factors must be set for each thermal zone, which is the whole house in this case (figure 13).

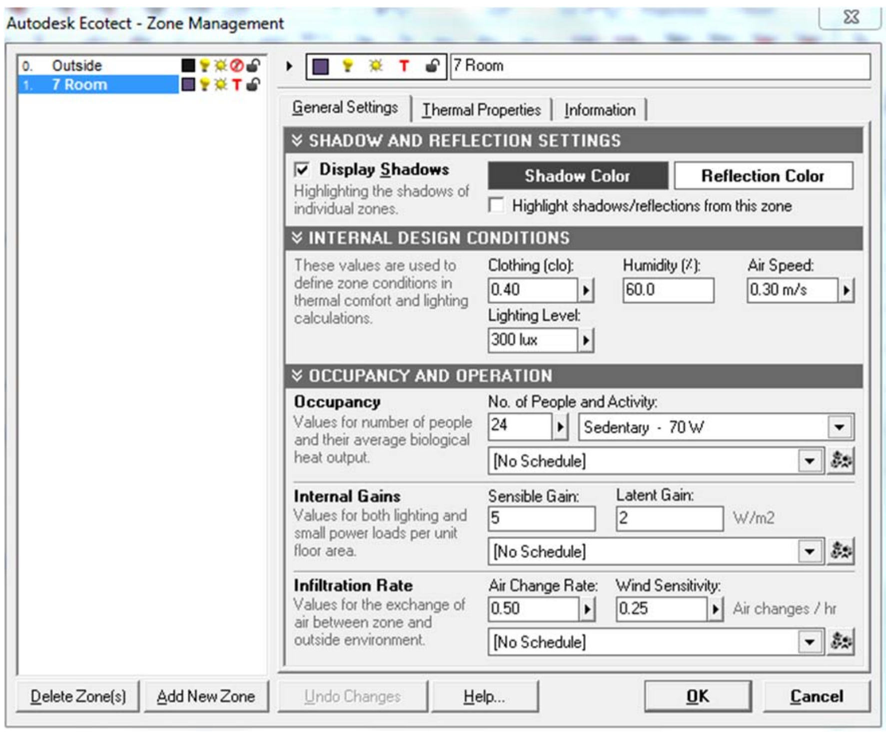



Figure 13: Thermal comfort factors assignment, Ecotect (2011)

For thermal comfort calculations, several factors must be considered in the software. In this study, factors are set based on ASHRAE standards and guidlines. Clothing factor is set to 0.6 - for using trousers and shirts in the house -, air speed to 0.3 m/s - for being barely noticeable -, lighting level to 300 lux, activity level to 70w which accounts for normal activity in a family house, air change per hour to 0.5 and, wind sensitivity to 0.25. Twenty two square meters - area divided by 5 people - is set for each person's activities in the model house. These factors kept unchanged for all case studies. Besides, for heating and cooling load calculations, a 95% efficient air conditioning system is assigned to the model, to achieve thermal comfort during day and night. Additionally, lower band of the temperature range was set to 18 while 26 degrees of centigrade was set for the upper band (figure 14).

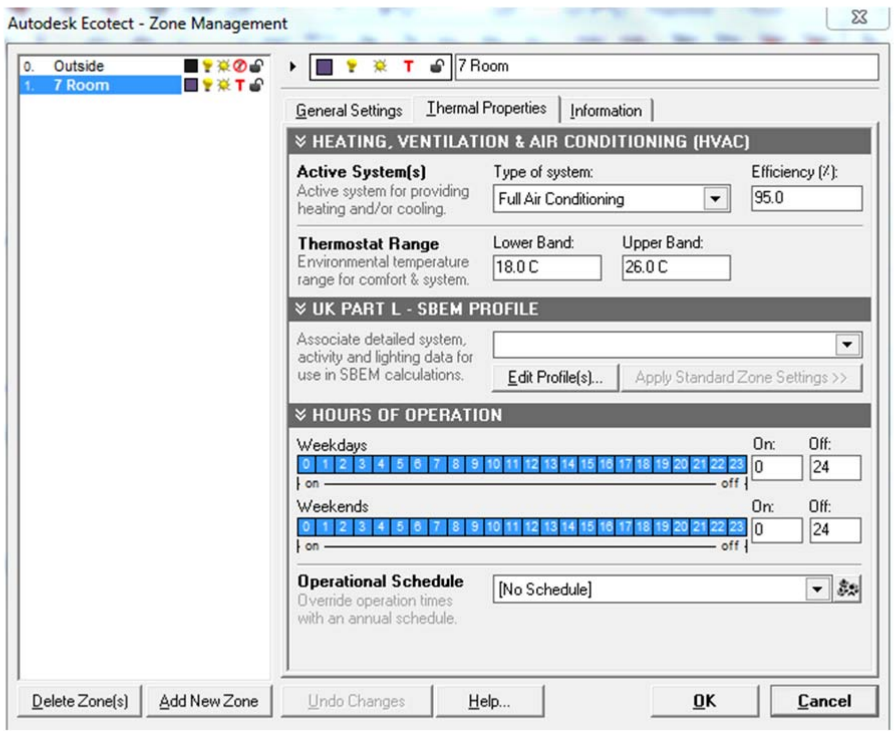


Figure 14: HVAC assignments, settings, and schedules, Ecotect (2011)

Thermal comfort was calculated by “monthly comfort times” method which shows total uncomfortable times each month. Applying “average adaptive comfort” according to Ecotect simulation tool, “assumes that people are adaptive in more controlled buildings but not as much as in free running”. By using the formula “T(c)=24.2+0.43(tave-22)x exp(-[(tave-22)/28.284]^2“ total thermal uncomfortable times were calculated.

Making an envelope with desired construction layers is possible by modifying the element library (figure 15).

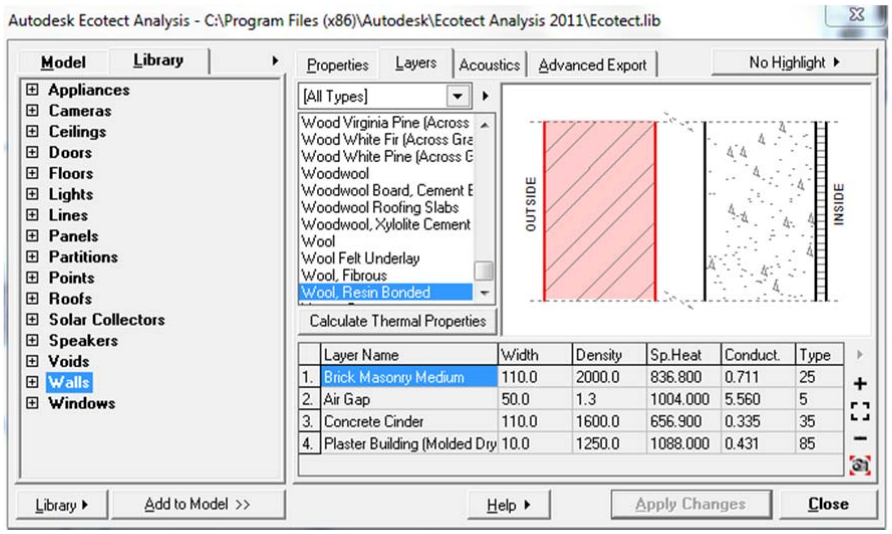


Figure 15: Envelope design by layers, Ecotect (2011)

All types of layers all available in the library by which a specific wall could be modified. Furthermore, by modifying the thickness - width - of any layer, envelopes with multifarious thicknesses are created. Entering desired figures for the density, specific heat, and thermal conductivity, it is possible to define new materials.

Finally, the overall thermal specifications of envelopes are calculated (figure 16) and, the envelopes are ready to be assigned to the model.

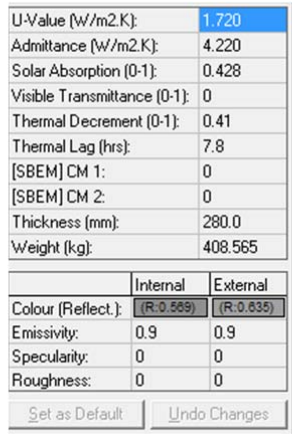


Figure 16: Envelope thermal properties, Ecotect (2011)

The location of project or case study must be selected from the weather data of Ecotect (figure 17) or it can be converted from different other formats available online.

The weather data is based on a typical meteorological year of a location which comprises different information about the climate condition of a location. The aforementioned data is normally collected from more than just one year and it represents the average conditions of that specific location. Information about rainfall amount, wind direction and speed, solar radiation and temperature is provided in a weather data.

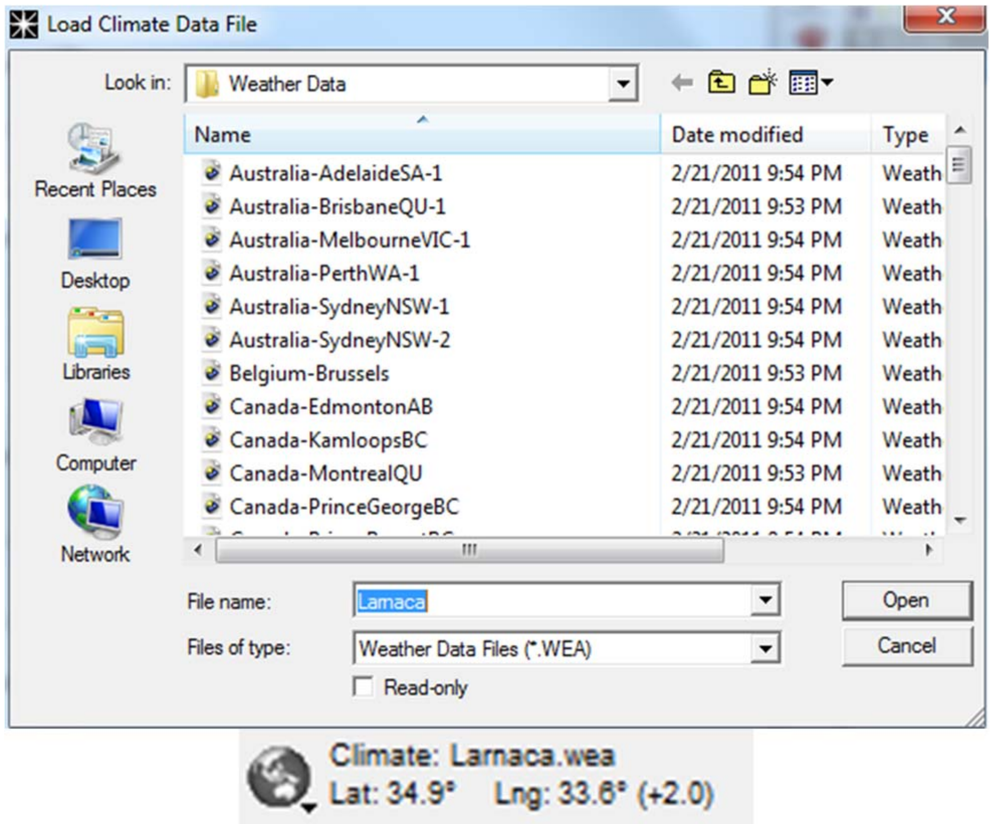



Figure 17: Weather data and specifications, Ecotect (2011)

At last, from the "calculate" tab, thermal analysis can be performed using which function, thermal zones' outside and inside temperature, relative contribution of different heat flow paths, heating, ventilation and cooling supply loads to maintain thermostat temperatures, times outside comfort or radiant temperature effects and comparative graphs for loads and temperatures could be calculated.

The assignment of air conditioning systems must be done prior to analysis performance else, no loads will be calculated (figure 18).

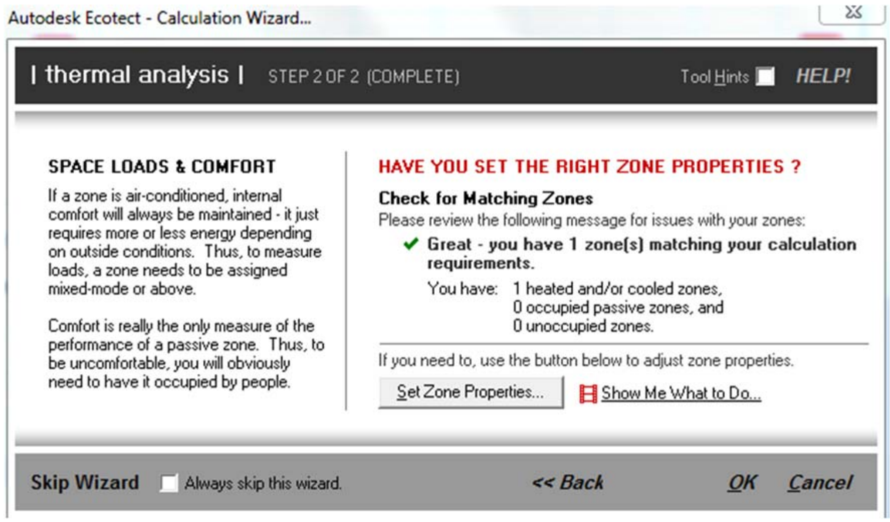
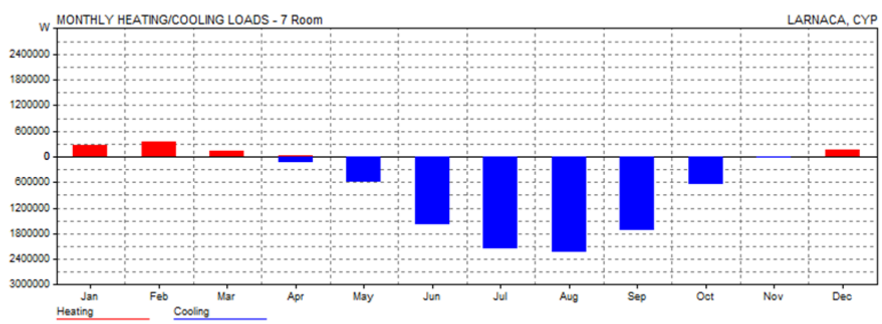


Figure 18: Thermal analysis procedure, Ecotect (2011)

Results are demonstrated as graphs as well as tables, according which the heating, cooling, and total energy consumption of the model could be viewed (graph 1 & table 4).



Graph 1: Heating and cooling load graph according to months, Ecotect (2011)

Table 4: Energy consumption as thermal analysis result, Ecotect (2011)

MONTHLY HEATING/COOLING LOADS

Zone: 7 Room
Operation: Weekdays 00-24, Weekends 00-24.
Thermostat Settings: 18.0 - 26.0 C

Max Heating: 4104 W at 05:00 on 4th February
Max Cooling: 7584 W at 13:00 on 15th August

| MONTH | HEATING (Wh) | COOLING (Wh) | TOTAL (Wh) |
|---|---|---|---|
| Jan | 264145 | 0 | 264145 |
| Feb | 337122 | 0 | 337122 |
| Mar | 124374 | 0 | 124374 |
| Apr | 33222 | 147456 | 180678 |
| May | 0 | 602549 | 602549 |
| Jun | 0 | 1584100 | 1584100 |
| Jul | 0 | 2164580 | 2164580 |
| Aug | 0 | 2231959 | 2231959 |
| Sep | 0 | 1729712 | 1729712 |
| Oct | 0 | 632983 | 632983 |
| Nov | 11899 | 18256 | 30155 |
| Dec | 156696 | 0 | 156696 |
| TOTAL | 927458 | 9111594 | 10039052 |
| PER M² | 8281 | 81354 | 89634 |
| Floor Area: | | 112.000 m2 | |

## 3.3 Available Thermal Insulation Materials in Cyprus

There are a variety of insulation materials available in the construction industry of Cyprus. Normally, the costs of the aforementioned materials are comparatively low but, due to high transportation costs in Cyprus, the final cost of these materials increases significantly.

Furthermore, as the majority of owners do not apply insulation to their buildings, the demand for such materials are noticeably low, which is another factor that contributes to the rise in the prices.

The most common materials available in Cyprus, could be derived from the official unit prices while, more precise and up-to-date information can be collected from local suppliers. In this case, data is gathered from C.E.E LTD which is one of the prominent material suppliers in Cyprus. A summary of the face to face interview is presented below (June 2012 prices):

1- Expanded polystyrene (EPS): It is available in 2 different densities (12 and 22 kg/m3). The price for the first type is 90 Turkish Lira per cubic meter and 190 TL for the second one. Having EPS cut to sheets, imposes an extra 15TL to the final price, if less than 5cm sheets are needed.

2- Extruded polystyrene (XPS): This type of polystyrene is one of the strongest insulation materials available with 2500 Pascal per cubic meter compressive strength and up to 32 kg/m3 density. Indeed, the cost is noticeably high (329TL per cubic meter).

3- Fiberglass: The density of this material is 14 kg/m3, and it is provided in rolls of 10m length, 1.2m width, and 8cm thickness. Its cost is 52TL per cubic meter. The 22 kg/m3 dense ones are provided in 1.2m by 0.6m by 8cm sheets and the cost is 85TL per cubic meter.

4- Rockwool could also be available in Cyprus in 2 densities, 52 and 150 kg/m3, which prices are 194 and 554TL per cubic meter respectively, provided in 1.2m by 0.6m by 5cm sheets.

5- A less common material namely perlite is also available and its price is 8.4TL per cubic meter.

Thermal insulation material's information is summarized in table 5. It should be noted that some prices where in US dollars, which presented in Turkish Lira so it is easier to make the comparison. The exchange rate which is used for changing US dollar to Turkish Lira is derived from official IS bank website.

Table 5: Available thermal insulation materials' information

| Name | Density (Kg/m3) | Thermal Conductivity | Price (TL/M3) | Additional Information |
|---|---|---|---|---|
| Expanded Polystyrene | 12 | 0.04 | 90 | Extra 15 TL for cutting up to 5cm |
| Expanded Polystyrene (High Density) | 22 | 0.035 | 190 | |
| Extruded Polystyrene | 28-32 | 0.027 | 329 | |
| Fiberglass | 14 | 0.04 | 52 | 8cm Sheets (12m2) |
| Fiberglass (High Density) | 22 | 0.035 | 85 | 5cm Sheets (8.64m2) |
| Rockwool | 52 | 0.045 | 194 | 5cm Sheets (0.72m2) |
| Rockwool (High Density) | 150 | 0.034 | 554 | 5cm Sheets (0.72m2) |
| Perlite | ---- | 0.031 | 8.4 | 200 Liter |

## 3.4 Conventional Building External Envelopes in Cyprus

In this study, typical materials used in residential building's external envelopes in Cyprus are selected. 10 types of wall, 4 types of floor, 3 types of roof, 2 types of windows and 2 types of doors are considered. Construction details are provided in this section (figure 19-39).

Besides, specifications of all materials such as the width, density, specific heat, and thermal conductivity, as well as thermal characteristics of external envelopes like the overall U-value, admittance, solar absorbance and thickness which are the most important factors affecting thermal performance of an envelope, are presented as screenshots taken from Ecotect simulation tool. Aforesaid screenshots are presented in tables 6-47.

### 3.4.1 Walls

#### 3.4.1.1 Wall Type 1

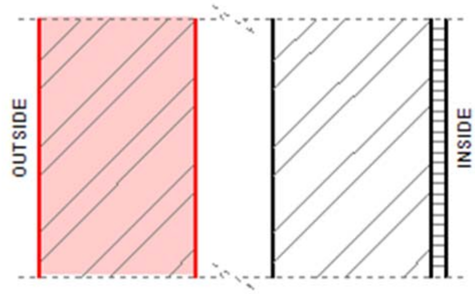



Figure 19: Wall type 1 layout, Ecotect (2011)

Table 6: Wall type 1 layers, Ecotect (2011)

| | Layer Name | Width | Density | Sp.Heat | Conduct. | Type |
|---|---|---|---|---|---|---|
| 1. | Brick Masonry Medium | 100.0 | 2000.0 | 836.800 | 0.711 | 25 |
| 2. | Air Gap | 50.0 | 1.3 | 1004.000 | 5.560 | 5 |
| 3. | Brick Masonry Medium | 100.0 | 2000.0 | 836.800 | 0.711 | 25 |
| 4. | Plaster Building (Molded Dry | 10.0 | 1250.0 | 1088.000 | 0.431 | 85 |

Table 7: Wall type 1 thermal properties, Ecotect (2011)

| | |
|---|---|
| U-Value (W/m2.K): | 1.510 |
| Admittance (W/m2.K): | 5.010 |
| Solar Absorption (0-1): | 0.559 |
| Visible Transmittance (0-1): | 0 |
| Thermal Decrement (0-1): | 0.03 |
| Thermal Lag (hrs): | 7.8 |
| [SBEM] CM 1: | 0 |
| [SBEM] CM 2: | 0 |
| Thickness (mm): | 260.0 |
| Weight (kg): | 412.565 |

| | Internal | External |
|---|---|---|
| Colour (Reflect.): | (R:0.490) | (R:0.490) |
| Emissivity: | 0.9 | 0.9 |
| Specularity: | 0 | 0 |
| Roughness: | 0 | 0 |

### 3.4.1.2 Wall Type 2

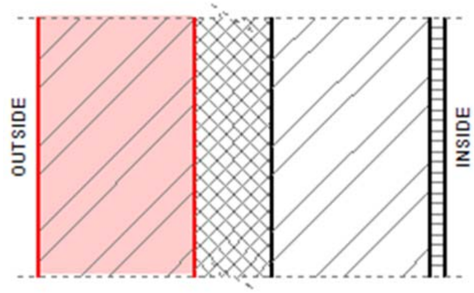



Figure 20: Wall type 2 layout, Ecotect (2011)

Table 8: Wall type 2 layers, Ecotect (2011)

| | Layer Name | Width | Density | Sp.Heat | Conduct. | Type |
|---|---|---|---|---|---|---|
| 1. | Brick Masonry Medium | 100.0 | 2000.0 | 836.800 | 0.711 | 25 |
| 2. | Foil-Faced, Glass-Fibre Rein | 50.0 | 32.0 | 920.000 | 0.019 | 95 |
| 3. | Brick Masonry Medium | 100.0 | 2000.0 | 836.800 | 0.711 | 25 |
| 4. | Plaster Building (Molded Dry | 10.0 | 1250.0 | 1088.000 | 0.431 | 85 |

Table 9: Wall type 2 thermal properties, Ecotect (2011)

| | |
|---|---|
| U-Value (W/m2.K): | 0.320 |
| Admittance (W/m2.K): | 4.990 |
| Solar Absorption (0-1): | 0.559 |
| Visible Transmittance (0-1): | 0 |
| Thermal Decrement (0-1): | 0.24 |
| Thermal Lag (hrs): | 7.8 |
| [SBEM] CM 1: | 0 |
| [SBEM] CM 2: | 0 |
| Thickness (mm): | 260.0 |
| Weight (kg): | 414.100 |

| | Internal | External |
|---|---|---|
| Colour (Reflect.): | (R:0.490) | (R:0.490) |
| Emissivity: | 0.9 | 0.9 |
| Specularity: | 0 | 0 |
| Roughness: | 0 | 0 |

### 3.4.1.3 Wall Type 3

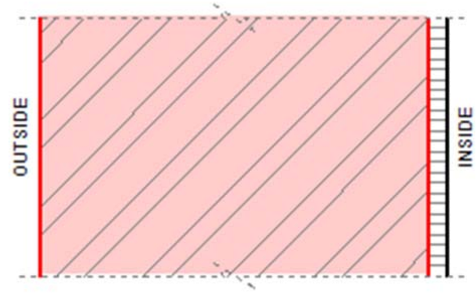



Figure 21: Wall type 3 layout, Ecotect (2011)

Table 10: Wall type 3layers, Ecotect (2011)

| | Layer Name | Width | Density | Sp.Heat | Conduct. | Type |
|---|---|---|---|---|---|---|
| 1. | Brick Masonry Medium | 200.0 | 2000.0 | 836.800 | 0.711 | 25 |
| 2. | Plaster Building (Molded Dry | 10.0 | 1250.0 | 1088.000 | 0.431 | 85 |

Table 11: Wall type 3 thermal properties, Ecotect (2011)

| | |
|---|---|
| U-Value (W/m2.K): | 2.070 |
| Admittance (W/m2.K): | 4.550 |
| Solar Absorption (0-1): | 0.418 |
| Visible Transmittance (0-1): | 0 |
| Thermal Decrement (0-1): | 0.44 |
| Thermal Lag (hrs): | 3 |
| [SBEM] CM 1: | 0 |
| [SBEM] CM 2: | 0 |
| Thickness (mm): | 210.0 |
| Weight (kg): | 412.500 |

| | Internal | External |
|---|---|---|
| Colour (Reflect.): | (R:0.569) | (R:0.647) |
| Emissivity: | 0.9 | 0.9 |
| Specularity: | 0 | 0 |
| Roughness: | 0 | 0 |

### 3.4.1.4 Wall Type 4

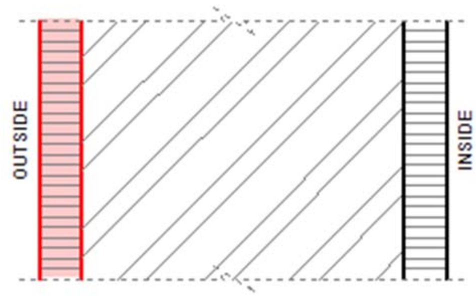



Figure 22: Wall type 4 layout, Ecotect (2011)

Table 12: Wall type 4 layers, Ecotect (2011)

| | Layer Name | Width | Density | Sp.Heat | Conduct. | Type |
|---|---|---|---|---|---|---|
| 1. | Plaster Building (Molded Dry | 20.0 | 1250.0 | 1088.000 | 0.431 | 85 |
| 2. | Block, Lightweight | 150.0 | 600.0 | 840.000 | 0.220 | 25 |
| 3. | Plaster Building (Molded Dry | 20.0 | 1250.0 | 1088.000 | 0.431 | 85 |

Table 13: Wall type 4 thermal properties, Ecotect (2011)

| | |
|---|---|
| U-Value (W/m2.K): | 1.050 |
| Admittance (W/m2.K): | 3.000 |
| Solar Absorption (0-1): | 0.428 |
| Visible Transmittance (0-1): | 0 |
| Thermal Decrement (0-1): | 0.73 |
| Thermal Lag (hrs): | 7.8 |
| [SBEM] CM 1: | 0 |
| [SBEM] CM 2: | 0 |
| Thickness (mm): | 190.0 |
| Weight (kg): | 140.000 |

| | Internal | External |
|---|---|---|
| Colour (Reflect.): | (R:0.569) | (R:0.635) |
| Emissivity: | 0.9 | 0.9 |
| Specularity: | 0 | 0 |
| Roughness: | 0 | 0 |

### 3.4.1.5 Wall Type 5

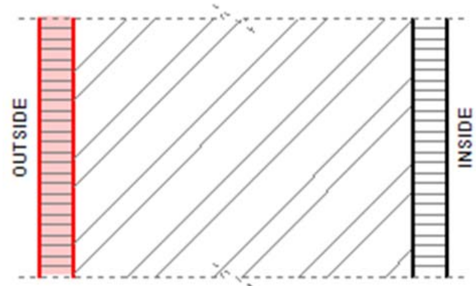



Figure 23: Wall type 5 layout, Ecotect (2011)

Table 14: Wall type 5 layers, Ecotect (2011)

| | Layer Name | Width | Density | Sp.Heat | Conduct. | Type |
|---|---|---|---|---|---|---|
| 1. | Plaster Building (Molded Dry | 20.0 | 1250.0 | 1088.000 | 0.431 | 85 |
| 2. | Block, Lightweight | 200.0 | 600.0 | 840.000 | 0.220 | 25 |
| 3. | Plaster Building (Molded Dry | 20.0 | 1250.0 | 1088.000 | 0.431 | 85 |

Table 15: Wall type 5 thermal properties, Ecotect (2011)

| | |
|---|---|
| U-Value (W/m2.K): | 0.850 |
| Admittance (W/m2.K): | 3.080 |
| Solar Absorption (0-1): | 0.428 |
| Visible Transmittance (0-1): | 0 |
| Thermal Decrement (0-1): | 0.58 |
| Thermal Lag (hrs): | 7.8 |
| [SBEM] CM 1: | 0 |
| [SBEM] CM 2: | 0 |
| Thickness (mm): | 240.0 |
| Weight (kg): | 170.000 |

| | Internal | External |
|---|---|---|
| Colour (Reflect.): | (R:0.569) | (R:0.635) |
| Emissivity: | 0.9 | 0.9 |
| Specularity: | 0 | 0 |
| Roughness: | 0 | 0 |

### 3.4.1.6 Wall Type 6

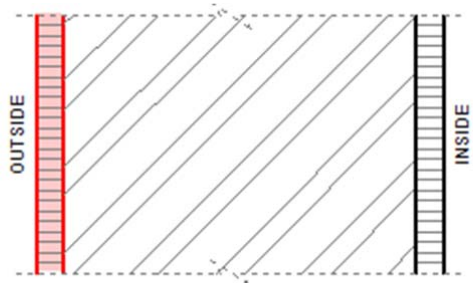



Figure 24: Wall type 6 layout, Ecotect (2011)

Table 16: Wall type 6 layers, Ecotect (2011)

| | Layer Name | Width | Density | Sp.Heat | Conduct. | Type |
|---|---|---|---|---|---|---|
| 1. | Plaster Building (Molded Dry | 20.0 | 1250.0 | 1088.000 | 0.431 | 85 |
| 2. | Block, Lightweight | 250.0 | 600.0 | 840.000 | 0.220 | 25 |
| 3. | Plaster Building (Molded Dry | 20.0 | 1250.0 | 1088.000 | 0.431 | 85 |

Table 17: Wall type 6 thermal properties, Ecotect (2011)

| | |
|---|---|
| U-Value (W/m2.K): | 0.710 |
| Admittance (W/m2.K): | 3.090 |
| Solar Absorption (0-1): | 0.428 |
| Visible Transmittance (0-1): | 0 |
| Thermal Decrement (0-1): | 0.44 |
| Thermal Lag (hrs): | 7.8 |
| [SBEM] CM 1: | 0 |
| [SBEM] CM 2: | 0 |
| Thickness (mm): | 290.0 |
| Weight (kg): | 200.000 |

| | Internal | External |
|---|---|---|
| Colour (Reflect.): | (R:0.569) | (R:0.635) |
| Emissivity: | 0.9 | 0.9 |
| Specularity: | 0 | 0 |
| Roughness: | 0 | 0 |

### 3.4.1.7 Wall Type 7

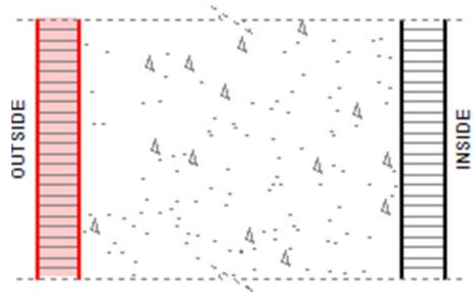



Figure 25: Wall type 7 layout, Ecotect (2011)

Table 18: Wall type 7 layers, Ecotect (2011)

| | Layer Name | Width | Density | Sp.Heat | Conduct. | Type |
|---|---|---|---|---|---|---|
| 1. | Plaster Building (Molded Dry | 20.0 | 1250.0 | 1088.000 | 0.431 | 85 |
| 2. | Block, Hollow, Lightweight, : | 150.0 | 780.0 | 840.000 | 0.760 | 35 |
| 3. | Plaster Building (Molded Dry | 20.0 | 1250.0 | 1088.000 | 0.431 | 85 |

Table 19: Wall type 7 thermal properties, Ecotect (2011)

| | |
|---|---|
| U-Value (W/m2.K): | 2.140 |
| Admittance (W/m2.K): | 3.640 |
| Solar Absorption (0-1): | 0.428 |
| Visible Transmittance (0-1): | 0 |
| Thermal Decrement (0-1): | 0.78 |
| Thermal Lag (hrs): | 7.8 |
| [SBEM] CM 1: | 0 |
| [SBEM] CM 2: | 0 |
| Thickness (mm): | 190.0 |
| Weight (kg): | 167.000 |

| | Internal | External |
|---|---|---|
| Colour (Reflect.): | (R:0.569) | (R:0.635) |
| Emissivity: | 0.9 | 0.9 |
| Specularity: | 0 | 0 |
| Roughness: | 0 | 0 |

### 3.4.1.8 Wall Type 8

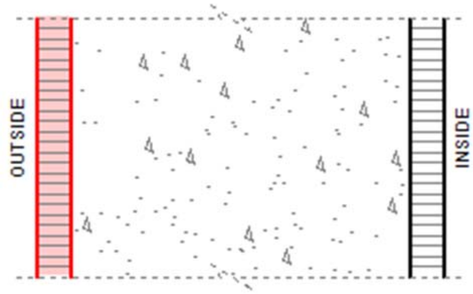



Figure 26: Wall type 8 layout, Ecotect (2011)

Table 20: Wall type 8 layers, Ecotect (2011)

| | Layer Name | Width | Density | Sp.Heat | Conduct. | Type |
|---|---|---|---|---|---|---|
| 1. | Plaster Building (Molded Dry | 20.0 | 1250.0 | 1088.000 | 0.431 | 85 |
| 2. | Block, Hollow, Lightweight, : | 200.0 | 780.0 | 840.000 | 0.760 | 35 |
| 3. | Plaster Building (Molded Dry | 20.0 | 1250.0 | 1088.000 | 0.431 | 85 |

Table 21: Wall type 8 thermal properties, Ecotect (2011)

| | |
|---|---|
| U-Value (W/m2.K): | 1.870 |
| Admittance (W/m2.K): | 3.770 |
| Solar Absorption (0-1): | 0.428 |
| Visible Transmittance (0-1): | 0 |
| Thermal Decrement (0-1): | 0.68 |
| Thermal Lag (hrs): | 7.8 |
| [SBEM] CM 1: | 0 |
| [SBEM] CM 2: | 0 |
| Thickness (mm): | 240.0 |
| Weight (kg): | 206.000 |

| | Internal | External |
|---|---|---|
| Colour (Reflect.): | (R:0.569) | (R:0.635) |
| Emissivity: | 0.9 | 0.9 |
| Specularity: | 0 | 0 |
| Roughness: | 0 | 0 |

#### 3.4.1.9 Wall Type 9

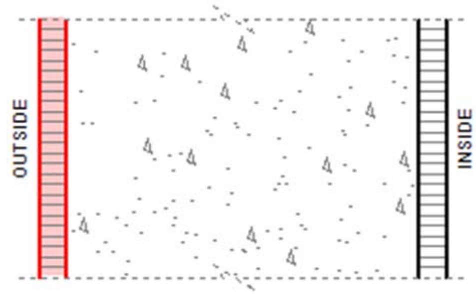



Figure 27: Wall type 9 layout, Ecotect (2011)

Table 22: Wall type 9 layers, Ecotect (2011)

| | Layer Name | Width | Density | Sp.Heat | Conduct. | Type |
|---|---|---|---|---|---|---|
| 1. | Plaster Building (Molded Dry | 20.0 | 1250.0 | 1088.000 | 0.431 | 85 |
| 2. | Block, Hollow, Lightweight, : | 250.0 | 780.0 | 840.000 | 0.760 | 35 |
| 3. | Plaster Building (Molded Dry | 20.0 | 1250.0 | 1088.000 | 0.431 | 85 |

Table 23: Wall type 9 thermal properties, Ecotect (2011)

| | |
|---|---|
| U-Value (W/m2.K): | 1.670 |
| Admittance (W/m2.K): | 3.850 |
| Solar Absorption (0-1): | 0.428 |
| Visible Transmittance (0-1): | 0 |
| Thermal Decrement (0-1): | 0.58 |
| Thermal Lag (hrs): | 7.8 |
| [SBEM] CM 1: | 0 |
| [SBEM] CM 2: | 0 |
| Thickness (mm): | 290.0 |
| Weight (kg): | 245.000 |

| | Internal | External |
|---|---|---|
| Colour (Reflect.): | (R:0.569) | (R:0.635) |
| Emissivity: | 0.9 | 0.9 |
| Specularity: | 0 | 0 |
| Roughness: | 0 | 0 |

### 3.4.1.10 Wall Type 10

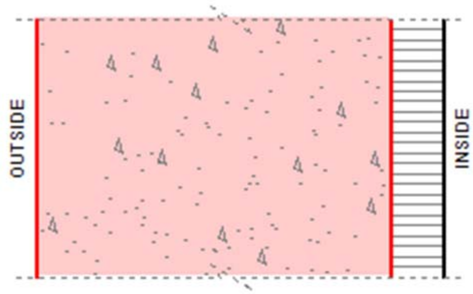



Figure 28: Wall type 10 layout, Ecotect (2011)

Table 24: Wall type 10 layers, Ecotect (2011)

| | Layer Name | Width | Density | Sp.Heat | Conduct. | Type |
|---|---|---|---|---|---|---|
| 1. | Concrete 1-4 Dry | 200.0 | 2300.0 | 656.900 | 0.753 | 35 |
| 2. | Plaster Building (Molded Dry | 30.0 | 1250.0 | 1088.000 | 0.431 | 85 |

Table 25: Wall type 10 thermal properties, Ecotect (2011)

| | |
|---|---|
| U-Value (W/m2.K): | 1.950 |
| Admittance (W/m2.K): | 4.210 |
| Solar Absorption (0-1): | 0.506 |
| Visible Transmittance (0-1): | 0 |
| Thermal Decrement (0-1): | 0.43 |
| Thermal Lag (hrs): | 5 |
| [SBEM] CM 1: | 0 |
| [SBEM] CM 2: | 0 |
| Thickness (mm): | 230.0 |
| Weight (kg): | 497.500 |

| | Internal | External |
|---|---|---|
| Colour (Reflect.): | (R:0.549) | (R:0.549) |
| Emissivity: | 0.9 | 0.9 |
| Specularity: | 0 | 0 |
| Roughness: | 0 | 0 |

### 3.4.2 Floors

#### 3.4.2.1 Floor Type 1

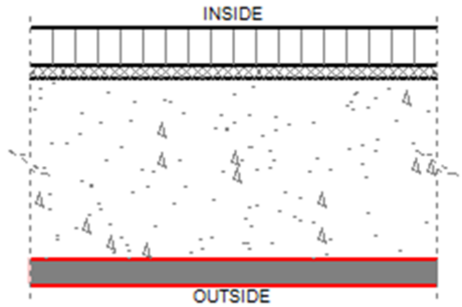



Figure 29: Floor type 1 layout, Ecotect (2011)

Table 26: Floor type 1 Layers, Ecotect (2011)

| | Layer Name | Width | Density | Sp.Heat | Conduct. | Type |
|---|---|---|---|---|---|---|
| 1. | Plaster Board | 10.0 | 1250.0 | 1088.000 | 0.431 | 85 |
| 2. | Concrete 1-4 Dry | 70.0 | 2300.0 | 656.900 | 0.753 | 35 |
| 3. | Carpet Underlay | 5.0 | 160.0 | 1732.000 | 0.045 | 95 |
| 4. | Carpet | 15.0 | 240.0 | 732.200 | 0.055 | 79 |

Table 27: Floor type 1 thermal properties, Ecotect (2011)

| | |
|---|---|
| U-Value (W/m2.K): | 1.470 |
| Admittance (W/m2.K): | 1.650 |
| Solar Absorption (0-1): | 0.324483 |
| Visible Transmittance (0-1): | 0 |
| Thermal Decrement (0-1): | 0.8 |
| Thermal Lag (hrs): | 4 |
| [SBEM] CM 1: | 0 |
| [SBEM] CM 2: | 0 |
| Thickness (mm): | 100.0 |
| Weight (kg): | 177.900 |

| | Internal | External |
|---|---|---|
| Colour (Reflect.): | (R:0.752) | (R:0.752) |
| Emissivity: | 0.9 | 0.9 |
| Specularity: | 0 | 0 |
| Roughness: | 0 | 0 |

### 3.4.2.2 Floor Type 2

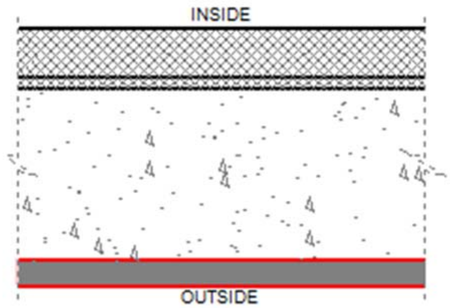



Figure 30: Floor type 2 layout, Ecotect (2011)

Table 28: Floor type 2 Layers, Ecotect (2011)

| | Layer Name | Width | Density | Sp.Heat | Conduct. | Type |
|---|---|---|---|---|---|---|
| 1. | Plaster Board | 10.0 | 1250.0 | 1088.000 | 0.431 | 85 |
| 2. | Concrete 1-4 Dry | 70.0 | 2300.0 | 656.900 | 0.753 | 35 |
| 3. | Carpet Underlay | 5.0 | 160.0 | 1732.000 | 0.045 | 95 |
| 4. | Tiles | 20.0 | 1200.0 | 1470.000 | 0.190 | 95 |

Table 29: Floor type 2 thermal properties, Ecotect (2011)

| | |
|---|---|
| U-Value (W/m2.K): | 1.960 |
| Admittance (W/m2.K): | 2.880 |
| Solar Absorption (0-1): | 0.324483 |
| Visible Transmittance (0-1): | 0 |
| Thermal Decrement (0-1): | 0.78 |
| Thermal Lag (hrs): | 4 |
| [SBEM] CM 1: | 0 |
| [SBEM] CM 2: | 0 |
| Thickness (mm): | 105.0 |
| Weight (kg): | 198.300 |

| | Internal | External |
|---|---|---|
| Colour (Reflect.): | (R:0.752) | (R:0.752) |
| Emissivity: | 0.9 | 0.9 |
| Specularity: | 0 | 0 |
| Roughness: | 0 | 0 |

### 3.4.2.3 Floor Type 3

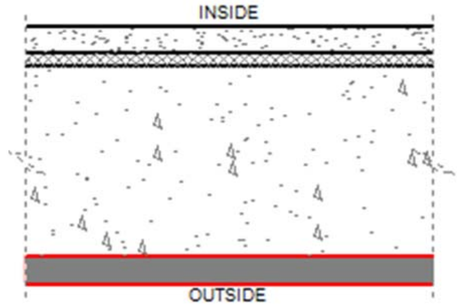



Figure 31: Floor type 3 layout, Ecotect (2011)

Table 30: Floor type 3 Layers, Ecotect (2011)

| | Layer Name | Width | Density | Sp.Heat | Conduct. | Type |
|---|---|---|---|---|---|---|
| 1. | Plaster Board | 10.0 | 1250.0 | 1088.000 | 0.431 | 85 |
| 2. | Concrete 1-4 Dry | 70.0 | 2300.0 | 656.900 | 0.753 | 35 |
| 3. | Carpet Underlay | 5.0 | 160.0 | 1732.000 | 0.045 | 95 |
| 4. | Timber | 10.0 | 720.0 | 1680.000 | 0.140 | 115 |

Table 31: Floor type 3 thermal properties, Ecotect (2011)

| | |
|---|---|
| U-Value (W/m2.K): | 2.100 |
| Admittance (W/m2.K): | 2.600 |
| Solar Absorption (0-1): | 0.324483 |
| Visible Transmittance (0-1): | 0 |
| Thermal Decrement (0-1): | 0.82 |
| Thermal Lag (hrs): | 4 |
| [SBEM] CM 1: | 0 |
| [SBEM] CM 2: | 0 |
| Thickness (mm): | 95.0 |
| Weight (kg): | 181.500 |

| | Internal | External |
|---|---|---|
| Colour (Reflect.): | (R:0.752) | (R:0.752) |
| Emissivity: | 0.9 | 0.9 |
| Specularity: | 0 | 0 |
| Roughness: | 0 | 0 |

### 3.4.2.4 Floor Type 4

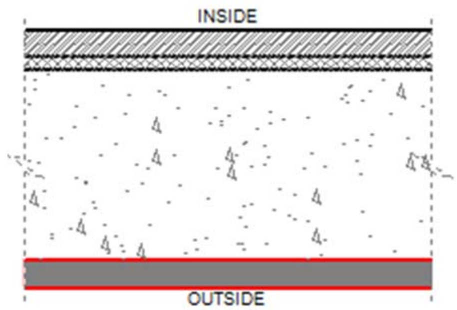



Figure 32: Floor type 4 layout, Ecotect (2011)

Table 32: Floor type 4 Layers, Ecotect (2011)

| | Layer Name | Width | Density | Sp.Heat | Conduct. | Type |
|---|---|---|---|---|---|---|
| 1. | Plaster Board | 10.0 | 1250.0 | 1088.000 | 0.431 | 85 |
| 2. | Concrete 1-4 Dry | 70.0 | 2300.0 | 656.900 | 0.753 | 35 |
| 3. | Carpet Underlay | 5.0 | 160.0 | 1732.000 | 0.045 | 95 |
| 4. | Ceramic Floor Tiles | 10.0 | 1700.0 | 850.000 | 0.800 | 25 |

Table 33: Floor type 4 thermal properties, Ecotect (2011)

| | |
|---|---|
| U-Value (W/m2.K): | 2.390 |
| Admittance (W/m2.K): | 3.060 |
| Solar Absorption (0-1): | 0.324483 |
| Visible Transmittance (0-1): | 0 |
| Thermal Decrement (0-1): | 0.84 |
| Thermal Lag (hrs): | 4 |
| [SBEM] CM 1: | 0 |
| [SBEM] CM 2: | 0 |
| Thickness (mm): | 95.0 |
| Weight (kg): | 191.300 |

| | Internal | External |
|---|---|---|
| Colour (Reflect.): | (R:0.752) | (R:0.752) |
| Emissivity: | 0.9 | 0.9 |
| Specularity: | 0 | 0 |
| Roughness: | 0 | 0 |

### 3.4.3 Roofs

#### 3.4.3.1 Roof Type 1

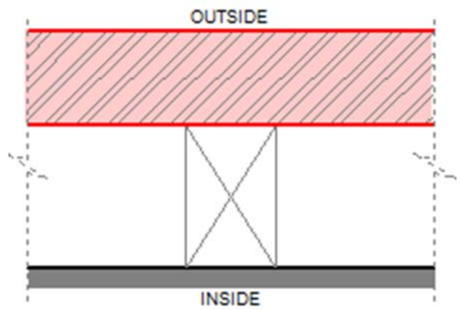



Figure 33: Roof type 1 layout, Ecotect (2011)

Table 34: Roof type 1 Layers, Ecotect (2011)

| | Layer Name | Width | Density | Sp.Heat | Conduct. | Type |
|---|---|---|---|---|---|---|
| 1. | Clay Tiles | 50.0 | 2760.0 | 836.800 | 18.828 | 25 |
| 2. | Air Gap | 75.0 | 1.3 | 1004.000 | 5.560 | 15 |
| 3. | Plaster | 10.0 | 1250.0 | 1088.000 | 4.310 | 85 |

Table 35: Roof type 1 thermal properties, Ecotect (2011)

| | |
|---|---|
| U-Value (W/m2.K): | 2.760 |
| Admittance (W/m2.K): | 0.980 |
| Solar Absorption (0-1): | 0.6 |
| Visible Transmittance (0-1): | 0 |
| Thermal Decrement (0-1): | 0.06 |
| Thermal Lag (hrs): | 0.2 |
| [SBEM] CM 1: | 0 |
| [SBEM] CM 2: | 0 |
| Thickness (mm): | 135.0 |
| Weight (kg): | 150.598 |

| | Internal | External |
|---|---|---|
| Colour (Reflect.): | (R:0.753) | (R:0.151) |
| Emissivity: | 0.9 | 0.9 |
| Specularity: | 0 | 0 |
| Roughness: | 0 | 0 |

**3.4.3.2 Roof Type2**

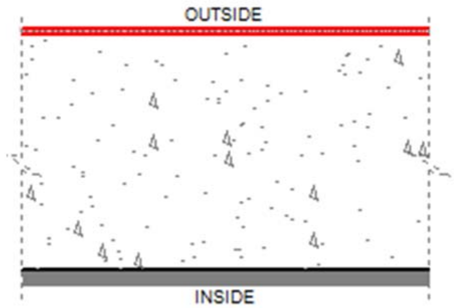



Figure 34: Roof type 2 layout, Ecotect (2011)

Table 36: Roof type 2 Layers, Ecotect (2011)

| | Layer Name | Width | Density | Sp.Heat | Conduct. | Type |
|---|---|---|---|---|---|---|
| 1. | AsphaltCover | 4.0 | 900.0 | 1966.000 | 0.088 | 45 |
| 2. | ConcreteLightweeight | 150.0 | 950.0 | 656.900 | 0.209 | 35 |
| 3. | Plaster Building (Molded Dry | 10.0 | 1250.0 | 1088.000 | 0.431 | 85 |

Table 37: Roof type 2 thermal properties, Ecotect (2011)

| | |
|---|---|
| U-Value (W/m2.K): | 1.040 |
| Admittance (W/m2.K): | 2.730 |
| Solar Absorption (0-1): | 0.9 |
| Visible Transmittance (0-1): | 0 |
| Thermal Decrement (0-1): | 0.71 |
| Thermal Lag (hrs): | 7 |
| [SBEM] CM 1: | 0 |
| [SBEM] CM 2: | 0 |
| Thickness (mm): | 164.0 |
| Weight (kg): | 158.600 |

| | Internal | External |
|---|---|---|
| Colour (Reflect.): | (R:0.753) | (R:0.337) |
| Emissivity: | 0.88 | 0.87 |
| Specularity: | 0 | 0 |
| Roughness: | 0 | 0 |

### 3.4.3.3 Roof Type3

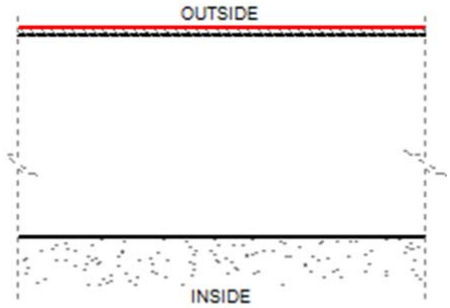



Figure 35: Roof type 3 layout, Ecotect (2011)

Table 38: Roof type 3 Layers, Ecotect (2011)

| | Layer Name | Width | Density | Sp.Heat | Conduct. | Type |
|---|---|---|---|---|---|---|
| 1. | Ethyl Vinyl Acetate | 0.2 | 1200.0 | 2301.000 | 0.075 | 95 |
| 2. | Tin | 2.0 | 7310.0 | 225.900 | 61.086 | 65 |
| 3. | Air Gap | 50.0 | 1.3 | 1004.000 | 5.560 | 0 |
| 4. | Gypsum (Mineral) | 12.0 | 2320.0 | 1088.000 | 1.297 | 115 |

Table 39: Roof type 3 thermal properties, Ecotect (2011)

| | |
|---|---|
| U-Value (W/m2.K): | 2.700 |
| Admittance (W/m2.K): | 2.090 |
| Solar Absorption (0-1): | 1 |
| Visible Transmittance (0-1): | 0 |
| Thermal Decrement (0-1): | 0.06 |
| Thermal Lag (hrs): | 0 |
| [SBEM] CM 1: | 0 |
| [SBEM] CM 2: | 0 |
| Thickness (mm): | 64.2 |
| Weight (kg): | 42.765 |

| | Internal | External |
|---|---|---|
| Colour (Reflect.): | (R:0.651) | (R:0.624) |
| Emissivity: | 0.84 | 0.89 |
| Specularity: | 0 | 0 |
| Roughness: | 0 | 0 |

### 3.4.4 Windows

### 3.4.4.1 Window Type 1

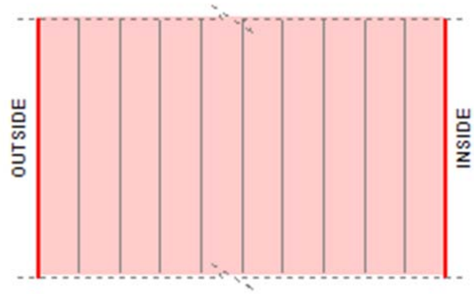



Figure 36: Window type 1 layout, Ecotect (2011)

Table 40: Window type 1 Layers, Ecotect (2011)

| | Layer Name | Width | Density | Sp.Heat | Conduct. | Type |
|---|---|---|---|---|---|---|
| 1. | Glass Standard | 6.0 | 2300.0 | 836.800 | 1.046 | 75 |

Table 41: Window type 1 thermal properties, Ecotect (2011)

| | |
|---|---|
| U-Value (W/m2.K): | 6.000 |
| Admittance (W/m2.K): | 6.000 |
| Solar Heat Gain Coeff. (0-1): | 0.94 |
| Visible Transmittance (0-1): | 0.753 |
| Refractive Index of Glass: | 1.74 |
| Alt Solar Gain (Heavywt): | 0.47 |
| Alt Solar Gain (Lightwt): | 0.64 |
| | |
| Thickness (mm): | 0.0 |
| Weight (kg): | 0.000 |

| | Internal | External |
|---|---|---|
| Colour (Reflect.): | (T:0.753) | (T:0.753) |
| Emissivity: | 0.1 | 0.1 |
| Specularity: | 0 | 0 |
| Roughness: | 0 | 0 |

Set as Default | Undo Changes

### 3.4.4.2 Window Type 2

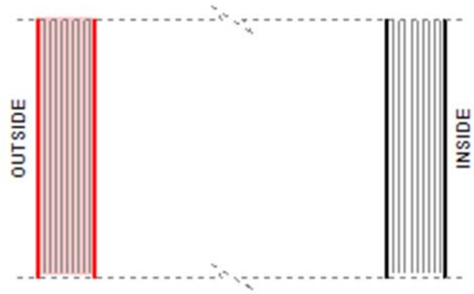



Figure 37: Window type2 layout, Ecotect (2011)

Table 42: Window type 2 Layers, Ecotect (2011)

| | Layer Name | Width | Density | Sp.Heat | Conduct. | Type |
|---|---|---|---|---|---|---|
| 1. | Glass Standard | 6.0 | 2300.0 | 836.800 | 1.046 | 75 |
| 2. | Air Gap | 30.0 | 1.3 | 1004.000 | 5.560 | 5 |
| 3. | Glass Standard | 6.0 | 2300.0 | 836.800 | 1.046 | 75 |

Table 43: Window type 2 thermal properties, Ecotect (2011)

| | |
|---|---|
| U-Value (W/m2.K): | 2.410 |
| Admittance (W/m2.K): | 2.380 |
| Solar Heat Gain Coeff. (0-1): | 0.75 |
| Visible Transmittance (0-1): | 0.611 |
| Refractive Index of Glass: | 1.74 |
| Alt Solar Gain (Heavywt): | 0.21 |
| Alt Solar Gain (Lightwt): | 0.29 |
| | |
| Thickness (mm): | 0.0 |
| Weight (kg): | 0.000 |

| | Internal | External |
|---|---|---|
| Colour (Reflect.): | (T:0.611) | (T:0.611) |
| Emissivity: | 0.78 | 0.78 |
| Specularity: | 0 | 0 |
| Roughness: | 0 | 0 |
| Set as Default | Undo Changes | |

### 3.4.5 Doors

#### 3.4.5.1 Door Type 1

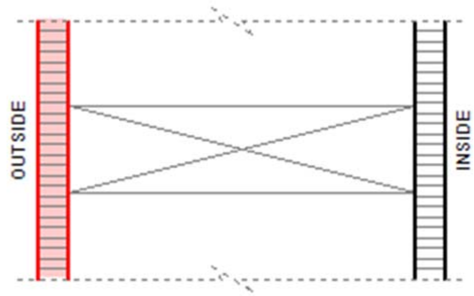



Figure 38: Door type 1 layout, Ecotect (2011)

Table 44: Door type 1 Layers, Ecotect (2011)

| | Layer Name | Width | Density | Sp.Heat | Conduct. | Type |
|---|---|---|---|---|---|---|
| 1. | Plywood | 3.0 | 530.0 | 1400.000 | 0.140 | 85 |
| 2. | Air Gap | 34.0 | 1.3 | 1004.000 | 5.560 | 15 |
| 3. | Plywood | 3.0 | 530.0 | 1400.000 | 0.140 | 85 |

Table 45: Door type 1 thermal properties, Ecotect (2011)

| | |
|---|---|
| U-Value (W/m2.K): | 2.980 |
| Admittance (W/m2.K): | 0.650 |
| Solar Absorption (0-1): | 0.55 |
| Visible Transmittance (0-1): | 0 |
| Thermal Decrement (0-1): | 0.98 |
| Thermal Lag (hrs): | 0.4 |
| [SBEM] CM 1: | 0 |
| [SBEM] CM 2: | 0 |
| Thickness (mm): | 40.0 |
| Weight (kg): | 3.224 |

| | Internal | External |
|---|---|---|
| Colour (Reflect.): | (R:0.500) | (R:0.500) |
| Emissivity: | 0.9 | 0.9 |
| Specularity: | 0 | 0 |
| Roughness: | 0 | 0 |

Set as Default | Undo Changes

### 3.4.5.2 Door Type 2

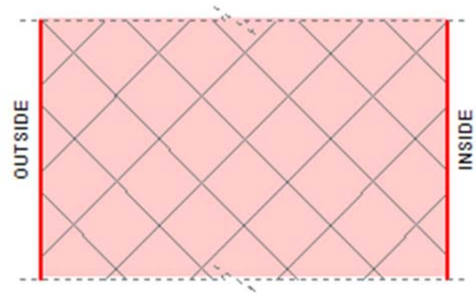



Figure 39: Door type 2 layout, Ecotect (2011)

Table 46: Door type 2 Layers, Ecotect (2011)

| | Layer Name | Width | Density | Sp.Heat | Conduct. | Type |
|---|---|---|---|---|---|---|
| 1. | Wood Pine (With Grain) | 40.0 | 550.0 | 2301.000 | 0.343 | 91 |

Table 47: Door type2 thermal properties, Ecotect (2011)

| | |
|---|---|
| U-Value (W/m2.K): | 2.310 |
| Admittance (W/m2.K): | 3.540 |
| Solar Absorption (0-1): | 0.404 |
| Visible Transmittance (0-1): | 0 |
| Thermal Decrement (0-1): | 0.98 |
| Thermal Lag (hrs): | 0.4 |
| [SBEM] CM 1: | 0 |
| [SBEM] CM 2: | 0 |
| Thickness (mm): | 40.0 |
| Weight (kg): | 22.000 |

| | Internal | External |
|---|---|---|
| Colour (Reflect.): | (R:0.663) | (R:0.663) |
| Emissivity: | 0.9 | 0.9 |
| Specularity: | 0 | 0 |
| Roughness: | 0 | 0 |

Set as Default | Undo Changes

## 3.5 Airtightness Effect

Panayiotou, et al. (2010) performed a statistical study on energy consumption profile of the residential sector in Cyprus, examining 482 dwellings and reported that more than 50% of residences use double-glazed windows. This is obviously to benefit from the thermal insulation characteristic of these elements. However, the construction implementation quality is comparatively low, that the industry suffers from airtightness problems. The reason behind is that heat is easily transferred between interior spaces and outside consequently; which according to an study by Chan, Nazaroff, Price, Sohn, & Gadgil (2005), is susceptive to extreme energy demand "because of the need to condition the infiltrating air". It is concluded by Kalamees (2007) that, airtightness is noticeably affected by supervision and workmanship quality, as well as the height of the building. In fact, the expected energy saving by improving building’s thermal performances is possibly abated by the airtightness problem as a result of low-quality construction implementation.

The effect of airtightness can be studied by changing the rate of air change per hour in Ecotect simulation tool, from the infiltration preferences which is located in the zone properties (figure 40).

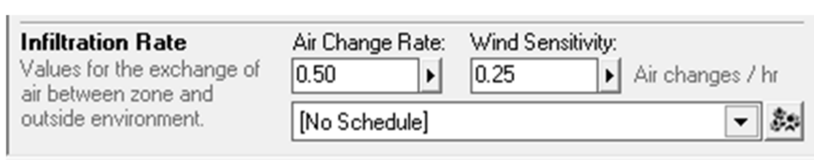



Figure 40: ACH setting, Ecotect (2011)

The rate of air change per hour can be a representative of the construction implementation’s quality, as if it is different in the operation phase from the rate at which the building is designed at the early design stage.

The effect of ACH is studied in the range of 0.25 ACH to 2.5 ACH for the optimum case.

## 3.6 Effect of Fenestration Area

Residential construction's characteristics have altered in different architectural periods due to people's preferences. The glazing area for instance, is increased from 9.15% in Ottoman period to an average of 19.25% in the modern period of Cypriot construction in urban areas Ozay (2005). The trend seems to be the same afterwards, as a result of the influence of modern architectural on the conventional construction. Although there are some studies on the design, construction, and operation phase of conventional dwellings in Cyprus, there has been little investigation done on the thermal performance of aforementioned facilities, taking into account the transformation of these dwellings to highly glazed houses. As the tendency is grown to live in houses with more fenestration areas, the importance of precise estimation of cooling and heating demand increases significantly; "the energy use for different highly glazed buildings may vary more than for buildings with traditional façades since the glazed alternatives are particularly sensitive to the outdoor conditions" said Poirazis, Blomsterberg, & Wall (2008).

Consequently, different glazing areas ranging from 20% to 60% are applied to walls in every directions and the impact of the aforesaid increase on the energy consumption profile of the optimum case is investigated.

Then, glazing area is modified in Autodesk Revit and the model is exported to Ecotect since modifications of such type is rather difficult and time consuming in Ecotect, as it is definitely not a drawing tool and, user-friendly tools for drawing purposes are not provided in this software.

# Chapter 4

# OPTIMIZATION METHODS

## 4.1 Introduction

There are several optimization methods used in construction sector to minimize costs and expenditures as much as possible, considering the required performance. Most popular optimization methods fall in engineering economics category, which are a function of analysis period as well as the interest rate. Optimization methods are as follow (Revelle, Whitlatch, & Wright, 2004):

1- Present worth analysis

2- Annual cash flow analysis

3- Incremental benefit-cost ratio analysis

4- Incremental rate of return analysis

5- Payback period

Among the aforementioned methods, "present worth analysis is the most commonly applied techniques in civil and environmental engineering economics" Revelle, Whitlatch, & Wright (2004) declared.

On the other hand, present worth analysis can satisfactorily be employed to investigate on the impact of a specific factor, by taking into account the costs and benefits as a result of the factor under-study, independently.

Additionally, while the optimum thickness of insulation materials can be calculated by employing computer simulation tools and applying present worth analysis technique, a rather simple mathematical optimization method namely P1-P2, could be used. P1-P2 is used to calculate the optimum insulation thickness, taking into account the climate condition, as well as the price of electivity, materials and the external envelope to which insulation is going to be applied.

## 4.2 Optimization Methods

### 4.2.1 P1-P2 Method

#### 4.2.1.1 Formula Description

P1-P2 method is initially proposed by (Duffie & Beckman , 1991) as one of the most prominent methods among which it is possible to calculate the present worth of the energy savings, as a result of applying insulation to building envelopes. Additionally, the optimization of insulation layer's thickness can be carried out by employing this method.

P1 is the factor for calculating the present worth of number of payments in future and can be calculated by formula 1:

$$P_1 = \mathrm{PWF}(N_e, i, d) = \sum_{j=1}^{N_e} \frac{(1+i)^{j-1}}{(1+d)^j} = \begin{cases} \frac{1}{d-i}\left[1 - \left(\frac{1+i}{1+d}\right)^{N_e}\right] & i \neq d \\ \frac{N_e}{1+i} & i = d \end{cases}$$

Formula 1: Calculating P1 factor, (Yu, Yang, Tian, & Liao, 2009)

Where Ne is the analysis period, i is the inflation rate for electricity cost and d is the discount rate.

P2 is the ratio of life cycle costs which imposed as a result of extra initial expenditure, to the capital investment, and is calculated by formula 2:

$$P_2 = D + (1 - D)\frac{\text{PWF}(N_{\min}, 0, d)}{\text{PWF}(N_L, 0, m)} + M_s\text{PWF}(N_e, i, d) - \frac{R_v}{(1 + d)^{N_e}}$$

Formula 2: Calculating P2 factor, (Yu, Yang, Tian, & Liao, 2009)

Where D is the ratio of operation and maintenance expenditures to the capital cost, Ms is the ratio of assorted cost to the capital cost and Rv is the ratio of salvage value to the capital cost. Nl is the term of loan and N min is "years over which mortgage payments contribute to the analysis period"

In case of thermal insulation materials, the operation and maintenance cost as well as the salvage value could be taken 0, which give the constant figure of 1 to P2 factor.

The cost of insulation material (C ins) can be calculated by multiplying the cost of the material (Ci) per cubic meter by the thickness (x).

Total life cycle cost of the energy demand and insulation material is formulated using P1-P2 method (formula 3):

$$LCT = P_1 \cdot C_E\left(\frac{0.024 \cdot U \cdot \text{CDD}^*}{\text{EER}} + \frac{0.024 \cdot U \cdot \text{HDD}^*}{\eta}\right) + P_2 \cdot C_i \cdot x$$

Formula 3: Total energy life cycle as a result of insulation, (Yu, Yang, Tian, & Liao, 2009)

Where Ce is electricity price per kilowatt hour, nou is heating system's efficiency factor and HDD and CDD are degree hours for heating and cooling per year respectively. Degree hours can be calculated with Autodesk Ecotect's weather tool (figure 41) or by formula 4:

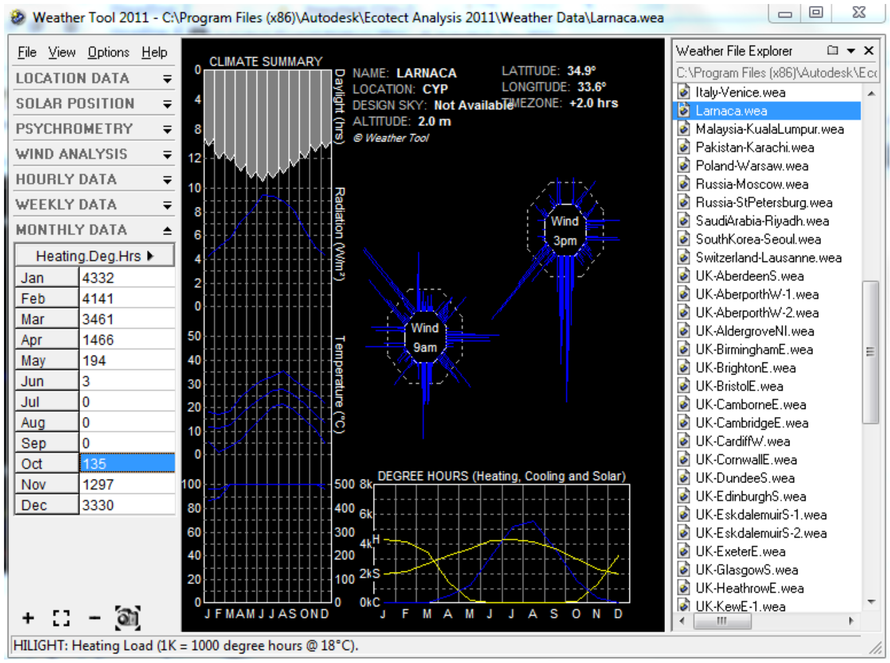



Figure 41: Ecotect weather tool, Ecotect (2011)

$$\mathrm{HDH} = (1 \ \ \mathrm{year}) \sum_{1}^{365} (1 \ \ \mathrm{day}) \sum_{1}^{24} (T_{\mathrm{b}} - T_{\mathrm{sa}})^{+}$$

$$\mathrm{CDH} = (1 \ \ \mathrm{year}) \sum_{1}^{365} (1 \ \ \mathrm{day}) \sum_{1}^{24} (T_{\mathrm{sa}} - T_{\mathrm{b}})^{+}$$

Formula 4: Heating and cooling degree hour calculation, (Bolatturk, 2008)

Where Tsa is sol-air temperature for each hour and Tb is the base temperature. Tsa can be calculated by the aforementioned weather tool or by formula 5:

$$T_{\mathrm{sa}} = T_{\mathrm{o}} + \frac{\alpha_{\mathrm{s}} \dot{q}_{\mathrm{solar}}}{h_{\mathrm{o}}} - \frac{\varepsilon \sigma (T_{\mathrm{o}}^{4} - T_{\mathrm{surr}}^{4})}{h_{\mathrm{o}}}$$

Formula 5: Sol-air temperature calculation, (Bolatturk, 2008)

The life cycle saving which is the difference between cumulative saving of expenditures for energy and the extra capital cost of the insulation is calculated (formula 6):

$$LCS = P_1 \cdot C_E\left(\frac{0.024 \cdot \Delta U \cdot \mathrm{CDD}^*}{\mathrm{EER}} + \frac{0.024 \cdot \Delta U \cdot \mathrm{HDD}^*}{\eta}\right) - P_2 \cdot C_i \cdot x$$

Formula 6: Total energy life cycle savings as a result of insulation, (Yu, Yang, Tian, & Liao, 2009)

Delta U is calculated as follow (formula 7):

$$\Delta U = \frac{1}{R_{wt}} - \frac{1}{R_{wt} + x/\lambda_{ins}}$$

Formula 7: Difference between U-Values of insulated and uninsulated cases, (Yu, Yang, Tian, & Liao, 2009)

The optimum insulation thickness, based on the heating and cooling load demand, can be finally calculated by minimizing the life cycle cost of energy (LCT) or maximizing the saving (formula 8):

$$x_{op} = \sqrt{\frac{0.024 C_E \cdot P_1 \cdot \lambda_{ins}}{P_2 \cdot C_i \cdot}\mathrm{DD}} - R_{wt} \cdot \lambda_{ins}$$

Formula 8: Optimum thermal insulation thickness, (Yu, Yang, Tian, & Liao, 2009)

In order to calculate the payback period for a specific insulation material, the net saving should be set equal to zero. This leads to formulas 9:

$$\begin{cases} N_p = \dfrac{\ln\left[1 - \frac{P_2 C_i\left(\lambda R_{wt}^2 + R_{wt} x\right)(d-i)}{0.024 C_E \cdot \mathrm{DD}}\right]}{\ln\left(\frac{1+i}{1+d}\right)} & i \neq d \\ N_p = \dfrac{P_2 C_i\left(\lambda R_{wt}^2 + R_{wt} x\right)(1+i)}{0.024 C_E \cdot \mathrm{DD}} & i = d \end{cases}$$

Formula 9: Payback period calculation, (Yu, Yang, Tian, & Liao, 2009)

Where Rtw is the total thermal resistance of the external wall, excluding the insulation material and k is insulation material’s thermal conductivity.

DD is explained "as the function of climate and energy efficiency of cooling and heating systems" (Yu, Yang, Tian, & Liao, 2009) which can be computed by formula 10:

$$DD = \frac{CDD^*}{EER} + \frac{HDD^*}{\eta}$$

Formula 10: Calculating DD factor, (Yu, Yang, Tian, & Liao, 2009)

Where EER is performance coefficient of the cooling system.

#### 4.2.1.2 Figure Assignment

Initially, price and thermal conductivity is defined for each thermal insulating material separately, and the overall thermal resistance of an insulated envelope is retrieved from Ecotect software.

Next, the electricity cost (C e) is retrieved from bills by subtracting extra charges for membership and electricity meter reading. The result is approximately 0.3 Turkish liras that make 0.16 US dollar (isbank, 2012).

Finally, heating and cooling degree hours are retrieved from the weather tool of Ecotect software and multiplied by 0.04166 to convert to degree days which are the proper format to use in formulas.

Besides, the energy efficiency ratio of the cooling load and the efficiency factor of heating system are set to 2.3 and 1.9 respectively (Yu, Yang, Tian, & Liao, 2009).

Consequently, the optimum insulation thickness for each wall type and each insulation material is calculated, following by the payback period and energy life cycle saving of each case.

### 4.2.2 Present Worth Analysis

#### 4.2.2.1 Formula Description

Net present value (NPV) concept takes into account the present value of the future cash flow of any project, comprising costs and benefits. Without employing NPV concept, it is impossible to figure out the net present value of the project, since expenditures and benefits which enter to the project's cash flow in the future, has different value than the present time. Therefore, in order to calculate the net present value of every single project, present value of costs is calculated and subtracted from the present value of benefits.

In the current study it is assumed that the project finished in the first year, which is quite realistic for a single family detached residence's project. Hence, the present worth calculations are not applied to costs which are spent in present year. Conversely, paying bills are commenced after the second year and the expenditure must be adjusted to transform to present values. Besides, the saving as a result of applying insulation is the same every year so, uniform series formulas are applied in this case (formula 11).

Compound amount:

$$F = A\left[\frac{(1+i)^n - 1}{i}\right] = A(F/A, i, n)$$

Sinking fund:

$$A = F\left[\frac{i}{(1+i)^n - 1}\right] = F(A/F, i, n)$$

Capital recovery:

$$A = P\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] = P(A/P, i, n)$$

Present worth:

$$P = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] = A(P/A, i, n)$$

Formula 11: Uniform series formulas, Revelle, Whitlatch, & Wright (2004)

The present worth formula is applied to annual saving and the accumulative savings are then compared to total expenditures.

#### 4.2.2.2 Figure Assignments

4% interest rate is considered in calculations, according to long term interest rates of money deposit in banks, and the analysis period is varied from 1 to 30 years in order to provide comparative analysis.

# Chapter 5

# RESULTS AND DISCUSSION

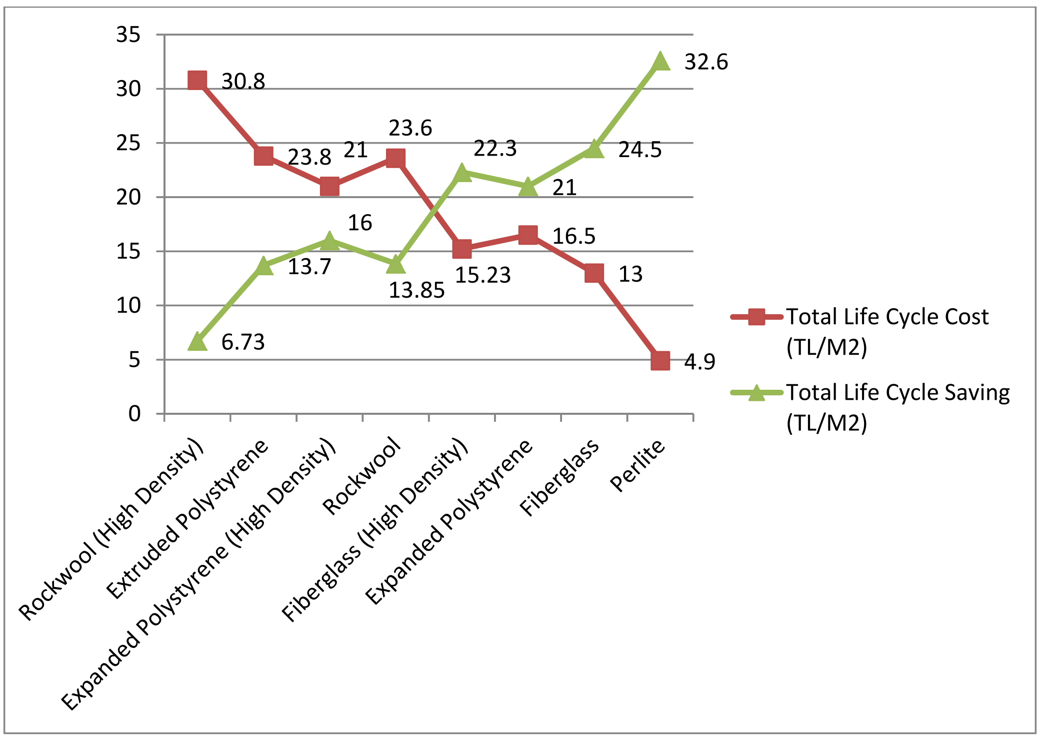
## 5.1 Introduction

Different categories of results were generated using optimization method as well as computer simulations. First, the insulation thickness of the available thermal insulation materials in Cyprus was optimized using P1-P2 method. Second, using computer simulation, among 120 combinations of conventional building envelopes in Cyprus, the best case which consumes the least energy annually was figured out. Results of the aforesaid simulation were summarized in the tables 48-54. Third, materials with corresponding optimum thicknesses were applied to the best case, and the annul energy consumption of each case under effect of applying each insulation material was computed. In the aforementioned stage, the effect of applying insulation to wall and roof, as well as the effect of replacing windows with double glazed windows and substituting doors were also studied and presented. Besides, thermal comfort of each case was also computed by Ecotect simulation engine. Forth, a sensitivity analysis of the number of years was carried out on the cost benefit analysis of the best insulation material. Then, the impact of airtightness on the optimum case was investigated using Ecotect software. Finally, the effect of increasing fenestration area on the load demand of the optimum case was also studied.

## 5.2 Results

### 5.2.1 Life Cycle Cost Analysis Based on P1-P2 Mathematical Model

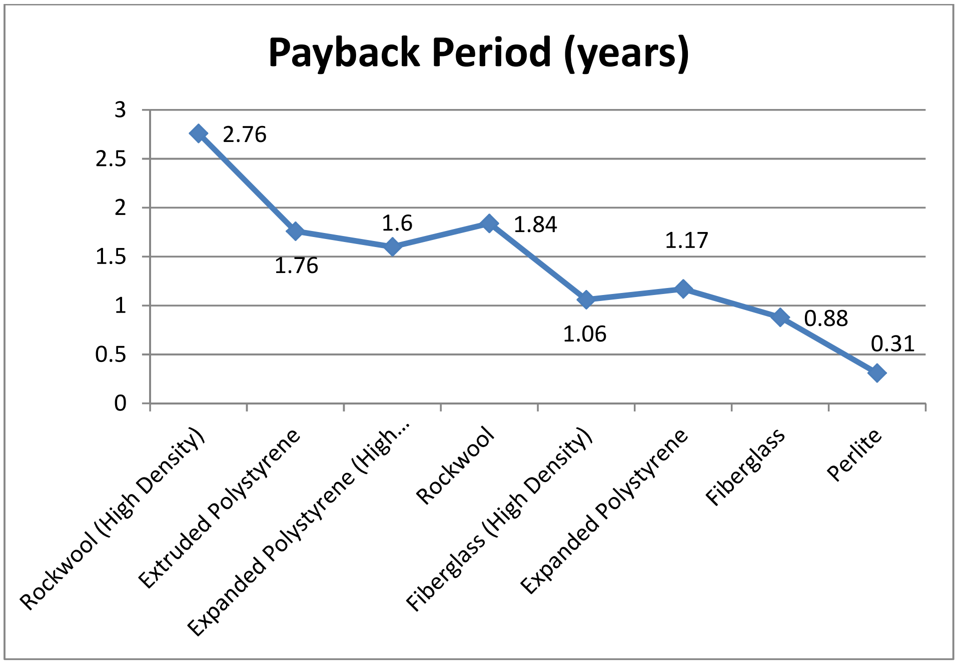
According to graph 2, applying high density Rockwool led to the least life cycle saving, accounting for 6.73 Turkish Lira per square meter, followed by low density Rockwool using which, saving nearly doubled. Conversely, perlite was the best material from life cycle saving point of view, which could lead to a saving as much as 32.6 TL per square meter. However, the available perlite in Cyprus was expanded perlite which is inappropriate for wall and roof installation. Expectedly, the cost of materials is quite low for perlite (4.9 TL/M2) while high density Rockwool imposed the highest initial cost - almost 31 TL/M2 - to the project.



Graph 2: Life cycle cost analysis based on P1-P2 mathematical model

### 5.2.2 Payback Period Calculation Based on P1-P2 Mathematical Model

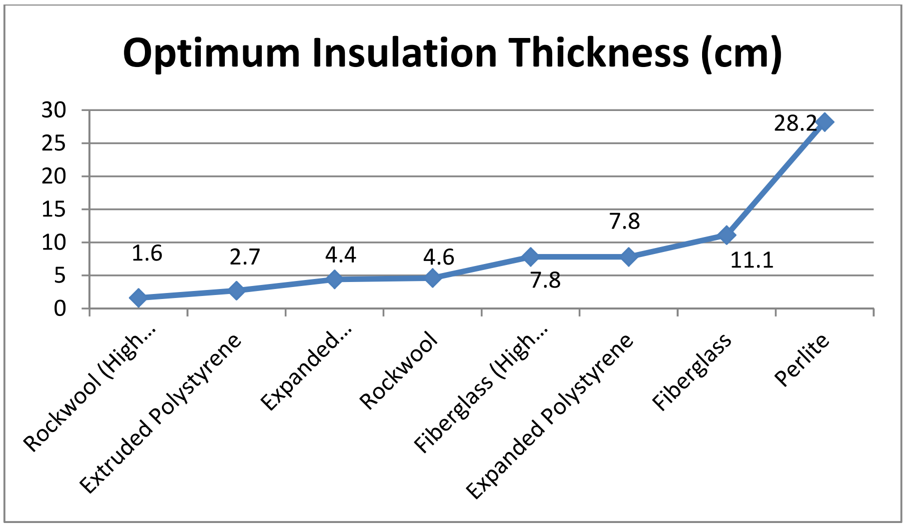
According to graph 3, using high density Rockwool led to the longest payback period (2.76 years), followed by low density Rockwool, while the period was 0.31 years for perlite followed by 0.88 years for normal density fiberglass.




Graph 3: Payback period calculation based on P1-P2 mathematical model

### 5.2.3 Insulation Thickness Optimization, Based on P1-P2 Mathematical Model

Based on graph 4, least thickness was calculated for high density Rockwool (1.6 cm), which was a result of its high cost and comparatively low thermal conductivity that contributes to proper performance. The density on the other hand, improves the thermal performance of the material. Indeed, the highest density among all available insulation materials was one of the most important reasons behind the smallest thickness for high density Rockwool. Perlite conversely, required more than 28 centimeters installation to perform as insulation material. Furthermore, very low density and the nature of expanded perlite, are two additional contributors to its inapplicability in residential construction. Therefore, fiberglass was considered as the material which required the greatest thickness for building envelope applications, with as much as 11 centimeters.



Graph 4: Insulation thickness optimization based on P1-P2 mathematical model

### 5.2.4 Annual Energy Demand Based on Conventional Construction Materials

12 series comprising a total of 120 cases were studied and the results demonstrated that the minimum energy demand corresponds to the application of floor type4, roof type 1 and wall type 1 together, which accounted for 7864 kwh energy consumption. This figure solely, was the result of consuming electricity to condition the inside air, in order to achieve desired temperature in different seasons while, the combination of floor type1, roof type 2 and wall type 7 created the worst combination amongst, from total load demand point of view (table 48-54).

Table 48: Annual loads demand (Wh) for series 1 and 2

| | Roof Type 1, Floor Type 1 | | | Roof Type 2, Floor Type 1 | | |
|---|---|---|---|---|---|---|
| Wall Type | Heating Load | Cooling Load | Total Load | Heating Load | Cooling Load | Total Load |
| 1 | 415032 | 9365625 | **9780657** | 583813 | 14757329 | **15341142** |
| 2 | 427544 | 10488202 | 10915746 | 308419 | 16318563 | 16626982 |
| 3 | 1313165 | 10915842 | 12229007 | 1484381 | 16065870 | 17550252 |
| 4 | 840738 | 11074415 | 11915153 | 927382 | 16771385 | 17698768 |
| 5 | 659009 | 10738934 | 11397943 | 694787 | 16435714 | 17130502 |
| 6 | 550507 | 10541871 | 11092378 | 542106 | 16250622 | 16792728 |
| 7 | 1602155 | 11931702 | 13533857 | 1959507 | 17431354 | 19390862 |
| 8 | 1238706 | 11309043 | 12547749 | 1530165 | 16909938 | 18440102 |
| 9 | 989854 | 10865684 | 11855538 | 1240881 | 16481215 | 17722096 |
| 10 | 1068270 | 10962868 | 12031138 | 1302470 | 16331852 | 17634322 |

Table 49: Annual loads demand (Wh) for series 3 and 4

| | Roof Type 3, Floor Type 1 | | | Roof Type 1, Floor Type 2 | | |
|---|---|---|---|---|---|---|
| Wall Type | Heating Load | Cooling Load | Total Load | Heating Load | Cooling Load | Total Load |
| 1 | 414409 | 9723424 | **10137833** | 381388 | 8439607 | **8820995** |
| 2 | 426288 | 10953099 | 11379387 | 393494 | 9473559 | 9867053 |
| 3 | 1304609 | 11270629 | 12575238 | 1245223 | 9913068 | 11158291 |
| 4 | 833601 | 11507808 | 12341409 | 791320 | 10032976 | 10824296 |
| 5 | 653838 | 11173956 | 11827794 | 613478 | 9708407 | 10321885 |
| 6 | 547017 | 11001187 | 11548204 | 509089 | 9502519 | 10011608 |
| 7 | 1580440 | 12297396 | 13877836 | 1534918 | 10940778 | 12475696 |
| 8 | 1223236 | 11709020 | 12932256 | 1179090 | 10339061 | 11518151 |
| 9 | 980401 | 11267269 | 12247670 | 936982 | 9887844 | 10824826 |
| 10 | 1059585 | 11334312 | 12393897 | 1009124 | 9972758 | 10981882 |

Table 50: Annual loads demand (Wh) for series 5 and 6

| | Roof Type 2, Floor Type 2 | | | Roof Type 3, Floor Type 2 | | |
|---|---|---|---|---|---|---|
| Wall Type | Heating Load | Cooling Load | Total Load | Heating Load | Cooling Load | Total Load |
| 1 | 545089 | 13607566 | **14152655** | 380650 | 8818279 | **9198929** |
| 2 | 287119 | 14023970 | 14311089 | 392373 | 9939822 | 10332195 |
| 3 | 1412499 | 14945374 | 16357873 | 1236870 | 10269064 | 11505934 |
| 4 | 854003 | 15513925 | 16367928 | 783138 | 10482248 | 11265386 |
| 5 | 626988 | 15145488 | 15772476 | 609377 | 10143060 | 10752437 |
| 6 | 488083 | 14968010 | 15456093 | 507013 | 9985648 | 10492661 |
| 7 | 1881311 | 16289830 | 18171140 | 1513599 | 11320403 | 12834002 |
| 8 | 1456425 | 15749032 | 17205458 | 1164771 | 10733372 | 11898143 |
| 9 | 1163570 | 15296519 | 16460089 | 927586 | 10292343 | 11219929 |
| 10 | 1237200 | 15197340 | 16434540 | 1002133 | 10347337 | 11349470 |

Table 51: Annual loads demand (Wh) for series 7 and 8

| | Roof Type 1, Floor Type 3 | | | Roof Type 2, Floor Type 3 | | |
|---|---|---|---|---|---|---|
| Wall Type | Heating Load | Cooling Load | Total Load | Heating Load | Cooling Load | Total Load |
| 1 | 364193 | 7974756 | **8338949** | 526957 | 12986647 | **13513604** |
| 2 | 375965 | 8936926 | 9312891 | 281741 | 13316912 | 13598653 |
| 3 | 1209973 | 9446042 | 10656015 | 1382230 | 14347020 | 15729250 |
| 4 | 765880 | 9528952 | 10294832 | 835958 | 14852456 | 15688414 |
| 5 | 590276 | 9214615 | 9804891 | 614991 | 14484897 | 15099888 |
| 6 | 488276 | 8984675 | 9472951 | 478885 | 14288917 | 14767802 |
| 7 | 1500434 | 10460790 | 11961224 | 1847236 | 15681364 | 17528600 |
| 8 | 1148193 | 9854997 | 11003190 | 1427960 | 15131419 | 16559379 |
| 9 | 909146 | 9407560 | 10316706 | 1138491 | 14674529 | 15813020 |
| 10 | 978530 | 9503961 | 10482491 | 1209280 | 14591628 | 15800908 |

Table 52: Annual loads demand (Wh) for series 9 and 10

| | Roof Type 3, Floor Type 3 | | | Roof Type 1, Floor Type 4 | | |
|---|---|---|---|---|---|---|
| **Wall Type** | **Heating Load** | **Cooling Load** | **Total Load** | **Heating Load** | **Cooling Load** | **Total Load** |
| **1** | 363749 | 8349880 | **8713628** | 454593 | **7409820** | **7864412** |
| **2** | 374978 | 9389097 | 9764075 | 351455 | 8121164 | 8472619 |
| **3** | 1201824 | 9804162 | 11005986 | 1158918 | 8696182 | 9855100 |
| **4** | 758787 | 9963909 | 10722696 | 728222 | 8736113 | 9464335 |
| **5** | 586312 | 9618748 | 10205060 | 556599 | 8406665 | 8963264 |
| **6** | 486303 | 9459455 | 9945758 | 458988 | 8196394 | 8655382 |
| **7** | 1480081 | 10836949 | 12317030 | 1448967 | 9709969 | 11158936 |
| **8** | 1134873 | 10244929 | 11379802 | 1103394 | 9115208 | 10218602 |
| **9** | 900664 | 9807537 | 10708201 | 868935 | 8679390 | 9548325 |
| **10** | 971788 | 9868070 | 10839858 | 934181 | 8764800 | 9698981 |

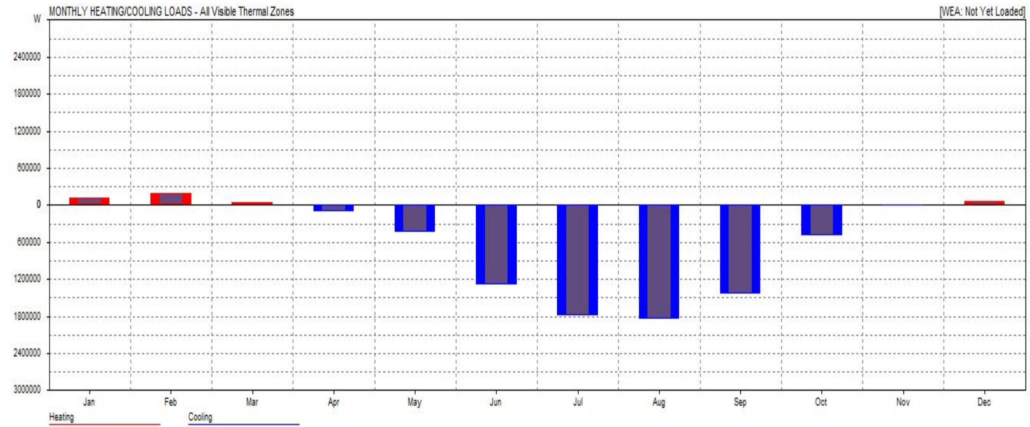
Table 53: Annual loads demand (Wh) for series 11 and 12

| | Roof Type 2, Floor Type 4 | | | Roof Type 3, Floor Type 4 | | |
|---|---|---|---|---|---|---|
| **Wall Type** | **Heating Load** | **Cooling Load** | **Total Load** | **Heating Load** | **Cooling Load** | **Total Load** |
| **1** | 500214 | 12048803 | 12549017 | 339211 | 7632114 | **7971325** |
| **2** | **272875** | 12257986 | **12530861** | 350516 | 8553712 | 8904228 |
| **3** | 1337595 | 13442460 | 14780055 | 1151093 | 9057973 | 10209066 |
| **4** | 800498 | 13864767 | 14665265 | 721629 | 9172639 | 9894268 |
| **5** | 577811 | 13468569 | 14046380 | 553445 | 8839643 | 9393088 |
| **6** | 456076 | 13266096 | 13722172 | 457217 | 8651466 | 9108683 |
| **7** | 1791733 | 14760225 | 16551958 | 1430696 | 10068948 | 11499644 |
| **8** | 1380132 | 14210566 | 15590698 | 1090268 | 9496827 | 10587095 |
| **9** | 1087966 | 13743091 | 14831056 | 860904 | 9079391 | 9940295 |
| **10** | 1165970 | 13667715 | 14833685 | 927458 | 9111594 | 10039052 |

Table 54: Minimum and maximum loads of all 120 cases (Wh)

| | Heating Load | Cooling Load | Total Load |
|---|---|---|---|
| MIN | 272875 | 7409820 | 7864412 |
| MAX | 1959507 | 17431354 | 19390862 |

A sample of detailed analysis results from Ecotect simulation engine is presented below, in graph 5 and table 55.




Graph 5: Monthly load demand for the best case, Ecotect (2011)

Table 55: Monthly load demand for the best case, Ecotect (2011)

| **MONTHLY HEATING/COOLING LOA** | | | |
|---|---|---|---|
| | | | |
| All Visible Thermal Zones | | | |
| Comfort: Zonal Bands | | | |
| | | | |
| Max Heating: 2939 W at 05:00 on 4th February | | | |
| Max Cooling: 6400 W at 13:00 on 15th August | | | |
| | | | |
| | **HEATING** | **COOLING** | **TOTAL** |
| **MONTH** | **(Wh)** | **(Wh)** | **(Wh)** |
| Jan | 122024 | 0 | 122024 |
| Feb | 200300 | 0 | 200300 |
| Mar | 47135 | 0 | 47135 |
| Apr | 15399 | 105222 | 120620 |
| May | 0 | 429985 | 429985 |
| Jun | 0 | 1293165 | 1293165 |
| Jul | 0 | 1786999 | 1786999 |
| Aug | 0 | 1843707 | 1843707 |
| Sep | 0 | 1443000 | 1443000 |
| Oct | 0 | 493063 | 493063 |
| Nov | 2520 | 14678 | 17199 |
| Dec | 67215 | 0 | 67215 |
| **TOTAL** | **454593** | **7409820** | **7864412** |
| | | | |
| **PER M²** | **4059** | **66159** | **70218** |
| **Floor Area:** | **112.000 m2** | | |

### 5.2.5 Construction Costs of Each Combination

In this section, construction cost of each combination which was calculated based on the official unit prices is presented. Additionally, some approximations were applied, in case of desired thickness was not available in the unit prices. In table 56, all layers which were used in the modeling process of wall, floors and roofs are presented and, price per square meter of each layer which was basically used in either one of the conventional envelopes are listed.

Table 56: Price per square meter of layers

| Name | Thickness (cm) | Price/m2 |
|---|---|---|
| | | |
| Brick Masonry Medium | 10 | 28 |
| Brick Masonry Medium | 20 | 46 |
| Plaster | 1 | 19 |
| Plaster | 2 | 23 |
| Plaster | 3 | 31 |
| Fiberglass | 5 | 8 |
| Lightweight Block | 15 | 44 |
| Lightweight Block | 20 | 55 |
| Lightweight Block | 25 | 60 |
| Hollow Lightweight Block | 15 | 44 |
| Hollow Lightweight Block | 20 | 50 |
| Hollow Lightweight Block | 25 | 55 |
| Concrete C16 | 20 | 84 |
| Concrete C16 | 15 | 63 |
| Concrete C16 | 7 | 30 |
| Plaster Board (Sap) | 1 | 4 |
| Carpet Underlay | 0.5 | 6 |
| Carpet | 1.5 | 28 |
| Tile | 2 | 38 |
| Timber | 1 | 46 |
| Ceramic Floor Tiles | 1 | 40 |
| Clay Tiles | 5 | 40 |
| Plaster | 1 | 19 |
| Asphalt Cover | 0.4 | 17 |

In tables 57-59, layer details of each type of wall, floor and, roof are demonstrated. Besides, the price of each type's construction was calculated per square meter, according to the prices of each layer. Consequently, considering corresponding area of each envelope, total construction cost of each type was computed.

Table 57: Construction cost of each wall type

| Envelope Type | Layers | Price (m2) | Area (m2) | Total Cost (TL) |
|---|---|---|---|---|
| Wall Type 1 | 100mm double brick<br>50mm air gap<br>100mm double brick<br>10mm plaster inside | 75 | 124.109 | 9308 |
| Wall Type 2 | 100mm double brick<br>50mm Foil-Faced Glass-Fibre<br>100mm double brick<br>10mm plaster inside | 83 | 124.109 | 10301 |
| Wall Type 3 | 10mm plaster inside<br>200mm brick<br>10mm plaster inside | 84 | 124.109 | 10425 |
| Wall Type 4 | 20mm plaster<br>150mm Block<br>20mm Plaster | 90 | 124.109 | 11170 |
| Wall Type 5 | 20mm plaster<br>200mm Block<br>20mm Plaster | 101 | 124.109 | 12535 |
| Wall Type 6 | 20mm plaster<br>250mm Block<br>20mm Plaster | 106 | 124.109 | 13156 |
| Wall Type 7 | 20mm plaster<br>150mm Block Hollow<br>20mm Plaster | 90 | 124.109 | 11170 |
| Wall Type 8 | 20mm plaster<br>200mm Block Hollow<br>20mm Plaster | 96 | 124.109 | 11914 |
| Wall Type 9 | 20mm plaster<br>250mm Block Hollow<br>20mm Plaster | 101 | 124.109 | 12535 |
| Wall Type 10 | 200mm concrete block<br>30mm plaster inside | 115 | 124.109 | 14273 |

Table 58: Construction cost of each floor type

| Envelope Type | Layers | Price (m2) | Area (m2) | Total Cost (TL) |
|---|---|---|---|---|
| | | | | |
| Floor Type 1 | 10mm Plaster Board<br>70mm Concrete<br>5mm CarpetUnderlay<br>15mm Carpet | 83 | 112 | 9296 |
| | | | | |
| Floor Type 2 | 10mm Plaster Board<br>70mm Concrete<br>5mm Carpet Underlay<br>20mm Tiles | 93 | 112 | 10416 |
| | | | | |
| Floor Type 3 | 10mm Plaster Board<br>70mm Concrete<br>5mm Carpet Underlay<br>10mm Timber | 101 | 112 | 11312 |
| | | | | |
| Floor Type 4 | 10mm Plaster Board<br>70mm Concrete<br>5mm Carpet Underlay<br>10mm Ceramic | 95 | 112 | 10640 |

Table 59: Construction cost of each roof type

| Envelope Type | Layers | Price (m2) | Area (m2) | Total Cost (TL) |
|---|---|---|---|---|
| | | | | |
| Roof Type 1 | 50mm Clay Tiles<br>75mm Air Gap<br>10mm Plaster inside | 59 | 112 | 6608 |
| | | | | |
| Roof Type 2 | 4mm AsphaltCover<br>150mm Concrete<br>10mm plaster inside | 99 | 112 | 11088 |
| | | | | |
| Roof Type 3 | 0.2mm EthylVinylAcetate<br>2mm Tin<br>50mm air gap<br>12mm Gypsum | 70 | 112 | 7840 |

Cosnstruction cost of each 120 combinations combinations are then calculated and listed in table 60.

Table 60: Construction cost of each combination

| Roof Type | Wall Type | Floor Type 1 | Floor Type 2 | Floor Type 3 | Floor Type 4 |
|---|---|---|---|---|---|
| | | | | | |
| Roof Type 1 | Wall Type 1 | 25212 | 26332 | 27228 | 26556 |
| | Wall Type 2 | 26205 | 27325 | 28221 | 27549 |
| | Wall Type 3 | 26329 | 27449 | 28345 | 27673 |
| | Wall Type 4 | 27074 | 28194 | 29090 | 28418 |
| | Wall Type 5 | 28439 | 29559 | 30455 | 29783 |
| | Wall Type 6 | 29060 | 30180 | 31076 | 30404 |
| | Wall Type 7 | 27074 | 28194 | 29090 | 28418 |
| | Wall Type 8 | 27818 | 28938 | 29834 | 29162 |
| | Wall Type 9 | 28439 | 29559 | 30455 | 29783 |
| | Wall Type 10 | 30177 | 31297 | 32193 | 31521 |
| | | | | | |
| Roof Type 2 | Wall Type 1 | 29692 | 30812 | 31708 | 31036 |
| | Wall Type 2 | 30685 | 31805 | 32701 | 32029 |
| | Wall Type 3 | 30809 | 31929 | 32825 | 32153 |
| | Wall Type 4 | 31554 | 32674 | 33570 | 32898 |
| | Wall Type 5 | 32919 | 34039 | 34935 | 34263 |
| | Wall Type 6 | 33540 | 34660 | 35556 | 34884 |
| | Wall Type 7 | 31554 | 32674 | 33570 | 32898 |
| | Wall Type 8 | 32298 | 33418 | 34314 | 33642 |
| | Wall Type 9 | 32919 | 34039 | 34935 | 34263 |
| | Wall Type 10 | 34657 | 35777 | 36673 | 36001 |
| | | | | | |
| Roof Type 3 | Wall Type 1 | 26444 | 27564 | 28460 | 27788 |
| | Wall Type 2 | 27437 | 28557 | 29453 | 28781 |
| | Wall Type 3 | 27561 | 28681 | 29577 | 28905 |
| | Wall Type 4 | 28306 | 29426 | 30322 | 29650 |
| | Wall Type 5 | 29671 | 30791 | 31687 | 31015 |
| | Wall Type 6 | 30292 | 31412 | 32308 | 31636 |
| | Wall Type 7 | 28306 | 29426 | 30322 | 29650 |
| | Wall Type 8 | 29050 | 30170 | 31066 | 30394 |
| | Wall Type 9 | 29671 | 30791 | 31687 | 31015 |
| | Wall Type 10 | 31409 | 32529 | 33425 | 32753 |

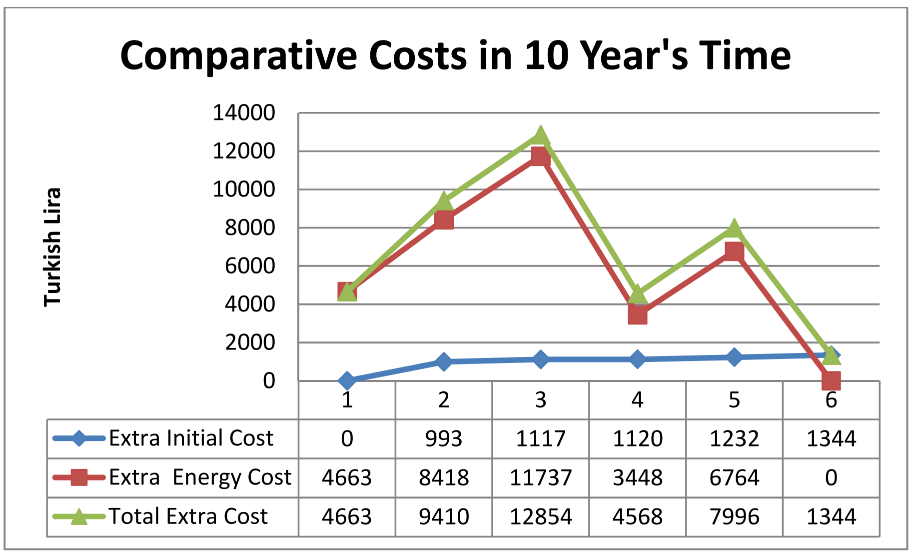
Minimum cases were identified step by step untill the best case - which presents best thermal performance and least annual electricity consumption - is reached. Totally, including the best case, 6 combinations were minimum, from the initial cost point of view. Accordingly, annual load demand of each case was derived from tables 48-54 and corresponding annual energy costs were computed. Then, for each case, extra initial cost was calculated based on case 1, which imposed the least initial cost among 120 cases to the project. Similarly, extra energy cost based on case 6 - as called the best case - which imposes the least annual energy price amongst was calculated. Results provide adequate information to compare different cases and choose the best one subsequently. For instance, in comparison to case 1, by choosing case 2, additional 993 turkish Lira is imposed to the project. On the other hand, extra annual 915 Turkish Lira is also imposed as the electricity cost. The latter was compared with the Best case (case 6). The most expensive case in terms of initial cost was case 6 with 1344 TL extra imposed cost, while in terms of annual cost, the worst case was 3 (table 61).

Table 61: Least expensive combinations

| Minimum Cases | Envelopes | Initial Cost | Annual Load | Annual Energy Cost | Extra Initial Cost | Extra Energy Cost |
|---|---|---|---|---|---|---|
| Case 1 | Roof Type 1<br>Wall Type 1<br>Floor Type 1 | 25212.175 | 9780657 | 2934.1971 | 0 | 574.8735 |
| | | | | | | |
| Case 2 | Roof Type 1<br>Wall Type 2<br>Floor Type 1 | 26205.047 | 10915746 | 3274.7238 | 992.872 | 915.4002 |
| | | | | | | |
| Case 3 | Roof Type 1<br>Wall Type 3<br>Floor Type 1 | 26329.156 | 12229007 | 3668.7021 | 1116.981 | 1309.3785 |
| | | | | | | |
| Case 4 | Roof Type 1<br>Wall Type 1<br>Floor Type 2 | 26332.175 | 8820995 | 2646.2985 | 1120 | 286.9749 |
| | | | | | | |
| Case 5 | Roof Type 3<br>Wall Type 1<br>Floor Type 1 | 26444.175 | 10137833 | 3041.3499 | 1232 | 682.0263 |
| | | | | | | |
| Case 6 | Roof Type 1<br>Wall Type 1<br>Floor Type 4 | 26556.175 | 7864412 | 2359.3236 | 1344 | 0 |

As the optimization method, Net Present Value concept was employed to carry out an analytical study on different cases. 4% interest rate was considered and the analysis was performed over a period of 6 years' time.

As the result, according to graph 6 the most expensive case was 3, followed by 2 and 5, which impose additional comparative 12854, 9410 and, 7996 Turkish Lira to the project respectively, during 10 years' time. Conversely, the least expensive choice was case 6, which consumes least energy annually. Although, the initial cost of this case was the highest amongst the selected group.



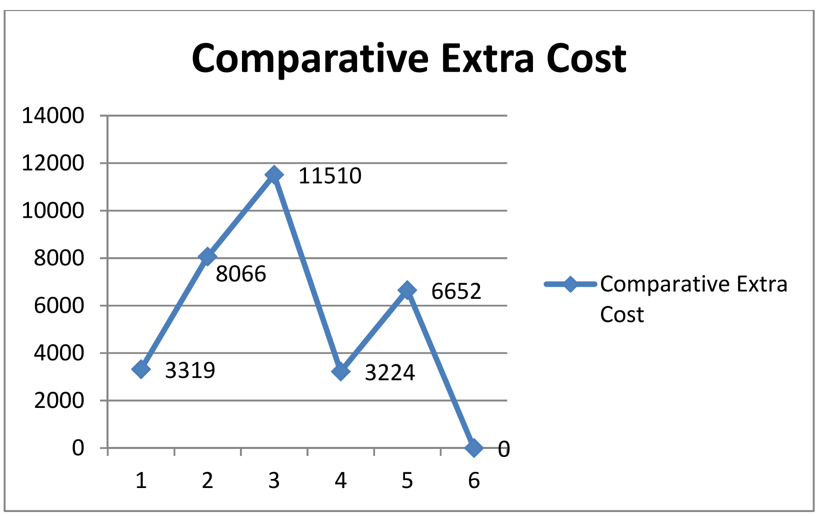

Graph 6: Comparative costs in 10 years' time

The most beneficial choice was case 6, which leads to the least energy consumption during the life cycle of a residence but, according to table 62, in one condition, which is taking 2 years as the analysis period, the optimum combination was not case 6. However, the life span of a dwelling is never less than two years that confirms the idea of choosing the combination of wall type 1, roof type 1 and, floor type 4 as conventional building envelopes in Cyprus.

Table 62: Comparative costs in 2 years' time

| Case Number | Extra Initial Cost | Extra Energy Cost | Total Cost |
|---|---|---|---|
| 1 | 0 | 1084 | 1084 |
| 2 | 993 | 2719 | 3712 |
| 3 | 1117 | 3587 | 4704 |
| 4 | 1120 | 1661 | 2781 |
| 5 | 1232 | 2518 | 3750 |
| 6 | 1344 | 0 | 1344 |

Taking the cheapest choice as reference, comparative costs in 10 years' time were calculated and, results are presented in graph 7. Loosing minimum 3224 TL in 10 years was due to taking any combination other than case 6. The figure surges to 11510 TL for case 3, only among the 6 most efficient cases. Therefore, case 6 was chosen as the "best case" among all 120 possible combinations of typical envelope types.




Graph 7: Comparative costs in 10 years' time (compared to case 6)

### 5.2.6 Present Worth Saving, and Total Cost Calculation for Applying Each Insulation Material After 6 Years

In this section, each insulation material was applied to building external envelopes separately and, the effect of placing the insulation layer as inside or outside layer was also studied separately. Additionally, substitutes for windows and doors were considered and, the annual energy consumption was computed in every stage. Annual saving, as a result of applying all revisions was then calculated. Finally, the net present value of every incremental change was compared with the extra expenditure that caused by the corresponding alteration (tables 63-70). Best insulation material, which leads to the most saving, was then proposed.

Table 63: Cost-Benefit analysis by applying Low Density Expanded Polystyrene

| Revision Type (Material: Expanded Polystyrene Low Density) | Total Annual Load (wh) | Difference with Base Case (wh) | Annual Saving (Turkish Lira) | Annual Cumulative Saving (Turkish Lira) | Area (m2) | Extra Cost Per m2 (Turkish Lira) | Total Extra Cost (Turkish Lira) | Saving Present Worth (Turkish Lira) |
|---|---|---|---|---|---|---|---|---|
| Wall | 7773383 | 91029 | 27.3087 | 27.3087 | 124.1 | 7.02 | 871.245 | 143.15594 |
| plus Roof (Inside layer) | 7305344 | 559068 | 140.412 | 167.7204 | 112 | 7.02 | 786.24 | 736.05735 |
| plus Roof (Outside layer) | 7028038 | 836374 | 223.604 | 250.9122 | 112 | 7.02 | 786.24 | 1172.1601 |
| plus Windows | 6547664 | 1316748 | 144.112 | 395.0244 | 19.14 | 45 | 861.255 | 755.45588 |
| plus Doors | 6492100 | 1372312 | 16.6692 | 411.6936 | 1.953 | 100 | 195.3 | 87.382228 |
| | | | | | | **Total** | **2714.04** | **2158.1542** |

Table 64: Cost-Benefit analysis by applying High Density Expanded Polystyrene

| Revision Type (Material: Expanded Polystyrene High Density) | Total Annual Load (wh) | Difference with Base Case (wh) | Annual Saving (Turkish Lira) | Annual Cumulative Saving (Turkish Lira) | Area (m2) | Extra Cost Per m2 (Turkish Lira) | Total Extra Cost (Turkish Lira) | Saving Present Worth (Turkish Lira) |
|---|---|---|---|---|---|---|---|---|
| Wall | 7776168 | 88244 | 26.4732 | 26.4732 | 124.1 | 8.36 | 1037.55 | 138.77614 |
| plus Roof (Inside layer) | 7416569 | 447843 | 107.88 | 134.3529 | 112 | 8.36 | 936.32 | 565.52015 |
| plus Roof (Outside layer) | 7076576 | 787836 | 209.878 | 236.3508 | 112 | 8.36 | 936.32 | 1100.2071 |
| plus Windows | 6302766 | 1561646 | 232.143 | 468.4938 | 19.14 | 45 | 861.255 | 1216.9254 |
| plus Doors | 6254028 | 1610384 | 14.6214 | 483.1152 | 1.953 | 100 | 195.3 | 76.64738 |
| | | | | | | **Total** | **3030.43** | **2532.556** |

Table 65: Cost-Benefit analysis by applying Extruded Polystyrene

| Revision Type (Material: Extruded Polystyrene) | Total Annual Load (wh) | Difference with Base Case (wh) | Annual Saving (Turkish Lira) | Annual Cumulative Saving (Turkish Lira) | Area (m2) | Extra Cost Per m2 (Turkish Lira) | Total Extra Cost (Turkish Lira) | Saving Present Worth (Turkish Lira) |
|---|---|---|---|---|---|---|---|---|
| Wall | 7777758 | 86654 | 25.9962 | 25.9962 | 124.1 | 8.883 | 1102.46 | 136.27564 |
| plus Roof (Inside layer) | 7450860 | 413552 | 98.0694 | 124.0656 | 112 | 8.883 | 994.896 | 514.09322 |
| plus Roof (Outside layer) | 7097339 | 767073 | 204.126 | 230.1219 | 112 | 8.883 | 994.896 | 1070.0549 |
| plus Windows | 6161684 | 1702728 | 280.697 | 510.8184 | 19.14 | 45 | 861.255 | 1471.4495 |
| plus Doors | 6111521 | 1752891 | 15.0489 | 525.8673 | 1.953 | 100 | 195.3 | 78.888393 |
| | | | | | | **Total** | **3153.91** | **2756.6684** |

Table 66: Cost-Benefit analysis by applying Low Density Fiberglass Low Density

| Revision Type (Material: Fiberglass Low Density) | Total Annual Load (wh) | Difference with Base Case (wh) | Annual Saving (Turkish Lira) | Annual Cumulative Saving (Turkish Lira) | Area (m2) | Extra Cost Per m2 (Turkish Lira) | Total Extra Cost (Turkish Lira) | Saving Present Worth (Turkish Lira) |
|---|---|---|---|---|---|---|---|---|
| Wall | 7771592 | 92820 | 27.846 | 27.846 | 124.1 | 5.772 | 716.357 | 145.97254 |
| plus Roof (Inside layer) | 7220604 | 643808 | 165.296 | 193.1424 | 112 | 5.772 | 646.464 | 866.50635 |
| plus Roof (Outside layer) | 7015907 | 848505 | 226.706 | 254.5515 | 112 | 5.772 | 646.464 | 1188.4213 |
| plus Windows | 6862355 | 1002057 | 46.0656 | 300.6171 | 19.14 | 45 | 861.255 | 241.48218 |
| plus Doors | 6802330 | 1062082 | 18.0075 | 318.6246 | 1.953 | 100 | 195.3 | 94.397779 |
| | | | | | | **Total** | **2419.38** | **1670.2738** |

Table 67: Cost-Benefit analysis by applying High Density Fiberglass

| Revision Type (Material: Fiberglass High Density) | Total Annual Load (wh) | Difference with Base Case (wh) | Annual Saving (Turkish Lira) | Annual Cumulative Saving (Turkish Lira) | Area (m2) | Extra Cost Per m2 (Turkish Lira) | Total Extra Cost (Turkish Lira) | Saving Present Worth (Turkish Lira) |
|---|---|---|---|---|---|---|---|---|
| Wall | 7772787 | 91625 | 27.4875 | 27.4875 | 124.1 | 6.63 | 822.843 | 144.09324 |
| plus Roof (Inside layer) | 7272244 | 592168 | 150.163 | 177.6504 | 112 | 6.63 | 742.56 | 787.17447 |
| plus Roof (Outside layer) | 7022584 | 841828 | 225.061 | 252.5484 | 112 | 6.63 | 742.56 | 1179.8 |
| plus Windows | 6643366 | 1221046 | 113.765 | 366.3138 | 19.14 | 45 | 861.255 | 596.3738 |
| plus Doors | 6585485 | 1278927 | 17.3643 | 383.6781 | 1.953 | 100 | 195.3 | 91.026037 |
| | | | | | | **Total** | **2621.96** | **2011.2931** |

Table 68: Cost-Benefit analysis by applying Low Density Rockwool

| Revision Type (Material: Rock Wool Low Density) | Total Annual Load (wh) | Difference with Base Case (wh) | Annual Saving (Turkish Lira) | Annual Cumulative Saving (Turkish Lira) | Area (m2) | Extra Cost Per m2 (Turkish Lira) | Total Extra Cost (Turkish Lira) | Saving Present Worth (Turkish Lira) |
|---|---|---|---|---|---|---|---|---|
| Wall | 7777554 | 86858 | 26.0574 | 26.0574 | 124.1 | 8.924 | 1107.55 | 136.59646 |
| plus Roof (Inside layer) | 7445408 | 419004 | 99.6438 | 125.7012 | 112 | 8.924 | 999.488 | 522.34644 |
| plus Roof (Outside layer) | 7095954 | 768458 | 204.48 | 230.5374 | 112 | 8.924 | 999.488 | 1071.9121 |
| plus Windows | 6165444 | 1698968 | 279.153 | 509.6904 | 19.14 | 45 | 861.255 | 1463.3582 |
| plus Doors | 6120767 | 1743645 | 13.4031 | 523.0935 | 1.953 | 100 | 195.3 | 70.260885 |
| | | | | | | **Total** | **3163.59** | **2742.1277** |

Table 69: Cost-Benefit analysis by applying High Density Rockwool

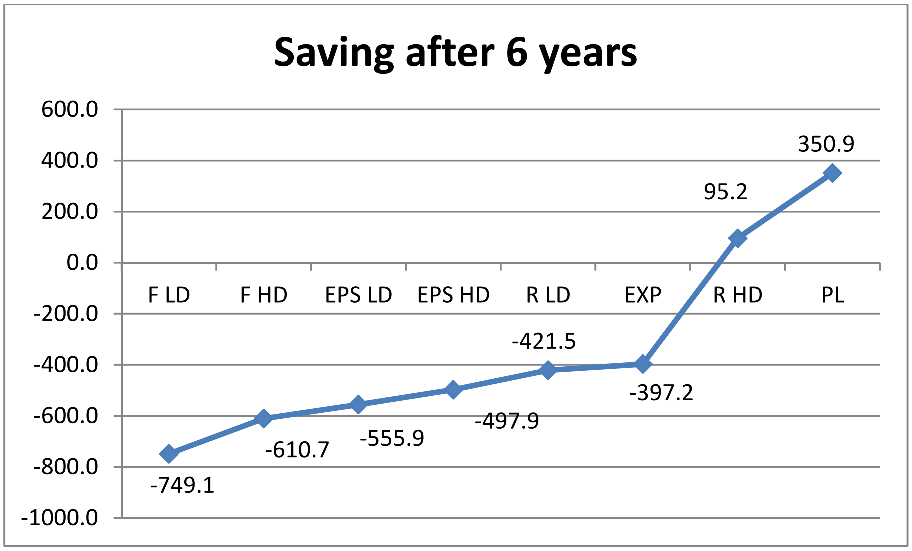
| Revision Type (Material: Rock Wool High Density) | Total Annual Load (wh) | Difference with Base Case (wh) | Annual Saving (Turkish Lira) | Annual Cumulative Saving (Turkish Lira) | Area (m2) | Extra Cost Per m2 (Turkish Lira) | Total Extra Cost (Turkish Lira) | Saving Present Worth (Turkish Lira) |
|---|---|---|---|---|---|---|---|---|
| Wall | 7785526 | 78886 | 23.6658 | 23.6658 | 124.1 | 8.864 | 1100.1 | 124.05936 |
| plus Roof (Inside layer) | 7569764 | 294648 | 64.7286 | 88.3944 | 112 | 8.864 | 992.768 | 339.31618 |
| plus Roof (Outside layer) | 7171870 | 692542 | 184.097 | 207.7626 | 112 | 8.864 | 992.768 | 965.06062 |
| plus Windows | 5847205 | 2017207 | 397.4 | 605.1621 | 19.14 | 45 | 861.255 | 2083.2226 |
| plus Doors | 5801244 | 2063168 | 13.7883 | 618.9504 | 1.953 | 100 | 195.3 | 72.280156 |
| | | | | | | **Total** | **3149.43** | **3244.6227** |

Table 70: Cost-Benefit analysis by applying Perlite

| Revision Type (Material: Perlite) | Total Annual Load (wh) | Difference with Base Case (wh) | Annual Saving (Turkish Lira) | Annual Cumulative Saving (Turkish Lira) | Area (m2) | Extra Cost Per m2 (Turkish Lira) | Total Extra Cost (Turkish Lira) | Saving Present Worth (Turkish Lira) |
|---|---|---|---|---|---|---|---|---|
| Wall | 7767820 | 96592 | 28.9776 | 28.9776 | 124.1 | 2.3688 | 293.989 | 151.90454 |
| plus Roof (Inside layer) | 7040781 | 823631 | 218.112 | 247.0893 | 112 | 2.3688 | 265.306 | 1143.3714 |
| plus Roof (Outside layer) | 6995720 | 868692 | 231.63 | 260.6076 | 112 | 2.3688 | 265.306 | 1214.2362 |
| plus Windows | 6686386 | 1178026 | 92.8002 | 353.4078 | 19.14 | 45 | 861.255 | 486.47135 |
| plus Doors | 6613798 | 1250614 | 21.7764 | 375.1842 | 1.953 | 100 | 195.3 | 114.15487 |
| | | | | | | **Total** | **1615.85** | **1966.7669** |

All revision types were applied together finally but, the application of insulation layer to roof, was done either as the inside layer or, as the outside layer. Hence, the calculation of total costs and benefits must be based on one of them. Since the energy consumption was comparatively low in case of the outside layer, figures corresponding to the inside layer case were not considered in the calculations. For instance, in table 69, saving's present worth is 339TL for applying the insulation layer as the inside layer of the roof, while the figure for outside is 965TL.

Considering 6 years as the analysis period in the calculations, demonstrated that the application of high density Rockwool and perlite leads to a positive annual saving of 95 and 351 Turkish Lira respectively (graph 8).



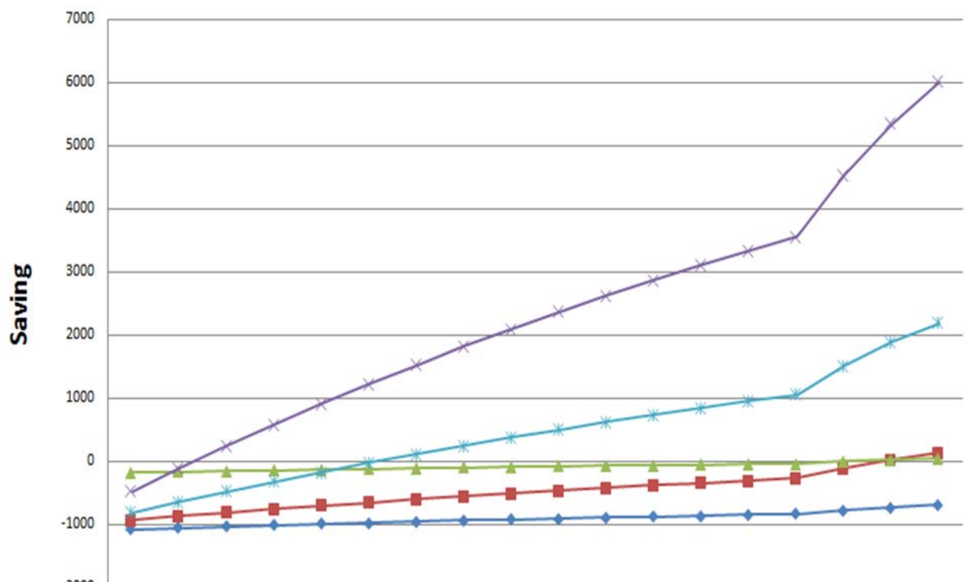
Graph 8: Saving of each material in 6 years' time

On the other hand, the optimum thicknesses for the aforementioned materials were totally different (1.6 and 28 centimeter respectively). Besides, perlite comes with a very low density and it is not available in sheets. Therefore, two barrier layers must be set and the material is poured in between, which is not applicable to walls and roofs. Consequently, however using perlite increases the annual saving dramatically; it was eliminated from available options. So, high density Rockwool was chosen as the best thermal insulation material in Cyprus, the optimum thickness is 1.6 centimeters and it should be applied as the outside layer of roof.

### 5.2.7 Present Worth Saving, and Total Cost Calculation for Taking Separate Measures After 30 Years

The saving as a result of applying 1.6cm high density Rockwool to wall, inside and outside layer of roof, substituting doors and windows are presented in graph 9. The expenditure for wall insulation does not pay back even after 30 years and the trend seems to be the same until the project's lifetime is thorough so, it is more beneficial to eliminate the extra imposed initial cost of wall insulation. Besides, substituting doors seems not to be a logical option since it commences to give positive saving only after 24 years. Likewise, placing the insulation layer as the inside layer of roof commences to give positive saving after 21 years' time.

Conversely, the positive impact of applying insulation as the outside layer of roof and substituting normal single glazed windows with double glazed ones on the project was considerable.



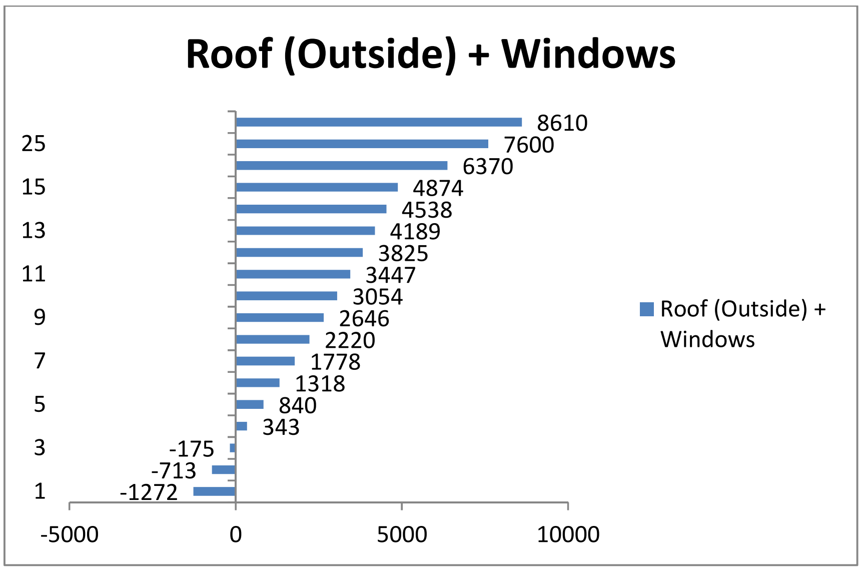

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 20 | 25 | 30 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wall | -1077 | -1055 | -1034 | -1014 | -995 | -976 | -958 | -941 | -924 | -908 | -893 | -878 | -864 | -850 | -837 | -778 | -730 | -691 |
| Roof (In) | -931 | -871 | -813 | -758 | -705 | -653 | -604 | -557 | -511 | -468 | -426 | -385 | -346 | -309 | -273 | -113 | 18 | 127 |
| Doors | -182 | -169 | -157 | -145 | -134 | -123 | -113 | -102 | -93 | -83 | -75 | -66 | -58 | -50 | -42 | -8 | 20 | 43 |
| Windows | -479 | -112 | 242 | 581 | 908 | 1222 | 1524 | 1814 | 2094 | 2362 | 2620 | 2868 | 3107 | 3337 | 3557 | 4540 | 5347 | 6011 |
| Roof (Out) | -816 | -646 | -482 | -325 | -173 | -28 | 112 | 247 | 376 | 500 | 620 | 735 | 846 | 952 | 1054 | 1509 | 1883 | 2191 |

Graph 9: Impacts of applying independent factors up to 30 years

Substituting windows imposes an extra cost of 861 Turkish Lira which is paid back in less than 5 years. Similarly, the application of insulation layer as the outside layer of roof, leads to positive saving after the 5th year and pays back after 14th year of operation.

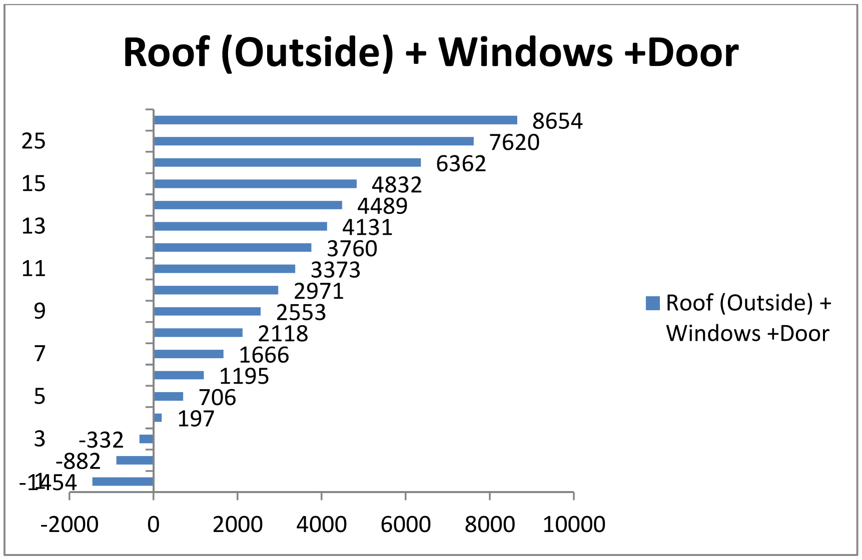
Eliminating wall insulation as well as applying insulation to the outside layer of roof saves the owner 8610 Turkish Lira in 30 years' time. The amount adds up to 8654 Turkish Lira by substituting doors as well (graph 10 and 11)

The investment on enhancing building's performance, by insulating roof and replacing windows with double glazed windows, which undoubtedly improves thermal performance of the house, imposes less than 1900 Turkish Lira extra investment cost, which leads to positive saving after the third year that adds up to 343 TL in forth year and accumulates to more than 8500 TL saving in 30 years' time (graph 10).



Graph 10: Saving by roof insulation and windows substitution

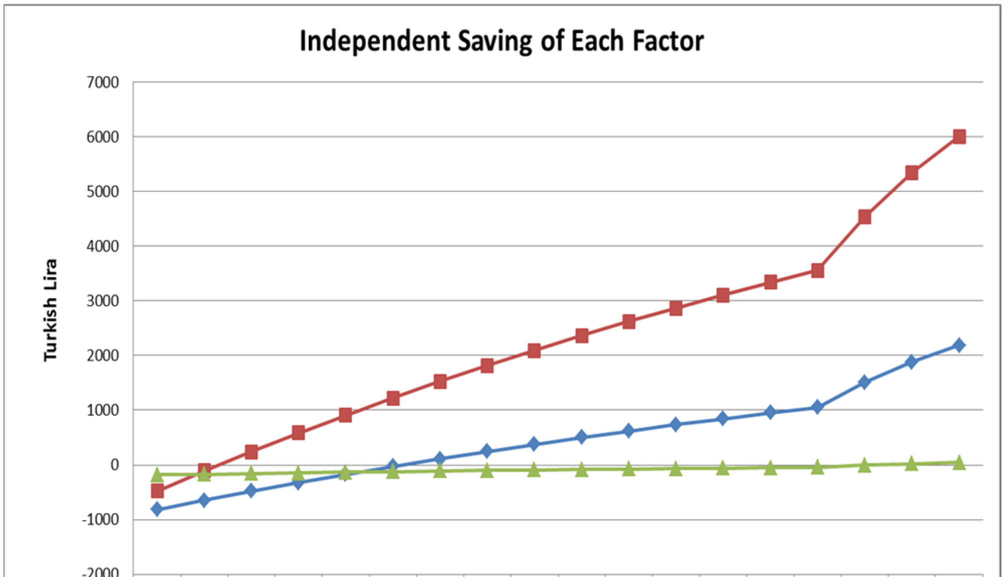
The investment on enhancing building's performance, by insulating roof and replacing windows with double glazed windows, which undoubtedly improves thermal performance of the house and, substituting doors with quality ones, imposes less than 2100 Turkish Lira extra investment cost which leads to positive saving after the third year that adds up to 197 TL in forth year and accumulates to more than 8654 TL saving in 30 years' time (graph 11).




Graph 11: Saving by roof insulation, windows and doors substitution

### 5.2.8 Investment Prioritizing

According to the imposed costs of each factor as well as the corresponding annual savings, in case of limited budget, the investment could be prioritized. Three factors which contribute to saving, taking 30 years as the analysis period were figured out. Independent savings are demonstrated in graph 12:




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 20 | 25 | 30 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Roof | -816 | -646 | -482 | -325 | -173 | -28 | 112 | 247 | 376 | 500 | 620 | 735 | 846 | 952 | 1054 | 1509 | 1883 | 2191 |
| Windows | -479 | -112 | 242 | 581 | 908 | 1222 | 1524 | 1814 | 2094 | 2362 | 2620 | 2868 | 3107 | 3337 | 3557 | 4540 | 5347 | 6011 |
| Door | -182 | -169 | -157 | -145 | -134 | -123 | -113 | -102 | -93 | -83 | -75 | -66 | -58 | -50 | -42 | -8 | 20 | 43 |

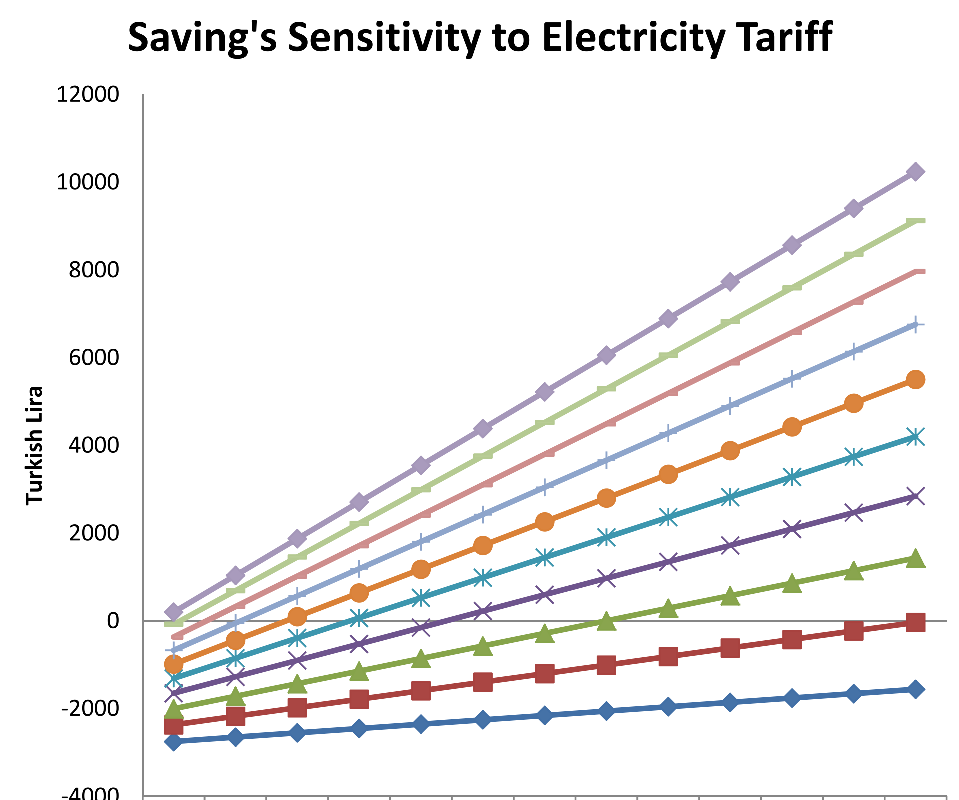
Graph 12: Independent saving of each factor

Based on results, in case of limited budget, it is suggested to invest on windows, insulating roofs with 1.6cm high density Rockwool from outside and substituting doors, respectively.

### 5.2.9 Sensitivity Analysis

All calculations are carried out based on the current prices and rates. Hence, results are reliable unless the aforesaid factors are altered. Electricity tariff, interest rate and material prices for instance, are main factors which influence the costs and benefits of the project during its life time.

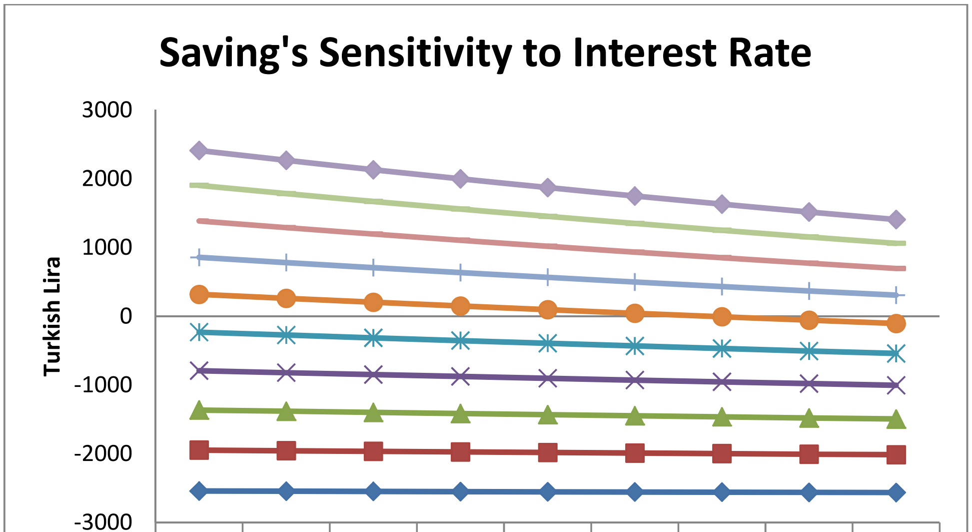
The sensitivity analysis was done regarding a span of 1 to10 years of analysis period. Obviously, the life span of a residence is quite longer than 10 years but, according to results after 10 years' time, projects leads to more saving and the situation is not critical as the analytical investigation is not required.




| | 0.2 | 0.25 | 0.3 | 0.35 | 0.4 | 0.45 | 0.5 | 0.55 | 0.6 | 0.65 | 0.7 | 0.75 | 0.8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -275 | -265 | -255 | -245 | -235 | -225 | -215 | -205 | -195 | -186 | -176 | -166 | -156 |
| 2 | -237 | -217 | -198 | -178 | -159 | -139 | -120 | -100 | -815 | -620 | -425 | -231 | -36 |
| 3 | -200 | -171 | -143 | -114 | -859 | -573 | -287 | 0 | 286 | 572 | 858 | 1145 | 1431 |
| 4 | -165 | -127 | -903 | -528 | -154 | 221 | 595 | 970 | 1344 | 1718 | 2093 | 2467 | 2842 |
| 5 | -131 | -853 | -394 | 65 | 525 | 984 | 1443 | 1902 | 2361 | 2821 | 3280 | 3739 | 4198 |
| 6 | -986 | -446 | 95 | 636 | 1177 | 1718 | 2258 | 2799 | 3340 | 3881 | 4421 | 4962 | 5503 |
| 7 | -673 | -54 | 566 | 1185 | 1804 | 2423 | 3042 | 3661 | 4281 | 4900 | 5519 | 6138 | 6757 |
| 8 | -371 | 323 | 1018 | 1712 | 2407 | 3101 | 3796 | 4491 | 5185 | 5880 | 6574 | 7269 | 7963 |
| 9 | -81 | 686 | 1453 | 2220 | 2987 | 3754 | 4521 | 5288 | 6055 | 6822 | 7589 | 8356 | 9123 |
| 10 | 197 | 1034 | 1871 | 2708 | 3544 | 4381 | 5218 | 6054 | 6891 | 7728 | 8564 | 9401 | 1023 |

Graph 13: Sensitivity of net saving to electricity tariff

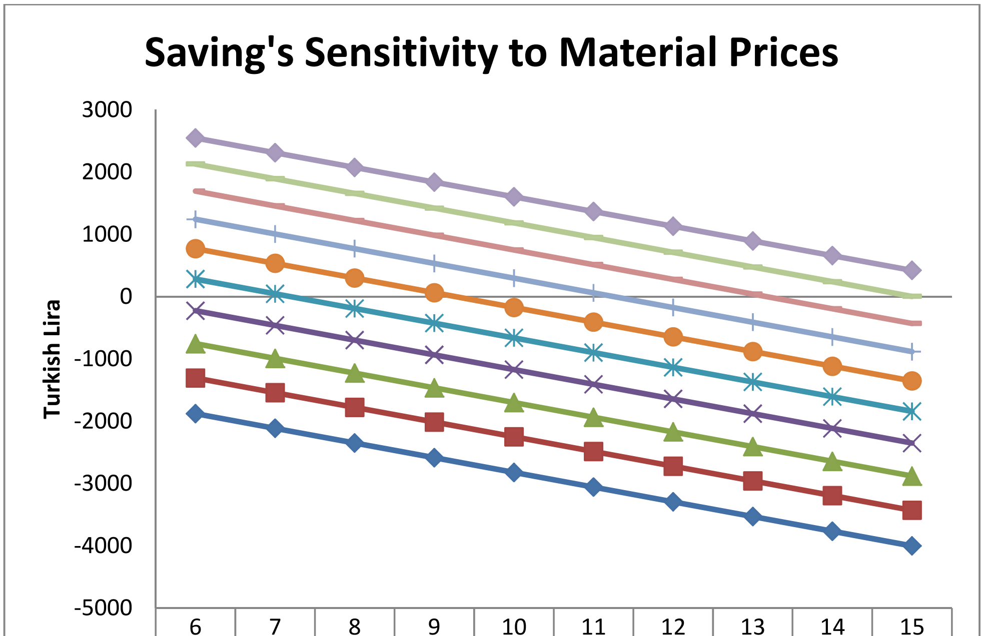
Current electricity tariff is 0.3 Turkish Lira per kilo watt hour which, leads to 95TL saving in the sixth year. In case of increase in electricity price up to 0.8TL/Kwh, the annual saving increases dramatically as it reaches to more than 10230TL net benefit after 10 years. Conversely, if the tariff decreases, payback period increases and endangers the feasibility of improving thermal performance of case studies. As longer analysis periods were regarded, the project became more beneficial. For instance, for 10 years' time, no matter how much is the electricity price, it leads to positive net present value. Conversely, if the period is considered 1 or 2 years, regardless of the electricity price, NPV is negative according to which the project is not feasible at all (graph 13).




| | 0.020 | 0.025 | 0.030 | 0.035 | 0.040 | 0.045 | 0.050 | 0.055 | 0.060 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | -2543 | -2546 | -2549 | -2551 | -2554 | -2557 | -2560 | -2563 | -2566 |
| 2 | -1948 | -1956 | -1965 | -1974 | -1982 | -1990 | -1999 | -2007 | -2015 |
| 3 | -1364 | -1382 | -1399 | -1415 | -1432 | -1448 | -1464 | -1480 | -1495 |
| 4 | -793 | -821 | -849 | -876 | -903 | -929 | -955 | -980 | -1005 |
| 5 | -232 | -274 | -315 | -355 | -394 | -432 | -470 | -506 | -542 |
| 6 | 318 | 260 | 204 | 149 | 95 | 43 | -8 | -57 | -106 |
| 7 | 856 | 781 | 707 | 635 | 566 | 498 | 432 | 368 | 306 |
| 8 | 1385 | 1289 | 1195 | 1105 | 1018 | 933 | 851 | 771 | 694 |
| 9 | 1903 | 1784 | 1670 | 1559 | 1453 | 1350 | 1250 | 1154 | 1060 |
| 10 | 2410 | 2268 | 2130 | 1998 | 1871 | 1748 | 1630 | 1516 | 1406 |

Graph 14: Sensitivity of net saving to interest rate

According to graph 14, the effect of increasing interest rate on the net saving as a result of enhancing the quality of thermal performance in dwellings seems to be negative. For instance, if the interest rate is raised to more than 0.50, the extra initial costs are not paid back by the sixth year. Although, as the life span of a residence is always considered much longer than 6 years, alteration of such type still seems to be a beneficial decision to make. For example, for more than 7 years as the analysis period, the benefit is guaranteed regardless of the rate of interest, as it leads to minimum 1400TL saving in the 10th year (for the worst interest rate). The project by the way is not anticipated to lead to positive NPV, before the 6th year.




| | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -1878 | -2114 | -2350 | -2586 | -2823 | -3059 | -3295 | -3531 | -3767 | -4003 |
| 2 | -1306 | -1542 | -1778 | -2014 | -2250 | -2486 | -2722 | -2959 | -3195 | -3431 |
| 3 | -756 | -992 | -1228 | -1464 | -1700 | -1936 | -2172 | -2408 | -2644 | -2881 |
| 4 | -226 | -463 | -699 | -935 | -1171 | -1407 | -1643 | -1879 | -2115 | -2351 |
| 5 | 282 | 46 | -190 | -426 | -662 | -898 | -1134 | -1371 | -1607 | -1843 |
| 6 | 771 | 535 | 299 | 63 | -173 | -409 | -645 | -881 | -1117 | -1354 |
| 7 | 1242 | 1006 | 770 | 533 | 297 | 61 | -175 | -411 | -647 | -883 |
| 8 | 1694 | 1458 | 1222 | 986 | 750 | 513 | 277 | 41 | -195 | -431 |
| 9 | 2129 | 1893 | 1657 | 1421 | 1184 | 948 | 712 | 476 | 240 | 4 |
| 10 | 2547 | 2311 | 2075 | 1839 | 1603 | 1366 | 1130 | 894 | 658 | 422 |

Graph 15: Sensitivity of net saving to insulation material's price

Thermal insulation material's price on the other hand, affects the cash flow of a project at the construction - initial – phase, which obviously is a one-time effect while, the other two factors affect annual expenditures. Allegedly, impacts on the initial cost could be satisfactorily compensated by annual savings.

The price of the insulation material - high density Rockwool - that had been identified as the most beneficial thermal insulation material for Cyprus had considerable effect on net saving of the project. If the price is increased to 15 Turkish Lira per square meter, instead of a benefit of 95TL in the sixth year, 1354TL cost should be tolerated. It is not to say that, the payback period is comparatively longer in this case. Similar to the findings of other two sensitivity analysis, after 10 years' time, positive NPV is guaranteed regardless of insulation material's cost. Actually, it leads to minimum 4 and 422 Turkish Lira in the 9$^{th}$ and 10$^{th}$ year respectively (in case of 15TL per square meter). Additionally, the project is not feasible for less than four years of analysis period (graph 15).

### 5.2.10 Thermal Comfort Comparison

Thermal comfort figures of the best case - modeled based on conventional construction materials - was compared with the optimum case (table 71).

Thermal comfort calculations were performed by Ecotect software according to degree hour concept and the percentage of time that the temperature of thermal zone was outside the comfort range.

Table 71: Thermal comfort comparison (%)

| | Uninsulated | | | Insulated | | |
|---|---|---|---|---|---|---|
| MONTH | TOO HOT | TOO COOL | TOTAL | TOO HOT | TOO COOL | TOTAL |
| Jan | 0 | 98.79 | 98.79 | 0 | 85.22 | 85.22 |
| Feb | 0 | 92.41 | 92.41 | 0 | 71.43 | 71.43 |
| Mar | 0 | 90.32 | 90.32 | 0 | 60.22 | 60.22 |
| Apr | 3.47 | 24.58 | 28.06 | 9.58 | 10 | 19.58 |
| May | 11.96 | 0 | 11.96 | 34.27 | 0 | 34.27 |
| Jun | 74.72 | 0 | 74.72 | 91.25 | 0 | 91.25 |
| Jul | 100 | 0 | 100 | 100 | 0 | 100 |
| Aug | 100 | 0 | 100 | 100 | 0 | 100 |
| Sep | 96.67 | 0 | 96.67 | 100 | 0 | 100 |
| Oct | 17.61 | 0 | 17.61 | 43.15 | 0 | 43.15 |
| Nov | 0 | 18.33 | 18.33 | 4.58 | 1.67 | 6.25 |
| Dec | 0 | 77.02 | 77.02 | 0 | 53.76 | 53.76 |
| TOTAL | 404.4 | 401.5 | 805.9 | 482.8 | 282.3 | 765.1 |

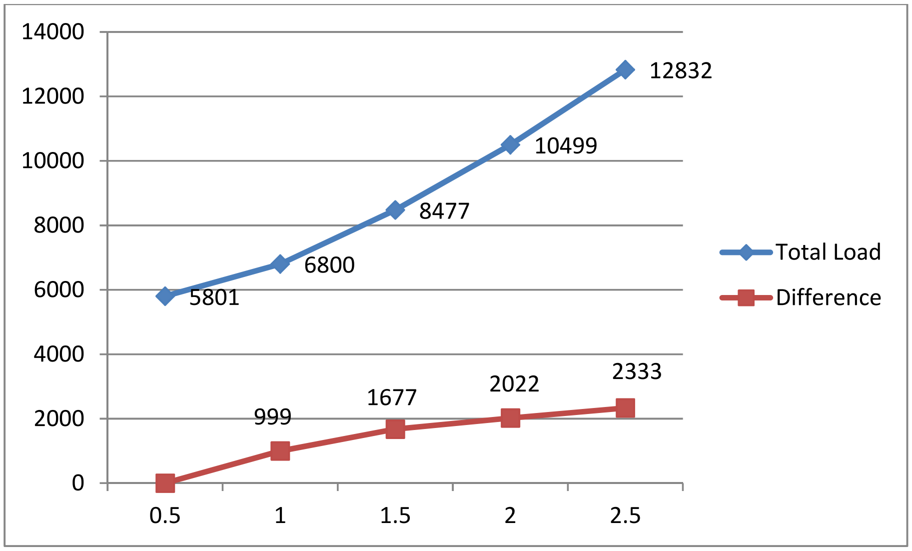
Base on the results, comparing 806% discomfort time to 765% for insulated case, improving thermal performance of residences led to noticeable rise in total comfort hours during which, without using air conditioner systems, inhabitants experience comfortable inside temperature in houses.

Besides, it seems that insulation increases thermal comfort in hot seasons significantly, which is due to the high Cyprus' summer temperature in July, August as September.

To conclude from this section, not only enhancing building thermal performance leads to a surge in monetary benefits, but also non-monetary benefits are achieved.

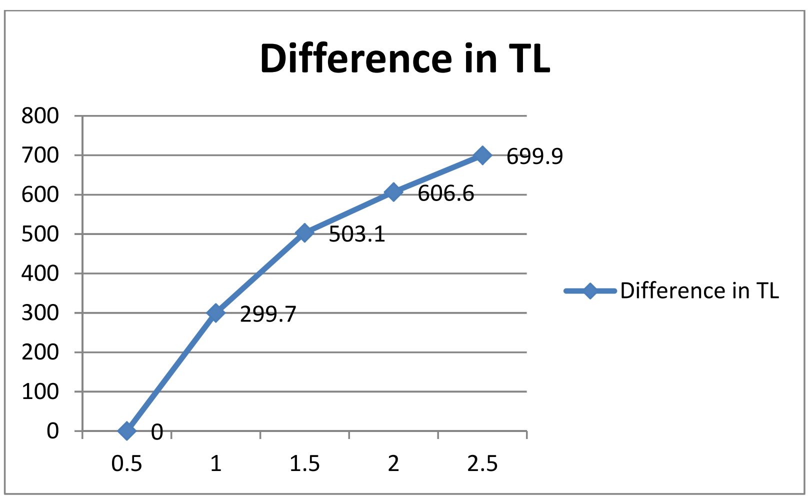
### 5.2.11 Airtightness Effect

The effect of increasing air change per hour which is a representative of low quality construction implementation was studied on the total load demand of the optimum case in a range of 0.5 to 2.5 ACH and results are demonstrated in the graph 16.



Graph 16: ACH Rate effect on annual energy consumption

Undoubtedly, total energy consumption increases dramatically as the result of leaky construction. Up to 2300 kWh increase in electricity consumption was observed as the ACH rate was increased to 2.5. This imposes up to 700 Turkish lira extra annual expenditure to the project (graph 17).

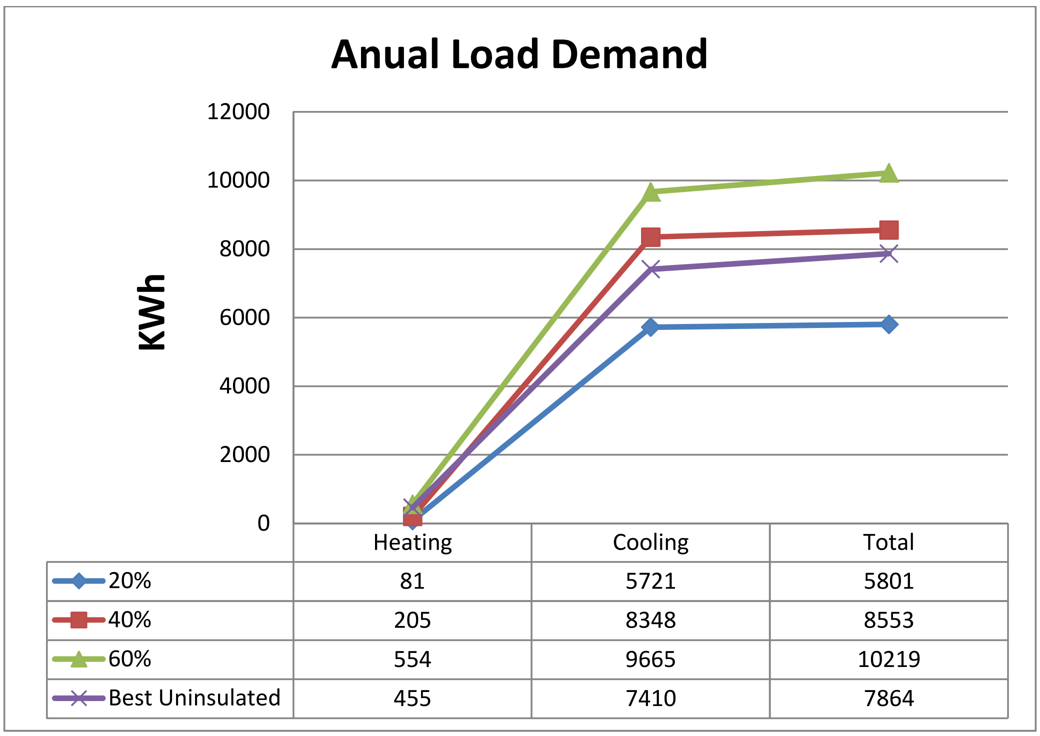


Graph 17: ACH Rate effect on annual expenditures

In comparison with 618 TL saving as the result of applying insulation as well as substituting windows and doors, the impact of poor construction implementation which imposes 700 TL annual expenditures can obviously overcome the desired savings. Consequently the importance of quality assurance in construction implementation and the significance of providing as less ACH rate as possible in residences were highlighted. Least ACH rate possible for residences should be 0.5 ACH according to ASHRAE standards, which was regarded in the whole modeling process for every case.

### 5.2.12 Effect of Increasing Glazing Area

The impact of enlarging the glazing area of the optimum case, from 20% to 40 and 60%, on the annual electricity consumption was investigated.




| | Heating | Cooling | Total |
|---|---|---|---|
| 20% | 81 | 5721 | 5801 |
| 40% | 205 | 8348 | 8553 |
| 60% | 554 | 9665 | 10219 |
| Best Uninsulated | 455 | 7410 | 7864 |

Graph 18: Effect of enlarging glazing area on the annual energy consumption

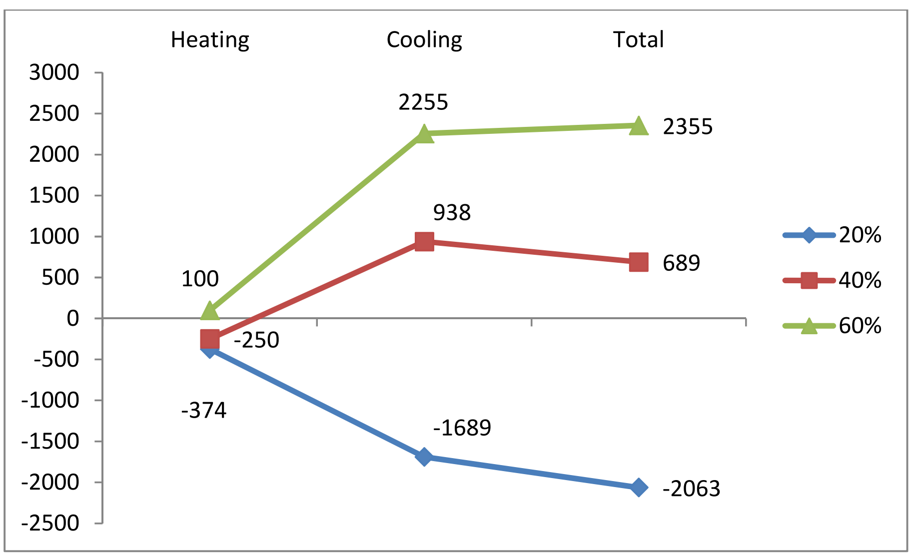
Expectedly, as the glazing area was enlarged, total annual energy consumption was increased. The trend is similar for heating and cooling load (graph 18) however, the impact on the cooling load is comparatively higher than the heating load.

Besides, the rise in load demand as the result of increasing windows area from 20 to 40% is higher than 40 to 60% increase.

Results of this study highlights the noticeable effect of glazing area on total load demand of residences in Cyprus, as 20% increase in the glazing area leads to such a surge in electricity usage that overcomes expected savings by applying insulation and double glazing windows.

Consequently, it is suggested that the glazing area is minimized as much as possible, in order to develop the most energy efficient building design.

In graph 19, differences of each case from the best case – uninsulated, normal windows - are presented.




Graph 19: Difference from the best uninsulated case

# Chapter 6

# CONCLUSIONS AND RECOMMENDATIONS

## 6.1 Conclusions

This research aimed at identifying measures taking which, higher security and living standards are achieved by minimizing the annual heating and cooling load demand of residential buildings in Cyprus. Furthermore, the impact of several factors such as the analysis period, interest rate, insulation material prices, airtightness and increasing glazing area on the effect of aforesaid measures was also studied.

Accordingly, an approximately 110 square meters residence, as a representative of typical single family house in Cyprus was modeled with Autodesk Revit and exported to Autodesk Ecotect to perform thermal performance modeling.

Consequently, it was established that the proper choice of conventional envelopes, reduces the annual load demand significantly. Constructing the house with the combination of floor type 4, roof type 1 and wall type 1 saved 11526kWh, in comparison with the combination of floor type 1, roof type 2 and wall type 7. Besides, from the initial cost point of view, the best combination was floor type 1, roof type 1 and wall type 1. However, taking more than 2 years as the analysis period, the choice remained the same since annual savings was compensated for the extra initial expenditure.

Subsequently, in order to amend thermal performance of the best combination, most beneficial measure with respect to their payback period is listed below:

1- To replace normal single-glazed windows with double glazed aluminum frame ones which payback period was less than 3 years with 242TL saving at the end of the third year.

2- To insulate the roof from outside, with 1.6 centimeter high density Rockwool which payback period was less than 7 years with 112TL saving at the end of the seventh year.

3- Substituting normal doors with solid core doors that present higher thermal performance which payback period was roughly 22 years with 20TL saving at the end of the twenty fifth years.

Undoubtedly, taking all the aforementioned measures maximizes the saving in long term to 8654TL at the end of thirtieth year but, in case of shorter analysis period or limited budget, a selective option would be preferred.

Besides, the sensitivity analysis divulged the intense dependency of net saving as the result of improving thermal performance of dwellings, on the interest rate, material price and electricity tariff changes. If the price of high density Rockwool was surged to 15TL/M2, payback period was increased to 9 years. Similarly a growth in the interest rate to 0.06, would alter the period to 7 years while, a rise in electricity tariff to 0.8TL/kWh reduced the payback period to less than 3 years.

Thermal comfort on the other hand, was 41% more in case of enhancing thermal characteristics of Cypriot dwellings, as inhabitants experience longer comfort times if they choose not to condition the inside air.

Furthermore, the effect of low quality construction implementation was found significant as up to 2300 kWh increase in electricity consumption was observed as the air change rate per hour was increased from the standard 0.5 to 2.5 which represents a poorly implemented construction project.

Similarly, enlarging fenestration area led to a surge in the annual load demand, as if increased from 20 to 60%, overcomes net saving of the 20%-glazed case which thermal performance had been improved. Hence, it is recommended that the glazing are is designed as small as possible.

Finally, it is highlighted that monetary benefits that were computed in this study, are additional benefits to non-monetary advantages which contribute to the improvement of living quality, standard, and security of the case study. Most important non-monetary benefits as the result of improving thermal performance of residential units are listed below:

1- Higher thermal comfort levels inside the building

2- Better physical and intellectual activities of inhabitants

3- Lower dehydration possibility

4- Decreased risk of diseases and allergies such as cardiovascular and lung diseases, blood clots, triggering inflammatory responses, constricting blood vessels, asthma, hayfever, allergies to humidity and changes in temperature

5- Increased productivity

6- Decreased fatigue

7- Reduced presence of insects inside the house

8- Improved security

9- Reduced unnecessary racket level

## 6.2 Recommendations

According to the current research which was based on one typical residential unit of Cyprus which floor area and architectural plan was considered fixed, a list of recommendation for future studies is provided as follow:

1- Taking into account the variety of plans and floor areas

2- Considering multi-story buildings as case studies for studying the annual energy demand and the proper placement of insulation layer

3- Performing complete life cycle costing

4- Assigning precise air conditioning schedule attributable to conventional living style of inhabitants

5- Considering the possibility of using other means of air conditioning for instance fuel or wood for winter time

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