A METHOD ON ENERGY-EFFICIENT RETROFITTING FOR EXISTING BUILDING ENVELOPES

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ABSTRACT

A METHOD ON ENERGY-EFFICIENT RETROFITTING FOR EXISTING BUILDING ENVELOPES

Starting in 1970s with the two major oil crises, conservation of non-renewable energy sources became an important concern. Buildings, which hold a large portion of energy consumed in the world, became subject to significant reductions through the energy consuming processes, especially for space heating and cooling energy consumption end uses. Strong initiatives are set in the world, promoting energy efficiency in buildings, both for new designs and existing building stock. However, energy-efficient improvement of existing building stock is a more challenging process for existing buildings; due to lack of energy conscious decisions, which were disregarded during design process. Energy-efficient retrofitting thus becomes an important focus of the research areas that aim to endorse efficiency in buildings.

Principally with Energy Performance in Buildings Directive of European Union, methodologies to optimize design decisions for energy-efficient retrofitting emerged. In Turkey, energy performance of buildings is recently introduced with a regulation in 2008. Prior to this regulation TS 825 Thermal Insulation in Buildings was the main control mechanism, which was only mandatory a decade ago. The lack of methodological approach and control mechanisms caused the relatively young Turkish building stock, become non-insulated or poorly insulated.

Therefore this research focuses on proposing a methodology for energy-efficient retrofitting of public building envelopes, particularly as building types which may raise public awareness on the necessity of energy efficiency in buildings. The dissertation aims to fill the gap of a structured methodology which can be applied throughout defined set of actions to diagnose the existing performance of a building, to propose retrofitting options and evaluate these options to assess an advantageous solution to energy-efficient retrofit of public building envelopes. The thesis aims to indicate the savings in annual energy consumption, reduction in CO2 emissions and improvement in indoor thermal comfort as a result of a retrofitting action applied due to a structured methodology.

ÖZET

MEVCUT YAPI KABUKLARI İÇİN ENERJİ ETKİN İYİLEŞTİRME YÖNTEMİ

1970'li yıllarda ortaya çıkan iki büyük petrol krizinden sonra, yenilenemeyen enerji kaynaklarının korunumu önem kazanmıştır. Binalarda ısıtma ve soğutma amaçlı tüketilen enerji, toplam tüketimin büyük bir dilimine karşılık gelmektedir.Bu sebeple binalarda enerji tüketiminin indirgenmesi önem kazanmış, dünyanın bir çok ülkesinde, yeni yapılar ve mevcut yapılarda enerji verimliliğinin sağlanması, enerji tüketiminin azaltılması gibi çalışmalar standartlar ve yönetmeliklerle belirlenen çerçevelerde uygulanmaya başlanmıştır. Yeni yapılar için tasarım aşamasında uygulanabilecek önlemler belirlenirken, mevcut yapıların enerji etkin iyileştirilmesi için de sistematik yaklaşımlar geliştirilmesinin gerekliliği gündeme gelmiştir.

Özellikle Avrupa Birliği'nin "Binalarda Enerji Performansı Yönetmeliği"ni (EPBD, 2002) yayınlamasından sonra, yeni yapılardaki önlemlerin yanı sıra, mevcut binalar için alınacak enerji etkin iyileştirme kararlarının da uygulanması bir zorunluluk halini almıştır. Türkiye bu yönetmeliğe uyum çerçevesinde 2008 yılında Binalarda Enerji Performansı yönetmeliğini yürürlüğe koymuştur. Bu yönetmelik yeni yapılar ile ilgili sınırlamalar getirirken, mevcut yapıların enerji etkin iyileştirilmesini öngörmekte, ancak bir yöntem önermemektedir. TS 825 Isı Yalıtım Yönetmeliğinin ancak 2000 yılında zorunlu olduğu Türkiye'de yalıtımsız/yetersiz yalıtılmış, çevreye duyarlı tasarım ana kararlarından yoksun, göreceli genç bir yapı stoku bulunmakta ve mevcut yapıların enerji etkin iyileştirilmesi için gerekli olan yöntemsel hesaplama ve kontrol mekanizmalarına işlerlik kazandırılması gerekmektedir.

Bu bağlamda, bu çalışma mevcut yapı kabuklarının enerji etkin iyileştirilmesi için bir yöntem önerisi geliştirmeyi hedeflemektedir. Yöntemin geliştirilebilmesi için, binanın mevcut durumdaki enerji performansının belirlenmesi, iyileştirme önerilerinin sunulması ve değerlendirilmesi gibi farklı aşamalar alan çalışması üzerinden örneklenerek uygulanmıştır. Diğer yandan, önerilen yönteme bağlı olarak yürütülen iyileştirme çalışmalarının sonucunda elde edilecek enerji tasarrufu, CO_2 emisyonlarının indirgenmesi ve iç mekan ısıl konfordaki iyileşmelerin saptanabilmesine olanak sağlamaktadır.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

With the oil crisis in early 1970's, the fossil fuel consumption became an important concern. Due to rapid technological and industrial growth, the need for energy in the world increased for the last decades. Figure 1 presents the rising consumption trend in primary energy consumption between 1998 and 2008. In a period of ten years, the amount of energy consumed increased almost 27 % (BP, 2009). Although energy conservation became a crucial subject of interest with the oil crisis in early 1970's, yet the consumption trend cannot be reversed, since utilization and integration of renewable sources are still emerging technologies. Therefore, continuing demand for non-renewable energy resources (fossil fuels) causes the ongoing depletion of natural sources and environmental degradation, which are both the inevitable outcomes of this consumption trend (D'haeseleer, 2003; IEEE, 2007).

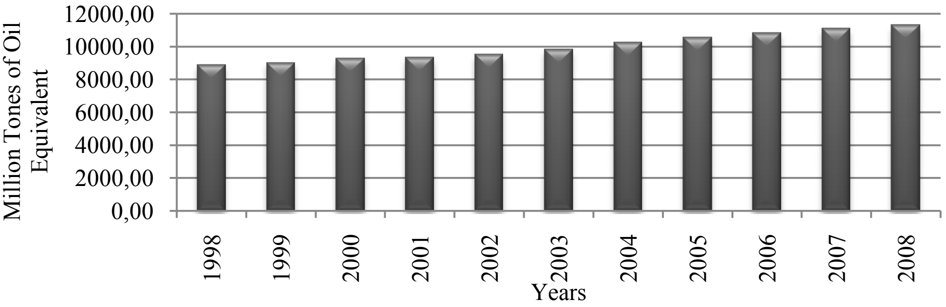


Figure 1. Primary energy consumption 1998-2008
(Source: BP 2009)

Utilizable energy (such as electricity etc.) is mainly produced from non-renewable energy resources (Figure 2). Due to the increasing trend in the energy consumption, depletion of these non-renewable energy resources become crucial and thus energy prices rise inevitably. Coupled with environmental problems (such as CO_2

emissions), this trend indicates the necessity to decrease the use of non-renewable energy sources for all consumption end-uses.

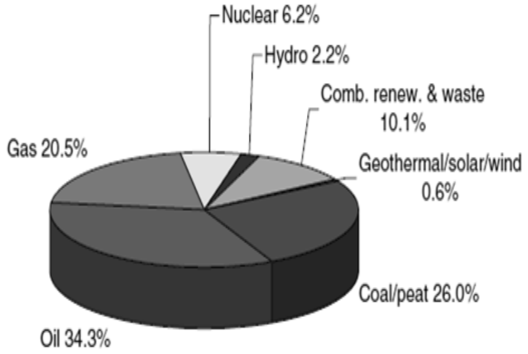


Figure 2. World share of total primary energy in 2006
(Sources: IEA 2008, IEA 2009)

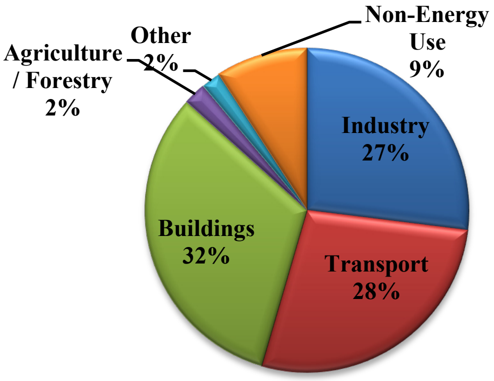


Figure 3. Percentage of world energy consumption by end-use
(Source: IEA 2006)

Statistical assessment of energy consumption according to end-use sectors indicates that approximately 30-40 % of energy is consumed by buildings (residential, commercial and public) (Figure 3). The building sector significantly contributes to the consumption of non-renewable energy resources during the service life of buildings, besides production of building materials and construction processes. In building level, energy consumption patterns vary from space heating and cooling, water heating, lighting to building services etc. (REEEP, 2007). Consumption measures become important for reducing the environmental impacts of the built environment, such as reduction of greenhouse gas emissions, life-cycle energy use of buildings and utilization of environmental friendly systems and materials (Dong, Kennedy, & Pressnail, 2005).

Since early 1990's a majority of European Countries work on defining and formulating methods to reduce energy consumption of buildings in different scales, from household even to district scale. Most significant regulatory action is submitted as a European Union Legislation in 2002, as "Directive on the Energy Performance of Buildings (2002/91/EC)". In general, this Directive asserts the necessity to increase energy efficiency, both for new and existing buildings, to develop certain methodologies to determine energy performance of buildings, and to prepare energy certificate programs for the building stock of European Union Countries (EPBD, 2002).

Parallel to acts on energy efficiency/performance of buildings, measures against global climate change is as well essential. The most effective act against global climate change, Kyoto Protocol (UN, 1998) proposes regulations to limit fossil fuel combustion to avoid release of products which cause greenhouse gas intensity to increase and to reduce deterioration of climatic balance of our world. Decrease of CO_2 emissions highly depend on reduction of fossil fuel consumption, thus Kyoto Protocol suggests the use of clean and renewable energy technologies for services where possible.

As a result, the general framework of "resource/production/consumption" and additional environmental problems and their consequences on global climate change, helped to define broad research areas concentrated on energy efficiency and energy performance of buildings. These broad expressions may cover sub areas such as, implementation of necessary regulations and benchmarks (national and/or international) in the design of new buildings, guidelines for construction/detailing of new buildings, improvements for existing buildings to achieve necessary efficiency levels. Figure 4 illustrates the broad research area as energy performance of buildings and one of the sub-research areas as energy-efficient retrofitting, and the major concerns.

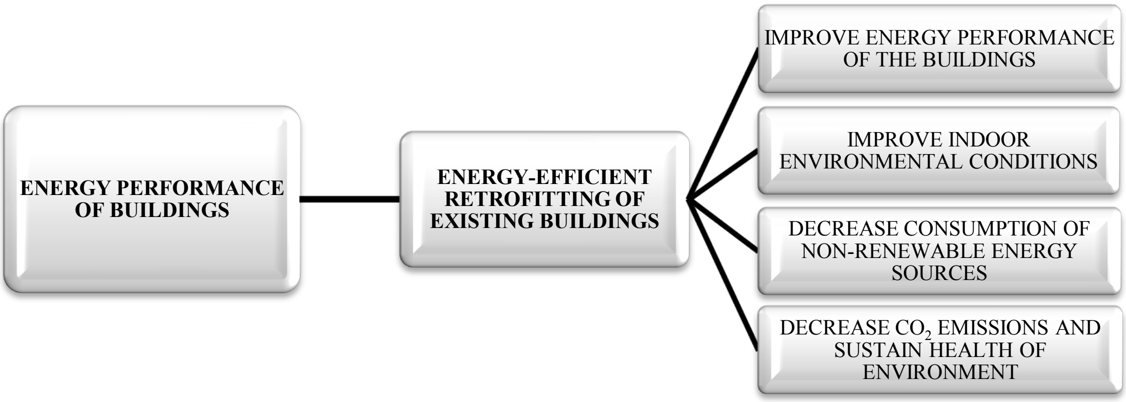


Figure 4. Broad and sub research area

Due to rising awareness in European countries, regulations and actions on improving the energy performance of buildings are extensively researched and applied in the last 20 years. However in Turkey, necessary awareness is still in the regulatory level. The standard TS 825 Thermal Insulation in Buildings became mandatory only in year 2000. In December 2005, Energy Performance of Buildings Directive was enacted, and consecutively in May 2007 Energy Efficiency Law was announced. These three important regulations/directives oblige the efficient use of energy in all energy end-use sectors. Therefore, it is possible to assert that there is a great potential of energy savings for Turkish building stock, yet the regulations are being applied in the last decade and demonstrative activities have started in recent years. Nevertheless, there is still a certain requirement for standardized methods to determine energy performance of buildings, to develop guides for achieving energy efficiency in buildings in Turkey. This area of knowledge can only develop with the cooperation of policy makers, experts and end-users.

Parallel to the current state in Turkey, this dissertation focuses mainly on one of the sub areas of energy efficiency/performance of buildings, specifically energy-efficient retrofitting of buildings. Since energy-efficient retrofitting is itself a broad area, the dissertation is limited to energy-efficient retrofitting of public building envelopes. The dissertation focuses explicitly on the question of “How to retrofit?” and aims to construct a holistic approach to propose a precise guide for the energy-efficient retrofitting of public building envelopes, particularly in Turkey.

The first and current chapter of the dissertation introduces the aim and scope of the study and general definitions and key points on the research area. With this chapter it is possible to gain association to the problem statement and the components of the problem.

In the second chapter, background studies on the research area are evaluated according to the main focus of the dissertation. The literature review is composed of three main parts. In the first part former studies are evaluated. In the second part directives and regulations that are restrictive on the subject area are summarized both in international and national level. In the third part, the studies in national context are summarized.

The third chapter aims to define and execute the methodology simultaneously. The case study conducted to formulate the methodology is explained in steps/tasks comprehensively. The aim of this chapter is to demonstrate the proposed methodology in an initial functional frame.

In the fourth chapter of the dissertation findings and analysis of the outcomes from methodology chapter (Chapter 3) will be discussed in detail and general results and discussion on the dissertation aims is be completed.

The fifth, thus the final chapter of the dissertation summarizes the methodology proposed by this study and discusses the shortcomings of the dissertation and further study suggestions.

1.1. Problem Definition, Aim and Scope of the Study

1.1.1. Problem Statement

World energy need has a rapid growth due to technological, demographical, and social developments. Overall energy consumption is mainly based on fossil fuels which are non-renewable and hazardous for the environment when combusted. For the last decades, the global concern is to decrease fossil fuel consumption for preservation of energy sources and environmental health.

With the oil crisis in 1973 fossil fuel consumption became an important of the world agenda. In the following years, the emphasis on the energy conservation uniting with the emphasis of environmental sustainability, developed into a more effectively researched and evaluated topic. Consequently, research areas on decreasing the percent of energy consumed in buildings, integrating renewable energy technologies into building design and systems, limiting the energy use for heating and cooling of buildings by providing necessary envelope measures, obtaining the optimal daylight for indoor environments, facilitating natural ventilation in buildings became more comprehensively examined and evaluated in today's engineering and architectural disciplines (D'haeseleer, 2003).

Increasing interest on decreasing energy consumption through buildings emerged the necessity of energy efficiency improvements of existing buildings, as well as energy-efficient new building designs. This interest developed into research areas such as monitoring and energy performance of existing buildings. With an evaluation in this framework, it is possible to suggest that Turkey needs to advance in these particular research areas, since the building stock, which dates before 2000, commonly lack thermal and moisture insulation. Therefore, this built stock consumes excessive energy for heating and cooling, almost 35 to 40 % of the total energy, and require systematical, methodological improvements especially for building envelope and installation systems (Özel, 2008). Regarding the insufficiencies and consumption patterns in Turkish building stock, energy efficiency improvements require a methodological approach to decrease the energy consumption through buildings. With the aim to achieve improvement measures that will help increasing energy efficiency, it is essential to define the set of applications to determine the existing energy performance of the building, and to suggest available interventions, to evaluate these interventions and to define criteria for final decision-making.

Within building and construction sector in Turkey, the preventative measures for energy efficiency are not incorporated in the processes of design, production, and service. On the other hand, the strategies for reducing energy consumption in buildings became inputs of design and refurbishment in European Countries (Chiedwuk, 2002). A significant portion of existing building stock is not energy-efficient in Turkey, since misapplications and unawareness on the building standards cause buildings to have inefficient energy conservation values (Oral, G K, Unpublished). Building stock in Turkey requires great attention in terms of energy- efficiency because of the factors stated above. Besides, Turkey should adapt its legislations to the European Union process. Directive 2002/91/EC on the Energy Performance of Buildings, defines an explicit frame on the methodology to determine (a) the energy performance of buildings, (b) the minimum performance requirements for new buildings, and (c) the minimum performance requirements for renovation of buildings (EPBD, 2002). As the legislation indicates its frame, it is essential to say that energy retrofitting should be done by renovating the building envelope and adapting heating/cooling installations up-to-date.

However, buildings are a complex and unique systems composed of physical, functional, and environmental characteristics. In cases where energy performance evaluation and/or retrofitting is necessary, it is crucial to apply methodological approaches which cover a holistic state of view, combined with national/international regulations and certifications. In Turkey, several regulations are being accredited with European Union regulations; yet there is still lack of methodology in terms of energy performance monitoring and energy-efficient improvements of buildings. Figure 5 summarizes the problem in the framework of building, procedure and methodology.

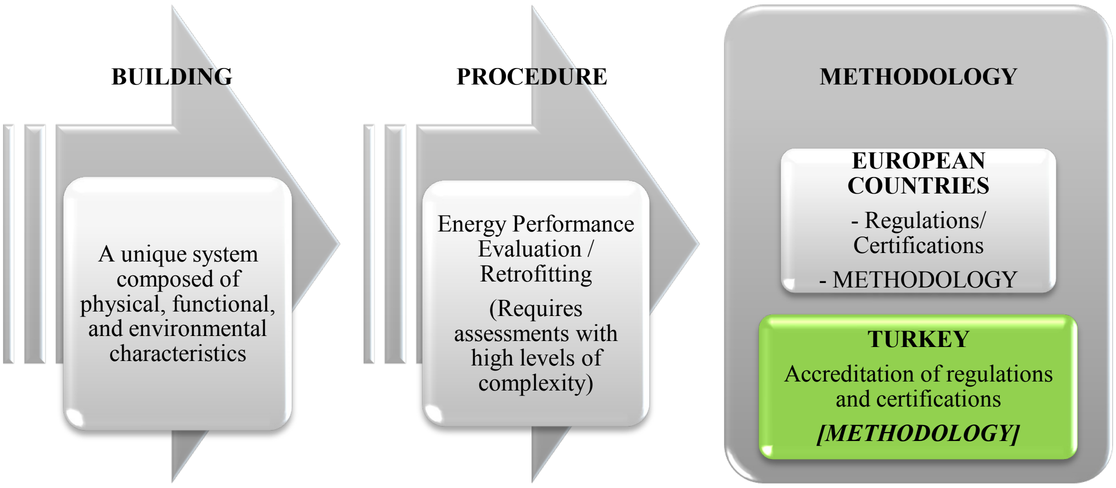


Figure 5. Problem statement

Energy-efficient building retrofit research presupposes a variety of potentials for Turkish building stock and overall energy-efficiency measures in Turkey. The retrofitting projects in buildings may contribute significantly to decrease energy consumption for heating and cooling of buildings and thus to increase the thermal performance of these buildings. Additionally, as the indoor environmental quality improves, the occupant health, performance, and occupancy patterns evolve. Energy-efficient building retrofit projects provide a variety of potentials, which might feasibly be applied throughout a sensitive methodology, and may lead the development of new methodologies, technologies, and systems.

Therefore this dissertation focuses on the necessity to formulate appropriate methodologies for energy-efficient improvements for the building envelope, particularly for public buildings in Turkey. The reasons for targeting public building stock can be listed as follows:

- Typical the plan arrangement, especially use of cell-office system provides a level of generalization in evaluation.
- Design and construction are completed through bidding process and in general the least bidder becomes the contractor. As a result, workmanship and detailing is negatively affected during construction process.
- Energy efficiency improvements in public buildings may offer collaborative approaches between policy makers, experts and end-users.
- Further demonstrations of energy efficiency improvements in public buildings can be a powerful tool to raise public awareness in terms of energy-efficient improvements of public buildings.

1.1.2. Aim and Scope of the Study

The dissertation "A method on energy-efficient retrofitting for existing building envelopes" aims to define a methodology for energy-efficient retrofitting of existing public building envelopes (roof, facades, floor on ground), which should be a guide for any further-planned retrofitting actions for Turkish public building stock. The proposed methodology is constructed from a set of applications, which can be assigned regardless of case-specific building characteristics (such as physical properties of building envelope, climate etc.).

Energy-efficient retrofitting of existing buildings is a complex system, where all building system and characteristics, environmental constraints differ from one building case to another. The necessity to develop a methodology, which helps to determine the certain weights affecting the energy consumption patterns of a unique building, is an inevitable task. However, the research area is wide in terms of limitations, information, and interrelations of complexity of retrofitting phenomena. Thus, besides the main aim of this dissertation several complementary aims can be suggested, in means of defining the scope of the study. These are:

- To exploit the crucial relationships in terms of energy consumption patterns between building, building element and installation design.
- To emphasize the necessity for regulations and control systems in building design in terms of energy efficiency.
- To assess the degree of degradation (effects of moisture or air leakage etc.) or insufficiency (misapplications through building design) in energy performance of a building.
- To establish the relationships between the investment costs for an energy-efficient retrofitting project and their payback in comparison with the expected decrease in energy bills.
- To attract the attention to the importance of energy savings (in annual heating and cooling energy loads) after retrofitting.
- To point out the importance of the quality of indoor environmental conditions.
- To raise the awareness of the authorities (public and private), and building inhabitants on the need to achieve optimization in energy consumption in the building sector.

1.2. General Definitions

This section of the chapter endeavors to present a small glossary for the terms and concepts which will be mentioned throughout the thesis. The following definitions of terms and concepts rank respectively from broader concepts to more specific ones.

1) Energy Performance of Buildings:

In Directive on the Energy Performance of Buildings 2009/91/EC of the European Parliament, energy performance of buildings is defined as the amount of energy consumed or estimated for standardized use of the building, including heating, hot water heating, cooling, ventilation and lighting. Additional indicators which effect the energy performance of a building are insulation, installation characteristics, design and positioning in relation to climatic aspects, solar exposure and influence of neighboring structures, energy generation, and indoor climate (EPBD, 2002). As a summary it is possible to state that energy performance of buildings is a numerical indicator which takes the energy consumption in consideration and expresses the level of performance of a building. For instance, CEN/TC 89 Thermal performance of buildings and building components asserts an overall indicator called “energy performance indicator (EP)” which represents (a) primary energy, (b) CO_2 emissions and (c) delivered energy (CEN/TC89, 2006).

2) Energy-Efficiency in Buildings:

ASHRAE Applications Handbook 1999 defines energy-efficiency in buildings as the result of a set of improvements to obtain energy conservation within an energy management program. For existing buildings, energy conservation components are listed as existing building thermal performance upgrading and energy-efficiency improvement (ASHRAE, 1999). In the Energy Efficiency in Buildings Part B Booklet energy-efficiency is described as a part of the building procurement process, which can represent a long-term commitment to energy bills (CIBSE, 2004). Another report declares that there is great potential for energy conservation in building sector and energy-efficiency interventions are only economic and practical when a building is retrofitted or newly erected (IEE, 2003). According to the definitions above, it is clear that energy-efficiency is directly related with the opportunities and precautions taken to decrease life-cycle energy use of building.

3) Thermal Performance of Buildings:

The definition of the concept can be summarized as a calculated outcome of heat gain and loses (from installations, solar exposure and other heat generators), heat capacity of the building components and their heat transfer characteristics (CIBSE, 2003; CEN/TC89, 2006). Buildings are expected to attain the defined minimum level of thermal performance measures, defined by local, national or international standards.

4) Thermal Comfort:

In ASHRAE Fundamentals Handbook 1997, thermal comfort is defined as condition of mind, which expresses satisfaction with the thermal environment. The indoor environmental measures should be calculated and controlled so that occupants' comfort is assured (CIBSE, 2006). Theoretically, three forms of heat transfer (conduction, convection, and radiation) should result in thermal neutrality to be able to mention complete satisfactory with thermal comfort. However, in practice, many buildings do not reach this neutrality level, therefore additional service systems are required to maintain levels of thermal comfort (ASHRAE, 1997).

5) Energy Audit:

The concept of "energy auditing" usually refers to assess the energy consumed in a building's all end uses by evaluating the existing data of consumption or utility bills. In broader explanation, it is the collected set of data to be analyzed and interpreted for determining the energy performance of a building or complex. Energy audit is carried out mostly before improvements for energy efficiency are started. It is regarded as a diagnostic tool to assess the existing level of energy performance of a building. Energy auditing may have different levels of detail. An overall energy audit refers to a quick audit with the collection of previous years' utility bills. Instead of diagnosing special problematic points in the building, this type of audit helps to evaluate the overall energy consumption patterns of a building. Detailed energy audit targets the end-use consumption patterns of all building services (heating, cooling, ventilation, lighting and equipment energy use), climatic variables and occupancy patters as well. This kind of audit usually lasts for a full year covering all seasonal periods. Besides the consumption data, indoor environmental quality is also monitored. Data analysis from a detailed energy audit may suggest the problematic components of a building in scope of energy performance measures (CRES, 2000; Anıl Ahuja, 2004).

6) Building Envelope:

Building envelope can be defined as a skin, which separates the indoor environment from the outdoor environment and is expected to establish thermal comfort, visual comfort and acoustic comfort (Oral, Yener, & Bayazit, 2004), which consists of the opaque elements (exterior walls), glazing and windows, the roof and the ground floor slab. Thermo-physical characteristics of these elements of the building envelope are essential parameters in determining the overall energy performance of a building where most of the heat loses and heat gains occur through the building envelope, and these characteristics depend on several parameters such as thickness, density, heat conduction coefficients, presence of a cavity, and presence of insulation layers (Yannas, 1994; Oral, Yener, & Bayazit, 2004; Lollini, Barozzi, Fasano, Meroni, & Zinzi, 2006).

7) Building Installation Systems:

Mechanical, electrical and sanitary systems can be regarded as the main building installation systems. Mechanical systems are utilized to provide indoor thermal comfort conditions at the pre-designed or user-required thermal comfort level. These mechanical systems may include heating systems, cooling systems, ventilation systems, and building automation systems (Brown & DeKay, 2000). In addition to the mechanical systems, sanitary services are important in terms of efficient distribution of hot water, utilization of rain water etc. (Hens, 2002). Finally it is important to introduce electrical services as a part of building installation systems, where lighting and equipment are directly related with the efficiency of electricity installations.

8) Retrofitting:

The concept is simply defined as "t*o provide (a jet, automobile, computer, or factory, for example) with parts, devices, or equipment not in existence or available at the time of original manufacture*" or "*to install or fit (a device or system, for example) for use in or on an existing structure, especially an older dwelling*" (Dictionary, 2007). Both definitions points out that, a system constructed with the preliminary equipment and systems may require an additional support or system that can be integrated to the existing state to provide more efficient outcomes of that system. Retrofitting is a combined concept in terms of constituting all the individual concepts that are defined in the previous section. Decision-making process for a building retrofitting requires first an energy audit, and then determination of building energy performance and finally formulating a retrofitting approach.

1.3. Conclusion

Regarding the insufficiencies in Turkish building stock, energy efficiency improvements require a methodological approach to decrease the energy consumption through buildings. With the aim to achieve improvement measures that help increasing energy efficiency, it is essential to define the set of applications to determine the existing energy performance of the building, and to suggest available interventions, to evaluate these interventions and to define criteria for final decision-making. In the following chapters, dissertation provides a case study for the formulated methodology for energy-efficient retrofitting of public buildings, whereas the main aim of this dissertation is to define a methodology for energy-efficient retrofitting of existing public building envelopes, which should be a guide for any further-planned retrofitting actions for Turkish public building stock.

CHAPTER 2

LITERATURE REVIEW

Literature review on the background of energy-efficient retrofitting of buildings will be evaluated in this chapter. Following sections of the chapter covers the following organization in presenting the background studies on the research area: (a) an overall analysis of the literature on building energy performance and energy-efficient retrofitting, (b) a focus on directives and regulations on building energy performance both in international and national context, and (c) energy performance and energy-efficient retrofitting studies in Turkey.

The literature on the research area which is reviewed in this chapter is presented in a chronological and comparative manner. The aim is to depict the level of research conducted in international and national field. The shortcomings and/or outstanding activities are potential research areas respectively to take as a model and/or to fulfill the gaps with further studies. Especially with the section concerned on research and regulative activities in Turkey, the problem statement of the dissertation will be supported explicitly.

The first section of the literature review starts from the broad actions and research & development activities concerning primarily energy-efficiency, energy performance and energy-efficient retrofitting of buildings. The section aims to review all collaborative, co-operative actions in the research area, and then individual scientific research which is significant in the area and their categorical approaches will be evaluated in detail. The second section of the literature review focuses more on the directives and regulations in international and national context. The third section aims to illustrate the state-of-the-art in Turkey, after reviewing international research activities. Finally, the fourth section a conclusive analysis of the literature review will be presented.

2.1. Literature Review on Energy Performance and Energy-Efficient Retrofitting of Buildings

2.1.1. Research Activities

The very first attention on energy conservation issues dates back to early 1970's, to the period when the first oil crisis stroke world agenda. The oil prices increased drastically and this price inflation caused oil to be one of the most valuable resources in the world (Barsky & Kilian, 2004). With this unexpected outbreak, reduction of fossil fuel consumption and their environmental impacts became a concern of discussions.

Sustainability was first introduced, in 1987 with the Brundtland Report of the World Commission on Environment and Development. The well-known statement of the report: *"the development that meets the needs of the present without compromising the ability of the future generations to meet their own needs"* summarize the idea of sustainability in very general limits. Brundtland Report also promotes use of renewable energy sources and their utilization in the application of heating and cooling mechanisms in all possible energy-consuming systems (Brundtland, 1987). The report led to the first Earth Summit - the UN Conference on Environment and Development - at Rio de Janeiro in 1992. Agenda 21 was the production of this conference, which addressed sustainability, conservation of resources, and environmentally sensitive actions (Agenda21, 1992).

As global actions such as Brundtland Report, Agenda 21 emphasized the vitality of sustainable development, many assemblies, conferences and development studies accelerated in 1990's. In 1997 The Kyoto Protocol, a treaty of United Nations Framework Convention on Climate Change (UNFCCC) put forward the act of developing national programs to reduce greenhouse gas emissions. Greenhouse gases such as carbon dioxide influence the energy balance of the atmosphere and cause global warming, a significant change in climate with increase of average temperatures (UN, 1998).

Consequently, the cycle caused by combustion of non-renewable energy sources, release of carbon dioxide and global warming becomes crucial in sustainability point of view. Therefore, with above protocols and acts, all nations are expected to decrease non-renewable resource consumption as much as possible, and facilitate these resources more in non-energy use (such as production of plastics etc.), and render the amount of greenhouse emissions to lower levels to protect climatic balance of the world.

A further act emerged in 16 December 2002 European Parliament 2002/91 /EC on the Energy Performance of Buildings Directive (EPBD). The directive states that, increased energy efficiency through all sectors represents an important part of the policies and measures needed to fulfill Kyoto Protocol requirements, thus good levels of energy conservation and environmental protection became fundamental requirements of the European Union and the candidate countries. Therefore, research on energy-efficiency of building sector, became a focus of the institutes, research centers in European Countries (EPBD, 2002). The directive suggests the following key issues in Article 1 to be achieved in design of the new buildings and improvement of the existing buildings:

- The necessity of a general framework for a methodology to calculate integrated energy performance of buildings in national or regional levels.
- The application of minimum requirements for energy performance for new buildings
- The application of minimum requirements on the energy performance of large existing buildings that are subject to major renovation.
- The necessity for energy certification of building.
- The necessity of regular inspection of heating, cooling and ventilation systems, and particularly the assessment of heating installations older than 15 years old (EPBD, 2002).

With the global key issues listed, it is possible to denote that energy performance of buildings became significant for EU countries, to fulfill the requirements of Kyoto Protocol, to achieve major energy savings in building sector and thus to decrease carbon dioxide emissions. As the directive emphasizes, one of the main concern of all EU countries put effort in defining a methodology for determination of energy performance of buildings. European Union, as the major medium offering energy efficiency policies and programs, advances the context of energy efficiency in buildings, which is promising in terms of policy making, potentially a considerable portion of the world population to contribute these policies, and the support of technological improvements in energy-efficient knowledge and systems (Janssen, 2004).

Besides European Union actions, a very effective collaboration of twenty-eight industrialized countries, International Energy Agency (IEA, founded in 1974) is an autonomous agency which is linked with the Organization for Economic Co-operation and Development (OECD). The global focuses of IEA can be summarized as energy resources, technologies, efficiency, and statistics. IEA promotes scientific research and development activities on the mentioned focuses. The IEA (International Energy Agency) Energy Conservation in Buildings and Community Systems (ECBCS) Programme is a research and development program which started in late 1970s. Main aim of the program is to promote research activities with a life span of 3 to 4 years. The results of these research & development projects are published named as "annexes". In further parts of the literature review the research belonging to this program will be referred as IEA Annexes (IEA, 2008).

In 1989, THERMIE Programme was introduced and the intention of the program was to present energy-efficiency through demonstration projects. The target sector was industry, and the aim of the program was (a) to improve energy efficiency in demand and supply sectors, (b) to promote extensive utilization of renewable energy sources, (c) to encourage cleaner use of fossil fuels, and (d) to optimize utilization of the EU's oil and gas resources. In 1993, THERMIE Programme coupled with JOULE Programme of EU, and since then the program is known as JOULE/THERMIE Programme, which aims to encourage activities in the field of clean and efficient energy technologies. The Programme, with seventy-three sub-research reports and publications on rational use of energy, clean and renewable energy technologies, lasted until 1998 (THERMIE, 2009; JOULE/THERMIE, 2009).

In October 1991, SAVE Programme focusing on non-technical measures on energy efficiency was initiated by European Union, and lasted until 1995. SAVE Programme was dedicated extensively to encourage energy efficiency and energy-saving behavior in industry, commerce, transport and domestic sector through policy measures, information, and demonstrative actions and the founding of local and regional energy management agencies (SAVE, 2005). Consequent to this programme, SAVE II was adopted by the Council in December 1996 (96/737/EC) for between 1996 and 2000. In February 2000 SAVE was integrated into the Energy Framework Programme which consists of three different programs during period 1998 and 2002. In 2005, European Commission prepared a report for the evaluation of SAVE and SAVE II Programmes (SAVE II, 2009). The report concludes with the following key points, which efficiently summarizes both the aim and outcomes of these two long-term programmes:

- To stimulate energy efficiency measures in all sectors.
- To encourage investments in energy conservation by public and private consumers and by industry
- To create framework conditions for improving the energy intensity of end-use consumption. (Projects such as labeling, methodologies, networks etc.) (SAVE II, 2009).

Parallel to above projects, CADDET (Center for the Analysis and Dissemination of Demonstrated Energy Technologies), a center supported by collaboration of IEA and OECD, started research activities conducted on energy-efficiency, energy saving in buildings, and energy management, and on energy-efficient retrofitting of buildings. In October 1992, CADDET published Analyses Series No. 8 Learning from experiences with Energy Efficient Retrofitting of Office Buildings, followed by Analyses Series No. 18 Learning from experiences with Energy Efficient Retrofitting of Residential Buildings in March 1996. These two analyses reports were both focusing on the concept of energy-efficient retrofitting.

CADDET Analyses Series No. 8 aims to explain possible retrofit procedures for office buildings since commercial buildings -office buildings in particular- exemplify higher energy consumption than residential buildings. The analyses report focuses on two main factors to be evaluated when retrofitting or refurbishment of an office building is necessary: (1) levels of current energy use - which can be detected through an energy audit and (2) reliable estimates of future savings after the implementation of a retrofitting/refurbishment procedure (Abel, Aronson, Jagemar, & Nilsson, 1992). The report has a clear methodology which aims to determine the existing situation of the building by energy auditing, then to propose refurbishment options including the most important factors related to a building's energy efficiency and then to assess the outcomes of these options by simulation and cost control including net present value (NPV) and simple pay back model. Through this methodology, the research targets different office buildings in three different climates from Stockholm (Sweden), Washington (USA), Kagoshima (Japan) (Abel, Aronson, Jagemar, & Nilsson, 1992).

The second CADDET report, Analyses Series No.18 aims to establish an information ground for residential property owners, administrators, tenants and governments to increase the awareness of the advantages of retrofitting the residential stock. The primary factors evaluated in retrofitting of residential buildings are the quality, age, structure of the building, existence of an acceptable indoor climate, and cost of energy supplied to a building. The main concern of the report can be summarized as decreasing energy usage in residential buildings by improving thermal efficiency and indoor comfort levels of that building (Nilsson, Aronsson, & Gusten, 1996). The analysis follows a brief methodology starting with the determination of the current condition of the existing residential buildings. Then proposes a retrofitting system for the envelope and installation systems, which is configured according to the necessity of the level of intervention the building requires. The interventions can be either on the building envelope or on the installation systems, or both. The next step requires measurements on the retrofitted buildings and the comparison of the initial and retrofitted values. Finally, the economics of retrofitting is evaluated in terms of investment and payback (Nilsson, Aronsson, & Gusten, 1996)

Complementary two projects from JOULE III Programme of 3rd and 4th Framework Programs of the European Union, EPIQR (Energy Performance and Indoor Environmental Quality Retrofit) and the following research action TOBUS (Tool for Selecting Office Building Upgrading Solutions) are important in terms of offering a decision-making methodology for building retrofits and computer software for diagnosis of the existing building conditions. EPIQR focuses on residential buildings, whereas the scope of TOBUS is office buildings (Allehaux & Tessier, 2002).

In detail, EPIQR is a two-year European research project (1998-2000), involving seven research institutions, with the objective to evaluate physical state of degradation of building elements and services, with respect to energy performance, energy consumption, and the indoor environmental quality. It is a methodology and a software tool for building audit, to describe the existing state of a residential building (older than 20 years) particularly on the construction and function of the building elements (such as envelope, mechanical installations, sanitary), energy consumption patterns, and quality of the indoor environment (TOBUS, 2007; Balaras, Droutsa, Argiriou, & Asimakopoulos, 2000; Bluyssen & Cox, 2002). The methodology in EPIQR (1998-2000) is constructed with following steps: (1) diagnosis stage in which the building element deteriorations are determined and corresponding refurbishment necessities are described, (2) processing occupant questionnaire results statistically to highlight the link between the occupant complaints and necessary refurbishment works, (3) calculation of energy balance of the building according to the European prEN832 method, (4) computational refurbishment scenario that allows the user to build up different alternatives, including investment information, and (5) reporting the present state of the building and its energy balance and the expected results of refurbishment scenarios (Flourentzos, Droutsa, & Wittchen, 2000).

TOBUS follows a similar methodology as EPIQR which aims to offer a tool for the evaluation of retrofitting needs of office buildings to estimate the refurbishment costs that meet the needs of improved energy performance and indoor environmental conditions. TOBUS software evaluates buildings in four major subject areas such as, the physical state of degradation of building elements, functional obsolescence of building services, energy consumption, and indoor environmental quality. This evaluation itself constitutes the exact elements of a decision-making process for refurbishment of office buildings (Caccavelli & Gugerli, 2002; Brandt & Rasmussen, 2002).

IEA ECBCS Annex 36 - Retrofitting in Educational Buildings - REDUCE 25 Case Study Reports from 10 different Countries is one of the examples to these research projects which focus on the retrofitting actions on educational buildings from 1999 to 2003. The aim of the Annex is to develop a tool for the education sector in order to take the correct actions during retrofitting projects. The research report argues that there is a lack of understanding in what has to be done when a retrofitting project should be proposed, and ineffective decisions can be given during the retrofit process. Therefore, the research proposes a common methodology for the estimation of integrated energy performance of buildings and the minimum standards, which should be applied for the construction of a new educational building or renovation of existing educational buildings (Erhorn, Mroz, Mørck, Schmidt, Schoff, & Thomsen, 2008; Kluttig, Erhorn, & Mørck, 2003).

Annex 36 focuses on the interventions on building envelope, heating systems, ventilation systems, solar control and shading, cooling techniques, lighting and electrical appliances and the management of the listed features. With a broad range of factors, the research compromises a holistic building retrofitting approach. Additionally a tool called Energy Concept Adviser (ECA) was introduced by Annex 36, which has been developed to provide advice on energy-efficient retrofit measures for the use of decision makers (Mørck & Erhorn, 2003).

BRITA in PuBs (Project Framework 6-Bringing Retrofit Innovation to the Application of Public Buildings) started in 2000 and ongoing within EU 6th Framework Programme, is based on decision-making models to consider financial mechanisms in European Union member countries for low energy retrofit of public buildings. Initially, the project determines eight case retrofits of different types of public buildings (such as colleges, cultural centers etc.) in four European regions (North, Central, South, East). Subsequently, the research concerns on socio-economic approach that focuses on the necessities in real project planning, financing strategies, the development of design strategy, and a quality control-tool box to secure a good long-term performance of buildings and systems (Citterio, et al., 2005; Kaklauskas, Zavadskas, & Raslanas, 2005). The aim of the project is to increase the market penetration of innovative and effective retrofit solutions to improve energy efficiency and promoting the implementation of renewable technologies, with moderate additional costs. The technology applications include measures at the building envelope like improved insulation and high-efficient windows, advanced ventilation concepts like hybrid systems, integrated supply technologies like combined heat and power units, energy-efficient lighting and integrated solar application (Citterio, et al., 2005).

The consequent Programme launched by EC is the Energy Framework Programme (1998-2002) which accommodates three sub-programmes (a) ALTENER II, (b) SAVE II, and (c) SYNERGY. This governing programme introduces two other programmes except SAVE. First one is ALTENER, operated between 1993 and 1997, aimed to increase the use and market share of renewable energy technologies. Conceptually, the programme was non-technical similar to SAVE, with the purposes to encourage activities in renewable energy utilization in all sectors. The second is the SYNERGY Programme (1998-2002), which aims to create dialogue and exchanges of information on energy policy. Unlike the other two component programs of the Energy Framework Programme, SYNERGY is more general in terms of its concern on policy making (CORDIS, 2002). The Energy Framework Programme has been superseded by the Intelligent Energy - Europe Programme (ManagEnergy, 2009a).

ManagEnergy, an umbrella initiative of European Commission started in March 2002, with the objective to provide support for the actors working on energy efficiency and renewable energies at the local and regional level. It is an important tool as a database for all European Union actions concerning energy, and useful in terms of finding partners for projects from different organizations and/or agencies

(ManagEnergy, 2009b). This umbrella initiative covers Intelligent Energy - Europe Programme, Sixth Framework Programme (FP6), Seventh Framework Programme (FP7), and other thematic programs of European Union initiatives. For instance, Eco-Buildings Program, an energy demonstration proposal of European Commission, which aims to develop innovative approaches for the design, construction, and operation of new and retrofitted buildings is a part of ManagEnergy and projects developed under this program are based on combination of two approaches: to reduce energy demand for heating, cooling and lighting and to supply energy necessary for heating and cooling and lighting efficiently (preferably based on renewable energy sources) (Ecobuildings, 2007; TUBITAK, 2007). Several projects such as BRITA in PuBs, DEMOHOUSE, ECO-Culture, SARA, and CONCERTO are components of the Eco-Buildings Program.

Another International Energy Agency annex, IEA ECBCS Annex 32 - Integral Building Envelope Performance Assessment, presented in 2003, aims to formulate a methodology for performance assessment to guide the initial design and the evaluation process of building envelopes by realizing significant energy savings and environmental and indoor comfort benefits. It is composed in two principal subtasks. Subtask A proposes a rational strategy for optimizing building envelopes by a comprehensive assessment methodology based on performance criteria. Subtask B is designed to test and evaluate the methodology proposed in Subtask A by case studies (Hendriks & Hens, 2000; Svendsen, Rudbeck, Stopp, & Makela, 2000).

Less acknowledged, however important research activities are also worth mentioning in the review. Such as DEMOHOUSE (Design and Management Options for improving the energy performances of Housing), an FP6 project, started in 2004 and ongoing. The core argument of the project is that only 2% of existing building stock is renewed annually and there exists a great potential of reduction of energy consumption based on non-renewable energy sources and integrating renewable energy sources in the operation of buildings. The project focuses on developing a decision-making tool, as well as other projects conducted in this research area (Kaan & Koene, 2005).

INTEREB (Integrated Energy Retrofitting in Buildings) is a collaborative project of four countries (Italy, France, Poland, and Bulgaria) with a content to meet the requirements of EC's Directive on Energy Performance of Buildings (Berardi, et al., 2005). The aim of INTEREB is to promote energy retrofitting measures within residential building retrofit (INTEREB, 2007; Berardi, et al., 2005). The project reviews the existing situation in four countries with regard to energy consumption measures through building sector, the residential building typologies, country specific laws and regulations and their effect on the expected energy conservation through retrofitting actions. The methodology can be summarized in steps as; determination of building stock characteristics, definition of case and area specific retrofit intervention alternatives, determination of size and characteristics of thermal insulation and retrofits, calculation of final heat transmission coefficient (U-value), evaluation of potential energy savings, and finally evaluation of necessary investments to carry out the measures. Necessary adaptations originating from changing circumstances in four different countries are included in the methodology (Berardi, et al., 2005).

2.1.2. Publications

Besides the research activities reviewed in the previous section, it is necessary to quote significant publications, independent or from collaborative studies in the last decade. Once more, the review follows a chronological flow in reference, and introduces the main methodological aspects briefly.

In 2000 Jaggs and Palmer published a paper concerning EPIQR methodology, emphasizing the necessity to reduce energy consumption of apartment buildings in Europe. The publication summarizes the main aspects EPIQR focused on, which are indoor environmental quality (IEQ), energy use, costs and retrofit measures. It is claimed that EPIQR methodology has the capacity to suggest suitable retrofitting scenarios for different building components (Jaggs & Palmer, 2000).

Likewise, Caccavelli and Gugerli (2002) and Wittchen and Brandt (2002) discussed TOBUS methodology in terms of its characteristic on decision-making process for energy-efficient retrofitting. Diagnosis and actions are the two main components in TOBUS methodology that provide the range of degree of degradation for building elements and refurbishment and upgrading options. According to Caccavelli and Gugerli (2002), a multi-criteria decision-making coupled with owner opinion and expert intuition is the key concept of the methodology in defining a retrofitting strategy for public buildings. The publication emphasizes the importance of the strength gained with multi-criteria decision-making methodology, and the essentiality of a structured diagnosis to observe energy-efficient retrofitting as a holistic process covering deterioration, functional obsolescence, energy consumption and indoor environmental quality (IEQ).

In 2002, another publication by Flourentzou and Roulet, concentrates on EPIQR methodology and denotes the importance of multi-criteria methodologies, instead of systematic approaches which usually depends on the free and intuitive choices of the expert (Flourentzou & Roulet, 2002).

Dascalaki and Santamouris (2002) pointed out the necessity of energy audits, building energy monitoring, and the potentials of retrofitting scenarios in regard to OFFICE Project funded by EU. The paper provides an analytical description of the Project, particularly covering the types of possible retrofitting scenarios such as: (a) actions to improve envelope of the building, (b) actions for reduction and/or elimination of air conditioning systems, (c) actions to decrease artificial lighting consumption, and (d) actions for improving efficiency of building installation systems. All scenarios are defined with possible sub-interventions, which can be applied independently or as packages according to the relative measures and financial possibilities. Similarly, Hestnes and Kofoed (2002) focuses on the same project (OFFICE) emphasizing the comparison of retrofitting measures according to the above listed scenarios which were applied to case buildings from different European Countries. As a conclusion, an estimation of total energy savings was assessed, which reports that the improvements on 10 case buildings would result to rank the retrofitted buildings in the same category with new buildings in terms of regulatory limitations.

A study focusing on retrofitting potential of residential buildings by Al-Ragom (2003) suggests the necessity of retrofitting measures for residential buildings which are older than 15 years old in Kuwait with hot and arid climate. To point out the optimal retrofitting scenario, several envelope retrofitting proposals were produced including glazing improvements, different wall and/or roof insulations and their combinations. The evaluation of these proposals were made according to their thermal performance and cost benefit analysis in Kuwaiti context. As a result the study suggests the possible energy savings through residential sector with efficient retrofitting measures.

In 2004, Rey defined the notion of a retrofitting strategy as a set of interventions formed by a consistent architectural attitude (interventions on the building envelope) and technical optimizations (interventions on the installation systems) in the publication “Office building retrofitting strategies: multi-criteria approach of an architectural and technical issue”. Rey identifies three main types of retrofitting strategies: (a) the stabilization strategy (STA), as a set of interventions that do not fundamentally modify the building elements or its appearance, (b) the substitution strategy (SUB), as the complete change of building envelope thus the appearance of the building, and (c) the double-skin façade strategy (DSF) as a strategy which partially stabilizes existing building envelope but adds a new glass skin. For evaluation of these strategies the author defines a set of criteria as follows: (1) environmental criteria: annual energy use, annual electricity use, annual emissions (2) socio-cultural criteria: thermal comfort, acoustic comfort, visual comfort, (3) economic criteria: renovation costs, annual maintenance costs. Rey evaluates all strategies corresponding to all criteria with a mathematical algorithm to conclude the research for selection of best possible retrofitting scenario (Rey, 2004).

A different study by Botsaris and Prebezanos (2004) aims to propose a method for certification of energy consumption of a building through thermal energy audit. The method simply builds itself upon temperature differences between indoor and outdoor, occupant behavior, to simulate heat losses of a building in mathematical interpretation.

Kaklauskas, Zavadskas, and Raslanas (2005) propose a multiple criteria analysis for the realization of an efficient building retrofitting in correspondence with all the unique factors that affect a building. The authors suggest a multi-variant design for retrofitting proposals with a wide range of intervention options (window, wall, roof improvements etc.) and evaluate these options according to both qualitative and quantitative criteria (such as cost, aesthetics, comfort, quality, etc.). The study is important in terms of serious integration of qualitative criteria and the number of alternatives evaluated in the model.

Another article from Verbeeck and Hens (2005) develops a methodology to evaluate the cost and benefit for retrofitted dwellings. The research focuses on the analysis of the degree of retrofitting, whether obtaining the maximum thermal comfort conditions through retrofitting is economically viable. Therefore, a set of parameters are defined to assess the weights of the interventions to be done in order to retrofit a building. This systematic approach aims to define a retrofitting strategy with limited investment, to obtain economic benefit at long term and thus the implementation of the energy saving interventions can be spread over time, starting from the most essential.

Diakaki, Grigoroudis, and Kolokotsa (2008) discuss that, for improvement of energy efficiency in buildings through decision-making process, it is essential to evaluate many available options for achieving targeted savings without the need for simulation, multi-criteria decision analysis techniques, etc. The authors propose a feasibility approach for glazing types, insulation types and their combinations, with a multi-objective approach. However, in conclusion it is stated that when energy-efficient improvement is the main problem, in real world there are difficulties contradicting the methodology. The authors as well denote that the research needs more detailed investigations, in terms of generalizing the approach to be a stand-alone tool for facilitating in energy-efficient improvements of buildings.

A recent publication by Juan, Gao, and Wang (2009) treat the problem in a different systematical approach, which first sets the criteria to be achieved then defines the sub-criteria under these main criteria group, and finally proposes assessment items in detail. The main criteria set in the research are sustainability of the site, energy efficiency, water efficiency, materials and resources, and indoor environmental quality. An example for sub criteria under the group of energy efficiency can be summarized as improvement of openings, thermal and moisture protection etc. More in detail the assessment items belong to these sub-criteria can be listed as orientation and area of openings, solar shading, daylight etc. To execute this decision-making proposal, it is necessary to score each assessment item in the existing situation and in the improved situation. The overall improved score helps to evaluate the effect of improvements on the total consumption.

2.1.3. Critical Evaluation of the Literature Review

Up to this point of the review, collaborative and/or individual research activities are assessed in detail. The review itself points out that a wide range of research on energy performance and energy-efficient retrofitting in building sector became significant for the last 20 years. The studies mentioned above are outstanding research examples that help to demonstrate the common concerns on the subject and can be broadened.

For a critical evaluation of the literature review it is necessary to summarize the common components evaluated in the literature.

- Determination of the necessity to retrofit existing buildings: The question of how to determine the necessity for energy-efficient retrofitting is a common question in almost all research quoted in the previous sections. The answers to this question range from walkthrough diagnosis of a building to extensive energy performance audits. Whichever tool is used, the determination should cover to highlight the existence of lack of indoor thermal comfort and environmental quality, high energy bills, high maintenance costs etc. (Zavadskas, Kaklauskas, & Kvederyte, 2004). It is necessary to keep in mind that energy-efficient retrofitting is not only a precaution taken against decreasing energy consumption, as well has impacts on ecology, social life and work performance.

- Evaluation of quantitative and qualitative factors: The evaluation of the occupant perception of indoor thermal properties should be gathered through qualitative surveys to support the quantitative results gathered by energy audit measurements in the building subject to a retrofitting action (Butala & Novak, 1999).
- Defining a methodology for energy-efficient retrofitting of buildings: The main concern of reviewed literature on energy-efficient retrofitting of buildings is to formulate methodology for buildings, where influences on each building may depend on different parameters and effects from its context. It is clear that developing an optimal methodology is still the main problem of this research area.
- Generation of retrofitting scenarios: Buildings are complex systems with architectural, mechanical, environmental, and social aspects. Therefore, generation of retrofitting scenarios is one of the main issues the literature focuses on, with the question of how to generate effective scenarios. This question is answered in some cases with the expertise and intuition of the decision maker, however to obtain a more scientific approach it is necessary to provide a ground for retrofitting alternatives in the frame of expected outcomes and weight of factors that affect these outcomes.
- Codes and Standards: For each context, the codes and standards should lead a base design scenario, if not fulfilled by the subject building. In case of inadequacy it is necessary to follow appropriate international guidelines to contribute for evolution of national/regional standards.

The general shortcomings in literature on energy-efficient retrofitting of existing buildings can be summarized as:

- Perception of indoor thermal comfort and occupancy patterns should be surveyed in detail for assessment of a discomfort and relatively the energy consumption patterns.
- The methodology for energy-efficient retrofitting is a contextual issue where climate, occupant needs, regulations, and building physics change from context to context, hence it is necessary to adopt applied methodologies or create appropriate approaches.
- Many of the research activities are in demonstrative level with a support of policy makers and/or stakeholders, however realization of energy-efficient retrofitting of buildings need to be generalized in all building sectors to achieve targeted energy savings and to decrease CO2 emissions as required in Kyoto Protocol.

2.2. Directive and Regulations on Building Energy Performance

In this section, the purpose is to review the directives, regulations and related implementations on energy performance and efficiency of buildings. The first part focuses on the current state in EU countries, specifically on Directive on Energy Performance of Buildings (2002/91/EC) of European Commission and its realization in different countries. The second part concentrates on Turkey, considering similar directives and regulations that mandate the energy performance and efficiency measures in buildings.

2.2.1. European Directives and Regulations

Energy Performance of Buildings Directive (2002/91EC) of the European Parliament and of the Council is the major umbrella document that legally binds the improvement activities for energy efficiency in buildings. The directive aims to propose a framework with two main key issues. The first one is the protection of the environment and natural resources, and the second one is decreasing energy consumption through building sector to reduce energy demand of the EU countries (EPBD, 2002).

To achieve these two main key issues, the Directive declares that there is certain necessity for methodological calculation of energy performance of buildings and development of standards directly considering building energy use and systems. The Directive focuses on renovation of existing buildings as well as energy-efficient new building designs. With a total of 16 articles the Directive sets energy performance criteria for buildings in regard to physical characteristics and building services (EPBD, 2002).

In Article 1 main objectives of the Directive is listed as follows:

- the general framework for a methodology of calculation of the integrated energy performance of buildings;
- the application of minimum requirements on the energy performance of new buildings;
- the application of minimum requirements on the energy performance of large existing buildings that are subject to major renovation;
- energy certification of buildings; and
- regular inspection of boilers and of air-conditioning systems in buildings and in addition an assessment of the heating installation in which the boilers are more than 15 years old.

Article 2 gives definitions on the general concepts regarding energy performance of buildings. The following two articles (Article 3 and 4) denote the importance of formulating a methodology on national/regional level, in respect to standards and norms in Member State legislation, and the importance of setting energy performance requirements (EPBD, 2002).

Articles 5 and 6 (respectively for new and existing buildings) point out the building systems and components where necessary measures for minimum energy performance should be taken. Consequent article emphasizes the necessity of energy certificates for buildings, which are mandatory for construction, sales or renting (Article 7). The certificates differ for residential and commercial/public buildings, and their validity differs, however cannot exceed 10 years. Additionally the range of indoor temperatures and climatic factors should be included in the certificate reports (EPBD, 2002).

The focus of articles 8 and 9 is on building installation systems. Article 8 particularly targets heating installations and propose regular inspection of boilers which are especially run by non-renewable liquid or solid fuels. On the other hand, Article 9 requires regular inspection of air conditioning systems. Consequently, as Article 10 suggests the necessity of independent qualified and/or accredited experts, Article 11 emphasizes complementary measures referring to renovation should be proposed as general incentives for further energy efficiency measures. Besides the applicative actions provided in the previous articles, Article 12 promotes the necessity to inform building users about energy performance through community campaigns and programs. The following latter 4 articles focus on the dissemination and application of the framework (EPBD, 2002).

In summary, as a result of the efforts in improving energy performance and energy efficiency in buildings since early 1990's, with the announcement of EPBD member states became responsible for implementing energy performance evaluation method and necessary preventative measures. To see the processes in implementation of EPBD, it is possible to make a country-specific evaluation in respect to achieved levels on development of regulations, standards and methodologies emphasized by the Directive. For this evaluation eight member countries of the European Union can be reviewed to make an assessment for implementation of EPBD.

In Austria, before the implementation of the EPBD, The Energy Action Programme was started in 1993, aiming to provide energy efficiency measures and reduce country's energy consumption intensity. The programme has been executed in nine autonomous provinces, achieving a goal of 70.000 energy performance certificates during the period until EPBD was in action. However, with EPBD, these certificates require revision. Therefore Austria announced OIB Directive 6 (Osterreichisches Institut für Bautechnik) parallel to EPBD, and since January 2009 revised energy certificates became mandatory for building construction, sales or renting. Austrian norms suggest energy performance indices for new and existing buildings, and the calculation procedures for energy demand is based on CEN Standards. Experts in energy performance of buildings are being accredited through special training courses. In general, the country aims to reduce energy consumption through buildings, 1 % per year and render CO_2 emissions by 4 million tons per year. Additionally, the establishment of a national standard for energy certificates is well advanced (Jilek, 2008; Janssen, 2004)

In Belgium, three different regions apply EPBD requirements individually. Flemish Region is more advanced in terms of necessary measures. The insulation measures were standardized with K55 standard in 1991 and Walloon Region approved this standard in 1997. Prior to EPBD, the country targeted to implement measures to improve energy efficiency with a national programme in 1994 and the major concern was reduction of CO2 emissions. In 2001, the goals were revised and the target reduction in greenhouse gas emissions aimed for 2008-2012 period was 7.5 % less than 1990 levels. The country started implementing EPBD in 2004. The calculation procedure is according to CEN Standards and energy certification of buildings is active in the country. Energy performance requirements are defined in national standards as K-value which corresponds to overall thermal insulation of a building envelope and E-value which corresponds to energy performance level of a building. The evaluation of energy performance for residential buildings became feasible for home owners, with freely accessible simplified software defined according to the regulations in Belgium. In the beginning of 2009 inspections of boilers and air-conditioning systems started by qualified technicians (Roelens, Piers, & Fourez, 2008; Janssen, 2004)

Denmark published the Action Plan for Energy in 1996, and revised this plan in the beginning of 2005 with the principle to prioritize EU initiatives. In June 2005, Denmark endorsed a new law on Energy Savings in Buildings as an implementation of EPBD. The Danish calculation procedure is based on “SBI-Direction 213: Energy Demand in Buildings”, including thermal bridges, solar gains, natural ventilation, lighting, boiler efficiency etc. Requirements for new and existing buildings are integrated to Danish Building Regulations with the objective to achieve goals EPBD proposed. Energy certificate of buildings cover new constructions, sales and renting of buildings and is given by trained energy consultants who are as well responsible for determining energy saving measures in immediate and extensive feasible energy saving measures. Energy labels are valid for only five years in residential sector. Since 2006, Denmark aims to decrease energy requirements by 25 to 30% in the best possible period and a further decrease of 25% is proposed until 2020 (Aggerholm, 2008; Janssen, 2004).

France announced a national energy efficiency plan in 2000 with the aim to reduce greenhouse gas emissions, energy consumption and enhance the use of renewable energy. Consequent to EPBD, France published a program law defining the scope of energy policy with the purpose of transferring EPBD requirements into French legislation in 2005. In 2006, both calculation procedures and requirements for new and existing buildings were revised by building codes and standards. Certifications cover energy consumption and the greenhouse effect of this consumption of buildings. Inspection of installation systems are still under regulative discussions (Roger, 2008; Janssen, 2004)

In Germany, EPBD aspects started being implemented by Energy Saving Regulation (Energieeinsparverordnung) in 2002. Calculation methodology, new building and refurbishment measures became obligatory with this regulation. However, energy certification and inspection of installations requirements were integrated into Energy Saving Regulation 2007. The necessity of re-arranging the level of calculation and measure requirements in accordance with certification and inspections were completed in 2008 and set in action with the 2009 version of the Regulation. Germany plans to revise the Regulation in 2012 along with the realization level of its level of implementation and effectiveness (Schettler-Köhler, 2008).

Greece regulated the process of setting regulations in line with EPBD in terms of design and inspection principles only in the beginning of 2009. Development of calculation procedures, building requirements, building certification, and inspection of installation systems is an ongoing procedure (Sofronis, 2008; Janssen, 2004).

Italy set goals of energy efficiency and conservation with National Energy Plan (NEP'98) in 1998. EPBD accreditation started with a first Legislative Decree in 2005 and revised several times until 2008. Integration of calculation methodologies and minimum requirements for cooling installation systems is yet incomplete in Legislations. Italy aims to fill the gaps on calculation methods and regulations and additionally integrate the use of renewable energy and monitoring system for energy certification of buildings (Antinucci, 2008).

In Netherlands, energy conservation was regarded high priority since Second Memorandum on Energy Performance in 1993. EPBD implementations where integrated into "Decree Energy Performance of Buildings (BEG) and Regulation on Energy Performance of Buildings (REG) in 2006. Since the beginning of 2008, energy performance certificates are obligatory in case of building sales or rent. Calculation methodology for new buildings is Energy Performance Standard (EPN) which is in use since 1995. For existing buildings Energy Performance Advice (EPA) is simplified and enhanced and in use since 2006. Inspection of boilers and air conditioning systems are fully implemented and community campaigns on overall energy issues promote the consumer information and awareness (van Ekerschot & Heinemans, 2008).

From the review of these eight countries it is possible to point out that EPBD as an umbrella document legalizes the main energy efficiency measures in buildings. Several EU countries are more developed in implementing and achieving the results of these measures, while a number of countries are still in progress of accrediting the national regulations and legislations. Prone to these efforts of EU countries, the goals on reduction of energy consumption, greenhouse gas emissions and energy-efficient rehabilitation of the building stock are closer accomplishments that are probable to conclude in success.

2.2.2. Turkish Directives and Regulations

Turkey, as the main context of the dissertation, became mostly dependent on importing energy sources (72%), since utilization of renewable energy sources is still limited with the lack of necessary regulations and expertise, and non-renewable sources are under risk of exhaustion. Thus, the energy need of Turkey has been increasing since 1980s (Figure 6) and Turkey started to import oil and gas from other countries. In addition, Figure 7 indicates that Turkey is mainly fossil fuel dependent as the primary energy source (MENR, 2007).

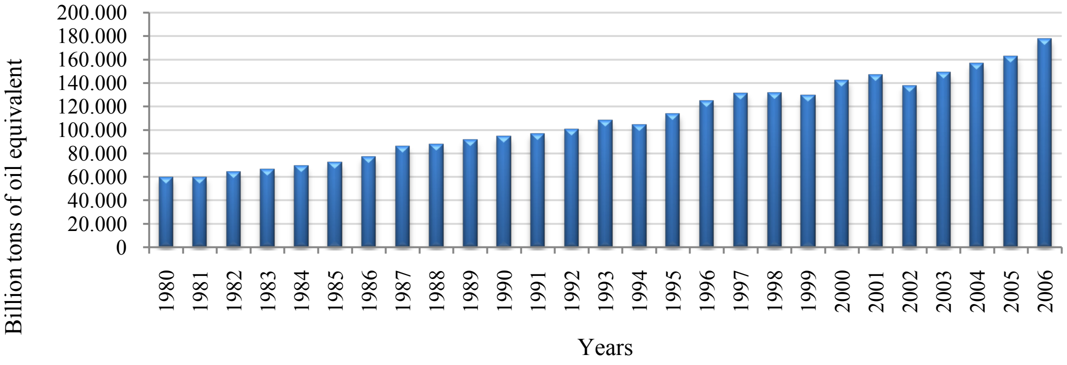


Figure 6. Total energy consumption in Turkey 1980-2006
(Source: MENR 2007)

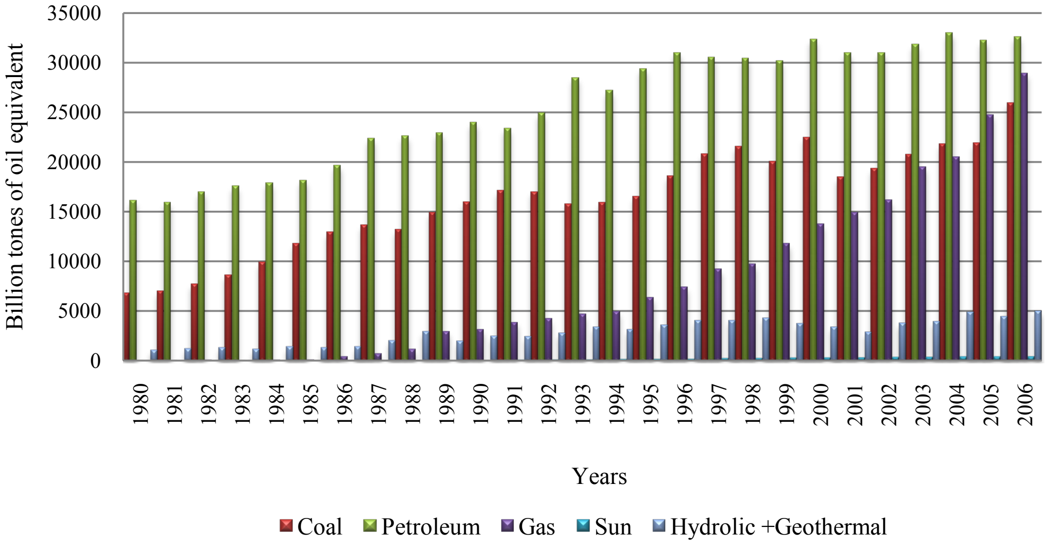


Figure 7. Primary energy resource consumption in Turkey 1980-2006
(Source: MENR 2007)

Turkey has a relatively young building stock, largely dated between 1950 and 2008, and building energy related regulations were not applied properly until the year 2000. Misapplications in building design and construction are based either on unskilled workers or lack in control mechanisms. In most cases, climatic considerations were disregarded during design phase. Coupled with the idea of “invest less/build more”, serious energy related problems are observed during service life of buildings.

On the other hand, Turkey has diverse climatic conditions through the country. In general, coastal parts of Turkey have milder climates with cool and rainy winters and hot and dry summers. The rest of Turkey has severely cold winters and extremely hot and dry summers (TSMS, 2009). These diverse climatic conditions require different building energy efficiency regulations, which could serve as a base guide in building design.

Turkey started taking measures on energy consumption in 1970s, due to the increasing trend in energy consumption; however the regulation that concerns building stock came in 1984, as “Regulation on Fuel Efficiency in Existing Buildings through Thermal Insulation and Reduction of Air Pollution”. However, in 1984 there was no standardization for thermal insulation in buildings, which caused this regulation to be inapplicable in most cases. Only in 1989, the Turkish Standard 825 – Thermal Insulation in Buildings was set in action. In 1998, the standard was revised by dividing

Turkey in four climatic zones and with a static method to calculate annual energy demand for heating. Recent version of TS 825 that became mandatory in June 14th, 2000, targets decreasing heating energy demand and calculation of energy saving potentials in buildings. Therefore, an evaluation in this framework points out that in Turkey, building stock dating before year 2000, commonly lack thermal and moisture insulation. The buildings that date back before year 2000 consume more energy for heating and cooling, and require systematical, methodological improvements especially for building envelope and installation systems. In Figure 8 it is possible to see the statistics of Ministry of Energy and Natural Resources (MENR) on the average energy consumption of buildings as per cent in total, which is almost very high with a ratio of 40%. This high pattern of energy consumption in buildings is directly related to lack of thermal insulation, inefficiency of heating and cooling systems, disregarding environmental and climatic factors in building design etc.

In this context where residential & commercial building sector holds nearly 40% of the whole energy consumption, there is significant need to decrease energy consumption for heating, cooling, and lighting of buildings and thus to increase the thermal performance of these buildings. Additionally, as the indoor environmental quality improves, occupant health, performance, and occupancy patterns evolve. Therefore, it is possible to say that obtaining energy efficiency in buildings provide a variety of potentials, which might feasibly be applied throughout a sensitive methodology, and may lead the development of new methodologies, technologies, and systems (Bolattürk, 2006; Gökçen, 2007).

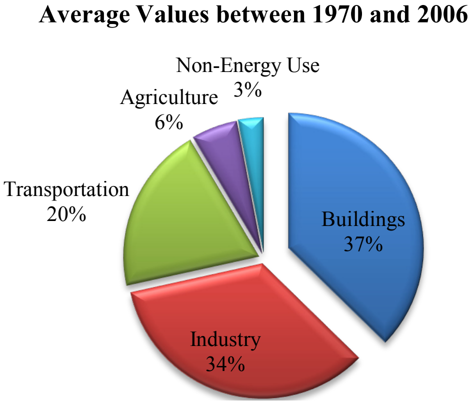


Figure 8. Energy use by end-sector in Turkey in 2006
(Source: MENR 2007)

Parallel to the revisions and mandatory application of TS 825, in 1997 a project was started by EIEI (General Directorate of Electrical Power Resources) and TURKSTAT (Turkish Statistical Institute), which can be addressed as the very first attempt to document the energy consumption in different sectors. The project has two parts, one based on building sector and the other based on transportation sectors. The aim of the part, which focuses on building sector, is to establish a statistical database of the relationships between the structural properties, insulation levels, installation systems, consumption levels, and climate relationship of existing buildings (EIEI, 2008). This project is the first auditing project through the large building stock of Turkey. The statistical results have been published by TURKSTAT in 2001. Another ongoing survey, which started in 1997, is titled as “Measures for Decreasing Energy Consumption of Public Buildings”. This survey targets all governmental public buildings (municipalities, governmental offices, university buildings etc.) and requires reports for the annual energy consumption for each building every year in May since 1998. The survey is going on and the current database is constituted by EIEI. Efforts point out that a level of awareness in decreasing energy consumption in buildings became an agenda of policy makers and stakeholders in Turkey (EIEI, 2008).

In November 2002, a project titled “Efficient Use of Energy in Buildings” started in the framework of the technical collaboration between Turkey and Germany (EIEI, 2008). This project piloted the city of Erzurum, Turkey. The aims of this project are, to decrease the amount of imported energy and CO2 emissions by utilization of energy efficiency in buildings, to raise community consciousness on utilization of energy efficiency in buildings, to decrease the necessary energy for heating of a volume by taking necessary measures, to provide an applicable methodology for other regions of Turkey through the experiences gathered in the pilot city Erzurum (Buyruk, 2005).

Through the project, “Efficient Use of Energy in Buildings”, three demonstration buildings in Erzurum and one in Ankara were monitored for an energy audit. After the audit, the necessary retrofitting actions were taken and the monitoring of the buildings continued. The project expects around 50% of decrease in energy consumption for demonstration buildings (Buyruk, 2005).

Latter to these standardization efforts and research activities Energy Efficiency Law has been accepted and constituted in February 22, 2007. First article states that aim of this law is to increase energy efficiency for prevention of over consumption, decreasing the effects of energy consumption on the economy and protection of the environment. This law obliges energy certificates for building projects for the first time for Turkish construction sector. Energy certificates should include minimum information about the building's energy need, insulation characteristics, and efficiency of heating & cooling installations (EEL, 2007; Hepbaşlı, 2007). Due to implementation of this law, decrease of energy consumption is aimed in different sectors.

Subsequent to the release of EPBD in 2002, EU countries started accrediting their standards and directives according to EPBD as the responsibility of membership to the union. Turkey as a candidate country is expected to fulfill this responsibility, in case of approved membership. Except for the policy making point of view, the common action on energy performance of buildings is a great potential in terms of contributing the sustainability of environmental systems. In this regard, two regulations have been released in Turkish Official Paper in 2008.

The first one released in October 25th, 2008 is the "Regulation on Increasing Efficiency in Utilization of Energy Resources and Energy" (2008). Overall, this regulation aims to organize fundamentals and practices on efficient use on energy. The scope of the regulation covers to promote activities and research on energy efficiency and management, energy audits, waste management and renewable energy technologies. The regulation introduces the concepts such as of building management, energy certificate, energy auditor and auditor certificate. Thus, requirements of EPBD are met in terms of regulating building energy performance evaluations and certifications, by means of trained energy consultants.

The second regulation is the "Energy Performance of Buildings Regulation (BEP)" published in the Official Paper in December 5th, 2008. The main aims of this regulation are as follows:

- To define energy performance calculation procedures for buildings, in regard to climatic context, indoor thermal requirements, spatial requirements and cost effectiveness.
- To classify buildings according to their primary energy use and CO2 emissions.
- To define energy performance requirements for new and existing buildings which require major renovation.
- To evaluate the utilization of renewable energy technologies for buildings.
- To inspect performance of building installation systems

- To define the framework and its execution for energy performance criteria of buildings (BEP, 2008).

With these aims, the regulation fulfills the responsibility of adapting the requirements of EPBD and is significant in terms of being a regulation that addresses national and international standards that corresponds to specific building energy-related sub-topics (BEP, 2008).

As BEP defines set of criteria regarding EPBD requirements, there is still a fundamental requisite for defining specific energy performance calculation methods for different building types. Consequently, a work group from Chamber of Architects and Engineers (MMO) published the "Standard Methodology for Evaluation of Energy Performance in Residential Buildings (KEP-SDM)" in June 2008. This methodology aims to focus specifically on residential buildings in Turkey, in terms of calculating the annual energy demand and annual CO_2 emissions, which provides information for energy certificates of these buildings. Calculation procedure is based on EN and ISO standards, concerning static (seasonal and monthly) and dynamic (basic hourly and detailed hourly) calculation methods (Toksoy, Arısoy, Gökçen, Mobedi, Yaman, & Kuzgunkaya, 2008).

Hence, it is important to provide calculation methodologies for different building types (office buildings, educational buildings, healthcare facilities etc.) The gaps in Turkish energy performance studies yet have potential to be researched.

2.3. Conclusion

As a concluding part to this chapter, it is necessary to summarize the findings of the literature review with comparison of EU countries and Turkey in terms of application of EPBD requirements, primary energy consumptions and CO_2 emissions.

In Table 1, the recent condition for reviewed EU Countries and Turkey is presented according to the implementation of main highlights in EPBD. Additionally, the table presents the existence of previous measures concerning energy efficiency, CO_2 emission reductions, and utilization of renewable energy technologies, before the announcement of EPBD in 2002.

It is clear that Turkey has a moderate level of implementation of EPBD requirements. The methodological approach providing energy certificates for new buildings and existing buildings has to be prepared by Turkey. On the other hand inspection of heating and cooling installation systems should be promoted and announced as mandatory, in accordance with the qualified energy expert trainings.

Table 1. Comparative checklist for implementation of EPBD

Countries	Existence of Building Codes and Standards Before EPBD			Implementation of EPBD Requirements						
	On reduction of energy consumption	On reduction of greenhouse gas emissions	On utilization of renewable energy sources	Energy performance calculation procedures	Energy Certificates	Requirements for New Buildings	Requirements for Existing Buildings	Qualified Experts	Inspection of heating installation systems	Inspection of cooling installation systems
Austria	X	X	X	X	X	X	X	X	X	X
Belgium	X	X	X	X	X	X	X	X	X	X
Denmark	X	X	X	X	X	X	X	X	X	X
France	X	X	X	X		X	X			
Germany	X	X	X	X	X	X	X	X	X	X
Greece	X			X	X	X				
Italy	X			X		X	X	X		
Netherlands	X	X	X	X	X	X	X	X	X	X
Turkey	**X**	**X**	**X**	**X**		**X**	**X**	**X**		

Table 2. Average primary energy and CO2 emissions in EU Countries and Turkey

Countries	Population in 2009	Average Total Primary Energy (Quadrillion Btu)		Average CO_2 Emissions (Million Metric Tons of CO_2)
		Production	Consumption	Total from Fossil Fuel Consumption
Austria	8.355.260	0,501	1,534	76,39
Belgium	10.754.528	0,496	2,751	147,58
Denmark	5.532.531	1,215	0,879	59,13
France	65.073.482	5,134	11,445	417,75
Germany	81.882.342	5,247	14,629	857,6
Greece	11.260.402	0,407	1,487	107,7
Italy	60.200.060	1,222	8,069	468,19
Netherlands	16.584.600	2,651	4,137	260,45
Turkey	**71.517.100**	**1,172**	**3,907**	**235,7**

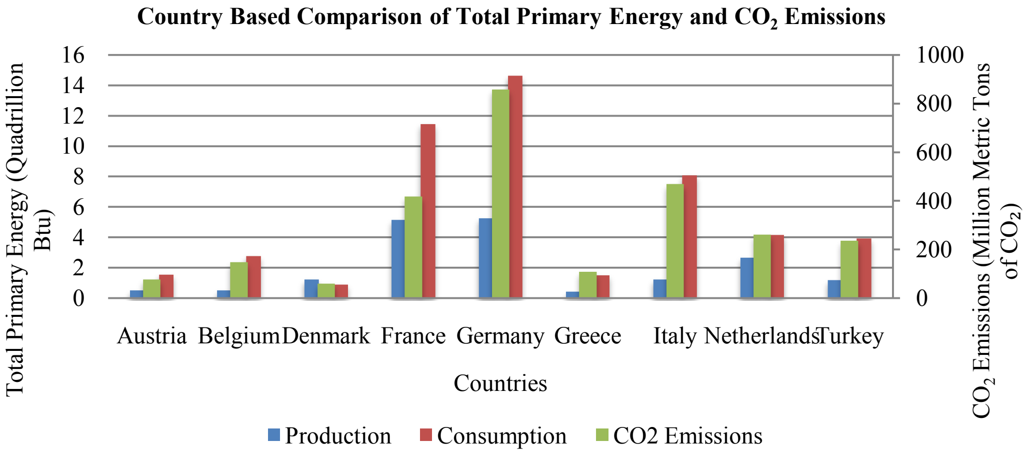


Figure 9. Average primary energy and CO_2 emissions in EU Countries and Turkey (Source: EIA 2009)

Another comparison can be done according to produced and consumed total primary energy and CO_2 emissions of selected EU countries and Turkey (Table 2 and Figure 9). The statistics are retrieved from Energy Information Administration of Official Energy Statistics of U.S. Government (EIA, 2009). The data on primary energy consumption and CO_2 emissions are averages of long terms (27-28 years). It is observed that energy and emission amounts should be evaluated according to the population and level of industrialization of the countries. According to the data, it is possible to state that Turkey consumes more energy, on daily function of buildings and facilities, less on industry and transport as a developing country. For instance, Netherlands, with a highly industrialized context, almost has one fifth of Turkish population, hence consumption amount is very close to Turkey. In a future projection of Turkey processing her development fully, the levels are likely to evolve close to contexts of France and Germany, which have closer populations. Therefore, it is necessary to take urgent precautions to limit energy use through buildings and facilitate the use of energy to industry and transportation.

As a result, the literature review points out the potential of building energy efficiency measures in Turkey after a detailed analysis of the level of research that is being conducted in European Countries. Turkey as a developing country with a moderately uncontrolled construction sector until the 1990’s, particularly of thermal characteristics of buildings, comprises a future of research in building physics and particularly in energy-efficient retrofitting of existing buildings.

More specifically, energy-efficient retrofitting/refurbishment of buildings accommodate numerous variables. Since the topic occupies a significant place in energy-efficiency research, it is essential to emphasize the importance of why to retrofit in Turkish building stock context.

- To decrease energy consumption of the Turkish building stock, particularly for heating, cooling and lighting of buildings, thus contribute overall energy saving in the country.
- To emphasize the potentials of energy saving in the building sector, thus decrease CO2 emissions and offer healthier environments for future generations.
- To raise the public and private sector awareness and the building investors’ and contractors’ responsibility on energy-efficiency and indoor environmental quality. Thus, all intermediating actors in building construction (owner, contractors, inhabitants etc.) will be able to establish the communication between the cost of consumed energy and the indoor environmental conditions.
- To stress the importance of the regulations and laws on energy efficiency and building insulation

Therefore, for further steps of this research, the objectives will be derived from the conclusion of this literature review for energy efficiency in buildings. The models and methodologies that are being studied and formulated in European Countries may represent a base, a starting point to construct a substantial approach and methodology for Turkish context.

CHAPTER 3

METHODOLOGY

As a broad research area, energy-efficient retrofitting accommodates numerous variables and is a complex process. Since the main aim of the dissertation is to define a methodology for energy-efficient retrofitting of existing public building envelopes, this chapter focuses on the application of this methodology through a case-study application. The main framework will be summarized in this introductory section. Following sections will cover the steps for execution of the proposed methodology.

To formulate a methodology on energy-efficient retrofitting of existing public building envelopes, the main steps should be defined in broad outlines as follows:

- To identify the requirement for energy-efficient retrofitting of a building
- To conduct a detailed energy monitoring of the building
- To examine the energy performance of the building through simulation, calculations and standards
- To generate appropriate retrofitting strategies according to the results of the examinations on existing performance of the building and to apply these strategies with the help of the most convenient analysis tool applied in previous step.
- To evaluate the results of the energy-efficient retrofitting strategies under constraints of energy performance and investment/benefit criteria, to assess the best appropriate retrofitting strategy.

Course of the main steps is summarized in Figure 10. As seen in the figure, key emphasis of the methodology is energy performance assessment of an existing building, both in initial and retrofitted state. This assessment helps to define the necessity of a retrofitting intervention and to what extent these retrofitting measures should be taken. Additionally, energy performance assessment provides the evaluation of a building according to performance indicators, before and after the retrofit interventions. The flowchart can simply be summarized as a set of applications concerning the physical and thermal characteristics of a building. For the performance assessment of existing buildings, envelope characteristics, climatic conditions, installation systems and building use and occupancy are the criteria in consideration. This evaluation facilitates generation of retrofitting strategies, which may accommodate interventions as a synthesis of multi-criteria decisions. The range of retrofitting strategies may alter according to the levels of physical, functional, mechanical obsolescence in the building that is subjected to a retrofitting action. Consequent to application of retrofitting scenarios, their effect on the energy performance of the building can be evaluated. According to the performance and cost benchmarks and the results can be investigated to understand whether sufficient level of improvement in energy performance is attained. In case of insufficient results the decisive parameters in the steps of the methodology may be altered and once more be executed to obtain better levels of performance.

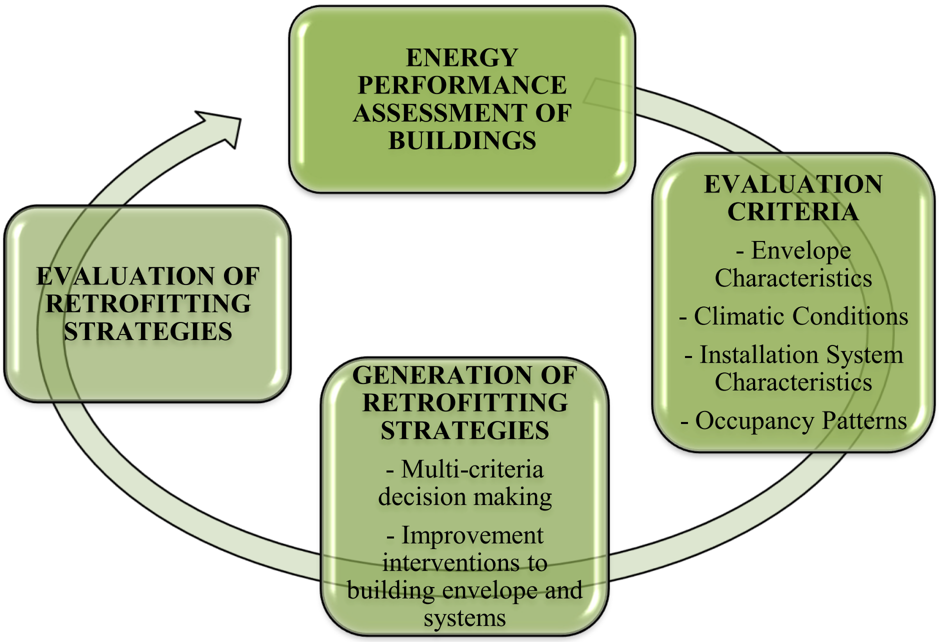


Figure 10. Theoretical relationships and course of the proposed methodology

According to this broad theoretical framework, the methodology is detailed in following steps:

1. Building energy performance analysis and determination of the accurate analysis tool
2. Generation of appropriate retrofitting strategies

3. Evaluation of the retrofitting strategies
4. Optimization of the most applicable retrofitting strategy

Case study method is selected to apply these steps of the projected methodology. Therefore a case building is selected in the campus area of Izmir Institute of Technology, due to evaluation of five buildings in the campus area, in regard to the consumption patterns and physical characteristics (Güçyeter, 2009).

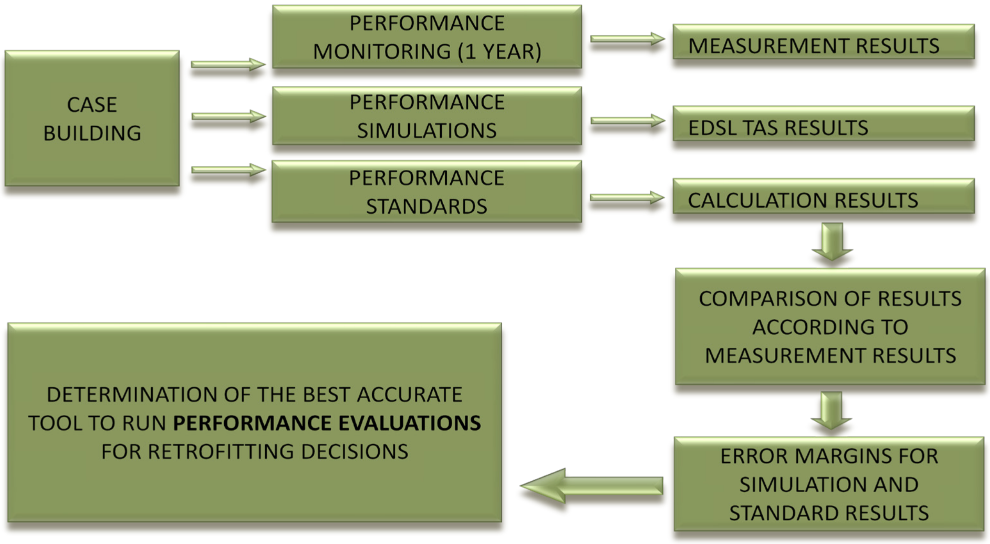


Figure 11. Energy performance analysis and determination of the accurate tool

Figure 11 presents the flowchart of the first step of the methodology. In the first step of the methodology, the main aim is to assess the energy performance of the existing case building via different tools for energy performance analysis, and determine the accurate tool for further analysis of retrofitting proposals. The case building is monitored for a total of 15 months, covering two heating and one cooling season. The monitoring data is accepted as the most realistic data set which presents the actual indoor temperature and humidity levels and energy consumption levels. The analysis of the monitoring data presents the monitoring data set. Thus, energy performance monitoring is accepted as a tool to determine the energy performance of the case building. The other tools facilitated in this step of the methodology is building energy simulation and building energy performance standards. For building energy simulation

EDSL Tas software is used and the outputs of the simulation are considered as the simulation data set. Building energy performance standard evaluation is applied according to TS 825 and the results of the analytical calculations present the calculation data set.

The results of these data sets are evaluated according to the performance monitoring data, with same parameters such as indoor temperature, kilowatts of energy use per meter square etc. The error margins for both simulation and standard calculation results are compared to monitoring data. This comparison points out the evaluation tool which has a better interpretation of the real conditions of the existing case building. In the further steps of the methodology, the execution of the more precise tool and its error margins are derived to assess a realistic retrofitting strategy.

The second step of the methodology comprises the generation of retrofitting strategies which support the integrated design and evaluation of building envelope alternatives that assure better quantitative levels of thermal mass and transmittance. The main aim in generating these retrofitting strategies is to realize the decrease in energy consumption of the building while increasing or maintaining the indoor thermal comfort parameters (Svendsen, Rudbeck, Stopp, & Makela, 2000).

Retrofitting existing building envelopes is an important intervention and it is relatively complicated than designing a new building envelope. The constraints on envelope retrofitting are directly related to environmental, technical and aesthetical realities of an existing building and its context. Therefore the optimal type of retrofit should be formulated and applied in consideration with these aspects to the every specific case building (Svendsen, Rudbeck, Stopp, & Makela, 2000).

The necessity to propose different strategies for evaluation targets optimization of a retrofitting solution rather than evaluating different envelope system performances. For instance, retrofitting of an existing exterior wall element may be implemented by various insulation types; however there exists a wide range of material and thickness options. Therefore there is certainly a requirement to construct different strategies to assess the best possible strategy under economical and indoor environmental constraints.

In this study, different levels of retrofit interventions on the building envelope, ranging from basic to complex, are proposed to generate retrofitting strategies for the case building. Interventions specifically cover some common individual measures which fit the minimum U-values required in Turkish Standard 825 – Thermal Insulation in Buildings (TS 825). In regard to the limitations of TS 825, each strategy has to fulfill the requirements for each building envelope element. Figure 12 summarizes this second step of the methodology and classification of retrofitting strategies. The strategies are proposed in a systematic approach, each time built upon the previous strategy, hence modified by additional/replaced interventions. Therefore, it is possible to assert that "Minor Intervention" represents basic requirements of TS 825. Consequent two intervention sets propose addition and/or replacement of different possible energy saving interventions for the building envelope.

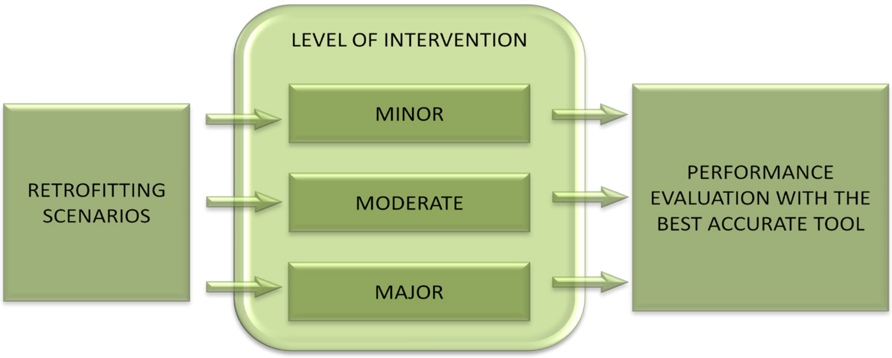


Figure 12. Generation of retrofitting strategies.

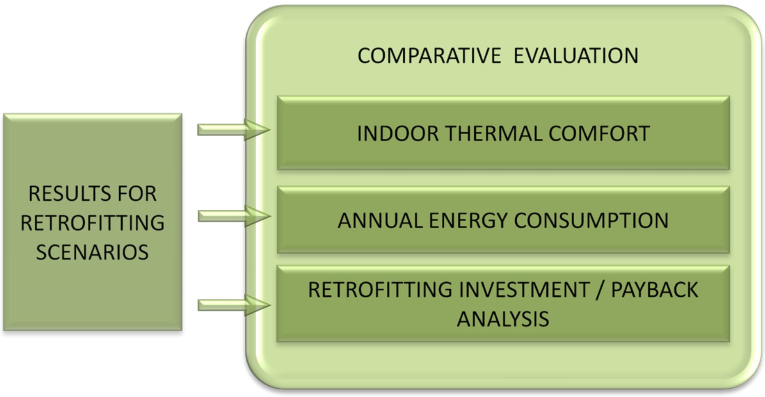


Figure 13. Comparative evaluation of retrofitting strategies

The third step, specifically the evaluation of retrofitting strategies, intends to evaluate the energy performance of the proposed envelope retrofitting strategies (Figure

13). The retrofitting strategies are evaluated with the best accurate evaluation tool, which is determined in the first step of the methodology. Comparative evaluation of the retrofitting strategies is conducted according to the following parameters:

- Indoor thermal comfort
- Annual energy consumption
- Retrofitting investment/payback analysis

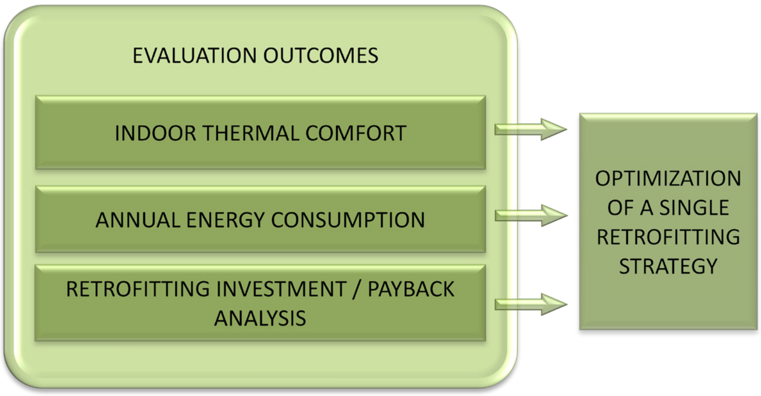


Figure 14. Optimization of a single retrofitting strategy

In the fourth and latter step of the methodology, the evaluation outcomes are optimized consistent with the requirements of comfort, consumption and cost (Figure 14). A thorough assessment of a single retrofitting strategy, which is to be applied to the case building, is finalized in this step.

According to the defined steps, the following sections cover a demonstrative realization of the methodology.

3.1. Building Energy Performance Analysis and Determination of the Accurate Analysis Tool

The current preliminary part of the methodology targets to analyze and demonstrate following aspects of the study:

- To introduce the case building, in terms of criteria that are influential of energy performance

- To demonstrate the building energy performance monitoring results
- To determine and compare the energy performance of the building via different analysis tools
- To assess the differences between tool predicted and measured energy performance parameters
- To select an analysis tool, which offer the best accuracy, for further modeling of the generated retrofitting scenarios

The following sub-sections of the first part of the methodology cover the listed aspects respective to the order as presented above.

3.1.1. Introduction and Investigation of the Case Building

3.1.1.1. General Building Characteristics and Location

Medico Building in Izmir Institute of Technology Campus Area is designed to accommodate predominantly office functions and started its service in June 2007. Constructed as a concrete structure with filled in brick walls, the building has a square symmetrical plan with a square atrium. It is a two storey building with four vertical circulation zones. Four wings of the building are designed as each oriented towards one direction. The normal of the north facing facade has an angle of 8.09° clockwise (Figure 15, Figure 16).

Figure 15. Aerial view of MEDICO Building
(Source: Google Earth 2009)

Figure 16. View of MEDICO Building (west & south facades)

The information on the location, orientation and environmental aspects are listed in Table 3. As seen in Figure 16, northern and eastern facades face an elevated ground level (approximately three-storey height). This height in the landscape does not cause any shadows on the building facades during hours of solar exposure.

Table 3. Building information

Location	Latitude	38°19'15.91”
	Longitude	26°38'26.86”
Orientation	North Facade	Angle of 8.09° (CW)
Environment	Open land	
	Free from shadow effect of close structures, trees etc.	

Table 4. General characteristics of the case building

Floor area (m^2)	5540
Floor height (m)	3,6
Volume (m^3)	19944
Surface area of the facades (m^2)	3515
Roof area (m^2)	2824
Glazing area (m^2)	816,2
Glazing ratio (%)	23,2
Compactness (A_{tot}/V_{tot})	0,32

In Table 4 general characteristics of the case building are represented. The building has a glazing ratio of 23,2%, which is higher than the limit glazing area of 12% defined by TS 825. Glazing ratio is calculated with a simple proportion of total surface area of glazing to the total surface area of opaque walls ($A_{tot\ glazing}$ / $A_{tot\ opaque\ walls}$) (TS 825, 2008). The technical drawings (floor plans and elevations) are presented in Figure 17 to Figure 26. According to the general characteristics of the building presentedin this part, it is possible to assess that square plan organization and almost equivalent treatment of the facades indicate that environmental design criteria for the building were neglected during design phase. Particularly, identical treatment of north and south facades emphasize this assessment, where south façade is subject to large amounts of solar exposure during summer period, hence north façade receives no direct sun. In addition, square plan organization causes higher number of spaces to be exposed to north and south directions.

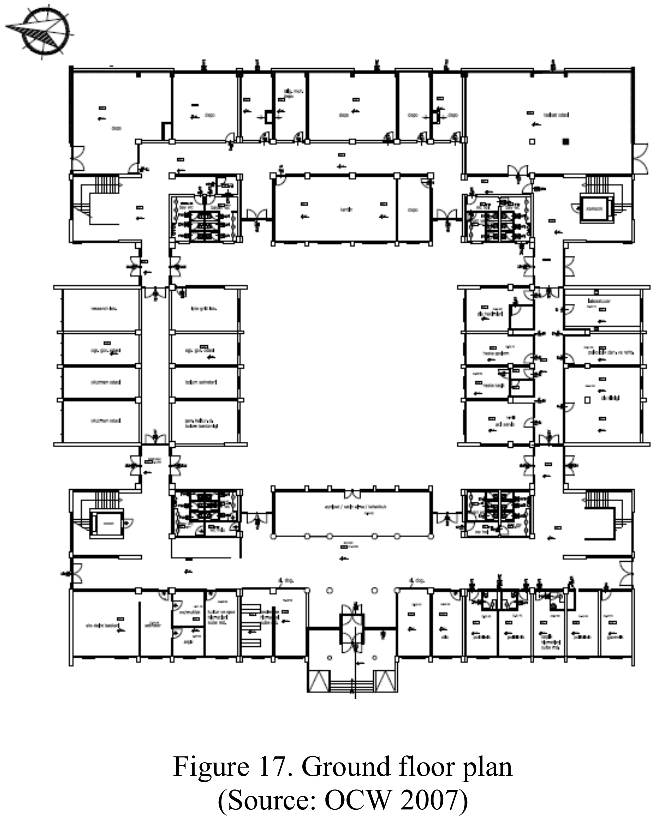


Figure 17. Ground floor plan
(Source: OCW 2007)

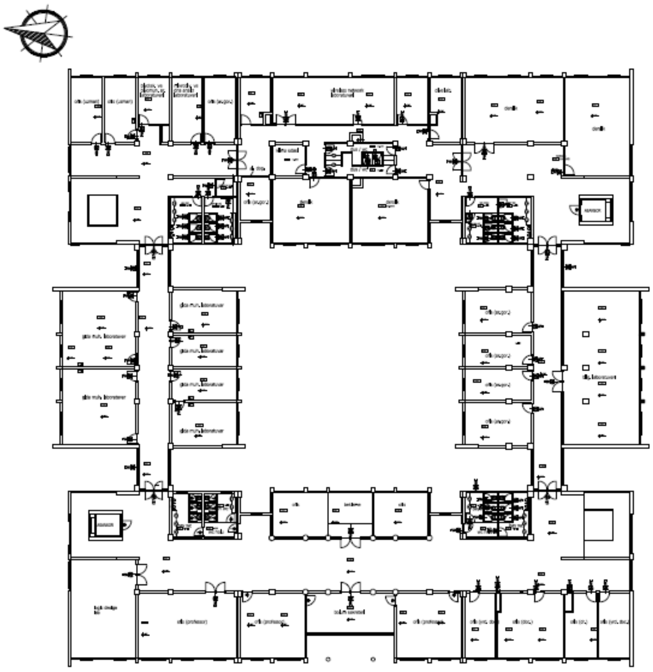


Figure 18. First floor plan
(Source: OCW 2007)

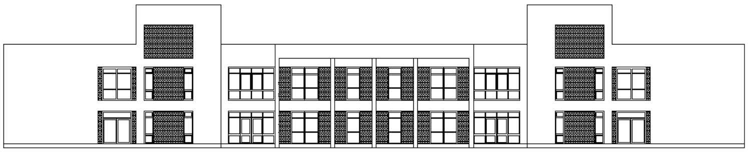


Figure 19. North facing exterior facade

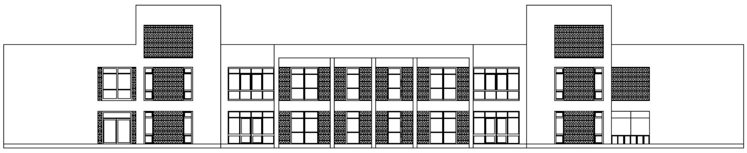


Figure 20. South facing exterior façade

Figure 21. West facing exterior façade

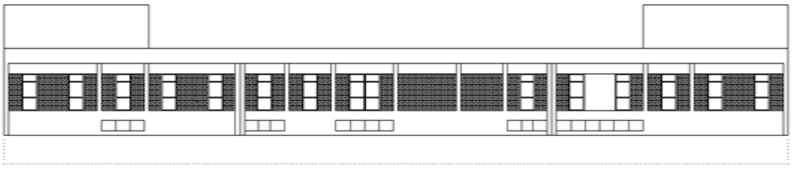


Figure 22. East facing exterior façade

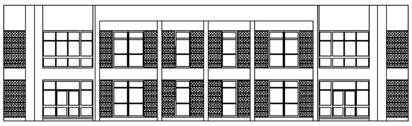


Figure 23. North facing interior façade

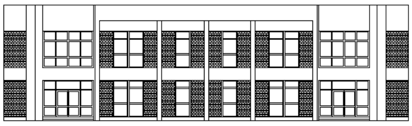


Figure 24. South facing interior façade

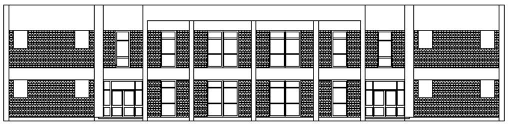


Figure 25. West facing interior façade

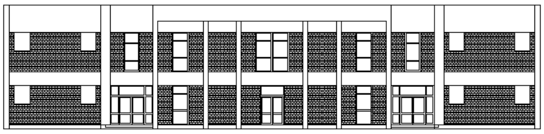


Figure 26. East facing interior façade

3.1.1.2. Building Envelope

Building envelope can be defined as a skin, which separates the indoor environment from the outdoor environment and is expected to establish thermal comfort, visual comfort and acoustic comfort (Oral, Yener, & Bayazit, 2004). Thermo-physical characteristics of these elements of the building envelope are essential parameters in determining the overall energy performance of a building where most of the heat loses and heat gains occur through the building envelope (Yannas, 1994; Oral, Yener, & Bayazit, 2004; Lollini, Barozzi, Fasano, Meroni, & Zinzi, 2006). Main building envelope parts defined as (a) exterior walls, (b) floors, (c) roof, and (d) glazing.

In addition to the main classification of building envelope components, surfaces that are in contact with unheated volumes in a building are considered as envelope components, whereas heat losses occur through these building parts as well.

For the case building, the envelope components are evaluated according to their construction principles and heat transfer coefficients (U-value). As construction principle, the two storey building is constructed as a concrete structure with filled in brick walls. Floor and roof slabs are reinforced concrete. Glazing elements are built in exterior brick walls.

The formulas and constants that are used in analytical calculations are listed in equations 3.1 to 3.4, where, d is material thickness in meters, λ is thermal conductivity (W/mK), R is thermal resistance (m^2K/W), h_e is the exterior convection coefficient with a value of 23 W/m^2K, h_i is the interior convection coefficient with a value of 8 W/ m^2K, and U is the overall heat transfer coefficient (W/m^2K). In the following part of this section thermal properties and section details of the case building are presented.

$$\mathrm{R} = \frac{d}{\lambda} \qquad (3.1)$$

$$\mathrm{R_e} = \frac{1}{h_e} \qquad (3.2)$$

$$\mathrm{Ri} = \frac{1}{h_i}$$

(3.3)

$$\mathrm{U} = \frac{1}{(R_e + R_{tot} + R_i)} \tag{3.4}$$

1) Exterior Walls

Two different exterior wall types are observed in the case building, which intermediate between heated volumes and external environment. First type is exterior clinker brick wall and second is the load bearing reinforced concrete walls. Additionally, on the eastern façade a retaining wall exists, which is in contact with ground with almost half storey height.

a) Exterior Clinker Brick Wall

In the case building, exterior clinker brick walls are constructed as fill-in walls where there is necessity to build between concrete columns and beams. A single clinker brick has the dimensions of 215x102x65 millimeters. The wall is constructed in two layers of brick, with an air cavity of 11 millimeters in between, originating from the dimensions of the brick module and construction principle (Figure 27).

In Table 5, the layers of the exterior clinker brick wall and the thermal properties of each layer are presented. Since there is no thermal insulation in the wall section, U-value of the wall composition (1,531 W/m^{2}K) is larger than the limit value of 0,70 W/m^{2}K, which TS 825 proposes for the climatic zone the building is located.

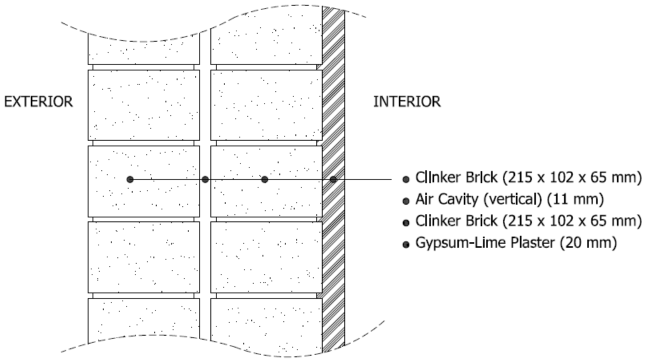


Figure 27. Section and construction principle of exterior clinker brick wall

Table 5. Thermal properties of exterior clinker brick wall

Exterior Clinker Brick Wall						
Layer	Material	Width (mm)	Conductivity (W/mK)	Convection Coefficient (W/m^2K)	Density (kg/ m^3)	Specific Heat (J/kgK)
Inside	Paint	1	999,00	0,001	0,001	0,00
2	Gypsum Lime Plaster	20	0,46	0,001	1200,000	1008,00
3	Clinker brick	102	0,70	0,001	2000,000	940,00
4	Air cavity	11	0,01	0,001	0,000	0,00
Outside	Clinker brick	102	0,70	0,001	2000,000	940,00
Flow Direction		U-value (W/m^2K)			R-value (m^2K/W)	
Horizontal		1,531			0,653	

b) Exterior Reinforced Concrete Wall

The second type of exterior walls in the case building is the reinforced concrete wall. Considerably large amount of wall envelope surface has reinforced concrete walls. There is no application of insulation materials; the section is a single layer of reinforced concrete with plaster on both sides (Figure 28).

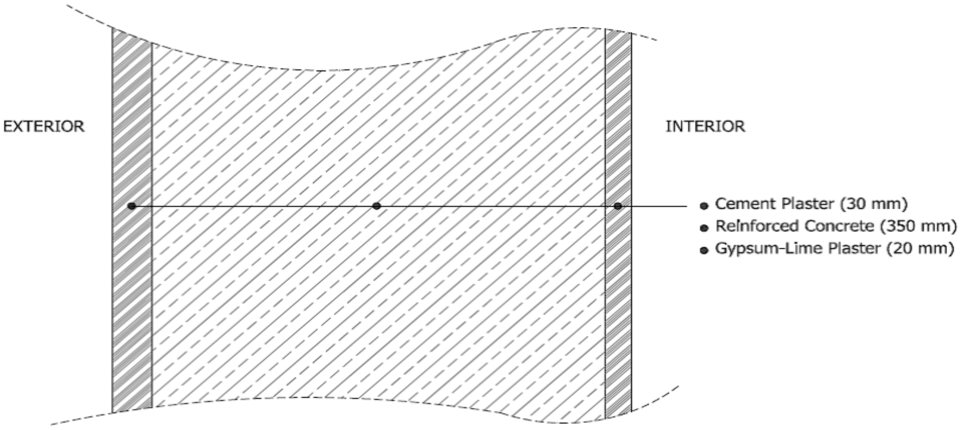


Figure 28. Section of the exterior reinforced concrete wall

Table 6. Thermal properties of exterior reinforced concrete wall

Exterior Reinforced Concrete Wall						
Layer	Material	Width (mm)	Conductivity (W/mK)	Convection Coefficient (W/m^{2}K)	Density (kg/m^3)	Specific Heat (J/kgK)
Inside	Paint	1	999,00	0,001	0,001	0,00
2	Gypsum Lime Plaster	20	0,46	0,001	1200,000	1008,00
3	Reinforced Concrete Wall	350	2,00	0,001	2400,000	950,00
4	Cement Plaster	30	1,20	0,001	2000,000	1008,00
Outside	Paint	1	999,00	0,001	0,001	0,00
Flow Direction		**U-value (W/m^{2}K)**			**R-value (m^{2}K/W)**	
Horizontal		2,418			0,413	

In Table 6, the layers of the exterior reinforced concrete wall and the thermal properties of each layer are presented. There is no thermal insulation in the wall section. Therefore, U-value of the wall composition (2,418 W/m^{2}K) is larger than the limit value of 0,70 W/m^{2}K, which TS 825 proposes. Additionally, column and beam structures of the building are constructed with the same principle as reinforced concrete walls.

c) Exterior Retaining Wall

Exterior retaining wall is constructed on ground floor, on the eastern façade, and is in contact with ground with half storey height. Retaining wall is an exterior wall for unheated spaces, therefore has minor influence on the interior comfort. The wall section is presented in Figure 29 and in Table 7 the thermal properties are presented.

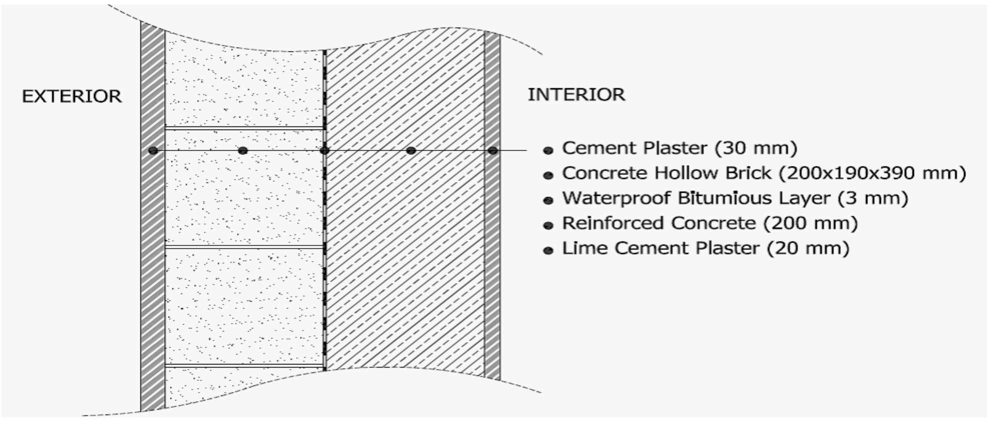


Figure 29. Section of the exterior retaining wall

Table 7. Thermal properties of exterior retaining wall

Exterior Retaining Wall						
Layer	Material	Width (mm)	Conductivity (W/mK)	Convection Coefficient (W/m^{2}K)	Density (kg/m^3)	Specific Heat (J/kgK)
Inside	Lime Cement Plaster	30	1,00	0,001	1800,000	830,00
2	Reinforced Concrete Wall	200	2,00	0,001	2400,000	950,00
3	Waterproof Bituminous Layer	3	0,13	0,001	1055,000	1332,00
4	Lightweight Concrete Brick	200	0,25	0,001	800,000	1008,00
5	Cement Plaster	30	1,20	0,001	2000,000	1008,00
Outside	Paint	1	999,00	0,001	0,001	0,00
Flow Direction		**U-value (W/m^{2}K)**			**R-value (m^{2}K/W)**	
Horizontal		0,879			1,138	

2) Interior Walls

a) Interior Brick Wall

The interior wall type investigated here is the interior separator walls which intermediate between heated and heated-unheated volumes in the building. All interior walls are constructed with brick and plaster on both sides (Figure 30) and its thermal properties are presented in Table 8. TS 825 standard limits R-values for building elements in contact with unheated volumes. The standard asserts that the R-values for such building parts should be equal or larger than 0,8 m^{2}K/W. According to this restriction the interior brick walls of the case building are appropriate to the standard with an R-value of 0,923 m^{2}K/W.

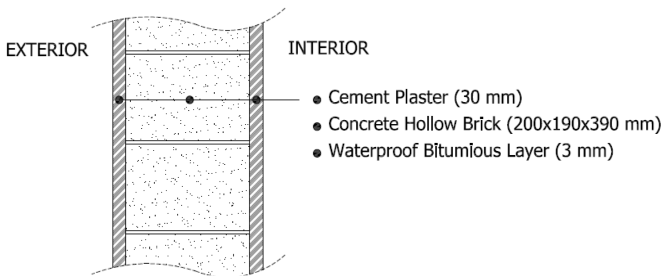


Figure 30. Section of interior brick wall

Table 8. Thermal properties of interior brick wall

<table>
<tr><th colspan="7">Interior Brick Wall</th></tr>
<tr><th>Layer</th><th>Material</th><th>Width (mm)</th><th>Conductivity (W/mK)</th><th>Convection Coefficient (W/m²K)</th><th>Density (kg/m³)</th><th>Specific Heat (J/kgK)</th></tr>
<tr><td>Inside</td><td>Paint</td><td>1</td><td>999,00</td><td>0,001</td><td>0,001</td><td>0,00</td></tr>
<tr><td>2</td><td>Gypsum Lime Plaster</td><td>20</td><td>0,46</td><td>0,001</td><td>1200,000</td><td>1008,00</td></tr>
<tr><td>3</td><td>Vertical Hollow Brick</td><td>190</td><td>0,33</td><td>0,001</td><td>1400,000</td><td>820,00</td></tr>
<tr><td>4</td><td>Gypsum Lime Plaster</td><td>20</td><td>0,46</td><td>0,001</td><td>1200,000</td><td>1008,00</td></tr>
<tr><td>Outside</td><td>Paint</td><td>1</td><td>999,00</td><td>0,001</td><td>0,001</td><td>0,00</td></tr>
<tr><th colspan="2">Flow Direction</th><th colspan="2">U-value (W/m²K)</th><th colspan="3">R-value (m²K/W)</th></tr>
<tr><td colspan="2">Horizontal</td><td colspan="2">0,923</td><td colspan="3">1,084</td></tr>
</table>

3) Floors

a) Concrete Floor on Ground

On ground level the floor is constructed as a concrete floor on ground and there is no thermal insulation applied in the construction. Layers that compose the structure and their thermal properties can be seen respectively in Figure 31 and Table 9. Concrete floor on ground has a U-value of 1,059 W/m^{2}K, which is higher than the limit U-value (0,70 W/m^{2}K) proposed by TS 825 (2008).

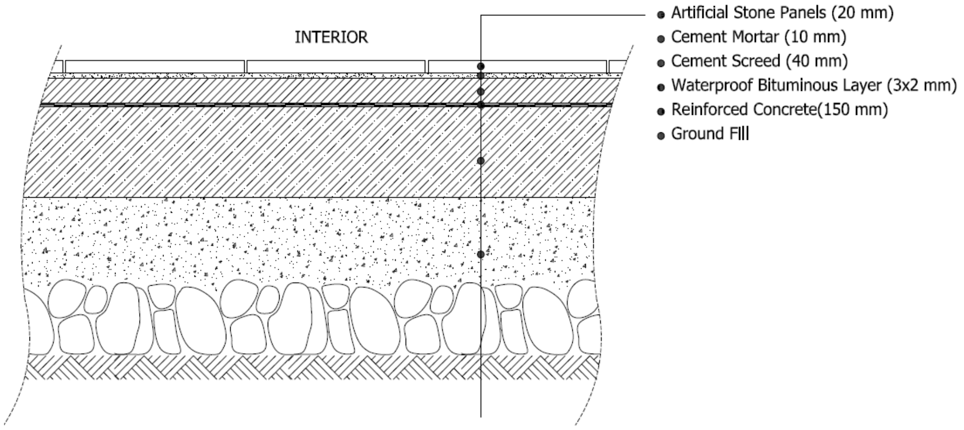


Figure 31. Section of concrete floor on ground

Table 9. Thermal properties of concrete floor on ground

Concrete Floor on Ground						
Layer	Material	Width (mm)	Conductivity (W/mK)	Convection Coefficient (W/m^{2}K)	Density (kg/ m^3)	Specific Heat (J/kgK)
Inside	Artificial Stone Tiles	30	1,20	0,001	2000,000	900,00
2	Cement Mortar	10	1,30	0,001	2000,000	1008,00
3	Cement Screed	20	1,30	0,001	2000,000	1000,00
4	Waterproof Bituminous Layer	6	0,13	0,001	1055,000	1332,00
5	Reinforced Concrete	150	2,00	0,001	2400,000	950,00
Outside	Gravel Ground Fill	300	0,52	0,000	2000,000	1800,00
Flow Direction		**U-value (W/m^{2}K)**			**R-value (m^{2}K/W)**	
Downward		1,059			0,944	

b) First Level Concrete Floor

First level has a concrete floor, finishing with artificial stone tiles. It is as well the ceiling of the ground floor with a cavity for installation systems and a suspended gypsum ceiling. Therefore the first level floor section is evaluated as a total section which services both levels. In Figure 32 the section is presented, and the thermal properties of this section are shown in Table 10. TS 825 requirement for transitional constructions between heated and unheated volumes is to have R-values higher than 0,80 m2K/W (Table 10). First level floor cannot achieve this requirement for spaces in contact with unheated volumes.

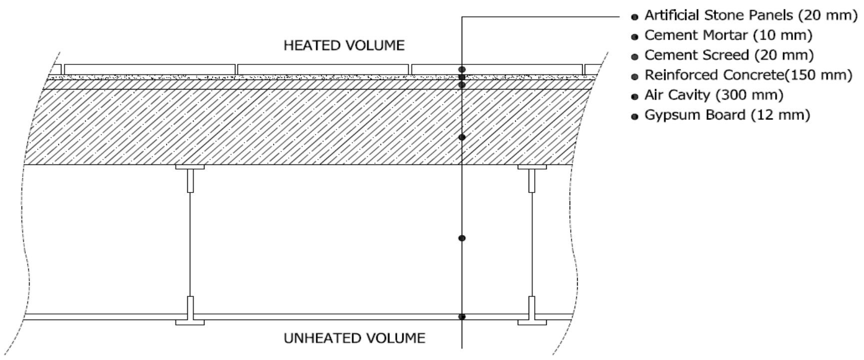


Figure 32. Section of the first level concrete floor

Table 10. Thermal properties of the first level floor

First Level Floor						
Layer	Material	Width (mm)	Conductivity (W/mK)	Convection Coefficient (W/m^2K)	Density (kg/m^3)	Specific Heat (J/kgK)
Inside	Gypsum Board Ceiling	12	0,22	0,001	900,000	1200,00
2	Installation Cavity	300	0,01	1,950	0,000	0,00
3	Reinforced Concrete	150	2,00	0,001	2400,000	950,00
4	Concrete Deck	50	1,50	0,001	2000,000	900,00
5	Cement Mortar	10	1,30	0,001	2000,000	1008,00
Outside	Artificial Stone Tiles	30	1,20	0,001	2000,000	900,00

Flow Direction	**U-value (W/m^2K)**	**R-value (m^2K/W)**
Upward	1,903	0,526
Downward	1,370	0,730

4) Flat Roof

The case building has a concrete flat roof with 5 centimeters thick extruded polystyrene thermal insulation material (XPS). Roof finishing is artificial stone tiles, and it is a load bearing roof cover. Figure 33 presents the section of the flat roof. Additionally, the U-value of the flat roof is very close to the requirement of TS 825 for specified climatic zone (Uroof= 0,447 W/m2K< Ureq= 0,45 W/m2K) (Table 11).

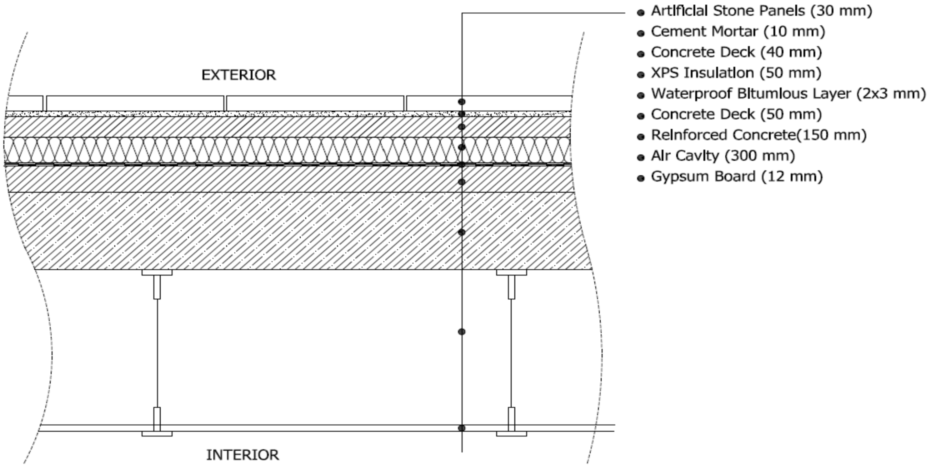


Figure 33. Section of the flat roof

Table 11. Thermal properties of the flat roof

Flat Roof						
Layer	Material	Width (mm)	Conductivity (W/mK)	Convection Coefficient (W/m^2K)	Density (kg/m^3)	Specific Heat (J/kgK)
Inside	Gypsum Board Ceiling	12	0,22	0,001	900,000	1200,00
2	Installation Cavity	300	0,01	1,950	0,000	0,00
3	Reinforced Concrete	150	2,00	0,001	2400,000	950,00
4	Concrete Deck	50	1,50	0,001	2000,000	900,00
5	Waterproof Bituminous	6	0,13	0,001	1055,000	1332,00
6	XPS Board Insulation	50	0,03	0,001	30,000	1400,00
7	Concrete Deck	50	1,50	0,001	2000,000	900,00
8	Cement Mortar	10	1,30	0,001	2000,000	1008,00
Outside	Artificial Stone Tiles	30	1,20	0,001	2000,000	900,00

Flow Direction	**U-value (W/m^2K)**	**R-value (m^2K/W)**
Upward	0,447	2,238

5) Glazing

The glazing system of the case building consists of aluminum frames with thermal break and double glazing with air cavity. Thermal properties of the double glazing are presented in Table 12. However glass surfaces occupy almost 85 to 90 % of the whole window/door area. Therefore, in consideration with U-value of the frame elements (aluminum with thermal break), the U-value is obtained from TS 2164 – Turkish Standard on Regulation on Heating Installation Design. The U-value that corresponds to the type of frame and glazing in the case building is assumed as 3 W/m^2K. Limit U-value from TS 825 is 2,4 W/m^2K, thus it is possible to assert that existing U-value of glazing components exceeds the requirement of the standard.

Table 12. Thermal properties of double glazed glass surfaces

Double Glazing (Window/Door)			
Layers	Thickness (m)	Thermal Conductivity (λ value) (W/mK)	R-Value (m^2K/W)
Glass	0,006	0,18	0,033
Air Cavity	0,012	0,294	0,041
Glass	0,006	0,18	0,033
		R-Value$_{total}$	0,107
		U-Value$_{total}$	3,624

3.1.1.3. Building Installation Systems

The building has heating, cooling and ventilation systems designed to acclimatize the indoor environment and to maintain indoor air quality. All systems for acclimatization and ventilation are located in the installation room located in the eastern part of the ground floor. The installation systems and their specifications are reviewed briefly under headings of heating installation, external weather compensation system, cooling installation, and ventilation unit.

1) Heating Installation

The heating system of the case building consists of two boilers with different capacities. The larger boiler has the capacity of 400.000 Kcal/h and the smaller boiler's capacity is 250.000 Kcal/h (Table 13). There are two combustion units which burn the fuel and retrieve to the boilers. Energy source to run the heating system is fuel oil which is stored in a storage tank with a capacity of 18000 liters.

The boiler type used in the case building is non-condensing. Non-condensing boilers are less efficient than condensing boilers. It is necessary to prevent long term condensation presence in the boilers to maintain efficiency. The boilers function only for heating purposes, there is no central hot water heating system connected to these boilers.

Table 13. Characteristics of the heating installations

	Boiler 1	**Boiler 2**
Capacity (Kcal/h)	400.000	200.000
Capacity (KW)	465	290
Efficiency (%)	87,00	84,00

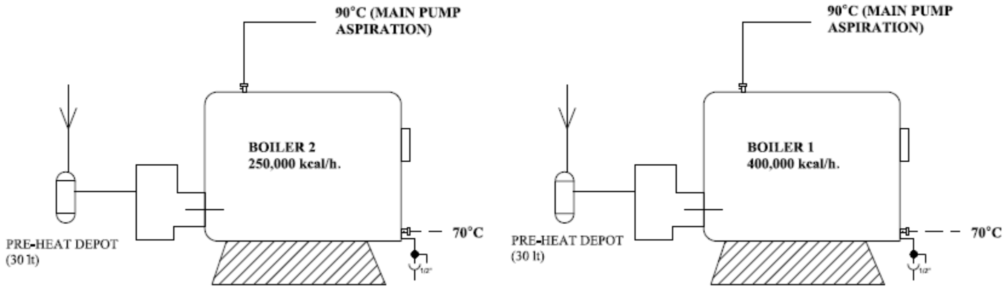


Figure 34. Schematic drawing of the boilers
(Source: OCW 2009)

The heated water in the boilers is transferred to the main aspiration pump with a maximum temperature of 90°C (Figure 34). Hot water heats the clean air in the ventilation unit and then is serviced to the spaces for conditioning. Distribution of heated air through insulated pipes (polyethylene, 1 cm) finalizes in convective ceiling type fan coils in the spaces. In spaces where there is no necessity for cooling, the heating emitters are panel radiators. All fan coils in the building function with a thermostat system with winter, summer, and on/off controls.

2) External Weather Compensation System

External weather compensation system for boilers started to function in the winter of 2008-2009 with the reason to control the boiler temperature according to the exterior temperature. The automation system functions on the principal of adjusting boiler temperatures according to exterior temperature swings. With the compensation system, the heating systems have the opportunity to function continuously, with lower set temperatures during occupancy hours of the building. Since the building does not cool down to exterior temperatures, the spaces reach to the required temperatures quicker and the heating system fuel consumption depends on weather conditions and the lesser amount of time indoor spaces reach up to the set point temperatures.

Water temperature of boilers, return water temperature, and exterior air temperature is recorded with 5 minutes interval and the data is accessible through a web page for monitoring.

3) Cooling Installation

Cooling installation of the case building is an air-cooled liquid chiller with heat recovery system. For heat recovery systems, refrigeration is the primary purpose and chiller control is based on chilled water cycle. Heat generated by the condenser is rejected in the system installed for the case building (Carrier, 2008). The system is composed of a chiller and a condenser tank (Figure 35). Evaporator temperature of the chiller is 12°C for entering and 7°C for leaving, which is compliant with related certifications (such as EuroVent). In Table 14, characteristics of the cooling system are presented.

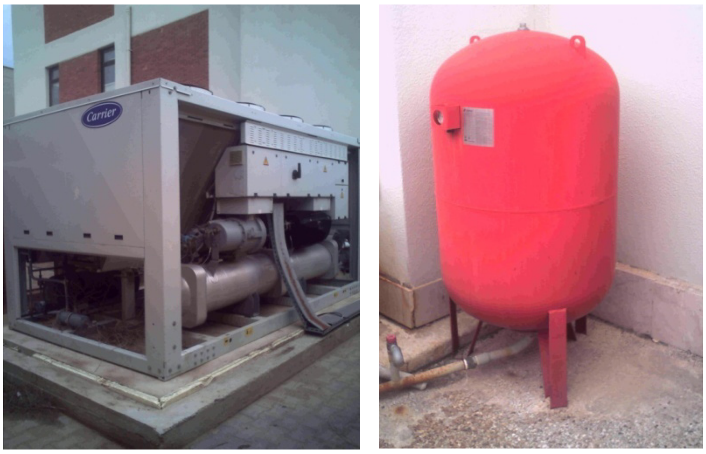


Figure 35. Chiller and condenser of the cooling installation

Table 14. Characteristics of the cooling system

	Cooling System
Net Cooling Capacity (KW)	536
Power Input (KW)	196
Heat Recovery Capacity (KW)	344
Evaporator	Shell and tube type
Condensers	Copper tubes

4) Air Handling Unit (Ventilation System)

Air handling unit (AHU) in the case building functions both with heating and cooling installations. The system works with the principle of collecting and mixing outdoor air with the air returning from the building space. The air mixture is then cooled or heated, after which it is discharged into the building space through the duct systems designed to facilitate acclimatized air through convective ceiling fan coils. The technical properties of the ventilation system can be seen in Table 15.

Two different air handling units are designed for ground (AHU-1) and first floor (AHU-2). For each air handling unit there are main parts of the system:

- Outside and Return Air Fans: Outside air fan unit provides intake of outside air into the system, where the return unit provides a part of the indoor exhaust air back into the system and outlets the remaining exhaust air.
- Mixing Unit: The portion of indoor exhaust air from the return fan and intake of outside air is mixed in the mixing and exhaust section of the system.
- Bag Filter, Supply Air Fan and Heating and Cooling Coils: In the next step the air mixture is filtered before entering the supply air fan. Supply air fan pressures air through the heating or cooling coil. When passing through heating coil, the air mixture is heated by hot water supply from the boiler and similarly when passing from the cooling coil, the air mixture is cooled by chilled water supplied from the chiller. The acclimatized ventilation air is then charged into the duct system.

Table 15. Technical properties of air handling units

	AHU-1	**AHU-2**
Exhaust Fan Air Flow (m^3/h)	3600	5220
Intake and Supply Air Flow (m^3/h)	10900	13400
Filter	EU4 Viscotecs	EU4 Viscotecs
Cooling Coil Capacity (KW)	105	121
Heating Coil Capacity (KW)	122	150
Cold Water Regime (°C)	07/12	07/12
Hot Water Regime (°C)	90 /70	90 /70

3.1.1.4. Building Comfort Ranges

The building comfort ranges in the case building are as follows:

- Offices Winter: 22 (±2) °C
  Summer: 24 (±2) °C
- Classrooms Winter: ±22 (±2) °C
  Summer: 24 (±2) °C

• Storage Spaces	Winter: No Conditioning Summer: No Conditioning
• Laboratories	Winter: 20 (±2) °C Summer: 24 (±2) °C
• Circulation	Winter: 20 (±2) °C Summer: 26 (±2) °C

3.1.1.5. Building Schedules and Occupancy

The building is occupied by academic and administrative staff and students. Due to the variable presence of the students, it is not possible to asses a definite occupancy for the building. However, the building is occupied by office and laboratory users which are approximately 90. It is possible to assert that the building services between 100 and 200 people including the students.

The building is occupied in weekdays between 08:30 and 17:30. Regarding this schedule, further energy performance evaluations concerning occupancy will be conducted between 08:00 and 18:00, whilst heating and cooling systems as well perform. The building is unoccupied on national holidays and weekends. Several academic staff uses the building in the weekends or evenings, however they are not the majority of the occupants.

3.1.2. Energy Performance Analysis of the Case Building via Different Analysis Tools and Comparison of the Results

The first step of the methodology, which is summarized as building energy performance analysis and comparison of the results to determine the most accurate analysis tool, is comprehensively explained in this section. Important considerations, limitations and sequential processes involving the different energy performance analysis methods are presented thoroughly to provide a methodology for further research.

The first step of the methodology includes following evaluations and considerations:

- Analysis of the results for energy performance monitoring of the case building: Results are presented according to indoor comfort conditions, energy consumption and indoor environmental response to weather conditions.
- Analysis of results for energy performance simulation of the case building: Simulation results are presented concerning indoor comfort conditions, energy consumption and indoor environmental response to exterior climatic conditions.
- Analysis of results for energy performance calculation of the case building according to Thermal Insulation Standard in Buildings (TS 825, 2008): Calculation results are evaluated with respect to energy consumption.
- Comparison of analysis results for different tools and definition of error margins: With the aim to predict the accuracy of simulation and calculation results, all analysis results are compared to energy performance monitoring results. Therefore, considering the monitoring results as the most realistic data set, this evaluation offers the possibility to define the deviation of simulation and calculation results from the monitoring results. This deviation is named as the error margin of an analysis tool in comparison to the monitoring results.

Additionally, the following parts of this section intend to denote the necessary equipment, method and tools to utilize in energy performance analysis of buildings along with the above stated analysis steps.

3.1.2.1. Energy Performance Monitoring of the Case Building

Energy performance monitoring can be defined as a set of measurements to gather field data which provide realistic and empirical information of actual energy performance of a building (ASHRAE, 1999). In literature energy performance monitoring may as well be referred as energy audit (CRES, 2000). However it is necessary to keep in mind that energy audits may have different levels of significance between walkthrough (simple) audits and comprehensive (detailed) audits. Energy performance monitoring best corresponds to comprehensive audits where the monitoring period covers minimum annual field data retrieval. CIBSE Guide H: Building Control Systems defines energy performance monitoring as a powerful tool to control and reduce energy consumption. The guide couples monitoring concept with targeting and defines its functions as (1) control of current energy consumption by performance monitoring and comparison of the consumption levels to benchmarks and (2) improvements in the efficiency of energy consumption through setting future targets (CIBSE, 2000). Therefore, energy performance monitoring is conducted with the aims to determine:

- Energy end use: Monitors to assess characteristics of specific energy end uses in building. Detailed data on end uses are measured. It helps to estimate the loads by end use and rate the energy performance of the building.
- Specific technology assessment: Monitors specific equipment or technologies that affect building energy consumption, such as building envelope, major end uses, and installation systems.
- Saving measurement and verification (M&V): Monitors to assess proper equipment and systems which have the potential to generate predicted energy savings through post retrofit measures and to evaluate the energy savings after the retrofit.
- Building operation and diagnostics: Monitors to indicate physical and/or operational characteristics that affect energy use in relation with operation and maintenance such as air tightness, indoor air quality, and system problems (ASHRAE, 1999).

According to the type of monitoring defined by ASHRAE, the energy performance monitoring characterized for this dissertation aims to propose a monitoring strategy which falls into the specific technology assessment, where the monitoring activity aims to assess specifically the influences of building envelope on energy consumption and end-uses. The main steps in designing the energy performance monitoring are derived from CIBSE Guide H, and can be listed as: (1) data collection, (2) data analysis and results, (3) action (CIBSE, 2000).

The energy performance monitoring of the case building started in January 2009 and ended in March 2010 covering 15 full months of monitoring. In the following sections first two the steps of monitoring application is explained in detail, under the above stated flow of monitoring steps. The third part which is defined as action indicates the determination of evaluation tools and designation of retrofitting strategies and is explained in further sections.

3.1.2.1.1. Data Collection for Energy Performance Monitoring

The 15 months long monitoring of the building (12 months for evaluation and 3 months for data control) includes the measurement applications presented in Table 16. The measurements conducted during the moitoring period are: temperature and humidity measurements from sample volumes, electricity consumption, fuel consumption, microclimatic data, and CO_2 emissions of the heating installation of the building.

Detailed continuous measurement of indoor and outdoor temperature is necessary for obtaining more accurate results to assess the indoor environmental profiles in the building (Santamouris, 2005). Therefore, indoor temperature and humidity is monitored with HOBO U12 Temperature and Humidity Data Loggers in 10 minutes interval (Figure 37). The accuracy of temperature measurement is ±0,35°C and of humidity measurement is ±2,5%.

Table 16. Monitored building energy performance parameters

Monitored Building Energy Performance Parameters		**Measurement Period**	**Measurement Interval**	**Typical Use**	**Measurement Equipment**
Indoor Temperature		Sequential / Continuous	10 minutes	Diagnostics	Data loggers
Indoor Humidity		Sequential / Continuous	10 minutes	Diagnostics	Data loggers
Electricity Consumption		Sequential / Continuous	Daily	Energy Use	Power Analyzer
Fuel Consumption		Manual Readings	Daily	Energy Use	Flow meter
Microclimatic Data	**Outdoor Temperature**	Sequential / Continuous	10 minutes	Diagnostics	Microclimatic Weather Station
	Outdoor Humidity				
	Global Horizontal Solar Radiation				
	Wind Speed				
	Wind Direction				
	Cloudiness	Continuous	Daily		Macroclimatic Weather Station
CO^2 Emission		Once		Diagnostics	Combustion Gas Measurement Equipment

Monitoring of indoor temperature and humidity is conducted in sample volumes. These volumes are determined according to the following criteria:

- Orientation of the space
- Volume of the space
- Possibility to cover volumes with similar/different functions for further comparisons

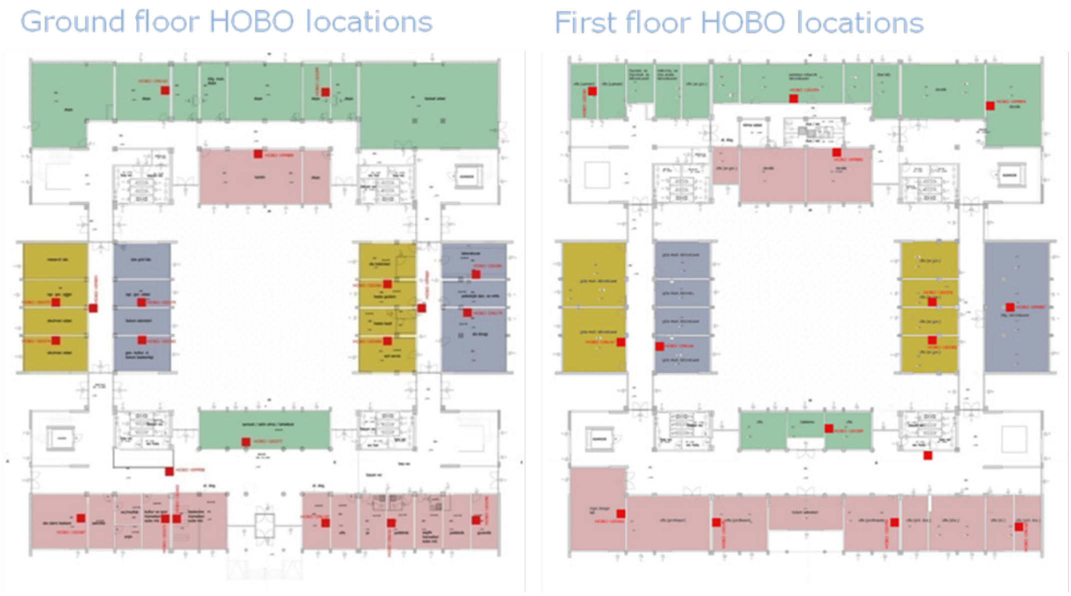
In Table 17 and Table 18 total number of data loggers and their distribution among building levels and spaces is presented. Similar volumes in different orientations were selected for locating the data loggers (Figure 36). The corner volumes in both floors are equipped with loggers. Only on ground floor, east facade corner volumes were neglected, since both are installation spaces with large volumes, and are not heated. Instead two storage spaces with different volumes are selected for ground floor. Another example for sampling spaces is on the west wing, ground floor, on both sides of the dilatation wall with similar volumes. Every wing of the building is being monitored on sides both facing exteriors of the building and the atrium.

Table 17. Data loggers installed in the case building

Number of HOBO U12 Data Loggers	
Total	35
On Ground Floor	25
On First Floor	10

Table 18. Distribution of data loggers

Number of HOBO U12 Data Loggers	
In Office Spaces	18
In Laboratory Spaces	4
In Classrooms	4
In Circulation Spaces	3
In Clinic Spaces	3
In Storage Spaces	2
In Common Spaces (Canteen)	1


Ground floor HOBO locations

First floor HOBO locations

Figure 36. Data logger locations in the case building


Figure 37. Data loggers in different spaces (classroom, office, and corridor)

Temperature and humidity data loggers (HOBO) are placed between 1.50 and 1.70 meters, aligned with the center of the space, avoiding exterior walls to remove the effects of irradiative temperature differences and avoiding direct solar exposure (Ghisi & Massignani, 2007; Fuller, Zahnd, & Thakuri, 2009).

Electricity consumption is monitored on both of the electricity boards for common use and cooling unit. On both boards, Power Analyzer MPR63 is installed, and configured for data logging every 15 minutes interval. The accuracy of the analyzer for electrical current is 0,5% and for electrical power is 1%. Daily electricity loads for equipment and cooling is monitored and calculated from the logger in units of KW from the power analyzer recordings for further analysis.

The heating system of the building runs on fuel combustion. To monitor the amount of fuel consumed by the system on daily basis two flow meters are installed on the pipes before the burner unit of the system. The flow meter is a standard one, Aquametro Contoil VZE 15 RC, with a measurement type of accumulative volume of the consumed fuel. The accuracy of the flow meters is ± 1% of the actual value. The fuel is heated to 50 to 60°C in the pre-heater depot to increase the viscosity of fuel. Consumption is monitored between these levels of pre-heated state; therefore it is necessary to consider the density of fuel in this temperature benchmark.

Micro-climatic data is monitored in the campus area with a DAVIS Vantage Pro2 weather station. Climatic data on outdoor temperature, outdoor humidity, global horizontal solar radiation, wind speed and wind direction is measured by the weather station with 10 minutes interval. The measurement ranges and the accuracy of each external weather component is presented in Table 19. Cloudiness index is retrieved from macro-climatic main weather station of Izmir (TSMS, 2009).

Table 19. Weather data monitored in IZTECH campus area

	Measurement Range and Unit	Accuracy
Outdoor Temperature	0-60°C	± 0,5°C
Outdoor Humidity	0-100%	± 3%
Global Horizontal Solar Radiation	0-1800 W/m^2	± 5%
Wind Speed	1-67 m/s	± 5%
	3-241 km/s	
Wind Direction	0-360°	4°

3.1.2.1.2. Data Analysis and Results for Energy Performance Monitoring

Monitoring data for the case building is analyzed according to following comparative criteria:

- Evaluation of hours outside design temperature for winter and summer during occupancy.
- Evaluation of indoor – outdoor temperature differences according to orientation and type of volumes.
- End use electricity and fuel consumption analysis.

1) Evaluation of Monitored Indoor Temperature Profiles:

Indoor temperature monitoring results are presented according to the evaluation of hours outside design temperature for winter and summer. Occupancy hour data is analyzed for this evaluation. The hourly temperature and humidity averages are calculated from monitoring data with 10 minutes interval, for the occupancy period between 08:00 and 18:00 hours for specific weekly workdays, which results in a total of 2520 occupancy hours in a year. The ratio of hourly temperature averages to the total hours of occupancy is presented in the following charts according to heating, cooling and non-conditioning periods. The monitored spaces are indicated in following analysis as Z17, Z21, Z33 etc. for ground floor and 101, 115, 131 etc. for first floor. The spaces which are acclimatized by heating and cooling systems during monitoring period are included for analysis.

Figure 38 presents the percentage of measured indoor temperatures below design temperature (20°C) during occupancy hours. The analysis covers the months of heating season (January, February, March and December 2009) and non-conditioned months (April and May 2009). According to the analysis, the graph points out that north oriented spaces distinctly have larger ratios of hours below comfort range (almost an average of 40 to 45 percent). The result indicates that north oriented spaces fail to attain indoor temperature levels since the building envelope is not adequately insulated.

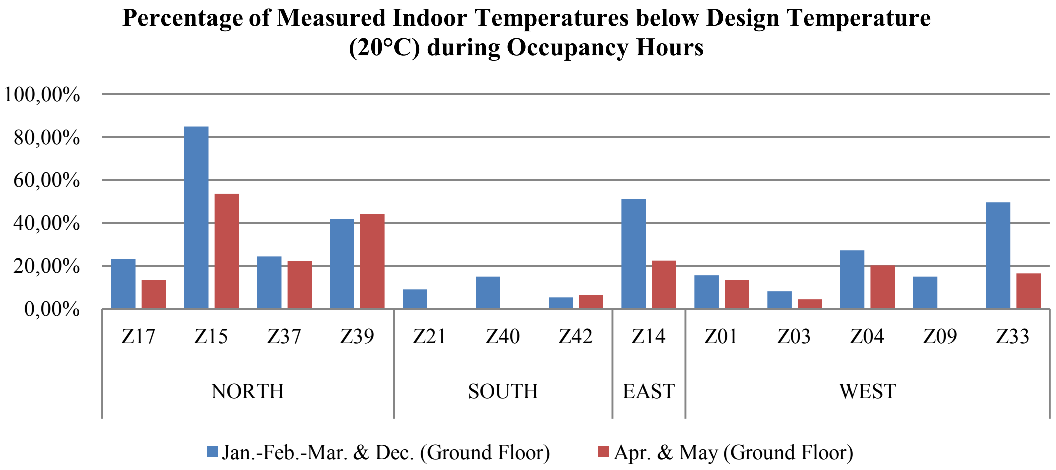


Figure 38. Ground floor – Percentage of measured indoor temperatures below design temperature (20°C) during occupancy hours

The dissimilar results for south oriented spaces originate from solar gains through the building envelope which affect the indoor environment temperature profile. Analysis of east and west oriented spaces as well denote a considerable ratio of hours below comfort range, which is directly in relation with the relatively low angles of solar inclination of winter sun and the decrease of solar gains. In April and May 2009 non-conditioned season, north oriented spaces are roughly 33 % below comfort range.

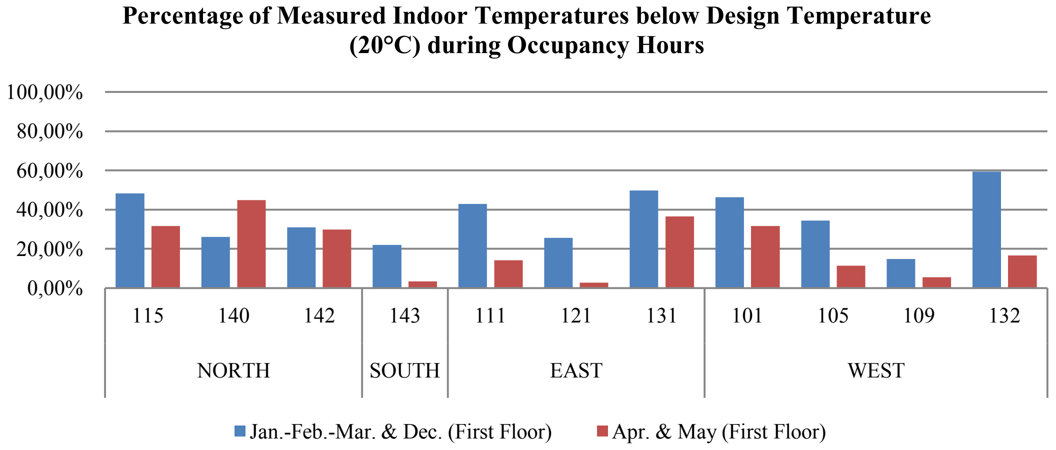


Figure 39. First floor – Percentage of measured indoor temperatures below design temperature (20°C) during occupancy hours

Monitored spaces in the first floor are as well analyzed according to the percentage of measured indoor temperatures below design temperature (20°C) during occupancy hours (Figure 39). The analysis of first floor data demonstrates that there is almost a similar case for every orientation. North oriented spaces have an average of 35%, in south oriented part of the building a single large space exists and it has 22%, east oriented spaces have an average of 40 %, and west oriented spaces have an average of 39 % of hours outside design comfort range in heating season. East and west spaces have very close percentages of hours outside comfort range. East spaces are in contact with unheated zones in the ground floor, therefore heat losses occur towards these zones from non-insulated floor. Additionally east and west oriented spaces have less solar gains during winter months.

North oriented spaces in the first floor have better conditions compared to ground floor analysis ($Av_{first}=33\% < Av_{ground}=48\%$). The reason for the better average of hours below design temperature is the heat loss from concrete ground on floor is eliminated and the roof of the building has an acceptable heat transfer coefficient, therefore first floor is only subject to heat losses from façade structure.

During April and May, the non-conditioned period, east and west oriented spaces illustrate an improvement in indoor temperatures, since the solar gains become more prominent. In contrary north oriented spaces demonstrate a poorer indoor temperature profile, since the heating systems are turned off.

Figure 40 presents the analysis of the percentage of measured indoor temperatures over design temperature (26°C) for cooling period. The results show that east and west oriented spaces have large percentages of hours exceeding 26°C during cooling season, which cause high cooling loads. In the west oriented spaces the difference of Z01 percentages originates from the area of the heat loss surface and the orientation, where the space is exposed to exterior air towards north with a reinforced concrete wall.

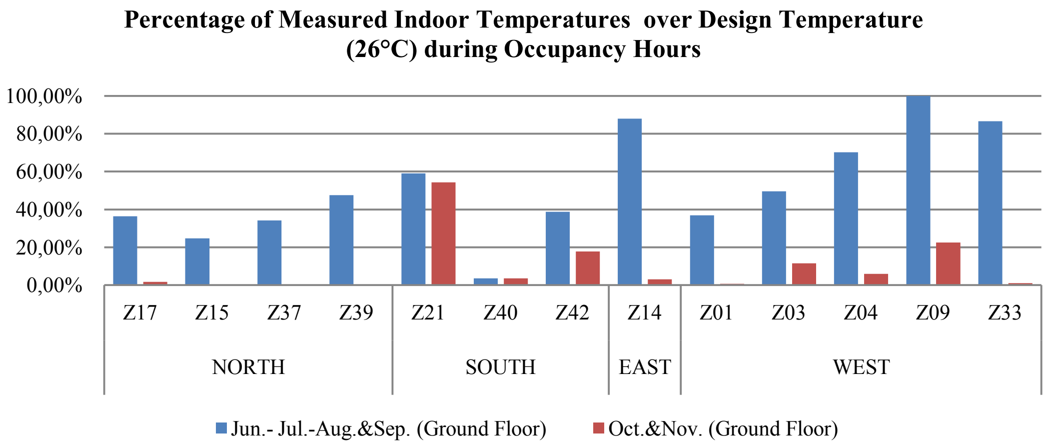


Figure 40. Ground floor – Percentage of measured indoor temperatures over design temperature (26°C) during occupancy hours

South oriented spaces Z40 and Z42 are supplied with standalone air conditioners in addition to the central cooling system; therefore the indoor temperatures are lower than the set point of Z21. Analysis of north oriented spaces summer months illustrate the least out of range percentages, where solar gains have no affect on indoor temperatures.

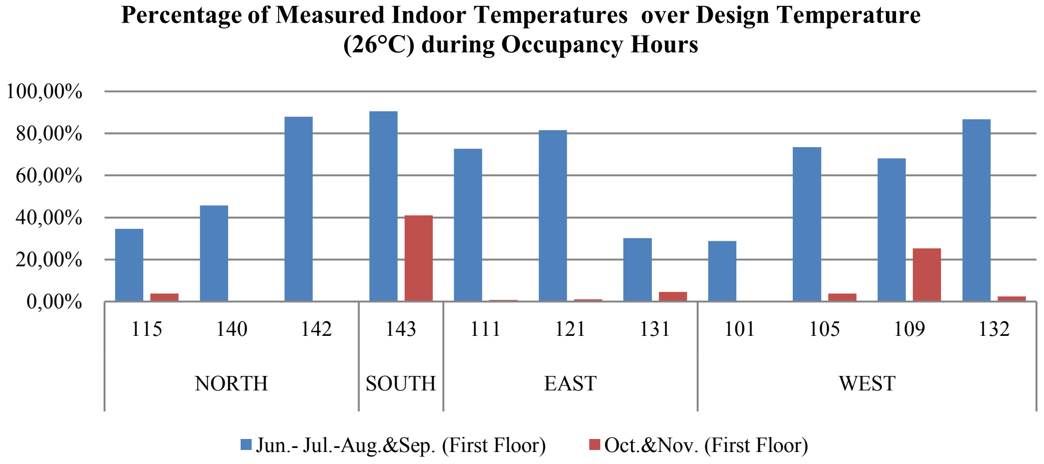


Figure 41. First floor – Percentage of measured indoor temperatures over design temperature (26°C) during occupancy hours

In Figure 41, parallel analysis results for first floor spaces are presented. The percentage of measured indoor temperatures over design temperature (26°C) for south east and west oriented spaces are very high, during the cooling season. For the north oriented spaces, the lowest results around 56% of hours over design temperature are attained. South and east oriented spaces in the first floor have higher percentages of hours over design temperature, vastly originating from overheating from the roof structure.

October and November profiles for both ground floor and first floor analysis show that the percentage of hours over design temperature is relatively small in regard to the decrease in outdoor temperatures, while the cooling system functions for lesser periods (Figure 40,Figure 41).

2) Evaluation of Monitored Indoor Response to Outdoor:

Indoor temperature and humidity parameters are examined in response to the fluctuations of outdoor parameters and are presented merely by monitoring data gathered from sample monitored volumes. The analysis is carried out according to orientation and the volume of the monitored spaces, regarding heating and cooling seasons. Table 20 (pp. 78-79) indicates the monitored spaces according to their exterior exposure, occupancy, and spatial characteristics. This classification yields the sub-sets of spaces which are evaluated according to outdoor temperature and humidity results.

Fluctuations of indoor temperature and humidity for two identical north oriented spaces in occupancy and volume in January 2009 is presented in Figure 42 (p.80). Indoor temperature for space 142 (first floor) is higher than Z15 (ground floor) in many instances, although both spaces have the heating system functioning.

The graph in Figure 43 (p.80) presents two sample spaces with the same volume and occupancy and their respond to exterior temperature and humidity levels. During July 2009, cooling system run in both spaces and monitored temperature fluctuations for these spaces are similar in trend, different in average values, which can be interpreted as an effect of solar gains from roof structure and different thermal comfort perception of the occupants.

Table 20. Exposure, occupancy, and spatial characteristics of monitored spaces

Zones	Main Orientation	Exposure Length to Main Orientation	Exposure Area to Main Orientation	Secondary Orientation	Exposure Length to Secondary Orientation	Exposure Area to Secondary Orientation	Tertiary Orientation	Exposure Length to Tertiary Orientation	Exposure Area to Tertiary Orientation	Area of Windows on Exposed Surfaces	Occupancy	Area	Height	Volume	Use
		(m)	(m2)		(m)	(m2)		(m)	(m2)	(m2)	# of people	(m2)	(m)	(m3)	
Z01	West	6,90	26,22	North	6,89	26,18	--------	--------	--------	6,84	1,00	48,79	3,80	185,40	Office
Z03	West	3,40	12,92	--------	--------	--------	--------	--------	--------	3,42	3,00	23,80	3,80	90,44	Office
Z04	West	6,90	26,22	South	2,82	10,72	--------	--------	--------	10,26	3,00	23,09	3,80	87,74	Office
Z06	West	6,90	26,22	North	3,46	13,15	--------	--------	--------	10,26	--------	23,80	3,80	90,44	Office
Z09	West	3,40	12,92	--------	--------	--------	--------	--------	--------	3,42	1,00	22,51	3,80	85,54	Office
Z12	West	3,30	12,54	South	6,90	26,22	--------	--------	--------	3,42	--------	22,75	3,80	86,45	Office
Z13	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	0,00	--------	--------	Corridor
Z14	East	16,60	63,08	North	2,20	8,36	South	2,20	8,36	11,80	4,00	78,85	3,80	299,63	Office
Z19	--------	--------	--------	North	9,25	35,15	South	9,25	35,15	45,88	--------	84,48	3,80	321,02	Corridor
Z17	North	3,40	12,92	--------	--------	--------	--------	--------	--------	3,42	2,00	27,53	3,80	104,61	Office
Z15	North	4,53	17,21	West	8,10	30,78	--------	--------	--------	6,84	3,00	36,65	3,80	139,27	Office
Z21	South	3,40	12,92	--------	--------	--------	--------	--------	--------	3,42	2,00	24,13	3,80	91,69	Office
Z23	South	4,53	17,21	West	7,10	26,98	--------	--------	--------	6,84	1,00	33,19	3,80	126,12	Office
Z26	East	6,68	25,38	--------	--------	--------	--------	--------	--------	5,50	--------	50,00	3,80	190,00	Storage
Z30	East	3,25	12,35	--------	--------	--------	--------	--------	--------	--------	--------	24,60	3,80	93,48	Storage
Z33	West	16,60	63,08	North	2,20	30,10	--------	--------	--------	13,68	12,00	89,60	3,80	340,48	Canteen
Z35	--------	--------	--------	North	9,25	35,15	South	9,25	35,15	45,88	--------	84,48	3,80	321,02	Corridor
Z37	North	3,40	12,92	--------	--------	--------	--------	--------	--------	3,42	1,00	23,30	3,80	88,54	Laboratory
Z39	North	4,53	17,21	West	7,10	26,98	--------	--------	--------	6,84	1,00	32,38	3,80	123,04	Patient Watch

(cont. on next page)

Table 20. (cont.)

Zones	Main Orientation	Exposure Length to Main Orientation (m)	Exposure Area to Main Orientation (m2)	Secondary Orientation	Exposure Length to Secondary Orientation (m)	Exposure Area to Secondary Orientation (m2)	Tertiary Orientation	Exposure Length to Tertiary Orientation (m)	Exposure Area to Tertiary Orientation (m2)	Area of Windows on Exposed Surfaces (m2)	Occupancy # of people	Area (m2)	Height (m)	Volume (m3)	Use
Z40	South	4,53	17,21	East	8,10	30,78	--------	--------	--------	6,84	2,00	35,84	3,80	136,19	Emergency Room
Z42	South	8,13	30,89	West	8,10	30,78	--------	--------	--------	10,26	2,00	65,80	3,80	250,04	Dental Clinic
101	West	6,85	26,03	North	10,50	39,90	--------	--------	--------	14,36	5,00	72,45	3,80	275,31	Laboratory
103	West	6,90	26,22	South	2,40	9,12	--------	--------	--------	10,26	1,00	47,60	3,80	180,88	Office
105	West	6,90	26,22	North	2,40	9,12	--------	--------	--------	10,26	1,00	47,60	3,80	180,88	Office
109	West	3,30	12,54	South	6,90	26,22	--------	--------	--------	3,42	1,00	22,75	3,80	86,45	Office
111	East	5,85	22,23	South	2,15	8,17	--------	--------	--------	3,42	1,00	27,50	3,80	104,50	Office
115	North	8,13	30,89	West	7,90	30,02	--------	--------	--------	10,26	3,00	64,20	3,80	243,96	Laboratory
117	South	4,53	17,21	West	6,90	26,22	--------	--------	--------	6,84	1,00	32,25	3,80	122,55	Laboratory
121	East	3,30	12,54	North	6,90	26,22	--------	--------	--------	3,42	2,00	22,70	3,80	86,26	Office
127	East	12,98	49,32	--------	--------	--------	--------	--------	--------	6,84	--------	63,50	3,80	241,30	Laboratory
132	West	8,20	31,16	South	2,15	8,17	--------	--------	--------	10,26	Not Known	56,17	3,80	213,45	Classroom
131	East	6,90	26,22	South	10,50	39,90	--------	--------	--------	14,36	Not Known	72,43	3,80	275,23	Classroom
143	South	16,45	62,51	East	8,10	30,78	West	8,10	30,78	20,52	Not Known	133,23	3,80	506,27	Laboratory
140	North	3,40	12,92	--------	--------	--------	--------	--------	--------	3,42	2,00	24,14	3,80	91,73	Office
142	North	4,53	17,21	West	7,10	26,98	--------	--------	--------	6,84	2,00	33,19	3,80	126,12	Office

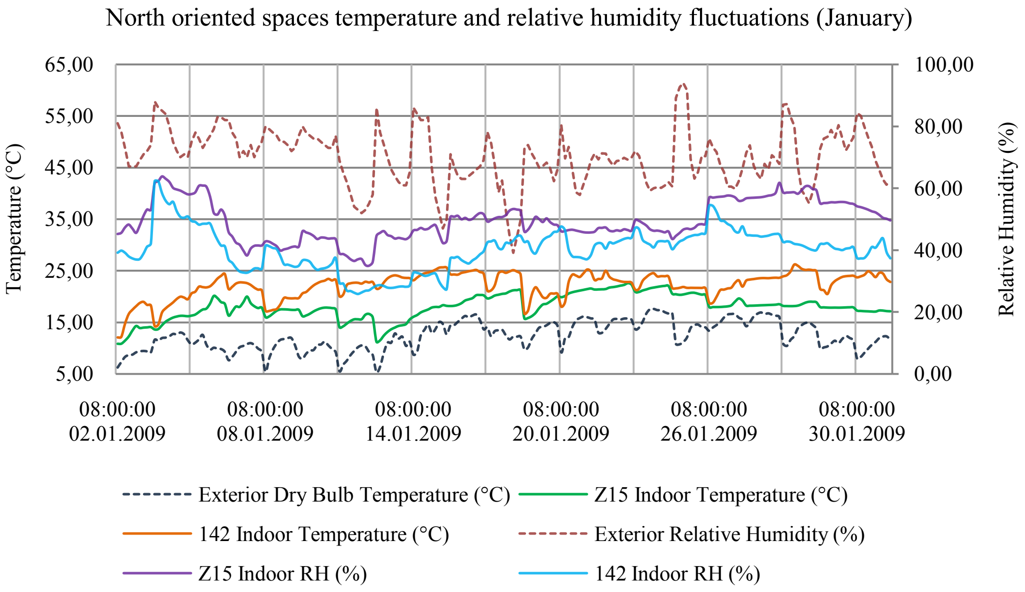


Figure 42. North oriented spaces temperature and relative humidity fluctuations (January-monitoring data)

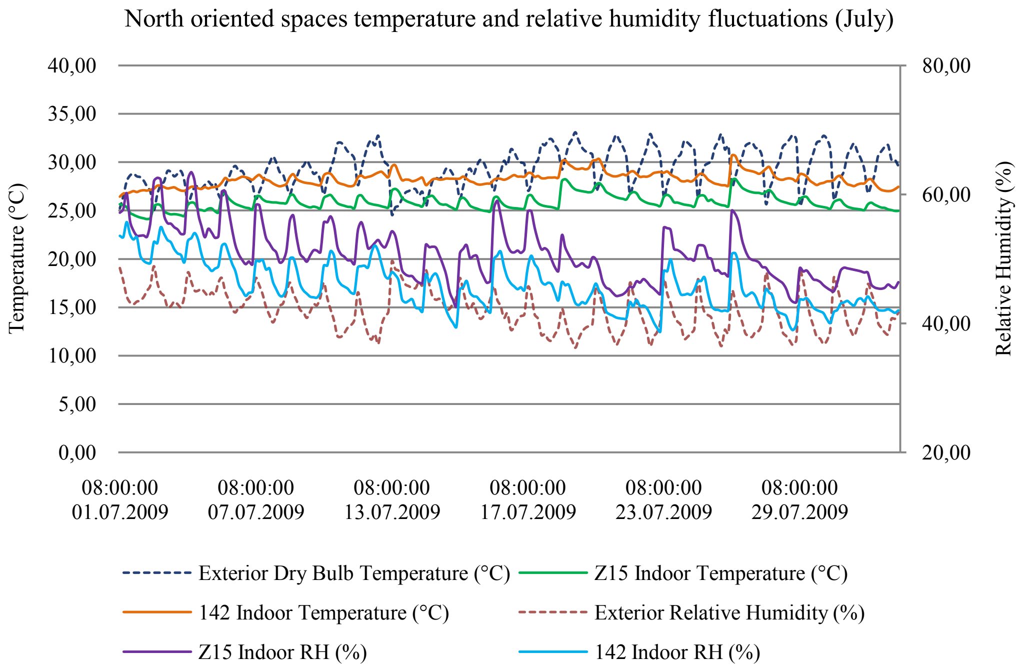


Figure 43. North oriented spaces temperature and humidity fluctuations (July-monitoring data)

In Figure 44, two sample west oriented spaces are analyzed according to the indoor temperature and humidity profiles in January 2009. In the previous analysis it is noticed that selected spaces have similar profiles for winter and summer hours outside design temperature range and their volumes and glazing areas are identical; however surface area for heat loss differ in two spaces. First floor office (109) has a large reinforced concrete wall facing south. Therefore the general trend of higher indoor temperatures in Z09 occurs.

West oriented spaces Z09 and 109 have more steady temperature and humidity fluctuations in July 2009. 109 have higher indoor temperature trend compared to Z09. The effect of south facing reinforced concrete and overheating from the roof surface is dominant in this higher indoor temperature profile (Figure 45).

Several comparisons between monitored spaces and orientations can be obtained from monitoring data and can be investigated for zone specific assessments. The results of this evaluation can be summarized as follows:

- North oriented spaces have poorer indoor temperature profiles compared to other orientations during heating season. The reason for indoor temperature problems in north oriented spaces originates mostly from the lack of thermal insulation in building envelope parts.
- Area of heat loss surfaces and the alteration in their structure (especially reinforced concrete walls) affect the indoor temperature profiles in all spaces.
- First floor spaces are largely affected by overheating during summer. The percentage of hours over design temperature is relatively high compared to ground floor spaces.
- Ground floor spaces present lower indoor temperatures during heating period due to the heat losses from the non-insulated concrete floor on ground.

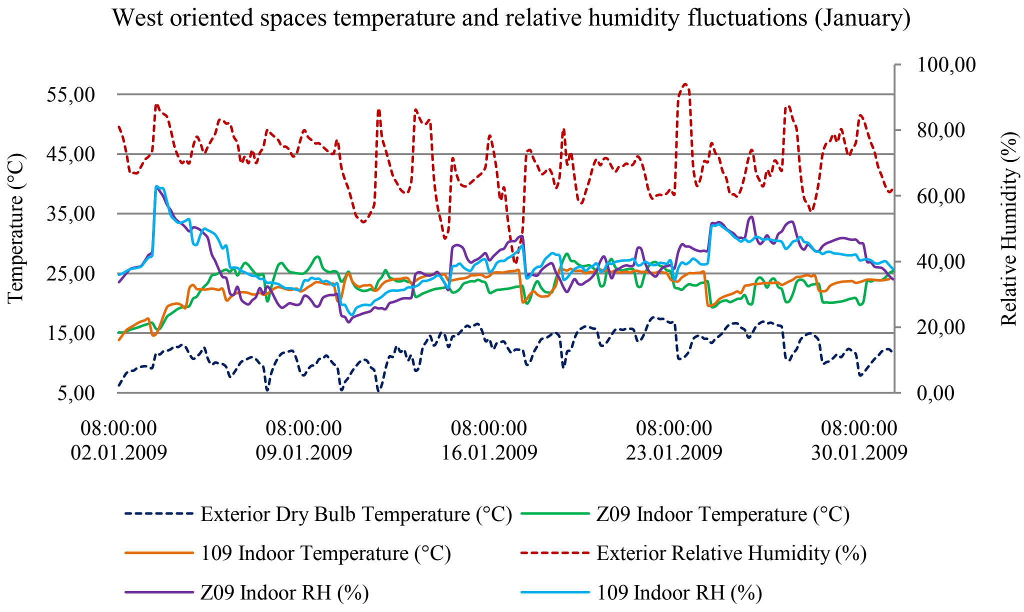


Figure 44. West oriented spaces temperature and relative humidity fluctuations (January-monitoring data)

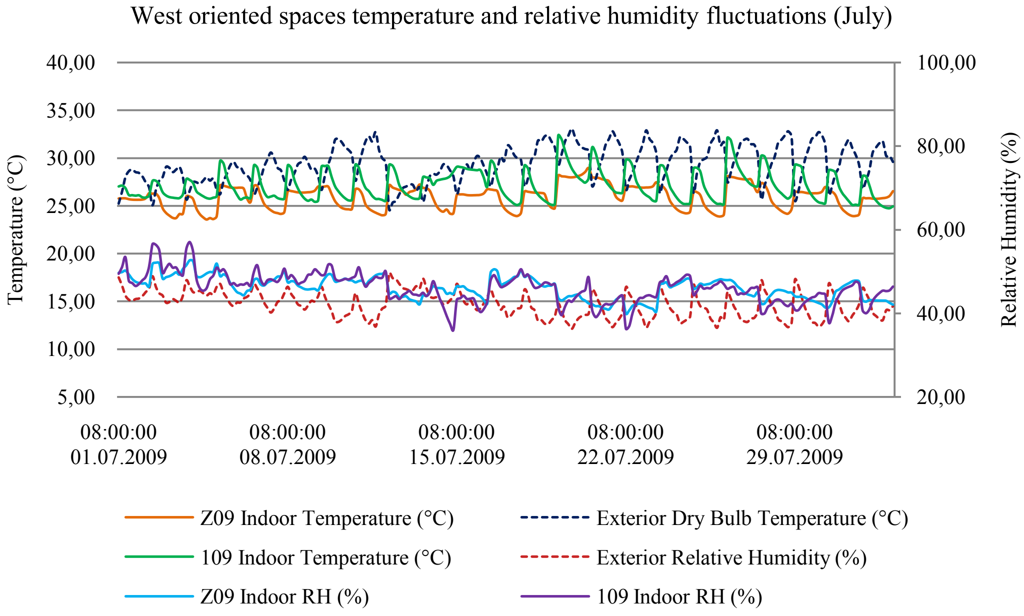


Figure 45. West oriented spaces temperature and relative humidity fluctuations (July-monitoring data)

3) Evaluation of Monitored Energy Consumption:

Electricity consumption is monitored with two power analyzers. Figure 36 presents the monthly total electricity consumption of the building starting from June 2007. Cooling system in the building started functioning in August 2008 and can distinctively be seen as an accumulative result to standard electricity use in the building. As a result, electricity consumption of the building has an increasing trend in 2009 when compared to previous years of occupancy. The highlighted part in the graph represents 2009 and in Figure 46, monthly electricity consumption regarding utility and cooling end-use are presented.

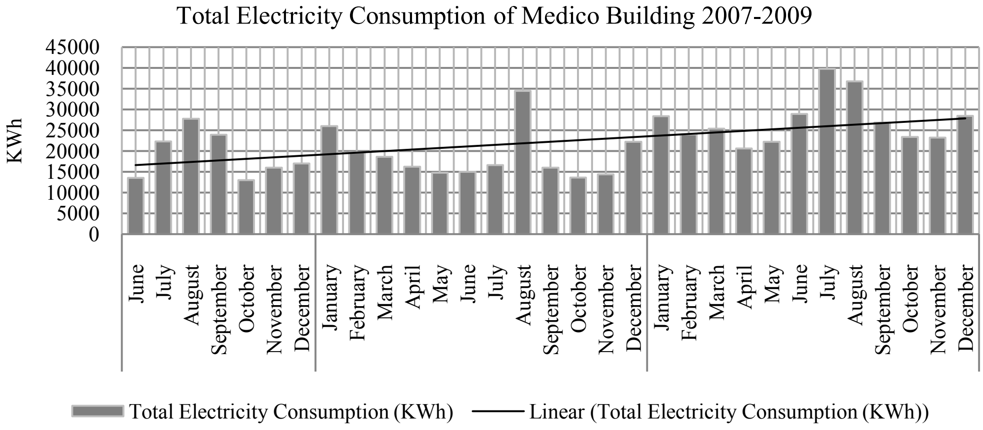


Figure 46. Total electricity consumption of the case building
(Source: OCW 2009)

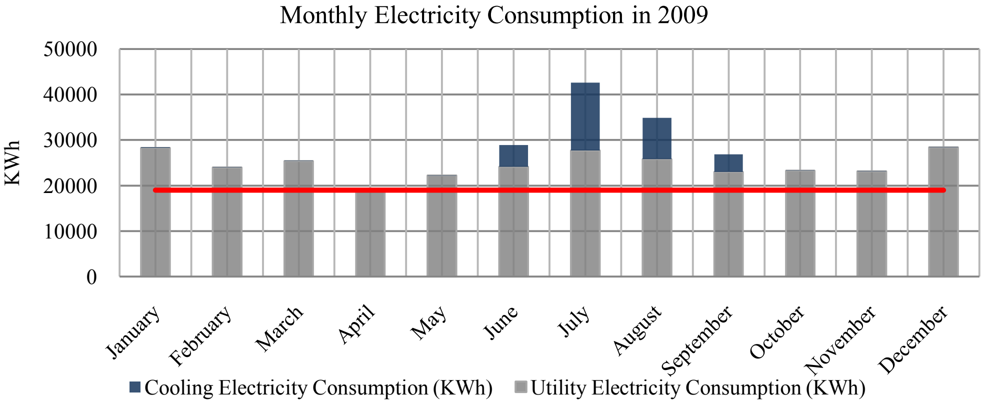


Figure 47. Monthly electricity consumption in 2009
(Source: OCW 2009)

According to the results from Figure 47, it is possible to make the following assumptions:

- Minimum electricity consumption is in April, with 18997 KWh, which can be accepted as a base value for all utilities such as lighting and equipment.
- Particularly for December-January and July-August, the excessive part of electricity consumed more than the assumed limit of 18997 KWh can be regarded as a sum of standalone heating and cooling appliances which function on utility electrical system and the electrical power to run the heating system.

The framework of above assumptions gives an annual consumption breakdown for utilities and cooling electricity consumption. Cooling energy consumption is the annual electricity consumption solely on room cooling and is assumed as the total value for the sum of cooling unit consumption and standalone coolers (Table 21).

Table 21. Monitored electricity consumption (utilities and cooling)

Monitored Electricity Consumption in 2009	
End Use	**kWh**
Utility Electricity Consumption	270132
Cooling Electricity Consumption	57282

Heating system functioned for 16 weeks (week 2-12 and week 48-52) during 2009. During 2009, fuel consumption is monitored by daily manual recordings and during 2010 the monitoring is conducted with flow meters installed to both of the boilers of the heating system. 2010 consumption data is collected to ensure the accuracy of 2009 consumption data. Additionally, daily data for boiler outlet water temperatures are obtained from the external weather compensation system (Figure 48). According to Figure 48 boiler temperatures respond to exterior temperature fluctuations. With lower exterior temperatures the boilers respond to higher heating temperatures.

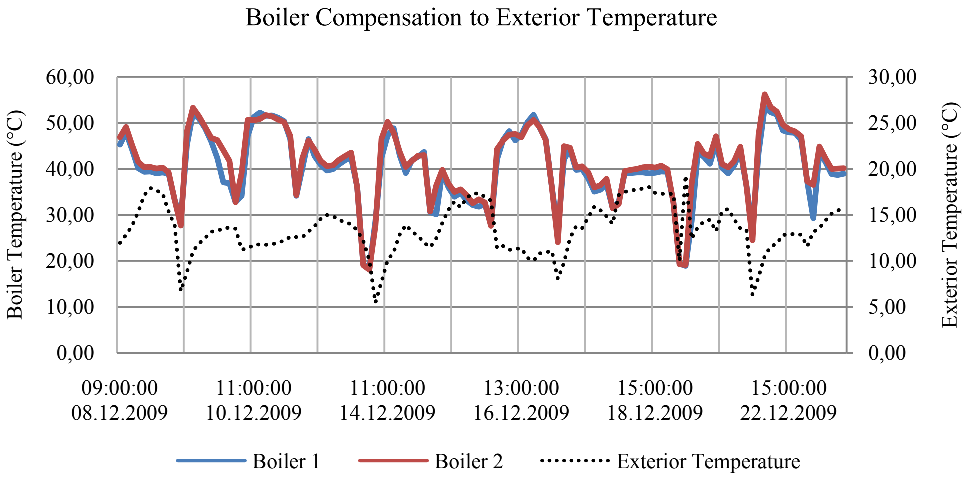


Figure 48. Boiler temperatures for exterior weather compensation

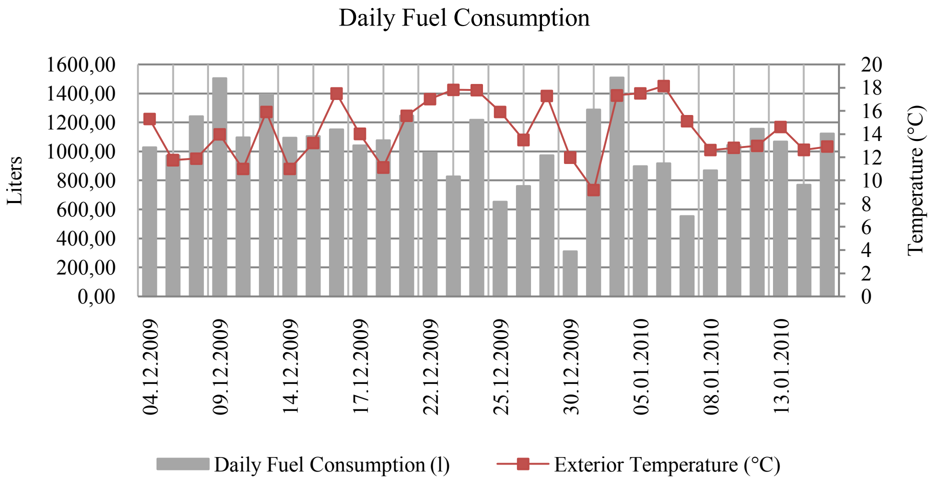


Figure 49. Fuel consumption of the case building during heating season 2009-2010

An exemplary correlation of daily fuel consumption to exterior temperatures can be seen in Figure 49, which presents the total daily fuel consumption, points out that even the external temperatures get higher the consumption pattern may not always result in a decreased amount. The reason for the inconsistency in the consumption pattern may depend on the following factors:

- Thermal lag of the building envelope: The envelope responds in a time lag to the exterior temperature changes. Therefore the occupants adjust the indoor thermostat settings to higher temperatures, which cause the heating system to switch off less; even the exterior temperature is high. Once the building is cooled down with the effect of external temperature it takes an amount of time for the thermal mass of the envelope components to balance their heat storage capacity (Manioglu & Yılmaz, 2006).

- Indoor surface temperatures: Since the U-value of the sections are high in the existing situation the indoor surface temperature differences for envelope components are relatively higher than any insulated mass wall system. Irradiative effects of indoor surface temperatures may cause occupant thermal discomfort which results in adjustment of thermostat controls of the heating system (Fanger, 1970).

These results indicate that fuel consumption and boiler compensation adjustments indicate that functioning and consumption pattern of the heating system is not only dependent on exterior temperature fluctuations, influence of building envelope and occupant perception is as well important on end use consumption.

To be able to make a high accuracy prediction for the heating consumption of the case building for 2009 heating season an artificial neural network model (ANN) is used to predict daily consumption from known boiler temperatures and exterior weather parameters (Güçyeter & Günaydın, 2010). The cumulative result of consumption can be seen in Table 22. These results are very close to the recorded purchase for fuel oil by OCW (2009).

Table 22. Monitored fuel consumption in 2009

Monitored Fuel Consumption in 2009	
Months	**kWh**
January	29823
February	27388
March	22815
December	25533
Total	105559

3.1.2.2. Energy Performance Simulation of the Case Building

EDSL Tas Building Energy Simulation program is used for the energy performance modeling of the case building. The program's validity is tested by the following authorities and pointed as an accurate simulation program:

- Dynamic Simulation Modeling (DSM) test based on based on "CIBSE TM33: 2006 - Test for software accreditation and verification"
- Building Energy and Environmental Modeling (BEEM) tests based on "CIBSE Applications Manual AM11: 1998 Building Energy and Environmental Modeling"
- HVAC equipment performance tests as required by ASHRAE 140-1 (2004).
- Compliance with EN ISO 13791 "Thermal performance of buildings -- Calculation of internal temperatures of a room in summer without mechanical cooling -- General criteria and validation procedures" (EDSL, 2009).

The software is a response factor based dynamic simulation tool, with a 3D design interface, databases on thermo physical properties of building elements, weather data, building schedules.

Time-step length of the calculations is hourly and offers a preconditioning time for the building simulation to include the thermal mass effect to the first simulation day. The program includes external solar radiation with separate treatment of direct and diffuse and internal solar distribution is calculated for each time-step during the simulation of the model.

For internal surfaces, the software uses separate convection and radiation networks, rather than combined convection and radiation coefficients, which helps to assess heat exchange between surfaces and the enclosed air. Additionally, external convection coefficients are calculated according to wind speed and temperature data at each time-step.

Heating and cooling load calculations, annual energy demand, hourly indoor temperature, humidity and surface temperature profiles, natural and mixed mode ventilation requirements, and daylight analysis are outputs of the EDSL Tas software.

The software has different interfaces to complete the energy performance analysis and a macro tool to assess parameters and/or systems such as plant sizing and thermal comfort etc. The composition of the simulation model for the case building is explained along to these interfaces in this section.

In 3D Modeler interface of EDSL Tas, the case building is modeled according to the following main considerations:

- Definition of general building features: Latitude, longitude, orientation, and close environmental attributes defined in section 3.1.1.1.
- Definition of building elements and characteristics depending on their architectural features: Exterior walls, interior walls, floors, roof and glazed areas are identified in the 3D model with respect to their major characteristics that are effective on building energy performance. For instance the exterior walls are defined in two different characteristics to represent exterior clinker brick walls and exterior reinforced concrete walls. The differentiation of exterior walls can be seen in Figure 50.
- Definition of zones in the case building: In general, zoning of the building for thermal performance analysis is planned according to their similarities in heating and cooling profiles. The number of zones defined in the simulation model is parallel to the actual divisions of the building, since a comparison of monitoring and simulation data is conducted in this study. The final 3D model for performance simulation is completed with 104 individual zones.

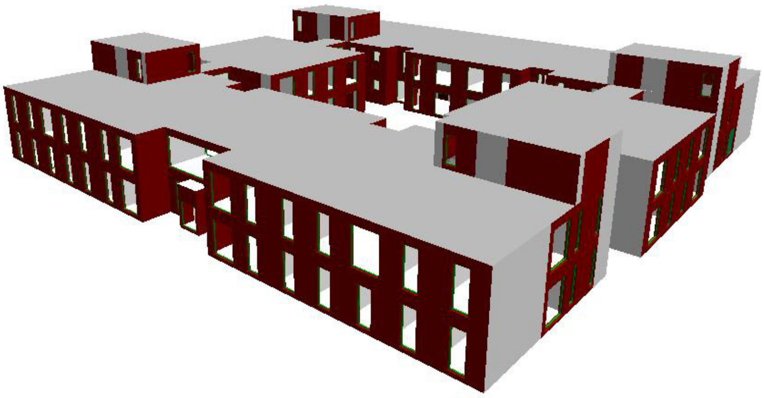


Figure 50. 3D model of the case building in EDSL Tas 3D Modeler

The second and the main interface of EDSL Tas is the Building Simulator, where all attributes in relation with energy performance are identified. These attributes can briefly be summarized as follows:

- Calendar: This module in the interface is concerned with defining the calendar for a whole year that the dynamic simulation is run. The calendar specifies the day type for every day of the year, for utilization in scheduling conditioning, internal conditions, air flow rates, etc. The day types defined for the case building can be listed as: Weekday/Workday, Weekday/Schooldays, Saturday, Sunday, Public Holidays. All day types present different characteristics, for instance Weekday/Schooldays covers Weekday/Workday as office work continues, and additionally helps to define the days in a year when students are occupying the case building (EDSL, 2009).
- Weather Data: For the case building location, the monitored weather data is incorporated in the software by weather data module. Weather data contains for whole year hourly information on parameters in Table 23. Existing monitored weather data from the campus is converted as an appropriate set of data and entered to the weather database of the software in a tabular format, with hourly average values (EDSL, 2009).

Table 23. Weather data parameters for EDSL Tas

Hourly weather variables	Details
Global Radiation (W/m2)	Total solar radiation intensity on a horizontal plane.
Diffuse Radiation (W/m2)	Diffuse sky radiation intensity on a horizontal plane.
Cloud Cover (0-1)	A number varying from 0 for a clear sky to 1 for overcast conditions. This quantity is used to estimate long-wave sky radiation during simulation.
Dry Bulb Temp. (C)	The dry-bulb temperature as measured in a Stephenson screen.
Relative Humidity (%)	The relative humidity as measured in a Stephenson screen.
Wind Speed (m/s)	The wind speed measured at a height of 10 meters above the ground
Wind Direction (°-Clockwise)	The direction from which the wind blows (degrees clockwise of north).

- Constructions: In setting up the 3D model, building elements were assigned as walls, floors and ceilings. In Building Simulator application, constructions are applied to these pre-set building elements. Constructions define the material composition and thermal properties and are retrieved from the building element compositions in section 3.1.1.2 (EDSL, 2009).
- Schedules: Schedules are set up to control the timing of the occupancy, internal gains, thermostat values, aperture types (for instance, opening and closing period of a window), ventilation regimes etc. In EDSL Tas, schedules are designed as a time-series of 0's and 1's, one value for each hour of the day. The value 0 denotes that certain gain, loss or regime do not contribute/effect the energy balance of an indoor space, simply they do not function. On the contrary, the value 1 denotes that in an indoor space a certain gain, loss or regime do exist and contribute the energy balance of the indoor environment (EDSL, 2009). An example schedule used in the simulation model can be seen in Table 24.

Table 24. Schedule examples used in EDSL Tas building simulation

Schedule Name	**Office Hours**	**Classroom Hours**	**Unoccupied Hours**	**24 Hours**
Hour				
0-1	0	0	1	1
1-2	0	0	1	1
2-3	0	0	1	1
3-4	0	0	1	1
4-5	0	0	1	1
5-6	0	0	1	1
6-7	0	0	1	1
7-8	0	0	1	1
8-9	1	1	0	1
9-10	1	1	0	1
10-11	1	1	0	1
11-12	1	1	0	1
12-13	1	0	0	1
13-14	1	1	0	1
14-15	1	1	0	1
15-16	1	1	0	1
16-17	1	1	0	1
17-18	1	1	0	1
18-19	0	0	1	1
19-20	0	0	1	1
20-21	0	0	1	1
21-22	0	0	1	1
22-23	0	0	1	1
23-24	0	0	1	1

- Internal Conditions: In the internal conditions module, energy gains and losses within a zone are described. Additionally specification of environmental control with thermostat settings and emitter characteristics, infiltration and ventilation are controlled in this module (EDSL, 2009). Table 25 presents several parameters used for internal conditions in modeling the case building. Varying thermostat control ranges are applied to different zones as a result of monitoring. Thermostat control ranges differ between 20°C (±2) to 22°C (±2) for heating period and 24 (±2) to 26 (±2) for cooling period. The building is considered as a building with low air-leakage, with infiltration rates differing between 0,2 to 0,3 ach. Lighting gains vary between 2 and 8 W/m2 according to the function of the space. Lighting schedules and durations vary as well, depending on spatial function. Equipment gains are assumed due to the present equipment density in each space.

Table 25. Internal condition parameters applied for EDSL Tas model

Internal Conditions			
		Set points (°C)	
		Heating (Min)	Cooling (Max)
Thermostat Control	Offices	22 (±2)	24 (±2)
	Classroom	22 (±2)	24 (±2)
	Laboratories	20 (±2)	24 (±2)
	Circulation	20 (±2)	26 (±2)
Infiltration		Rate (ach)	
		0,2 - 0,3	
Lighting		Gain (w/m^2)	
		2-8	
Occupancy		Metabolic Rate (W/person)	
		120	
Equipment		Variable	

Major parameters in building energy simulation are summarized above. Subsequent to application of these parameters, the building simulation is run in the Building Simulation interface of the software. Third interface of the software is the Results Viewer, in which the hourly dynamic simulation results are stored. The interface allows to create different output sets with the results, such as indoor temperatures (dry bulb, radiant and resultant), indoor relative humidity, sensible loads, latent loads, and different surface filters (interior and exterior surface temperatures, amount of solar radiation on envelope surfaces etc.) (EDSL, 2009).

Simulation data stored in the Results Viewer interface can further be processed in Excel macros to explore certain sets of results and present them in tabular or graphical formats or to carry out further calculations. Annual loads, indoor temperature frequencies, thermal comfort (PMV &PPD), peak loads, and plant sizing and simulation are the important macros embedded in the software.

The simulation results can be briefly summarized in this section to point out that the tool is applicable for an evaluation, and necessary steps to complete this evaluation are executed.

1) Evaluation of Simulated Indoor Temperature Profiles:

Similar to monitoring results, a simple analysis of hours outside comfort range can be presented for the spaces that are monitored. The total annual occupancy hours (2520) and comfort ranges are evaluated with the identical approach for monitoring evaluation.

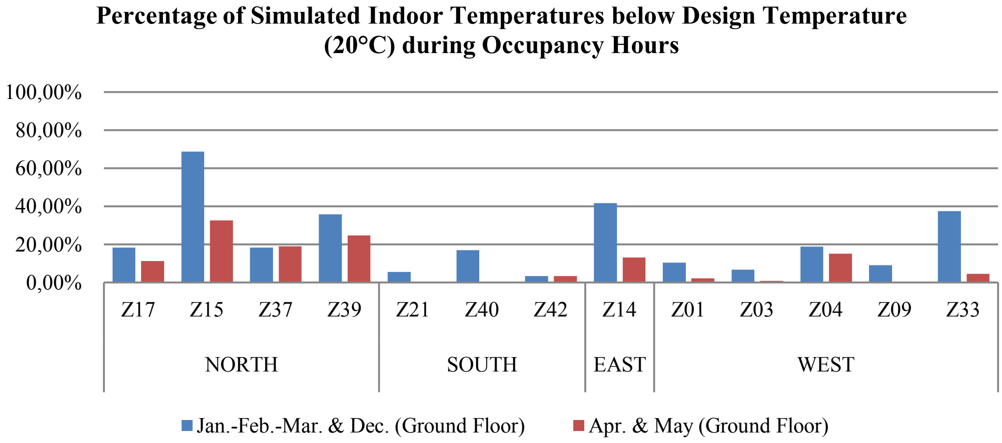


Figure 51. Ground floor – Percentage of simulated indoor temperatures below design temperature (20°C) during occupancy hours

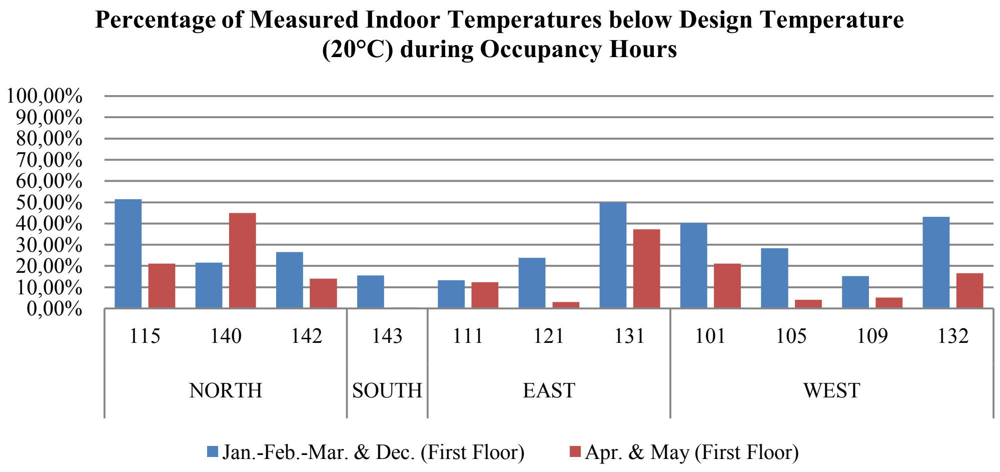


Figure 52. First floor – Percentage of simulated indoor temperatures below design temperature (20°C) during occupancy hours

Simulation results for ground floor indicate that north oriented spaces have significant percentage of hours (35 %) outside comfort range during heating season. For the months April and May, percentage of hours outside comfort range is higher for north oriented spaces than spaces on other directions (Figure 51). First floor percentages of simulated indoor temperatures below comfort range can be seen in Figure 52. Average percentages for north, south, east and west oriented spaces are respectively 33%, 16%, 29 and 32%.

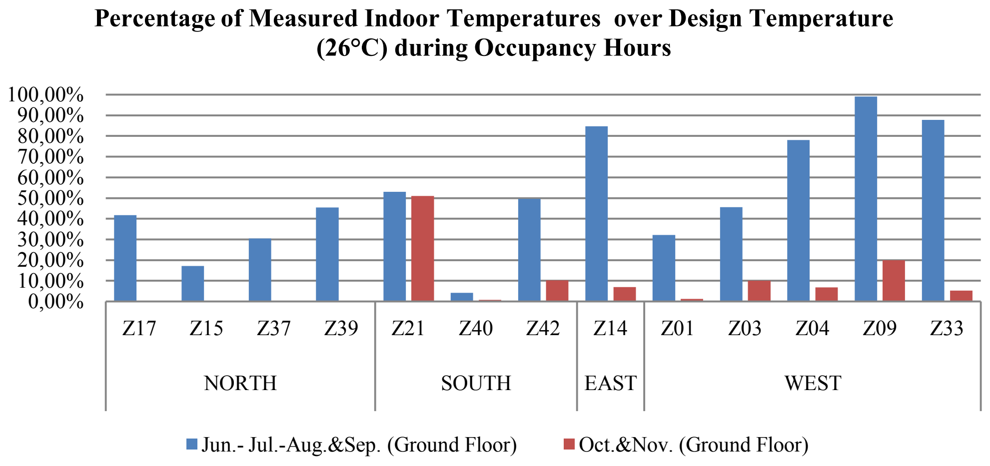


Figure 53. Ground floor – Percentage of simulated indoor temperatures over design temperature (26°C) during occupancy hours

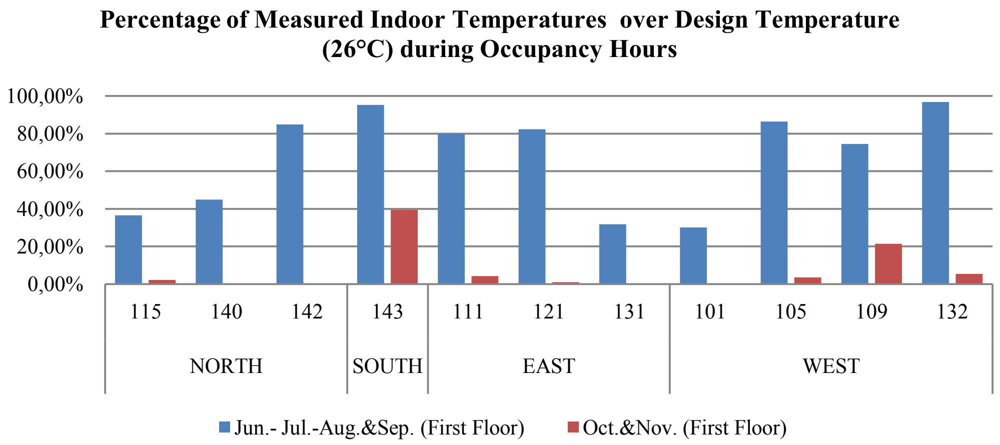


Figure 54. First floor – Percentage of simulated indoor temperatures over design temperature (26°C) during occupancy hours

In Figure 53 and Figure 54cooling period analysis for percentage of simulated indoor temperatures over design temperatures are presented. For both storeys there is high level of hours over design temperature of the building. Average percentage of hours exceeding design temperatures for ground floor is approximately 50 % and for first floor the average is around 68 % which are relatively high. Further evaluations for simulation results and comparisons of simulation data with monitoring data are accessible in section 3.1.2.4.

2) Evaluation of Simulated Indoor Response to Outdoor:

The evaluation of simulation data for indoor environment parameter response to outdoor fluctuations (temperature and relative humidity) is presented with a similar manner to monitoring results.

Simulated fluctuations of indoor temperature and humidity for two identical north oriented spaces in occupancy and volume in January 2009 is presented in Figure 55. The results present similar fluctuations to monitoring data, and indoor temperature and relative humidity profiles for space 142 (first floor) is higher than Z15.

The graph in Figure 56 indicates simulation results from two sample spaces with same volume and occupancy and covers July 2009 with cooling system functioning in both spaces. Simulation results provide very similar trends for temperature and relative humidity fluctuations where in monitoring there are certain deviations for the analysis of same spaces and periods. The reason of this deviance between measurement and simulation can be interpreted as an effect of difference in occupancy tendencies related to thermal comfort.

In Figure 57 (p.96), simulated indoor temperature and humidity values of two west oriented spaces (Z09 and 109) are presented according to outdoor fluctuations. Both spaces have very close trends and fluctuations in response to exterior climate.

During July 2009, Z09 and 109 have minor fluctuations for temperature and humidity, due to outdoor parameters. 109 have higher indoor temperature trend compared to Z09. The effect of south facing reinforced concrete and overheating from the roof surface is dominant in this higher indoor temperature profile (Figure 58, p.97).

The similarity of simulation results support the findings drawn from monitoring results, hence an additional point of concern arises, which is the effect of changes in occupancy and occupant control may cause distinctions between measured and simulated results. This concern is one of the important aspects, which necessitate calibration of the simulation model, which is explained in further sections.

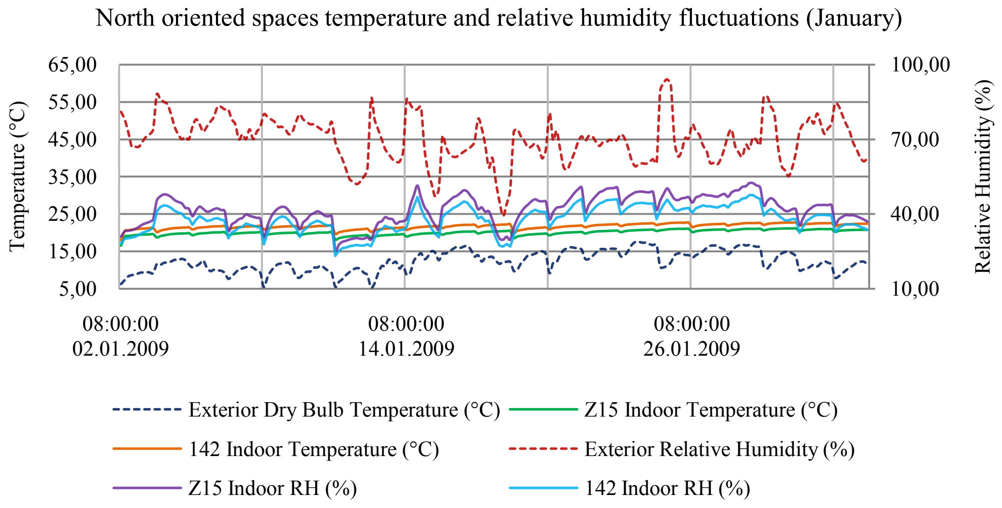


Figure 55. North oriented spaces temperature and relative humidity fluctuations (January-simulation data)

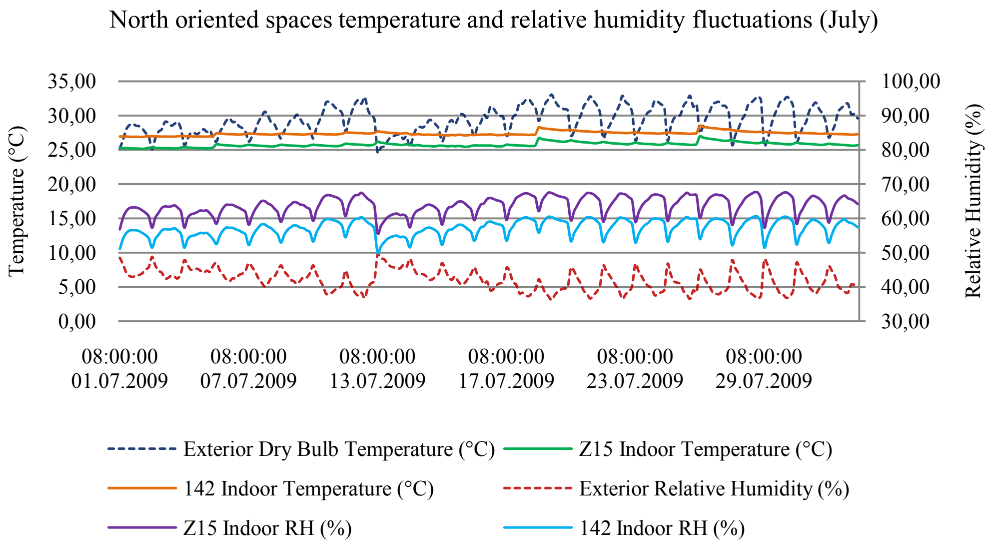


Figure 56. North oriented spaces temperature and relative humidity fluctuations (July-simulation data)

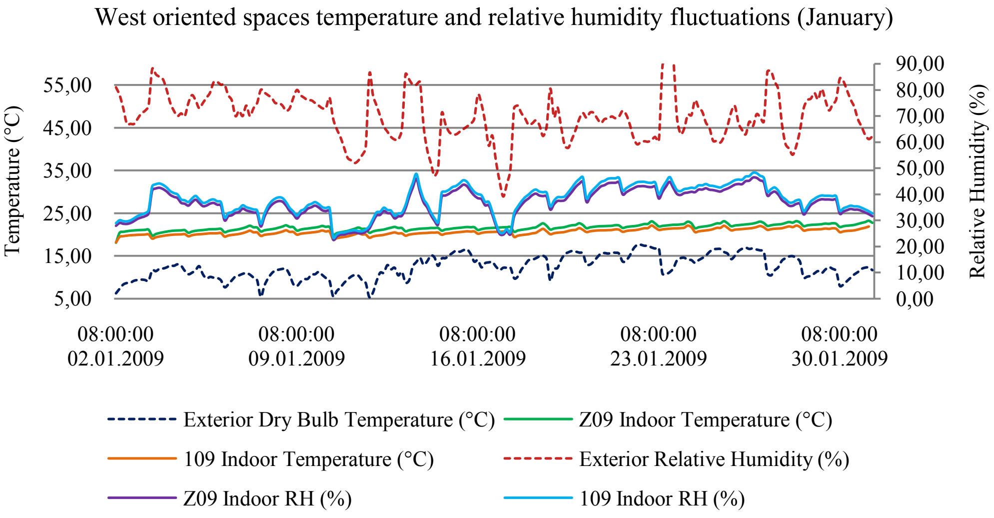


Figure 57. West oriented spaces temperature and relative humidity fluctuations (January-simulated temperatures)

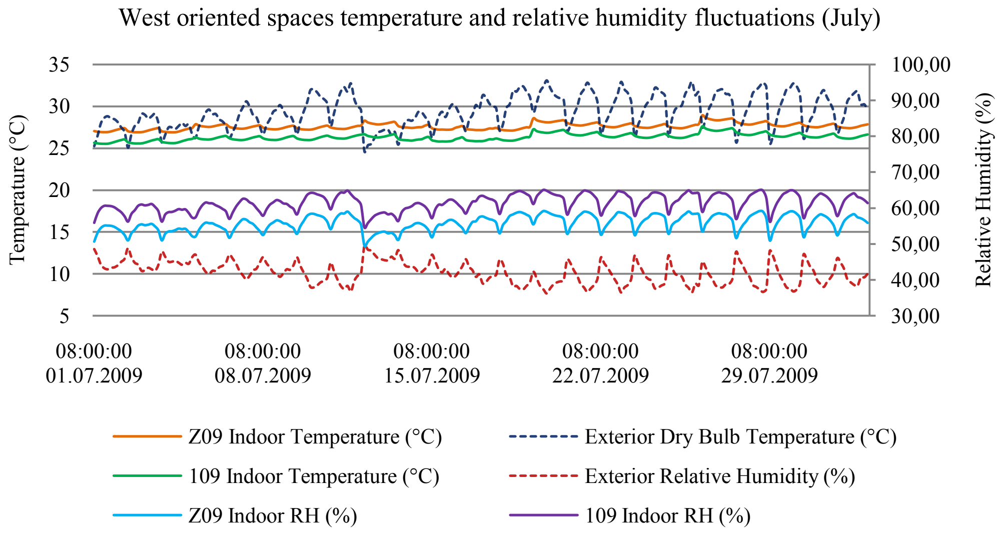


Figure 58. West oriented spaces temperature and relative humidity fluctuations (July-simulated temperatures)

3) Evaluation of Simulated Energy Consumption:

In order to investigate average consumption patterns of the building, it is necessary to evaluate the annual loads and energy consumption of the building through the results of the calibrated (explained in 3.1.2.4) base case (existing situation) simulation model. Different macros are defined in the software as mentioned earlier in this section. Two of these macros are used to determine the loads and consumption, first annual loads macro is used to find the total loads for case building simulation on a yearly, monthly, daily or hourly basis. Figure 59 presents the existing case annual results for year 2009. Cooling demand is the higher demand (145981 kWh), in response to the local climatic characteristic of the area. Heating demand is around 125963 kWh and the other end use demands are predicted as in the figure. Moreover, monthly load breakdown for heating and cooling can be seen in Figure 60.

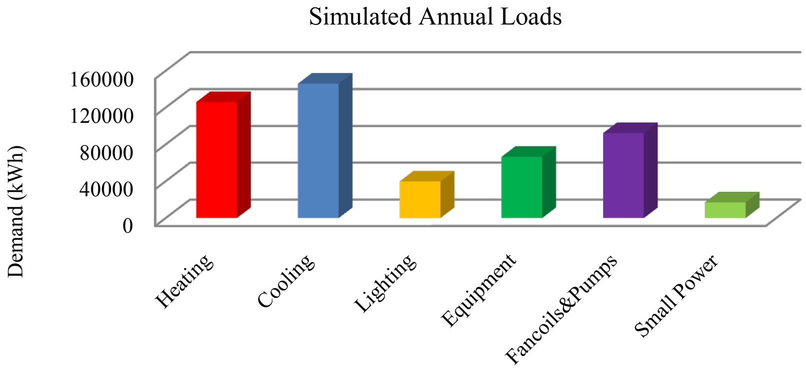


Figure 59. Simulated annual loads

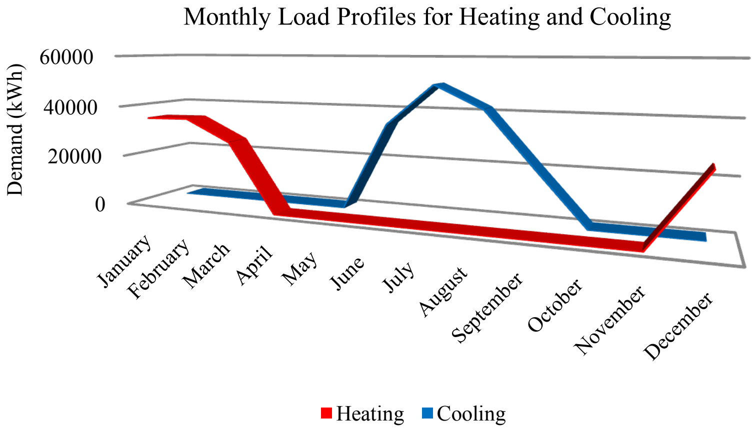


Figure 60. Simulated monthly loads for heating and cooling

Second macro used for evaluations is plant sizing and simulation. As it is recognized that to predict the energy consumption, it is necessary to model the installation systems to evaluate their consumption to compensate this simulated demand. Modeling existing heating and cooling installations and air handling unit require the installation system characteristics (section 3.1.1.3) and their efficiencies. The efficiency of heating system is measured during monitoring and the cooling system COP (coefficient of performance) is calculated from the system data sheets. In plant sizing and simulation macro, it is necessary to supply the macro with information on conditioned and unconditioned spaces, simulated hourly data for these spaces, ventilation systems and regimes if exists, and the specifications on installation systems. These specifications are summarized in Table 26.

Table 26. Installation system characteristics used in plant simulation

		Installation System Specifications		
		Efficiency (%)	**Capacity of Total (%)**	**Distribution Efficiency (%)**
Heating System	**Boiler 1**	87,00	60,00	90,00
	Boiler 2	84,00	40,00	
Cooling System		**COP (%)**	**Capacity of Total (%)**	**Distribution Efficiency (%)**
		2,3	100,00	95,00

In addition to annual, monthly and/or hourly consumption parameters, plant simulation macro provides results such as CO_2 emissions, consumption breakdown, and cost if unit prices for energy sources are given.

Monthly consumption results obtained from are presented in Figure 61. It is noticeable that there is a certain deviation for electricity consumption/cooling demand rendition (Figure 60). This deviation originates from the performance of the cooling system COP and distribution efficiency, which results in lower electricity consumption in kWh when compared to annual demand for cooling.

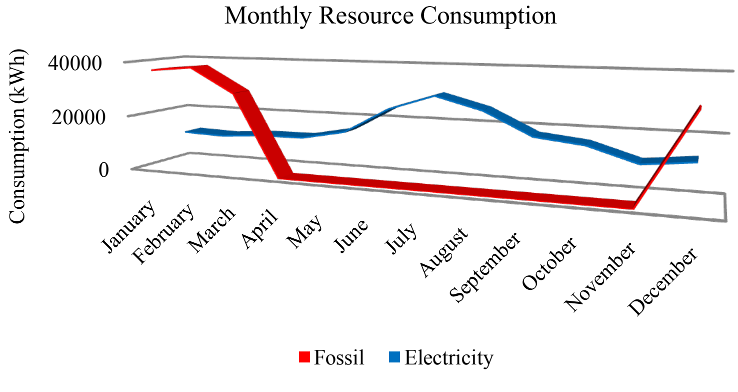


Figure 61. Simulated monthly resource consumption

Figure 62 presents the annual energy consumption breakdown in kilowatt-hours according to the space conditioning, lighting and installation end uses. Space heating and system fans (AHU and ceiling type fan coils) have the first two larger shares, respectively 113768 kWh (%31,54) and 84883kWh (%23,54). Space cooling has the third largest share with 52129 kWh (%14,45). The total annual energy consumption for the above end uses is 360659 kWh, which results in 32,56 kWh/m3 and 105,63 kWh/m2 for the conditioned space and volume of the case building.

In Figure 63, CO_2 emissions by energy end use breakdown are available in $kgCO_2$. Total annual emission of the building is 126,2 $tonCO_2$. System fans, space heating and space cooling has the largest shares, respectively 35,8 $tonCO_2$ (%28,39), 30,1 $tonCO_2$ (%23,89), and 22,0 $tonCO_2$ (%17,43).

General results of the energy performance simulation results for the case building is summarized and in section 3.1.2.4 these results are compared to monitoring data comprehensively.

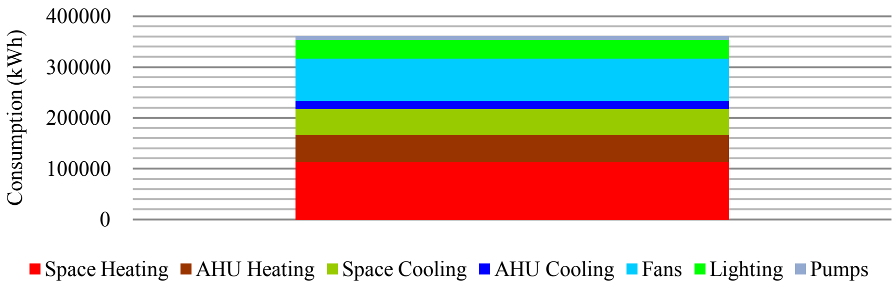


Figure 62. Simulated annual energy consumption breakdown

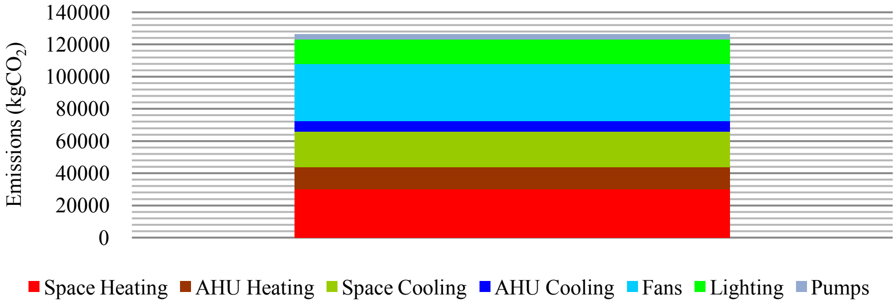


Figure 63. Simulated annual CO_2 emissions

3.1.2.3. Energy Performance Evaluation of the Case Building According to TS 825

The calculations for the case building according to TS 825 – Thermal Insulation in Buildings (2008) are completed to obtain the existing buildings energy performance evaluation according to this standard. The calculation methodology of the standard is in monthly time-steps and the building is processed as a single volume in these calculations. The results denote only the annual heating load of the building as a performance measure, hence ignores the cooling loads.

The standard defines four climatic zones in Turkey, with different levels of annual heating load requirements and U-values. Izmir is in the first zone, with a Mediterranean climate, where hot and humid summers and cool winters are typical characteristics. TS 825 accept degree-day method and uses solar radiation and exterior temperature from reference year weather data according to these climatic regions. Following evaluation according to TS 825 is subject to the requirements of the first climatic zone (TS 825, 2008). Necessary parameters for TS 825 calculation can be listed as follows:

1) Area to Volume Ratio (A/V):

This ratio is the main decision factor of TS 825 in defining the benchmark energy demand levels a building may require. The surface area of the volumes exposed to exterior space or unheated volumes are accepted as the heat loss surfaces and the area in this ratio is defined by the total area of these surfaces. Volume of the building refers to the total heated volume. The ratio A/V is used to assess the maximum annual heating load in units of kWh/m^2 or kWh/m^3. The difference of units originates from the net floor height. In cases where floor height do not exceed 2,60 meters, heating load is calculated according to the heated floor area of the building and in cases where the net floor height exceeds this limit the calculation is done according to heated volume of the building. In our specific case, net floor height is 3,60 meters therefore the annual heating load is calculated in units of kWh/m^3. A/V ratio calculation is 0,61 m^{-1} for the case building, given the following parameters in Table 27.

Table 27. Parameters for heated spaces in the case building

Parameters of the case building	
Heat Loss Surface Area (A, m²)	6743,19
Heated Floor Area (m^2)	3414,24
Heated Volume (V, m^3)	11075,56
A/V (m^{-1})	0,61

2) Calculation Design Parameters:

This set of parameters include the indication of climatic zone, type of building for indoor set temperatures, air change rate (for case building ventilation system parameters), and definition of internal gains as normal or high. Table 28 indicates these design parameters for the case building. All parameters are assumptions of TS 825 according to classification of climatic considerations, building types and regulations.

Table 28. TS 825 Calculation design parameters

Calculation Design Parameters for TS 825	
Climatic Region	1
Indoor Design Temperature (°C)	22
Air change rate per hour (n_h)	0,8
Internal Gains	Normal (for schools, office buildings)

3) Building envelope characteristics:

Building envelope characteristics are defined on component level (wall, roof, glazing etc.) with U-value parameters and heat loss surface area exposed to exterior and unheated volumes. Table 29 presents the calculations for building envelope components adjacent to unheated volumes, thus subject to heat loss. Additionally, to assess the overall heat loss of the building ventilation heat losses are calculated and included in the total heat loss of the building.

Table 29. U-values and heat loss surface area for building envelope components.

Building Envelope Component	**Existing U-value (W/m²K)**	**Limit U-value (W/m²K)**	**Heat Loss Surface Area (A, m²)**	**Heat Loss (AxU or 0,5xAxU, W/K)**
Exterior Double Layer Clinker Brick Wall	1,531	0,700	728,42	1115,21
Exterior Reinforced Concrete Wall	2,418	0,700	811,76	1962,84
Concrete Floor on Ground	1,059	0,700	1508,00	798,49
Flat Roof	0,447	0,450	1906,00	851,98
Glazing	3,000	0,450	703,81	2111,43
Interior Wall in Contact with Unheated Volume	0,923		718,20	331,45
Interior Floor in Contact with Unheated Volume	1,370		420,3	287,91
Envelope Losses (H_T, Total)				7459,30
Ventilation Losses (H_v=0,33. n_h.V_h, (Total)				3095,25
Total Losses				10554,55

4) Glazing Area, Orientation and Solar Gains:

Solar gains are calculated for the case building according to the parameters in Table 30.

Table 30. Glazing characteristics according to the orientation of heated volumes

Glazing Area for Heated Volumes (m²)		**Shading Coefficient (r_i)**	**Solar Transmission Factor (g-value)**
North Total	198,16	0,85	0,75
South Total	200,68	0,85	0,75
East Total	94,13	0,85	0,75
West Total	210,84	0,85	0,75

According to the above defined parameters, monthly heating load can be calculated via Table 31. The equations and parameters in the calculation procedure are explained in the relevant order.

Table 31. Heating load calculation of the case building by TS 825

Months	Heat Loss			Heat Gain			Monthly Gain/Loss Ratio	Gain Utilization Factor	Heating Load
	Specific Heat Loss	Temperature Difference	Heat Losses	Internal Gains	Solar Gains	Total Gains			
	$H=H_T+H_V$ (W/K)	$(\Theta_i - \Theta_e)$ (K,°C)	$H(\Theta_i - \Theta_e)$ (W)	ϕ_i (W)	ϕ_s (W)	$\phi_T = \phi_i + \phi_s$ (W)	$\gamma = \frac{(\phi_{i,m} + \phi_{s,m})}{H \times (\Theta_{i,m} - \Theta_{d,m})}$	$\eta_m = 1 - e^{(-1/\gamma_m)}$	$Q_m = \begin{bmatrix} H(\Theta_i - \Theta_e) \\ -\eta_m(\phi_{i,m} + \phi_{s,m}) \end{bmatrix} \times t$ (kJ)
January	10554,55	11,30	119306	17720	15547	33267	0,28	0,96	150.975.398
February		12,39	130764		19759	37479	0,29	0,94	165.081.887
March		10,54	111237		24341	42061	0,38	0,85	130.438.606
April		0,00	0		27845	45565	0,00	0,00	0
May		0,00	0		32691	50411	0,00	0,00	0
June		0,00	0		34498	52218	0,00	0,00	0
July		0,00	0		33547	51267	0,00	0,00	0
August		0,00	0		31070	48790	0,00	0,00	0
September		0,00	0		25592	43312	0,00	0,00	0
October		0,00	0		20145	37865	0,00	0,00	0
November		7,15	75418		14885	32605	0,43	0,86	0
December		8,74	92281		13538	31258	0,34	0,96	107.607.594
								$Q_{annual}=\sum Q_m$	554.103.485

The first column value specific heat loss (H) is the value calculated in Table 29. It is a sum of envelope and ventilation losses and accepted as a monthly value for total heat loss of the building. The second column contains the average temperature differences for the climatic zone of Izmir. The values are given for each climatic zone in the Appendix 2 in TS 825. The third column calculates the monthly heat losses according to the given indoor outdoor temperature difference with the equation 3.5.

$$Q_{loss,m} = H(\Theta_i - \Theta_e) \quad (W) \quad (3.5)$$

For this study, the climatic parameters are accepted as the monitoring year data, 2009. Monthly average temperatures (°C) for 2009 are used for the calculation, to be able to make further comparisons between different calculation methodologies and monitoring data. Figure 64 presents the trend of monthly average temperatures between monitoring year and present meteorological data for the case area. It can be observed that 2009 monthly average temperatures slightly differ from the five year averages of the climatic data. Additionally, it is possible to assert that 2009 winter is a milder season when compared to the five year averages, and will be evaluated in further steps of the research.

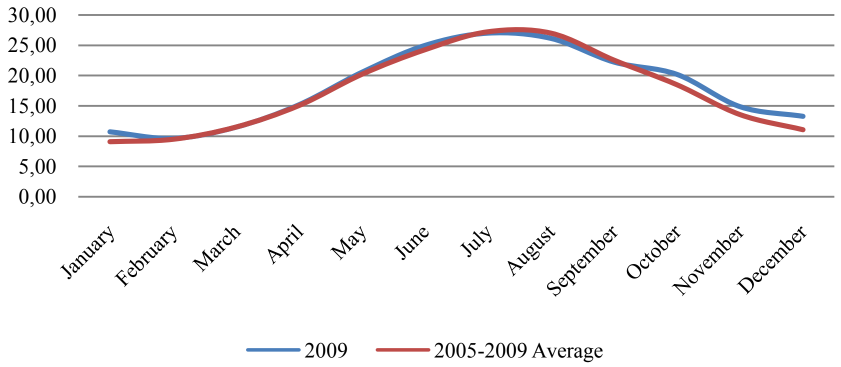


Figure 64. Monthly average temperatures for 2009 and 2005-2009 averages

Internal gains are calculated with a postulation in TS 825. There is an assumption for a “normal level” of internal gains (schools, office buildings, residential buildings are defined as spaces with normal level of internal gains) for the case building therefore equation 3.6 is used to calculate internal gains, where, ϕ_i is the internal gains and A_n is the floor area which equals to 0,32*V_{heated}.

$$\phi_i \leq 5 \times A_n \qquad (W) \qquad (3.6)$$

For the calculation of solar gains, the standard proposes average horizontal solar radiation values (W/m²) of all directions for the climatic zone of the building. Equation 3.7 is used for the calculation of solar gains, where; $\phi_{s,m}$ *is the* monthly solar gain, $r_{i,m}$ is the shading coefficient of the glazing in direction i, $g_{i,m}$ is the solar transmission factor of the glazing in direction i, $I_{i,m}$ is the average horizontal monthly solar radiation from direction i, $A_{glazing}$ is the total glazing area on direction i.

$$\phi_{s,m} = \sum r_{i,m} \times g_{i,m} \times I_{i,m} \times A_{glazing} \qquad (W) \qquad (3.7)$$

The values for shading, transmission coefficients are selected from the range the standard offers, according to the specific characteristics of the building. Finally, in the sixth column monthly gains are calculated by addition of monthly internal gains and solar gains. Monthly gain loss ratio is calculated in the seventh column, with equation 3.8, where; γ is the monthly gain/loss ratio, $\phi_{i,m}$ is the monthly internal gains, $\phi_{s,m}$ is the monthly solar gains, H is the total losses, $\Theta_{i,m}$ is the monthly average indoor temperature, $\Theta_{d,m}$ is the monthly average outdoor temperature. If this ratio is equal to or larger than 2,50, no heating load calculation is done for that month.

$$\gamma = \frac{(\phi_{i,m} + \phi_{s,m})}{H \times (\Theta_{i,m} - \Theta_{d,m})} \qquad (-) \qquad (3.8)$$

In the eighth column gain utilization factor is calculated with equation 3.9, where; η_m is the gain utilization factor and γ_m is the monthly gain/loss ratio. The necessity to use this factor is to render the effect of solar and internal gains since these gains might vary dependent on different factors.

$$\eta_m = 1 - e^{(-1/\gamma_m)} \qquad (-) \qquad (3.9)$$

In the last column total monthly heating load is calculated by equation 3.10. The gains are subtracted from the losses to retrieve the necessary heat load in one second and then multiplied with 86400 seconds and 22 days. The weekends are eliminated from the calculation since the building is not utilized in the weekends.

$$Q_m = \left[H(\Theta_i - \Theta_e) - \eta_m(\phi_{i,m} + \phi_{s,m})\right] \times t \qquad (kJ) \quad (3.10)$$

As a result the annual heating load for the building is calculated as 554.103.485 kJ. The next step after this calculation is to check the heating load result to the requirement of the standard. Since the floor height in the building is larger than 2,60, volumetric assessment is applied for the case building. Calculated annual heating load is converted to kilo-watt hours, and is 154.041 kWh. Equation 3.11 is the volumetric ratio of this annual heating load.

$$Q = \frac{Q_{annual}}{V_{heated}} \qquad (kWh/m^3) \quad (3.11)$$

The result yields a value of 13,91 kWh/m³ for the case building. However, if the limit value is calculated according to the first climatic zone by equation 3.12, the result yields a lower limit. The limit for this building is 11 kWh/m³.

$$Q_{design} = (14{,}1 \times \frac{A}{V}) + 3{,}4 \qquad (kWh/m3,year) \quad (3.12)$$

The standard defines an energy efficiency index for buildings according to this limit value when following energy levels are fulfilled:

- C Type – Standard Building $(Q_{annual} \leq 0{,}99 \times Q_{design})$ = 10,89 kWh/m^3,year

- B Type – Energy-efficient Building $(Q_{annual} \leq 0{,}90 \times Q_{design}) = 9{,}90$ kWh/m^3,year
- A Type – Low Energy Building $(Q_{annual} \leq 0{,}80 \times Q_{design}) = 8{,}80$ kWh/m^3,year

As a result following conclusions are drawn from the evaluation of energy performance analysis of the case building:

- The exterior heat loss surfaces of the building have higher U-values than the limit values proposed by the standard, therefore there is a necessity of improvement of thermal transmission coefficients in the building envelope.
- Interior surface temperature and indoor temperature differences are more than 3°C for external double layer brick walls, external reinforced concrete walls, and for concrete floor on ground in winter months. The temperature differences should be less than 3°C to limit irradiative effects of the interior surface temperatures
- Figure 65 presents the calculated heat loss from building envelope. Exterior concrete walls, concrete floor on ground, glazing elements and exterior double layer clinker brick wall are the major heat loss surfaces in the case building.

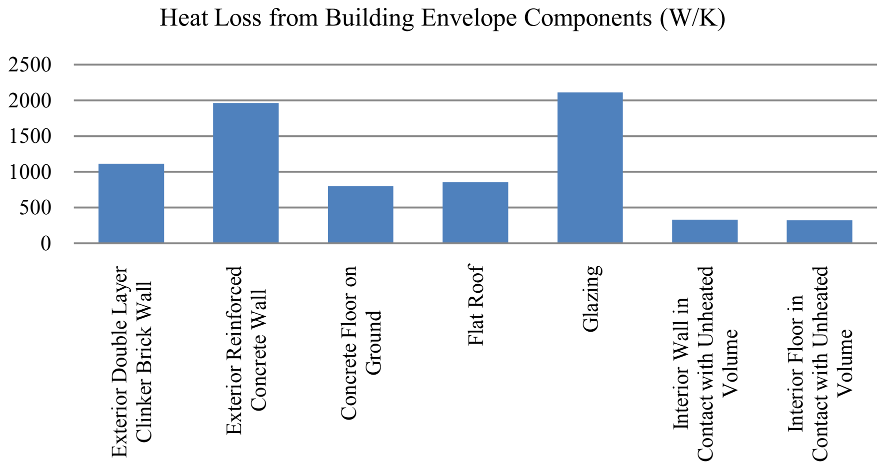


Figure 65. Calculated heat loss from building envelope components

3.1.2.4. Comparison and Definition of the Error Margins between Analysis Tools

Energy performance of an existing building can be evaluated via different tools as utilized in the previous three sections. However, every evaluation tool has a level of inaccuracy since energy performance is a complicated physical process between the existing building characteristics (envelope, orientation etc.), environmental effects (climate, shading etc.), and occupancy patterns. Therefore it is possible to assert that evaluation tools may predict the reality with different levels of accuracy, since it is challenging to replicate the real context that the existing building responds to all environmental and occupancy factors (Pan, Huang, Wu, & Chen, 2006). Decision on which tool is more appropriate depends on strength of the tool to interpret various inputs, and translation of these input information into a reliable set of output data. Since decision on the most appropriate tool depends on comparison, specific to this study, it is necessary to make essential adjustments to be able to compare results of these tools. Applied adjustments to evaluation tools are explained in this section in detail.

In this part of the study, main concern is to determine the energy performance evaluation tool and expected error margin for this tool. The reason behind this concern is based on the thesis methodology, to accurately evaluate proposed retrofitting strategies with a specific evaluation tool. Therefore, the following sub-sections cover discussions on the accuracy of evaluation tools, simulation and analytical calculation. The discussions are based on statistical error analysis to have a common ground on comparison.

To be able to conduct reasonable comparisons for the evaluation tools, monitoring data is accepted as the base data set, which corresponds to the real energy performance respond for the case building. Section 3.1.2.1 explains the results of building energy monitoring in detail. Monitoring data is the main consistent data set in this study, since it is the assessment of the energy performance of the case building with a whole year building data documentation. All physical phenomena involved with energy performance takes place under the real influences of parameters, therefore it is possible to appraise that monitoring results represent the most accurate results. Adjustments applied to monitoring data involve only calibration of measurement equipment and integration of the accuracies (±) to the measurement data. Therefore monitoring data set is accepted as the base data set that as well qualifies the adjustments for the other evaluation tools. Only with this qualification characteristic of monitoring data, other evaluation tools can be adjusted to attain higher accuracies. In the following sub-sections, accuracy of simulation and calculation methods and final evaluation are presented.

3.1.2.4.1. Simulation Accuracy - Calibration

Existing situation of the case building is simulated with the building energy simulation software EDSL Tas v9.1 as introduced in section 3.1.2.2. Usually dynamic building energy simulation tools such as EDSL Tas yield results that deviate from the real conditions with an error margin depending on the algorithm of the software integrated as a calculation methodology and way of handling extensive parameter sets that affect the energy performance of a building in reality (Clarke, Strachan, & Pernot, 1993).

To define this error margin, comparison with the monitoring data becomes necessary. However it is essential to decrease this error margin to the extent that is possible, with a procedure which is addressed as calibration of a building energy simulation model. Various methods are applied for calibration of simulation models, ranging from monthly to hourly calibration methods, depending on the data retrieved from monitoring measurements. However, there is no absolutely defined calibration approach; hence there are methods to increase the accuracy of the model. These models are emphasized in different standards and research. The major standards that define calibration procedures and benchmarks are ASHRAE Guideline 14-2002 Measurement of Energy and Demand Savings (ASHRAE, 2002), International Performance Measurement & Verification Protocol - Concepts and Options for Determining Energy and Water Savings Volume I (IPMVP, 2001), and Measurement and Verification for Federal Energy Projects Version 3.0 (M&V, 2008).

According to the standards mentioned in the previous paragraph, computer simulation for energy performance assessment is a powerful tool, that allows to model the building and mechanical systems in order to predict building energy use both before (in existing situation) and after the application of ECMs (Energy conservation measures), retrofit measures. Precision of the model is ensured by using monitoring data to depict the existing situation and/or retrofitting measures. Therefore saving and cost estimations for retrofitting/conservation measures become available when precisely constructed simulation models constructed models are used (ASHRAE, 2002; IPMVP, 2001; M&V, 2008).

Calibration techniques are not specifically explained in these standards, since each simulation model may need to calibrate different data set/sets to achieve necessary levels of accuracy. Most common calibration procedures are hourly and monthly data calibration. Hourly/monthly end-use data are utilized to confirm the calibrated model consistency (ASHRAE, 2002). On the other hand calibration parameters are based on other operating data than the end-use. Calibration parameters may include indoor set point temperatures, occupancy, weather data, schedules and efficiencies for installations, ventilation, and infiltration (IPMVP, 2001; Bou-Saada, 1994).

In this study, employed calibration parameters can be listed as:

- Hourly indoor temperature data (8760 hourly monitored data)
- Schedules
- Infiltration rates (assumed)
- Ventilation rates (assumed)

Additionally, the steps in calibrating the simulation can be listed as follows:

- Integration of assumed parameters to the simulation model and run the hourly dynamic simulation.
- Examination of hourly simulation results, according to their level of accuracy for indoor space temperatures and relative humidity levels.
- Comparison of simulated energy consumption and demands with monitored monthly data.
- Revision of the calibration parameters in the first step according to the analyses conducted in steps two and three, to achieve predicted results reasonably close to monitored data (IPMVP, 2001; M&V, 2008).

According to the method with stated characteristics, the calibrated simulation model is assumed to be the closest interpretation of the actual behavior of a building, yet is expected to yield a certain range of error in the margins defined by ASHRAE 14-2002 (2002), IPMVP (2001) and M&V (2008). In this research main purpose of attaining best calibration for the simulation model is based on the concentration of the study on predicting further effects of proposed retrofitting measures in section 3.3.

As the base model was established it was recognized that there is large amount of discrepancy between indoor environment values for the monitored zones. To achieve the most accurate model re-calibration, the simulation model is run 13 times by changing one parameter at a time, with the purpose to obtain a coherent model between indoor environment and load/consumption data. The final model results are presented briefly in this section to point out the accuracy of the model.

The results for the calibrated model can be presented in two steps as the calibration method is set up. For the second step, hourly comparison of simulated indoor resultant temperature to monitored indoor temperatures results are presented in Table 32. All zones are evaluated with a full year hourly (8760 hours) comparison, investigating their correlation and hourly error. Correlation is a linear analysis aiming to simplify the level of hour to hour correspondence of simulated and measured temperatures without focusing on the error margins. Error analysis on the other hand, intends to check the deviation of simulated temperatures from monitoring data. Root mean square error (RMSE) and mean bias error (MBE) analyses are used to determine the error between simulated and measured hourly indoor temperatures. Equation 3.13 and 3.14 show the formulas for RMSE and MBE, where, N is the number of observations, T_{ma} is the average measured temperatures for N observations, T_s is the simulated hourly temperatures and T_m is the measured hourly temperatures.

$$RMSE = (\frac{100}{T_{ma}}) \times \left[\frac{1}{N} \times (\sum (T_s - T_m)^2 \right]^{0,5} \qquad (\%) \quad (3.13)$$

$$MBE = (\frac{100}{T_{ma}}) \times \frac{\left[\sum (T_s - T_m) \right]}{N} \qquad (\%) \quad (3.14)$$

As seen in Table 32, linear correlation coefficients (R) for simulated and monitored hourly indoor temperatures for each zone range between 0,84 and 0,98. Approximately 86% of the correlation coefficients are between 0,90 and 0,98. The correlation yields an approximate R value of 0,90 for all zones data (8760 hours for each of 34 zones).

Percentage of root mean square error (RMSE) presents the percentage of deviation, therefore the level inconsistency of the model for a single zone. Percentage

RMSE values range between 6,84% and 12,89%, and the value for all zones data is 9,78%, which can be interpreted as the simulation model consistency for the indoor temperature profiles is 90,22% (Table 32).

Table 32. Comparison between simulated and measured indoor hourly temperatures (8760 hours)

Comparison between simulated and measured indoor hourly temperatures (8760 hours)				
Zones	**Correlation Coefficient (R)**	**RMSE (%)**	**MBE (%)**	**RMSE$_{value}$(°C)**
z15	0,93	8,87	1,86	1,86
z17	0,93	8,26	-2,83	1,87
z23	0,89	9,52	1,38	2,14
z21	0,87	9,09	-3,85	2,15
z39	0,91	11,25	-0,20	1,99
z37	0,86	9,50	-0,21	2,09
z42	0,84	11,25	-2,99	2,63
z01	0,91	10,00	1,17	2,26
z03	0,89	11,85	3,38	2,76
z04	0,92	10,27	5,08	2,34
z06	0,98	11,10	8,12	2,47
z09	0,89	8,78	-0,35	2,11
z12	0,97	8,31	-2,20	1,85
z14	0,95	7,43	3,26	1,64
z26	0,93	12,60	-6,02	2,69
z30	0,96	10,33	0,19	2,17
z33	0,92	11,55	6,78	2,61
z35	0,88	11,33	6,07	2,48
z13	0,95	9,27	6,71	1,98
z19	0,92	10,36	6,35	2,25
115	0,95	6,84	-0,45	1,53
117	0,95	6,99	2,63	1,56
142	0,90	8,97	1,12	2,03
140	0,86	8,81	-0,98	2,00
143	0,92	8,52	0,14	2,09
101	0,94	10,58	6,77	2,29
103	0,94	12,89	9,83	2,94
105	0,92	11,21	6,84	2,61
109	0,91	10,78	-6,03	2,59
111	0,94	7,24	1,98	1,64
132	0,92	12,53	8,77	2,85
131	0,89	9,63	1,02	2,10
127	0,96	11,26	-3,59	2,52
121	0,96	7,99	-5,03	1,82
Average	0,92	9,86	1,61	2,20
All Zones	0,90	9,78	1,38	2,20

Percentage of mean bias error MBE for the comparison of simulated and monitored hourly indoor temperatures represents the systematic error which is a constant residue amount in all observations. MBE result predicts an overestimation if the value is positive and underestimation if the value is negative. Strength of estimation, therefore the model prediction is higher if both positive and negative values are close or equal to zero. In Table 32, the values for MBE range between -6,03% and 9,83%, and for all zones the value is 1,38%. According to these values for 24% of the monitored zones the simulation model underestimated indoor temperatures, for 15 % of the monitored zones there is a very strong estimation and for 53% there exists overestimation.

RMSE values (°C) correspond to the standard deviation between simulated and monitored hourly indoor temperatures. Values range between Percentage RMSE 1,53 °C and 2,94 °C and the value for the totality of the zones is 2,20 °C.

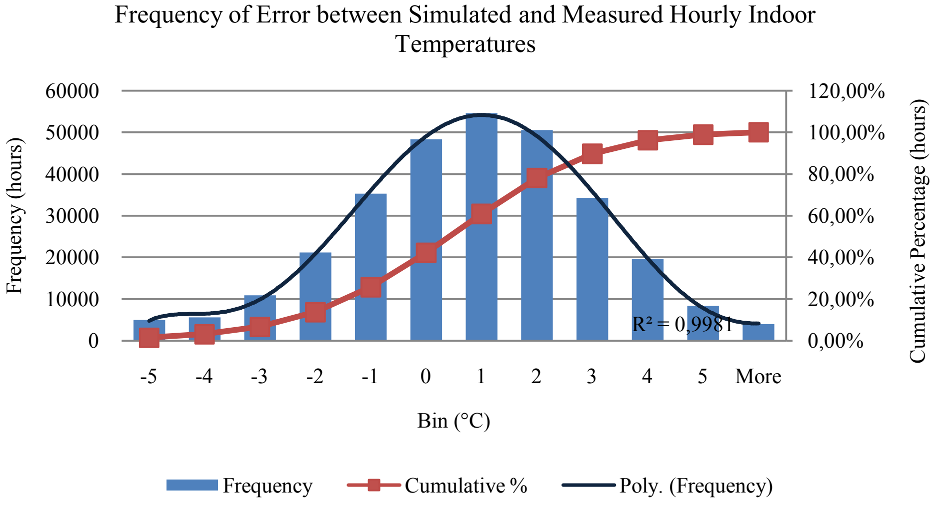


Figure 66. Frequency of error between simulated and monitored hourly indoor temperatures

In addition to standard deviation values of the model the frequency of errors all compared hourly indoor temperatures (8760 hours for each of 34 zones) are presented in Figure 66. The graph indicates that there is roughly a normal distribution of errors and the confidence level is 0,99 for the distribution of errors between simulated and monitored hourly indoor temperatures.

Simulated heating energy consumption of the building is as well compared to monitored monthly end-use data. Monthly simulation and monitoring data are presented in Table 33 and Figure 67. As a general trend, the simulation model estimates monthly consumption values with a higher deviation than the monitoring values for four heating months in 2009.

Percentage of root mean square error (RMSE) for comparison of simulated and monitored values yields a result of 11,24%. This value represents the inconsistency of simulation model in predicting the monthly consumption values. In other words, the model is 88,76 % accurate in predicting the monthly heating energy consumption of the building. Additionally percentage of mean bias error (MBE) is 7,78 %, which corresponds to the ratio of overestimation of monthly heating energy consumption by the simulation model. This result supports the trend in Figure 67. The RMSE value is 2965,19 kWh, a standard deviation value for simulation predictions.

Table 33. Monthly comparison of simulated and monitored heating energy consumption

Monthly Comparison of Simulated and Monitored Heating Energy Consumption in 2009		
Month	**Simulated Heating Energy Consumption (kWh)**	**Monitored Heating Energy Consumption (kWh)**
January	32235,28	29823,42
February	32577,70	27388,43
March	24176,78	22814,81
April	0,00	0,00
May	0,00	0,00
June	0,00	0,00
July	0,00	0,00
August	0,00	0,00
September	0,00	0,00
October	0,00	0,00
November	0,00	0,00
December	24778,35	25533,50
Total	113768,11	105559,16

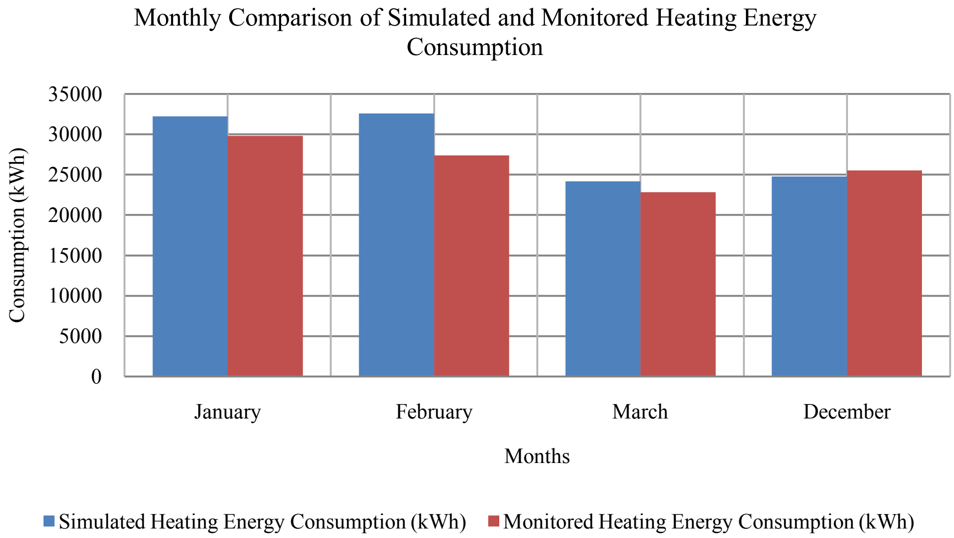


Figure 67. Monthly comparison of heating energy consumption for simulation and monitoring

Simulated cooling energy consumption of the building is evaluated in a similar manner and related data are presented in Table 34 and Figure 68. Monthly simulation results predict lower consumption values when compared to monitoring values for cooling season in 2009.

RMSE (%) for comparison of simulated and monitored values offer a result of 13,67%, which helps to make the assumption that this value refers to the inconsistency between monthly simulation data and monitoring data. Therefore it is possible to assert that simulation model is only 86,33 % accurate when monthly cooling energy consumption values are compared to monitoring values.

MBE for the same comparison is -9,00 %, which suggests that the magnitude of simulation prediction is below monitoring values as seen in Figure 68. The RMSE value is 1956,94 kWh, a standard deviation value for simulation predictions.

Table 34. Monthly comparison of simulated and monitored cooling energy consumption

Monthly Comparison of Simulated and Monitored Cooling Energy Consumption in 2009		
Month	**Simulated Cooling Energy Consumption (kWh)**	**Monitored Cooling Energy Consumption (kWh)**
January	0,00	0,00
February	0,00	0,00
March	0,00	0,00
April	0,00	0,00
May	0,00	0,00
June	9488,57	9936,00
July	19788,57	23628,00
August	15405,46	15872,00
September	7446,81	7846,00
October	0,00	0,00
November	0,00	0,00
December	0,00	0,00
Total	52129,41	57282,00

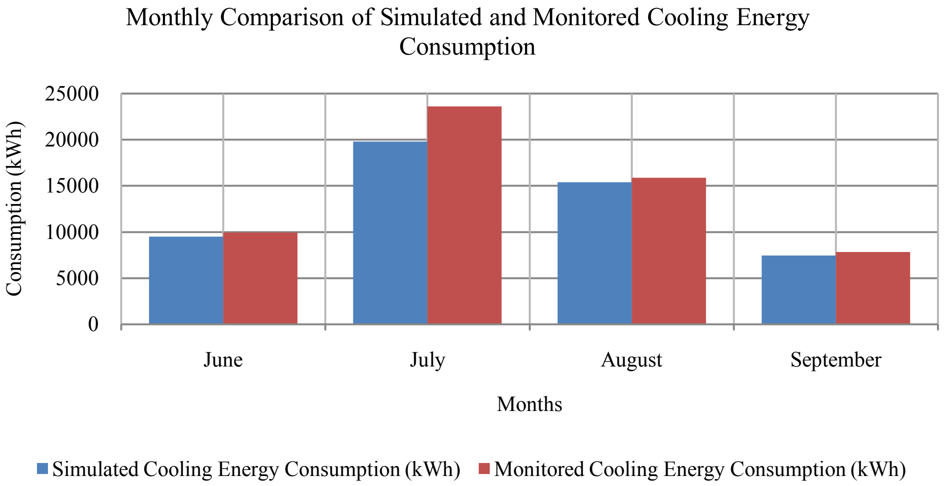


Figure 68. Monthly comparison of cooling energy consumption for simulation and monitoring

As necessary comparisons are completed, it is essential to check their reliability according to the benchmarks defined by ASHRAE (2002), IPMVP (2001), and M&V (2008). Table 35 presents the calibration benchmarks and results for error analysis for calibrated simulation of the case building. The error margins are higher for hourly calibration techniques, since calibration to monthly data is more holistic in comparison to hourly data and should be more precise in results.

The case building is calibrated with monitored hourly indoor temperatures and their effects on the results for monthly energy consumption. Therefore the calibration benchmark for the case building is hourly values. The guidelines and standards do not define benchmark values for indoor temperature consistency; however it is possible to assume for the case building that simulated and monitored hourly temperatures are strongly consistent (Table 35).

Error analysis for monthly heating energy consumption between simulated and monitored data fits in the hourly calibration acceptable values defined by the guidelines. MBE value 7,78 % is lower than the benchmark defined as ±10% and RMSE value 11,24% is lower than the defined value of 30%. Similarly, error analysis for monthly heating energy consumption provides a MBE value of -9,00% and 13,67% both lower values than defined benchmarks.

As a result it is possible to assert that heating and cooling energy consumption precision of the calibrated simulation model fits well in the defined error margins, and can be used as a calibrated model to apply necessary retrofitting interventions in the next section.

Table 35. Acceptable values for simulation calibration

Calibration Benchmarks						
Calibration Type	**Acceptable Value***					
	ASHRAE (2002)		**IPMVP (2001)**		**M&V (2008)**	
	MBE	**RMSE**	**MBE**	**RMSE**	**MBE**	**RMSE**
Hourly	±10%	30%	-	10-20%	±10%	30%
Monthly	±5%	15%	±20%	-	±5%	15%
* Lower values indicate better calibration (M&V, 2008)						
Case Building Hourly Calibration with Indoor Environment Parameters	**Indoor Temperature**		**Heating Energy Consumption**		**Cooling Energy Consumption**	
MBE	1,38%		7,78%		-9,00%	
RMSE	9,78%		11,24%		13,67%	

3.1.2.4.2. TS 825 Accuracy

In section 3.1.2.3, TS 825 – Thermal Insulation in Buildings (2008) is introduced and utilized for energy performance evaluation of the case building. However, it is necessary to remind once more that the calculation methodology of the standard is a static method in monthly time-steps and the building is processed as a single volume for calculations. Calculation methodology only covers monthly/annual heating load of the building as a performance measure and ignores the cooling loads.

Monthly heating load calculated by TS 825 methodology can be compared to monthly monitoring data, since they represent the most accurate results. The adjustments/calibrations applied to the calculation methodology are as follows:

- The calculation methodology is based on degree-day method and utilizes the difference between monthly exterior temperature averages and indoor set point temperature. Generally reference year data is used in TS 825 calculations. For this study, to have a common ground for comparison, 2009 weather data is used in TS 825 calculations.
- Monthly calculation methodology handles the month as 30 days. For this study only the number of workdays is integrated in the calculation.

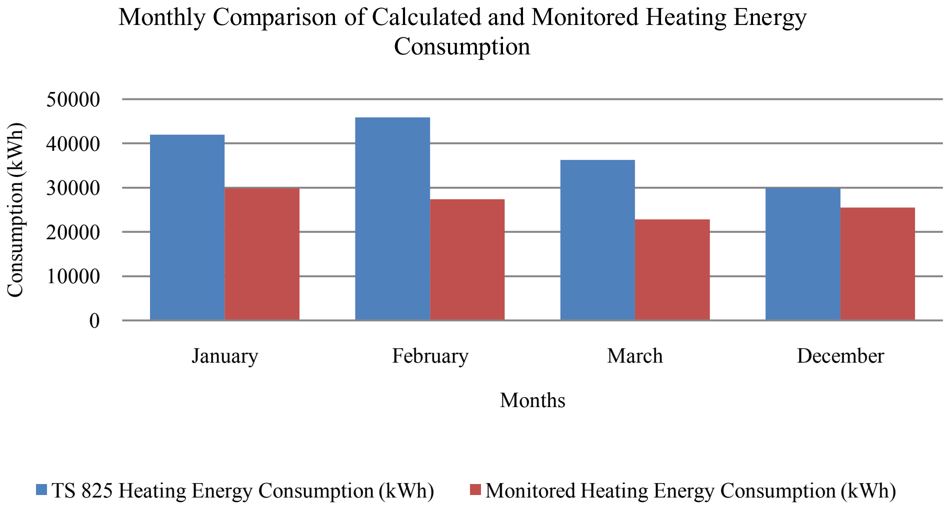


Figure 69. Monthly comparison of heating energy consumption for calculation and monitoring

The result of a similar error analysis compared to monitoring data yields large percentage error for RMSE and MBE, respectively 49,77% and 45,93%. Deviations between monthly TS 825 predicted and monitored heating energy consumption is presented in Figure 69. The results indicate that there is a very large gap in prediction of monthly energy consumption for TS 825. The reason behind this imprecision may be:

- Assumed static internal and solar gains
- Disregarded building schedule and occupancy patterns

As a result it is possible to assert that TS 825 calculation methodology fails to predict close consumption patterns to the monitored data, due to the static calculation methodology in monthly-time steps.

3.1.2.4.3. Result: Determination of Energy Performance Evaluation Tool

The main concern of this section is solely describes as an evaluation to determine the appropriate energy performance analysis tool and define its error margins for further evaluation of proposed retrofitting strategies in section 3.3. Up to here accuracy evaluation for the energy performance analysis tools suggested obvious distinction between results. Therefore in this sub-section, previously completed analyses are recapitulated.

Annual heating and cooling loads for all evaluation methods including monitoring results are presented in Figure 70. Monitored and simulated annual heating and cooling energy consumption for 2009 indicates that the results are close with reasonable deviations. However TS 825 calculation results have a large deviation when compared to monitoring and simulation. In Table 36, the obvious deviation between TS 825 and simulation results are presented due to completed error analysis

As presented in section 3.1.2.4.1, the error analysis results show that calibrated simulation approach fulfill the requirements of related guidelines with 7,78% MBE for annual heating energy consumption and -9,00% MBE for annual cooling load. On the other hand, calculation methodology of TS 825 highly overestimates the heating loads almost with 50 %.

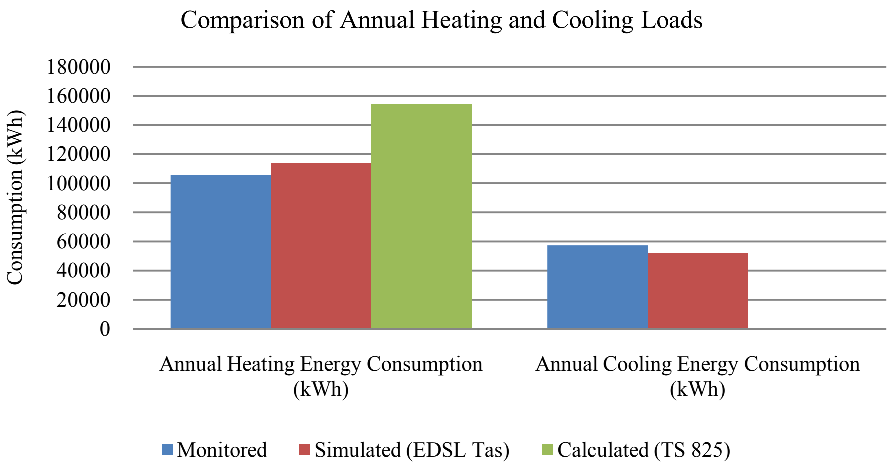


Figure 70. Comparison of annual heating and cooling loads for different evaluation tools

Table 36. RMSE and MBE values for simulation and calculation results

	Simulated (EDSL Tas)		Calculated (TS 825)	
	MBE	RMSE	MBE	RMSE
Annual Heating Energy Consumption (kWh)	7,78%	11,24%	45,93%	49,77%
Annual Cooling Energy Consumption (kWh)	-9,00%	13,67%		

As a result, it is reasonable to establish the utilization of calibrated simulation approach as a building energy performance evaluation tool. Use of calibration simulation approach offers following advantages:

- To evaluate the effect of different retrofitting strategies through the calibrated model
- To evaluate effects of individual interventions that compose a retrofitting strategy
- To forecast savings and costs offered by retrofitting strategies

3.2. Assessment of Retrofitting Strategies

Retrofitting strategies mainly aim to improve the energy performance and indoor environmental quality of a building. To generate an efficient building envelope retrofitting scenario, it is necessary to control one, combination or all of the following thermal characteristics: a) reduction of transmission, b) reduction of infiltration and ventilation losses and c) reduction or increase of solar gains through the envelope (Dascalaki & Santamouris, 2002). As a following step, it is necessary to define the sub-measures which can be structured as components of the retrofitting strategies to be generating, aiming solely the building envelope improvement. The set of possible sub-measures can be listed as follows: thermal insulation of opaque elements, improvement of insulation standard of window panes, reduction of infiltration rate, use of mass walls or ventilated walls, use of reflective solar shading systems etc. (Hestnes & Kofoed, 2002).

Many studies deal with the question of structuring retrofitting strategies. The major decisive criterion is assumed as the existing performance of the building. Thus the retrofitting scenarios can be generated according to the requirements the building performance analysis proposes. However, there is a certain necessity to define an approach in generating retrofitting strategies, since the number of alternatives is numerous and the main concern is to identify the strategies those are expected to be more efficient and dependable in long term. With the great extent of varieties for retrofitting strategies, the decision maker has to consider the environmental, energy, financial and social factors to attain the most reliable solution (Diakaki, Grigoroudis, & Kolokotsa, 2008).

In general there are two approaches to generate retrofitting strategies. The first approach is to diagnose the existing building and pre-define several alternative strategies, which are evaluated through simulation. The result of this approach is usually dependent on the experience and vision of the decision-maker for retrofitting strategies (Dascalaki & Santamouris, 2002; Diakaki, Grigoroudis, & Kolokotsa, 2008).

An example to the first approach is the OFFICE Project, which was implemented as an EU project, which proposes detailed evaluation in generation of retrofitting strategies. Three levels of activities are suggested by OFFICE Project:

- Individual retrofitting measures: such as improvement of insulation, use of shading devices, reducing air change rates, and improved heating cooling systems. These measures can be implemented independently according to the necessity the performance analysis proposes.
- Combinations of retrofitting measures in following categories: a) building envelope improvements, b) use of passive cooling techniques, c) lighting improvements, and d) HVAC improvements
- Combination of all retrofitting measures, covering building envelope improvements, using passive cooling techniques, lighting and HVAC improvements (Hestnes & Kofoed, 2002; Dascalaki & Santamouris, 2002).

The second approach is based on decision-making methodologies, where multi-objective optimization through retrofitting strategies is the main aim. Kaklauskas, Zavadskas, and Raslanas (2005) proposed a methodology which can be an example for multi-objective optimization for retrofitting strategies. All possible interventions in component level (such as insulation measures, replacement of windows etc.) are grouped in a decision-making matrix which leads to different levels of building retrofitting strategies through evaluating the weights of each intervention, in terms of significance, utility degree and priority. The results of such an approach allow making a retrofitting strategy assessment considering all building related aspects (economy, comfort, performance etc.). The number of interventions designed on component level is high and comprehensive in terms of pinpointing the strengths and weaknesses of any pre-designed retrofitting strategy.

Different approaches in defining retrofitting strategies try to establish a rational way of strategy assessment in regard to the existing condition and flexibilities the case building offer. The framework for generating retrofitting strategies for this dissertation is formulated in regard to these two approaches (1) diagnose and pre-define retrofitting strategies and (2) multi-objective optimization of retrofitting strategies. Since the dissertation focuses on retrofitting the building envelope, it is specifically a set of individual retrofitting measures, where improvements of building envelope components are investigated in detail. In the evaluation and optimization part of a single retrofitting scenario the set of retrofitting measures proposed in generated strategies are optimized to conclude with a final retrofitting strategy assessment.

To generate retrofitting strategies for the demonstrative case building study, the main aims are as follows:

- To define a base level of retrofit intervention which interferes minimum with indoor use, mainly through application of exterior insulation
- To propose further interventions which help decreasing energy consumption and CO2 emissions
- To determine the level of necessary set of interventions for a specific retrofitting strategy regarding indoor environment, energy consumption, and investment.

Consequently, it is necessary to define design decision parameters and the strategy approach for generating more accurate retrofitting alternatives.

3.2.1. Parameters for Energy-Efficient Envelope Retrofitting Strategies

3.2.1.1. Qualitative Design-Decision Parameters

Generation of retrofitting strategies requires case specific design-decisions. The structural, architectural aspects and the limitations for intervention to the building envelope are subject to consideration in decision-making. Therefore it is necessary to define the key parameters and limitations for retrofitting interventions for a building subject to retrofitting. For Medico building as case study, the general design decisions and limitations can be listed as follows:

- No fundamental change (such as replacement) in the structural elements of the building (concrete beams, columns, and reinforced concrete walls)
- Minimum change in architectural appearance of the building.
- Decision to maintain existing envelope elements with approximate thermal transmittance values to the limit values by TS 825.

The aim of the retrofitting strategies has to be coherent with these design decisions to maintain feasibility of applications. The possible interventions on envelope component level should be identified in terms of maximum feasibility of the application. On envelope component level following assessments can be made:

1) Opaque Components of the Building Envelope:

For built in brick walls of the case building, the level of intervention may vary from maintaining the existing wall composition and additions of external insulation to tearing down filled in walls and constructing a new wall system. The degree of intervention to the indoor environment gets superior when the design decision tends to extend to demolishment and rebuilding. The feasibility of application becomes a questionable matter, since the existing layer of walls may provide a mass wall layer and can be utilized for additional thermal improvements

All the envelope components built in reinforced concrete are structural elements of the building. As a principle the structural elements of the building is kept intact, hence enhanced with necessary thermal retrofitting measures.

External retaining wall constructed in the ground floor of east façade is not in contact with heated volumes in the existing use of the building. A set of improvement may be proposed for future utilization and acclimatization of these spaces.

The retrofitting measures for concrete floor on ground is a less feasible, hence a necessary intervention. Any retrofitting measure for the concrete floor on ground results in indoor space occupancy to be interrupted, since the retrofitting measures have to be applied by removal of the existing floor finishing up to concrete floor deck and then the application of necessary levels of thermal insulation and floor finishing.

Existing flat roof of the building is the single building envelope component with a thermal transmittance close to the requirements of TS 825. Thus, the roof may optionally be re-insulated as an additional retrofitting measure or preferably may be kept intact.

2) Transparent Components of the Building Envelope:

Glazing system of the building is cast in window/door components composed of aluminum frame with thermal break and double glass pane (6-12-6) with air cavity. The glazing components can be retrofitted in two ways, depending on the necessary level of intervention: either with replacement of glass panes or with frame and pane replacement. For the case building replacement of glass panes is feasible, sealing of frame elements is a supplementary measure to reduce infiltration.

Table 37. Scale of intervention and feasibility on building envelope component level

Building Envelope Components			**Scale of Intervention**	**Feasibility**				
				Affects Indoor Use		Maintains Original Structure		
				Yes	No	Yes	No	Partial
OPAQUE COMPONENTS	Exterior double layer clinker brick walls	Exterior Insulation	Mass Wall Improvement: Utilizing the existing mass wall and exterior thermal insulation measures with exterior finishing		**X**	**X**		
			Ventilated Cavity Wall Improvement: Utilizing the existing mass wall and exterior thermal insulation measures with exterior finishing		**X**	**X**		
			Replacement of walls with a new Cavity Wall: Rebuilding of the exterior wall as a barrier wall.	**X**			**X**	
	Exterior reinforced concrete walls and structural elements	Exterior Insulation	Mass Wall Improvement:Utilizing the existing mass wall and exterior thermal insulation measures with exterior finishing		**X**	**X**		
			Ventilated Cavity Wall Improvement:Utilizing the existing mass wall and exterior thermal insulation measures with exterior finishing		**X**	**X**		
	External retaining wall	Interior Insulation	Mass Wall Improvement: Retrofitting with a capillary active material - calcium silicate board for interior insulation	**X**		**X**		
	Concrete floor on ground	Interior Insulation	Insulation Improvement: Application of a thermal insulation layer on the concrete deck	**X**				**X**
	Flat roof	Exterior Insulation	Insulation Improvement: Replacement of the existing insulation		**X**			**X**
TRANSPARENT COMPONENTS	Glazing System	Replacement	1. Replacement of double glass panes with Low-e glazing 2. Replacement double glas panes with Low-e glazing + Replacement of frames		**X**			**X**

Table 37 presents a range of qualitative design-decisions for building envelope on component level regarding the scale of intervention and feasibility of application. Structural and aesthetical aspects for the building should be evaluated as well on intervention to envelope components.

The selection of the scale of intervention for building components is mainly based on the maintaining the existing qualities of the building but enhancing the thermal characteristics with necessary retrofitting measures. Therefore the following assessments in generating strategies are the results of the qualitative design-decision parameters:

- Maintaining the existing characteristics of the built in brick walls, improvement with different applications of external insulation and exterior finishing.
- Maintaining the existing structural system and improvement with different applications of external insulation and exterior finishing.
- Providing minimum insulation level for concrete floor on ground.
- Evaluating the possible savings with re-insulation of existing flat roof.
- Evaluating the possible savings with interior insulation of exterior retaining wall
- Evaluating the possible savings with replacement of double glass panes with low-e glazing and replacement of frames.

3.2.1.2. Quantitative Design-Decision Parameters

Since the limitations and qualitative design decisions are assessed in the previous section, it is necessary to denote the quantitative parameters in decision of retrofitting strategies. Quantitative parameters that are effective on the retrofitting strategies can be summarized as:

- Type of insulation material
- Insulation thickness
- Cost of insulation material
- Cost of energy consumed for heating and cooling.

The parameters listed above are evaluated through a method for determination of optimum insulation thickness for building elements. Several studies were conducted to assess optimum insulation thickness that offers the minimum cost for insulation investment and maximum energy savings. The optimization is simply based on local degree-days, and life-cycle cost analysis of insulation materials and both methods are briefly introduced in this section.

Fundamentally degree-day method presumes the heating and cooling periods and loads based on exterior temperature. For heating season, heating degree days (HDD) are calculated with equation 3.15, and for cooling season, cooling degree days (CDD) are calculated with equation 3.16 (ASHRAE, 2005).

$$HDD \times (t_{bal,h}) = \sum_{days} (t_{bal,h} - t_o) \tag{3.15}$$

$$CDD \times (t_{bal,c}) = \sum_{days} (t_{bal,c} - t_o) \tag{3.16}$$

Equations 3.15 and 3.16 introduce two balance temperatures $t_{bal,h}$ and $t_{bal,c}$ for heating and cooling periods. Balance temperatures present the levels of exterior temperature where heating and cooling is necessary. For this specific study, $t_{bal,h}$ is 15,6°C, where heating system starts functioning as outdoor temperature goes roughly below this value and correspondingly, $t_{bal,c}$ is determined as 24°C. The notation t_o indicates the average daily exterior temperature. Thus, DDs are calculated for each day, according to the difference between these balance temperatures and average daily temperatures and their sum for heating and cooling seasons provide the HDD and CDD values (ASHRAE Fundamentals, 2005). For this study HDD and CDD are calculated for the case area with an average weather year data calculated from recordings between 2005 and 2009. Table 38 presents the parameters for degree day calculation and HDD/CDD values.

Table 38. Balance temperatures and degree days for the case area

Temperature (°C)	
$t_{bal,h}$	15,60
$t_{bal,c}$	24,00
Temperature (°C-days)	
HDD	729,86
CDD	224,22

Optimum insulation thicknesses for different retrofitting interventions on the building envelope can be calculated according to their life-cycle cost analysis. Since heat losses occur from building envelope elements (walls, roof, floors etc.) the calculation is based on heat losses per unit area of envelope elements. Following equations are derived from several studies conducted for different climatic regions of Turkey (Bolattürk, 2006; Bolattürk, 2008; Gölcü, Dombaycı, & Abalı, 2006; Özel, 2008).

Heat loss from per unit area of an envelope component is calculated with equation 3.17, where U is the overall heat transfer coefficient, T_{bal} is the balance temperature and T_o is the mean daily outside temperature. A parallel equation to calculate the annual heat loss can be written as in 3.18, where q_A is annual heat loss from unit area of the envelope component and DD is the degree-days. The multiplier 86400 denotes the seconds in a day.

$$q = U \times (T_{bal} - T_o) \tag{3.17}$$

:

$$q_A = 86400 \times DD \times U \tag{3.18}$$

Annual energy requirement E_A due to heat loss q_A can be formulated as equation 3.19, where η_s is the efficiency of the heating or cooling system.

$$E_A = \frac{86400 \times DD \times U}{\eta_s} \tag{3.19}$$

Heat transfer of an envelope element with insulation layer can be extended as in equation 3.20, where R_i and R_o are convection coefficients (m^2K/W), respectively for inside and outside, R_w is the resistance of the wall structure except the insulation layer. R_{ins} is the thermal resistance (m^2K/W) of the insulation layer and is calculated by equation 3.21, where x is the thickness and k is the thermal conductivity (W/mK) of the insulation layer.

$$U = \frac{1}{(R_i + R_w + R_{ins} + R_o)} \tag{3.20}$$

$$R_{ins} = \frac{x}{k} \tag{3.21}$$

Equation 3.22 can be re-written using R_{tw} as a total thermal resistance of the envelope element, excluding the insulation layer.

$$U = \frac{1}{(R_{tw} + R_{ins})} \tag{3.22}$$

Finally, equations 3.23 and 3.24 are obtained, yielding annual heating load (E_A) and annual fuel consumption (m_{fA}) respectively, where LHV is the lower heating value of the consumed fuel (J/kg, J/m^3 or J/kWh).

$$E_A = \frac{(86400 \times DD)}{(R_{tw} + \frac{x}{k}) \times \eta_s} \tag{3.23}$$

$$m_{fA} = \frac{86400 \times DD}{(R_{tw} + \frac{x}{k}) \times LHV \times \eta_s} \tag{3.24}$$

Up to here the calculation method provides the results for annual heating/cooling load and the amount of energy consumed to compensate this load. The latter step is to integrate the life-cycle cost analysis to consider the total cost of energy consumption and it is correlation with different insulation thicknesses. Total heating cost for N years is evaluated as present value, which includes interest rate (i) and inflation rate (g), and adjusted according to expected inflation. Interest rate adjusted for inflation rate r is given by following formulas for the cases;

- If $i > g, r = \dfrac{(i-g)}{(1+g)}$ and
- If $i < g, r = \dfrac{(g-i)}{(1+i)}$. Equation 3.25 is used to determine the present value (PV), where N is the lifetime for insulation materials

$$PV = \frac{N(1+r)^N - 1}{r \times (1+r)^N} \tag{3.25}$$

Additionally, in case $i = g$, present value is calculated as in equation 3.26.

$$PV = \frac{N}{(1+i)} \tag{3.26}$$

Therefore, annual cost for heating (C_A) can be determined from equation 3.27, where C_f is the cost for consumed fuel type (TL/kg, TL/m^3 or TL/kWh).

$$C_A = \frac{86400 \times DD \times C_f}{(R_{tw} + \frac{x}{k}) \times LHV \times \eta_s} \tag{3.27}$$

Cost of insulation (C_{ins}) can be calculated by equation 3.28, where C_i is the cost of insulation material (TL/m^3) and x is the insulation thickness (m).

$$C_{ins} = C_i \times x \tag{3.28}$$

Total cost (C_t) for an insulated envelope component is given by equations 3.29 and 3.30.

$$C_t = \frac{C_A \times PV}{C_i \times x} \tag{3.29}$$

$$C_t = \left[\frac{86400 \times DD \times C_f \times PV}{(R_{tw} + \frac{x}{k}) \times LHV \times \eta_s} \right] + (Ci \times x) \qquad (3.30)$$

Optimum insulation thickness is obtained from equation 3.30 by the derivative of C_t with respect to x in equation 3.31.

$$x_{op} = \left[293{,}94 \times \left(\frac{DD \times C_f \times k \times PV}{LHV \times C_i \times \eta_s} \right)^{0,5} \right] - (k \times R_{tw}) \qquad (3.31)$$

The parameters for this study, which are used in equation 3.31 are listed in the following tables. Table 39 introduces the envelope components that are subject to retrofitting interventions with different finishing options. For optimization of insulation thicknesses for retrofitting strategies of building elements, section interventions are pre-assessed to calculate their R-values without the insulation layer.

Table 39. R-values for possible retrofitting interventions on building envelope components

Thermal Properties of Possible Interventions (Excluding the Insulation Layer)	
Exterior Clinker Brick Wall	**R-Value**
Finishing with Plaster	0,697
Finishing with Brick Cladding	0,721
Finishing with Wooden Facade Cladding	0,896
Exterior Concrete Wall	**R-Value**
Finishing with Plaster	0,44
Finishing with Brick Cladding	0,464
Finishing with Wooden Facade Cladding	0,64
Floor on Ground	**R-Value**
Finishing with Tiles	0,944

Table 40. Parameters for optimum insulation thickness calculation

Parameters		**Values**	**Units**
Degree Days	HDD	729,86	°C-days
	CDD	224,22	°C-days
Fuel Types	Fuel Oil ($C_{f,\ heating}$)	4,13E+07	J/m^3
	Electricity ($C_{f,\ cooling}$)	3,60E+06	J/kWh
Insulation Types	Extruded Polystyrene (XPS)	0,030	W/mK
	Expanded Polystyrene (EPS)	0,035	W/mK
	Mineral Wool (MW)	0,040	W/mK
Prices in 2009	Fuel Oil	2,050	TL/kg
	Electricity	0,280	TL/kWh
	Extruded Polystyrene (XPS)	225,00	TL/m3
	Expanded Polystyrene (EPS)	160,00	TL/m3
	Mineral Wool (MW)	218,00	TL/m3
Economic Parameters in 2009	Inflation Rate (g)	0,0653	
	Interest Rate (i)	0,1438	
	Adapted Interest Rate (r)	0,0737	
	Lifetime (n)	10	years
	Present Value (PV)	6,9054	

In Table 40, the calculation parameters are listed. All information on prices and economic parameters are gathered from the corresponding institution databases (CBRT, 2009; MPWS, 2009; SHELL, 2009)

Optimum insulation thickness is completed for both HDD and CDD values and for all pre-proposed retrofitting interventions. Calculation results are presented in Figure 71 and Figure 72. The results in these figures cover the insulation intervention for exterior clinker brick wall, finishing with plaster for heating and cooling degree-days respectively. For this evaluation XPS (Extruded Polystyrene Board) is used as the insulation material as an example for how results are obtained. Both graphs present the calculation results in regard to their costs for different insulation thicknesses. It is observed that fuel cost (C_f) decreases exponentially as the insulation thickness increases. On the other hand, insulation cost (C_{ins}) increases linearly as insulation thickness increases. The total cost $(C_t = C_f + C_{ins})$ therefore, presents a parabolic function, and the optimum insulation thickness is determined on this parabola as the limit thickness value up to the total consumption decreases.

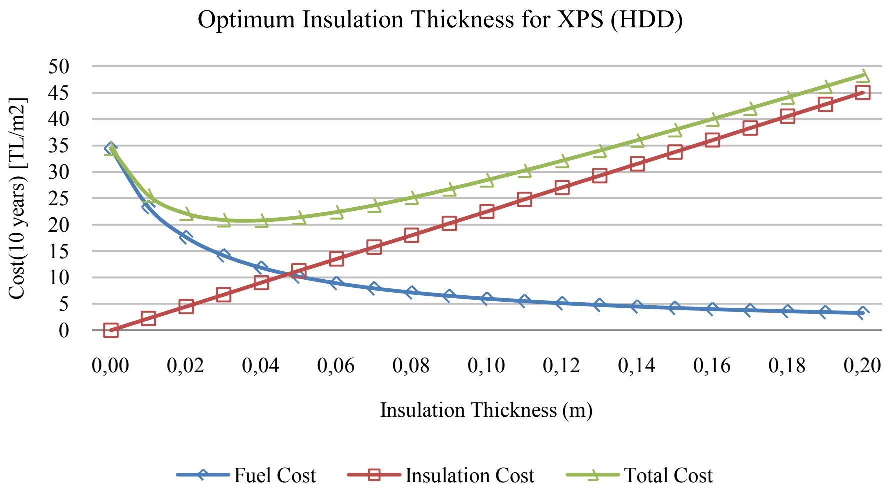


Figure 71. Optimum XPS thickness for exterior clinker brick wall with plaster finishing for HDD

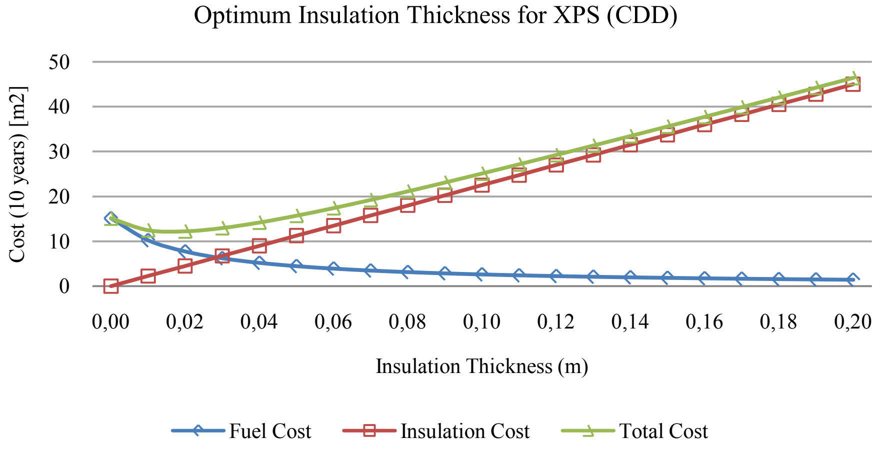


Figure 72. Optimum XPS thickness for exterior clinker brick wall with plaster finishing for CDD

The optimum insulation thicknesses determined for exterior clinker brick wall (plaster finishing) indicate that heating season requires larger thicknesses to decrease consumption which originates from heat losses per unit area. On the contrary, in cooling season the same wall section requires less insulation thickness, since increasing thermal mass may cause an adverse effect on the cooling loads. Figure 73 presents this differentiation between seasonal requirements and additionally provides information on thickness efficiencies of different insulation materials. According to this comparison for insulation thickness requirements, the larger thickness should be chosen to compensate both seasonal requirements. Additionally it should be noted that EPS (Expanded Polystyrene Board) requires higher thicknesses when compared to XPS (Extruded Polystyrene Board) and MW (Mineral Wool) according to life-cycle cost analysis.

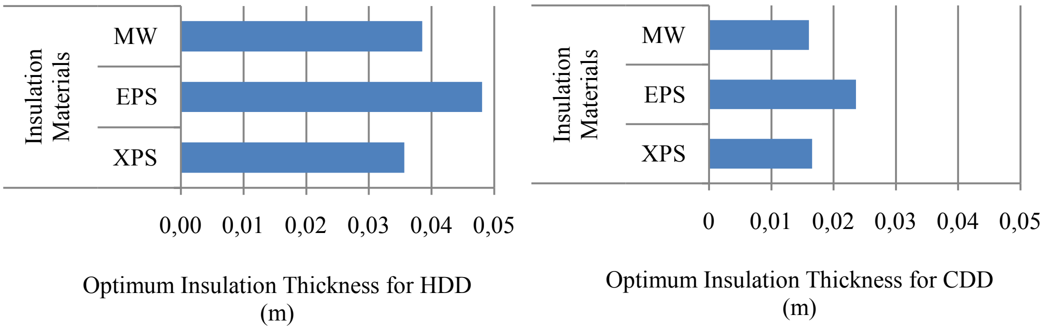


Figure 73. Optimum thickness for different insulation materials

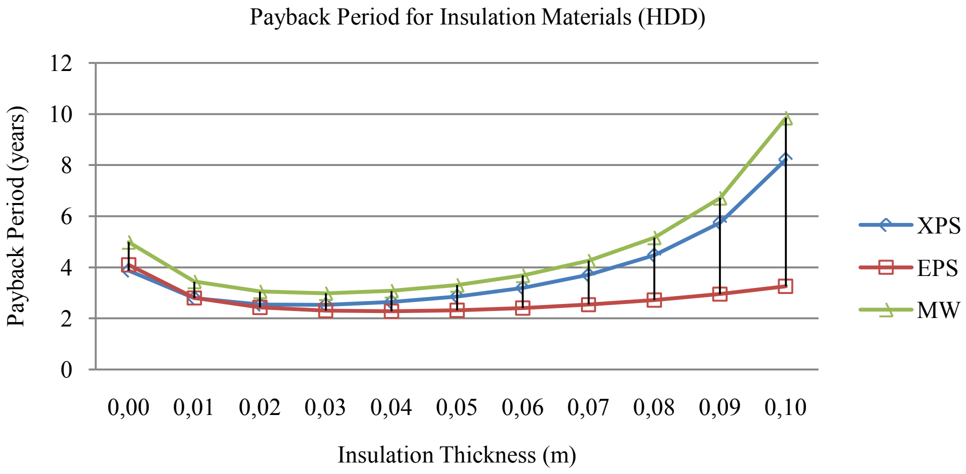


Figure 74. Payback period for insulation materials for HDD

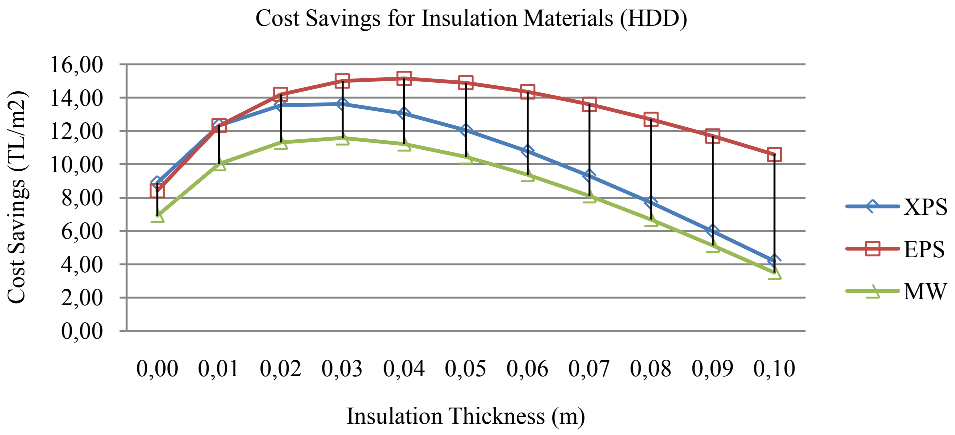


Figure 75. Cost savings for insulation materials for HDD

Payback period and cost savings for different insulation materials are presented in Figure 74 and Figure 75. According to these analyses it is possible to assert that:

- Payback periods of different insulation materials are considerably close up to 40 mm's of thickness
- Payback periods increase for XPS and MW as the insulation thickness increases.
- Cost savings are high for EPS due to low unit cost. XPS and MW at same thicknesses have close trends for cost savings.
- Both payback periods and cost savings point out the optimum insulation thicknesses at their maximum/minimum of the parabolic curve

Considering all results, the insulation material for this specific study is selected as XPS (Extruded Polystyrene Board). The determined optimum thicknesses for different retrofit interventions and their payback period per cubic meter can be seen in Table 41. The reasons for selecting XPS as the insulation material can be listed as:

- Has a lower thermal conductivity (0,030 W/mK) (EPS = 0,035 W/mK and MW = 0,040 W/mK)
- Provides optimum results with lower thicknesses (Figure 73)
- Has lower payback periods for low thicknesses (Figure 74)
- Provides optimum savings with lower thicknesses (Figure 75)

Table 41. Determined optimum thicknesses and payback period for XPS

Constructions		Optimum Insulation Thickness (m)		XPS Thickness (m)	Payback Period (years)
Exterior Clinker Brick Wall	R-Value	HDD	CDD		
Finishing with Plaster	0,697	0,036	0,017	0,040	2,64
Finishing with Brick Cladding	0,721	0,035	0,016	0,040	2,78
Finishing with Wooden Facade Cladding	0,896	0,030	0,011	0,030	3,81
Exterior Concrete Wall	R-Value				
Finishing with Plaster	0,44	0,043	0,024	0,050	1,75
Finishing with Brick Cladding	0,464	0,043	0,024	0,050	1,82
Finishing with Wooden Facade Cladding	0,64	0,037	0,018	0,040	2,51
Floor on Ground	R-Value				
Finishing with Tiles	0,944	0,028	0,009	0,030	4,32

Additionally it is necessary to summarize the selection on exterior insulated finishing systems. As seen in Table 41 there is a slight difference of R-values, optimum thicknesses and payback periods between a plaster finishing and clinker brick cladding for both exterior wall types. Therefore, regarding the aesthetical considerations, the interventions will be designed reliable to the existing appearance of the building. Insulation and plaster finishing is proposed as the minimum level of intervention for existing reinforced concrete walls and insulation and brick cladding finishing is proposed as the minimum level of intervention for existing brick walls. Ventilated cavity and wooden façade finishing option appears as an intervention with better R-values. These types of wall constructions are known to have better performance in decreasing sensible cooling loads (Naboni, 2007). With the low U-values and effect of cooling loads, ventilated cavity application is proposed as an advanced intervention to the exterior wall types.

As a result it is possible to consider that as an exterior insulation material XPS is advantageous with optimum thicknesses and various finishing and wall composition alternatives. These results will be evaluated to assess their benefits for indoor environmental conditions, heating/cooling loads, energy end use, CO_2 emissions, and retrofitting investment. Following section focuses on assessment of energy-efficient envelope retrofitting strategies and optimum insulation thickness values will be integrated to the proposed strategies.

3.2.2. Assessment of Energy-Efficient Envelope Retrofitting Strategies

According to the above stated qualitative and quantitative parameters the retrofitting strategies are classified in this section. The main aim is to define a set of coherent interventions on the envelope, with adequate levels of retrofitting measures in consideration to qualitative and quantitative parameters for the case building. The design of the strategies starts from a minor level and integrates and/or replaces one or two set of supplementary intervention on building envelope components when defining the next level of intervention. By this approach, three different coherent levels of interventions are defined as retrofitting strategies. Figure 76 explains this coherent relationship and degree of intervention designed for the level of intervention for the retrofitting strategies

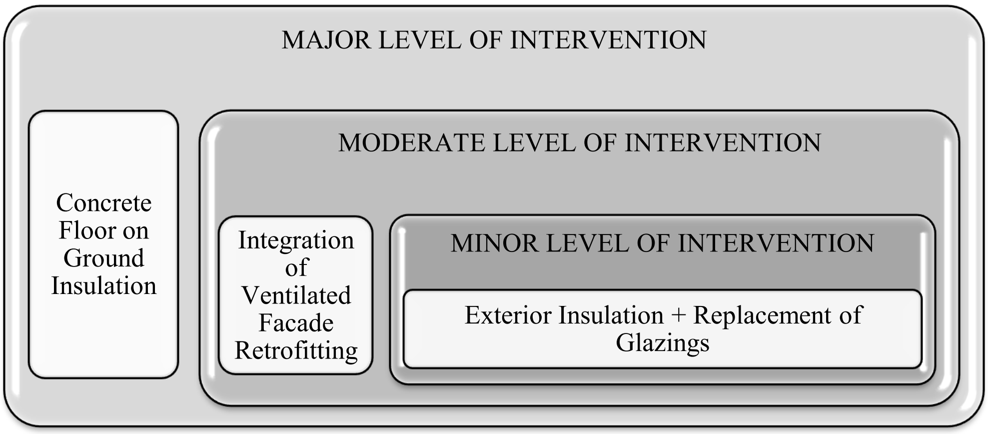


Figure 76. Degree of intervention for three coherent strategies

Three levels of retrofitting strategies suggest following characteristics, if reviewed in detail. Other interventions are retrieved from the previous level (moderate level of intervention). Table 42 presents these characteristics in regard to scale of intervention.

Minor Level of Intervention: Defines a base intervention level, which focuses on the opaque and glazed building envelope elements, without interfering indoor use of the building. The retrofitting of opaque surfaces is solely with addition of optimum levels of external insulation and cladding which is reliable to the aesthetical existing appearance of the building.

Moderate Level of Intervention: Keeps the previous decision for exterior reinforced concrete wall in the first strategy. Proposes a replacement of retrofitting intervention for filled in brick walls with an insulation layer, a ventilated cavity and a wooden façade cladding. In addition to the replacement of glazing in the minor level strategy, in this level, replacement of frames are as well evaluated.

Major Level of Intervention: Majorly integrates insulation intervention to concrete floor on ground. Additionally, replacement of the exterior reinforced wall retrofitting intervention with a ventilated cavity and wooden façade cladding system is as well evaluated in this level. Other interventions are retrieved from the previous level (moderate intervention).

Table 42. Characteristics of proposed retrofitting strategies in scale of intervention

	MINOR INTERVENTION	MODERATE INTERVENTION	MAJOR INTERVENTION
EXTERNAL CLINKER BRICK WALL	40 mm XPS Insulation / Finishing with Clinker Brick (U-value= 0,487 W/m²K)	30 mm XPS Insulation / Ventilated Cavity / Finishing with Wooden Facade Cladding (U-value= 0,527 W/m²K)	30 mm XPS Insulation / Ventilated Cavity / Finishing with Wooden Facade Cladding (U-value= 0,527 W/m²K)*
EXTERNAL BRICK WALL	50 mm XPS Insulation / Finishing with Insulating Plaster (U-value= 0,475 W/m²K)	50 mm XPS Insulation / Finishing with Insulating Plaster (U-value= 0,475 W/m²K)*	40 mm XPS Insulation / Ventilated Cavity / Finishing with Wooden Facade Cladding (U-value= 0,507 W/m²K)
GLAZING	Replacement of Double Glass Panes with Low-e Double Glass (U-value=1,643 W/m²K)	Replacement of Double Glass Panes with Low-e Double Glass (U-value=1,643 W/m²K) + Replacement of Frames with high thermal break	Replacement of Double Glass Panes with Low-e Double Glass (U-value=1,643 W/m²K) + Replacement of Frames with high thermal break*
FLAT ROOF	X	X	X
FLOOR ON GROUND	X	X	30 mm XPS Insulation / Finishing with Tiles (U-value= 0,514 W/m²K)

Above proposed retrofitting strategies are explained according to their specifications in the following sections. The methodology then continues with implementation of these strategies through the calibrated simulation model. In addition, the main idea behind the implementation of retrofitting strategies is constructed by application of each intervention than evaluating their effects on consumption to be able to derive the sensitivities of the simulation model to each individual intervention in a strategy.

3.2.2.1. Specifications for Minor Level of Intervention

Minor level of intervention is based on exterior insulation of opaque surfaces and replacement of glazing panes with double glazed low-e panes. In this strategy, the first intervention is applied to the existing exterior brick wall structures which in current situation have a U-value of 1,531 W/m^{2}K. The retrofitting intervention for exterior brick wall alters this U-value to 0,487 W/m^{2}K. The layers of the construction can be seen in Table 43. For the retrofitting intervention of this building envelope component XPS insulation is used with an optimum thickness of 40 millimeters, calculated in section 3.2.1.2. The exterior finishing is chosen as clinker brick cladding, with the purpose to maintain the architectural appearance of the case building.

Table 43. Thermal properties of exterior clinker brick wall retrofitted with XPS insulation and brick cladding finishing

XPS Insulation + Brick Cladding Finishing						
Layer	Material	Width (mm)	Conductivity (W/mK)	Convection Coefficient (W/m^{2}K)	Density (kg/m^3)	Specific Heat (J/kgK)
Inside	Paint	1	999,00	0,001	0,001	0,00
2	Gypsum Lime Plaster	20	0,46	0,001	1200,000	1008,00
3	Clinker brick	102	0,70	0,001	2000,000	940,00
4	Air cavity	11	0,01	0,001	0,000	0,00
5	Clinker brick	102	0,70	0,001	2000,000	940,00
6	Cement Plaster	20	1,20	0,001	2000,000	1008,00
7	XPS Board Insulation	40	0,03	0,001	30,000	1400,00
	Fixing Plaster	10	0,72	0,001	1680,000	837,00
Outside	Brick Cladding	30	0,81	0,001	1760,000	920,00
Flow Direction		**U-value (W/m^{2}K)**			**R-value (m^{2}K/W)**	
Horizontal		0,487			2,054	

The second individual intervention of this strategy is applied to the external reinforced concrete walls of the case building. The existing U-value for reinforced concrete wall is shifted from 2,418 W/m^{2}K to 0,475 W/m^{2}K, with the application of XPS insulation material and exterior plaster finishing. The thickness for XPS insulation is calculated as optimum thickness, 50 millimeters. Retrofitting measures are applied to the existing construction from exterior. The details are presented in Table 44.

Table 44. Thermal properties of exterior reinforced concrete wall retrofitted with XPS insulation and plaster finishing

XPS Insulation + Plaster Finishing						
Layer	Material	Width (mm)	Conductivity (W/mK)	Convection Coefficient (W/m^{2}K)	Density (kg/m^3)	Specific Heat (J/kgK)
Inside	Paint	1	999,00	0,001	0,001	0,00
2	Gypsum Lime Plaster	20	0,46	0,001	1200,000	1008,00
3	Reinforced Concrete Wall	350	2,00	0,001	2400,000	950,00
4	Cement Plaster	30	1,20	0,001	2000,000	1008,00
5	XPS Board Insulation	50	0,03	0,001	30,000	1400,00
6	Insulating Plaster	10	0,37	0,001	1300,000	837,00
Outside	Paint	1	999,00	0,001	0,001	0,00

Flow Direction	**U-value (W/m^{2}K)**	**R-value (m^{2}K/W)**
Horizontal	0,475	2,107

To conclude, the third intervention of the first strategy is the replacement of standard exterior double glazed panes (3,00 W/m^{2}K). The proposed replacement for the glazing panes is a low-e air filled double glazed pane with a U-value of 1,643 W/m^{2}K. Glazing properties for low-e panes are presented in Table 45. Additionally it is necessary to emphasize the placement of low-e coating. Since the cooling loads are higher for the case building, the glazing is chosen with a low-e coating on the outer pane’s cavity facing surface.

Table 45. Glazing replacement with low-e panes

Low-e Glazing Parameters		
Light	Transmittance	0,797
	Reflectance	0,144
Solar Energy	Direct Transmittance	0,353
	Direct Reflectance	0,244
	Direct Absorptance	0,403
	Total Transmittance (G value)	0,429
Shading Coefficients	Short Wavelength	0,406
	Long Wavelength	0,087
	Total	0,493
U-value	1,643 W/m^{2}K	

3.2.2.2. Specifications for Moderate Level of Intervention

In the second retrofitting strategy (moderate level of intervention) previous measure for external reinforced concrete walls is maintained. However, the measure taken for the exterior brick wall is altered with a ventilated cavity and wooden cladding finish. The intervention is lower in U-value (0,527 W/m^{2}K) when compared to the previous measure, yet still fulfills the standard requirement (TS 825, 2008) with a lower value than 0,70 W/m^{2}K. The intention on employment of a ventilated cavity wall is to investigate the capability of such system on reduction of cooling demand. Thermal properties of ventilated cavity wall can be seen in Table 46

The second measure in this strategy is an addition to the replacement of glazing coupled with replacement of frames. In the existing situation the building has metal (aluminum) frame with 20 mm thermal break. Aluminum is highly conductive (U-value = 5,6W/m^{2}K) and even with thermal break the values are only between 1,9 and 3,5 W/m^{2}K. Therefore, replacement of aluminum frames with vinyl frames is proposed for this strategy. The selected vinyl frame is 70 millimeters, including five insulation filled hollow chamber. The U-value of the frame component is calculated as 1,40 W/m^{2}K, which is a very close value to the low-e glazing U-value.

Table 46. Thermal properties of exterior clinker brick wall retrofitted with XPS insulation, ventilated cavity and wooden façade cladding

XPS Insulation + Ventilated Cavity + Wooden Façade Cladding						
Layer	Material	Width (mm)	Conductivity (W/mK)	Convection Coefficient (W/m^2K)	Density (kg/m^3)	Specific Heat (J/kgK)
Inside	Paint	1	999,00	0,001	0,001	0,00
2	Gypsum Lime Plaster	20	0,46	0,001	1200,000	1008,00
3	Clinker brick	102	0,70	0,001	2000,000	940,00
4	Air cavity	11	0,01	0,001	0,000	0,00
5	Clinker brick	102	0,70	0,001	2000,000	940,00
6	Cement Plaster	20	1,20	0,001	2000,000	1008,00
7	XPS Board Insulation	30	0,03	0,001	30,000	1400,00
8	Ventilated Cavity	30	0,00	1,950	0,000	0,00
Outside	Wooden Cladding	6	0,14	0,001	640,000	1420,00
Flow Direction		**U-value (W/m^2K)**			**R-value (m^2K/W)**	
Horizontal		0,527			1,896	

3.2.2.3. Specifications for Major Level of Intervention

Major level of intervention is the most extensive retrofitting strategy evaluated in this research. Different than the previous strategy, first altered intervention is employed to exterior reinforced concrete wall. In the first and second strategy, exterior reinforced concrete wall is evaluated with an improvement of XPS insulation and plaster finishing. In this strategy, the effect of ventilated cavity application for existing reinforced concrete wall similar to brick wall construction. The U-value for the first intervention is 0,507 W/m^2K and the thermal properties are in Table 47.

The second and final individual intervention designed for major level of retrofitting strategy is improvement of concrete floor on ground. The existing structure has a U-value of 1,059 W/m^2K. In the first two strategies, the improvement of concrete floor on ground is not evaluated due to the flexibility of TS 825 (2008), which states that only one of the building elements may exceed the limit U-value if all other building elements are compatible. In the major level of intervention, the effects of ground floor insulation are evaluated. The improvement is proposed by removing the existing layers until the waterproof layer, making necessary maintenances, than application of XPS insulation and finishing layers. U-value of the proposed improvement is 0,514 almost half of the existing value. The construction layers are presented in Table 48.

Table 47. Thermal properties of exterior reinforced concrete wall retrofitted with XPS insulation, ventilated cavity and wooden façade cladding

XPS Insulation + Ventilated Cavity + Wooden Façade Cladding						
Layer	Material	Width (mm)	Conductivity (W/mK)	Convection Coefficient (W/m^2K)	Density (kg/m^3)	Specific Heat (J/kgK)
Inside	Paint	1	999,00	0,001	0,001	0,00
2	Gypsum Lime Plaster	20	0,46	0,001	1200,000	1008,00
3	Reinforced Concrete Wall	350	2,00	0,001	2400,000	950,00
4	Cement Plaster	30	1,20	0,001	2000,000	1008,00
5	XPS Board Insulation	40	0,03	0,001	30,000	1400,00
6	Ventilated Cavity	30	0,00	1,950	0,000	0,00
Outside	Wooden Cladding	6	0,14	0,001	640,000	1420,00
Flow Direction		**U-value (W/m^2K)**		**R-value (m^2K/W)**		
Horizontal		0,507		1,973		

Table 48. Thermal properties of concrete floor on ground retrofitted with XPS insulation

Floor on Ground						
Layer	Material	Width (mm)	Conductivity (W/mK)	Convection Coefficient (W/m^2K)	Density (kg/m^2)	Specific Heat (J/kgK)
Inside	Artificial Stone Tiles	30	1,20	0,001	2000,000	900,00
2	Cement Mortar	10	1,30	0,001	2000,000	1008,00
3	Cement Screed	20	1,30	0,001	2000,000	1000,00
4	XPS Board Insulation	30	0,03	0,001	30,000	1400,00
5	Waterproof Bituminous Layer	6	0,13	0,001	1055,000	1332,00
6	Reinforced Concrete	150	2,00	0,001	2400,000	950,00
Outside	Gravel Ground Fill	300	0,52	0,000	2000,000	1800,00
Flow Direction		**U-value (W/m^2K)**		**R-value (m^2K/W)**		
Downward		0,514		1,944		

3.3. Comparative Evaluation of the Generated Retrofitting Strategies

The retrofitting strategies are designed and defined in the previous section. In this section the strategies are simulated with the previously calibrated simulation model. Each level of intervention is evaluated with simulation of every individual measure separately or coupled with a previous one to determine their impartial and/or coupled effects on the indoor environment parameters, heating and cooling loads of the building, to provide ground for the sensitivity analysis of these measures in section 3.4.1. After evaluating measures and their effects on consumption outputs, each strategy is simulated in specified levels of intervention, including the defined measures. The individual measures and strategies are coded for simplicity of identification in evaluation of the simulation results (Table 49).

Evaluation of a single strategy is based on determination of the weights of applied measures on every retrofitting strategy. Therefore, following sub sections provide evaluation results for each of the individual measure and each retrofitting strategy.

Table 49. Codes for individual measures and strategies

Strategy	Code	Individual Measure	Code
Minor Level of Intervention	**S1**	Exterior brick wall + XPS insulation + brick cladding	**S1A**
		Exterior concrete wall + XPS insulation + plaster	**S1B**
		Replacement of glazing with low-e	**S1C**
Moderate Level of Intervention	**S2**	Exterior brick wall + XPS insulation + ventilated cavity + wooden facade cladding	**S2A**
		Replacement of glazing with low-e	**S2B**
		Replacement of frames with insulated vinyl frame	
Major Level of Intervention	**S3**	Exterior concrete wall + XPS insulation + ventilated cavity + wooden facade cladding	**S3A**
		Concrete floor on ground + XPS Insulation	**S3B**

3.3.1. Evaluation for Performance of Retrofitting Strategies

The calibrated simulation results for case building represent the actual energy performance of the building for year 2009. Any energy conservation measure therefore has to be evaluated in comparison to the results of the base case, to determine the efficiency of that measure on the energy performance of the case building. Several parameters are used in this section for this comparative evaluation and are listed as follows:

- Indoor temperature and humidity comparison for sample spaces on different orientations for peak heating and peak cooling day
- Comparison of heating and cooling load and consumption

Compliant with above comparisons, individual measures and retrofitting strategies are evaluated in the following sub-sections.

3.3.1.1. Evaluation of Minor Level of Intervention

Evaluation of minor level of intervention strategy (S1) is conducted on the simulation results of each individual measure and the strategy itself, which is composed of all measures. Analysis results for the first retrofitting strategy are presented in the following sub-sections, mainly focusing on the previously stated evaluation parameters.

3.3.1.1.1. Indoor Temperature and Relative Humidity

Assessment of indoor temperature and relative humidity differences between base case calibrated simulation model, simulated individual measures for the first strategy, and simulation of the strategy as a whole are presented in this section. The aim is to clarify direct effect of proposed energy saving measures on the indoor environment parameters. Orientation of spaces and peak heating/cooling days are the main means in representing changes in indoor temperature and relative humidity. Sample space from different orientations are selected to elucidate the changes in indoor parameters due to varying in retrofitting measures, and explained comprehensively. Peak heating and cooling days (February 23 and July 27) are obtained from the monitored weather data of 2009 as a mean daily temperature, respectively 5,43 °C and 28 °C. In the following paragraphs, the results of peak day evaluation are presented for sample spaces.

Sample north oriented space–Zone 115: A laboratory space (zone 115) is presented as a sample space for north orientation. Heat loss surfaces for this space is external brick wall (28,63 m^2), glazed areas (10,26 m^2) oriented north, and a side façade of external concrete wall (30,89 m2) oriented west. In Figure 77 and Figure 78, indoor temperature and relative humidity comparisons for peak heating day are presented respectively. Each graph includes monitored exterior temperature, monitoring results, simulated base case results, and simulated retrofitting intervention results for the specific date.

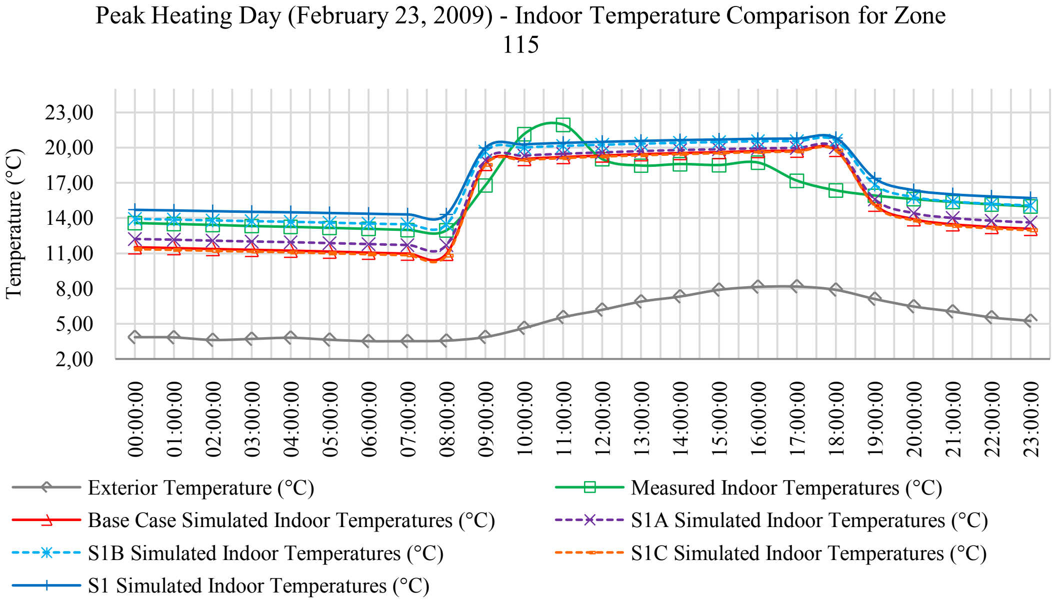


Figure 77. Minor level of intervention – north oriented space indoor temperature comparison on peak heating day

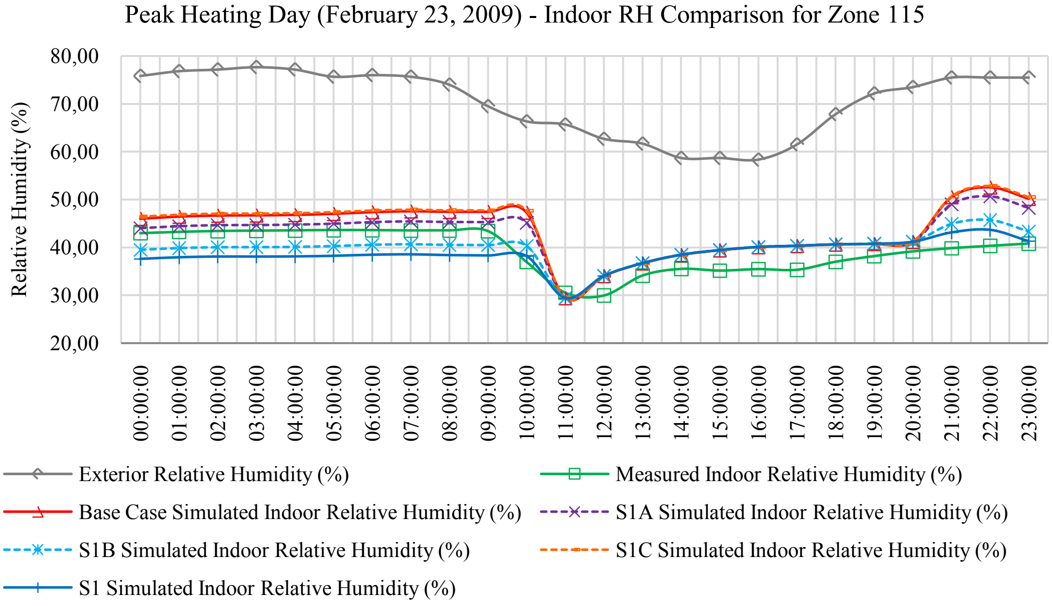


Figure 78. Minor level of intervention – north oriented space indoor relative humidity comparison on peak heating day

Several conclusions can be drawn from the analyses and are as follows:

- Simulated results for the base case during peak heating day provide lowest indoor temperature and highest relative humidity profiles due to lack of any energy efficiency measures in the existing situation of the case building.
- Via application of individual measure S1A (Exterior brick wall + XPS insulation + brick cladding), indoor temperature increase around 0,7°C and 0,3°C respectively during unconditioned and conditioned hours on peak heating day in 2009. Relative humidity decreases around 2 %, only during unconditioned hours, depending on the increase in indoor temperature.
- S1B (Exterior concrete wall + XPS insulation + plaster) provides an increasing shift in indoor temperatures during unconditioned hours, approximately 2,50 °C for the peak heating day and around 0,8 to 1°C during conditioned hours. On the other hand, relative humidity decreases around 6 to 7% during unconditioned hours.
- Via the improvement S1C (Replacement of glazing with low-e) peak heating day indoor temperature and relative humidity profiles indicate no improvement for north oriented spaces where solar gains do not exist.
- Application of the retrofitting strategy (S1) covering all indicated individual measures provide enhanced temperature and relative humidity results for indoor environment, when compared to base case and all individual measure results. During unconditioned hours increase in indoor temperature is around 3,2 °C and decrease in relative humidity is around 8,5%. During conditioned hours increase in indoor temperature and relative humidity is around 1,2 °C and 6,5 % respectively.

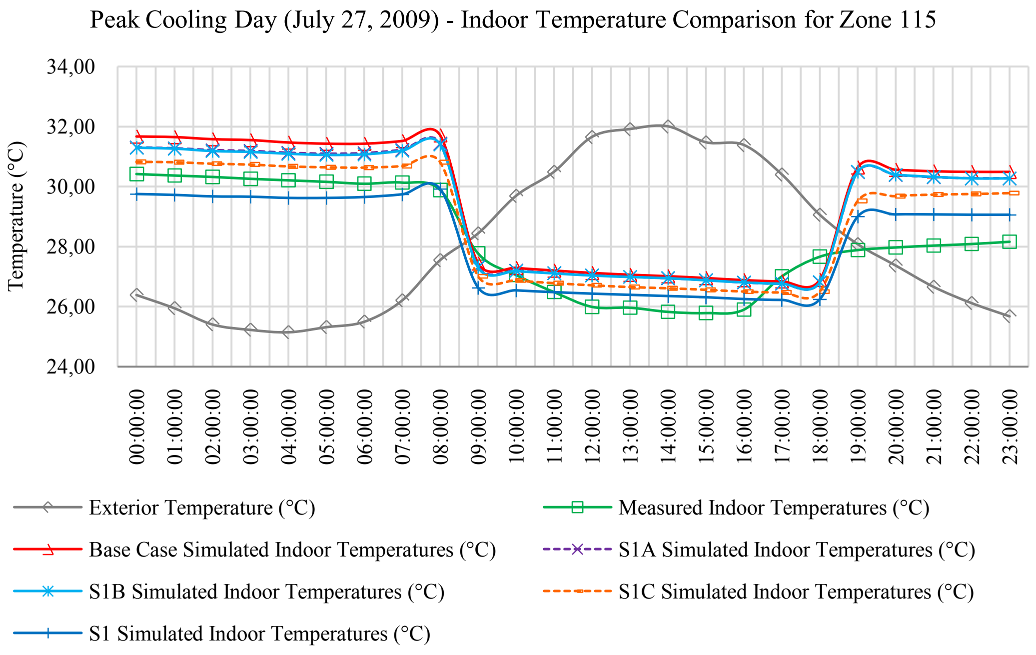


Figure 79. Minor level of intervention – north oriented space indoor temperature comparison on peak cooling day

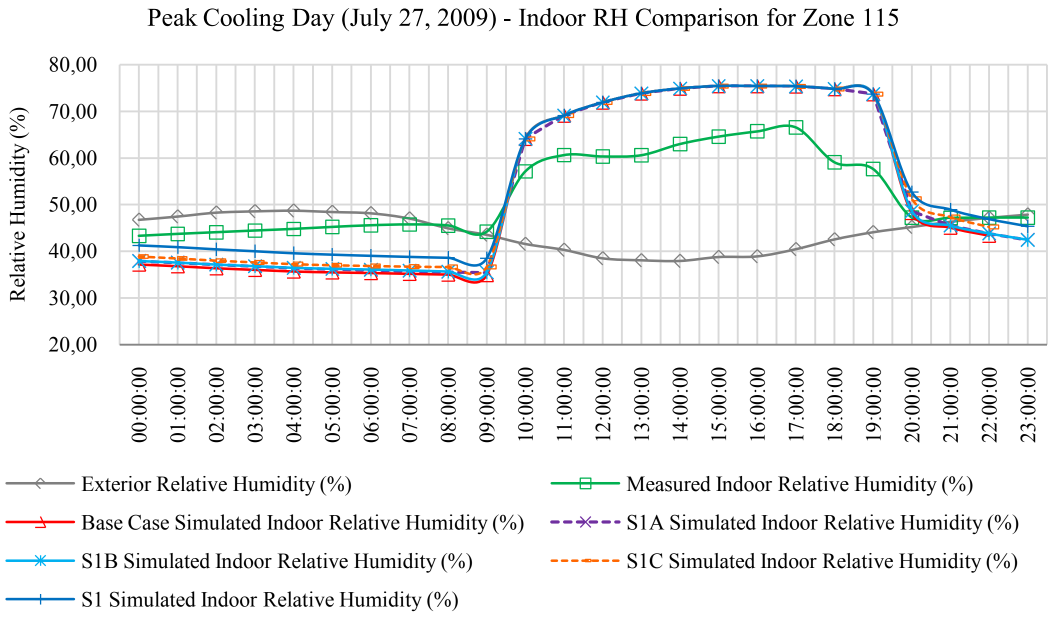


Figure 80. Minor level of intervention – north oriented space indoor relative humidity comparison on peak cooling day

Figure 79 and Figure 80 (p.149) presents peak cooling day results (indoor temperature and relative humidity) for minor level of intervention strategy and its sub measures. The results can be interpreted as:

- Base case results indicate that during unconditioned hours the indoor temperature fluctuates is around 32°C. The indoor temperature fluctuation of base case results has the highest values when compared to individual measure and strategy results.
- S1A (Exterior brick wall + XPS insulation + brick cladding) provides a decrease in indoor temperatures, approximately 0,3 °C during unconditioned hours and a very slight decrease of 0,1 °C during conditioned hours in comparison to base case results. With the application of S1A, there is only a negligible increase in relative humidity for peak cooling day in 2009.
- By means of S1B (Exterior concrete wall + XPS insulation + plaster) similar improvements similar to S1A are obtained for indoor environment.
- Improvement S1C (Replacement of glazing with low-e) offers a decrease in indoor temperatures around 0,8 °C during unoccupied hours and 0,4 °C for conditioned hours when compared to base case. Relative humidity increases approximately 1,6% for all hours during peak cooling day 2009.
- Retrofitting strategy (S1) as a set of individual measures provide a decrease in indoor temperatures of 1,7 °C and 0,7 °C, respectively for unconditioned and conditioned hours during peak cooling day in 2009. Relative humidity values increase around 3,8 % only during unconditioned hours and remains same for conditioned hours.

Sample south oriented space–Zone Z42: A medical office is selected as an example for south orientated spaces. Heat loss surface for the specific zone is 20,63 m^2 for external brick wall and 10,26 m^2 glazed area oriented south. There is significant heat loss from the west oriented external concrete wall (30,78 m^2). Figure 81 and Figure 82 provides indoor temperature and relative humidity comparisons for peak heating day in 2009. Results of the analysis are:

- Simulation results for the individual retrofitting measure S1C (Replacement of glazing with low-e) point out the lowest indoor temperature and highest relative humidity profiles. In comparison to base case results the retrofitting measure cause the peak heating day indoor temperatures to decrease around 0,5 °C. In parallel, relative humidity increase as a function of decreasing temperature profile, with an approximate value of 2,0 %.

- S1A (Exterior brick wall + XPS insulation + brick cladding) provides an increase of indoor temperatures around 0,4°C during unconditioned hours. The increase is less for conditioned hours and is around 0,2 °C for peak heating day in 2009. Relative humidity decreases around 1,2 %, only during unconditioned hours.
- Via the individual measure S1B (Exterior concrete wall + XPS insulation + plaster) 2,2 °C increase is obtained for indoor temperatures during unconditioned hours and 0,8 °C for conditioned hours. Due to increase in temperature relative humidity decreases approximately 5,7 % during unconditioned hours.
- The retrofitting strategy (S1), including all measures, offer improved temperature and relative humidity results for indoor environment, in comparison to base case and individual measure results. During unconditioned hours increase in indoor temperature is around 1,9 °C and decrease in relative humidity is around 6%. During conditioned hours increase for indoor temperatures is approximately 0,6 °C and relative humidity indicates no change.

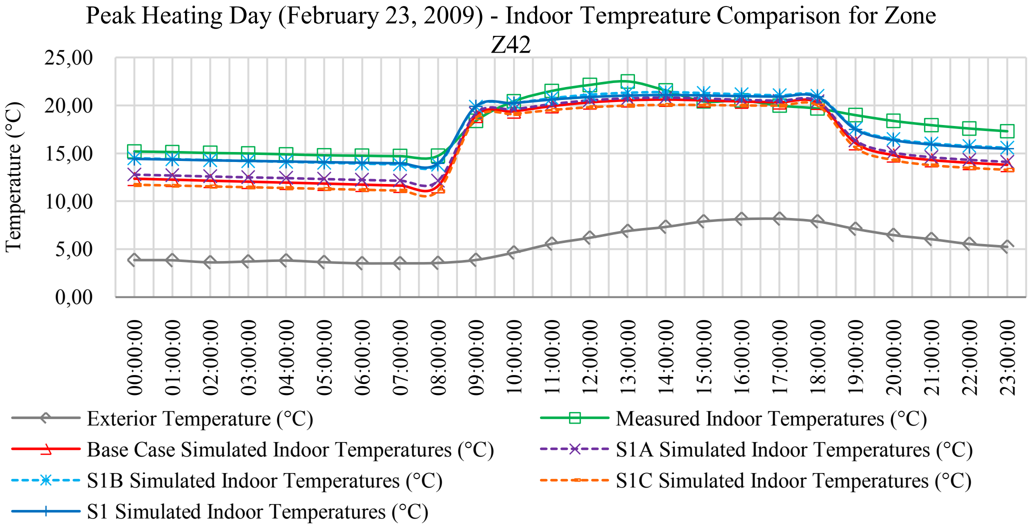


Figure 81. Minor level of intervention – south oriented space indoor temperature comparison on peak heating day

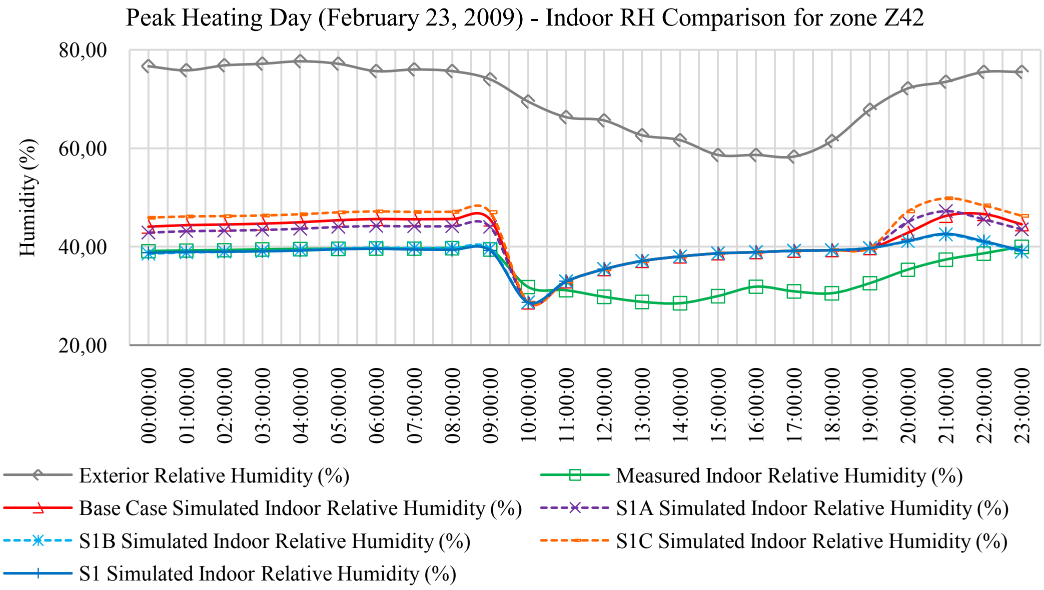


Figure 82. Minor level of intervention – south oriented space indoor relative humidity comparison on peak heating day

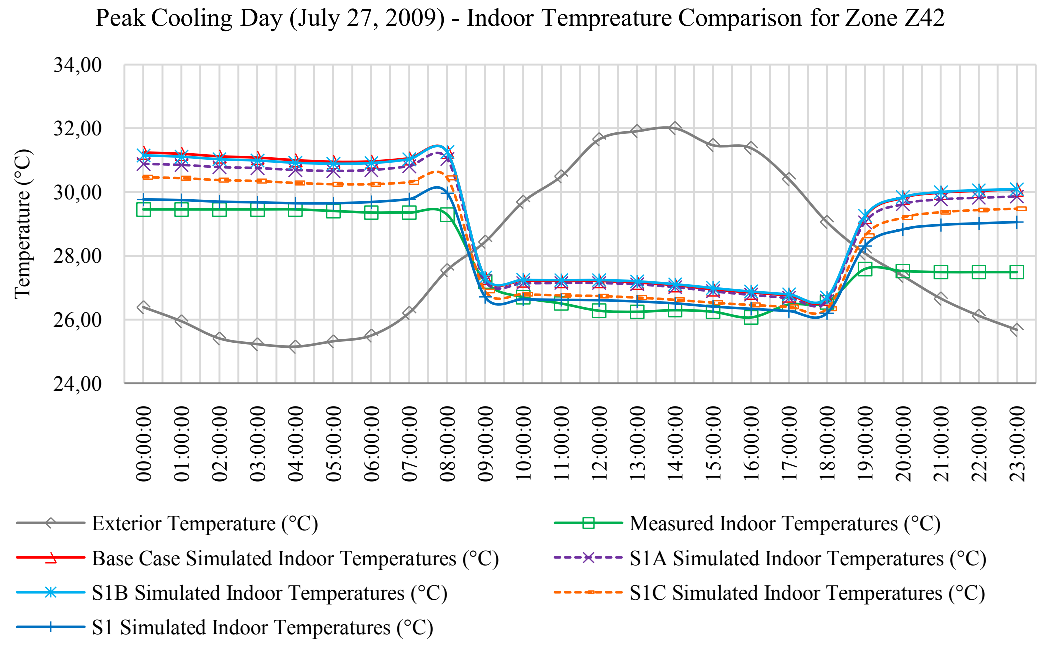


Figure 83. Minor level of intervention – south oriented space indoor temperature comparison on peak cooling day

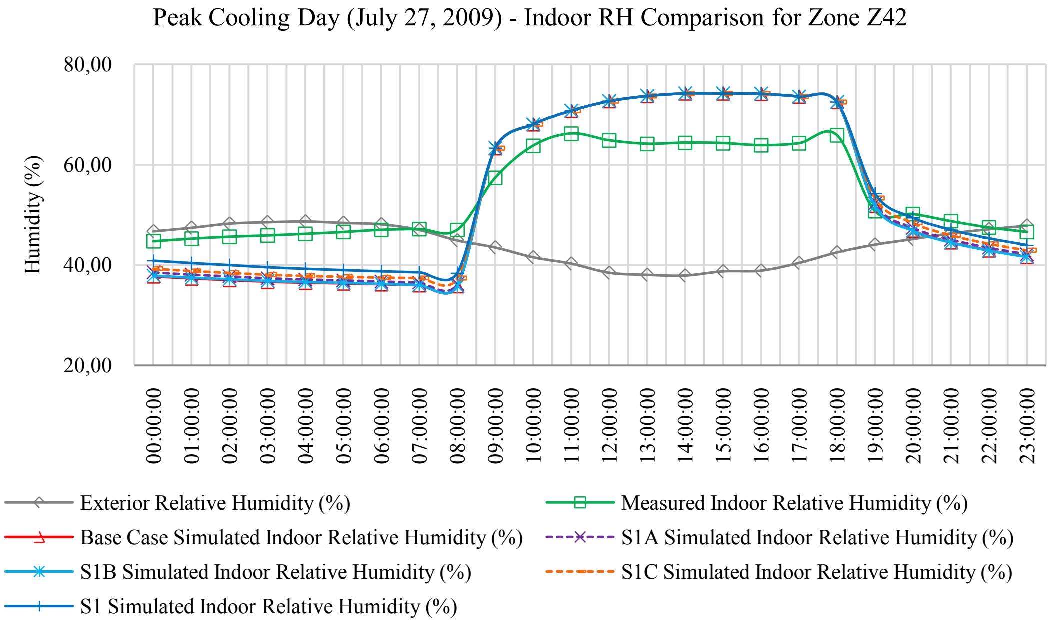


Figure 84. Minor level of intervention – south oriented space indoor relative humidity comparison on peak cooling day

In Figure 83 and Figure 84 peak cooling day results for indoor temperature and relative humidity in a south oriented zone is presented. The following conclusions can be drawn from this analysis:

- Similar to north oriented space, in south oriented space base case results indicate highest indoor temperature fluctuations between 30°C and 31°C and are the highest values when compared to individual measure and strategy results.
- Via measure S1A (Exterior brick wall + XPS insulation + brick cladding) approximately 0,3 °C of decrease is obtained during unconditioned hours and a very slight decrease of 0,1 °C during conditioned hours in comparison to base case results. Relative humidity increase has a negligible value for peak cooling day in 2009.
- S1B (Exterior concrete wall + XPS insulation + plaster) provide negligible improvement in indoor environment parameters.
- Measure S1C (Replacement of glazing with low-e) offers a decrease in indoor temperatures around 0,8 °C during unoccupied hours and 0,4 °C for conditioned hours when compared to base case. There is 1,3% increase in relative humidity values for peak cooling day 2009.

- For south space, retrofitting strategy (S1) provide a decrease in indoor temperatures around 1,1 °C and 0,6 °C, respectively for unconditioned and conditioned hours during peak cooling day in 2009. Relative humidity values increase around 2,5 % only during unconditioned hours and remains equal to base case values for conditioned hours.

Sample west oriented space–Zone Z04: A typical office space is evaluated as an example for west orientated spaces. West exposure of the space is composed of external brick wall (15,69 m^2) and glazed area (10,26 m^2). Secondary exposure of the space is oriented towards south is constructed from external brick wall (10,72 m^2). Concrete elements that cause heat loss surfaces are only the load bearing structure and act as thermal bridges. In Figure 85 and Figure 86 comparison results for indoor temperature and relative humidity during peak heating day in 2009 are presented. The analysis provides following outcomes:

- S1C (Replacement of glazing with low-e) gives the lowest indoor temperature and highest relative humidity profiles in comparison to base case results. The retrofitting measure is responsible for a decrease around 0,6 °C for day indoor temperatures during peak heating day. Thus, relative humidity increase as a function of decreasing temperature profile, with a value around 1,4 %.
- Retrofitting measure S1A (Exterior brick wall + XPS insulation + brick cladding) provides an increase of indoor temperatures around 0,9°C during unconditioned hours and 0,4 °C during conditioned hours, when compared to base case results. Relative humidity decreases around 2,0 %, only during unconditioned hours.
- S1B (Exterior concrete wall + XPS insulation + plaster) causes negligible improvements both for indoor temperature and humidity results.
- Strategy S1 provides slightly improved temperature and relative humidity results for indoor environment, in comparison to base case and individual measure results. During unconditioned hours the improve in indoor temperatures is around 0,4 °C and decrease in relative humidity is around 0,8%. During conditioned hours the increase in indoor temperatures results are approximately 0,3 °C and relative humidity indicates no change.

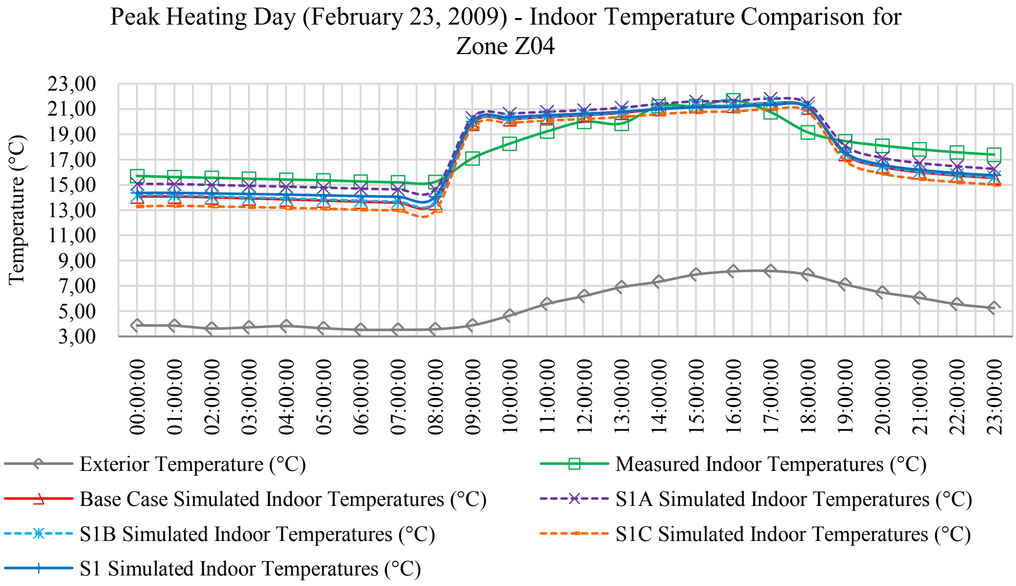


Figure 85. Minor level of intervention – west oriented space indoor temperature comparison on peak heating day

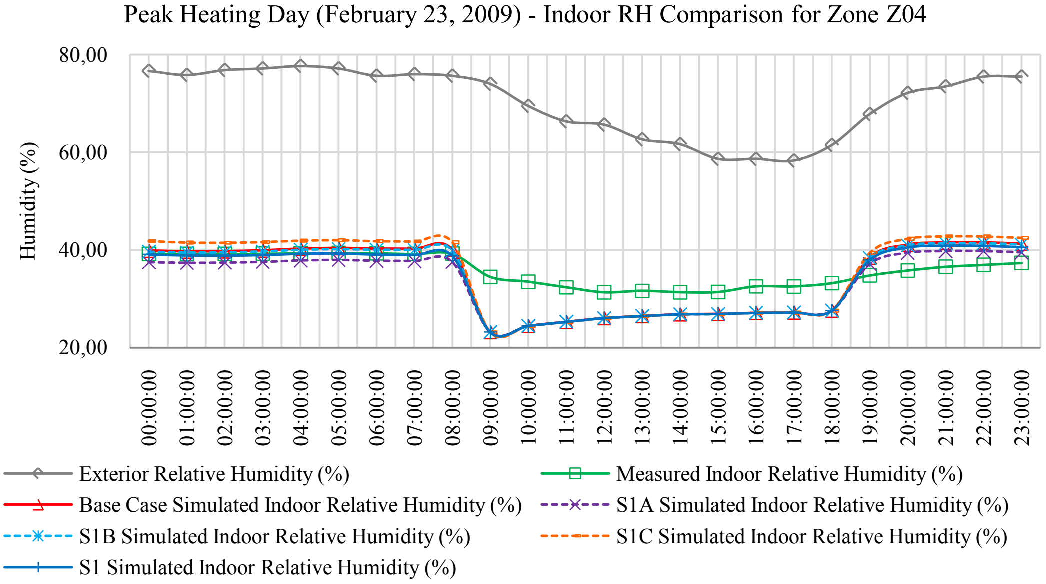


Figure 86. Minor level of intervention – west oriented space indoor relative humidity comparison on peak heating day

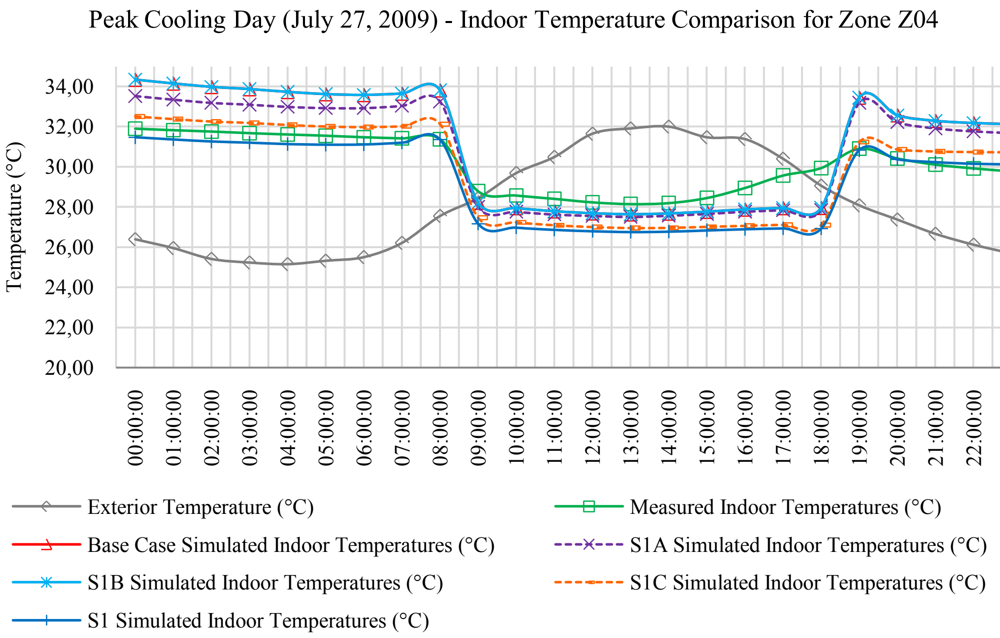


Figure 87. Minor level of intervention – west oriented space indoor temperature comparison on peak cooling day

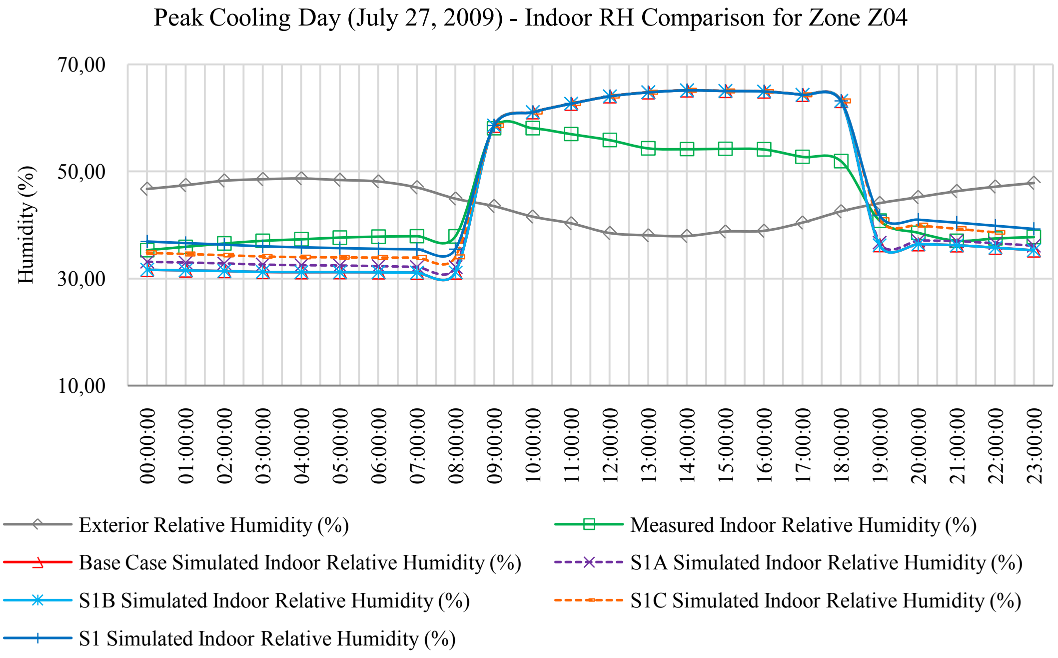


Figure 88. Minor level of intervention – west oriented space indoor relative humidity comparison on peak cooling day

Figure 87 and Figure 88 (p.156) present peak cooling day results for indoor temperature and relative humidity in a west oriented zone. Conclusions drawn from the analysis are:

- For west oriented space, base case indicate highest indoor temperature fluctuations between 33°C and 34°C and are the highest values when compared to individual measure and strategy results.
- Via measure S1A (Exterior brick wall + XPS insulation + brick cladding) approximately 0,7 °C of decrease is obtained during unconditioned hours and a very slight decrease of 0,5 °C during conditioned hours in comparison to base case results. Relative humidity increase is around 1,0 % for peak cooling day.
- S1B (Exterior concrete wall + XPS insulation + plaster) provide insignificant improvement in indoor environment parameters.
- S1C (Replacement of glazing with low-e) provides approximately 1,7 °C decrease in indoor temperatures during unoccupied hours and 0,8 °C during conditioned hours when compared to base case. There is 4,6 % increase in relative humidity values due to increasing temperature profiles.
- Retrofitting strategy (S1) provide a decrease in indoor temperatures around 2,4 °C and 1,0 °C, respectively for unconditioned and conditioned hours during peak cooling day for a west oriented space. Relative humidity values increase around 2,5 % only during unconditioned hours and remains equal to base case values for conditioned hours.

Sample east oriented space–Zone 121: An office space oriented to east and is evaluated as an example to compare indoor temperature and relative humidity profiles with respect to applied individual measures and the first retrofitting strategy. The exposed surface is composed of external brick wall (5,70 m^2) and glazed area (6,84 m^2). Side elevation of the space is oriented north and constructed as a concrete wall with a heat loss surface area of 26,22 m^2. In Figure 89 and 90 (pp. 158-159) comparison results for peak heating day in 2009 are presented. The analysis provides following outcomes:

- S1C measure (Replacement of glazing with low-e) gives lowest results significantly close to base case results when lowest indoor temperature and highest relative humidity profiles are compared.

- S1A (Exterior brick wall + XPS insulation + brick cladding) improves indoor temperatures around 0,5°C during unconditioned hours and 0,2 °C during conditioned hours in comparison to base case results. Relative humidity decreases around 1,5 %, only during unconditioned hours.
- Via application of S1B (Exterior concrete wall + XPS insulation + plaster) 3,0 °C improvement is obtained for indoor temperatures during unconditioned hours. Improvement for conditioned hours is around 1,2°C. On the other hand relative humidity values decrease by 8,7 % during unoccupied hours due to application of the individual measure.
- Strategy S1 provide increased indoor temperature profiles in comparison to base case and individual measure results. During unconditioned hours the improve in indoor temperatures is around 3,6 °C and decrease in relative humidity is around 10,2 %. During conditioned hours the increase in indoor temperatures results are approximately 1,4 °C and relative humidity indicates no change.

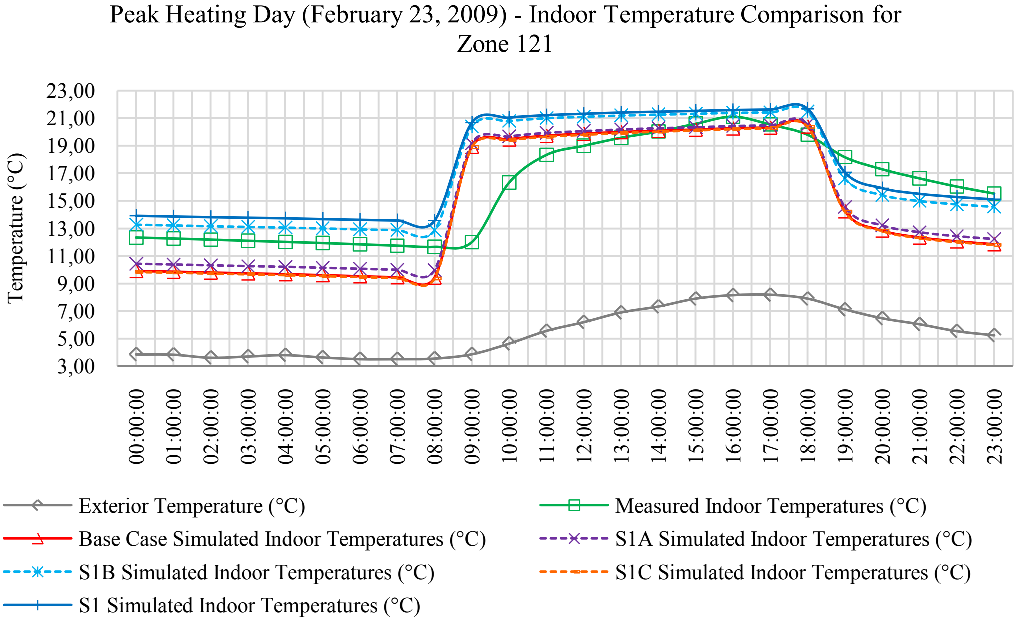

Peak Heating Day (February 23, 2009) - Indoor Temperature Comparison for Zone 121

Figure 89. Minor level of intervention – east oriented space indoor temperature comparison on peak heating day

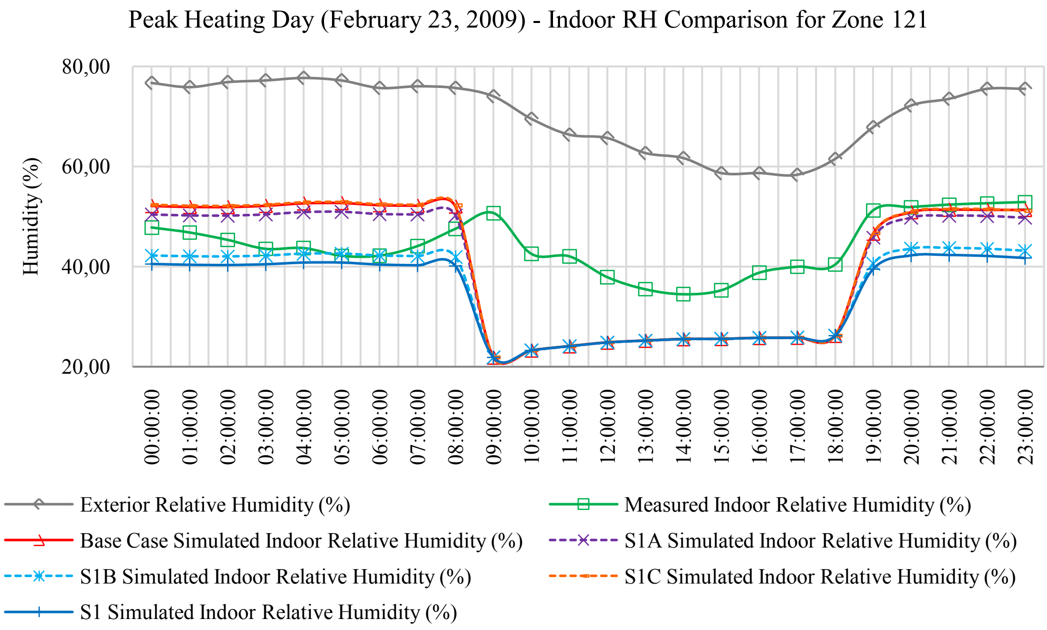


Figure 90. Minor level of intervention – east oriented space indoor relative humidity comparison on peak heating day

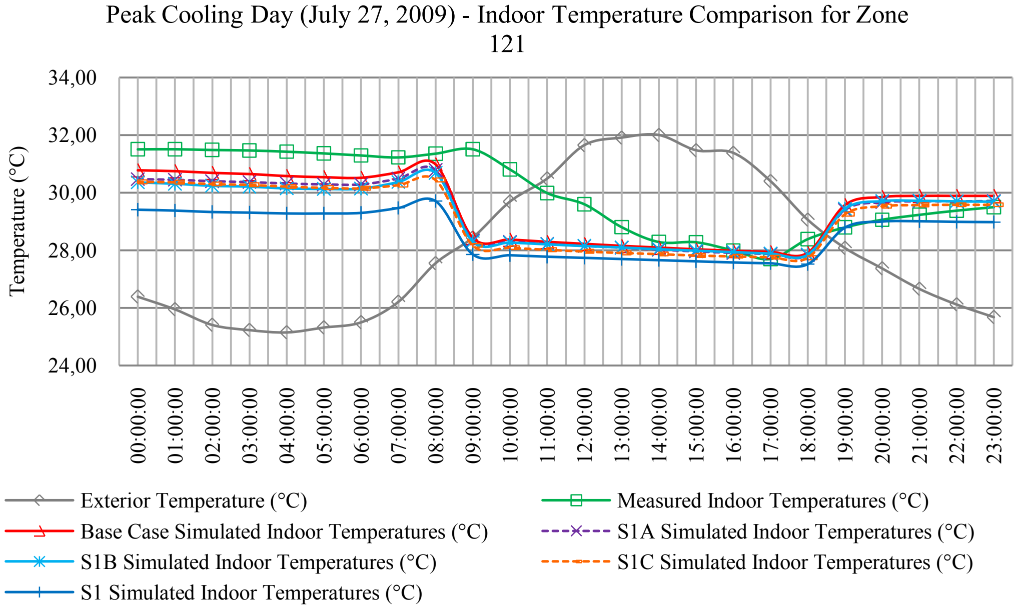


Figure 91. Minor level of intervention – east oriented space indoor temperature comparison on peak cooling day

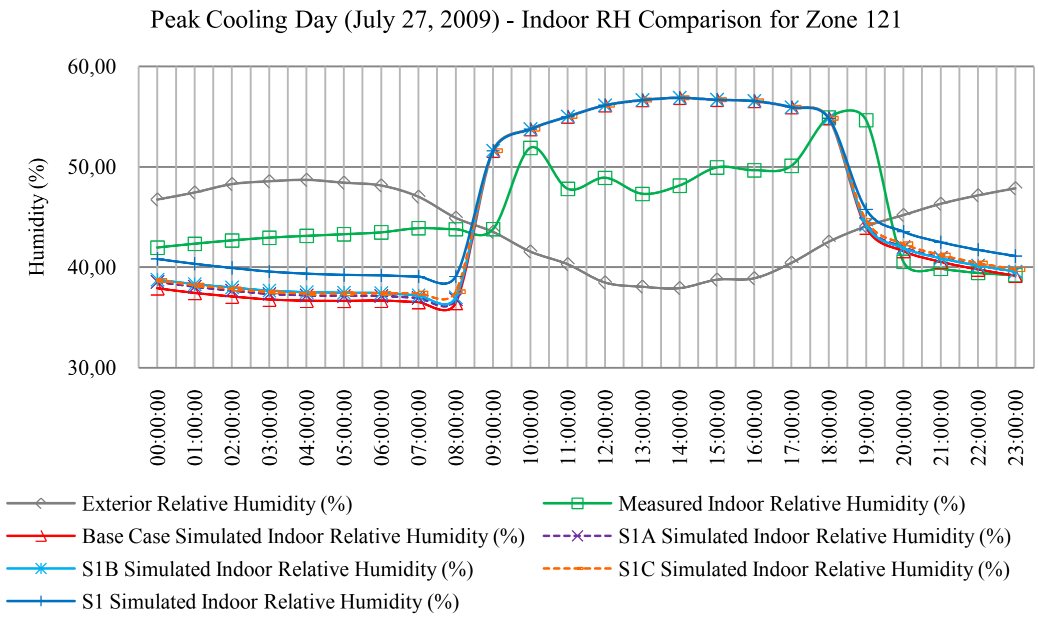


Figure 92. Minor level of intervention – east oriented space indoor relative humidity comparison on peak cooling day

Figure 91 and Figure 92 present peak cooling day results for indoor temperature and relative humidity. The conclusions of the analysis are:

- For west oriented space, base case indicates highest indoor temperature fluctuations around 31°C and lowest relative humidity profile.
- Measure S1A (Exterior brick wall + XPS insulation + brick cladding) offer approximately 0,2 °C of decrease is for indoor temperatures during unconditioned hours. The decrease during conditioned hours in comparison to base case results is insignificant. Relative humidity increase is around 0,5 % for peak cooling day.
- S1B (Exterior concrete wall + XPS insulation + plaster) provide an improvement for indoor temperature profile with a decrease 0,3 °C during unconditioned hours. The increase in relative humidity is very small and around 0,6%.
- S1C (Replacement of glazing with low-e) provides approximately 0,4 °C decrease in indoor temperatures during unoccupied hours and 0,2 °C during conditioned hours when compared to base case. There is 0,6 % increase in relative humidity values, which is a very insignificant value.

- Via application of the retrofitting strategy (S1) provide a decrease in indoor temperatures around 1,1 °C and 0,5 °C, respectively for unconditioned and conditioned hours during peak cooling day for a west oriented space. Relative humidity values increase around 2,3 % only during unconditioned hours and remains equal to base case values for conditioned hours.

Thus far, numeric results are presented for peak heating and cooling days; however it is necessary to summarize these results to establish the relationship of the interventions with the shifts in indoor environment parameters. The results are presented in Table 50

According to Table 50, in comparison to base case simulation results, the deviations for peak heating and cooling days via individual measures and minor level of intervention strategy, following assessments can be done specific for each measure:

1) Measure S1A (Exterior brick wall + XPS insulation + brick cladding):

Improvement of exterior brick wall with 40 mm XPS insulation and brick cladding results with an average of 0,58 °C increase for indoor temperature on a peak heating day during unconditioned period and 0,26°C increase for conditioned period. The outcome of this improvement for peak cooling day is lower, with an average of 0,32 °C decrease for indoor temperatures during unconditioned hours. Due to increasing thermal mass for the specific building envelope component, the improvement becomes considerably effective for winter indoor temperatures, moreover presents a slight effect on summer indoor temperatures. Relative humidity deviations are inversely proportional to the changes in temperature, especially in unconditioned hours. It is possible to state that measure S1A has an average effect both on heating and cooling period indoor temperature profiles.

2) Measure S1B (Exterior concrete wall + XPS insulation + plaster):

Improvement of exterior reinforced concrete walls with 50 mm XPS insulation and plaster finishing provides an average of 2,37 °C increase for indoor temperature on a peak heating day during unconditioned period and 0,97°C increase for conditioned period. The higher increases in temperature are for north and east oriented spaces, where solar gains are considerably less effective. West oriented space is neglected in this result since there is no major reinforced concrete surface for the zone which acts as a heat loss surface. The improvement for indoor temperatures during peak heating day is significant, and the measure itself contributes to indoor environment parameters for heating season. Additionally, there is a very slight decrease of indoor temperatures (around 0,2°C) due to the application of S1B during peak cooling day. As a result, insulation improvement for reinforced concrete surfaces a significant effect on both heating period indoor temperature profiles.

Table 50. Comparison results for individual measures and minor level of intervention strategy – deviations for peak heating and cooling days

Applied Intervention	Day Type	Parameters	Orientation			
			North	**South**	**West**	**East**
S1A	**Peak Heating**	ΔT_U (°C)	0,63	0,40	0,86	0,44
		ΔT_c (°C)	0,27	0,19	0,38	0,19
		ΔRH_U (%)	-1,58	-0,56	-2,05	-1,44
	Peak Cooling	ΔT_U (°C)	-0,27	-0,25	-0,54	-0,22
		ΔT_c (°C)	-0,08	-0,07	-0,14	-0,07
		ΔRH_U (%)	0,53	0,57	0,98	0,47
S1B	**Peak Heating**	ΔT_U (°C)	2,18	1,95	0,07	2,98
		ΔT_c (°C)	0,90	0,81	0,02	1,21
		ΔRH_U (%)	-1,81	-4,53	-0,17	-8,67
	Peak Cooling	ΔT_U (°C)	-0,28	-0,02	0,00	-0,28
		ΔT_c (°C)	-0,08	0,03	0,00	-0,07
		ΔRH_U (%)	0,53	0,05	0,00	0,59
S1C	**Peak Heating**	ΔT_U (°C)	-0,12	-0,54	-0,61	-0,06
		ΔT_c (°C)	-0,09	-0,41	-0,36	-0,06
		ΔRH_U (%)	0,27	1,93	1,40	0,13
	Peak Cooling	ΔT_U (°C)	-0,84	-0,67	-1,67	-0,36
		ΔT_c (°C)	-0,40	-0,42	-0,75	-0,23
		ΔRH_U (%)	1,71	1,44	3,14	0,75
S1	**Peak Heating**	ΔT_U (°C)	2,90	1,90	0,28	3,58
		ΔT_c (°C)	1,15	0,63	0,03	1,43
		ΔRH_U (%)	-6,90	-4,51	-0,81	10,20
	Peak Cooling	ΔT_U (°C)	-1,67	-1,17	-2,39	-1,08
		ΔT_c (°C)	-0,68	-0,55	-0,96	-0,46
		ΔRH_U (%)	3,46	2,62	4,62	2,33

3) Measure S1C (Replacement of glazing with low-e):

Replacement of double glazed panes with low-e glazing provides an average of 0,9 °C decrease for indoor temperature on a peak cooling day during unconditioned period and 0,45°C increase for conditioned period. The highest decrease in indoor temperature is obtained in the evaluation of south space (1,67°C) due to long periods of exposure to solar radiation during peak cooling day. Contrary to the improvements during peak cooling day, indoor temperatures as well decreased around 0,3 °C during peak heating day, which is not desirable. This is a result of low-e coating position in the glazing panes, and their reflective effects for solar energy, which turns out to be an unutilized gain during winter period. Therefore it is possible to assert that, replacement of low-e glazing contributes a decrease for indoor temperatures during cooling period, however causes winter indoor temperatures as well.

4) Retrofitting Strategy S1 (Minor Level of Intervention):

Measures are applied as a set that constitutes the first retrofitting strategy. The results present an average of 2,17 °C increase for indoor temperature on a peak heating day during unconditioned period and 0,81°C increase for conditioned period. It is observed that the interaction of all measures present a very close result to the best increase obtained by S1B. On peak cooling day, an average decrease of 1,58°C is achieved for indoor temperatures during unconditioned period, which is a very close result to S1C. It is possible to affirm that the strategy is balanced with the application of all individual measures together and able to attain good levels of indoor temperature parameters when compared to the simulated base case and individual retrofitting measures.

The evaluation of individual measures and retrofitting strategy can be supported with the analysis in Figure 93. The analysis represents the change in maximum and minimum performance values obtained in the hourly simulation model. These maximum and minimum values are obtained from the simulation model without considering any zone or orientation properties. According to the graph it is possible to support the previous findings from orientation and peak day analysis. For instance, maximum temperatures decrease significantly with the application of S1, and there is a parallel decrease for cooling loads. Furthermore, S1C causes minimum temperatures to decrease vaguely, however increases the maximum heating load due to limitation of solar gains during winter period. Better results are obtained for all parameters with the application of a combined improvement approach S1 (minor level of intervention).

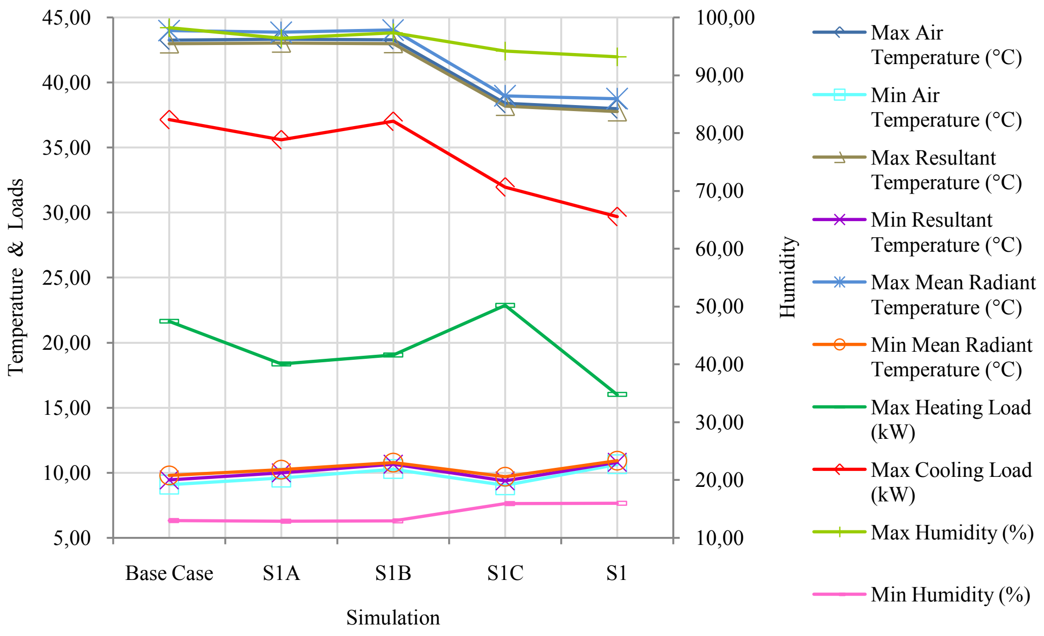


Figure 93. Performance values of simulation results for individual measures and minor level of intervention

It is essential to emphasize that sample volumes do not represent all volumes, since there are different influential factors on indoor parameters, such as presence of less heat loss surface area. However, the examples are useful in terms of indicating the indoor responses to the improvements and/or improvement sets as strategies. Holistic evaluation of the improvements is thus presented in the following subsection, with respect to load and consumption patterns of the building.

3.3.1.1.2. Loads and Consumption

The comparison of loads and consumption values for the whole building simulation results are evaluated in this section with the purpose to determine the efficacy of individual measures (S1A, S1B and S1C) and the proposed retrofitting strategy (S1). Figure 94 and Figure 95 present the comparison of simulated annual loads for retrofitting measures to the simulated annual loads and consumption.

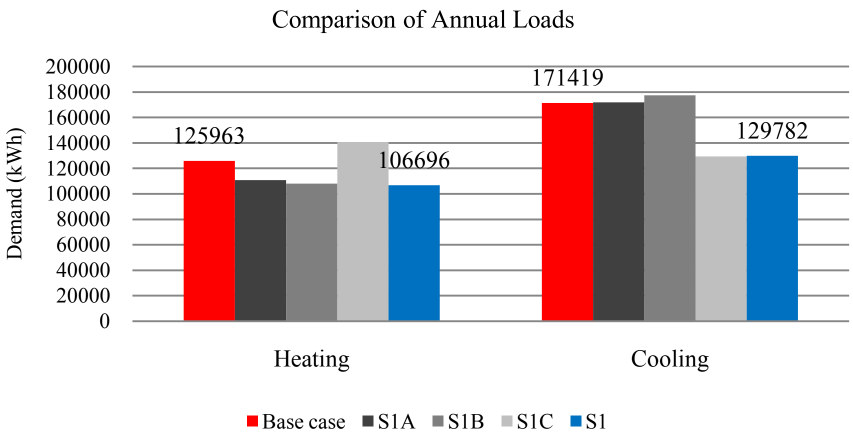


Figure 94. Comparison of simulated annual loads for base case and minor level of intervention

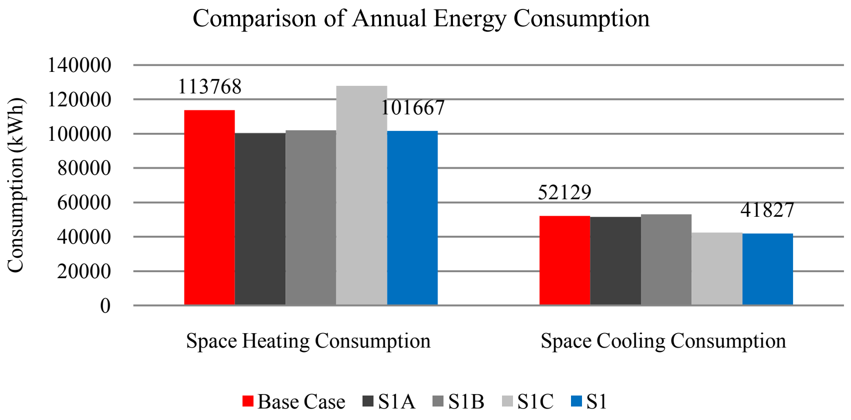


Figure 95. Comparison of simulated annual energy consumption for base case and minor level of intervention

The analysis results can be evaluated as:

1) Measure S1A (Exterior brick wall + XPS insulation + brick cladding) results in 14 % reduction on annual heating loads, and 0,2% increase in cooling loads which is negligible. The measure is effective on heating loads for whole building retrofit assessment and contributes a decrease of 12% in annual heating energy use.
2) Measure S1B (Exterior concrete wall + XPS insulation + plaster) has similar results to S1A when results for heating load reduction is compared. The reduction is 12% and the annual heating energy consumption decreases by 10%.

In addition, annual cooling loads increase via S1B 4% and the energy consumed for cooling increases vaguely, by 2%. The individual measure provides efficiency for heating energy consumption of the building.

3) Measure S1C, replacement of double glazed panes with low-e glazing effect both annual heating load and energy use for heating to increase by 12%. On the contrary, this measure has a significant improvement with a decrease of 25% in annual cooling load of the building. This decrease on annual cooling load reflects on the end use consumption with a decrease of %18. The measure provides efficiency for cooling energy performance of the building however has an inverse effect on the heating energy performance.
4) Retrofitting strategy S1 (minor level of intervention), as a set of all measures, provide a reduction of 15 % in annual loads, which reflect on annual energy use as 11%. Annual cooling load and annual cooling energy consumption are reduced as well, with proportions of 24% and 20% respectively.

3.3.1.2. Evaluation of Moderate Level of Intervention

Evaluation of moderate level of intervention strategy (S2) is conducted on the simulation results of each individual measure and the strategy composed of these measures. The minor level of intervention is retrieved from previous analysis including measures, which offer best results on heating and cooling loads for the first strategy, and is denoted as S1′. Introduced measures for this strategy will be applied as an addition or replacement to S1′, which includes S1B (Exterior concrete wall + XPS insulation + plaster) and S1C (Replacement of glazing with low-e).

Individual measures that constitute the retrofitting strategy, S2 - moderate level of intervention are S2A, which is an improvement for exterior clinker brick walls with 30 millimeters of XPS insulation, 30 millimeters of ventilated air cavity and wooden façade cladding with a U-value of 0,527 W/m^{2}K. This improvement is a replacement for the S1A in the previous strategy. S2B is an additional improvement to S1C, by replacement of glazing frames with insulated vinyl frames, U-value = 1,40 W/m^{2}K (Section 3.2.2.2).

The analysis results for retrofitting strategy S2 (moderate level of intervention) are presented in the following sub-sections. For simplicity, the evaluation of indoor temperature and humidity profiles is not presented on detailed graphical basis hence on tabular basis as in section 3.3.1.1.1.

3.3.1.2.1. Indoor Temperature and Relative Humidity

Indoor temperature and relative humidity differences between the base case calibrated simulation results, individual measures and the strategy composed with these measures are evaluated in this section. The aim is to present the effects of these measures on the indoor environment parameters.

The evaluation is conducted parallel to the previous strategy in regard to orientation and peak heating/cooling days, to investigate the changes in indoor temperature and relative humidity. Identical spaces are used for the same peak heating and cooling days (February 23 and July 27) in 2009. Table 51 presents the comparison results, based on the deviations for indoor temperature and relative humidity parameters. Results for S1′ are presented in this table as well, to define the pre-accepted interventions retrieved from the previous strategy.

According to comparisons in Table 51, following assessments can be made on each individual measure and the strategy:

1) Measure S2A (Exterior brick wall + XPS insulation + ventilated cavity + wooden facade cladding):

S2A, which is a replacement measure for S1A (40 millimeters of XPS insulation and brick cladding finishing), requires 30 millimeters XPS insulation as determined with an optimum insulation thickness evaluation in section 3.2.1.2. With the addition of S2A to S1′, indoor temperatures for peak heating day increases with an average of 2,12 °C (<2,17°C of S1) during unconditioned hours and 0,79°C (<0,81°C of S1) during conditioned period. For peak cooling day, average decrease for indoor temperatures is 1,57 °C (<1,58°C of S1) during unconditioned hours and 0,66°C (=0,66°C of S1) for conditioned hours in comparison to base case simulation results. The deviation of indoor temperature results for S1 and S2A are very close, despite the increase of U-value of S2A measure (from 0,487 W/m^{2}K to 0,527 W/m^{2}K. Decreased insulation thickness is well compensated with the ventilated cavity, which acts as a buffer barrier for exterior weather. Ventilated cavity itself does not contribute to heating load reduction but helps to decrease applied insulation thickness (Naboni, 2007). It is possible to state that measure S2A coupled with S1′ has a balanced indoor temperature adjustment close to results of S1.

Table 51. Comparison results for individual measures and moderate level of intervention strategy – deviations for peak heating and cooling days

Applied Intervention	Day Type	Parameters	Orientation			
			North	**South**	**West**	**East**
S1'	**Peak Heating**	ΔT_U (°C)	2,07	1,36	-0,54	2,92
		ΔT_c (°C)	0,80	0,37	-0,34	1,15
		ΔRH_U (%)	-1,37	-3,48	1,23	-8,56
	Peak Cooling	ΔT_U (°C)	-1,29	-0,83	-1,68	-0,78
		ΔT_c (°C)	-0,55	-0,45	-0,75	-0,35
		ΔRH_U (%)	2,93	1,81	3,15	1,64
S2A	**Peak Heating**	ΔT_U (°C)	2,85	1,86	0,23	3,54
		ΔT_c (°C)	1,13	0,61	0,01	1,41
		ΔRH_U (%)	-3,48	-4,84	-0,69	-10,12
	Peak Cooling	ΔT_U (°C)	-1,66	-1,17	-2,38	-1,08
		ΔT_c (°C)	-0,68	-0,55	-0,95	-0,46
		ΔRH_U (%)	3,83	2,60	4,59	2,31
S2B	**Peak Heating**	ΔT_U (°C)	2,14	1,42	-1,10	2,97
		ΔT_c (°C)	0,82	0,39	-0,61	1,17
		ΔRH_U (%)	-1,56	-3,67	1,06	-8,67
	Peak Cooling	ΔT_U (°C)	-1,27	-0,82	-2,08	-0,77
		ΔT_c (°C)	-0,55	-0,45	-1,04	-0,35
		ΔRH_U (%)	2,90	1,77	3,23	1,62
S2	**Peak Heating**	ΔT_U (°C)	2,92	1,93	0,30	3,59
		ΔT_c (°C)	1,16	0,64	0,04	1,43
		ΔRH_U (%)	-3,68	-5,04	-0,87	-10,25
	Peak Cooling	ΔT_U (°C)	-1,65	-1,15	-2,36	-1,06
		ΔT_c (°C)	-0,68	-0,55	-0,95	-0,46
		ΔRH_U (%)	3,80	2,56	4,54	2,29

2) Measure S2B (replacement of glazing frames with insulated vinyl frames):

S2B as an additional measure to S1′, which only intervenes by replacement of existing aluminum thermal break frames with insulated vinyl frames.S2B provides an average of 1,36 °C increase for indoor temperature on a peak heating day during unconditioned period and 0,44°C increase for conditioned period in comparison to base case results. On peak cooling day, decreases for indoor temperatures in comparison to base case are 1,24 °C and 0,60 °C, respectively during unconditioned and conditioned hours. Slight temperature deviations are observed for north, south and east spaces around 0,06°C, when compared to S1´ results, which indicates that insulated vinyl frames has a minor influence on indoor environment parameters.

3) Retrofitting Strategy S2 (Moderate Level of Intervention):

S2 (moderate level of intervention), which is proposed with additional measures of S2A and S2B to S1´ presents an average of 2,19 °C (>2,17°C of S1) increase for indoor temperature on a peak heating day during unconditioned period and 0,82°C (>0,81°C of S1) increase for conditioned period, in comparison to base case results. An average decrease of 1,56°C (<1,58°C of S1) is achieved for indoor temperatures during unconditioned period and 0,66°C (=0,66°C of S1) during conditioned hours, on peak cooling day. There is a negligible difference for indoor temperature deviations of S2 and S1, although U-value for the exterior clinker brick wall improvement has increased and the effect of insulated vinyl frames are proved to have a minor influence.

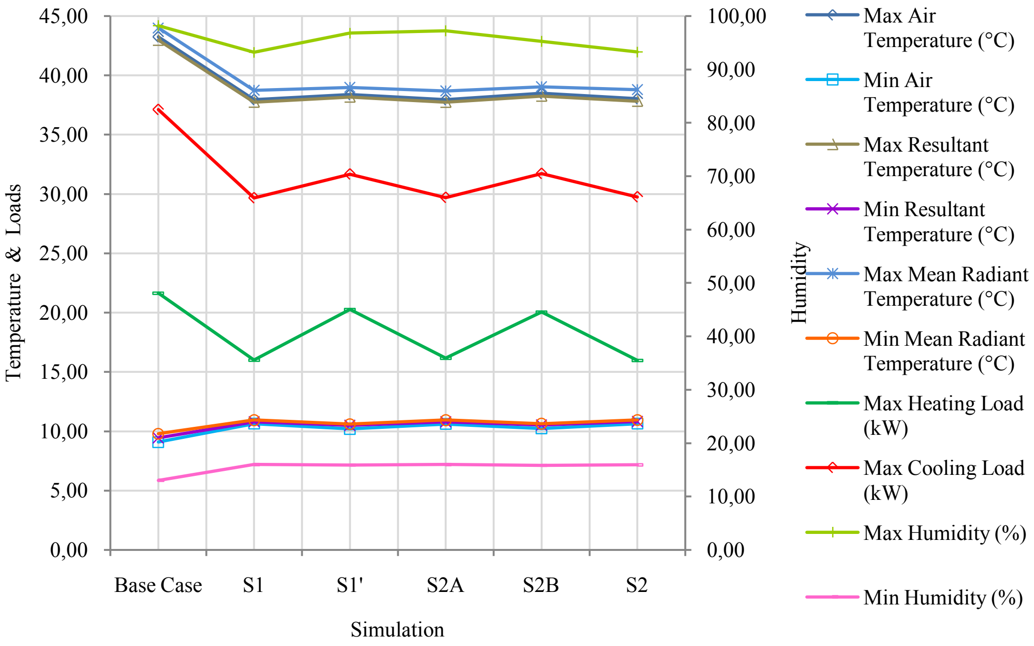


Figure 96. Performance values of simulation results for individual measures and moderate level of intervention

Further evaluation of individual measures and retrofitting strategy can be maintained with the analysis in Figure 96, which represents the change in maximum and minimum performance values obtained from the hourly simulation model. The analysis helps to support the general findings for the above comparison of indoor temperature and humidity. If base case and S1 results are considered as main comparison benchmarks and where S1′ only integrates exterior concrete wall insulation and replacement of glazing with low-e, it is possible to make the following assessments:

- Individual measure S2B which integrates replacement of existing frames with insulated vinyl frames as an addition to S1′ points out that there is no significant change for all parameters in Figure 96.
- Individual measure S2A is applied as an addition to S1′, via substituting previous exterior brick wall improvement of 40 millimeters XPS insulation and brick cladding, with 30 millimeters XPS insulation, ventilated cavity and wooden façade cladding. The results are very close between S1and S2A.
- Retrofitting strategy S2 (moderate level of intervention) has close values obtained by strategy S1 (minor level of intervention), despite the higher U-value of ventilated cavity intervention and replacement of existing frames.

As a result it is possible to assert that the comparison between base case, retrofitting strategy S1 (minor level of intervention) and S2 (moderate level of intervention) presents results that both strategies offer improvements for the indoor environment parameters, hence not significant differences.

3.3.1.2.2. Loads and Consumption

In this part of the evaluation, moderate level of intervention simulation results are investigated, on the basis of annual loads and consumption to determine the effects of individual measures and the retrofitting strategy as a whole. The comparison set includes simulation results for base case, S1, S1′, individual measures S2A and S2B (as an addition to S1′), and S2 (moderate level of intervention).Figure 97 and Figure 98 present comparison results for these simulation results and can be evaluated as follows:

1) Measure S2A (S1′ + exterior brick wall improvement with 30 millimeters XPS insulation, ventilated cavity and wooden façade cladding) provides 14 %

reduction on annual heating loads, and 24% in cooling loads, in comparison to simulated base case results. Cutback on energy consumption is 10% for heating and 20% for cooling in comparison to base case. Annual loads and consumption values are very close to S1, even though the measure applied for external brick walls is altered with a ventilated cavity application, which has a higher U-value. The measure provides a similar efficiency with higher U-value and lower insulation thickness due to application of a ventilated cavity wall.

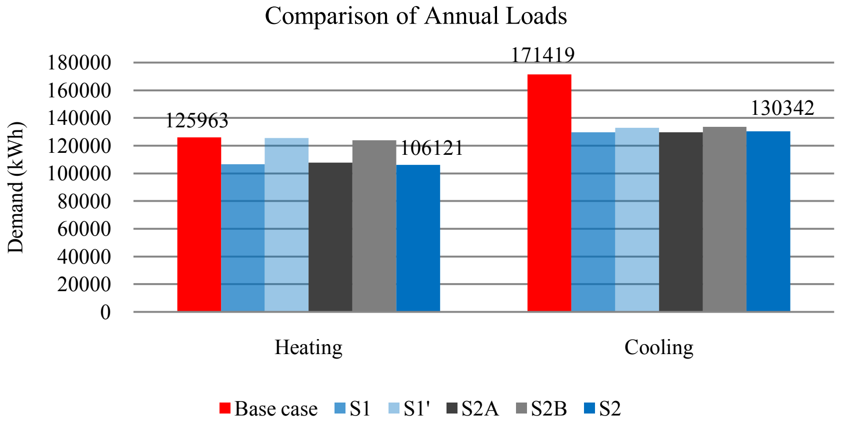


Figure 97. Comparison of simulated annual loads for base case and moderate level of intervention

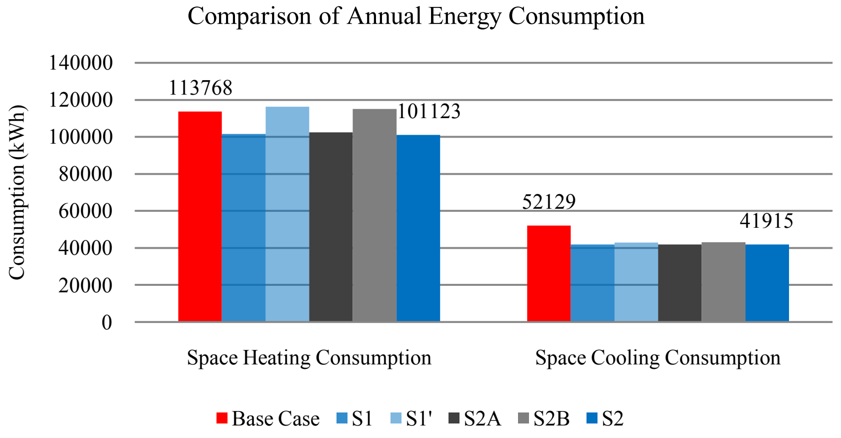


Figure 98. Comparison of simulated annual energy consumption for base case and moderate level of intervention

2) Measure S2B (S1′ + replacement of existing frames with insulated vinyl frames) offers no improvement on heating loads when built up with S1′. The effect of measures that constitute S1′ is more effective on the result, therefore the evaluation of insulated vinyl frames provide no significant reduction on heating and cooling loads.
3) Retrofitting strategy S2 (moderate level of intervention), as a set of all individual measures, provide a reduction of 16 % (>15% reduction by S1) in annual heating loads, which reflect on annual energy use as 11% (=11% reduction by S1). Annual cooling load and cooling energy consumption are reduced as well, by 24% and 20% respectively and equal to the reductions achieved by S1.

3.3.1.3. Evaluation of Major Level of Intervention

Major level of intervention strategy (S3) is evaluated according to simulation results of each individual measure and the strategy composed of these measures. Measures that are preserved from moderate level of intervention are denoted as S2′. Measures established for this strategy are applied as an addition or replacement to S2′, which includes S2A (Exterior brick wall + XPS insulation + ventilated cavity + wooden facade cladding) and S2B (Replacement of glazing with low-e + replacement of frames with insulated vinyl frames).

First individual measure that constitutes retrofitting strategy S3 is S3A, which is an improvement for exterior concrete walls with 40 millimeters of XPS insulation, 30 millimeters of ventilated air cavity and wooden façade cladding with a U-value of 0,507 W/m^{2}K (Section 3.2.2.3). This improvement is a replacement for the S1A , applied in the previous two strategies. S3B is as well an additional improvement, for concrete floor on ground, by adding 30 millimeters of XPS insulation and attaining a U-value of 0,514 W/m^{2}K (Section 3.2.2.2). The analysis results for retrofitting strategy S3 (major level of intervention) are presented in the following parts.

3.3.1.3.1. Indoor Temperature and Relative Humidity

Simulation results for major level of intervention (S3) and individual measures that are included in this strategy are evaluated according to indoor temperature and relative humidity deviations from base case result. Identical spaces are used with the previous two strategies. Table 52 presents the comparison results, based on the deviations for indoor temperature and relative humidity parameters. Simulation results for S2´ are presented in as well, to define the pre-accepted interventions retrieved from the previous strategy.

Table 52. Comparison results for individual measures and major level of intervention strategy – deviations for peak heating and cooling days

Applied Intervention	**Day Type**	**Parameters**	**Orientation**			
			North	**South**	**West**	**East**
S2'	**Peak Heating**	ΔT_U (°C)	0,53	-0,13	0,23	0,39
		ΔT_c (°C)	0,18	-0,21	0,01	0,13
		ΔRH_U (%)	-1,73	0,95	-0,70	-1,32
	Peak Cooling	ΔT_U (°C)	-1,14	-0,96	-2,35	-0,60
		ΔT_c (°C)	-0,50	-0,50	-0,95	-0,31
		ΔRH_U (%)	2,63	2,11	4,53	1,26
S3A	**Peak Heating**	ΔT_U (°C)	2,92	1,95	0,31	3,57
		ΔT_c (°C)	1,15	0,64	0,04	1,42
		ΔRH_U (%)	-8,67	-5,08	-0,90	-10,20
	Peak Cooling	ΔT_U (°C)	-1,53	-1,08	-2,36	-0,92
		ΔT_c (°C)	-0,63	-0,52	-0,95	-0,39
		ΔRH_U (%)	3,53	2,40	4,45	1,97
S3B	**Peak Heating**	ΔT_U (°C)	0,67	0,62	1,31	0,49
		ΔT_c (°C)	0,23	0,14	0,44	0,17
		ΔRH_U (%)	-2,15	-1,43	-3,22	-1,62
	Peak Cooling	ΔT_U (°C)	-1,15	-0,99	-2,03	-0,63
		ΔT_c (°C)	-0,51	-0,55	-0,92	-0,32
		ΔRH_U (%)	2,65	2,29	3,92	1,32
S3	**Peak Heating**	ΔT_U (°C)	3,18	3,19	1,44	3,75
		ΔT_c (°C)	1,26	1,19	0,49	1,50
		ΔRH_U (%)	-9,37	-8,38	-3,51	-10,66
	Peak Cooling	ΔT_U (°C)	-1,56	-1,16	-2,04	-0,96
		ΔT_c (°C)	-0,64	-0,57	-0,02	-0,41
		ΔRH_U (%)	3,60	2,68	3,93	2,07

According to comparisons in Table 52, following assessments can be made on each individual measure and the strategy:

1) Measure S3A (Exterior concrete wall + XPS insulation + ventilated cavity + wooden facade cladding):

S3A is a replacement for S1B (50 millimeters of XPS insulation and plaster finishing), which requires 40 millimeters XPS insulation (Section 3.2.1.2). Due to addition of S3A to S2′, indoor temperatures for peak heating day increases with an average of 2,19 °C (=2,19°C of S2) for unconditioned hours and 0,81°C (<0,82°C of S2) for conditioned period. For peak cooling day, the average reduction for indoor temperatures is 1,47 °C (<1,56°C of S2) for unconditioned hours and 0,62°C (<0,66°C of S2) for conditioned hours in comparison to base case simulation results. The deviation of peak heating day indoor temperature results for S2 and S3A are close, despite the increase of U-value of S3A measure (from 0,475 W/m^{2}K to 0,507 W/m^{2}K of S1B). However a decrease is observed in peak cooling day indoor temperatures, especially for north and east oriented spaces.

2) Measure S3B (concrete floor on ground + XPS insulation):

S3B is an additional measure to S2′, which only intervenes by improvement of concrete floor on ground with 30 millimeters XPS insulation. S3B provides an average of 0,77 °C increase for indoor temperature on a peak heating day during unconditioned period and 0,25°C increase for conditioned period in comparison to base case results. It is necessary to notice the effects of this measure in comparison to S2′. The improvement is almost three times larger than the improvement offered by S2′ which does not include exterior concrete wall improvement. On peak cooling day, decreases for indoor temperatures in comparison to base case are 2,11 °C and 1,20 °C, respectively during unconditioned and conditioned hours. The decrease of indoor temperatures for peak cooling day is high due to no insulation measures for external concrete walls with lower thermal mass. Non-insulated concrete walls cause an irradiative cooling effect especially when oriented to north and east.

3) Retrofitting Strategy S3 (Major Level of Intervention):

S3 presents an average of 2,89 °C (>2,19°C of S2) increase for indoor temperature on a peak heating day during unconditioned period and 1,11°C (>0,82°C of S2) increase for conditioned period, in comparison to base case results. Average decrease of 1,43°C (<1,56 °C of S2) is achieved for indoor temperatures during unconditioned period and 0,41°C (<0,66°C of S2) during conditioned hours, on peak cooling day. There is significant difference for indoor temperature deviations of S3 and S2 for peak heating day, which is an apparent result of improved measures for concrete floor on ground. On the other hand, slight decrease between peak cooling day indoor temperature deviations is a result of increased thermal mass, yet the measures of S3 provide decrease in peak cooling day indoor temperatures.

Figure 99 presents the deviations of maximum and minimum performance values obtained from the hourly simulation model, due to changing measures and strategies. Via Figure 99 it is possible to sustain the general findings of the above comparison on indoor temperature and humidity. For comparison of parameters in this figure, base case and S2 results are accepted as benchmarks. On the other hand S2´ is the transitional parameter set derived from S2 which only integrates exterior concrete wall insulation and ventilated cavity replacement and concrete floor on ground insulation addition. According to Figure 99, it is possible to make the following assessments:

- Highest reduction on maximum cooling loads is obtained by S2 and individual measures applied in major level of retrofitting strategy (S3) does not have significant effect on cooling loads.
- In comparison to all previously evaluated measures and strategies, S3 provides highest decrease in maximum heating loads and peak increase for minimum indoor temperatures.

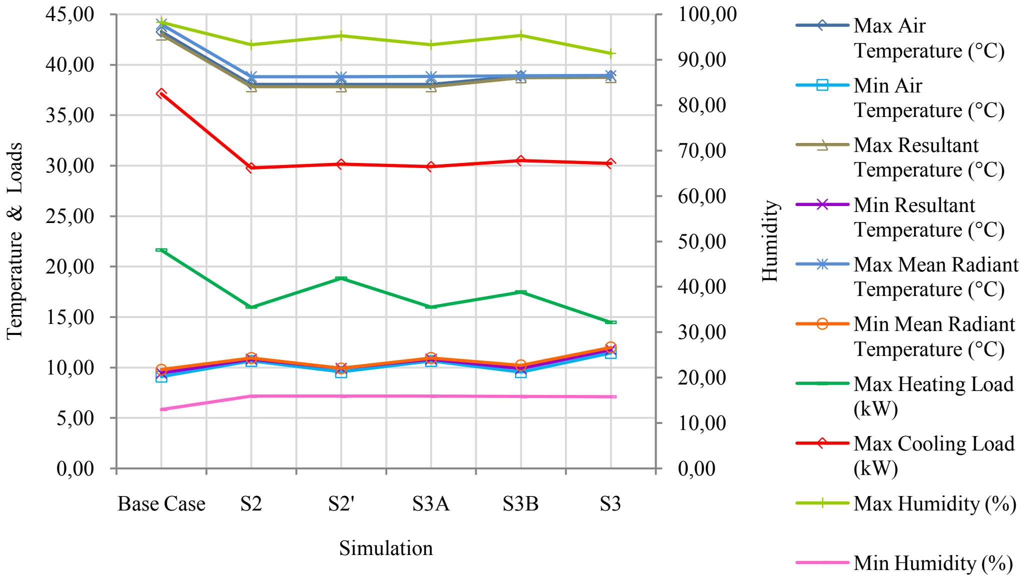


Figure 99. Maximum and minimum performance values of simulation results for individual measures and major level of intervention

Comparison between base case, retrofitting strategy S3 (major level of intervention) provides best indoor temperature deviances for peak heating day than S1 and S2 (minor and moderate level of intervention). Peak cooling day results decrease due to the increase in thermal mass via the measure S3B – insulation improvement of concrete floor on ground.

3.3.1.3.2. Loads and Consumption

Supplementary to indoor environmental parameter comparison, major level of intervention simulation results should be examined according to annual loads and consumption to determine the effects of individual measures and the retrofitting strategy as a whole. The comparison set includes simulation results for base case, S2–minor level of intervention, S2´-retrieved measures from the second strategy, individual measures S3A and S3B (as an addition to S2´), and S3 – major level of intervention.

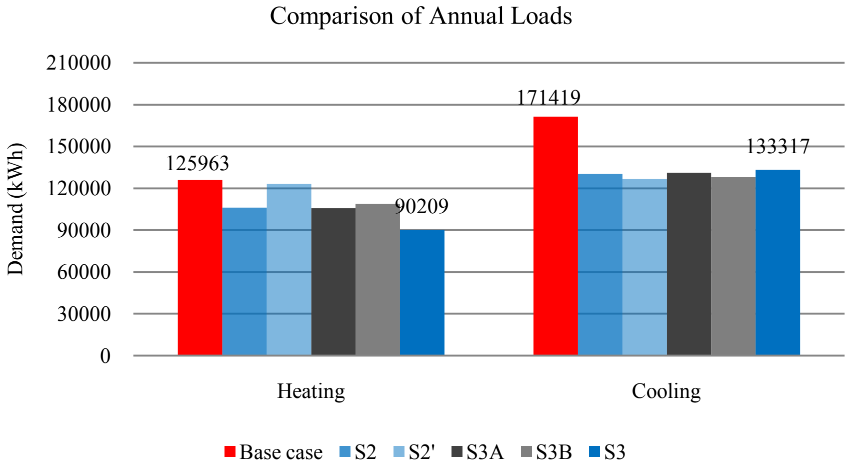


Figure 100. Comparison of simulated annual loads for base case and major level of intervention

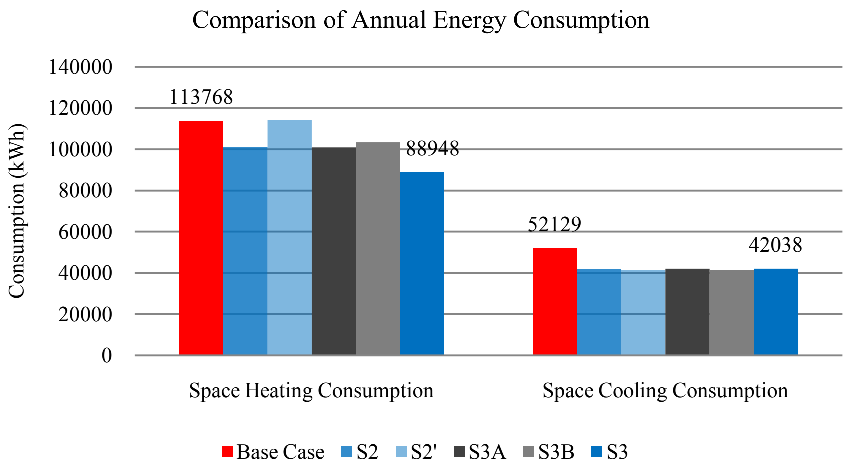


Figure 101. Comparison of simulated annual energy consumption for base case and major level of intervention

Figure 100 and Figure 101 present comparison results for these simulation results and can be evaluated as follows:

1) S3A (S2´ + exterior concrete wall improvement with 40 millimeters XPS insulation, ventilated cavity and wooden façade cladding) results in 16 % reduction on annual heating loads, and 23% in cooling loads, in comparison to simulated base case results. The result is very close to the result obtained by S2 (moderate level of intervention), with only changing improvement measure for external concrete walls from plaster finishing to ventilated cavity and wooden façade cladding, with decreased insulation thickness from 50 millimeters to 30 millimeters. Reduction on energy consumption is 11% for heating and 19% for cooling in comparison to base case. Annual load and consumption values are very close to S2, even though the measure applied for external concrete wall walls is altered with a ventilated cavity application, which has a higher U-value. As a result it is possible to assert that the measure provides a similar efficiency with higher U-value and lower insulation thickness due to application of a ventilated cavity wall.
2) Retrofitting strategy S3 (major level of intervention), as a set of all individual measures, provide a reduction of 28 % in annual heating loads, which reflect on annual energy use as 22 %. Annual cooling load and cooling energy

consumption are reduced as well, by 22 % and 19 % respectively and larger than reductions obtained by previous strategies

3.3.2. Results for Energy Performance Evaluation of Retrofitting Strategies

Thus far, each individual measure and retrofitting strategy is evaluated according to indoor environment, annual loads and consumption parameters. In this section the results for retrofitting strategies are summarized in comparison to calibrated base case model, to determine the finalized efficiencies with the application of the retrofitting strategies. Broader comparisons are presented in this section, through evaluations that are based on previous parameters for indoor environment and annual loads.

3.3.2.1. Indoor Environment Parameters

In the previous section, the analysis of indoor environment parameters is conducted through peak heating and cooling day analysis on sample spaces. In this section a different evaluation is conducted in regard to temperature frequency analysis and thermal comfort.

The frequency analysis aims to demonstrate the hourly temperatures outside comfort range for the whole building. Temperature set points for the building are defined in Section 3.1.1.4 and range between 22 (±2) °C for winter and 24 (±2) °C for summer period. Therefore, the set point temperatures provide a minimum of 20°C and a maximum of 26 °C, for the evaluation to be conducted outside these limits. All conditioned spaces are evaluated for this analysis, during the occupancy hours for all year, which is 2520 hours and includes free running and conditioned periods. The analysis is performed for calibrated base case simulation model and applied retrofitting strategies simulation models (S1, S2 and S3). Figure 102 presents the variation between base case and retrofitting strategies, for frequency of hours outside comfort range.

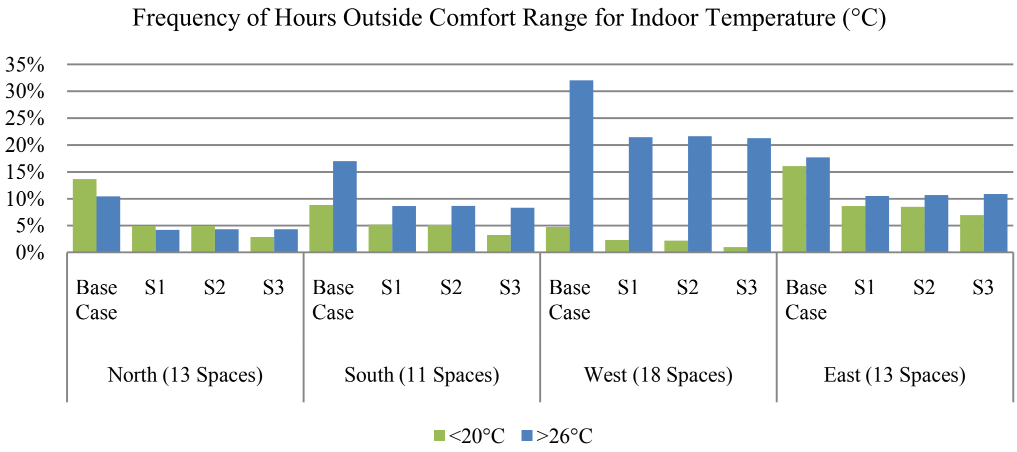


Figure 102. Comparison for frequency of hours outside comfort range for indoor temperatures

According to Figure 102 it is possible to make the following assumptions:

- The major indication of the analysis is the high percentage of hours over 26 °C for west oriented spaces, with a value of 32,00%. Via application of S1 (minor level of intervention), this value decreases to 21,42%. This improvement is due to low-e glazing replacement measure offered by strategy S1. For the other two strategies, this level of percentage is closely maintained via the presence of this measure.
- The second important indication appears for east oriented spaces, with a 17,67% of hours over 26°C. Through the application of retrofitting strategy S1, this value decreases to a level of 10,56%. Similar to west oriented spaces, S2 and S3 maintains a close level attained by S1.
- Yet for east oriented spaces, the analysis results yield a 16,06% of hours below 20 °C. Via application of S1, the ratio drops to 8,60% and of S2 to 8,49%. Best percentage, 6,91% is attained by S3, which is a retrofitting intervention that increases the thermal mass of the building via insulation of concrete floor on ground. Similar results for S3 can be observed for different orientations.
- In the base case calibrated simulation, which represents the actual situation of the building, for north and east spaces, hours below 20°C is 13,63% and 16,06% respectively. Via application of S1 (minor level of intervention) these levels decrease to 4,87% and 8,60%, which is a good level of improvement attained by application of S1.

- Despite the decreasing insulation thickness introduced with ventilated cavity application for exterior clinker brick wall in retrofitting strategy S2, there is no significant change between results of S1 and S2.

Second indoor parameter evaluation is carried out by PMV-PPD indices introduced by Fanger (1970). PMV (personal mean vote) and PPD (predicted percentage of dissatisfied) indices aim to determine the comfort level of the indoor environment. Indoor environment thermal comfort is a combined result of six different parameters which are; 1) metabolism rate , 2) clothing level, 3) air temperature, 4) mean radiant temperature, 5) air velocity and 6) relative humidity. PMV is a seven degree scale which is ranged as follows; [+3] is hot, [+2] is warm, [+1] is slightly warm, [0] is neutral, [-1] is slightly cool, [-2] is cool, and [-3] is cold. PPD is a percentage scale which represents the percentage of dissatisfied due to PMV results (Fanger, 1970). The parameters used in PMV calculation can be seen in Table 53.

Table 53. PMV calculation parameters

PMV Calculation Parameters	
Metabolic Rate (met)	1,2
External Work (W/m²)	0
Air Velocities (m/s)	0,15 - 0,30
Clothing Values (clo)	(0,65-1,00) – (0,50-0,75)

Metabolic rate defined in Table 53 is the rate for a person who does light work such as office work. External work is accepted as zero for this evaluation which is a measure for rate of work, in W/m^2, which is being done by the occupants of the room. Air velocities are defined with a minimum and maximum, which represent the assumed lower and upper speed of the air flow in the room. Clothing values accepted for heating period is between 0,65 and 1,00 which refers to a light office clothing to a suit clothing. For cooling period clothing is accepted with lower value range of 0,50 to 0,75. PMV values are calculated, according to changes in the indoor environment, using the lower air speed and upper clothing value and using the upper air speed and the lower clothing value to represent the occupant behavior for changing the airflow and clothing to achieve the highest comfort levels (EDSL, 2009).

PMV evaluation is carried out according to the frequency of the indices for the periods when the building is conditioned during winter and summer. For PMV results are accumulated according to their frequency for winter from 1st to 90th day and 335th to 365th day (total occupancy hours of 860 for a single space), and for summer from 161st to 273rd day (total occupancy hours of 790 for a single space). The evaluation for heating and cooling periods is presented in Figure 103. The results in this figure represent the orientation based average PMV values obtained from conditioned spaces. The results indicate that for base case, thermal perception of indoor environment for occupants is close to neutral (0), due to space conditioning. However, it is possible to observe that there is a tendency towards (+1) warm during summer period. Additionally, perception of indoor environment for winter period for occupants of base case deviates from (0) neutral, almost with an average value of 0,20 PMV. Due to application of retrofitting strategies, PMV values shift closer to (0) neutral level. Best average PMV indices are obtained by S3, while S1 and S2 present close results.

In addition to average PMV indices, cumulative frequency distributions for PMV indices are presented in Figure 104 and Figure 105. The analysis is carried out for all spaces, except conditioned circulation and services. In Figure 104, cumulative frequencies for PMV are presented during heating season. 12,14 % of the results indicate the thermal sensation of the environment is almost cool ($-1,0 \leq PMV < -0,5$) , where 73,71 % of the results are closer to neutral sensation of the environment ($-0,5 \leq PMV < 0$). Due to application of S1, S2 and S3 the PMV value between -1,0 and -0,5 decreases respectively to 4,73 %, 4,67 %, and 3,15 %. For S1 and S2, PMV values between -0,5 and 0 remain close to the base case simulation results, where the results for S3 decreases to 70,84 %. PMV values between 0 and +0,5 which indicate a warm perception of the thermal environment close to neutral, increases to 20,62 %, 20,75%, and 25,81%, for S1, S2 and S3 respectively, where base case results are 13,35%. The results indicate that there is a shift to more neutral and warm perception of thermal comfort for occupants via the application of retrofitting strategies.

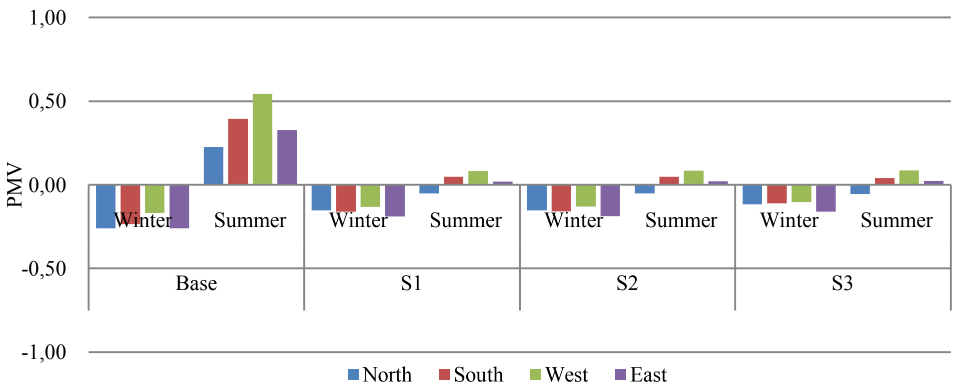


Figure 103. Average PMV comparison for base case and retrofitting strategies

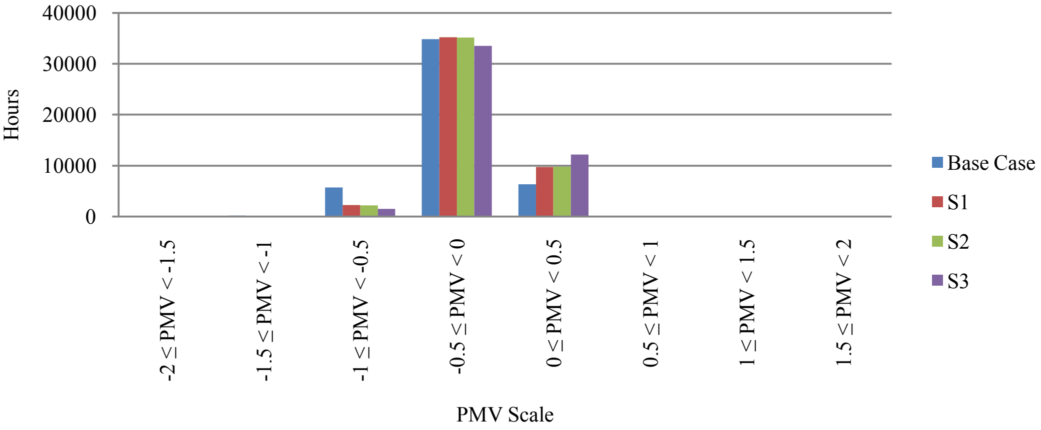


Figure 104. Comparison for cumulative frequencies of PMV – Heating period

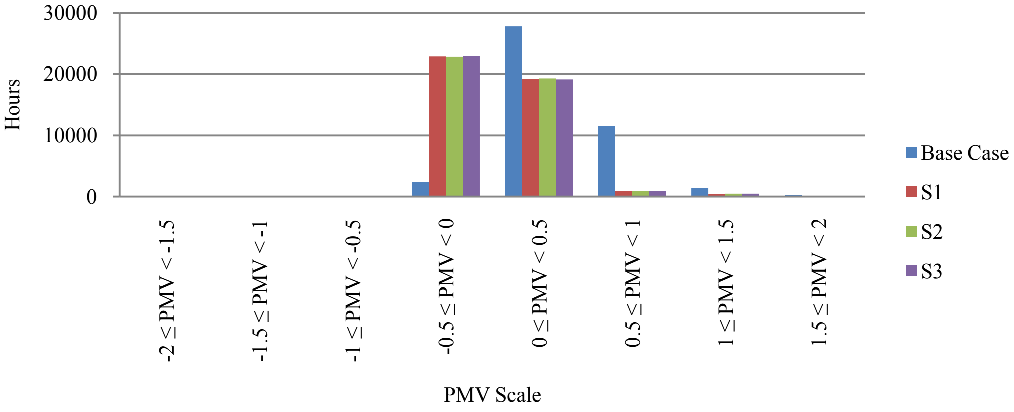


Figure 105. Comparison for cumulative frequencies of PMV – Cooling period

Similar to heating period evaluation, Figure 105 presents the cumulative frequency for PMV results during cooling period. The most significant indication of the analysis for cooling period is the large shift of PMV values from warmer perception to a cooler perception for base case results due to application of retrofitting measures. Base case analysis indicates a large percentage of hours between neutral (0) and warm (+1), where only 5,52 % is perceived between cool (-1) and neutral (0). Due to application of retrofitting measures approximately 50 % of hours are perceived between cool (-1) and neutral (0). It is obvious that this result originates from an individual measure common to all retrofitting strategies, glazing replacement with low-emissivity window panes. Therefore, not solely the strategies, hence an individual measure provides a shift to more cool and neutral perception of thermal comfort for occupants.

As well as achieved improvements on indoor environment during occupancy, free running periods and unoccupancy hours have significant improvements as presented in section 3.3. A large portion of energy is consumed during a start up of a conditioning system to obtain the set point temperature for the spaces. Therefore main savings originate from day start for heating and cooling consumption. Due to increase in thermal mass, indoor temperatures during unoccupancy period increase. This results in a decreasing temperature difference between a state of non-conditioned and conditioned periods for a space. This decrease in deviation of indoor temperatures for occupancy and unoccupancy periods provides energy savings for space conditioning.

3.3.2.2. Annual Energy Consumption

Annual energy consumption evaluation is carried out with the aim to compare energy consumption for space conditioning for calibrated base case simulation and retrofitting strategies. The evaluation is previously conducted in evaluation of each retrofitting strategy. In this section a holistic comparison only for major strategies will be evaluated.

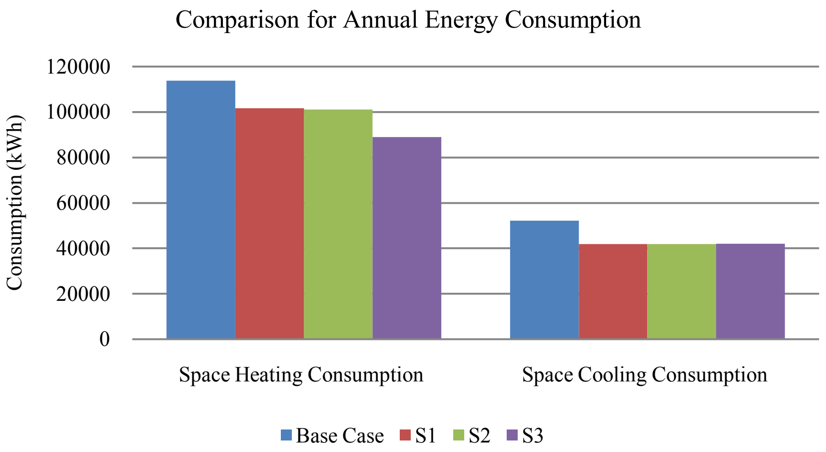


Figure 106. Comparison of annual energy consumption for space conditioning – base case and retrofitting strategies

Figure 106 presents the annual energy consumption for space heating and cooling for the calibrated base case simulation model, and applied retrofitting strategies S1 (minor level of intervention), S2 (moderate level of intervention), and S3 (major level of intervention). Due to application of S1 and S2, decrease in space heating consumption is obtained with 10,64 % and 11,12 % respectively. Retrofitting strategy S3 offers an annual reduction in heating energy consumption by 21,82%, which is the best level reduction achieved. Reductions in space cooling consumption is close for all three of the retrofitting strategies with the values 19,76%, 19,60%, and 19,36%, respectively for S1, S2, and S3. According to the results of simulated retrofitting strategies, S3 has the most significant reduction in total with a reduction of 34911 kWh. When compared to base case results, the total consumption for space conditioning decreases by 21,04 %. It is possible to assess that in the consideration of annual consumption reduction S3 is the most energy-efficient retrofitting strategy proposed for the case building.

3.4. Optimization of the Final Retrofitting Strategy

Pre-assessed retrofitting strategies may not be the most appropriate set of measures to retrofit a building, even though indoor parameters and consumption efficiencies are obtained for each pre-assessed strategy. Response of an existing building to each measure may not result with the expected level of efficiency or may require high level of investment costs that may not be compensated in a short payback period. Therefore it is necessary to optimize a strategy in regard to offered efficiency, return on investments as savings for energy consumption.

In this section sensitivity of each individual measure on annual end-use energy consumption is evaluated in comparison to base case simulation results. The savings for annual energy consumption is normalized with respect to the error margins (MBE) determined in section 3.1.2.4.1. Due to application of these error margins, simulated savings for each individual measure is normalized, hence become more realistic in comparison for their savings return on investment. In the first sub-section, the sensitivity of the individual measures on annual consumed energy for heating and cooling end-uses is investigated. The second sub-section covers the investment / pay back analysis for each individual measure, similarly in comparison to the savings in space conditioning costs. In the third sub-section, a final optimized retrofitting strategy is determined with regard to investment and saving costs.

3.4.1. Sensitivity of Individual Measures on Annual End-Use Consumption

The sensitivity of each individual measure on annual energy consumption is investigated with the purpose to determine the weights of these measures for the obtained efficiency. Figure 107 presents the effects of each individual measure on annual energy consumption in comparison to base case annual consumption results. In addition, Table 54 presents the individual measures, applied insulation thickness for these measures, heat loss surface area for the measures, and percentage efficiencies and/or inefficiencies obtained due to application of these measures.

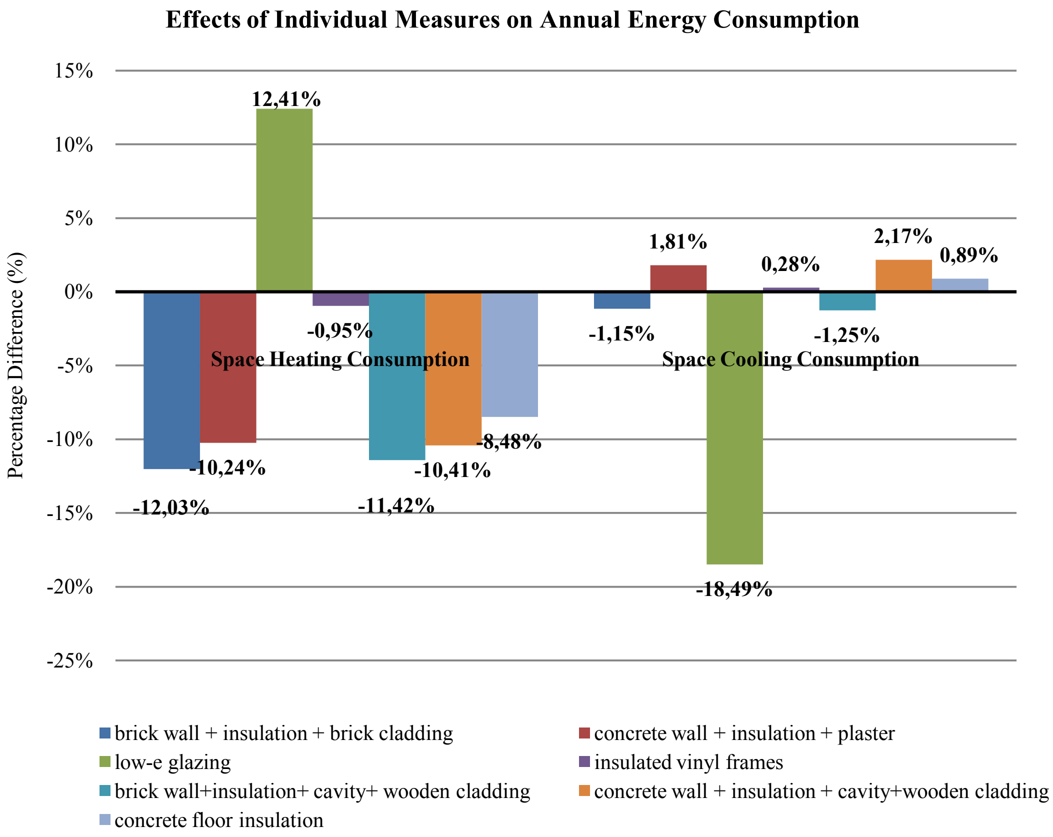


Figure 107. Percentage difference of space heating and cooling consumption to base case results for each measure

According to data in Figure 107 and Table 54, it is possible to make the following assessments for each individual retrofit measure:

1) Brick wall + insulation + brick cladding:

The individual measure proposes a U-value of 0,487 W/m^{2}K with an optimized insulation thickness of 40 millimeter. Retrofit heat loss surface area for brick wall is 831,85 m^2. Due to the measure, there is 12,03 % and 1,15% savings for heating and cooling consumption respectively. Total decrease in annual consumption in comparison to base case is 8,61%.

2) Concrete wall + insulation + plaster:

A U-value of 0,475 W/m^{2}K with an optimized insulation thickness of 50 millimeters, contributes to annual heating energy consumption with a reduction of 10,24 %. However, a slight increase can be observed in cooling energy consumption, 1,81 %.

This occurrence can be explained in accordance with the potential irradiative cooling effect of not insulated concrete walls. Larger thermal mass due to insulating concrete wall causes an increase in mean radiant indoor surface temperatures, which effects space cooling consumption to increase by a minor amount. Overall annual energy savings is -6,46 %.

Table 54. Properties of individual measures and difference on annual consumption in comparison to base case

Individual Measure	**U-value (W/m^2K)**	**Insulation Thickness (mm)**	**Heat Loss Surface Area (m^2)**	**Difference in Heating Consumption (%)**	**Difference in Cooling Consumption (%)**	**Total Difference in Annual Consumption (%)**
brick wall + insulation + brick cladding	0,487	40	831,85	-12,03%	-1,15%	-8,61%
concrete wall + insulation + plaster	0,475	50	921,85	-10,24%	1,81%	-6,46%
low-e glazing	1,643	-	504,96	12,41%	-18,49%	2,70%
insulated vinyl frames	1,40	-	76,44	-0,95%	0,28%	-0,56%
brick wall + insulation + cavity + wooden cladding	0,527	30	831,85	-11,42%	-1,25%	-8,23%
concrete wall + insulation + cavity + wooden cladding	0,507	40	921,85	-10,41%	2,17%	-6,45%
concrete floor on ground + insulation	0,514	30	3414,24	-8,48%	0,89%	-5,54%

3) Low-e glazing:

The measure is significant in terms of providing the most drastic changes for annual heating and cooling loads among all measures. Due to placement of low-e coating in the interior surface of the outer pane, solar gains are reduced. This reduction in solar gains provide a cutback of 18,49 % in annual cooling energy consumption when compared to base case simulation results. However, the reduction in solar gains during heating season results in an undesired increase in annual heating energy consumption, with a value of 12,41 %. Therefore, for total annual energy consumption there occurs no savings, on the contrary an increase of 2,70 % when compared to base case model.

4) Insulated vinyl frames:

The individual measure provides the less significant effects on both heating and cooling annual energy consumption in comparison to base case results. There is a total reduction of 0,56 % on annual energy consumption for space conditioning, in comparison to base case results.

5) Brick wall + insulation + cavity + wooden cladding:

The individual measure proposes a U-value of 0,527 W/m^{2}K with an optimized insulation thickness of 30 millimeter. The measure is a variation for brick wall improvement and has a higher value in comparison to insulation + brick cladding option. Due to the measure, there is 11,42 % and 1,25% savings for heating and cooling consumption respectively. A higher U- value results in the savings to slightly decrease for heating consumption and increase in cooling consumption. Total decrease obtained by this measure for annual consumption in comparison to base case is 8,23%, a very close result to the previous measure for brick wall improvement.

6) Concrete wall + insulation + cavity + wooden cladding:

Concrete wall improvement with insulation, cavity and wooden façade cladding provides a U-value of 0,507 W/m^{2}K with an optimized insulation thickness of 40 millimeters. The measure contributes to annual heating energy consumption with a reduction of 10,41 %. However, an increase of 2,17 % is observed for annual cooling energy consumption. Overall annual savings are 6,45% for this specific measure. Close results are observed with the insulation + plaster option, despite a lower U-value.

7) Concrete floor on ground + insulation:

The improvement measure for concrete floor on ground with a U-value of 0,514 W/m^{2}K and an insulation thickness of 30 millimeters provide a 8,98 % of decrease in annual heating energy consumption. The improvement results in an very minor increase in cooling loads, with a value of 0,89%, which is a result of increasing thermal mass. Total annual savings in energy consumption due to application of this measure is 5,54%.

Consequently, it is possible to assess that, two different retrofitting strategies for opaque envelope elements (brick wall and concrete wall) have very close savings and should be evaluated due to investment analysis. Frame improvement can be neglectable according to the insignificant improvements offered. Glazing improvement cannot be considered as an effective measure without the compensation of any other measure which helps decreasing annual heating energy consumption. In the following section investment / payback evaluation is presented to be able to determine the most effective strategies which constitute the optimized final retrofitting strategy.

3.4.2. Investment / Payback Analysis

A simple investment / payback evaluation for individual measures are carried out with the purpose to evaluate the return of construction costs for an individual measure in regard to the cost savings obtained from reduced energy consumption. The cost evaluation is based on NPV (Net Present Value) calculation to determine the payback period (years) of investment costs (De Troyer, 2008).

Prior to starting cost evaluation, achieved savings and/or increases in annual end-use energy consumption values are normalized with the error margins determined in the simulation calibration approach in section 3.1.2.4.1. Calibrated simulation accuracy for the base case is defined by mean bias error (MBE) for heating energy consumption, which is determined as 7,78%, and indicates an overestimation of annual heating energy consumption. Annual cooling energy consumption is underestimated by the calibrated base case simulation model with an MBE of -9,00%. These error margins are integrated in the simulated consumption values to obtain more realistic savings and/or increase in consumption to acquire more accurate cost analysis results. Table 55 presents the normalized consumption values for simulation results of individual measures. Furthermore, for each individual measure, differences for annual energy consumption in comparison to normalized base case results are presented in this table.

Since the simulated consumption results for individual measures are obtained it is possible to conduct the cost analysis based on NPV approach. To be able to define the investment costs, necessary construction steps are defined and documented in Table 56. The unit prices for necessary interventions are obtained from the annual parameters defined by the Turkish Ministry of Public Works and Settlement (MPWS, 2009) for year 2009, to be able to make a coherent comparison on an annual basis that covers resource prices and construction prices in the period the simulation models are evaluated.

Table 55. Normalized consumption values for simulated individual measures

Simulated Base Case and Individual Measures	Annual Energy Consumption (kWh)		MBE (%)		Normalized Annual Energy Consumption (kWh)		Difference for Annual Consumption in Comparison to Normalized Base Case (kWh)	
	Heating	Cooling			Heating	Cooling	Heating	Cooling
Base Case	113768	52129	7,78%	-9,00%	104917	56821		
brick wall + insulation + brick cladding	100084	51528			92298	56165	12619	656
concrete wall + insulation + plaster	102113	53074			94169	57850	10748	-1029
low-e glazing	127890	42493			117940	46318	-13023	10503
insulated vinyl frames	112689	52276			103922	56981	995	-160
brick wall + insulation + cavity+ wooden cladding	100772	51479			92932	56112	11985	709
concrete wall + insulation + cavity + wooden cladding	101928	53262			93998	58056	10919	-1235
concrete floor insulation	104115	52594			96015	57328	8902	-507

Table 56. Construction costs for individual retrofitting measures

Exterior Brick Wall Insulation, Finishing with Brick Cladding					
Application	Price (TL)	Unit	Applied (Area, Volume or Unit)	Unit	Price (TL)
Plaster	5,00	TL/m^{2}	831,85	m^{2}	4159,23
Fixing of XPS	5,00	TL/m^{2}	831,85	m^{2}	4159,23
XPS (40 mm)	225,00	TL/m^{3}	33,27	m^{3}	7486,61
Plaster Net	0,40	TL/m^{2}	831,85	m^{2}	332,74
Fixing Plaster	0,49	kg	4991,07	kg	2445,62
Brick Cladding (215X65X30mm)	0,45	TL/unit	55000,00	unit	24750,00
				TOTAL	43333,42
Exterior Concrete Wall Insulation, Finishing with Plaster					
Application	Price (TL)	Unit	Applied (Area, Volume or Unit)	Unit	Price (TL)
Fixing of XPS	5,00	TL/m^{2}	831,85	m^{2}	4159,23
XPS (50 mm)	225,00	TL/m^{3}	46,09	m^{3}	10370,79
Plaster Net	0,40	TL/m^{2}	831,85	m^{2}	332,74
Plaster Finishing (Colored)	9,23	TL/m2	921,85	m^{2}	8508,65
				TOTAL	23371,40
Low-e Glazing					
Application	Price (TL)	Unit	Applied (Area, Volume or Unit)	Unit	Price (TL)
6+12+6 mm Low-e pane	66,50	TL/m^{2}	504,96	m^{2}	33579,77
				TOTAL	33579,77
Insulated Vinyl Frames					
Application	Price (TL)	Unit	Applied (Area, Volume or Unit)	Unit	Price (TL)
6+12+6 mm Low-e pane	12,56	m	955,44	m^{2}	12000,30
				TOTAL	12000,30
Insulation for Concrete Floor on Ground					
Application	Price (TL)	Unit	Applied (Area, Volume or Unit)	Unit	Price (TL)
Removal of Existing Layers	15,38	TL/m^{3}	51,213525	m^{3}	787,66
Fixing of XPS	5,00	TL/m^{2}	831,85	m^{2}	4159,23
XPS (30 mm)	225,00	TL/m^{3}	24,96	m^{3}	5614,95
Concrete Deck	4,58	TL/m^{2}	3414,235	m^{2}	15637,20
Floor Finishing	17,00	TL/m^{2}	3414,235	m^{2}	58042,00
				TOTAL	84241,03

(cont. on next page)

Table 56. (cont.)

Exterior Brick Wall Insulation, Cavity, Wooden Facade Finishing					
Application	Price (TL)	Unit	Applied (Area, Volume or Unit)	Unit	Price (TL)
Plaster	5,00	TL/m^2	831,85	m^2	4159,23
Fixing of XPS	5,00	TL/m^2	831,85	m^2	4159,23
XPS (30 mm)	225,00	TL/m^3	24,96	m^3	5614,95
Wooden facade cladding (with structure)	37,50	TL/m^2	831,85	m^2	31194,19
				TOTAL	45127,59
Exterior Concrete Wall Insulation, Cavity, Wooden Facade Finishing					
Application	Price (TL)	Unit	Applied (Area, Volume or Unit)	Unit	Price (TL)
Fixing of XPS	5,00	TL/m^2	831,85	m^2	4159,23
XPS (40 mm)	225,00	TL/m^3	33,27	m^3	7486,61
Wooden facade cladding (with structure)	37,50	TL/m^2	921,85	m^2	34569,29
				TOTAL	46215,12

NPV calculation helps to estimate the difference between the present value (PV) of an investment cost in the future and the cash flows obtained due to this investment. In other words, NPV is the sum of all values in a predicted lifetime, with respect to parameters such as compound interest, growth rate etc. (De Troyer, 2008). For this study, investment cost is the construction cost and cash flows are the savings obtained in consumption by application of individual measures. Monetary statistics such as interest rate, inflation rate are obtained from Central Bank of the Republic of Turkey website (2009). Additionally, statistics on price growth on fuel and electricity is retrieved from Energy Market Regulatory Authority (EMRA, 2009). The rates used in NPV calculation are presented in Table 57.

Table 57. Economic parameters used in NPV calculation

Economic Parameters	
Inflation Rate	0,065
Interest Rate	0,144
Adapted Interest Rate	0,074
Lifetime (years)	15,000
Growth rate $_{\text{fuel}}$	0,290
Growth rate $_{\text{electricity}}$	0,099

The results of the NPV analysis for each individual measure are presented graphically in Figure 108 to Figure 114 (pp.193-195). The parameters presented in the graphs are: (1) the change in present value of investment in years, due to compound (adapted) interest rate, (2) the change in total energy savings, due to growth rate of energy prices, and (3) the change of return on investment in years, which is the difference between present value of investment cost and growing value of savings for energy costs.

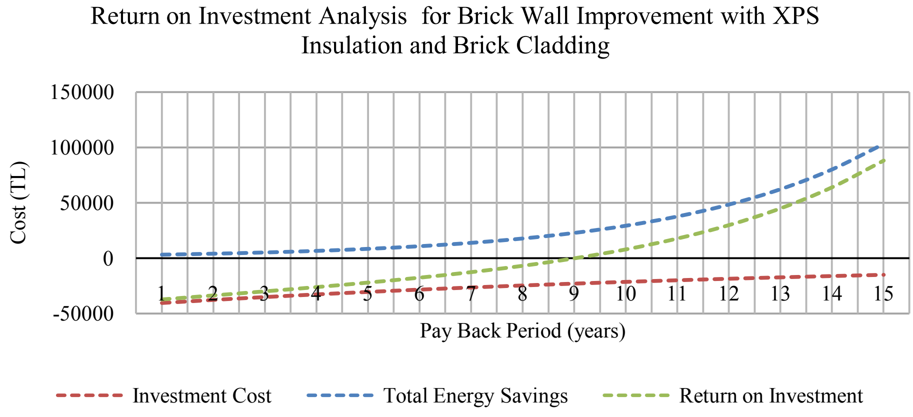


Figure 108. Return on investment for brick wall with brick cladding

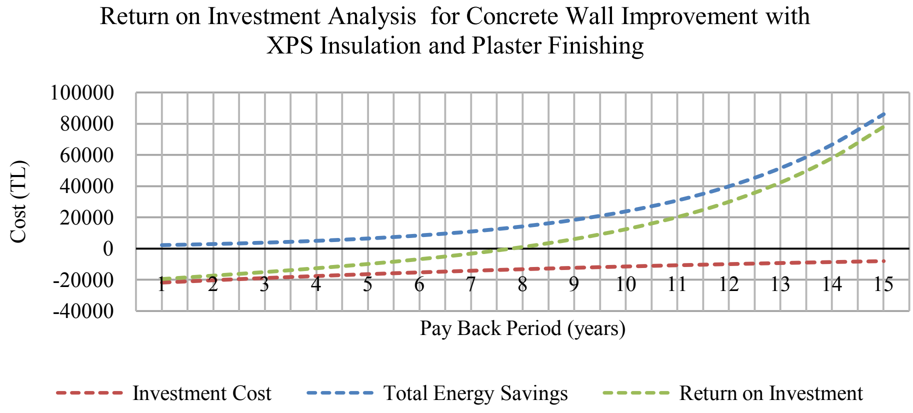


Figure 109. Return on investment for concrete wall with plaster finishing

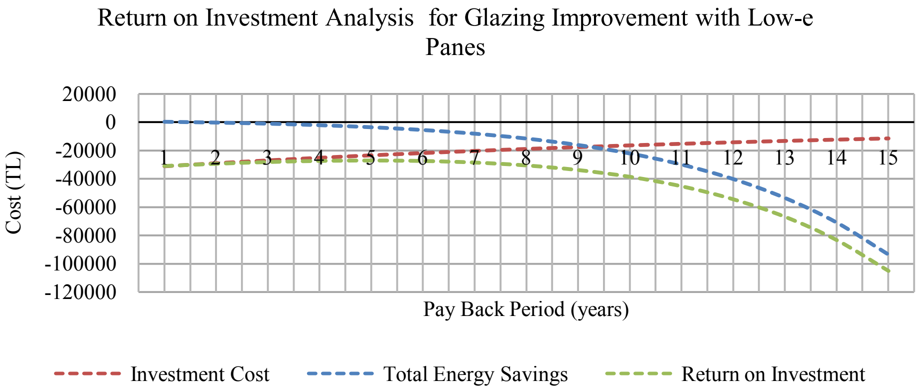


Figure 110. Return on investment for low-e glazing

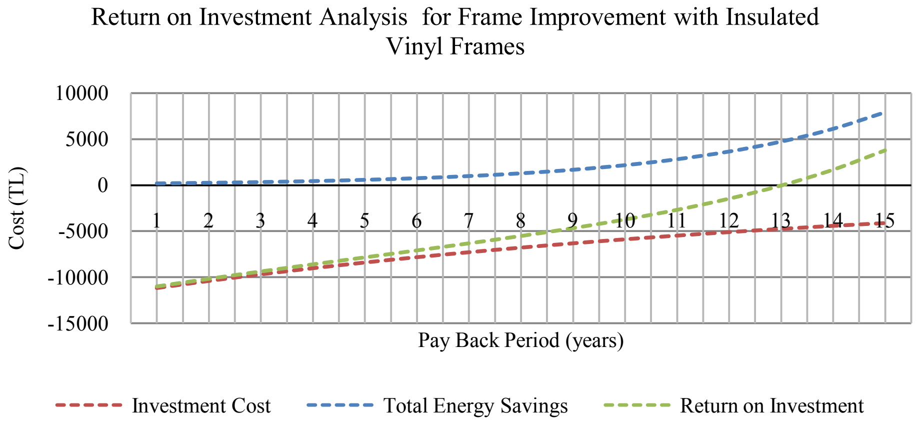


Figure 111. Return on investment for insulated vinyl frames

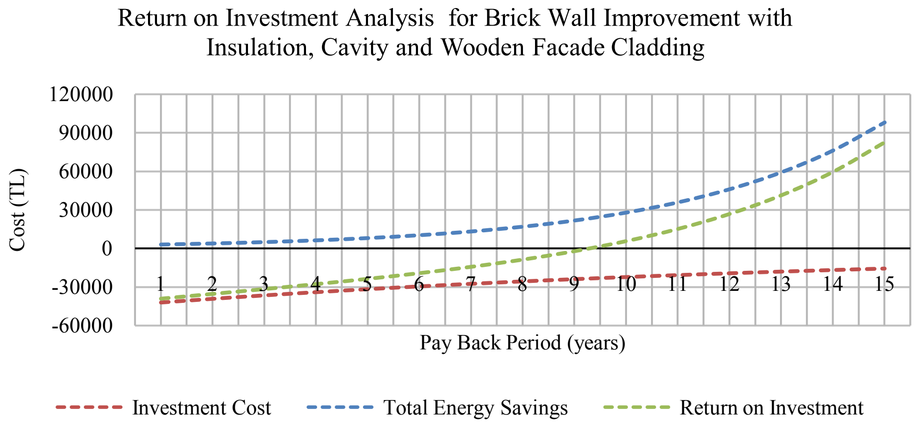


Figure 112. Return on investment for brick wall with wooden façade cladding

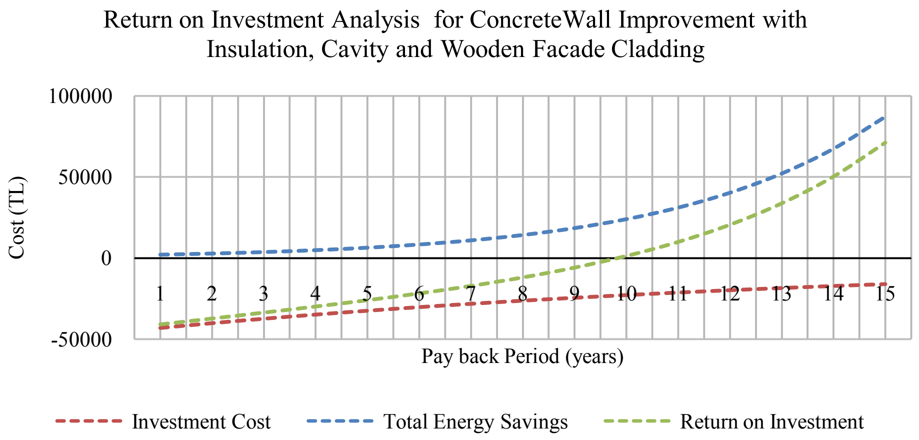


Figure 113. Return on investment for concrete wall with wooden façade cladding

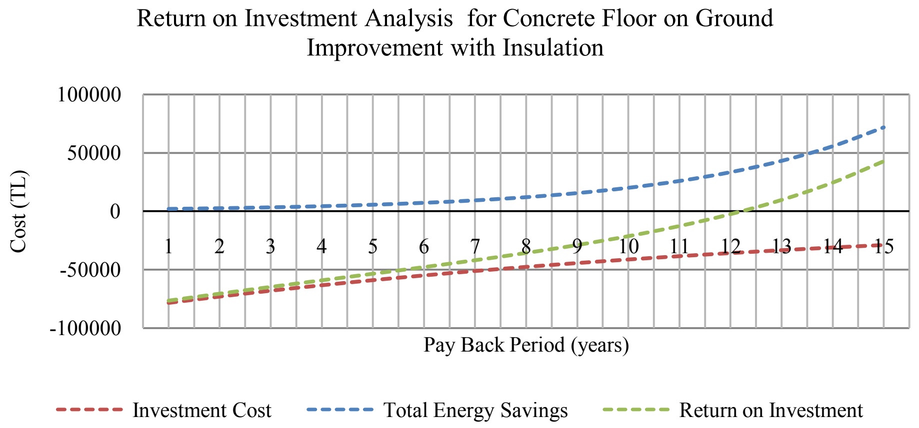


Figure 114. Return on investment for insulated concrete floor on ground

In Figure 108 to Figure 114, the time series indicator line for return on investment presents the payback period at the point where intersects the payback period axis. Payback period is the term in years, which points out the time period that the savings on energy consumption compensates the investment cost which is facilitated for the individual measure in year zero. The results from the graphs for cost analysis can be summarized in Table 58.

Table 58. Payback periods obtained by NPV analysis for individual measures.

Individual Measure	Investment Cost (TL)	Annual Saving (TL)		Total Annual Saving (TL)	Payback Period by NPV (years)
		Fuel	Electricity		
brick wall + insulation + brick cladding	43333	2282	184	2465	9,05
concrete wall + insulation + plaster	23371	1943	-288	1655	7,75
low-e glazing	33580	-2355	2941	586	-
insulated vinyl frames	12000	180	-45	135	13,04
brick wall+insulation+ cavity+ wooden cladding	45128	2167	199	2366	9,34
concrete wall + insulation + cavity+wooden cladding	46215	1974	-346	1628	9,81
concrete floor insulation	84241	1610	-142	1468	12,25

According to Table 58, following conclusions can be drawn:

- The most cost effective measure, when applied individually, is the concrete wall improvement with insulation and plaster finishing. The cost for energy savings may compensate the investment cost applied for this measure. The payback period is 7,75 years, a high rate of return, however when the lifecycle of the retrofit improvement is considered as 10 to 20 years, the measure contributes solely in energy saving cost for the remaining period. Similar measure for concrete brick wall with insulation, cavity and wooden façade cladding provides higher investment, lower savings and higher payback period.
- Brick wall insulation and finishing with brick cladding is the second advantageous measure among all individual measures. Payback period for the measure is 9,05 years and the measure provides the largest annual savings. Investment cost of the measure is lower than the similar measure which facilitates cavity and wooden façade cladding, and provides larger savings.
- Individual measure for replacement of glazing with low-e panes provides no payback, since the measure causes an increase in annual fuel consumption. However it is necessary to evaluate this measure with supplementary opaque construction measures to evaluate its effects.
- Replacement of frames with insulated vinyl frames offer the highest payback period in between all individual measures. The annual savings obtained by this measure is as well low.

- Individual measure for concrete floor on ground with application of insulation has a very large investment cost due to the large surface area of application and necessity to remove specific layers of the existing construction (Table 56). Therefore the payback period is higher when compared to annual savings obtained due to application of this measure.

As a result, it is possible to assess that all individual measures are applicable if there is no limitation on the budget; there is no necessity to compensate the investment costs in a predicted time period. However, for this study, a more optimized approach will be evaluated to balance economy, efficiency and ecology parameters. In the next sub-section assessment of the final retrofitting strategy is introduced.

3.4.3. Assessment of the Final Retrofitting Strategy

In the light of all investigated parameters concerning indoor environment, annual energy consumption and cost analysis for different retrofitting options and individual measures, a final optimized retrofitting strategy including following measures is assessed:

1) Brick wall improvement with insulation and brick cladding:
    (a) provides shorter payback period (section 3.4.2)
    (b) provides larger decrease in annual energy consumption (section 3.4.1)
    (c) provides increase in indoor temperatures (section 3.3.1.1.1)
2) Concrete wall improvement with insulation and plaster finishing
    (a) provides shorter payback period (section 3.4.2)
    (b) provides good level of decrease in annual energy consumption and less increase on cooling energy consumption (section 3.4.1)
    (c) provides good levels of increase in indoor temperatures (section 3.3.1.1.1)
    (d) has lower investment costs, when compared to the parallel measure with insulation, cavity and wooden façade cladding (section 3.4.1).
3) Replacement of glazing with low-e panes
    (a) provides high level of decrease in cooling loads (section 3.4.1)
    (b) increase in heating loads caused by the individual application of the measure is compensated with increasing thermal mass due to opaque surface improvements (section 3.3.1.2.2 and 3.3.1.3.2).

4) Replacement of frames with insulated vinyl frames
    (a) due to lower investment cost for the individual measure, it is integrated in the optimized strategy to ensure the applicability of low-e glazing and detailing the retrofitted façade components as a whole (Verbeeck & Hens, 2005).

Individual measure for concrete floor on ground improvement is discarded with the reason of long payback period and non-feasibility of the application since there is large interruption for functioning of workspace in the case building.

The optimized model is simulated with the same calibrated simulation approach to determine the savings in annual energy consumption, payback period of the investment costs. The findings and analysis of the optimized final retrofitting strategy is presented in Chapter 4, as a result of the applied methodology in this chapter.

CHAPTER 4

FINDINGS AND ANALYSIS

In this chapter, the final results and analysis for simulation model of the optimized final retrofitting strategy are presented, in comparison to calibrated base case model. The purpose is:

- To determine annual savings in energy consumption
- To determine annual CO_2 emission reduction
- To determine improvement in indoor environment parameters
- To determine the payback period for investment costs for the case building in response to the optimized retrofitting strategy.

The approaches in conducting above determinations are parallel to the methodological tools utilized in various phases of the methodology in Chapter 3.

4.1. Annual Savings in Energy Consumption of the Case Building

Comparison between base case calibrated model and optimized final retrofitting strategy indicates decrease in heating and cooling loads all occupied spaces in the case building (including unconditioned circulation spaces, wet spaces etc.) Annual heating demand of the case building is reduced by 17,05 % due to the measures applied with optimized retrofitting strategy. Annual cooling load reduction is higher, with a value of 23,60%. Whole building annual load reduction results with a percentage of 20,83. Figure 115 presents the changes in annual loads as a result of optimized retrofitting strategy.

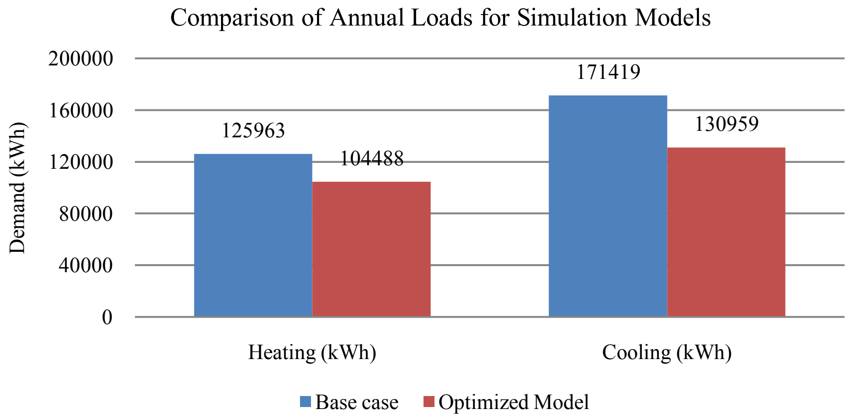


Figure 115. Comparison of annual loads for base case and optimized retrofitting model

Annual energy consumption results for conditioned spaces are compared for calibrated base case and optimized retrofitting strategy simulations (Figure 116). Results present reductions for annual energy consumption as an outcome of optimized retrofitting strategy. The annual energy consumed for space heating decreases by 12,32 % in comparison to base case results. Annual cooling energy consumption reduction is 19,42 % due to the application of optimized retrofitting strategy. Annual energy efficiency obtained is 24133 kWh which corresponds to an annual decrease of 14,55% in comparison to base case simulation results.

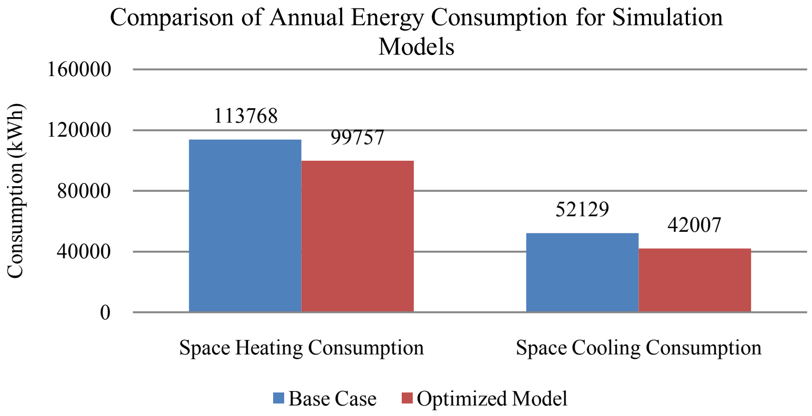


Figure 116. Comparison of annual energy consumption for base case and optimized retrofitting model

In comparison to the start of this study, where no insulation exists in the building envelope it is proven that improved building envelope elements provide savings in energy consumption, thus provide efficiency. It is possible to assess that optimized retrofitting strategy with the pre-determined optimum thicknesses is beneficial in terms of reduction of energy consumption of the building by 14,55 %. Similar studies point out a range between 13 to 30 % improvements in overall annual energy consumption, depending on different pre-determined measures (Dascalaki & Santamouris, 2002; Hestnes & Kofoed, 2002; Al-Ragom, 2003; Eskin & Türkmen, 2008).

4.2. Annual Reduction of CO2 Emissions for the Case Building

In addition simulation estimated savings in annual energy consumption, optimized retrofitting strategy helps to achieve a total annual reduction of CO_2 emissions of 19,27 %, when compared to the existing situation (base case model) of the building. Reduced heating energy consumption results in a decrease in CO_2 emissions due to fuel combustion, by 12,32 %. On the other hand CO_2 emissions that originate from annual space cooling consumption decrease by 28,80 % (Figure 117).

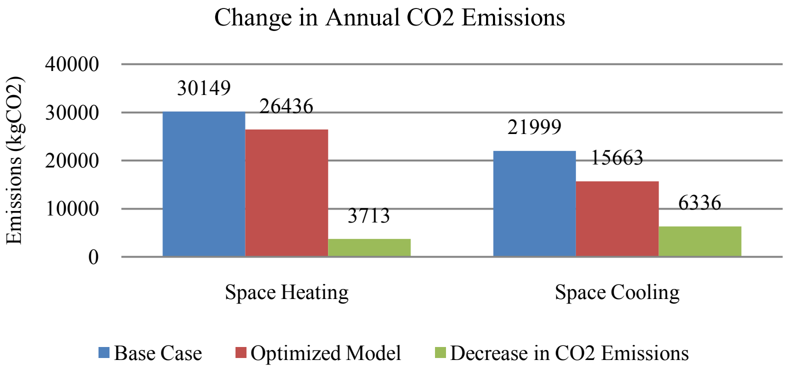


Figure 117. Change in annual CO2 emissions due to optimized retrofitting strategy

The overall result is promising for reduction of CO_2 emissions in ecological point of view, if considered not on a single building, yet as a building stock or premises, even in a larger context, a city. Consequently, one of the main emphases of the retrofitting strategies is to decrease energy consumption and contribute reduction of CO_2 emissions. This specific study only focuses on improvement of building envelope as a component of energy-efficient retrofitting; therefore the reduction in CO_2 emissions is limited. However, there is a large potential to render greenhouse gas emissions originated from building functions, such as promotion of efficient artificial lighting, natural ventilation, integration of renewable energy technologies for space heating and cooling etc.

4.3. Improvement in Indoor Thermal Environment for the Case Building

Both simulations for base case calibrated model and optimized retrofitting strategy model, frequency analyses are conducted to demonstrate the hourly temperatures outside comfort range for the whole building. Temperature set points for both simulations range between 22 (±2) °C for winter and 24 (±2) °C for summer period, as calibrated according to one full year monitoring of sample spaces. These set point temperatures provide a minimum of 20°C and a maximum of 26 °C, and these temperature limits are used as frequency benchmarks. The analysis covers all occupancy hours for the year 2009, which is 2520 hours and includes free running and conditioned period. Figure 118 presents the improvement in indoor temperature percentage of frequencies below and over the defined limit indoor temperatures (20°C and 26°C).

It is observed that for each specific orientation, the optimized retrofitting strategy provides improved (decreased) percentage frequencies below 20°C and over 26°C. For instance, relatively high percentage of indoor temperatures below 20°C for east oriented spaces, decreases almost with an average of 50,00 %. This result indicates that there is good level of improvement in indoor temperatures. A different pattern can be seen for west spaces, 32,00 % of hours over 26°C decreases to a level of 22,01 %, due to application of optimized retrofitting strategy. In summary, it is possible to assess that for each orientation, there is good levels of improvement for indoor temperature profiles, accumulating more in the temperature set point ranges measured during monitoring period.

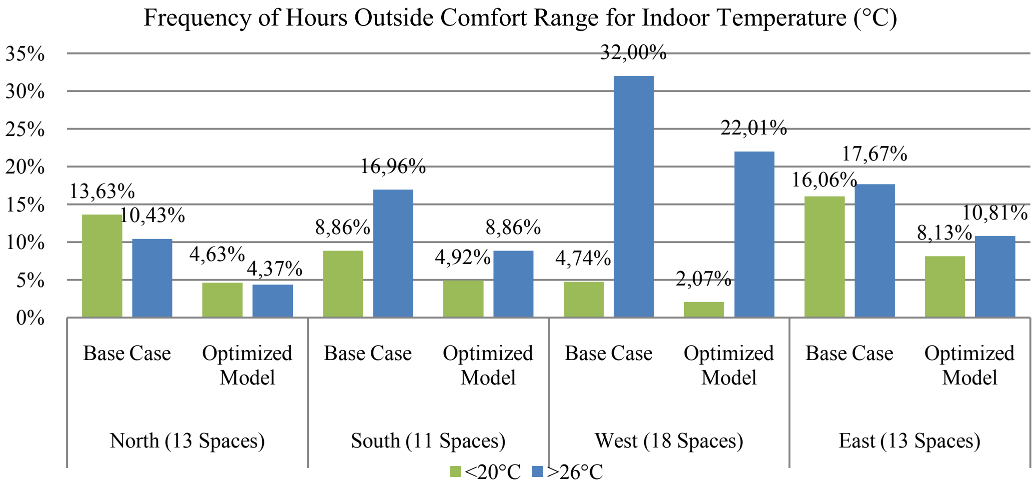


Figure 118. Comparison for frequency of hours outside comfort range for base case and optimized retrofitting strategy models

On the other hand, PMV (personal mean vote) analysis introduced in section 3.3.2.1 can be re-conducted for a more concrete assessment, with the aim to determine the comfort levels for the indoor environment. Figure 119 present the result of PMV evaluation for base case model and optimized retrofitting strategy. The evaluation covers winter and summer periods when space conditioning is active, and the presented results are orientation based average PMV values obtained from conditioned spaces. The results indicate that for base case, thermal perception of indoor environment for occupants is close to neutral (0), due to space conditioning. Yet, still there is a tendency towards (+1) warm during summer period. In addition, perception of indoor environment for winter period for occupants of base case deviates from (0) neutral to (-1) cool, almost with an average value of -0,23 PMV. Optimized retrofitting strategy model provides an average for indoor thermal perception (PMV) values move closer to (0) neutral level.

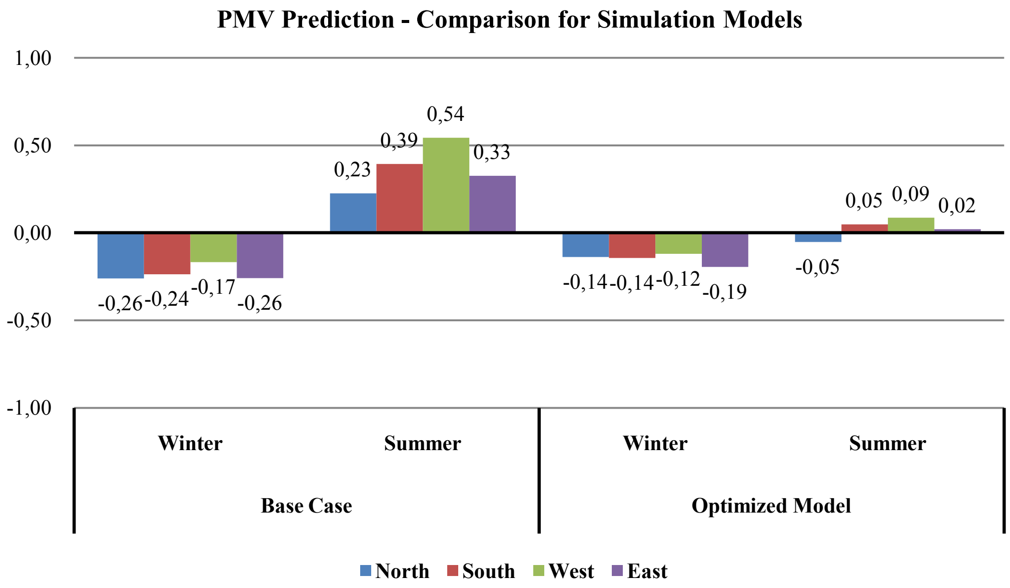


Figure 119. Comparison of PMV prediction for base case and optimized retrofitting strategy

Above comparison can be supported via Figure 120 and Figure 121. Cumulative frequency distributions for PMV indices for all spaces, except conditioned circulation and services are presented in these figures for heating and cooling season separately. In Figure 120, cumulative frequencies for PMV are presented during heating season. Thermal perception of the environment for almost cool ($-1,0 \leq PMV < -0,5$), decreases by 63,60% when base case and optimized model results are compared. Same percent of frequencies are obtained for both cases between $-0,5 \leq PMV < 0$ a cool sensation close to neutral. Due to application of optimized retrofitting strategy, PMV values that indicate warmer perception of indoor environment ($0 < PMV \leq 0,5$) increase by 37,23%.

In Figure 121, cumulative frequency of PMV results during cooling period is presented. A significant indication of a large change in PMV values from warmer perception to a cooler perception is observed for cooling period, when base case results and optimized retrofitting strategy results are compared. Base case analysis indicates a large percentage of hours between neutral (0) and warm (+1), where only 5,52 % is perceived between cool (-1) and neutral (0). Due to application of retrofitting measures, 52,01 % of hours are perceived between cool (-1) and neutral (0). There is a large improvement of indoor thermal environment from warmer perception to cooler.

As a result, it is possible to state that indoor thermal environment benefits from the optimized retrofitting strategy, especially for occupant thermal perception of indoor environment.

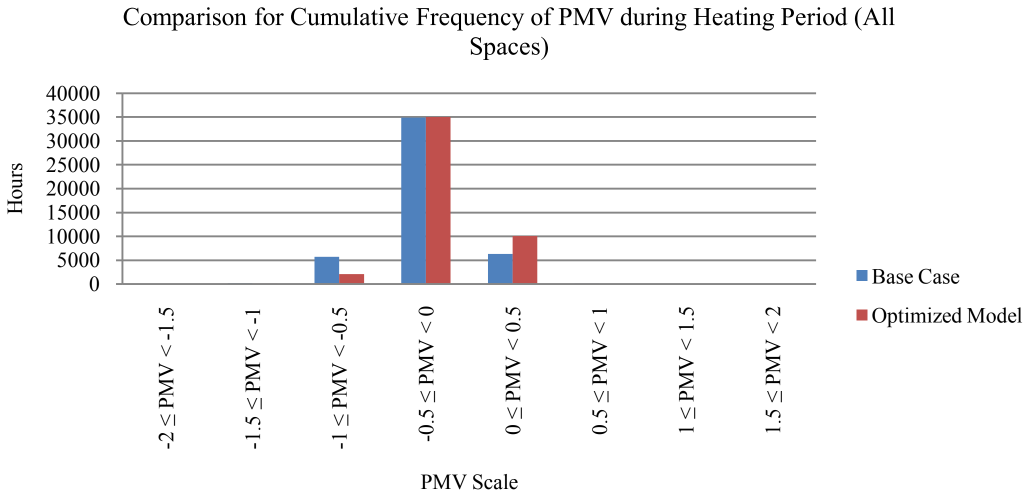


Figure 120. Comparison of cumulative frequencies of PMV during heating period – base case and optimized retrofitting model

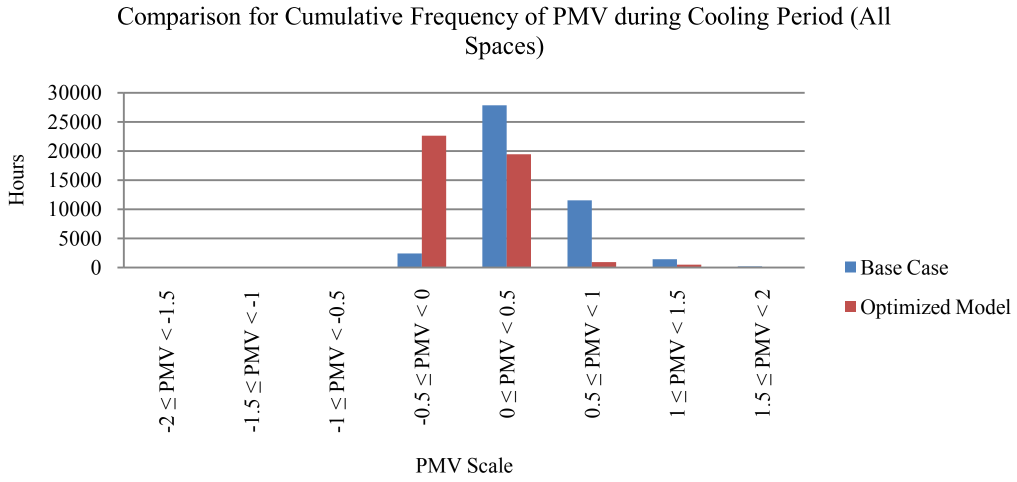


Figure 121. Comparison of cumulative frequencies of PMV during cooling period – base case and optimized retrofitting model

4.4. Investment / Payback Analysis for the Optimized Retrofitting Strategy

In section 3.4.2, the basic approach for investment / payback analysis is explained in detail. Optimized retrofitting strategy is evaluated with the similar approach, and the results are presented in this section as an important parameter to estimate the future savings due to a retrofitting investment.

Investment / payback analysis of the optimized retrofitting strategy for the case building is presented in Table 59 and Figure 122. Annual heating and cooling consumption savings are normalized with the defined error margins in section 3.1.2.4.1. Total investment cost for the optimized strategy is 112.285 Turkish Liras. Total annual savings achieved due to reduced energy consumption via the retrofitting strategy is 5244 Turkish Liras. According to the total present values of investment and savings, the payback period for the investment is determined as 11,55 years.

Table 59. Investment, savings and payback period for optimized retrofitting strategy

Individual Measure	**Investment Cost (TL)**	**Annual Saving (TL)**		**Total Annual Saving (TL)**	**Payback Period by NPV (years)**
		Fuel	Electricity		
Optimized Model	112.285	2155	3090	5244	11,55

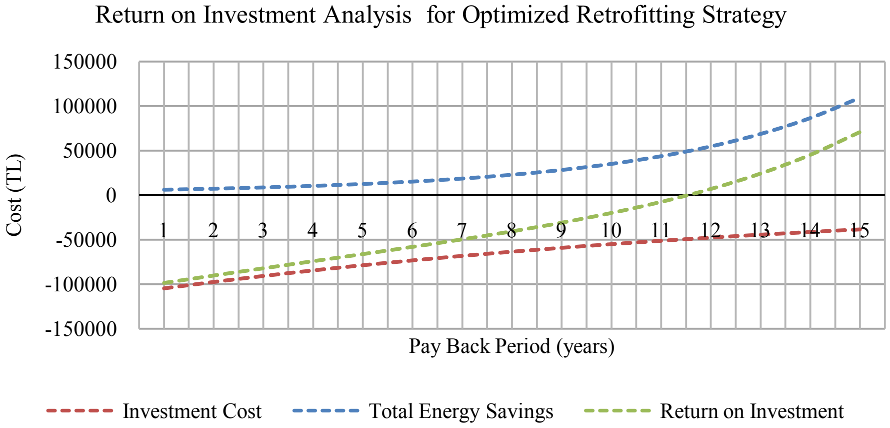


Figure 122. Return on investment analysis for the optimized retrofitting strategy

In general, energy efficiency improvements in the building envelope are costly. In literature for office building retrofitting strategies, payback periods for holistic envelope improvements are long, however permissible due to energy savings, improvement in indoor environment, reduction of CO_2 emissions etc. (CRES, 2000). For the case building, the retrofit measures are assumed to have a lifecycle of minimum 20 years (Rey, 2004), due to mild climatic and environmental conditions. Therefore, 11,55 years of payback period is promising, where parallel studies have similar payback periods (Dascalaki & Santamouris, 2002; Hestnes & Kofoed, 2002; Al-Ragom, 2003). Table 60 presents the annual present values for investment and total energy saving costs. The table once more indicates the payback period. Moreover, the savings achieved after the payback period is relatively high according to the scenario of increasing fossil energy costs in the close future.

Table 60. Annual present values for investment and total energy saving costs

Years	Investment Cost (TL)	Fuel Cost (TL)	Electricity Cost (TL)	Total Energy Savings (TL)	Return on Investment (TL)
0	-112285	2155	3090	5244	-
1	-104579	2776	3394	6170	-98408
2	-97401	3578	3728	7306	-90096
3	-90717	4610	4095	8706	-82011
4	-84491	5941	4499	10440	-74051
5	-78692	7655	4942	12597	-66095
6	-73291	9865	5429	15293	-57998
7	-68261	12712	5963	18675	-49586
8	-63576	16380	6551	22931	-40646
9	-59213	21107	7196	28303	-30910
10	-55149	27199	7905	35104	-20046
11	-51364	35049	8683	43732	-7632
12	-47839	45164	9539	54702	6863
13	-44556	58198	10478	68676	24120
14	-41498	74994	11510	86504	45006
15	-38650	96637	12644	109281	70631
16	-35997	124526	13890	138416	102419
17	-33527	160465	15258	175722	142195
18	-31226	206775	16761	223535	192309
19	-29083	266450	18412	284861	255779
20	-27087	343347	20225	363572	336486

4.5. Results

An optimized retrofitting strategy developed according to the methodology executed in Chapter 3 results with following outcomes:

- Reduction of annual energy consumption is around 15 %, which is a good level of achievement in consideration to designed individual measures based on optimum insulation thickness. Use of larger insulation thicknesses may be more beneficial, yet more expensive.
- Annual CO_2 emissions are reduced by 19,27%, 10049 $kgCO_2$ per annum, only due to reductions in annual heating and cooling loads.
- Due to the application of the optimized retrofitting strategy, there is perceivable improvement in the indoor thermal environment.
- Payback period of the strategy is 11,55 years, which is long, yet may become profitable after the payback period due to the increasing energy costs over a decade.

CHAPTER 5

CONCLUSION

Since the energy crisis in 1970s, reduction of fossil energy consumption became a point of concern, which evolved nowadays into a worldwide action, with the aim to preserve the remaining natural resources, to utilize renewable energies and protect the balance of the environment. Consequently, buildings which are responsible for a large portion of world energy consumption, turned out to be a centre of attention with their great potential in conserving energy, and that they necessitate improvements to reduce consumption, to become sustainable over their lifetime, or even produce and utilize clean energy. With these aims, many research actions and initiatives were taken, to improve energy efficiency in buildings (Chapter 2).

Measures which are defined to construct new buildings in an energy-efficient / sustainable approach are feasible and possible, in presence of well defined regulations and experienced control mechanisms. However, for existing buildings the process to obtain energy efficiency is a more complex task, where numerous parameters are involved as explained in the introductory part of this research.

Hence, the dissertation "A method on energy-efficient retrofitting for existing building envelopes" is structured with the aim to define a methodology for energy-efficient retrofitting of existing public envelopes, which should be a guide for any further-planned retrofitting actions for Turkish building stock. In regard to this aim, the approach of the dissertation is demonstrated through a case study. The complex set of applications in determination of energy performance of buildings, definition of retrofitting strategies, and evaluation of these strategies demand a systematic approach, which is addressed as a "method" in this study, are thoroughly executed via the defined steps of the suggested methodology in Chapter 3. Therefore, in this last chapter, the main steps that constitute the methodology is summarized, in regard to the suggested evaluation parameters: energy, environment and cost. Additionally, shortcomings of the research and potential further research areas are discussed, to provide ground for advanced and essential improvements for the formulated and evaluated methodology.

5.1. The Methodology

The aim in constructing this methodology is to be able to define a coherent set of retrofitting actions for existing building envelopes, which results in reduction in energy consumption, CO_2 emissions and improvement in indoor thermal performance. Since existing buildings account for a large portion of energy consumed, there is certain necessity to retrofit existing buildings to become more energy-efficient, however the limitations of feasibility of application and cost-effectiveness are the major problems that are faced during decision-making process of a retrofitting approach. Through the methodology this study proposes, it becomes possible to evaluate different retrofitting approaches for buildings either in an overall optimized strategy covering several building components, or selection of retrofitting alternatives a single building component. Therefore, to be able to optimize a retrofitting strategy and/or to decide application of individual retrofitting measures, a systematically layered methodology is proposed in view of the following main considerations, which are the basis this study is built on:

- Diagnostics: To evaluate the existing energy performance of a case building
- Assessment of improvements: To formulate the optimum applicable retrofitting strategy with the aim to limit energy consumption to a lesser extent, thus reduce CO_2 emissions.
- Performance: Any measure and/or set of measures proposed should be evaluated in regard to performance parameters which involve indoor environment, annual energy consumption and investment cost/payback period of the proposed retrofitting strategy.

The methodology itself is a decision-making process, with detailed steps that fit in the above stated fundamental concepts. Therefore, it is possible to summarize these fundamental concepts with reference to implementation of the proposed methodology through a case study, which is comprehensively explained in Chapter 3. The steps of the methodology are:

1) Determination of the energy performance of the case building: It is essential to determine the existing energy performance of a building prior to any retrofitting design decisions. The level of necessary improvements is directly related to the existing state of the building, thus a thorough understanding of how the building responds to environmental factors, climate, user requirements, occupancy patterns etc. is necessary prior to an energy-efficient retrofit of a building envelope. Therefore, following evaluations and analysis are completed for the case building. These highlights of these steps are valid to any further employment of the methodology:

- Determination of necessary building information can be completed via following analysis (Section 3.1.1)
    - Documentation of the site analysis of the building with respect to its location, orientation, altitude and environmental characteristics.
    - Collection of architectural and mechanical information, through blueprints for the building including architectural and mechanical drawings, construction details that include the composition of building envelope layers.
    - Inspection of building installation systems, to provide information on their technical characteristics and operating schedules.
    - Inspection of the building, to determine functional characteristics of different spaces, to document occupancy patterns and schedules that the building functions along with.
- An energy performance monitoring of the building which is subject to retrofitting intervention, which covers minimum 12 months (better if possible for 24, 36 or 48 months) is necessary to determine the actual response of the building to its context (Section 3.1.2.1):
    - Indoor environmental parameters: Indoor temperature and relative humidity should be monitored continuously with 10 minutes interval. The data set of these parameters reflects the actual response of the building during the monitoring period.
    - Energy consumption: Energy end uses for heating, cooling and utilities should be monitored minimum with monthly intervals. Best is to monitor the end use consumptions hourly, to be able to compare the dynamic response of the building to changing parameters (such as weather data, change in set point temperatures, occupancy etc.)

  - Efficiencies of installations: The efficiencies of installations especially used for indoor acclimatization (heating and cooling) is directly related to the consumption patterns and CO_2 emissions.
  - On site or very approximate monitoring of the weather data: Microclimatic weather data provides higher accuracy in determination of existing energy performance of a building. Therefore, it is necessary to monitor the microclimate for higher accuracy in predicting the existing energy performance of a building. Monitored weather data should cover the minimum parameter data set of (1) exterior dry bulb temperature (°C), (2) exterior relative humidity (%), (3) global horizontal solar radiation (W/m^2), (4) wind speed (m/s), (5) wind direction (degrees), and (6) cloudiness / clearness index. Additionally measurement of diffuse solar radiation is highly beneficial if necessary equipment is available.
- Due to collection of building information and monitoring data for a minimum of 12 months, the energy performance of the existing building can be evaluated through analytical calculations, dynamic calculation methodologies proposed by different standards, or through simulation models. Selection of the evaluation tool is important and can be chosen according to following design decisions:
  - A performance evaluation tool which will be employed in determination of the energy performance of the case building can be chosen due to expertise of previous applications
  - In case of no previous expertise, each tool can be executed and then evaluated for their accuracy in comparison to the long term monitoring data gathered from the building. The tool with the highest accuracy of real conditions can be assigned for energy performance evaluation of the case building (Section 3.1.2.4).

2) Determination of error margins of energy performance analsis tools: Error margins between energy performance predictions of employed performance tools and monitoring results is a necessary step to closely forecast effects of further energy conservation measures. Since no prediction tool is completely accurate, it is necessary to define a case specific error margin for the accuracy of the prediction tool (Section 3.1.2.4). This error margin can be utilized for normalization of simulation results for further evaluation of improvements

through the selected tool. In case of selection of a simulation tool, it is necessary to process a calibrated simulation model. This calibrated simulation model is best obtained with simulating the existing performance of the building, which is addressed as base case simulation model. The discrepancy between calibrated simulation model and the monitoring data may provide the level of inaccuracy between simulation and measurement.

3) Assessment of energy-efficient retrofitting strategies: Consequent to the selection of the appropriate energy performance analysis tool and definition of its error margins for a specific case building, it becomes possible to address the obsolescence and insufficiencies in the building envelope, which directly influences indoor thermal comfort energy consumption, and CO_2 emissions of the building. Therefore necessary retrofitting interventions should be assessed according to the previous analysis conducted on the building. The main parameters in assessment of retrofitting strategies for a building envelope improvement are mainly based on (1) reduction of transmission losses, (2) reduction or increase of solar gains through the envelope, and (3) reduction of infiltration and ventilation losses. Generally all retrofitting initiatives are taken with the necessity to improve minimum one or more of these measures. However, the main problem is the diagnostic and decision on which improvements are necessary (Section 3.2.1). Therefore:

- The extensive set of information collected in the previous step of the methodology is evaluated to diagnose the necessary improvements in a holistic perspective (necessity for insulation improvements for all building envelope elements or specific elements such as necessity for replacement of existing glazing etc.)
- Qualitative aspects of the building such as existence of fundamental change in structure of the building (replacement of the structural elements etc.), requirement for minimum change in architectural appearance of the building, interruption occupancy of the building should be evaluated in decision-making should be evaluated (Section 3.2.1.1).
- Quantitative decisions on the level of insulation measures to determine an appropriate thickness for each improvement defined for building envelope elements may be necessary to avoid over or underestimation of the insulation

thicknesses. This measure will provide efficiency in limiting number of trials for determining appropriate insulation thickness in testing performance of energy conservation measures. Additionally, optimization of insulation thickness helps to avoid over-insulated building parts, which may result in high investment costs (Section 3.2.1.2).

- All assessed retrofitting strategies should be evaluated either on individual measure basis or as strategies compiled with these measures (Section 3.3). The main parameters for the evaluation of efficiency of these measures are:
    - Indoor environmental parameters
    - Annual energy consumption
    - Investment / payback evaluation.
- An optimization is necessary for a single retrofitting strategy due to the performance criteria obtained by above parameters. Beneficial measures on annual energy consumption and indoor environment may be utilized together to construct a final optimized retrofitting strategy. Cost analysis is as well a vital determinate in this optimization step (Section 3.4).

4) Evaluation of the final optimized retrofitting strategy: Optimized retrofitting strategy should be evaluated with the pre-determined evaluation tool and the final findings and analysis of the proposed final strategy should be documented in terms of annual energy savings, indoor environment and retrofitting investment and payback due to energy savings. As a result, the applied methodology is valid in terms of (1) diagnosing the energy performance of an existing building, (2) determination of an error margin between prediction and monitoring of the existing energy performance of the building, (3) evaluation of assessed retrofitting measures and strategies, and (4) evaluating the performance of an optimized retrofitting strategy.

The steps of this methodology are common to several measurement and verification guidelines defined by different authorities in the world, which are concerned on energy-efficient building diagnosis and refurbishment (ASHRAE, 2005; ASHRAE, 2002; CRES, 2000; IPMVP, 2001; M&V, 2008). Hence, in regard to previously emphasized insufficiencies for Turkish building stock and energy-efficiency regulations, the methodology is proven to be applicable for energy-efficient envelope retrofits for existing buildings. The methodology proposes a set of steps that can be applied to different retrofitting decisions, without the constraints of unique building characteristics. The potential of simulation tools in comparison to analytical calculations is as well proven as a strong component of the methodology, since a response factor based dynamic simulation tool has close capability to replicate actual building energy performance. Therefore, even in design phase the use of simulation models would help to render the inefficient design decisions.

Overall, the study indicates the obsolescence in buildings, caused by inefficient applications, disregarded efficiency measures, and environment responsive design decisions, and proposes the applicability of retrofit measures, in regard to improvement in indoor thermal comfort, reduction in annual energy consumption, reduction in CO2 emissions and evaluates the investment of energy-efficient envelope retrofitting actions. The methodology has the potential to be utilized for evaluation of the building envelope retrofits in an integrated perspective.

5.2. Shortcomings of the Dissertation

The scope of this study may yield shortcomings when a comprehensive evaluation of building energy performance is considered. The dissertation solely deals with energy-efficient improvement of building envelope, which is one of the aspects of energy efficiency in buildings. However, other energy consumption end-uses in a building such as artificial lighting, mechanical ventilation, heating and cooling installations may be subject to retrofitting improvements to promote the obtained efficiency due to envelope retrofits. Thus, the energy performance of a building may be improved in a holistic perspective.

Especially, efficiency measures for heating and cooling installations could be improved or renewable energy technologies could be integrated to endorse the reduction of fossil fuels and CO_2 emissions.

Additionally, an uncertainty analysis for monitoring results could be useful in terms of more accurate assessment of existing performance measures. The uncertainty analysis may as well be useful on calibration of the simulation model, to decrease the error margins between monitoring and simulation data. Therefore simulation results for a retrofitting strategy can be normalized to more realistic results.

Therefore, further research can be developed with respect to these shortcomings. Several possibilities on future research can be summarized as follows:

- Retrofits on artificial lighting can be integrated to reduce consumption costs.
- A hybrid ventilation regime can be proposed for the building via integration of natural ventilation to the existing mechanical ventilation. The measure surely reduces energy consumption due to ventilation, thus contribute the overall energy consumption of the building.
- Utilization of renewable heating and cooling systems could be integrated to the retrofitted building, and their effect on energy performance could be evaluated.

5.3. Concluding Remarks

The dissertation “A method on energy-efficient retrofitting for existing building envelopes” is structured on the aim to define a methodology for energy-efficient retrofitting of existing public building envelopes (roof, facades, floor on ground), which should be a guide for any further-planned retrofitting actions for Turkish public building stock.

The emphasis on the necessity of a methodology for energy-efficient building retrofits is one of the major keystones of the study. EPBD regulations, which are announced as mandatory for all member and candidate countries is a binding process which needs to be fulfilled. Simply even the requirement of an energy certificate is a massive problem for existing Turkish building stock, where insulation measures are only applied for a uncertain portion of the building stock, which are built in the last decade.

Due to the BEP directive which became obligatory in 2008, construction sector took initiative to insulate existing buildings with stereotypical exterior thermal improvement actions, as a newly introduced profitable area of construction works. However, even BEP is unable to define a dynamic calculation methodology to identify the energy responses of a building to numerous parameters such as environmental factors, climatic considerations etc. Therefore, there is still a necessity to define a systematic approach for energy-efficient retrofitting of existing envelopes.

Therefore this study proposes a methodology which is capable of integrating dynamic responses of a building for energy performance. The methodology may be utilized to fill the gap for Turkish regulations, and calculation methodologies for determination of energy performance of existing buildings. Via the application of this methodology, thermal improvement of existing buildings may become more than a coincidence proposed by common contractors of the building sector.

Conscious decision-making for retrofitting strategies is of vital importance, where the investment costs are high and payback periods are long for these improvements. Therefore there is a certain requirement of precise determination the optimum measures, along to a coherent calculation methodology or retrofitting strategy.

In addition, the research targets the public buildings with the reasons to provide demonstrative retrofitting interventions, which may help to raise the awareness of the community on the benefits of energy-efficient retrofitting of existing buildings. Public buildings may be a medium to communicate with the society to introduce the necessity of energy-efficient buildings.

On the other hand, the methodology is flexible in terms of application to different buildings with different typologies and architectural aspects. Demonstrative case study building which is evaluated in Chapter 3 supports this argument with a large open atrium in the middle and with large heat loss surface are when compared to a more enclosed building. Therefore it is possible to assess that the methodology can be applied to different buildings with different typologies and architectural aspects. It is a flexible methodology which can be applied for residential buildings as well with the integration of different facilities (such as domestic hot water).

As a result, the study fills the gap of a guideline for energy-efficient retrofitting of existing buildings and provides potential of integrating different needs and measures to different steps of the methodology.

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