DYNAMIC ENERGY AND EXERGY ANALYSIS OF AN EXISTING BUILDING IN IZTECH

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ABSTRACT

DYNAMIC ENERGY AND EXERGY ANALYSIS OF AN EXISTING BUILDING IN IZTECH

Primary objective of this thesis is to find out energy level of an existing building and investigate the opportunities in order to improve its energy level by retrofitting the envelope and using exergy analysis methods on alternative HVAC systems. To arrive at the objective, an existing building, Izmir Institute of Technology (IZTECH), Faculty of Architecture Block C, has been used as the case study. This building cannot comply with TS-825 standards (Turkish Standard Assessment) and energy efficiency parameters due to the building components and HVAC systems. According to the recorded outdoor climatic conditions, the building was modeled and simulated; and the retrofitting was tried in EDSL-TAS energy simulation software package. Simultaneously, exergy analyses for the situations before and after refurbishments were employed. Different from the most studies in the literature, this thesis carries out the exergy analyses using the dynamic data instead of the steady state ones. By the evaluation of these analyses together, energy level and the climatic comfort of the building have been seriously increased and the building's loads have been decreased with ratio of 69.42% for heating system and 34.4% for cooling system after retrofitting. In exergy calculations, exergy efficiency of the system ranges between 2-14% with existing HVAC applications, 4-18% with Air Source Heat Pump (ASHP) and 8-21% with Ground Source Heat Pump (GSHP).

ÖZET

İYTE'DEKİ MEVCUT BİR BİNANIN DİNAMİK ENERJİ VE EKSERJİ ANALİZİ

Bu tezin ana amacı, mevcut bir yapının enerji seviyesini belirleyerek, bu seviyeyi bina kabuğunda yapılacak iyileştirmeler ve alternatif HVAC sistemleri üzerinde ekserji analizleri uygulayarak iyileştirmektir. Bu amaca ulaşmak için, İzmir Yüksek Teknoloji Enstitüsü Mimarlık Fakültesi C blok binası alan çalışması konusu olarak seçilmiştir. Söz konusu yapının mimari bileşenleri ve HVAC sistemlerinin, TS-825 standartlarına göre enerji verimlilik parametrelerini ve konfor koşullarını sağlamadığı bilinmektedir. Tez kapsamında yapı, mimari detaylarına ve malzeme bilgisine uygun olarak EDSL-TAS yazılımı ortamında üç boyutlu olarak modellenmiştir. Ayrıca bu model üzerine, çeşitli aletlerle bir yıl boyunca kaydedilmiş olan bina dışı iklimsel veriler ve malzeme bilgisi programa girilerek yapının mevcut ve iyileştirme sonrası durumları incelenmiştir. Buna paralel olarak, yapının iyileştirme öncesi ve sonrası durumları için ekserji analizleri de yapılmıştır. Bu analizler, daha önceki çalışmalardan farklı olarak, yapının kararlı durumu yerine zamana bağlı veriler üzerinden yapılmıştır. Her iki analiz ve simülasyon aracının verdiği sonuçların beraber değerlendirilmesi ile, yapının iklimsel konfor koşulları ve enerji seviyesi iyileşmiş, yapılan kabuk iyileştirmesi neticesinde, binanın ısıtma yükleri %69.42, soğutma yükleri %34.4 azalmıştır. Ekserji hesaplamaları sonucunda ise, binanın mevcut HVAC sisteminin ekserji verimi %2-14 arası; hava kaynaklı ısı pompası kullanımında %4-18 arası, zemin kaynaklı ısı pompası kullanımında ise %8-21 arası ekserji verimi oluşacağı bulunmuştur.

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CHAPTER 1

INTRODUCTION

For decades, energy consumption has been increasing parallel to the increase in the population and industrial growth. The consumed energy has been met mostly by non-renewable resources like fossil fuel and nuclear resources all over the world (Figure 1.1). However fossil fuel resources will extinct in the near future, and their amounts of production cannot meet the demand of the whole world. Today, because of the increment in consumption and the crucial depletion of fossil fuel resources, energy prices rise inevitably.

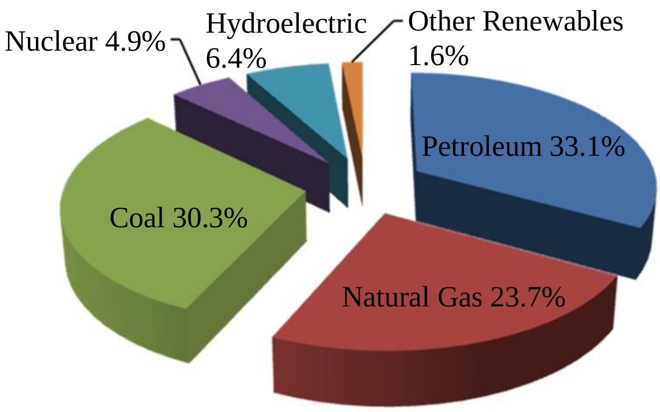


Figure 1.1. Global Energy Resources
(Source: BP Statistical World Review of Energy, 2012)

Beside the economic problems, non-renewable energy resources cause important ecological problems. According to the common research studies, widespread use of these resources increases CO_2 emission, therefore environmental pollution and global climate change risks, too. Against the global climate changes, many international precautions have been signed until now. The most known act in this context, Kyoto Protocol (1997), promotes the regulation to limit fossil fuel consumption to decrease CO_2 (greenhouse gas) emissions. Thereby, this regulation restrains from deterioration of climatic balance of the world. Decrease of CO_2 emissions highly depends on reduction of fossil fuel consumption, thus Kyoto Protocol suggests that, the use of clean and renewable energy technologies should be encouraged as possible (Güçyeter, 2011). As a summary, because of the crucial increase in the energy need, extinction of the fossil fuel resources and increasing ecological problems caused by non-renewable energy resources, contribution of the renewable energy and waste-energy-reuse have gained importance all around the world.

Buildings are one of the most important energy consumers. According to the European Commission's reports, an important amount of all produced energy is consumed by buildings (Figure 1.2) (ec.europa.eu, 2012). Growth in population, increasing demand for building services and comfort levels, together with the rise in time spent inside buildings, assure the upward trend in energy demand will continue in the future. For this reason, energy efficiency in buildings is today a prime objective for energy policy at regional, national and international levels (Lombard et al, 2008).

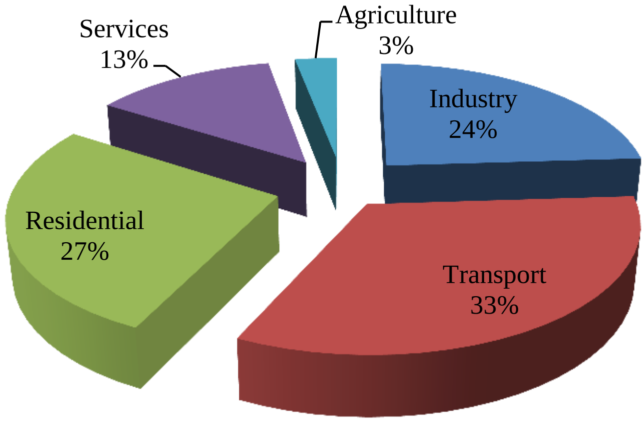


Figure 1.2. Global Energy Consumption according to Sectors
(Source: http://ec.europa.eu, 2009)

This situation is similar in Turkey, as well. According to Turkish Electricity Distribution Company (TEDAŞ), 47% of the whole energy is consumed by governmental, residential and commercial buildings (Figure 1.3). According to the growth of population, it is expected that the percentage will increase in the near future.

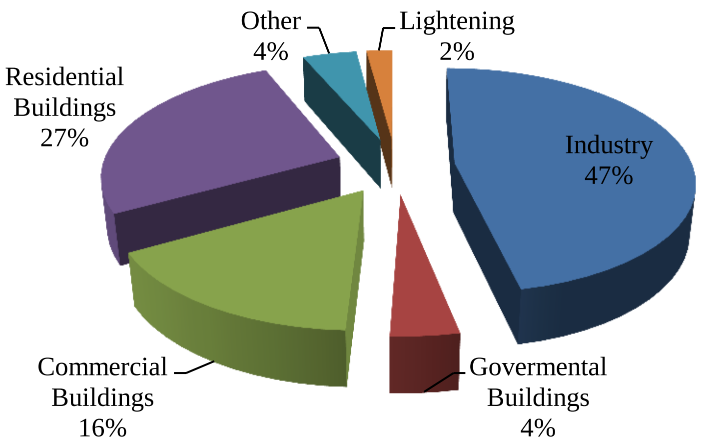


Figure 1.3. Energy Consumption in Turkey according to Sectors
(Source: TEDAŞ, 2011)

As a big energy consumer, an ordinary building has many energy consumptive systems. As an example study on the topic, a globally performed research study chose many commercial buildings as experiment subjects to analyze energy usage in terms of dispersion in the building percent as average. It should be noted that HVAC systems are the most important components of a building in the context of energy consumption (Figure 1.4). With this information about high energy consumptions of buildings, the heating and heat loss can be thought as another important problem, which should be solved for a building.

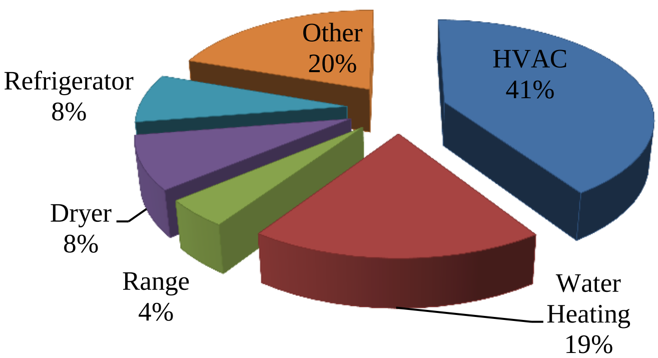


Figure 1.4. Energy consumption dispersion of commercial buildings
(Source: http://nap.edu, 2013)

In order to decrease the energy consumption and take some precautions against the waste of energy, a majority of European Countries has been working on defining and formulating methods since early 1990's. Most significant regulatory action is revealed as European Union Legislation in 2002, which is "Directive on the Energy Performance of Buildings (2002/91/EC)". Generally, this assessment is required to increase the energy efficiency for new and existing buildings, in this regard certain methodologies have been developed to determine energy performance of buildings, and to prepare energy certificate programs for the buildings in European Union Countries (EPBD 2002).

Turkey is still in regulatory level in terms of energy assessment. The Turkish standard of TS-825, Thermal Insulation in Buildings, became an obligation in 2000. In December 2005, Energy Performance of Buildings Directive was enacted and consecutively in May 2007 Energy Efficiency Law was issued (Yaman 2009).

1.1. Problem Statement

Until now, many research studies have focused on decreasing the energy consumption of buildings, and tried to find solutions to design energy efficient buildings. In order to reach this aim, vast majority of these previous works have included the following topics:

- Energy assessment
- Retrofitting of the architectural design and refurbishment of the HVAC system,
- Exergy concept

However, to the best of the author's knowledge, none of the previous research studies in the literature have interested in time dependent energy and exergy concepts along with HVAC system in the buildings. This deficiency constitutes the problem are of this thesis.

1.2. Objectives of the Research

Primary objectives of this thesis are "to find out energy level of an existing building" and "investigate the opportunities in order to improve its energy level by retrofitting the building's envelope and taking some precautions to decrease the energy losses of HVAC systems by using exergy analyses".

All analyses of the building are carried out in computer medium as existing state, after the building retrofitting and HVAC system's refurbishment.

To arrive at this aim, an existing building has been used as case study. This building cannot meet comfort levels and energy efficiency parameters due to the building components and HVAC systems. The aim is to increase the energy level of the building and reach the comfort level with less energy consumption by retrofitting the building envelope and refurbishing the HVAC system within usage of energy and exergy calculations.

1.3. Significance of the Research

The research studies in the literature deal with the exergy analysis, generally benefits from the annual energy data in their analyses. For this reason, these studies ignore the instant changes in thermo physical properties. This situation decreases the accuracy of the calculations. Different from the previous studies, this thesis makes the exergy analyses of the HVAC systems using the hourly energy data and obtains more dynamic and accurate results on the decrease of energy losses. Thus, this thesis exposes a more accurate exergy analysis and this is the original contribution of the thesis.

As the second significance and contribution, this study reviews process and relations of the exergy analysis. This review will also serve as a future reference for researchers to see all exergy analysis methods and relations at the same time.

1.4. Methodology

The study employs "Simulation and Modeling" as the primary research methodology. Simulation and modeling includes all mathematical models and computer simulations employed during the research process. Steps of the research and the contributions of the methodological framework to the study are shown in Figure 1.5.

In the first phase of the study, a thorough and critical literature survey was conducted and the study exposed the terminology related to the thesis study. Secondly, case building has been selected and the exterior climate data of this building has been collected by special equipment.

According to the obtained data, existing energy consumption and climatic condition of the selected building are analyzed using the EDSL-TAS software package. Simultaneously, exergy destruction is defined using LowEx calculation tools. Both of the examination methods expose comfort level of the building and give some clues about the possible opportunities to increase the energy level.

After these steps, some retrofitting on the building envelope by additional insulation layers and HVAC system refurbishment are made using different alternatives, and all the EDSL_TAS and LowEx analyses are repeated for each actual condition. During these modifications on the building, skylight was removed. According to these analyses, a feasible and suitable solution has been found to increase the climatic condition and to decrease the energy consumption of the building considered.

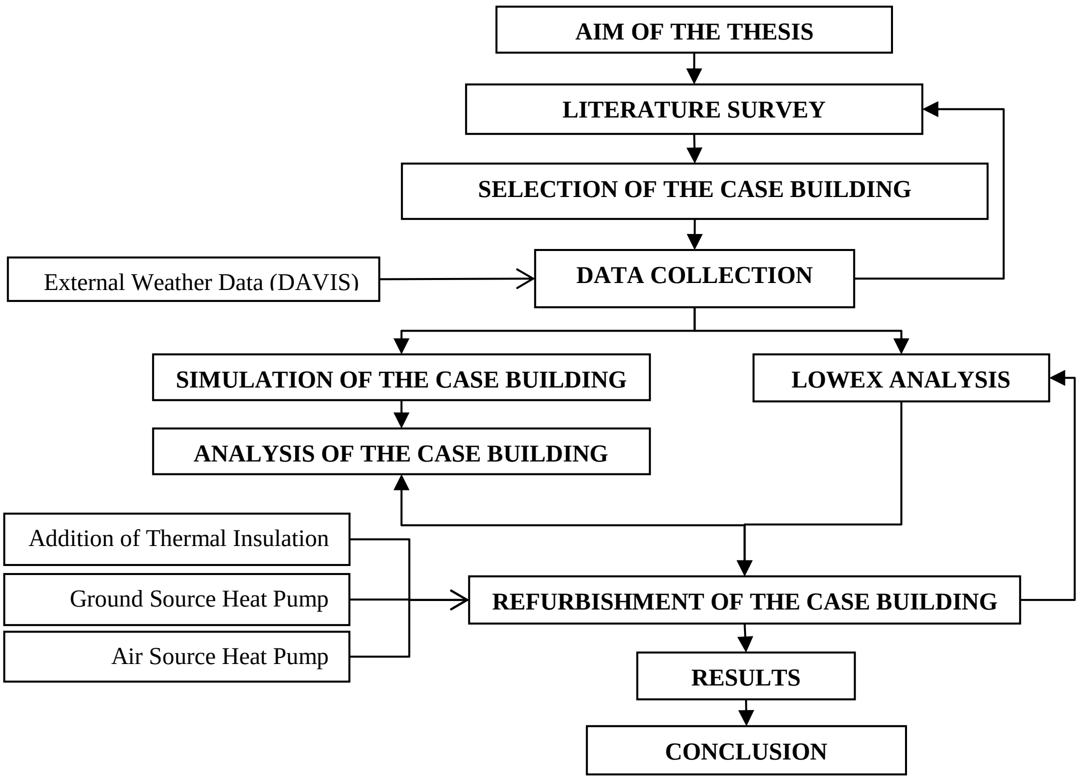


Figure 1.5. Process of the Thesis

CHAPTER 2

LITERATURE REVIEW AND DEFINITION OF THE TERMS

This chapter introduces the concepts, regulations, previous similar research studies in the literature and the relations related to the energy and exergy analysis, which are used in the thesis.

2.1. Literature Review

Literature review includes a summary of previous studies and a discussion and evaluation on their achievements in the context of energy and exergy efficiencies. The originality and the superiority of this thesis are highlighted as well. Literature review consists of four parts, as listed below: The

(a) Energy assessment in the world,

(b) Overall analysis of the literature on building energy performance and HVAC systems,

(c) Focus on exergy analysis in the buildings in terms of building properties and HVAC systems.

In order to comprehend the research studies on the topic; first, concepts, reports, acts and regulations released for a few decades should be understood. Sustainability was introduced in 1987 with 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",* expresses the idea of sustainability briefly (Güçyeter 2010). This report promotes the use of renewable energy sources and their utilization in the application of heating and cooling mechanisms in all possible energy-consuming systems as well (Brundtland 1987). This report led to the first Earth Summit-the UN Conference on Environment and Development – at Rio de Janeiro in 1992. Agenda 21 was published after this conference, which focused on sustainability, conservation of resources, and environmentally sensitive actions (Agenda21 1992).

After the global actions like Brundtland Report and Agenda 21, which emphasized the vitality of sustainable development; many conferences and development studies were organized in 1990's. As the most effective one, the Kyoto Protocol put forward the act of the national programs to reduce greenhouse gas emissions in 1997. Greenhouse gases such as CO_2 influence the energy balance of the atmosphere negatively and cause global warming (UN, 1998). On the Energy Performance of Buildings Directive (EPBD), European Parliament (no: 2002/91/EC) stated that, all sectors 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 (EPBD 2002).

Beside the actions of European Union (EU), International Energy Agency (IEA), a very effective collaboration of twenty-eight industrialized countries, focused on energy resources, technologies, efficiency, and statistics; and promoted scientific research and development activities on the abovementioned topics. For instance, Energy Conversation in Buildings and Community Systems (ECBCS) program of IEA is a research and development program which started in the late 1970s. Main aim of the program was to promote research activities with a life span of 3-4 years. The results of these research and development projects were published as "annexes". In further parts of the literature review, research studies from this program will be referred as IEA Annexes (IEA 2008).

Parallel to the regulations of European Union, (Center for the Analysis and Dissemination of Demonstrated Energy Technologies) CADDET, a center supported by IEA and OECD, started to study on energy efficiency and management in buildings and energy efficient retrofitting. In October 1992, CADDET published a report and exposed a clear methodology to determine the energy level of an existing building, refurbishment options and cost control with a simple payback model. Abel et al.'s study (1992) benefited from this methodology and evaluated different office buildings from different parts of the world such as Stockholm (Sweden), Washington (USA) and Kagoshima (Japan).

The second report of CADDET, Analyses Series No 18, aims to establish an information base 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 this report are 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 use in residential buildings by improving thermal efficiency and indoor comfort levels of that building (Nilsson et al. 1996).

IEA ECBCS Annex 32 - Integral Building Envelope Performance Assessment, presented in 2003, exposes a methodology for performance assessment to guide the initial and the evaluation process of building envelopes by realizing significant energy savings and environmental and indoor comfort benefits (Hendricks and Hens 2000, Svendsen and Rudbacekk 2000; Stopp and Makela 2000).

IEA ECBCS Annex 36 - Retrofitting in Educational Buildings – is one of the examples to the research projects focusing on the retrofitting actions on educational buildings from 1999 to 2003. The aim of this Annex is to develop a tool for education buildings in order to follow a correct strategy during retrofitting projects. The research proposes a common methodology for 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 (Kluttig et al. 2003; Erhorn et al 2008).

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 Advisor (ECA) was introduced by Annex 36, which provides advice on energy – efficient measures for the use of decision makers (Merck and Erhom 2003).

LowEx, the international low temperature heating systems research program (IEA ECBCS Annex 37), is part of the International Energy Agency's (IEA) Energy Conservation in Buildings and Community Systems program (ECBCS). The aim of the program was to promote rational use of energy by encouraging the use of low temperature heating systems and high temperature cooling systems of buildings. In Annex 37, these systems are called low exergy (or LowEx) systems (Schmidt and Dietrich 2001; Schmidt and Shukuya 2003).

In Turkey, the Turkish Standard 825–Thermal Insulation in Buildings was set in action in 1989. In 1998, the standard was revised and Turkey was divided into four climatic zones. In addition, a method to calculate annual energy demand for heating was exposed. Recent version of TS-825 that became mandatory in June 2000, aims to decrease heating energy demand and to calculate energy saving potentials of buildings. Before the publication of this standard, building stock of Turkey commonly do not have sufficient thermal and water insulation in particular. This means, the buildings constructed before 2000 consume more energy for heating and cooling, and require systematical, methodological improvements especially for building envelope and installation systems. Parallel to the revisions and obligatory applications of TS-825, in 1997 a project was started by General Directorate of Renewable Energy (EIE) and Turkish Statistical Institute (TURKSTAT) which can be addressed as the very first attempt to document the energy consumptions in different sectors. The project has two parts, one based on building sector and the other based on transportation sectors. The aim of the first part 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).

According to the regulations and concepts introduced in the aforementioned acts and reports, many research studies have tried to increase the energy efficiency of the buildings. As the first example, Gratia and Herde et al (2003) made a design for low energy office buildings, based on two dynamic thermal programs focusing on heat gains from the electrical lighting, floor plans, wider use of false ceiling, overheating, size of windows, walls' heights, bioclimatic habitats etc. They used the "Opti" software package and "TAS" program with architectural design, climatic data, details, components of building and infiltration etc. In the study of Arsan and Sökmen (2009), energy assessment was carried out as to evaluate energy simulation and probable causes, after finding results, they made calibration by using "Design Builder" simulation program, their aim was to find error ratios of digital model and real model using weather data and internal data (via HOBO). They found the difference between the results according to data and then, they made the results better, by this way to get more accurate results. In energy efficiency with calibration issue, Rexhepi and Mahdavi investigated thermal performance of five traditional buildings in Kosovo, where cooling is not required. They made calibration and also assumed the possible improvements of the buildings to improve comfort levels of the buildings (Rexhepi et al 2010), as also reported by Fuller et al. (2009).Building energy performance was made using TRNSYS program; and this study included a strategy, which could be made easily in terms of investment cost. In addition to these studies, Koranteng and Mahdavi (2011) also investigated thermal performance and calibration of selected office buildings based on some case simulation scenarios with internal/ external conditions data and interviewing the 64 occupants.

In terms of comparison with Energy Simulation Program, Crawley et al (2008) compared twenty energy programs around the world according to the following categories: general modeling features, zone loads, building envelope and day lighting and solar, infiltration, ventilation, multizone air flow, renewable energy systems, electrical systems, HVAC systems, environmental emissions, economic evaluation, climate data availability, results reporting, user interface.

As a study about complementary systems, Bi et al. (2004) designed a solar ground source heat pump with a vertical double spiral coil ground heat exchanger, while a solar energy source heat pump was alternatively used to meet the heating load. They made some experiments to investigate COP and energy analysis of the systems as a complementary system. Özgener (2010) included analyzed thermal loads of geothermal and passive heating solar greenhouses and investigated wind energy utilization in greenhouse heating interested in some properties such as individual performances of main components, energy production performance and general analysis of the system. A similar study of Bakırcı et al (2011) included solar collectors, a ground heat exchanger, a liquid to liquid vapor compression heat pump and water circulating system equipment to analyze heating system in cold climate, Erzurum. They designed a heating system related to location and requirements, calculated COP, economical level and made an uncertainty according to climate properties. Fei and Pingfang (2012) made an application of performance of heat pump in terms of energy and exergy analysis method in China. In this study, they analyzed COP of the chillers and system, fluid exergy and destruction of equipment (compressor, heat exchanger etc.). Dikici et al (2008) studied solar assisted heat pump system with flat plate collectors was installed in Fırat University, Elazığ. They took some measurements (such as solar radiation condenser inlet and outlet temperatures etc.) and experimental setup was built according to the measurements. They obtained the mass, energy and exergy balance equations for the case study.

Another analysis, which was also included in this thesis, is a LowEx calculation tool by Dovjak et al (2010). Exergy value, possible useful work, was investigated in their study. Schmidt et al (2010) illustrated radiant exergy flow rate from interior surfaces, infiltration, details and the components of buildings were examined in this study. They made a comparison between energy and exergy analyses of fossil plant ground and air source heat pump building heating system, which included the simulation program IDA-ICE. The system was examined in terms of energy, exergy and thermal comport level, and people designed a model related to sink. (Torio and Schmidt 2010), Framework for analysis of solar energy systems in the built environment from an exergy perspective, investigated contradictions and physical inconsistencies, which result from including the conversion of solar radiation, and also energy and exergy loses connected with the natural degradation of solar radiation, therefore, in this paper included direct solar systems, indirect uses of solar radiation. Güngör et al. (2008) investigated values of exergy flow through the buildings and components. In addition to this one, this study included heating system energy and exergy analysis. Low exergy systems were examined (Shukuya 2008), which was about energy, entropy, exergy flows through the selected buildings and LowEx systems in applications. HVAC Systems' energy and exergy analysis were investigated in this paper using the LowEx. They selected a building, found energy demand and according to it, they designed different appropriate HVAC applications for the building. They analyzed all the HVAC systems in terms of energy and exergy (Sakulpipatsin et al. 2010).To design a complementary system using a ground source heat pump and a PV panel, Meggers et al analyzed HVAC system of the selected buildings in terms of energy and exergy using the LowEx tool (Meggers et al. 2012).

Energy and exergy performance of residential heating systems with separating mechanical ventilation was studied by Zmeureanu et al. For designing of HVAC systems and domestic hot water, Engineering Equation Solver (EES) software to model the system mathematically for a house as a case study in Montreal, included in this study (Zmeureanu and Yu Wu 2007). Exergy analysis of renewable energy-based acclimatization systems for buildings: A critical view, which focused on the air handling unit (AHU) for cooling, dehumidification and reheating of the buildings. They explained the dead state (reference state), exergy indicators of the buildings and they examined the building in terms of dynamic exergy analysis by using LowEx tools, indicates exergy balances along with whole/variety systems (building, heating, cooling systems, environment temperature, heat pump, solar heating system and some complementary systems etc..) (Torío et al. 2009). Energy and exergy analysis of a ground source (geothermal) heat pump system was analyzed in this paper, The purpose of this study was to present an energy and exergy analysis of a GSHP system with a 50 m vertical 1.25 in. nominal diameter by using U-bend ground heat exchanger to meet a case building in Ege University in Izmir. The exergy diagram (the Grassmann diagram) presents for the GSHP system to give quantitative information regarding the proportion of the exergy input that is dissipated in the various system components. They measured some properties of building system, which are volumetric flow rate of the existing HVAC system, ambient temperature and pressure, condenser and evaporator pressures. This study also included the uncertainty analysis and mass, energy, exergy balances (Hepbasli and Akdemir 2004). The other paper of Hepbaşlı was about LowEx, including three different heating systems were selected to meet energy demand of a greenhouse and then, energy and exergy analysis had been carried out (Hepbasli 2011). Comprehensive exergy analysis of a ground-source heat pump system for both building heating and cooling modes were examined the building and whole ground source heat pump system of the building during heating and cooling modes. They investigated exergy analysis of the building and system for each process and equipment, to illustrate, compression, throttling processes and GSHP cycle. They selected a hotel building in Beijing to examine, and building properties such as components, heating and cooling system, and then they get the results of the building. (Bi et al. 2009)

Until today, research studies explained above have studied on decreasing the energy consumption of buildings, and tried to find solutions to design energy efficient buildings. In order to reach this aim, most of these studies have focused on energy assessment, retrofitting of the architectural design or HVAC system and exergy concept. However, none of the aforementioned papers and articles focused on either energy within envelope or exergy concept along with HVAC system in the buildings. The other difference of this thesis is the way of refurbishment. Beyond jacketing the building with thermal insulation layers, the whole building has been healed according to the exergy analysis of the building and HVAC systems. For this, energy and exergy analysis have been revealed in terms of monthly, daily and hourly. Finally, the case study building was simulated by using an energy simulation program (EDSL-TAS) based on European Standards by choosing the components according to Turkish Standards (TS-825).

2.2. Concepts of Energy and Exergy for the Buildings

Energy and exergy concepts are the key points for finding the energy assessments of the buildings. In this section, definitions and concepts of energy and exergy are introduced and the main equations and calculations are presented briefly.

It is difficult to define energy; but it can be said that energy is directly observed quantity which is formed as ability of a physical system to do work on other physical systems. Each building has an energy value, and this value is dissipated to passive and active systems. Passive systems are the envelope systems of the buildings which let the building benefit from the transferred heat from the sun, wind and other illuminate and heat loss/gains. Active systems are mechanical applications with electrical components in the building consisting of fans, pumps and heat pumps etc. which are called as HVAC systems. HVAC systems use fossil fuel, renewable resources or electricity as the energy resource (Çengel and Boles 2006).

Energy is to be conserved so that the energy flowing in must be equal to the sum of the energy stored within the system and the energy flowing out from the system. This energy balance can be expressed as follows;

$$(Energy\ input) = (Energy\ stored) + \ (Energy\ output) \qquad (2.1)$$

Under steady-state condition, energy storage does not occur, therefore; the equation above turns out to be the following simpler form;

$$(Energy\ input) = (Energy\ output) \qquad (2.2)$$

In this thesis, heat gain and loss are occurred via sun, wind according to internal conditions and thermo physical properties of the building, whereas; work is demand for heat pump, HVAC system etc. and mass is air leads to infiltration.

$$E_{in} - E_{out} = (Q_{in} - Q_{out}) + (W_{in} - W_{out}) - \left(E_{mass,in} - E_{mass,out}\right) = \Delta E_{system} \qquad (2.3)$$

where W is the work, Q is the heat transfer between interior and exterior, E_{mass} is the energy amount of mass.

Energy balance is also important in terms of rate form;

$$\frac{dE_{in}}{dt} - \frac{dE_{out}}{dt} = \frac{dE_{system}}{dt} \tag{2.4}$$

To find out energy value of the building, solar radiation, outdoor temperature and thermo physical properties have important roles. In order to analyze a building, whether envelope's thermo physical properties comply with limitation of U values according to climatic regions specifically determined for Turkey using degree-day method. Heat demand is calculated monthly including specific heat loss, efficiency factor, internal and solar gains in Equation 2.5 and 2.6

The following relations are taken from Yaman 2009, as;

$$Q_{year} = \sum Q_m \tag{2.5}$$

$$Q_m = \left[H\left(T_{i,m} - T_{d,m}\right) - \eta m\left(\varphi_{i,m} - \varphi_{g,m}\right)\right]t \tag{2.6}$$

H, building's specific heat loss including ventilation specific heat loss (H_i) and conductive specific heat loss (H_h).

$$H = H_i + H_h \tag{2.7}$$

Ventilation specific heat loss has a form as following equation according to the EN ISO 13790 (2008).

$$H_h = 0.33 n_h V_h \tag{2.8}$$

Air change rate per hour is chosen as 1 for all types of buildings, whereas EN ISO 13790 (2008) refers value ranging from 0.5 to 1.3 depending on construction type and exposed surface of the building. Conductive specific heat loss is defined as the sum of heat loss due to building elements (ΣAU) and thermal bridging effect (IUL).

$$H_i = \sum AU + IUL \tag{2.9}$$

Thermal bridging effect is taken into account with length of the element (I) and longitudinal heat loss coefficient (U_L) according to TS EN ISO 14683 (2004). Specific heat loss and total heat loss due to building components are given in Equation 2.10 including external walls (D), windows (P), floor (t) and roof (T).

$$\sum AU = U_D A_D + U_p A_p + 0.8 U_T A_T + 0.5 U_t A_t \tag{2.10}$$

Overall heat transfer coefficient (U) of building elements is determined by Equation 2.11 where h_i and h_o are indoor and outdoor convective heat transfer coefficients, respectively.

$$U = \frac{1}{\frac{1}{h_i} + \sum \frac{L}{k} + \frac{1}{h_0}} \tag{2.11}$$

In TS 825, monthly solar gains are calculated from Equation 2.12.

$$\phi_{g,m} = \sum r_{i,m} g_{i,m} I_{i,m} A_i \tag{2.12}$$

where $r_{i,m}$ and $g_{i,m}$ are shading and transmission factors. These values are listed in TS-825 and EN ISO 13790 (2008). Gain utilization factor (η) is used to correct the total internal and solar gains in order to calculate average monthly useful gains in a statistical way (Equation 2.13 and 2.14).

$$H_m = 1 - e^{\left(1/KKO_m\right)} \tag{2.13}$$

$$KKO_m = \frac{\left(\varphi_{i,m} + \varphi_{g,m}\right)}{H\left(T_{i,m} - T_{d,m}\right)} \tag{2.14}$$

2.2.1. Concept of Exergy related to Entropy Definition

Figure 2.1 illustrates the energy, exergy and entropy flows through the envelope in the buildings. According to the heat transfer rules, high temperature has medium 1 is indoor air or vice versa. Providing that, dry bulb temperature of medium 1 is higher than medium 2, heat flows from medium 1 to medium 2. By this way, heat transfer and entropy transfer is occurred. But entropy transfer leads to the entropy generation in the medium 2. In addition to this one, exergy transfer is released, and exergy is destructed.

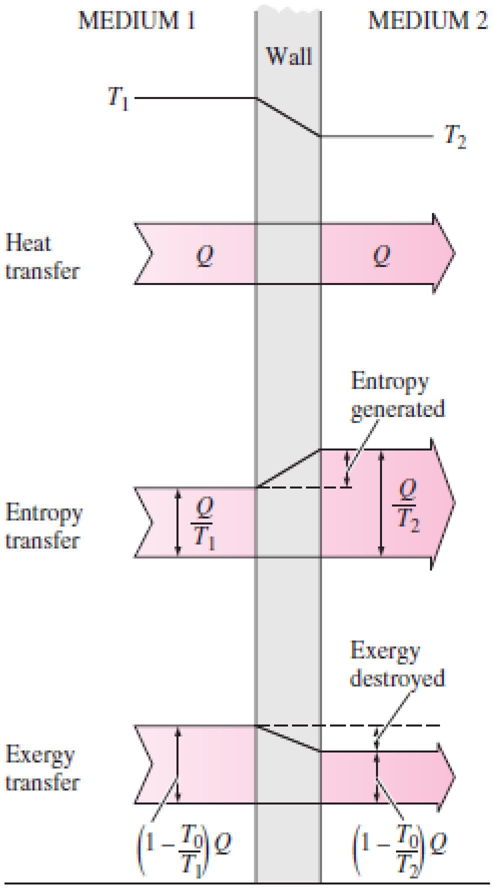


Figure 2.1. Flow of Energy, Exergy, Entropy in the Envelope
(Source: Çengel and Boles 2006)

Entropy equation is defined the as following equations. Energy can flow into the system as heat, therefore; is an energy transfer mechanism due to dispersion, by this way, entropy necessarily flows into the system as heat flows in and some amount of entropy is generated inevitably within the system in the course of heat transmission. The sum of the entropy input and the entropy generated must be in part stored or in part flows out of the system. Therefore; the entropy balance equation can be expressed in the following form (LowEx.net 2010).

$$(Ent._{input}) + (Ent._{generated}) = (Ent._{stored}) + (Ent._{output}) \qquad (2.15)$$

In the steady-state condition, entropy storage doesn't occur as well as energy storage. Therefore, the above entropy balance equation can be written as;

$$(Entropy_{input}) + (Entropy_{generated}) = (Entropy_{output}) \qquad (2.16)$$

The outgoing entropy from the system includes the generated entropy within the system and the system disposes of the generated entropy with the entropy output.

To obtain exergy balance equation, energy and entropy balance relations are combined. According to the balance equation or it's rate, entropy (or entropy rate) has a dimension of J/K (or W/K) and energy (or energy rate) has a dimension of J (or W). Therefore; entropy values of the system (input, generation, and output) can be calculated with other definition; an energy resource has an ability to disperse into the environmental space, filled with dispersed energy. The dispersed energy level of the resource surrounded by the environmental space can be defined as the product of the entropy contained by the resource and its environmental temperature in the Kelvin scale. By this way, entropy balance can be written as following equation.

$$(Entropy_{input}) \times T_e + (Entropy_{generated}) \times T_e = (Entropy_{output}) \times T_e \qquad (2.17)$$

where T_e is the environmental temperature. The product of entropy and environmental temperature is called anergy, which means dispersed energy. By using the term anergy and anergy balance equation can be given as following form;

$$(Anergy_{input}) + (Anergy_{generated}) = (Anergy_{output}) \qquad (2.18)$$

Exergy is a quantity of the dispersion energy. When energy balance equation (2.1) and anergy balance equation (2.18) are combined, the result brings about the following equation;

$$\left[\left(Energy_{inp.}\right) - \left(Anergy_{inp.}\right)\right] - \left(Anergy_{gen.}\right) = \left[\left(Energy_{outp.}\right) - \left(Anergy_{outp.}\right)\right] \qquad (2.19)$$

Anergy generated using energy with ability to disperse and that has just dispersed. This means that exergy is consumed. Anergy generation equals to exergy consumption. Using the term exergy, following equation can be obtained;

$$\left(Exergy_{input}\right) - \left(Exergy_{consumed}\right) = \left(Exergy_{output}\right) \qquad (2.20)$$

Equation 2.20 depicts exergy balance equation for a system under steady-state condition such as the building envelope system. Exergy consumed equals to anergy generated, which is the product of entropy generated and the environmental temperature (seen in Equation 2.21).

$$\left(Exergy_{consumed}\right) = \left(Environmental\ temperature\right) \times \left(Entropy_{generated}\right) \qquad (2.21)$$

2.2.1.1. Thermal Exergy Types in terms of Environment and Medium Temperature

Contained exergy by a substance varies with its own temperature and environment temperature. To illustrate, thermal exergy contained by as an example of thermal exergy contained by $81m^3$ (= 6m x 5m x 2.7m) of air, in an environmental temperature is 288 K (=15°C). It should be noted that air has a certain amount of exergy for both case, which are when the air temperature is higher than the environment and when the air temperature is lower than the environment. In this case, thermal contained exergy value formula can be expressed following form;

$$X_{ra} = c_{air} m_{ra} \left\{ (T_r - T_0) - T_0 \ln \frac{T_r}{T_0} \right\} \qquad (2.22)$$

where X_{ra} is thermal exergy contained by a volume of room air (kJ), c_{air} is specific heat of air (kJ/kgK), m_{ra} is mass of room air, T_r is room temperature in the Kelvin scale and T_0 is outdoor temperature in the Kelvin scale, as well.

If the exergy contained by air at a temperature higher than its environment is an ability of thermal energy contained by the air to disperse into the environment, the exergy called as warm exergy. On the other hand, the exergy contained at a temperature lower than its environment is an ability of the air, in which there is a lack of thermal energy compared to the environment, to let the thermal energy in the environment flow into it, it is called as cool exergy (Shukuya 1996).

2.2.1.2 Thermal Exergy Concepts

Exergy is the maximum useful work possible during a process that brings the system into equilibrium with a heat reservoir. Exergy balance is known as the Second Law of the Thermodynamics. Either “warm” exergy or “cool” exergy described above is a quantity of state contained by a substance. Providing that, room temperature higher than the outdoor environment when the space is heated, it is called that room air has “warm” exergy as a quantity of state. On the other hand, a room temperature lower than the outdoor environment, room air has “cool” exergy as a quantity of state.

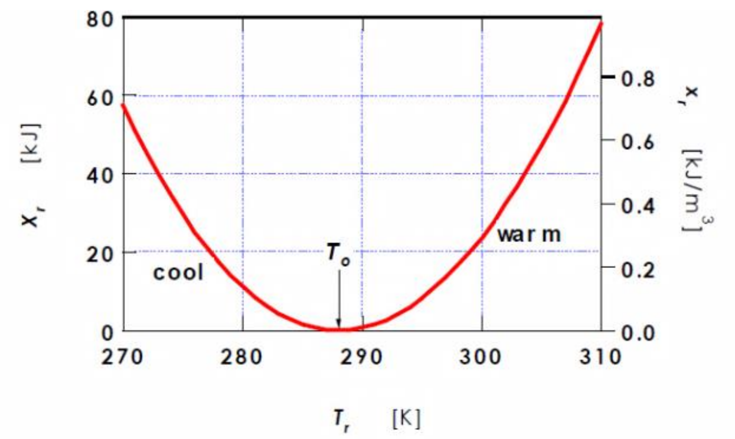


Figure 2. 2.Thermal exergy contained by air as a function of temperature related to the example (Source: http://www.lowex.net 2010)

Thermal exergy, whether it is warm exergy or cool exergy, flows through the envelope of the building, by a combination of convection, conduction, and radiation. The case in Figure 2.2 shows the situation when the environmental outdoor temperature, namely outdoor temperature, is lower than the indoor temperature. In this scenario, “warm” exergy flows in the internal surface and out the external surface of the building envelope system. If the environmental temperature is higher than the indoor temperature, namely the summer condition, the room air has “cool” exergy, which flows through the building envelope.

The direction of energy flow changes depending on the temperature profile, whether the indoor temperature is higher or lower than the outdoor temperature, but the direction of exergy flow is always the same from the indoors to the outdoors, external environment. What changes is whether it is warm exergy or cool exergy depending on, whether indoor temperature is higher or lower than the outdoor temperature. Whether space heating systems are low-exergy consuming or not, are the systems that supply and consume exergy for keeping warm exergy as a quantity of state 16 contained by room space in a certain desired range. On the other hand, whether space cooling systems are low-exergy consuming or not, are the systems that supply and consume exergy for keeping cool exergy as a quantity of state contained by room space in a certain desired range. As it mentioned before, exergy consumption is always accompanied with entropy generation, thus the generated entropy must be discarded constantly from the room space to the outdoor environment to keep warm or cool exergy within a desired range.

2.2.1.3. Exergy-Entropy Process of Passive Systems

This part of this thesis describes the general characteristics of six passive systems from the viewpoint of exergy-entropy process (Shukuya 1998) and (Shukuya, 2000). As suggested above, rational passive (bio-climatic) design would be prerequisite to realize low-exergy systems for heating and cooling.

a) Day lighting: Exergy consumption occurs when solar radiation is absorbed by the interior surfaces of building envelopes, after absorbing solar radiation, warm exergy is produced as a result of solar exergy consumption for lighting; the product can be used for space heating (Asada and Shukuya 1999).In the process, the entropy is produced in the course of solar exergy consumption for lighting must be dissipated into the atmosphere via ventilation, cooling or mechanical cooling, hopefully by a low-exergy system for cooling.

b) Passive heating: this is to control the rate of solar exergy consumption during daytime and nighttime by forming the built-environmental space with the appropriate materials, which has low thermal conductivity and high thermal-exergy storage capacity. It is also to consume, during nighttime, the thermal exergy produced during daytime. Most of the entropy generated is discarded spontaneously through the building envelopes into the atmosphere (Shukuya and Komuro 1996).

c) Shading: Shading applications such as fins are used to let the excess solar exergy, namely the rest of exergy necessary for day lighting, which must be consumed before it enters the built environment. By this way, to reduce the entropy generated within the built environment is revealed so that mechanical equipment for cooling is required to consume less exergy to remove the entropy generated within the built environment. Exterior shading devices are very much attractive in this regard, because the entropy generated at the devices is effectively discarded into the atmosphere via convection (Asada and Shukuya 1999).

d) Ventilation cooling: (Free cooling) this is to consume kinetic exergy of atmospheric air, producing the exergy-entropy process (Shukuya and Komuro 1996) as to remove the entropy generated within the built environment, such as the entropy discarded from the body surface of the occupants and that from the lighting fixtures, electric appliances and others, into the near-ground atmosphere.

e) Water spraying: this is to consume the wet exergy contained by liquid water, which is very large compared to thermal exergy, namely warm or cool exergy, to decrease the warm exergy produced by solar exergy consumption and possibly to produce cool exergy (See (Nishikawa and Shukuya 1999), and (Saito and Shukuya 1998)). Such as roof spraying and uchimizu, which is to scatter rainwater on the road surface, are also due to this process. The consumption of wet exergy to produce cool exergy or to decrease warm exergy play a very important role in photosynthetic system of leaves (Saito and Shukuya, 1998) and the temperature-regulating system of human body (Saito and Shukuya 2000).

f) Composting: In building, entities of microorganism can produce the warm exergy. The process of composting is used to let microorganisms consume actively a large amount of exergy contained by garbage and hence turn it into fertilizer. The warm exergy produced as a result of micro-organisms consuming chemical exergy can be rationally consumed for maintaining the temperature inside the container at a desired level. This is realized by making the walls of a container thermally well insulated (Takahashi and Shukuya 1998). The entropy generated in the process of composting is dissipated into the surrounding of the container and finally into the near-ground atmosphere.

2.2.1.4. LowEx Concept for the Buildings

Relations in this part are taken from Hepbaşlı 2011. The heat loss through the building envelope includes two types, first one is total transmission heat loss rate with neglected thermal bridges, which means the sum of the losses from all surfaces can be given following form (Yaman 2009);

$$\dot{Q}_T = \sum (U_i A_i F_{xi})(T_i - T_0) \tag{2.23}$$

where $\dot{Q}_T$ (W) is the transmission heat loss rate and U_i (W/m^{2}K) is the transmission coefficient, A_i (m^2) is the area of the surface i and Fx_i is their specific temperature correction factor.

The second one is ventilation heat loss rate $\dot{Q}_V$ (W) can be calculated by using following equation;

$$\dot{Q}_V = \left(C_p p V \eta_d (1 - \eta_v)\right)(T_\iota - T_0) \tag{2.24}$$

where η_d and η_v are the air exchange rate (ach/h) and the heat exchanger efficiency of mechanical ventilation system with heat recovery has been installed.

The solar heat gain rate is calculated from

$$\dot{Q}_s = \sum \left(I_{sJ}\left(1 - F_f\right) A_{wJ} g_J F_{sh} F_{no}\right) \tag{2.25}$$

where $\dot{Q}_S$ is the solar heat gain rate (W), I_{sj} is the solar radiation value (W/m^2), F_f is the window frame fraction, A_{wj} is the total window areas, g_j is the total energy transmittance value of the glazing, F_{sh} is the possible shading effects coefficient of other surrounding buildings and the F_{no} correction for non-orthogonal radiation on the windowpanes.

The internal gain is occurred by heat gains from occupants and from equipment. Heat gain from occupants can be expressed as;

$$\dot{Q}_0 = Q_0^{"} n o_0 \tag{2.26}$$

where $\dot{Q}_0^{"}$ is heat gain per capita.

The heat gain from equipment is written as;

$$\dot{Q}_e = Q_e^{"} A_N \tag{2.27}$$

where $\dot{Q}_e^{"}$ is the heat gain rate from equipment per m^2.

Other usage of electricity is demand for artificial lighting and ventilation, can be defined as;

$$P_I = p_I \times A_N = \dot{Q}_I \tag{2.28}$$

$$P_V = p_v \times V \tag{2.29}$$

where P_I, p_I and $\dot{Q}_I$ are lighting power, specific power and lighting gains rate, respectively. P_v is the ventilation power and p_v specific ventilation power.

All heat flows, heat losses via the envelope, heat gains via equipment etc.. (Internal gains) are combined as to find out heat demand rate of a mass and it creates following energy balance, which refers to the first law of thermodynamics:

Heat demand rate = Sum of heat losses rate – Sum of heat gains rate

$$\dot{Q}_h = \left(\dot{Q}_T + \dot{Q}_V\right) - \left(\dot{Q}_S + \dot{Q}_O + \dot{Q}_e + \dot{Q}_l\right) \tag{2.30}$$

Using the term of heat demand rate, in order to compare different buildings, specific number is usually expressed in a specific number;

$$Q_h^{"} = \frac{\dot{Q}_h}{A_N} \tag{2.31}$$

For the -energy source in the primary energy transformation given parameters, F_p and $F_{q,s}$ are the figures of the primary energy factor and the quality factor of the energy source, respectively. F_R is a fraction factor for the environmental.

The thermal efficiency of the distribution system can be found using following equation;

$$\eta_{dis} = 0.98 \times f_{emp} \times f_{dt} \times f_{td} \tag{2.32}$$

where f_{emp} is insulation placement, f_{dt} is design temperature as interval and f_{td} temperature drop of the HVAC system values are taken from Schmidt (2004).

The auxiliary energy factor $p_{aux,dis}$ of the system can be obtained from;

$$p_{aux,dis} = \frac{\Delta p \times \dot{v}}{\eta_{circ}} \tag{2.33}$$

where η_{circ} is the electrical efficiency of the circulation pump. And the pressure drop, Δp, in the distribution system is calculated from;

$$\Delta p = (1 + N) \times R \times l_{max} \times A_N + p_{ex} \tag{2.34}$$

where N is the percentage of equipment resistances with a typical value of 0.3 and R is the pressure drop of the pipe with a typical value of 100 Pa/m. The maximal pipe length of the distribution is given as an area specific value l_{max} with a typical value of 0.25m/m^2. p_{ex} is the extra pressure losses occurring within the system.

Under design conditions, the average volumetric flow at design conditions $\dot{v}$ is calculated through;

$$\dot{v} = \frac{1}{1.163 \times \Delta T_{dis} \times 0.0036 s/m^3 K} \tag{2.35}$$

where ΔT_{dis} is the temperature difference in the distribution system.

For the quality factor of the indoor air $F_{q,air}$ is calculated by;

$$F_{q,air} = 1 - \frac{T_0}{T_i} \tag{2.36}$$

where T_o and T_i are the reference temperature and room temperature.

The exergy load rate can be given by;

$$\dot{E}x_{air} = F_{q,air} \times \dot{Q}_h \tag{2.37}$$

The surface temperature of the radiator, T_{heat} is estimated using the logarithmic mean temperature of the carrier medium with the inlet, T_{in} and return temperature, T_{ret} of the heating system.

$$T_{heat} = \frac{T_{in} - T_{ret}}{\ln\left((T_{in} - T_i) - (T_{ret} - T_i)\right)} \times \frac{1}{2} + T_i \tag{2.38}$$

where T_{in} and T_{ret} are inlet and return temperatures of the radiator.

Using the above given temperature, a new quality factor at the heater surface can be calculated from;

$$F_{q,heat} = 1 - \frac{T_{ref}}{T'_{heat}} \tag{2.39}$$

where heater surface temperature is absolute temperature in K.

$$T'_{heat} = T_{heat} + 273.15K \tag{2.40}$$

The exergy load rate at the heater is;

$$\dot{E}x_{heat} = F_{q,heat} \times \dot{Q}_h \tag{2.41}$$

Since the energy efficiency of the distribution system (η_E) is not 100%, an energy load calculation first has to be performed and the heat loss rates have to be calculated as;

$$\dot{Q}_{loss,HS} = \dot{Q}_h \left(\frac{1}{\eta_{HS}} - 1 \right) \tag{2.42}$$

Heating system is a subsystem of the distribution system.

By keeping the derivation of the exergy demand rate of the heating system as calculated from;

$$\Delta \dot{E}x_{HS} = \frac{\dot{Q}_h + \dot{Q}_{loss,HS}}{T_{in} - T_{ret}} \left\{ (T_{in} - T_{ret}) - T_{ref} \ln \left(\frac{T_{in}}{T_{ret}} \right) \right\} \tag{2.43}$$

The exergy load rate of the heating system becomes;

$$\dot{E}x_{HS} = \dot{E}x_{heat} + \Delta \dot{E}x_{HS} \tag{2.44}$$

The heat loss rate of the distribution system results in;

$$\dot{Q}_{loss,dis} = \left(\dot{Q}_h + \dot{Q}_{loss,HS} \right) \times \left(\frac{1}{\eta_{dis}} - 1 \right) \tag{2.45}$$

where $\eta_{dis}$is the energy efficiency of the distribution system.

The demand on auxiliary energy or electricity of the distribution system is given by;

$$P_{aux,dis} = P_{aux,dis} \left(\dot{Q}_h + \dot{Q}_{loss.HS} \right) \tag{2.46}$$

The exergy demand rate of the distribution system becomes;

$$\Delta \dot{E}x_{dis} = \frac{\dot{Q}_{loss,dis}}{\Delta T_{dis}} \left\{ T_{dis} - T_{ref} \ln \left(\frac{T_{dis}}{T_{dis} - \Delta T_{dis}} \right) \right\} \tag{2.47}$$

where the inlet temperature of the distribution system is the mean design temperature T_{dis} and the return temperature is the design temperature minus the temperature drop ΔT_{dis} (not: used here as absolute temperatures in K):

The exergy load rate of the distribution system becomes;

$$\dot{E}x_{dis} = \dot{E}x_{HS} + \Delta\dot{E}x_{dis} \tag{2.48}$$

If a seasonal storage is integrated into the system design, some of the required heat is covered by thermal solar power with a certain solar fraction F_S. The required energy to be covered by the heat production is;

$$\dot{Q}_{HP} = \left(\dot{Q}_h + \dot{Q}_{loss,HS} + \dot{Q}_{loss,dis}\right)(1 - F_S)\frac{1}{\eta_{HP}} \tag{2.49}$$

The demand rate on auxiliary energy of the heat production system to drive pumps and fans can be calculated by:

$$P_{aux,HP} = p_{aux,HP}\left(\dot{Q}_h + \dot{Q}_{loss,HS} + \dot{Q}_{loss,dis}\right) \tag{2.50}$$

The exergy load rate of the heat production is calculated by;

$$\dot{E}x_{HP} = \dot{Q}_{HP} \times F_{q,s} \tag{2.51}$$

where $F_{q,S}$ is the quality factor of source.

The production of domestic hot water (DHW) is calculated in a similar way as the heat production system for heating. The DHW energy demand is estimated according to the considered system and the number occupants.

$$P_W = \frac{V_W \times \rho \times C_p \times \Delta T_{DHW} \times no_o}{\eta_{DHW}} \tag{2.52}$$

As a second step, the exergy load rate of other building service appliances, such as lighting, ventilation are taken into consideration and, in this case, named “plant”.

$$\dot{E}x_{plant} = (P_l + P_V)F_{q,el} \quad (2.53)$$

The overall energy and exergy load rates of the building are expressed in the required primary energy and exergy input rates. For the fossil or non-renewable part of the primary energy, the result becomes;

$$\dot{E}_{p,tot} = \dot{Q}_{HP}F_P + \left(P_l + P_V + P_{aux,HP} + P_{aux,dis} + P_{aux,HS}\right)F_{p,el} + P_W \times F_{DHW} \quad (2.54)$$

where F_p is the primary energy factor.

If the heat production system utilizes a renewable energy source or extracts heat from the environment, as heat pumps or solar collectors do, the additional renewable energy load rate is estimated by;

$$\dot{E}_R = \dot{E}_{HP} \times F_R + \dot{E}_{env} \quad (2.55)$$

The total exergy load rate of the building becomes;

$$\dot{E}x_{tot} = \dot{Q}_{HP}F_PF_{q,s} + \left(P_l + P_V + P_{aux,HP} + P_{aux,dis} + P_{aux,HS}\right)F_{p,el} + \dot{E}_RF_{q,R} + P_WF_{DHW}F_{q,s,DHW} \quad (2.56)$$

Other important concepts of the LowEx are exergy efficiency and exergy flexibility factor definitions; which can be found by;

$$Y_{sys} = \frac{E_{x_{building}}}{E_{x_{total}}} \quad (2.57)$$

$$F_{flex} = \frac{E_{x_{hs}}}{E_{x_{total}}} \quad (2.58)$$

CHAPTER 3

BUILDING DESCRIPTION

3.1. General Information about Case Study Building

The selected case study building, Block C of the Faculty of Architecture, is located in Izmir Institute of Technology Campus area, Gülbahçe, Izmir at 38^{o} 19' 15.91" latitude and 26^{0} 38" 26.86" longitude in coordinates. The building is constructed between two other buildings of Faculty of Architecture (Block D and E), and the main façade of the building is on the west direction (Figure 3.1). The building is used as an office building and has two floors, which are ground floor and first floor.

Figure 3.1. Exterior View of the Case Study Building

Table 3.1 represents some of the architectural and dimensional characteristics of the case study building. According to this table, the building has a glazing ratio as 34%, which is calculated by dividing the total glazing area to the area of total opaque components ($A_{tot\ glazing}/A_{tot\ opaque\ walls}$). According to TS-825 (2008), glazing ratio is limited as 12%.

Table 3.1. Main Characteristics of the Case Study Building

Floor area (m^2)	522
Floor height (m)	3.6
Volume (m^3)	3758.4
Surface area of the facades (m^2)	745.92
Roof area (m^2)	522
Glazing area (m^2)	259.4
Glazing ratio (%)	0.34
Compactness (A_{tot}/V_{tot})	0.27

At the beginning of the case study work, a building survey was made and the as built plans (ground floor, first floor and roof plan) of the case study building were drawn using Autodesk AutoCAD R2013© (See Figure 3.2-3.4). In these drawings, conceptual plans and locations of the selected architectural details can be seen, as well.

As can be seen in the plan drawings, each floor of the building has 12 office rooms and one restroom. As a very important characteristic, the building has an atrium space and skylight on the roof. In the atrium; eight, in the restrooms; five and in each office rooms; two lighting apparatuses exist. As mentioned before, lighting has an energy and exergy value in the assessment of the buildings. In addition to these lighting apparatuses, each office room includes two fan coils, the atrium includes four fan coils, and the restrooms include one fan coil.

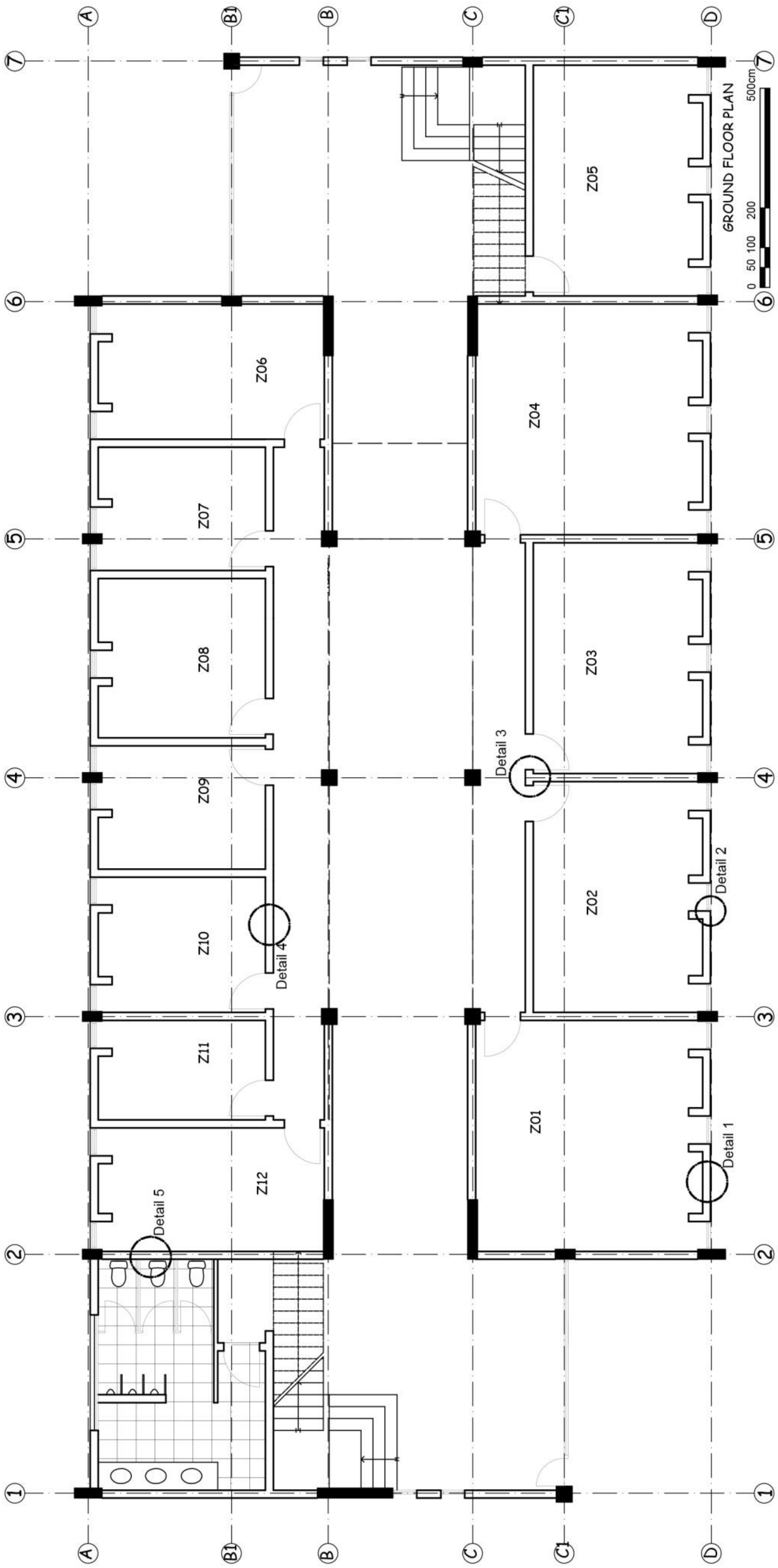


Figure 3.2. Ground Floor Plan of the Case Study Building

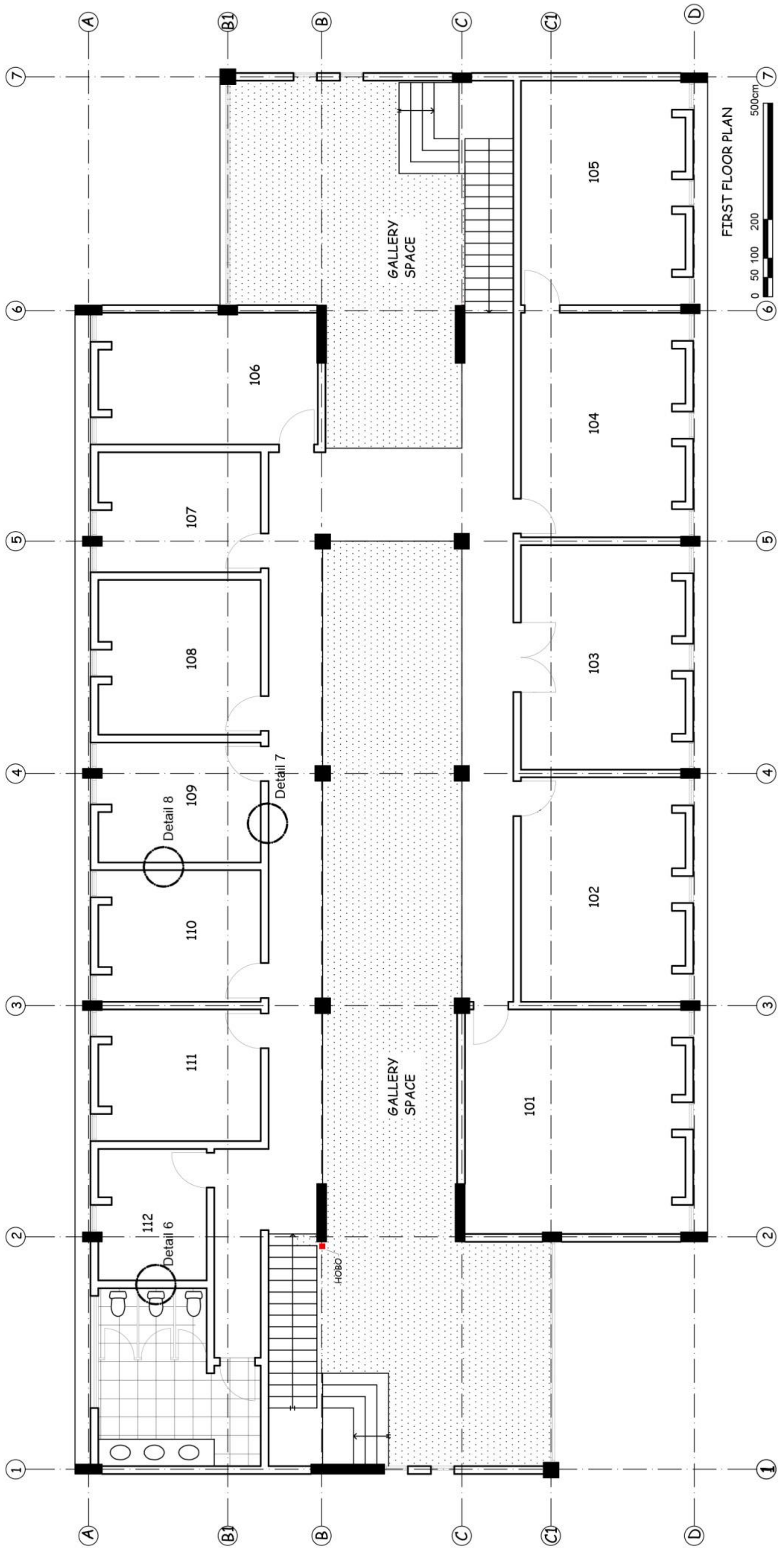


Figure 3.3. First Floor Plan of the Case Study Building

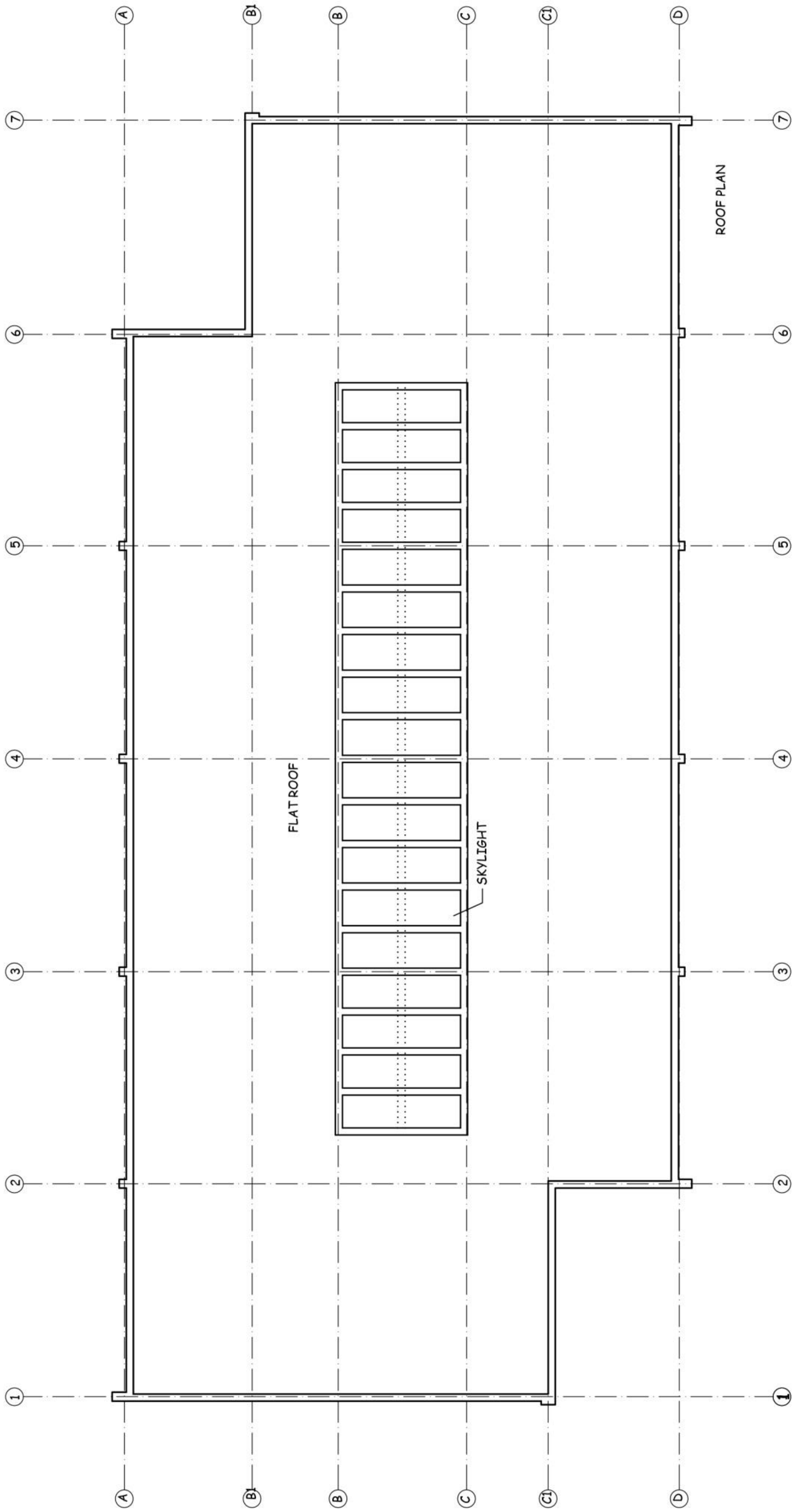


Figure 3.4. Roof Plan of the Case Study Building

3.2. Building Components and Structures before Retrofitting

In order to simulate the current situation (before retrofitting) of the case study building correctly in EDSL-TAS medium, architectural design and details were investigated thoroughly; and all the building components were defined according to TS-825's materials lists. During this definition, all materials were tried to be selected as realistic as it can be. However, for some components, some assumptions were made with consultancy of the specialist architects.

Thermo-physical characteristics of the building components are important to determine energy and exergy efficiencies. In terms of energy efficiency, resistances of all the components (R) and overall heat convection coefficient (radiation, convection, conduction) values are determined by using following formula,

$$R = \frac{L}{k} \tag{3.1}$$

$$R_o = \frac{1}{h_o} \tag{3.2}$$

$$R_i = \frac{1}{h_i} \tag{3.3}$$

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

where, L is thickness of the material (m), k is thermal conductivity of material (W/mK), R is thermal resistance coefficient (m^2K/W), h is convection coefficient, U is overall heat transfer coefficient (W/m^2K).

All exterior walls and doors and windows lead to infiltration from interior to exterior or vice versa during the year. Internal walls and interior doors lead to infiltration as well from zone to zone. In this part, properties of the building components are explained obviously. Building components in the case study building are exterior walls, interior walls, slabs and floors, roof, doors and windows and glazing.

All of the calculations in this study are revealed by EDSL-TAS simulation program with correction factor to find overall heat transfer coefficient (*U*) values, therefore, in methodology part; all *U* values of the components are going to be given for the building and retrofitting of the building components. With this analysis, energy level of the building can improve to a better level than the current situation.

3.2.1. Exterior Walls as Building Component

According to the building survey, it was seen that all exterior walls of the case study building were comprised of solid bricks with the dimension of 10x6x21.5cm. The walls are bonded by double layers of these solid bricks and cement based mortar as adhesive material. From bottom to top, section of the ground floor is composed of following layers; compacted soil (1 m.), hardcore (0,3 m), gravel (0,05 m), lean concrete (0,1 m), leveling layer (0,02 m), mortar (0,01 m) and marble tile (0,02 m). Architectural detail of a typical exterior wall on the ground floor can be seen in Figure 3.5; and the thermal and physical properties of this wall and floor materials are represented in Table 3.2 and Table 3.3.

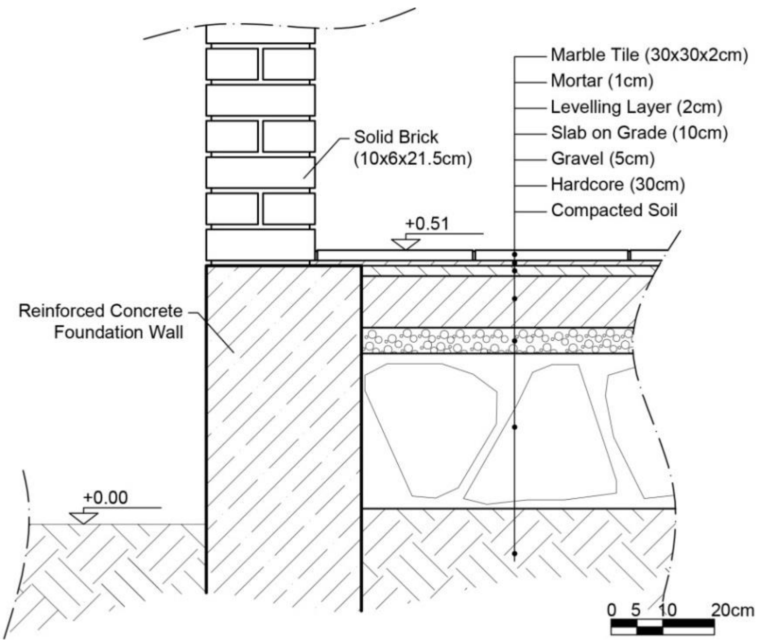


Figure 3.5. Section of Ground Floor and Exterior Wall

Table 3.2. Physical Properties of the Exterior Wall Components

Name of the Component	Material Name	Thickness (m)	Conductivity (W/mK)	Specific Heat (J/kgK)	Density (kg/m^3)	Thermal Absorbance (emissivity)
Solid Brick Common	Solid Brick	0.215	0.6	920	2400	0.93

Table 3.3. Physical Properties of the Ground Floor Components

Name of the Component	Material Name	Thickness (m)	Conductivity (W/mK)	Specific Heat (J/kgK)	Density (kg/m^3)	Thermal Absorbance (emissivity)
Marble Tile	Tile	0.02	2	753	2700	0.94
Mortar	Plaster	0.01	0.42	837	1000	0.9
Leveling Layer	Plaster	0.02	0.5	837	1200	0.9
Concrete	Slab on Grade	0.1	0.2	920	600	0.9
Gravel	Soil	0.05	0.52	1824	2050	0.91
Hardcore	Stone	0.3	2.9	900	2640	0.9
Compacted Soil	Soil	1	0.577	880	1400	0.9

3.2.2. Interior Walls as Building Component

In the case study building, material and details of the interior walls and related slabs differ from each other according to the belonging floors and zones. For example, interior walls include two types of the walls: first one is built between office rooms and atrium which are composed of double layers of solid bricks and cement based mortar; second one is between two office rooms, which are composed of horizontal perforated bricks, cement based mortar and plaster. Architectural details of the first wall alternative can be seen in Figure 3.6, and second wall alternative in Figure 3.7. Thermal and physical properties of these walls' materials are represented in Table 3.4 and Table 3.5. Both of these details are taken from the ground floor, so the slab layers are the same with the previous exterior wall details. For the thermal properties of these materials, please see Table 3.3.

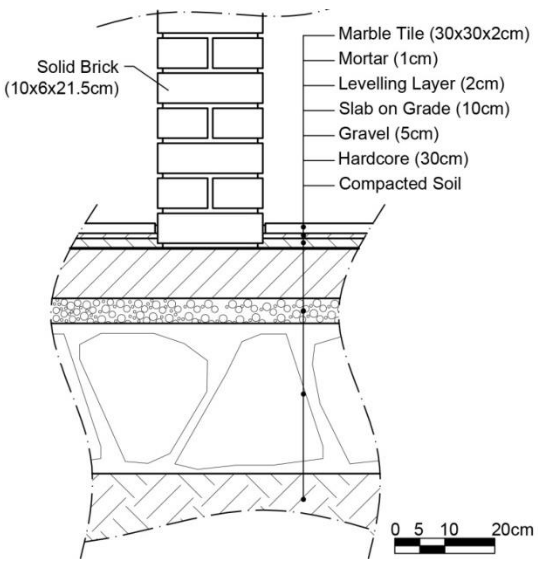


Figure 3.6. Ground Floor Interior Wall I: Between Office Rooms and Atrium

Table 3.4. Physical properties of Interior Wall-I

Name of component	**Material Name**	**Thickness (m)**	**Conductivity (W/mK)**	**Specific heat (J/kgK)**	**Density (kg/m^3)**	**Thermal absorbance (emissivity)**
Solid Brick Common	Solid Brick	0.215	0.96	920	2000	0.93

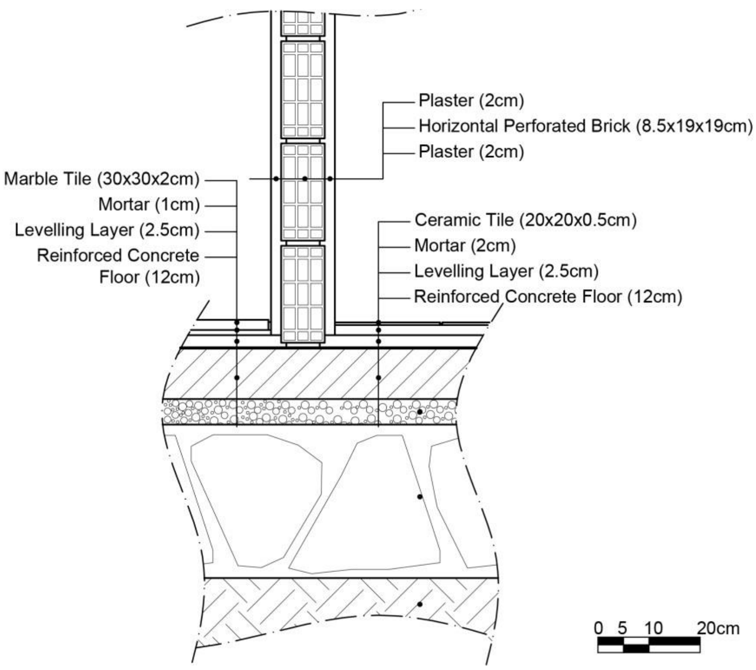


Figure 3.7. Ground Floor Interior Wall II: Between Two Office Rooms

Table 3.5. Physical properties of Interior Wall-II

Name of component	Material Name	Thickness (m)	Conductivity (W/mK)	Specific heat (J/kgK)	Density (kg/m^3)	Thermal absorbance (emissivity)
Plaster	Plaster	0.02	1.6	850	2000	0.55
Horizontal Perforated Brick	Solid Brick	0.19	0.58	870	1400	0.93
Plaster	Plaster	0.02	1.4	1000	2000	0.55

3.2.3. Slabs and Floors as Building Component

The case study building has two floors. In ground floor, slab on grade is constructed rather than a reinforced concrete slab; and details and component properties of this floor are represented in the exterior wall details (Figure 3.5 and Table 3.3). The other floor type is the slab between ground floor and first floor which is called suspended floor. This floor is composed of a reinforced concrete slab (12 cm), a leveling layer which is a kind of mortar (2.5 cm), cement based mortar (1 cm) and the marble or ceramic tile as the finishing material. The finishing material changes according to the function of the zone. In restrooms, ceramic tile is used, in the corridors and offices marble tiles are used. A typical detail from the first floor, which represents the corridor and office room connection, can be seen in Figure 3.8, and thermal and physical properties of the materials in Table 3.6.

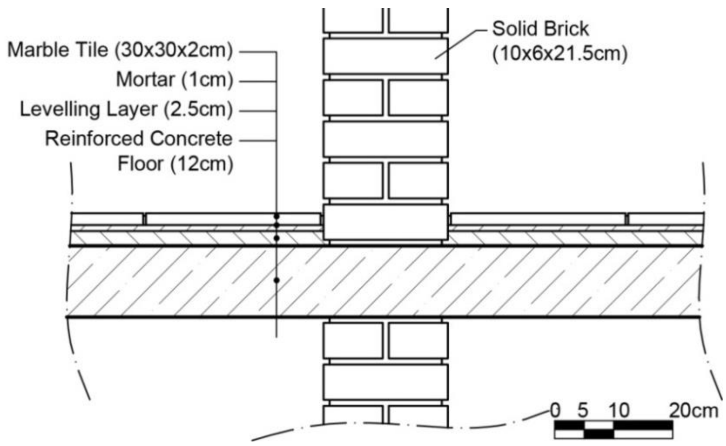


Figure 3.8. First Floor Interior Wall I: Between Office Rooms and Atrium

Table 3.6. Physical Properties of First Floor Interior Wall I

Name of component	Material Name	Thickness (m)	Conductivity (W/mK)	Specific heat (J/kgK)	Density (kg/m^3)	Thermal absorbance (emissivity)
Marble Tile	Tile	0.02	3.5	900	2800	0.88
Mortar	Plaster	0.01	1.6	850	2000	0.9
Leveling Layer	Plaster	0.025	0.7	837	2100	0.9
Reinforced Concrete	Concrete	0.12	2.5	1500	2300	0.86

The other detail from the first floor, which represents the office room and restroom connection, can be seen in Figure 3.9 and Table 3.7.

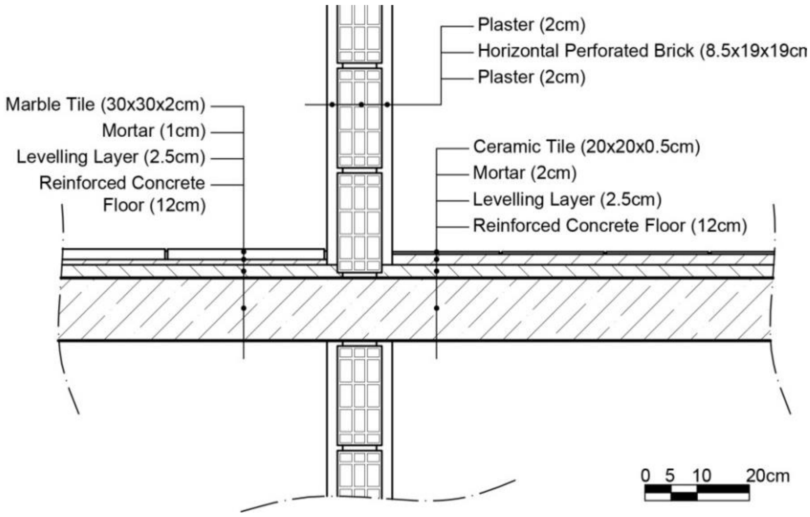


Figure 3.9. First Floor Interior Wall II: Between Office Room and Restroom

Table 3.7. Physical Properties of First Floor Interior Wall II

Name of component	Material Name	Thickness (m)	Conductivity (W/mK)	Specific heat (J/kgK)	Density (kg/m^3)	Thermal absorbance (emissivity)
Ceramic Tile	Tile	0.05	3.5	900	2800	0.88
Mortar	Plaster	0.01	1.6	850	2000	0.9
Leveling Layer	Plaster	0.025	2.1	850	2000	0.55
Reinforced Concrete	Concrete	0.12	2.5	1500	2300	0.86

3.2.4. Doors and Windows as Building Component

The case study building has 58 dual glass windows, two external doors and 26 interior doors. All these windows and exterior doors are made up of aluminum profiles and use the same connection details. These details are represented in Figure 3.10, and their physical and thermal properties in Table 3.8.

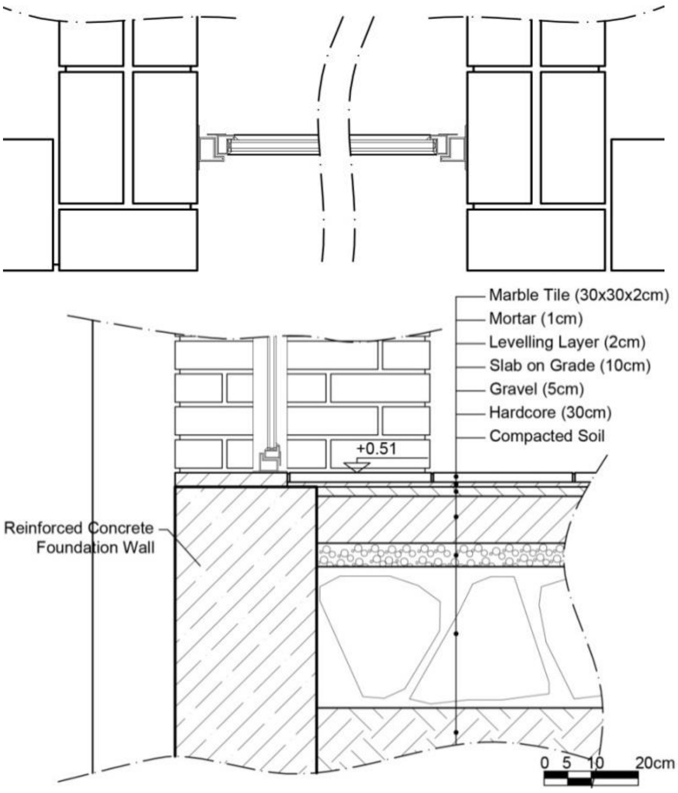


Figure 3.10. Aluminum Window and Door Detail

Table 3.8. Physical Properties of Aluminum Windows and Doors

Name of component	Material Name	Thickness (m)	Conductivity (W/mK)	Specific heat (J/kgK)	Density (kg/m^3)	Thermal absorbance (emissivity)	Name of component
Window	Aluminum Frame	Frame	0.05	2.9	1670	320	0.9
Plain Glass	Glass	0.004	2.4	-	0.12	0.81	0.34
Cavity	Cavity	0.01	2.5	-	-	-	-
Plain Glass	Glass	0.004	2.4	-	0.12	0.81	0.34

Interior doors (doors of the office rooms and restrooms) are all made up of wood. Details of these doors can be seen in Figure 3.11 and the thermal and physical properties can be seen in Table 3.9.

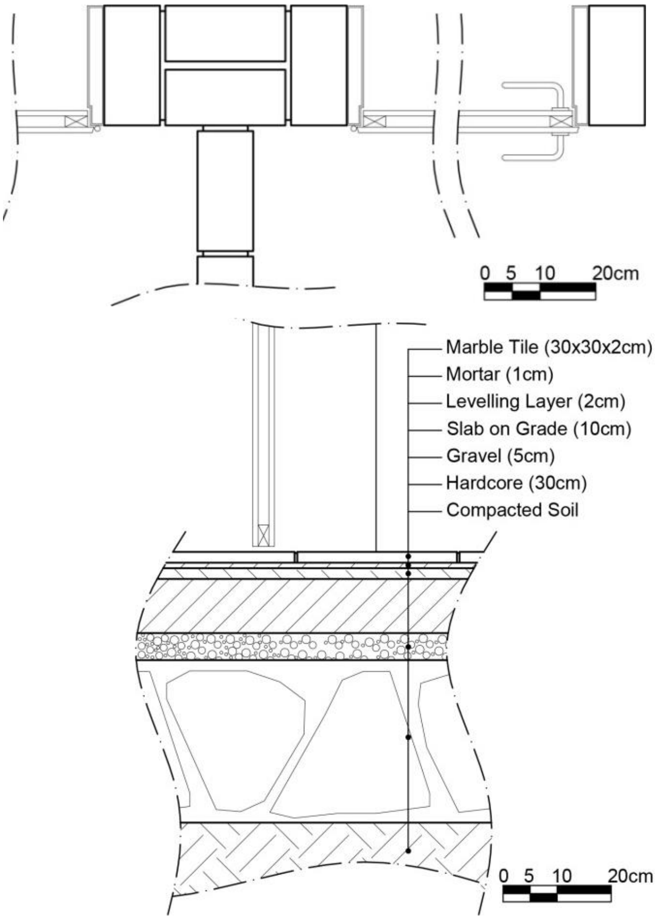


Figure 3.11. Interior Door Detail

Table 3.9. Physical Properties of Wood Interior Doors

Name of component	**Material Name**	**Thickness (m)**	**Conductivity (W/mK)**	**Specific heat (J/kgK)**	**Density (kg/m^3)**	**Thermal absorbance (emissivity)**	**Name of component**
Door	Wood	0.05	3.6	1670	320	0.8	

3.2.5. Roof as Building Component

Roof of the case study building is generally made up of reinforced concrete slab and a glass skylight. The reinforced concrete slab (12 cm) is covered by a leveling concrete (3cm), water insulation which is single layer bitumen based membrane (0.5 cm), steam equalizer membrane (1 cm) and gravel (10 cm). This detail is represented in Figure 3.12, and the thermal properties of the materials in Table 3.10. Total heat transfer coefficient of the roof is 0.452 $W/m^2 .^oC$

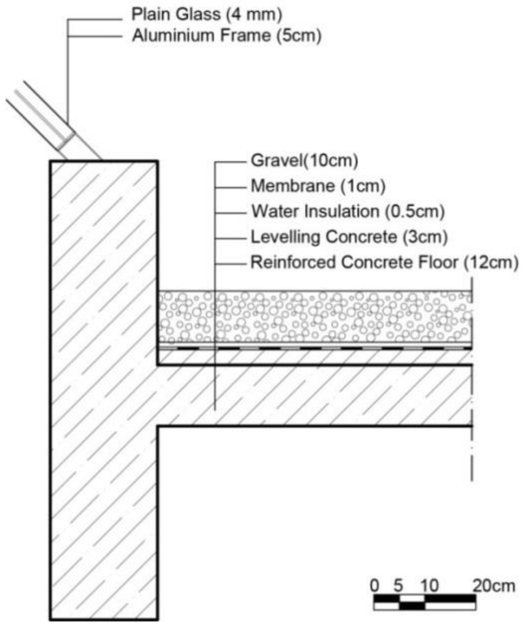


Figure 3.12. Roof Section before Retrofitting

Table 3.10. Physical Properties of the Roof

Name of component	**Material Name**	**Thickness (m)**	**Conductivity (W/mK)**	**Specific heat (J/kgK)**	**Density (kg/m^3)**	**Thermal absorbance (emissivity)**
Gravel	Gravel	0.1	0.577	880	1400	0.9
PVC	Membrane	0.01	0.23	1000	70	0.6
Water Insulation	Insulation	0.005	0.05	670	500	0.9
Leveling Layer	Plaster	0.03	0.7	837	2100	0.9
Reinforced Concrete	Concrete	0.12	2.5	1500	2300	0.86

3.3. Building Components and Structures after Retrofitting

As it can be seen in the following parts of the thesis, some of the aforementioned details of the case study building have been retrofitted in order to increase the thermal quality of the whole building. All these modifications are made within the knowledge of the building’s architect. Because of this retrofitting, some of the above represented details have been modified. As the first modification, external walls have been retrofitted by the addition of some extra layers over the external solid bricks. From interior to exterior, extra layers of the external wall are adhesive mortar (1 cm), thermal insulation (5cm), plaster (0.5 cm), fiber mesh, plaster (0.5 cm) and paint as the finishing. Architectural detail of a typical exterior wall after retrofitting can be seen in Figure 3.13; and the thermal and physical properties of these extra layers are represented in Table 3.11.

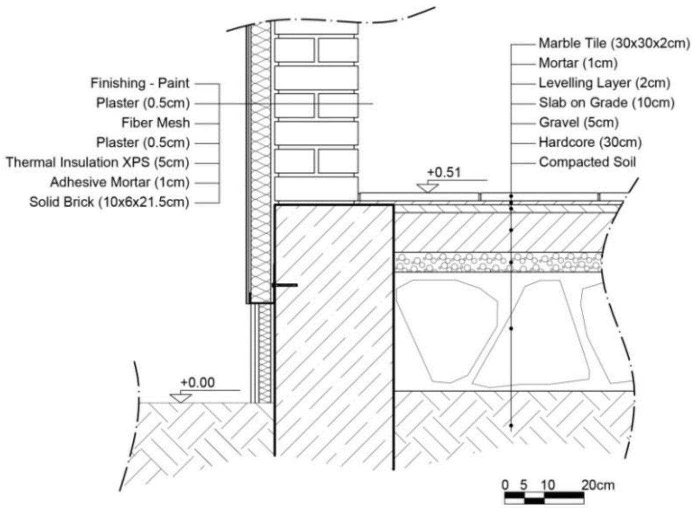


Figure 3.13. Section of Ground Floor and Exterior Wall after Retrofitting

Table 3.11. Physical Properties of Extra Layers of the External Wall

Name of component	**Material Name**	**Thickness (m)**	**Conductivity (W/mK)**	**Specific heat (J/kgK)**	**Density (kg/m^3)**	**Thermal absorbance (emissivity)**
Thermal Insulation	XPS	0.05	0.036	200	30	0.8
Plaster	Plaster	0.03	0.7	837	2100	0.9

The other modification is about the roof. Insulation of the roof surface has been retrofitted with additional layers and the windows of the skylight have been changed with PVC frames and three layers low emissivity (low-e) glasses. From bottom to top, all layers of the roof are plaster (2 cm), reinforced concrete slab (12 cm), leveling concrete (3 cm), steam blocker (0.5 cm), double layers of thermal insulation (10 cm), double layers of water insulation membrane (1cm), separator layer (0.2 cm) and the gravel (5 cm). This detail is represented in Figure 3.14, and the thermal properties of the materials in Table 3.12.

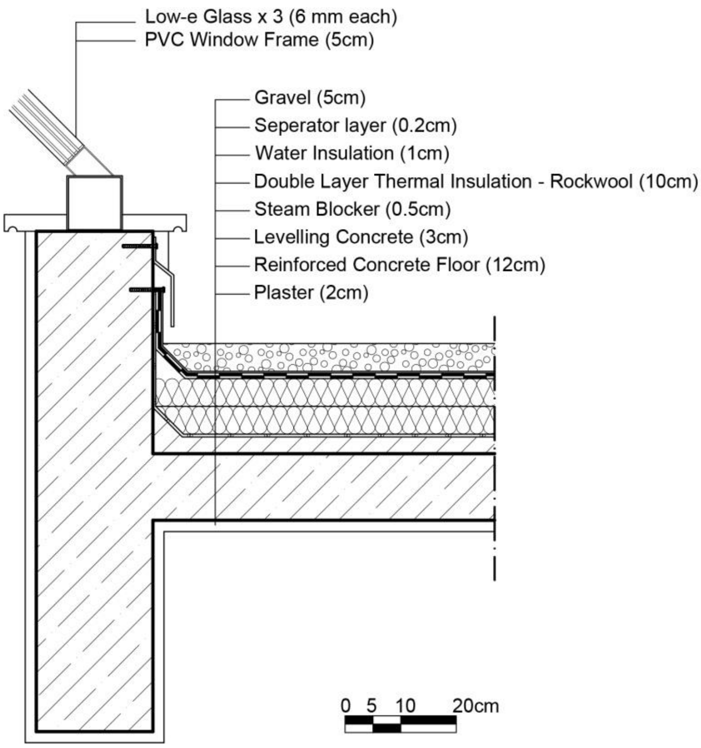


Figure 3.14. Roof Section after Retrofitting

Table 3.12. Physical Properties of Extra Layers of the Roof

Name of component	Material Name	Thickness (m)	Conductivity (W/mK)	Solar Absorbance (%)	Total Transmittance G Value	R Value ($m^2.^oC/W$)	Emissivity
Low-e 3L-Glass	Glass	4-12-4-12-4	1.272	0.417	0.456	0.956	0.840

3.4. Heating and Cooling Systems before Refurbishment

Beside the definition of the materials and dimensions of architectural elements, HVAC system of the building is important for the EDSL-TAS simulations as well. As a preparation for the computer simulation, first HVAC system of the building has been investigated. It is known that heating system of the building is active for around 182 days per year. These days are called as heating days and central heating, which uses fuel oil is active. Central cooling system is active for around 183 days. For cooling, the building has a VRF heat pump. The building has a domestic hot water system, too. However this system is not used during the year.

Heating capacity of the current HVAC system of the case study building was designed as 84.302 kW This is the capacity of hot water boiler. This boiler keeps the water between 70^{o}C and 90^{o}C. Design criteria for the heating system can be defined as;

$$\dot{Q}_T = \dot{Q} \times n_c = 84.302 \times 0.9 = 75.87\ kW$$

The value of the heating system design capacity corresponds to 75.87 kW. Correction factor of the system is (n_c) 0.9 in the boiler and the result value of 75.87 kW is the maximum energy value of the heating system.

Cooling capacity of the Air to Water Chiller system of the case study building was designed as 162.79 kW, and this system keeps the water inside between 8 ^{o}C and 14 ^{o}C. However, the temperature of the interior is between 24 ^{o}C and 37 ^{o}C. According to this data, design capacity can be calculated as;

$$\dot{Q}_T = \dot{Q} \times n_c = 162.79 \times 0.9 = 146.51\ kW$$

Correction factor of the air to water chiller system is 0.9 and according to the factor, the cooling system capacity is 146.54 kW.

Hot water boiler's capacity is 5.58 kW. Total consumption of the building is 240 lt, and the hot water in the system is between 10 ^{o}C and 60 ^{o}C. Heating Fluid's temperature is between 70 ^{o}C and 90 ^{o}C. Design criteria can be calculated as;

$$\dot{m}_s = \dot{m}_{ss} \times n_c = 240 \times 0.4 = 96\ lt/h$$

$$\dot{Q} = m_s \times C \times (t_e - t_i) = 96000 \times 4.18 \times \frac{(60 - 10)}{3600} = 5.58\ kW$$

Correction factor of the domestic hot water system is 0.9 and 4800 kcal/h equals to 5.58 kW. Schematic plan of the current HVAC system of the building with domestic hot water system is presented in Figure 3.15.

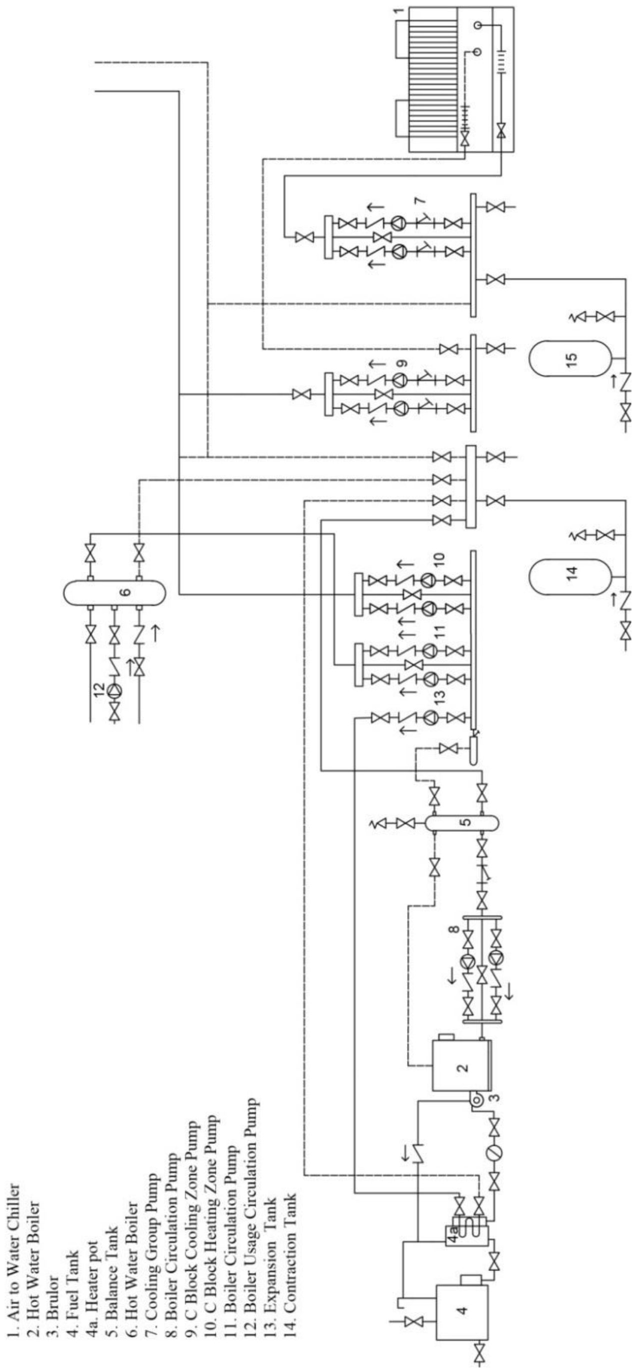


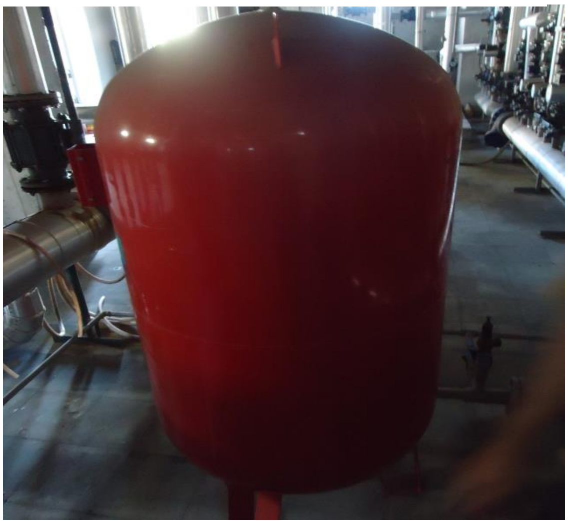
Figure 3.15. HVAC and Domestic Hot Water System of the Case Study Building

Some important components of the HVAC system such as “air to water chiller system”, “furnace system with burner”, “collector and pressure balance tank” can be seen in Figure 3.16.

a.) Air to Water Chiller System

b.) Furnace System with Burner

c.) Collector



d.) Pressure Balance Tank

Figure 3.16. Components of the HVAC System

A chiller is a machine that removes heat from a liquid via a vapor-compression or absorption refrigeration cycle. This liquid can then be circulated through a heat exchanger to cool air or equipment as required. As a necessary byproduct, refrigeration creates waste heat that must be exhausted to ambient or, for greater efficiency, recovered for heating purposes. Concerns in design and selection of chillers include performance, efficiency, maintenance, and product life cycle environmental impact (Figure 3.16a).

Burner in the system is an oil burner is a heating device which burns fuel oil, the oil is atomized into a fine spray usually by forcing it under pressure through a nozzle. This spray is usually ignited by an electric spark with the air being forced through by an electric fan (Figure 3.16b).

Collector with pumps is used to spread out the main fluid flow into the two channels and in return flow, the system is used to collect the fluid flow (Figure 3.16c).

Pressure balance tank is used to balance pressure in the pipe or columns and prevents the system from precipitate decrement or increments of the pressure (Figure 3.16c).

CHAPTER 4

METHODOLOGY

After documentation of the climatic data and analysis of the current building components, their thermophysical properties and the HVAC system, the case study building was analyzed in terms of energy and exergy; and some retrofitting on the building's envelope, skylight and refurbishment on the HVAC system were made in order to improve the energy level of the building. To arrive at this aim, firstly EDSL-TAS, energy simulation program, and finally LowEx, an exergy calculation tool, were used to assess energy level of the building. This chapter introduces the methodology and steps of these computer simulations.

Energy simulation software package, which is used in this thesis, is called EDSL-TAS (Environmental design Solution Limited). This software package was introduced in 1999 in England and can be used to find out energy assessment, energy consumption and thermal comfort level by simulating the building according to the orientation, architectural design of the whole building, shading. Besides, in this thesis, the program has been used to investigate the opportunities to reach the required thermal comfort and energy amount for the case study building. Calibration and uncertainty analysis of the data aren't included by the thesis because of deficiency in the data collection

The other simulation and calculation tool is called LowEx, which is based on the exergy analysis. LowEx was introduced in Germany in 1980s. In order to improve energy level of the buildings, exergy examination is a requirement because of energy implantation. In the LowEx systems, one or more systems are used to decrease heating, cooling and ventilation loads. Moreover, exergy tool can find out a useful energy value to reuse in the building by implanting some application.

4.1. Measurements

As the first step of the simulation, exterior climatic data were taken via a climatic data station is Cabled Vantage Pro2^{TM} DAVIS Plus with Standard Radiation

Shield, which is located on the roof of the Block A building of the Faculty of Architecture. This data station collects the temperature, solar radiation, relative humidity and wind speed/ direction data within the periods of ten minutes during the year. In this thesis, the data of DAVIS was collected for one year (01.01.2012 – 31.12.2012) and all this data was entered to EDSL-TAS software package hour by hour in order to obtain a dynamic simulation. EDSL-TAS calculates the instant climatic condition of the building and necessary heating/ cooling loads for any moment.

Figure 4.1. Cabled Vantage Pro2^{TM} DAVIS Plus with Standard Radiation Shield

In Figure 4.2 and Figure 4.3, dry bulb temperature and relative humidity values taken by DAVIS are demonstrated. The values of the measurements are averaged summing the measurements and averaging the values to the time in terms of months. According to the measured data, relative humidity is in the range from 23% to 96%, whereas dry bulb temperature is in the range from 1.7 ^{o}C to 45.7 ^{o}C during the year.

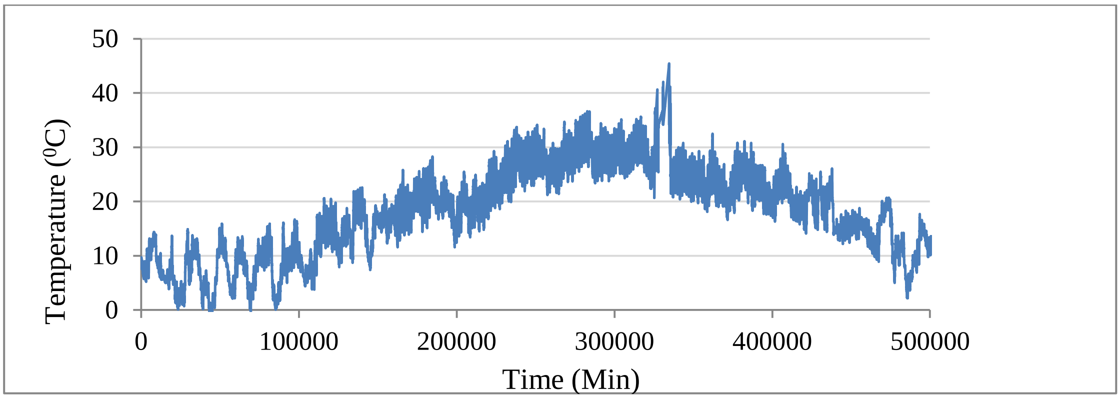


Figure 4.2. Dry Bulb Temperature (^{o}C) in Gülbahçe in 2012

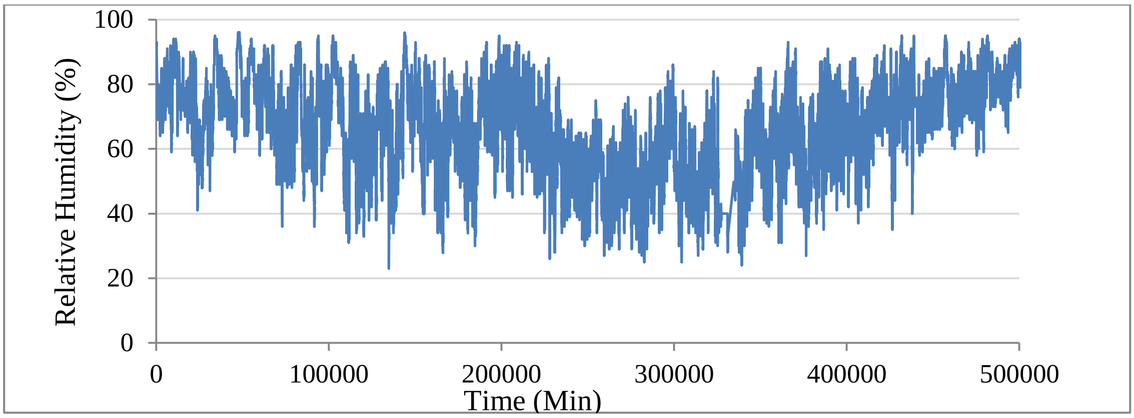


Figure 4.3. Relative Humidity (%) in Gülbahçe in 2012

Figure 4.4 depicts the monthly changes of global radiation. In order to obtain the required data, first, average global radiation of each hour has been found for whole year. Then this hour based data has been classified according to the months.

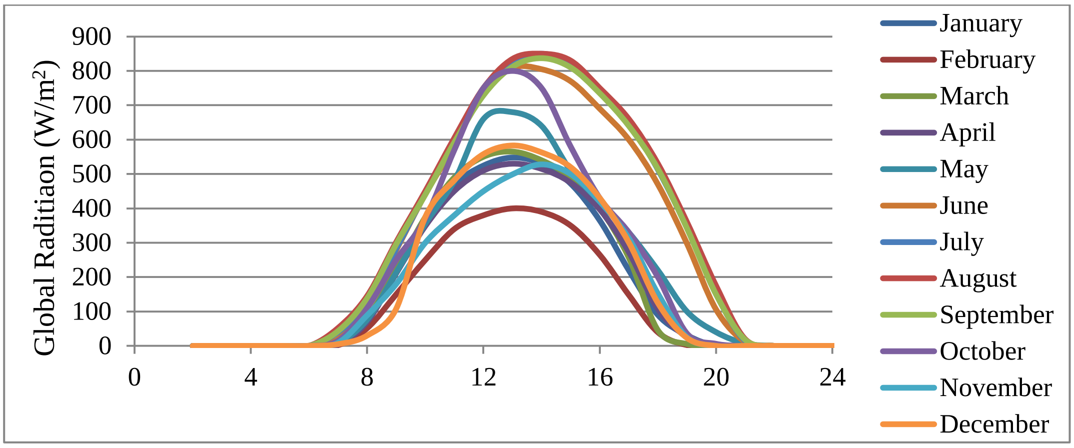


Figure 4.4. Global Radiation Average (W/m^2) in 2012

4.2. EDSL-TAS Simulation

Architectural design of the building was drawn in the EDSL-TAS both in 2D and 3D according to the building survey. In order to simulate the building in EDSL-TAS, all building components, and their thermophysical properties according to TS-825 were attached to the components on the 2D and 3D drawings. In addition, external climatic conditions, components and capacity of the HVAC system, schedule of the HVAC system, aperture type, number of users, equipment list etc. were entered to the program. EDSL-TAS interests in not only the orientation, external, internal data, but also the HVAC systems and schedule of active hours for the buildings. Therefore, the building components and their retrofitting were selected from the tables and lists in TS-825, and energy level of the building was found along with the thermophysical properties of these components. The retrofitting was released in the same simulation program, and then the improvements were seen in the results of the energy level.

In Table 4.1, thermophysical properties of the components before retrofitting, and in Table 4.2 after retrofitting can be seen. All these materials were chosen from TS-825 material list by the help of the specialist architects.

Table 4.1. Thermo physical Properties of the Building Components before Retrofitting

Horizontal	Internal U values (W/m^2.^{o}C)	External U values (W/m^2.^{o}C)	Internal R values (m^2.^{o}C/W)	External R values (m^2.^{o}C/W)
Door	3.651	5.438	0.274	0.184
External Wall	2.066	2.538	0.484	0.394
External Wall-II	2.89	3.906	0.346	0.256
Ground Floor	0.361	0.373	2.772	2.682
Internal Wall	2.066	2.538	0.484	0.394
Internal Wall-II	2.056	2.522	0.486	0.396
Roof	1.837	2.201	0.544	0.454
Suspended Floor	2.812	3.764	0.356	0.266
Window	3.607	5.341	0.277	0.187

Table 4.2. Thermo physical Properties of the Building Components after Retrofitting

Horizontal	Internal U values (W/m^2.^{o}C)	External U values (W/m^2.^{o}C)	Internal R values (m^2.^{o}C/W)	External R values (m^2.^{o}C/W)
Door	1.316	1.493	0.76	0.67
External Wall	0.465	0.485	2.151	2.061
External Wall-II	0.497	0.52	2.013	1.923
Ground Floor	0.361	0.373	2.772	2.682
Internal Wall	2.066	2.538	0.484	0.394
Internal Wall-II	2.056	2.522	0.486	0.396
Roof	0.452	0.471	2.211	2.121
Suspended	2.812	3.764	0.356	0.266
Window	1.046	1.203	0.956	0.850

In the next step, 2D and 3D models of the building were prepared in EDSL-TAS by defining components' dimensions according to the architectural plans in Figure 3.2 and Figure 3.3. The final 2D plan drawing of the ground floor in EDSL-TAS medium can be seen in Figure 4.5. The program defines the spaces zone by zone as an atrium, 12 office rooms and a restroom. The building has two floors, first floor and ground floor, which are very similar to each other. In the roof, there is one skylight with 120 m^2, and a flat roof. 3D model of the building with the defined materials can be seen in Figure 4.6. At this step, whole building and all used components were entered to the module with real measurements and physical properties as to generate the building simulation.

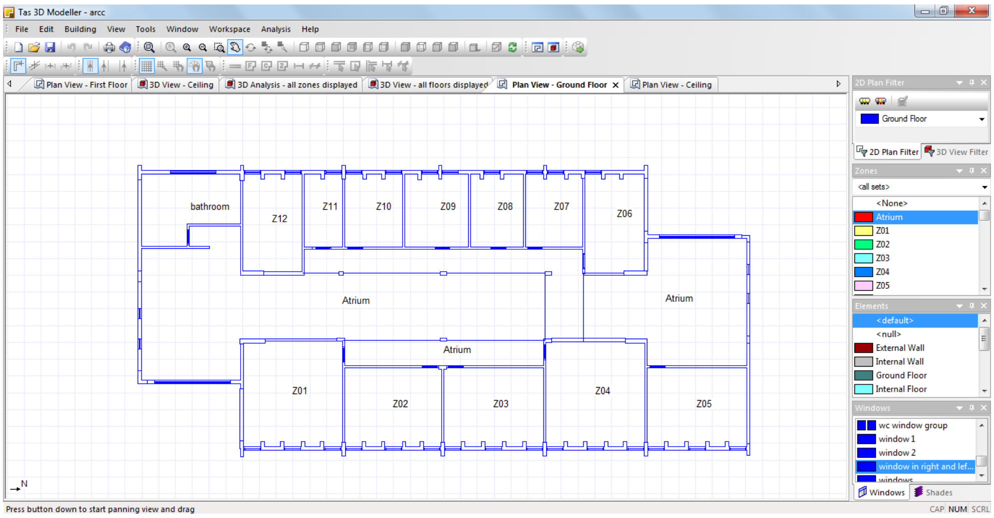


Figure 4.5. EDSL-TAS Interface showing 2D Model of the Ground Floor

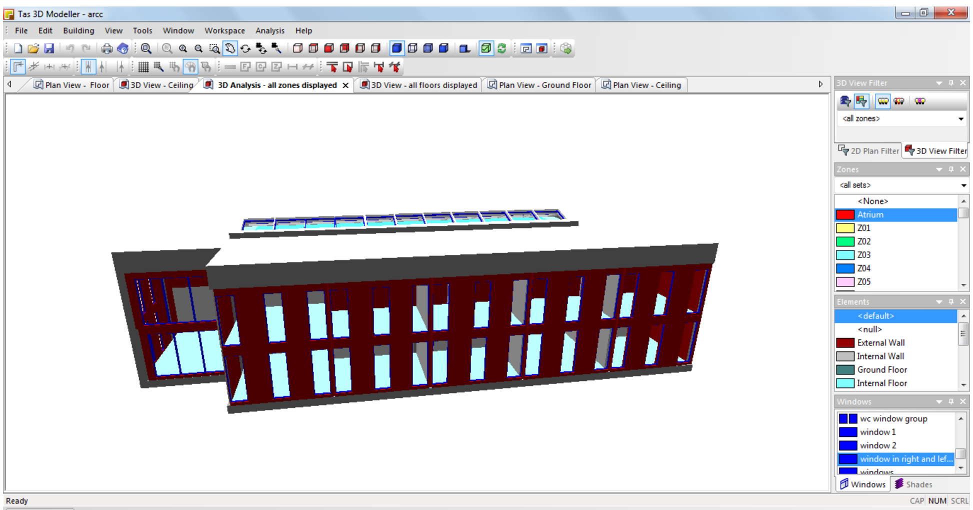


Figure 4.6. EDSL-TAS Building Simulator Interface showing 3D Model of the Building

After generating the building's 2D plan with their real material properties, weather data, which includes wind direction (^{o}), wind speed (m/s), diffuse radiation (W/m^{2}), global radiation (W/m^{2}), dry bulb temperature (^{o}C), humidity (%) and cloud cover (0-1) was entered to the building simulator module. Besides, the weather data for 365 days was collected via DAVIS climatic data station and entered to the program hour by hour. Figure 4.7 depicts the interface of the weather module of EDSL-TAS for the 1st day of 2012. In this module, longitude, latitude, ground temperature, diffuse radiation, global radiation, wind direction etc. should be entered hourly in order to perform the building simulation dynamically (simulation with respect to the time).

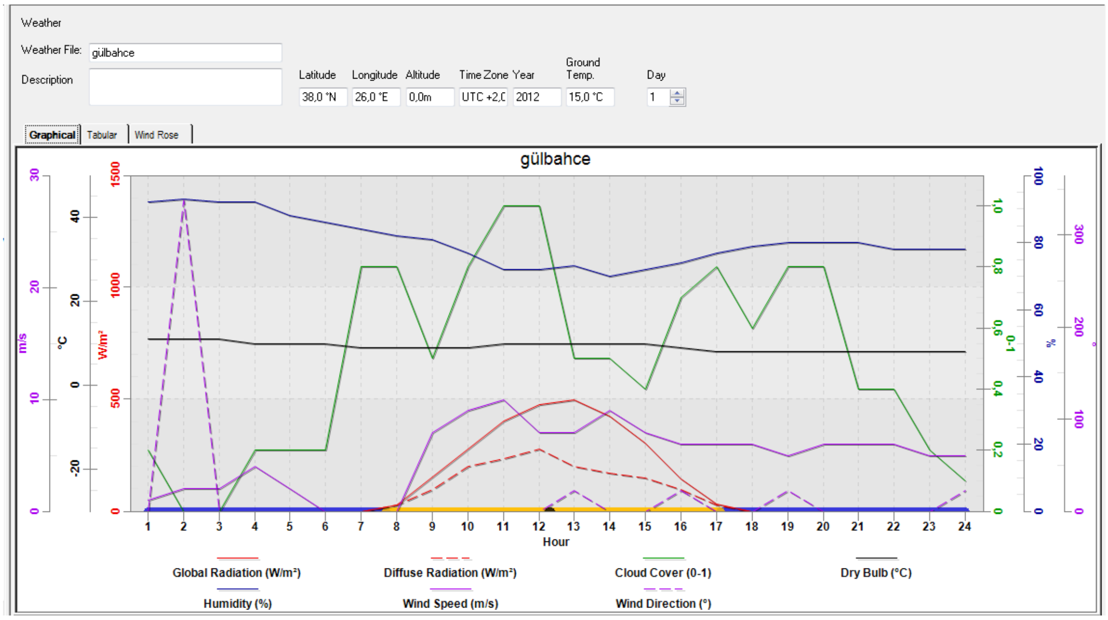


Figure 4.7. EDSL-TAS Building in the Weather Database Module

In addition, surface output specifications (such as solar gain, conduction, convection, condensation etc.), aperture types of the building components, thermal properties of the components, heating/cooling schedules and capacities of the HVAC system, internal zone air movements and internal condition data with infiltration values were entered to the program. In Figure 4.8, interface of the building components' selection module can be seen with the ground floor layers. At the bottom of the module's interface, internal and external U values of the component are displayed.

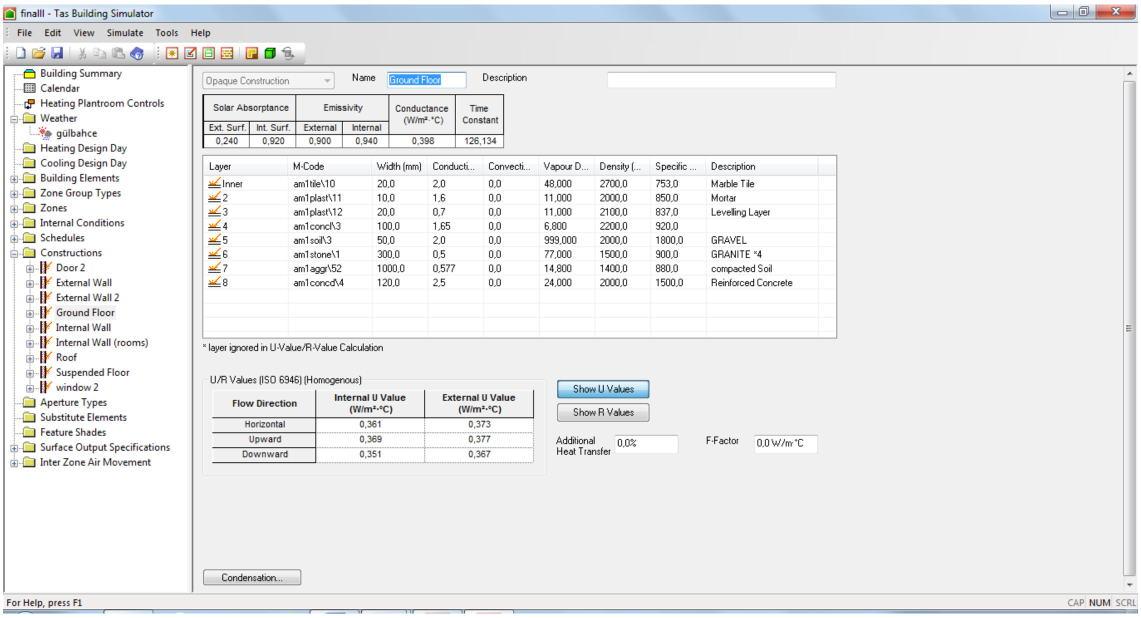
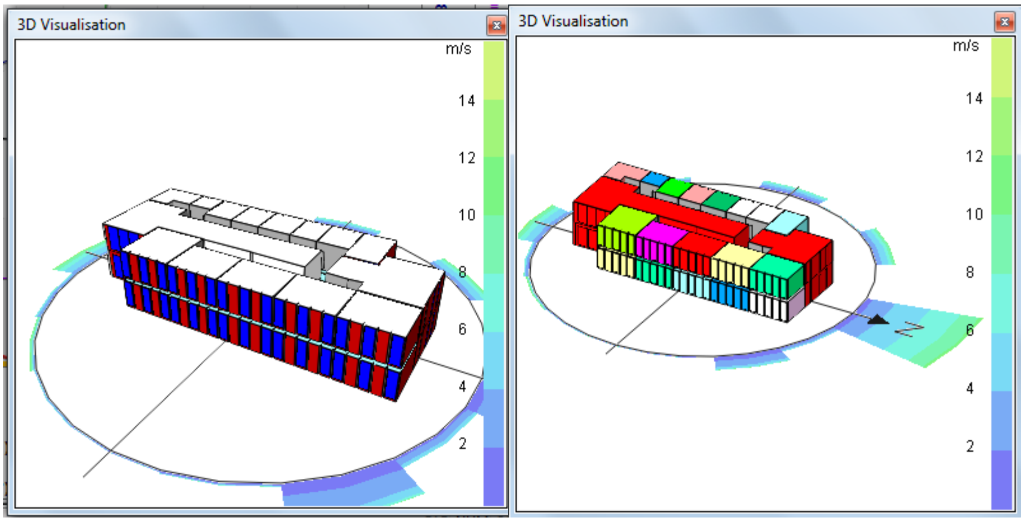


Figure 4.8. EDSL-TAS Building Simulator in the Construction Database Module

The heating system of the case study building is active between the dates of 24th October and 3rd April and the cooling system is active between 3rd April and 24th October. In addition, heating and cooling periods during the day are from 08:00 to 18:00 o'clock in workdays. The system is off during the weekends.

After the entrance of all this data, simulation of the building was revealed. According to the variety and accuracy of the entered data, EDSL-TAS can simulate the building in different ways. In Figure 4.9, some example simulations taken from the simulator module can be seen. During the energy analysis of the building, wind directions, volumes of the building zones and components' properties are important. For example, the components determine the temperature distribution in the building, and dominant wind direction is important because of temperature and infiltration value of the building components.



According to the Components According to the Wind Direction

Figure 4.9. Example Views taken from EDSL-TAS Simulator Module

4.3 LowEx Calculation Tool

LowEx, is the exergy calculation tool for the buildings, which interests in thermal conductivity of the components, surfaces areas of the building with orientations, HVAC system's properties (such as distribution, insulation etc...), solar energy and exergy gains, occupants energy and exergy gains and equipment energy gains etc…

In this thesis, for the existing system and the situation after retrofitting of the envelope and refurbishment of the HVAC system, the building's components and the HVAC system were used to find exergy value with reference to dead state. The existing HVAC system is air to water chiller system with roof top system for summer, whereas furnace with fuel oil is used for winter. During the refurbishment, in addition to the building components, HVAC system's capacity was improved and reached to an efficient level as to meet energy demand of the building. After the refurbishment, ground source heat pump and air source heat pumps were chosen to meet energy demand of the building. All analyses of the building were revealed for the situation before the refurbishment in the building components and HVAC system and situation after the refurbishment, which are explicitly:

- The existing building with existing HVAC systems: Roof top system and air to water chiller system for summer, Furnace with fuel oil for winter.

- Efficient COP – Air Source Heat Pump (VRF/VRV system) with refurbishment of the building components for summer and winter
- Efficient COP – Ground source heat pump with existing building components for summer and winter

During the analyses, following values for the environmental climate conditions are assumed: In winter, dead state, temperature of the ground was assumed as 0 ^{o}C, whereas indoor air temperature state was assumed as 22 ^{o}C when HVAC system on and off values as 20 ^{o}C. In summer, dead state, temperature of the ground was assumed as 10 ^{o}C, outdoor air temperature is 34 ^{o}C, whereas indoor air temperature state was assumed as 26 ^{o}C when HVAC system on and off value as 17 ^{o}C.

In LowEx calculation tool, generation, storage, distribution, emission, domestic hot water production properties of the HVAC system were selected according to the real values of the building. After finding out the energy and exergy values with these properties, refurbishments of these properties were revealed to determine energy and exergy value. By this way, comparison of the situation before refurbishment with situation after refurbishment was defined, explicitly.

Figure 4.10 illustrates the energy flow from the overall HVAC system. Firstly, primary energy transformation leads to heat loss, and then heat production system, distribution system, heating/cooling system, indoor air and envelope cause heat loss. After the final heat loss is revealed from the envelope, rest of heat corresponds to the heating/cooling load rate of the building.

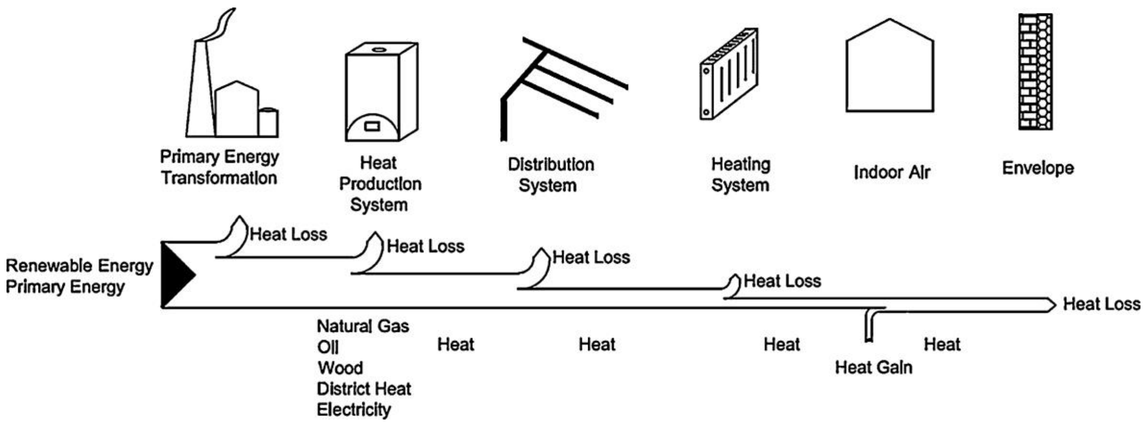


Figure 4.10. Energy Flows from Primary Energy Transformation to the Environment in the Existing Building HVAC System (Source: Hepbaşlı 2011)

Table 4.3 represents the mechanical properties of HVAC system which were used at LowEx calculations and dynamically related to the EDSL-TAS results. Retrofitting of the building is related to the building envelope and improvement of its thermo physical properties. The existing system uses standard boiler for heating the building during winter, whereas roof top air heat pump for cooling the building during summer. Efficiency of the boiler is 0.8; COP of the air to water chiller system is 2.5. Distribution is revealed during the year. Temperature drop is 20 ^{o}C, when it is 6 ^{o}C in summer. Finally, emission system is air heating/cooling system (fan coil).

At the existing situation of the case study building, insulation is used in neither building components nor HVAC systems. Therefore, options in the LowEx were revealed according to the real conditions. However, in the retrofitting phase, sufficient insulation layers have been installed to the building. In addition, it was assumed that there were two occupants in each office room, two lighting components, two computers and one fan coil.

Table 4.3. Mechanical Properties of HVAC System before and after Refurbishment

LowEx	**Existing Circumstance**	**Refurbishment-1**	**Refurbishment-2**
Refurbishment in the Components	-	✓	✓
Generation	Boiler	Air heat pump	GSHP
Efficiency/COP	0.8	2.5	3.53
Storage	-	-	-
Distribution	✓	-	✓
Boiler Envelope Position	-	Inside	Inside
Insulation	No Insulation	Good Insulation	Good Insulation
Design Temperature	Middle (<50 ^{o}C)	Middle (<50 ^{o}C)	Middle (<50 ^{o}C)
Temperature Drop	High	High	High
Emission System	Air	Air	Air Heating/Cooling
DHW	-	-	-

LowEx interests in HVAC system and components thermal heat conductivity coefficient of the buildings. Therefore, the building in this study, assumed with some refurbishments. Air heat pump and ground source heat pump were used to find exergy value in terms of useful energy value.

Another refurbishment is about Heat Pump System, which is Ground Source Heat Pump with COP value of 3.53, approximately, but it changes along with temperature internal and external condition. Results of all analysis and these COP values can be seen in Chapter 5.

Other selected values are about the existing and new HVAC systems.

Table 4.4 depicts the values of these important points. According to the calculations, A_{net} is net area of the building, whereas V_{net} is net volume of the building. f_{emp} is emplacement of the insulation in the distribution system; it can be outside envelope, inside envelope and no distribution. f_{ins} is insulation situation in the distribution system. f_{dt} is distribution system's design temperature, and the value can be changed by choosing low temperature (<35 ^{o}C), middle temperature (<50 ^{o}C), high temperature (>50 ^{o}C) and no distribution options. f_{td} is temperature drop of the distribution system ranging from high temperature drop (>10 K) to no distribution, according to the value of the drop, f_{td} changes between 0.98 and 1. dT_{dis} is temperatures of the enter and return to the heating/cooling system. In the heating season, for the existing boiler system's temperature and air to water chiller system's changes are changes are 20 ^{o}C and 8 ^{o}C, respectively. After refurbishment, in the scenario which includes ASHP, the temperatures of return and enter are same as the existing circumstances. In the GSHP scenario of the building, the temperature drops are 10 ^{o}C in the heating season and 8 ^{o}C in the cooling season, respectively.

The other constants are N, l_{max}, n_{hs}, f_{hp}, F_p,$F_{q,el}$, $F_{q,s}$; N, percentage of equipment resistance with typical value of 0.3, R is the pressure drop of the pipe with a typical value of 100 Pa/m. The maximal pipe length of the distribution (l_{max}) has a typical value of 0.25 m/m^2. Extra pressure losses value is given as p_{ex}, and it is chosen 0.

Input and return temperatures are 80 ^{o}C and 60 ^{o}C in the existing system, respectively. In the cooling season the input and return temperatures are 8 ^{o}C and 14 ^{o}C, respectively. In the scenario of ASHP and GHSP, the temperatures are the same as the existing system.

In the thesis, f_{dt}, f_{td}, f_{in}, f_{emp}, $F_{p,el}$, $F_{q,s}$ and F_p are calculated by using LowEx calculation tool for each scenario.

Table 4.4. Selected Properties of HVAC System before and after refurbishment

<table>
<tr><th>Selected Properties for Building</th><th colspan="2">Before refurbishment</th><th colspan="4">After refurbishment</th></tr>
<tr><td>A_{net} (m^2)</td><td colspan="2">896</td><td colspan="4">896</td></tr>
<tr><td>V_{net} (m^3)</td><td colspan="2">3222</td><td colspan="4">3222</td></tr>
<tr><td>f_{emp}</td><td colspan="2">0.9</td><td colspan="4">1</td></tr>
<tr><td>f_{ins}</td><td colspan="2">0.7</td><td colspan="4">1</td></tr>
<tr><td>f_{dt}</td><td colspan="2">0.7</td><td colspan="4">1</td></tr>
<tr><td>f_{td}</td><td colspan="2">1</td><td colspan="4">1</td></tr>
<tr><td>dT_{dis} (^oC)</td><td>20</td><td>8</td><td>20</td><td>8</td><td>10</td><td>8</td></tr>
<tr><td>N</td><td colspan="2">0.3</td><td colspan="4">0.3</td></tr>
<tr><td>R</td><td colspan="2">100</td><td colspan="4">100</td></tr>
<tr><td>l_{max}</td><td colspan="2">0.25</td><td colspan="4">0.25</td></tr>
<tr><td>p_{ex}</td><td colspan="2">0</td><td colspan="4">0</td></tr>
<tr><td>n_{hs}</td><td>0.8</td><td>2.5</td><td colspan="2">2.5</td><td colspan="2">3.53</td></tr>
<tr><td>$T_{hs,in}$ (^oC)</td><td>80</td><td>8</td><td colspan="2">80</td><td colspan="2">8</td></tr>
<tr><td>$T_{hs,ret}$ (^oC)</td><td>60</td><td>14</td><td colspan="2">60</td><td colspan="2">14</td></tr>
<tr><td>$F_{p,el}$</td><td colspan="2">3</td><td colspan="4">3</td></tr>
<tr><td>$F_{q,s}$</td><td colspan="2">0.95</td><td colspan="4">0.95</td></tr>
<tr><td>F_p</td><td colspan="2">1.3</td><td colspan="4">1.3</td></tr>
</table>

CHAPTER 5

RESULTS AND DISCUSSION

5.1 EDSL-TAS Results

This chapter mainly includes the simulation results of the building and the interpretations of these results. In the EDSL-TAS medium, the building was drawn and modeled both 2D and 3D with its real dimensions and material properties. After modeling the building, some important data needed such as weather data, thermophysical properties of the building components, aperture types, internal zone air movements (zone by zone, from indoor to outdoor or vice versa), internal condition including occupants gain, equipment gain, schedules of the HVAC system and calendar properties for the dynamic simulation was entered to the program. In addition, exterior weather data, which had been taken with the period of 10 minutes for 365 days, was entered to the program. Consequently, by using the related module, dynamic simulation was revealed. In this chapter, simulation results showing the situations of before refurbishment and after refurbishment analysis have been introduced and investigated.

5.1.1. EDSL-TAS Results before Retrofitting

EDSL-TAS gives the heating/cooling loads for each zone individually or for the whole building; exterior temperature and relative humidity distributions. Table 5.1 represents the building summary at the situation before retrofitting including the maximum/minimum external temperature, and the exact times which require the maximum heating/cooling loads during the year. According to the table, maximum heating load rate for a zone is 36.09 kW, and it was needed in atrium on 04:00 AM on 49th day (18th February, 2012). Similarly, maximum cooling load rate has been found again in atrium on 04:00 PM on 232nd day (19th August, 2012) as 26.63 kW.

Table 5.1. Building Summary from EDSL-TAS

	Value	Unit	Zone	Day	Hour
Max Air Temp	44.71	°C	110	196	17
Min Air Temp	5.87	°C	106	49	4
Max Humidity	100	%	Z01	208	19
Min Humidity	0.24	%	Atrium	320	24
Max Heating Load	36.09	kW	Atrium	49	1
Max Cooling Load	26.63	kW	Atrium	232	14
Max External Temp	36.0	°C	External	196	17
Min External Temp	-1.0	°C	External	49	4
Max External Humidity	100.0	%	External	322	8
Min External Humidity	0.0	%	External	91	24

EDSL-TAS calculates all loads and climatic values zone by zone for 365 days and 24 hours. However, only two extreme moments will be investigated in this section: As the first extreme moment, Figure 5.1 demonstrates temperature versus heating loads zone by zone for a period around 04:00 AM on 49th day. Heating load rate is at maximum level at this exact time as 36.09 kW in the atrium. In addition, according to the figure, it can be claimed that the first floor's rooms are warmer than ground floor's office rooms.

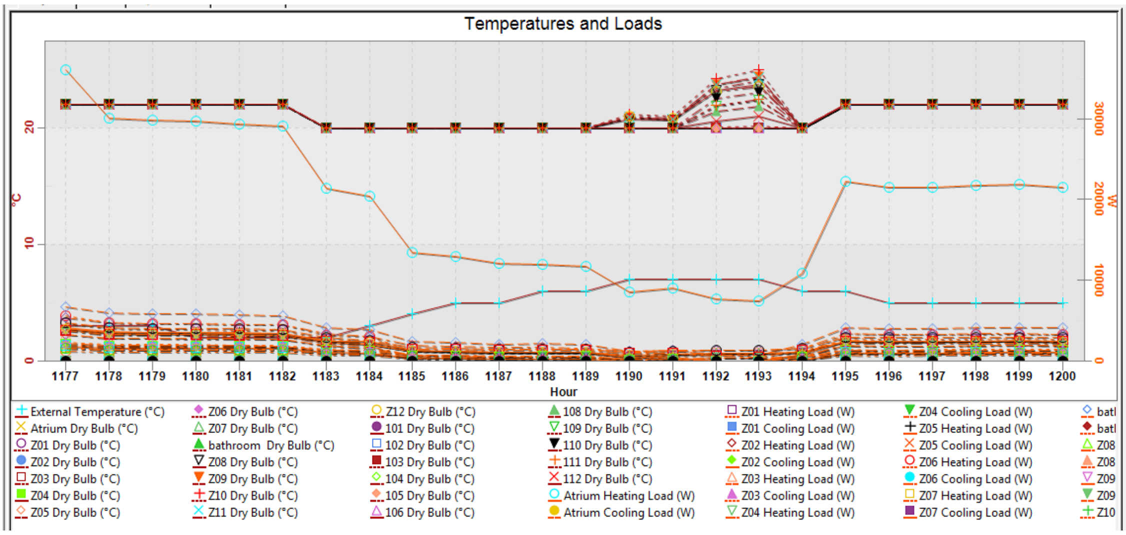


Figure 5.1. Temperature and Load Rate for 04.00AM on 49th day in 2012 (before retrofitting)

Similar to Figure 5.1, humidity and loads distribution values for the same time period can be seen in Figure 5.2. As it is seen from the figure, each zone has different humidity values because of orientation, infiltration and gains.

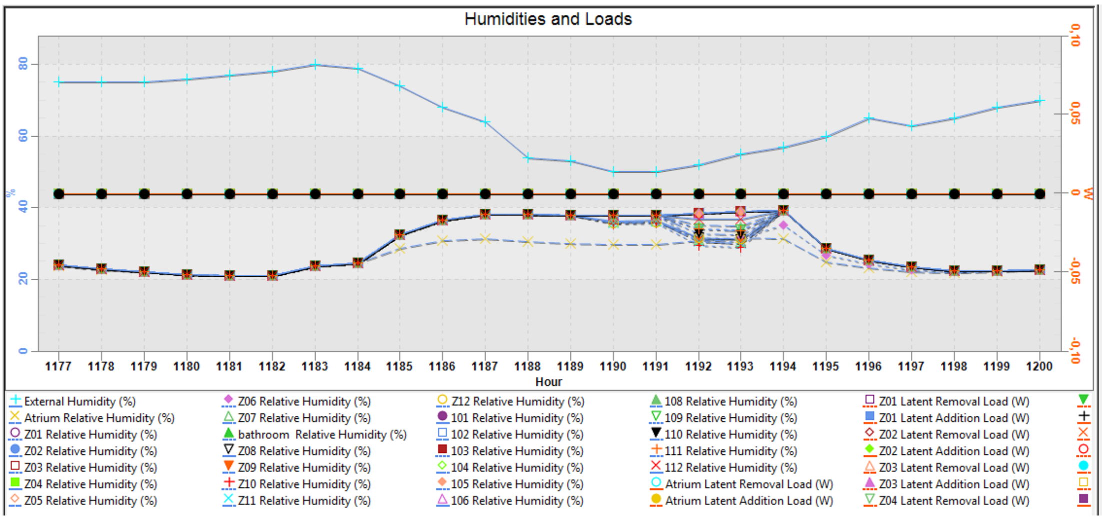


Figure 5.2. Humidity and Load Rate for 04.00AM on 49th day in 2012 (before retrofitting)

It should be reminded that EDSL-TAS finds the heating and cooling loads for reaching comfort level for each zone. For this reason, there may be heating or cooling loads apart from the active hours of the HVAC system. In Figure 5.3, maximum heating load rate profile of the building for the 49th day of 2012 can be seen.

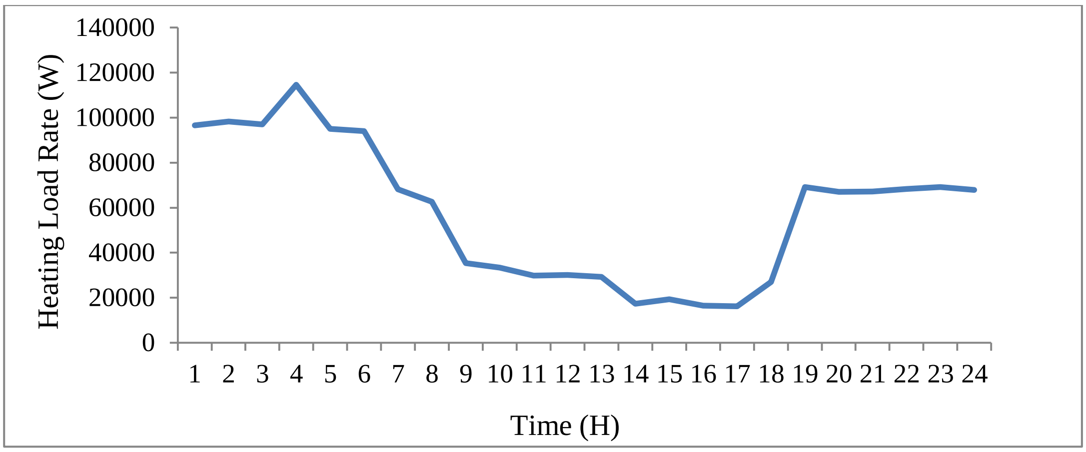


Figure 5.3. Heating Load Rate Profile for Whole Building on 49th day in 2012 (before retrofitting)

Beside the 2D linear representations, EDSL-TAS can also give graphical results defining the building in 3D. In Figure 5.4, dry bulb temperature in the whole building at the same time period is depicted. Temperatures in the building have different values between 2 ^{o}C and 4.4 ^{o}C; and the wind flows from North direction with 3.7m/s.

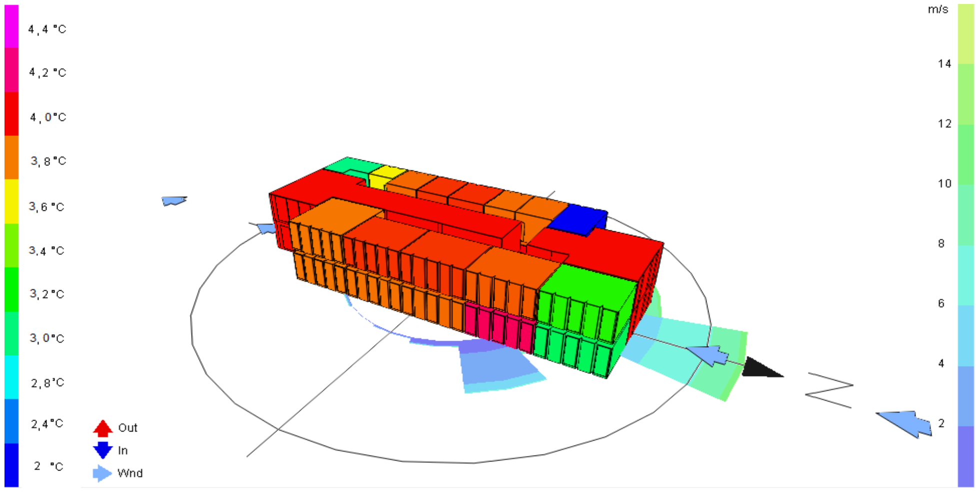


Figure 5.4. Dry Bulb Temperature (^{o}C) on 04:00AM on 49th day in 2012 (before retrofitting)

Figure 5.5 illustrates relative humidity distribution in the whole building at the same time. According to the results, the restroom's relative humidity is 67.47% whereas the room 106's is 77.56%, the atrium's is 53.18%, the room 105's is 66.37% and the rest of the building ranges from 50%-60%.

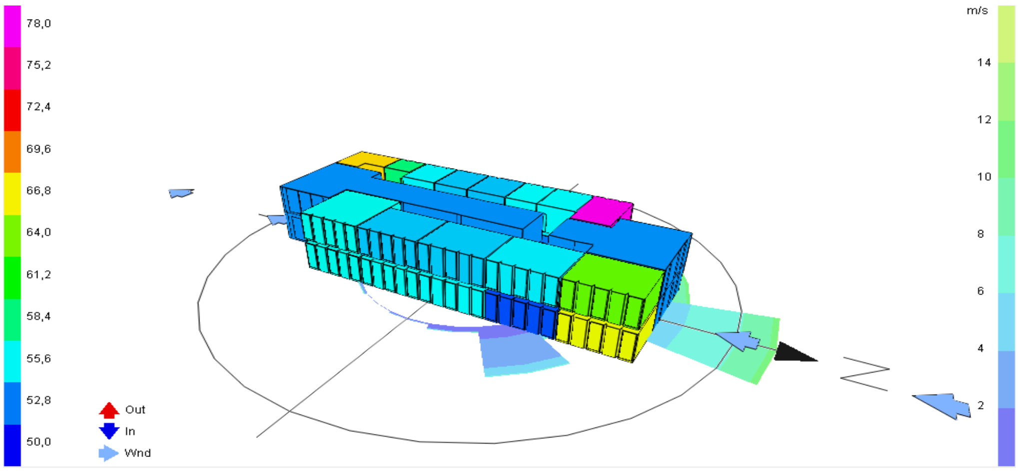


Figure 5.5. Relative Humidity (%) on 04:00AM on 49th day in 2012 (before retrofitting)

Figure 5.6 represents the heating loads on the aforementioned time (04:00 AM on 49th day). According to this figure, the atrium has the biggest amount of heating loads comparing the other parts of the buildings. The maximum heating load rate is revealed in Atrium with a value of 18.88 kW and the rest of the building heating load rates are ranging from 2.6 kW to 7.2 kW.

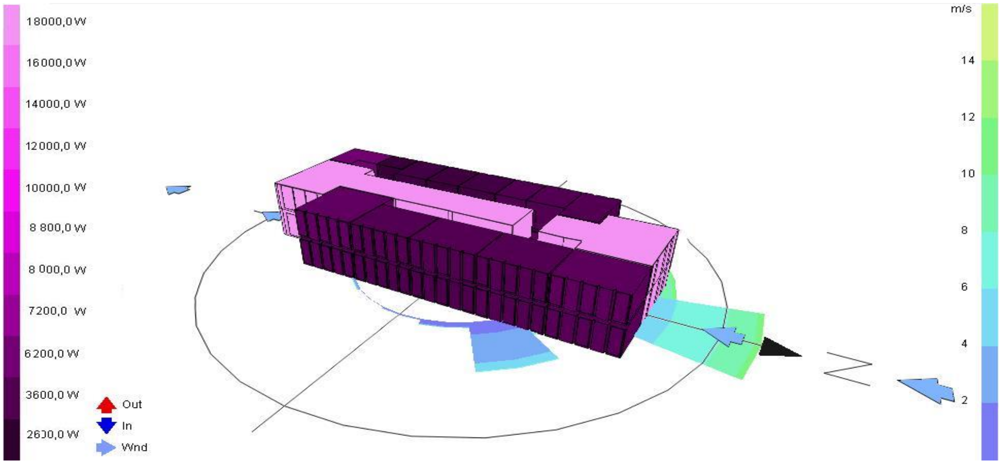


Figure 5.6. Heating Load Rate (W) on 04:00AM on 49th day in 2012 (before retrofitting)

In Figure 5.7, building heat transfer rate distribution on 04:00 AM of the 49th day can be seen. The atrium has the highest value as -10 kW, approximately. For the rest of the building, heat transfer rate values are between -4 and 0 kW.

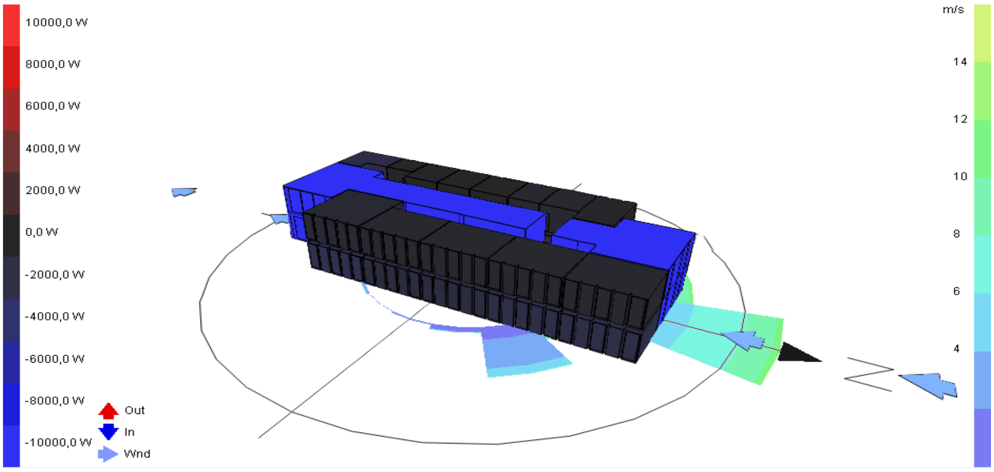


Figure 5.7. Building Heat Transfer Rate (W) on 04:00AM on 49th day in 2012 (before retrofitting)

Figure 5.8 demonstrates the external conduction opaque rate values, which means heat loss/gain is occurred via conduction according to the zones and ground etc. The atrium has maximum value, which is -14.80 kW, whereas rooms in the first floor have same value -4.98 kW and rest of the building has same value approximately, -2.05 kW.

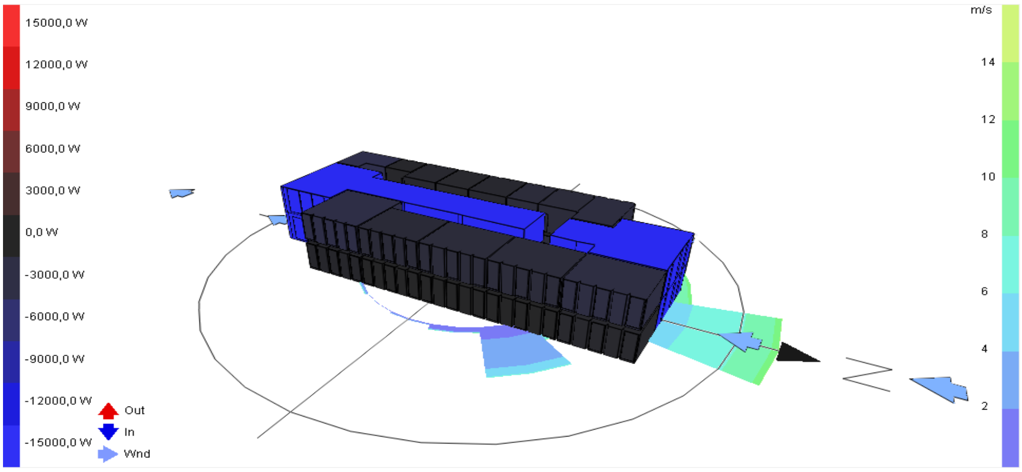


Figure 5.8. External Conduction Opaque Rate (W) on 04:00AM on 49th day (before retrofitting)

When the aforementioned figures are investigated thoroughly, it can be seen that the atrium is the most important volume for heating/cooling of the building. In addition, during the winter (when the heating system is active), heat transfer from building, infiltration, air movement and ventilation gain are higher than the other zones in atrium. Therefore, infiltration is revealed from atrium to outside during the year, or vice versa. However, relative humidity in the atrium is lower than the other zones.

After the extreme moment in winter (maximum heating load), the other extreme point is 04:00PM on the 232nd day (19th August) in 2012. During this hour, the biggest amount of cooling load rate(26.625 kW) for a zone has been measured again for the atrium. Figure 5.9 depicts the temperatures and cooling load rate profile during a period around 02:00 PM on the 232nd day in terms of zones. As it can be seen in the figure, the temperature in the zones varies between 22 ^{o}C and 36 ^{o}C.

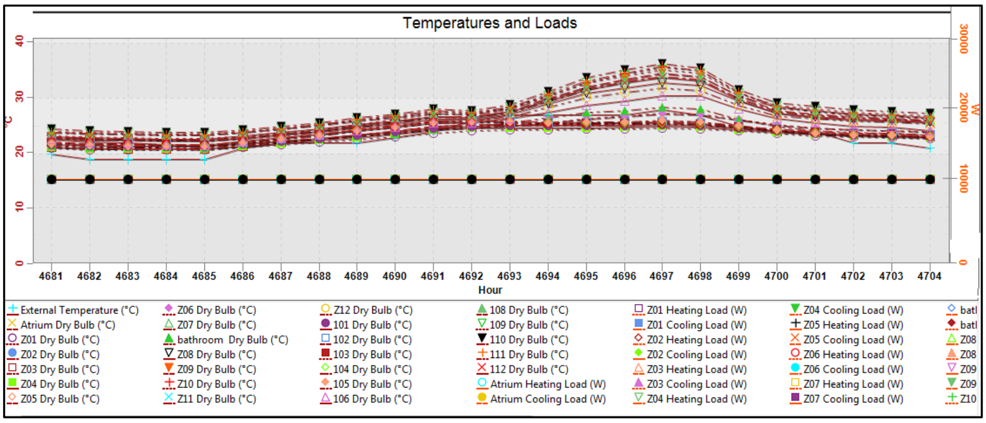


Figure 5.9. Temperature and Load Rates for 02:00PM on 232nd day in 2012 (before retrofitting)

Figure 5.10 demonstrates the humidity values versus loads in terms of zones. As it is seen from the figure, each zone has different humidity values changing between 20% and 63%, because of orientation, infiltration, gains and temperatures.

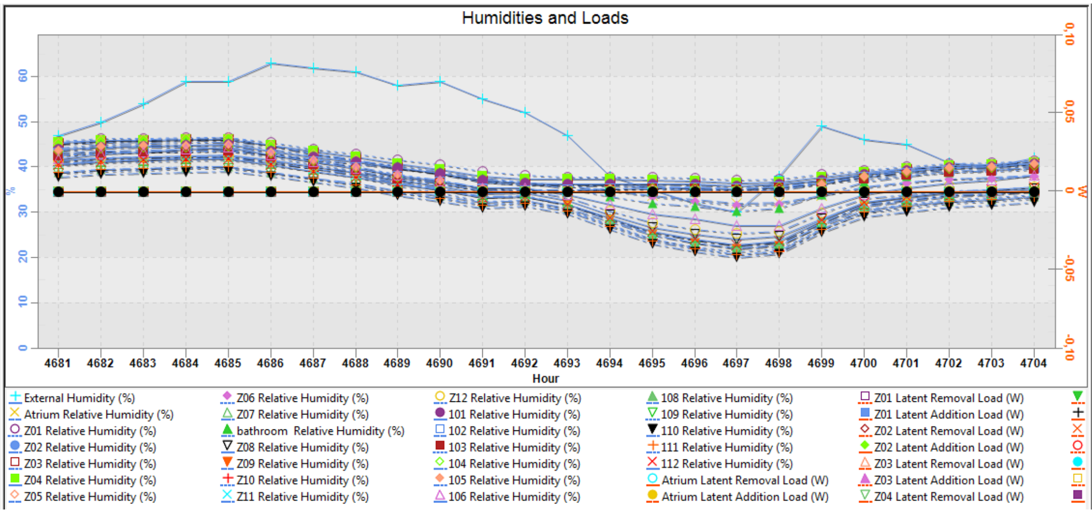


Figure 5.10. Humidity and Load Rates for 02:00PM on 232nd day in 2012 (before retrofitting)

In Figure 5.11, maximum cooling load rate profile of the building for the 232nd day of 2012 can be seen. As it can be seen, the maximum total load increases in the afternoon till 02:00 PM. After this time, the cooling load ratebegins to decrease.

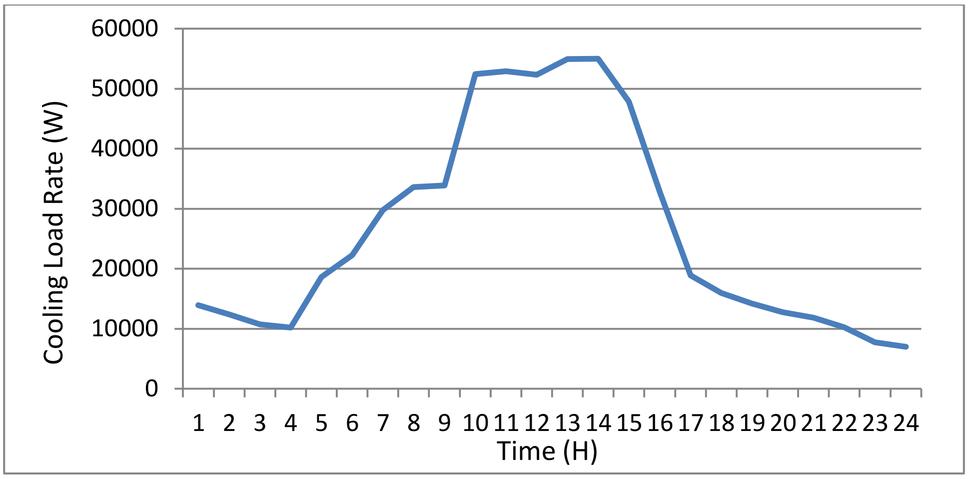


Figure 5.11. Cooling Load Rate Profile for Whole Building on 232nd day (before retrofitting)

In Figure 5.12, dry bulb temperature of the whole building on 02:00 PM is depicted. Contrary to the 49th day, temperatures of the zones are very similar around 30 °C, and wind flows again from the North direction.

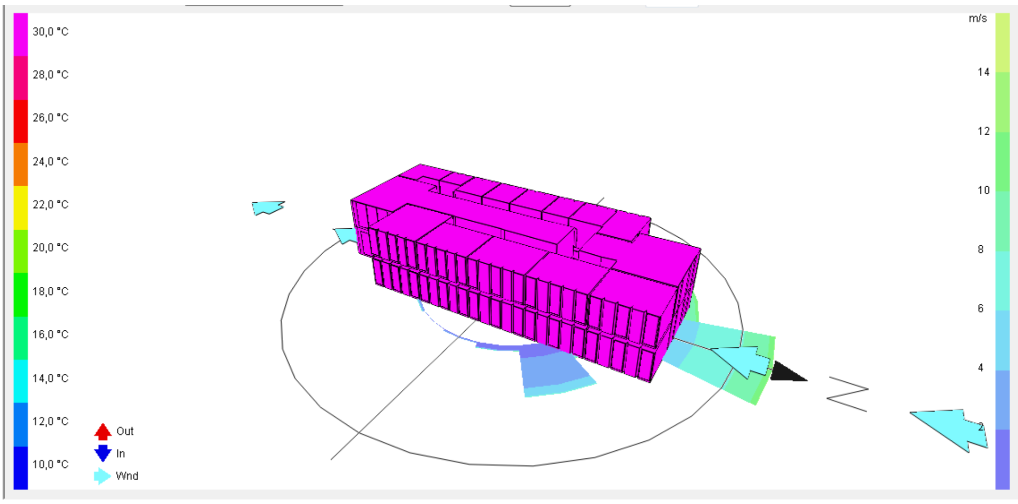


Figure 5.12. Dry Bulb- Temperature (°C) on 02:00PM on 232nd day (before retrofitting)

Figure 5.13 illustrates relative humidity distribution in the whole building at the same time. According to the results, the rooms on the east direction have less humidity (20%) than the other parts of the building (40-50%). Again, the atrium does not have a big difference from the other parts of the building.

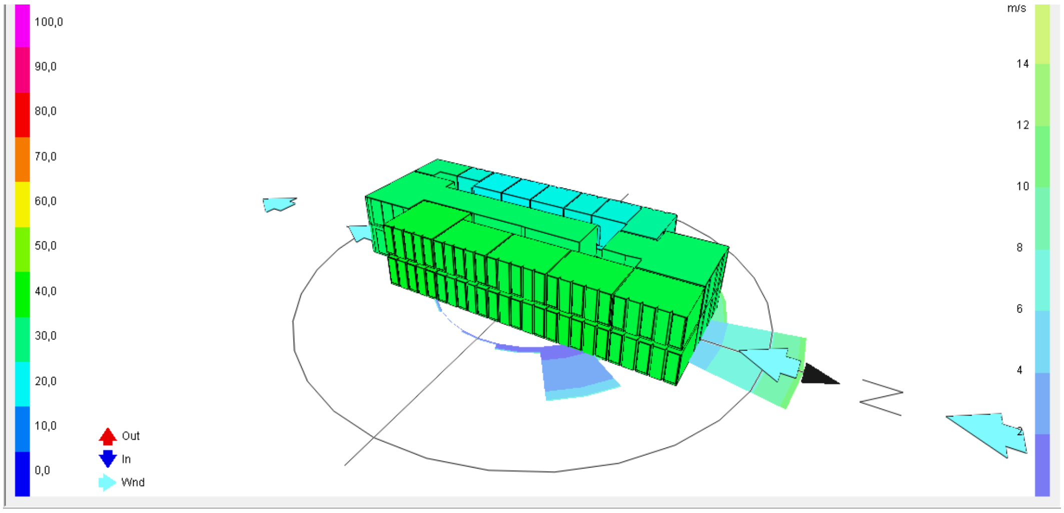


Figure 5.13. Relative Humidity (%) on 02:00PM on 232nd day in 2012 (before retrofitting)

Figure 5.14 represents the cooling loads on the aforementioned time (04:00 PM on 232nd day). According to this figure, the atrium has the biggest amount of cooling loads comparing the other parts of the buildings. This result is similar to the results of 49th day. The atrium is the most problematic zone of the building. The maximum cooling load rate is 13.0 kW for atrium, and the rest of the building is ranging from 1.5 kW to 11.7 kW.

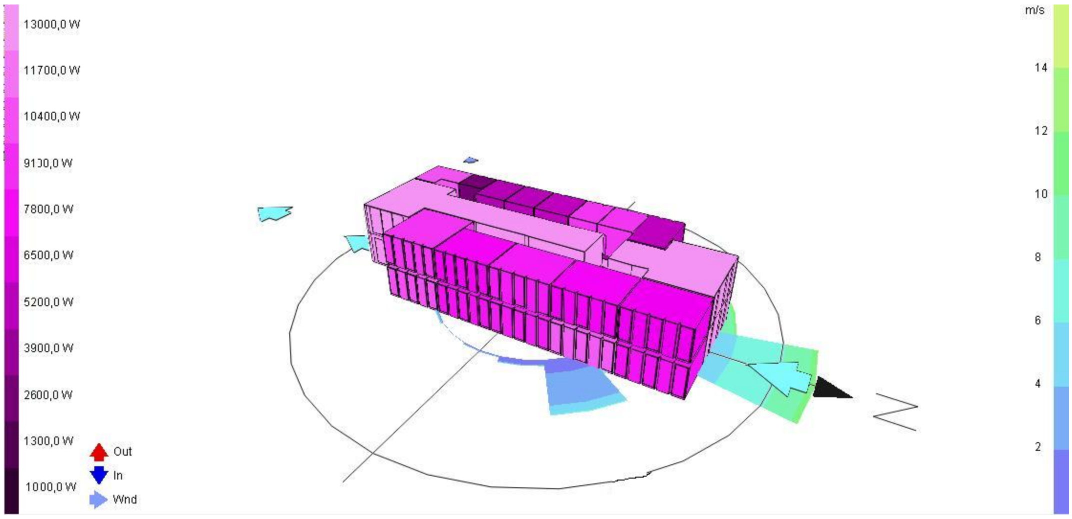


Figure 5.14. Cooling Load Rate (W) on 02:00PM on 232nd day in 2012 (before retrofitting)

In Figure 5.15, building heat transfer rate distribution on 02:00 PM of the 232nd day can be seen. The atrium has the highest value as -1.3 kW, approximately. For the rest of the building, heat transfer values are between -0.5 and 0 kW.

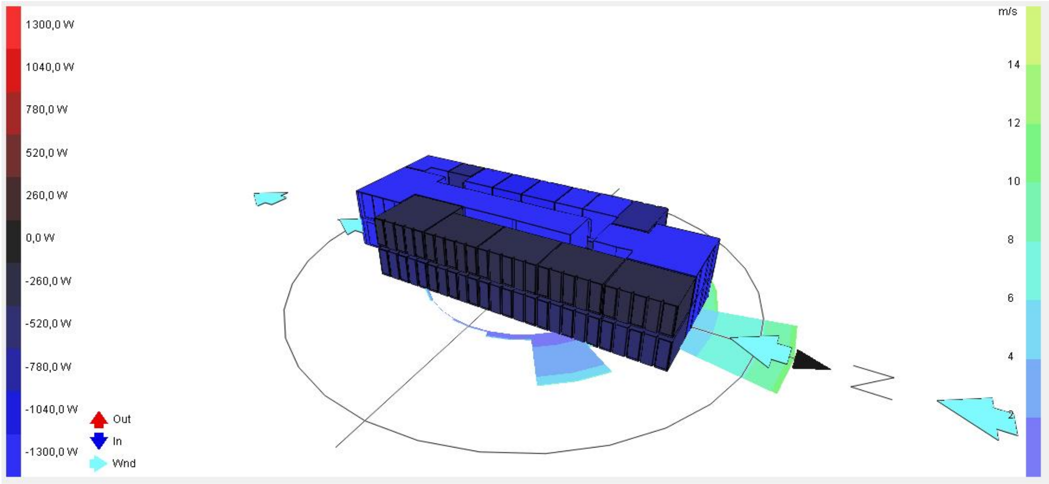


Figure 5.15. Building Heat Transfer Rate (W) on 02:00PM on 232nd day (before retrofitting)

Figure 5.22 demonstrates the external conduction opaque values, which means heat loss/gain is occurred via conduction according to the zones and ground etc. The atrium has again the maximum value with the rooms on the east side as -1.3 kW, whereas the other rooms have the values between -1.30 and 0.55 kW.

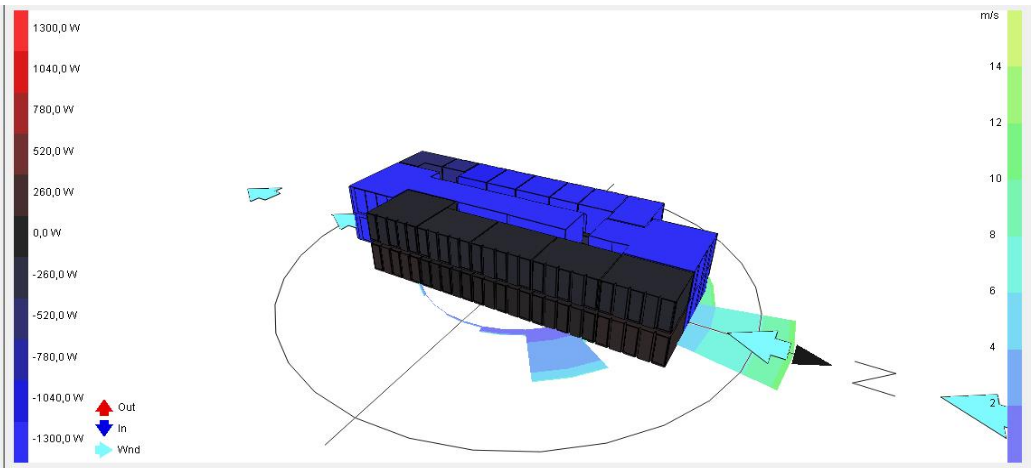


Figure 5.16. External Conduction Opaque Rate (W) on 02:00PM on 232nd day (before retrofitting)

After the analyses about the climatic conditions of the individual zones and the whole building, total heating and cooling loads have been calculated by summing the hourly loads. According to EDSL-TAS simulation, building's heating and cooling loads are represented in Figure 5.17. The annual heating load rate is 63605.23 kWh and the cooling load rate is 82427.48 kWh. From these values, total annual load can be calculated as 146032.80 kWh.

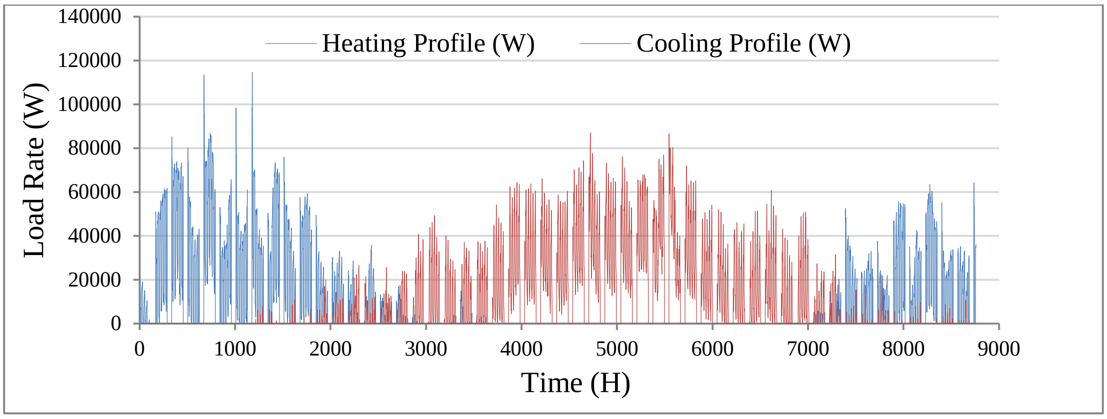


Figure 5.17. Annual Heating and Cooling Load Rates before retrofitting in 2012

5.1.2. EDSL-TAS RESULTS AFTER RETROFITTING

After the analysis of the current situation of the case study building, the situation after retrofitting was analyzed. As it is explained in Chapter 3, retrofitting of the building includes the addition of extra insulation layers (XPS), plaster and paint to the façades and a good thermal and water insulation to the roof. In addition, exterior aluminum doors and windows were switched with PVC ones with low emissivity glasses. Finally and the skylight was removed. Detailing and the layers of these retrofitting can be seen in section 3.2.

In this phase, the case study building was simulated in EDSL-TAS medium with the same climatic conditions but with the retrofitted envelope. In Figure 5.18, temperature versus loads graph can be seen for all zones for the period around 04:00 AM of the 49th day. According to this analysis, heating load rate of the atrium is 17.013 kW and this value is smaller with decrement value of 19.085 kW than the heating load rate of the atrium before retrofitting.

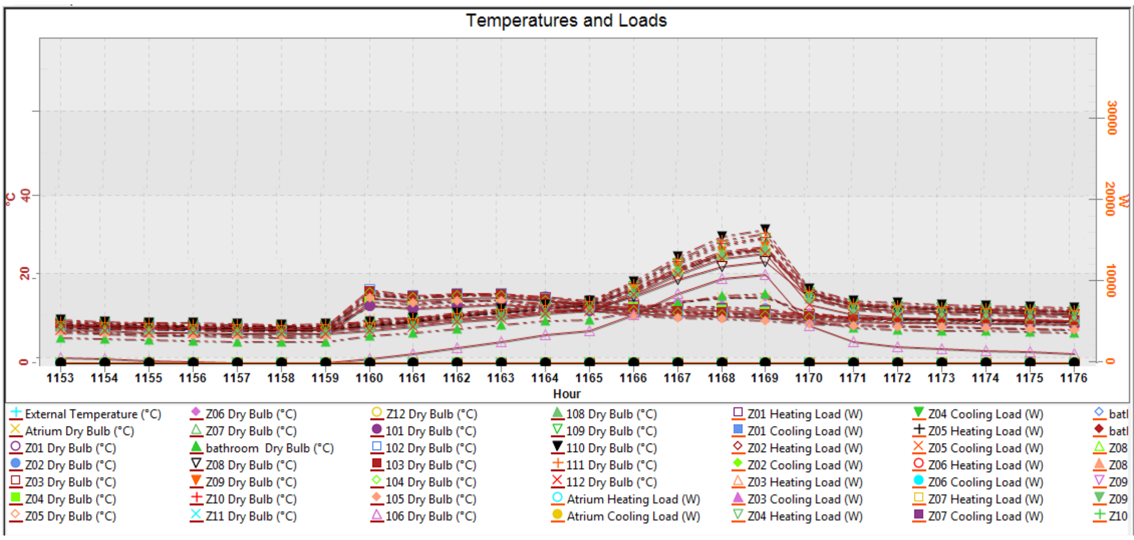


Figure 5.18. Temperatures versus Loads for 04.00AM on 49th day in 2012 (after retrofitting)

In Figure 5.19, humidity values can be seen zone by zone. Even though external humidity changes significantly, relative humidity of the internal zones do not change in important ranges.

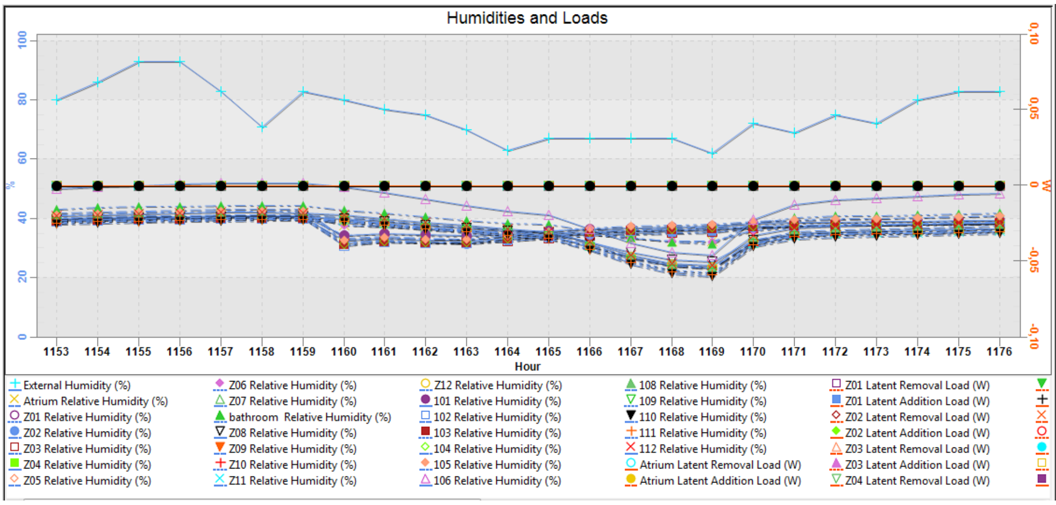


Figure 5.19. Humidity and Loads for 04.00AM on 49th day in 2012 (after retrofitting)

Figure 5.20 represents the total heating load rate profile on the 49th day of 2012. When the total load rate profiles of the existing situation and after retrofitting are compared, it can be seen that the heating load rate is lower with rate of 67.8% than the existing situation on the same day after retrofitting.

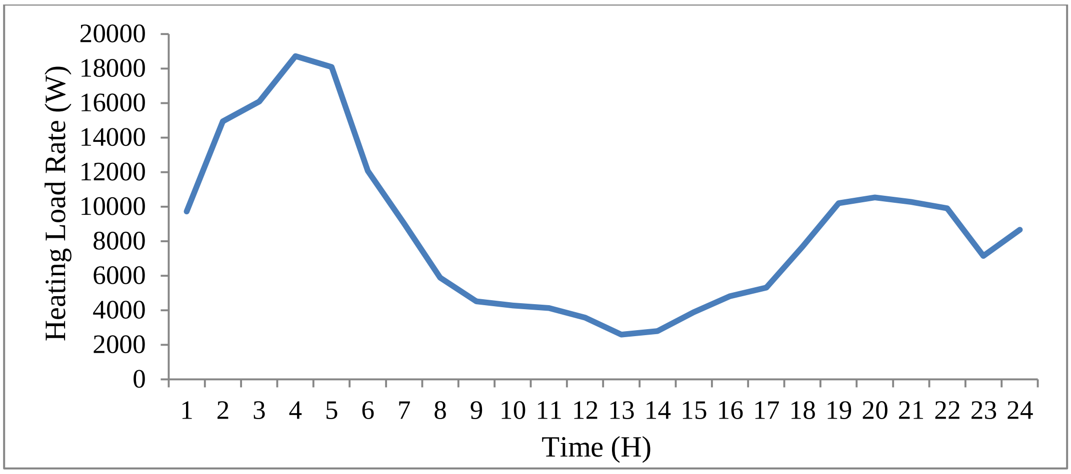


Figure 5.20. Heating Load Rate Profile for the Whole Building on 49th Day (after retrofitting)

In Figure 5.21, dry bulb temperature in the whole building on 04:00AM of the 49th day is depicted. Contrary to the situation before retrofitting, temperature of the zones is very similar to each other.

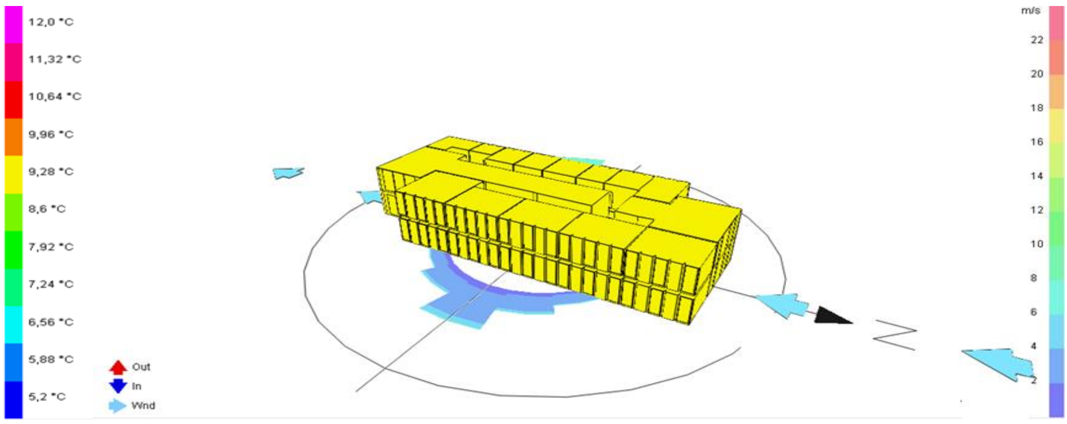


Figure 5.21. Dry Bulb Temperature for 04.00AM on 49th day in 2012 (after retrofitting)

Figure 5.22 illustrates relative humidity distribution in the whole building at the same time. According to the results, again the humidity of the whole building is at equilibrium around 40%. This is again opposite to the situation before retrofitting.

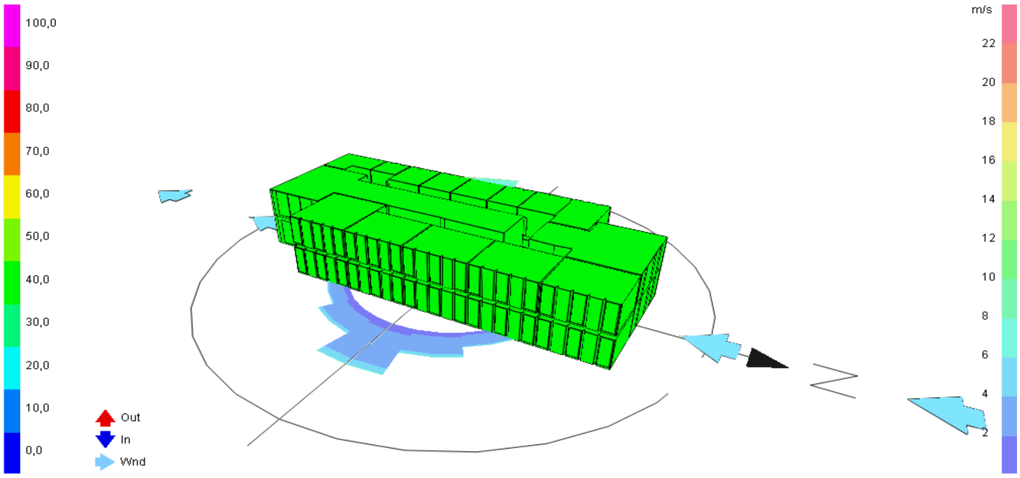


Figure 5.22. Relative Humidity for 04.00AM on 49th day in 2012 (after retrofitting)

Figure 5.23 represents the heating loads on the aforementioned time (04:00 AM on 49th day). According to this figure, the atrium still has the biggest amount of heating loads comparing the other parts of the buildings; but the amounts are smaller than the situation before retrofitting. The maximum heating load rate is 1.3 kW for atrium and the rest of the building's heating load rate is between 0.7 kW and 0.9 kW.

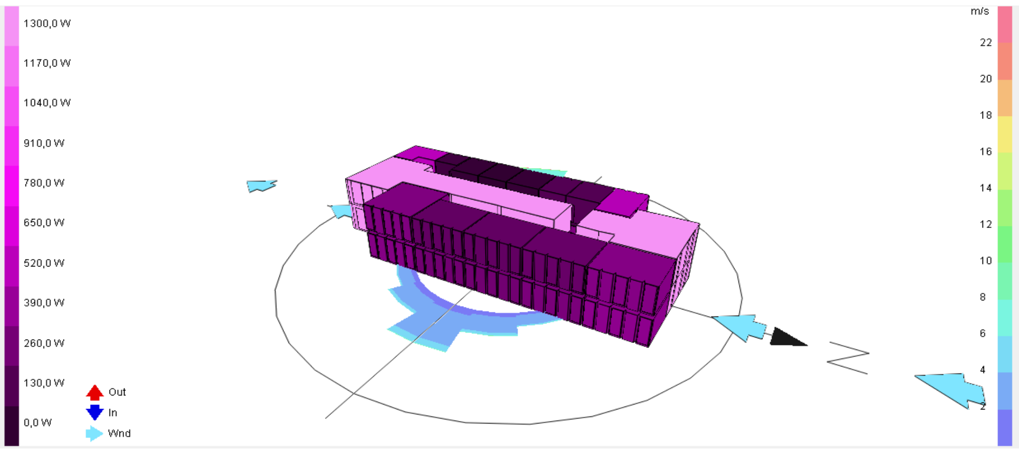


Figure 5.23. Heating Load Rate for 04.00AM on 49th day in 2012 (after retrofitting)

In Figure 5.24, building heat transfer rate distribution on 04:00 AM of the 49th day can be seen. When the situations before and after retrofitting are compared, it can be seen that the heat transfer is through the building before retrofitting, but it is opposite after retrofitting.

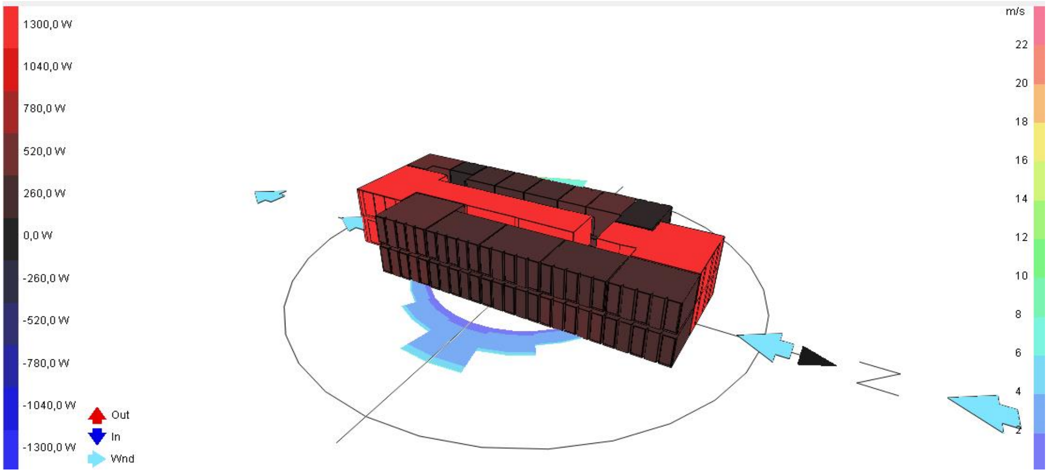


Figure 5.24. Building Heat Transfer Rate (W) for 04.00AM on 49th day in 2012 (after retrofitting)

Figure 5.25 demonstrates the external conduction opaque values, which means heat loss/gain is occurred via conduction according to the zones and ground etc. The atrium again has the maximum value comparing to the rest of the building. The maximum external conduction opaque rate is -0.68 kW for the atrium and the rest of the building is between -0.26 kW and 0.5 kW.

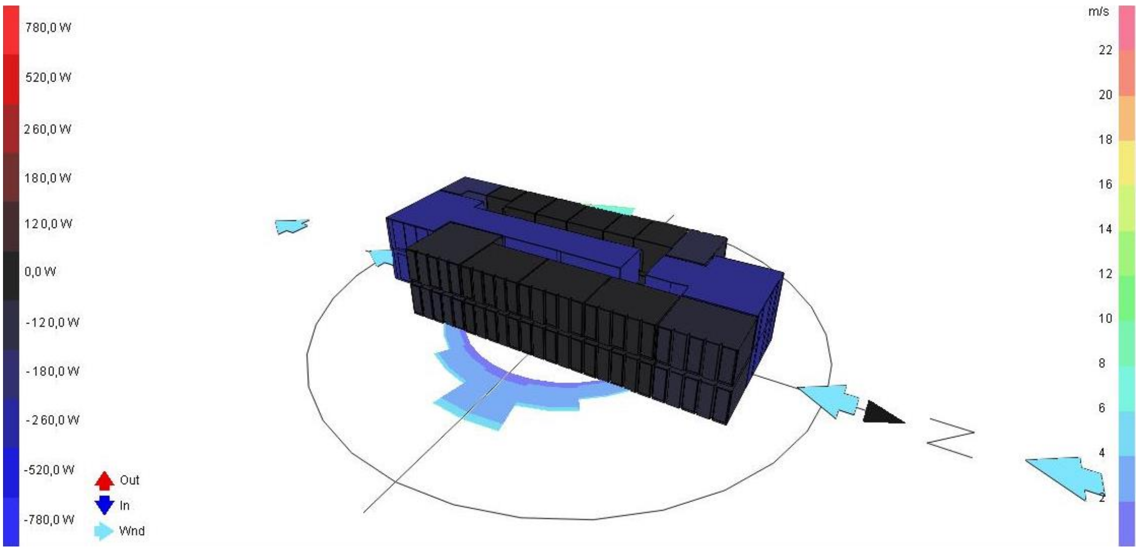


Figure 5.25. External Conduction Opaque Rate for 04.00AM on 49th day in 2012 (after retrofitting)

As the next step, the analysis was carried out for the 04:00 AM of the 232nd day again; and the results were compared with the current situation of the building. Figure 5.26 depicts the temperatures versus cooling loads in terms of zones. According to this analysis, cooling load rate of the atrium is 13.32 kW and this value is smaller with value of 13.30 kW than the cooling load rate value of the atrium before retrofitting.

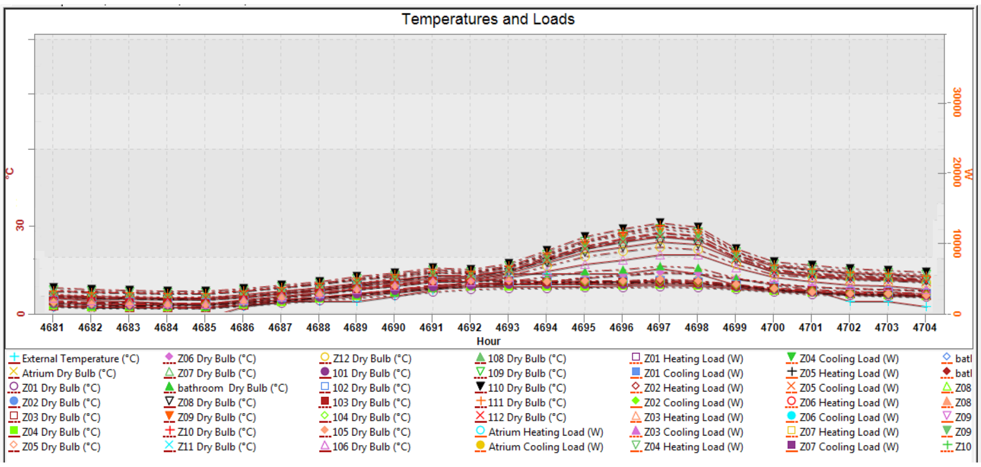


Figure 5.26. Temperature versus Loads for 04.00AM on 232nd day in 2012 (after retrofitting)

Figure 5.27 demonstrates the humidity values versus loads in terms of zones. As it is seen from the figure, relative humidity in the building is much lower than the external humidity and it ranges between 20-45%.

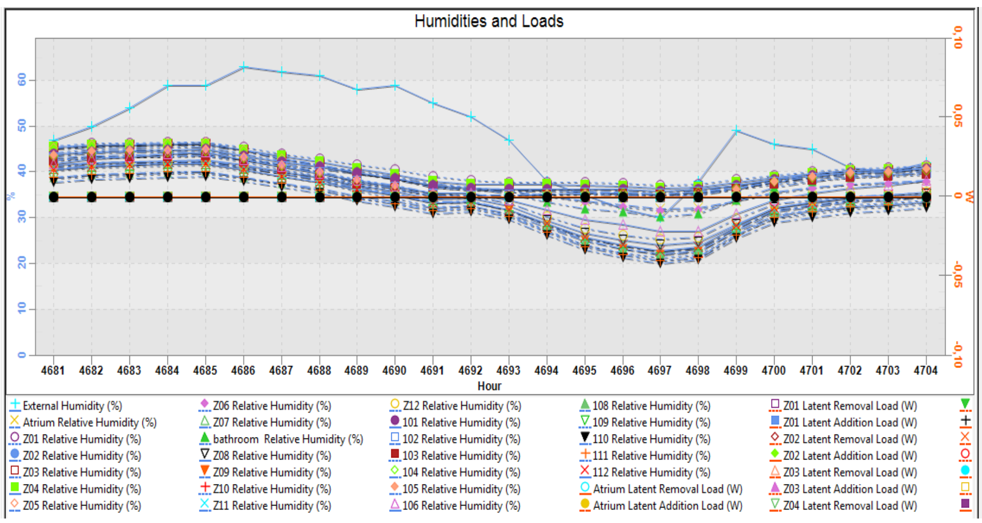


Figure 5.27. Humidity and Load Rate for 04.00PM on 232nd day in 2012 (after retrofitting)

In Figure 5.28, maximum cooling load rate profile of the building after retrofitting for the 232nd day of 2012 can be seen. As it can be seen, the maximum total load increases in the afternoon till 02:00 PM. After this time, the cooling load rate begins to decrease. However, total load distribution after retrofitting is much lower than the loads before retrofitting.

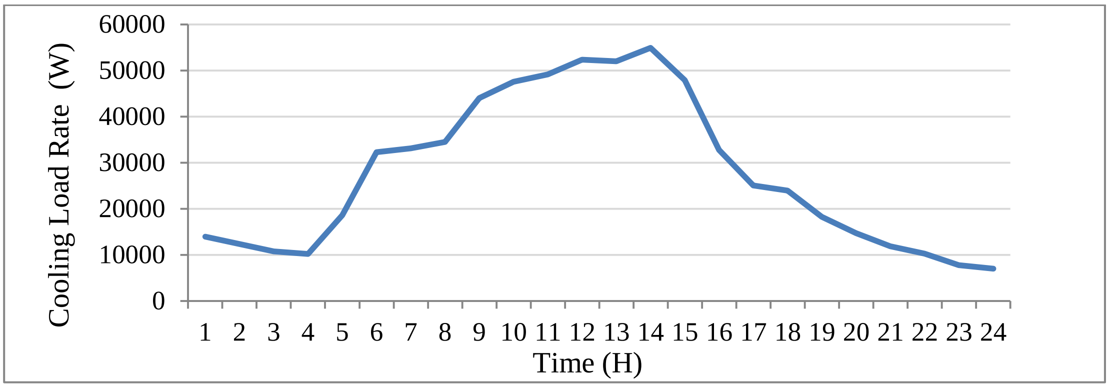


Figure 5.28. Cooling Load Rate Profile for Whole Building on 232nd day (after retrofitting)

In Figure 5.29, dry bulb temperature of the whole building on 04:00 PM is depicted. Similar to the situation before retrofitting, general temperature in the building ranges between 18 and 22 °C. The office rooms looking at the west direction are cooler than the other parts of the building.

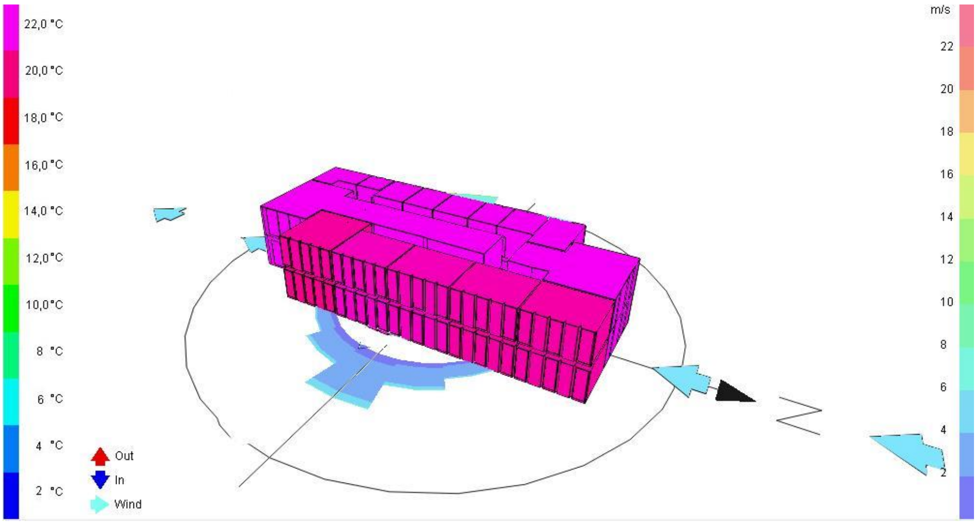


Figure 5.29. Dry Bulb Temperature (°C) on 04:00PM on 232nd day (after retrofitting)

Figure 5.30 illustrates relative humidity distribution in the whole building at the same time. According to the results, it can be seen that the whole building has approximately the same humidity value, which is around 40%.

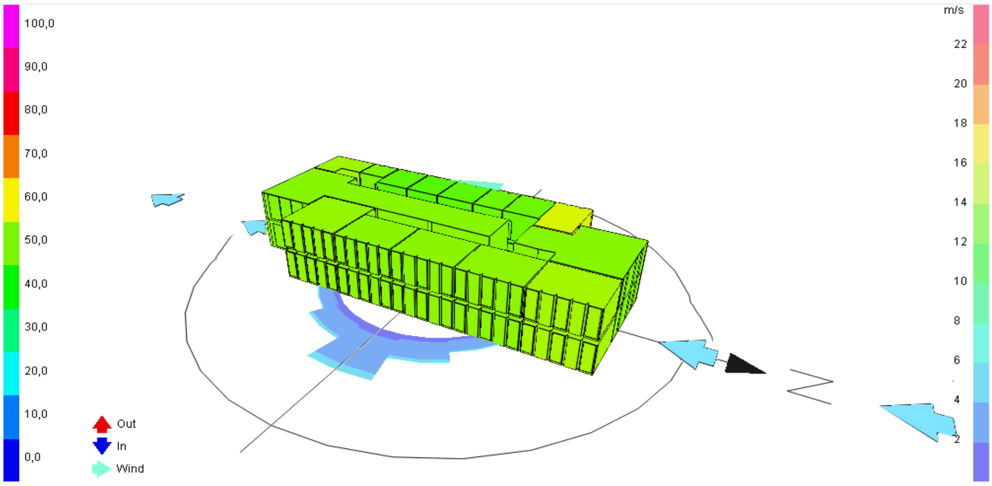


Figure 5.30. Relative Humidity (%) on 02:00PM on 232nd day in 2012 (after retrofitting)

Figure 5.31 represents the cooling loads on 04:00 PM on 232nd day. According to this figure, like the situation before retrofitting, the atrium has the biggest amount of cooling loads comparing the other parts of the buildings. However, the load differences between the zones are lower than the current situation. The maximum cooling load rate is 1.3 kW for the atrium and the rest of the building is ranging from 0.5 kW to 1.12 kW.

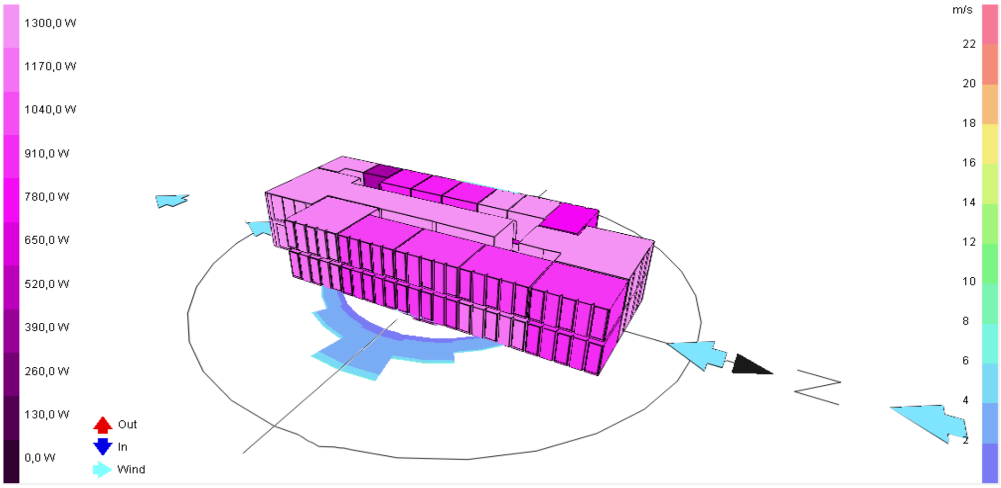


Figure 5.31. Cooling Load Rate (W) on 02:00PM on 232nd day in 2012 (after retrofitting)

In Figure 5.32, building heat transfer rate distribution for the same moment can be seen. When the current situation of the building and the figure below are compared, it can be claimed that the heat transfer between zones have decreased. The building heat transfer rate is -1.04 kW for the atrium and the rest of the building is between -0.52 kW and 0.22 kW.

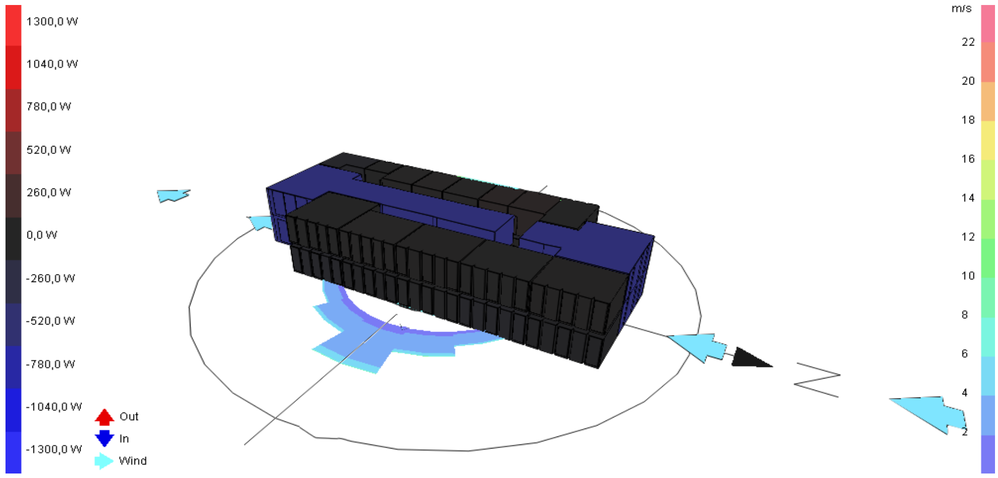


Figure 5.32. Building Heat Transfer Rate (W) on 04:00PM on 232nd day (after retrofitting)

Figure 5.33 demonstrates the external conduction opaque values, which means heat loss/gain is occurred via conduction according to the zones and ground etc. The atrium has the biggest amount.

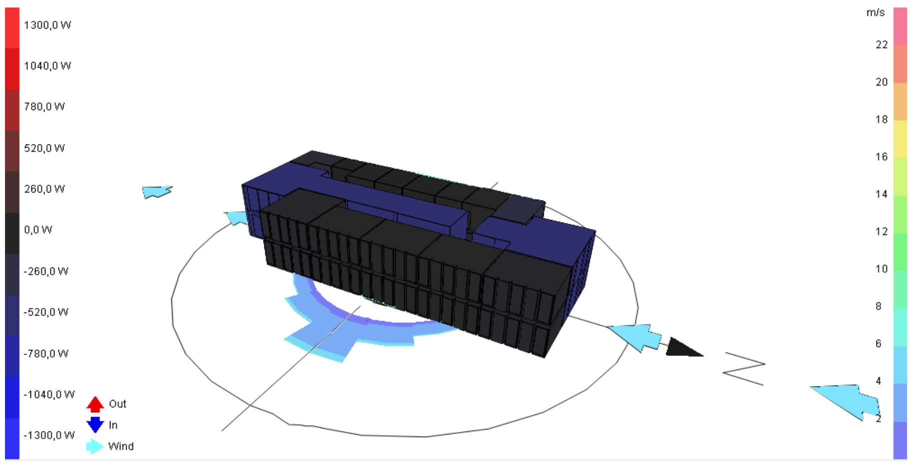


Figure 5.33. External Conduction Opaque Rate (W) on 02:00PM on 232nd day (after retrofitting)

Like the situation before retrofitting, total heating and cooling loads have been calculated again by summing the hourly loads. According to EDSL-TAS simulation, building’s heating and cooling loads after retrofitting are represented in Figure 5.34. The annual heating load rate is 19445.01 kWh and the cooling load rate is 54032.97 kWh. From these values, total annual load can be calculated as 73477.97 kWh. These values are much lower than the situation before retrofitting; and this result proves the benefit of a good insulation to a building.

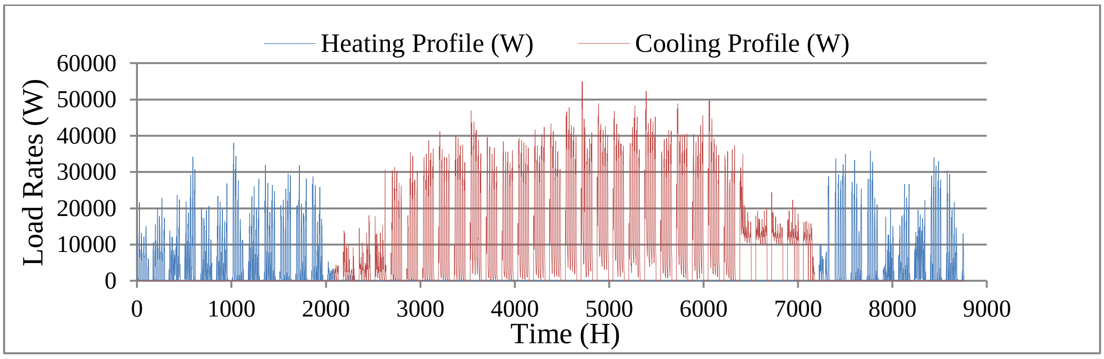


Figure 5.34. Annual Heating and Cooling Load Rates after Retrofitting in 2012

EDSL-TAS provides the heat loss rates of the building zone by zone, dynamically.

According to the EDSL-TAS analyses, annual heating and cooling loads of the case study building can be seen in Table 5.2;

Table 5.2. Annual Total Energy Loads before and after Retrofitting

	Before Retrofitting		After Retrofitting	
	Heating	Cooling	Heating	Cooling
(kWh)	63605.32	82427.48	19447.39	54036.19

The maximum heating load rate is revealed at 04:00 PM in 49th day, which equals to 114.589 kW before retrofitting and 18.706 kW after retrofitting. On the other hand, maximum cooling load rate is revealed at 18:00 in 232th day. The results of before retrofitting and after retrofitting are 86.99 kW and 23.94 kW, respectively. In addition to these analyses, EDSL-TAS provides to find infiltration, heat transfer through the components, heat dispersion etc.., related to these results, atrium is the most different part as to heating/cooling because of the floor height, sizes of medium and window areas in this part.

According to the Table 5.3, the heating and cooling load rate before and after retrofitting per square meter and per volume values can be seen below;

Table 5.3. Heating and Cooling load rate per m^2 and per volume before and after Retrofitting

	Heating Load		Cooling Load	
	kWh/m^2	kWh/ m^3	kWh/m^2	kWh/m^3
Before Retrofitting	70.98	19.74	91.99	25.58
After Retrofitting	21.70	6.03	60.3	16.77

LowEx results illustrate the maximum useful energy possible value in the scenarios, which are the existing building, before and after retrofitting for winter and summer times. Air heat pump and ground source heat pump as heating/cooling system, aforementioned EDSL-TAS part, retrofitting in the building were used in the analyses as the retrofitting. According to the time dependent exergy analysis, electrical energy demand before and after retrofitting, Table 5.4 is obtained.

5.2. LowEx Results

In this part, exergy calculations of the whole building before refurbishment and after refurbishment results were given. According to the Chapter 4.3 and
Table 4.4, given options in the tables were selected in LowEx calculation tools.

In the primary energy transform, energy and exergy flows are revealed with the most value for; system energy total, heat energy, electrical energy, renewable energy, solar gains, system exergy total, exergy gains. The second one is storage of the components in the building.

In the thesis, HVAC system and components' thermal heat conductivity coefficient were entered to the exergy tool with existing properties (two occupants in one office room, two lighting components, two computers, two fan coils). COP of the air heat pump was assumed as 2.1. Boiler envelope positions were entered to LowEx with changed insulation orientation; boiler design temperature for domestic heat water was assumed less than 50 ^{o}C during a year, whereas temperature drop assumed 20 ^{o}C in winter and 10 ^{o}C in summer. Emission system was selected as fan coil or air heating/cooling system. After getting some results with this application, the refurbishments in the building components and HVAC systems were analyzed. Ground source heat pump with COP value of 3.53 as taken over Air heat pump with COP value of 2.5 in the retrofitted building and some refurbishments in the HVAC system were selected used to find exergy value in terms of useful energy.

5.2.1. LowEx Results before Refurbishment

In the existing situation of the building, LowEx evaluation results are given in following graphs. In Figure 5.35, heat loss/gain of the heating/cooling system, one of them is boiler as to heat the building and the other one is air to water chiller system in order to cool the building. The heat loss/gain of the heating/cooling system means the boiler and air to water chiller system according to the HVAC system efficiency (it was calculated by using equation of 2.5, and the value of the efficiency system is chosen as 0.8 for boiler in winter, air to water chiller system efficiency is chosen 2.5 in summer. Distribution system's heat loss rate is calculated according to the Equation 2.45. Therefore, all heating system's heat loss rate is found using these equations together

Actually, the graph has negative and positive parts, but in the LowEx calculation it is carried out by using absolute values. And also, the main problem is that the interior temperature of the building has had negative effect due to the building components' thermophysical properties. The maximum heat loss rate value is revealed as 17.73 kW for the heating system; the maximum heat loss rate is 15.62 kW for the cooling system. The values contain the heating/cooling system heat loss rate and also distribution system heat loss rate.

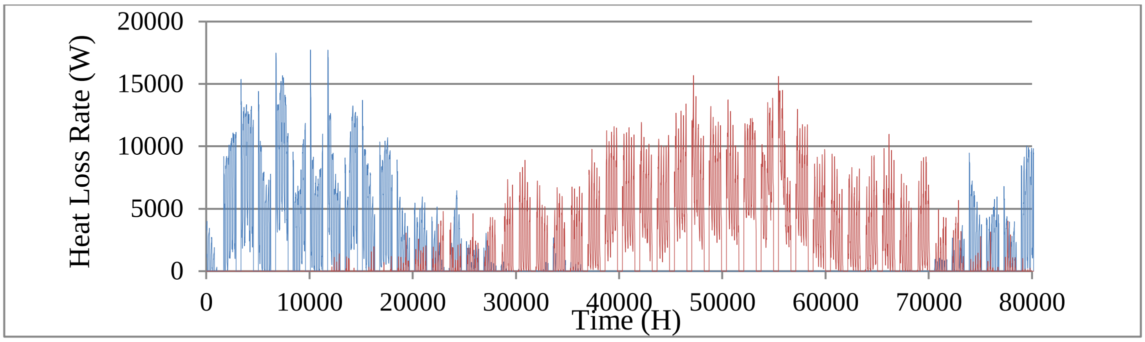


Figure 5.35. Heat Loss Rate of the Heating/Cooling System

In Figure 5.36, the exergy load rate of the heating/cooling system during the year is illustrated. For calculating the values, Equation 2.44 was used. At this equation, return water temperature to the air to water chiller system (T_{ret}), inlet water temperature of the fan coil (T_{in}) and reference dry bulb temperature (environment temperature, T_{ref}) are chosen as 333.15 K, 353.15 K, 273.15 K for the winter, respectively. And for the summer, inlet water temperature to the air to water chiller system (T_{ret}), inlet water temperature of the fan coil (T_{in}) and reference dry bulb temperature (environment temperature, T_{ref}) are chosen as 279.15 K, 287.15 K and 309.15 K, respectively. The maximum exergy load of the heating system was found as 38.55 kW and the cooling was found as 31.32 kW, respectively.

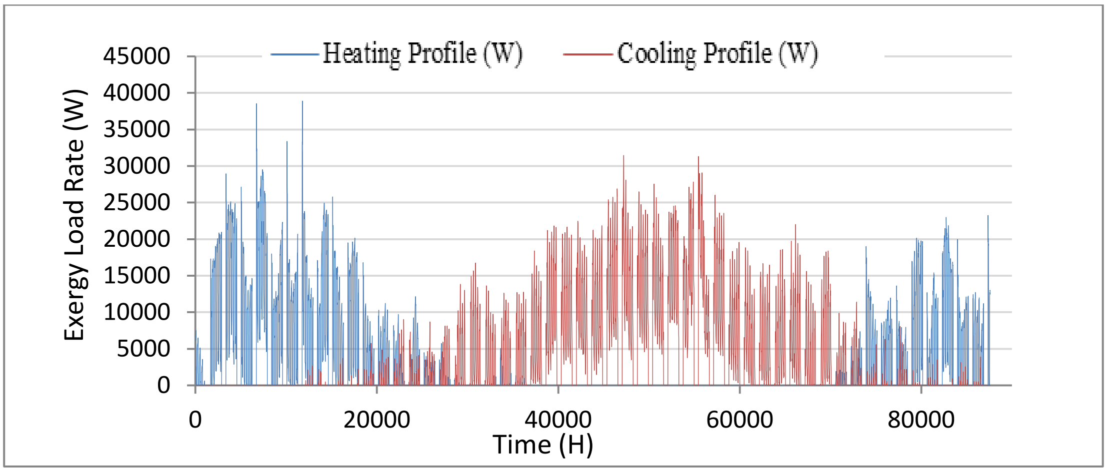


Figure 5.36. Exergy Load Rate of the Heating/Cooling System

In Figure 5.37, exergy demand rate values of the heating/cooling systems are shown. The calculations were carried out by using Equation 2.43. The maximum exergy demand rate for the heating system was revealed as 29.18 kW, whereas exergy demand rate of the cooling system was 28.23 kW.

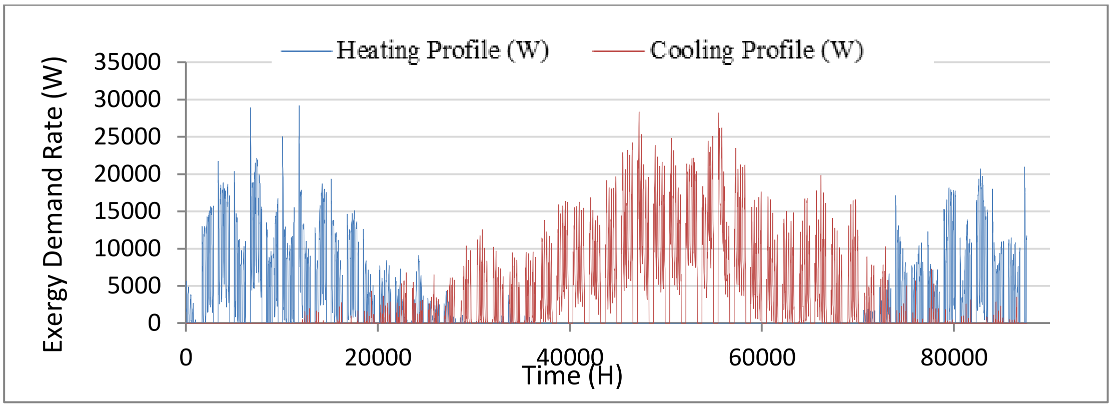


Figure 5.37. Exergy Demand Rate of the Heating/Cooling system

In Figure 5.38, energy demand rate of the heating/cooling system can be seen, explicitly. In order to analyze the heating/cooling system in terms of energy demand, Equation 2.49 was used, and the values of the heating system efficiency is 0.8 for the boiler in winter and solar fraction factor of the storage system is chosen as 0. However, in the summer, the solar fraction factor is stable and HVAC system efficiency was chosen as 2.5 because of the air to water chiller system. The maximum points are 308.69 kW for heating system and 178.24 kW for the cooling system.

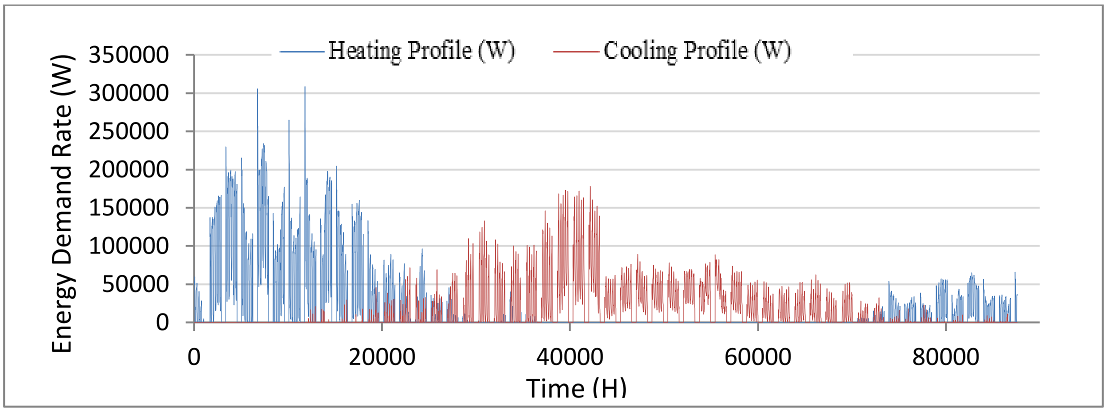


Figure 5.38. Energy Demand Rate of the Heating/Cooling system

Figure 5.39 depicts the exergy efficiency of the system for the maximum heating load rate day. The maximum exergy efficiency value is 14.46 % corresponding to the minimum external temperature and the maximum heating load rate time and therefore the minimum external temperature.

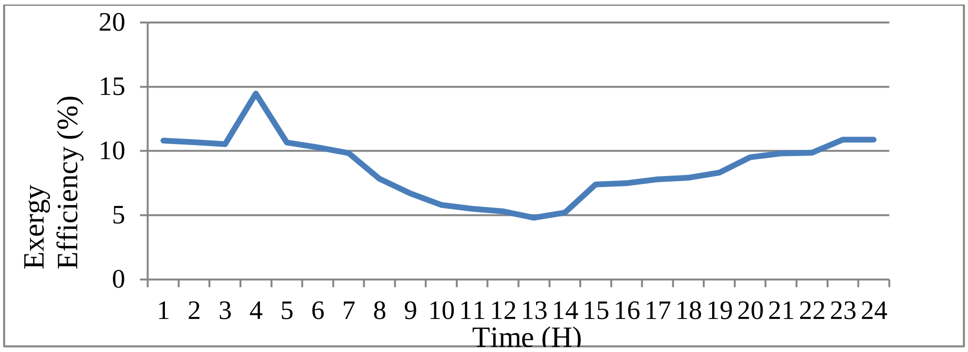


Figure 5.39. Exergy Efficiency of the Heating System on 49th day in 2012 (before retrofitting and refurbishment)

Figure 5.40 illustrates the exergy efficiency of the heating/cooling system during the year. As mentioned before, the maximum exergy efficiency average is 14.01 % in January, whereas the minimum exergy efficiency average is 2.11 % in August due to the fact that difference between environment and indoor temperature. During the year, exergy efficiency value of the heating/cooling system changes between 2.01-14.46%.

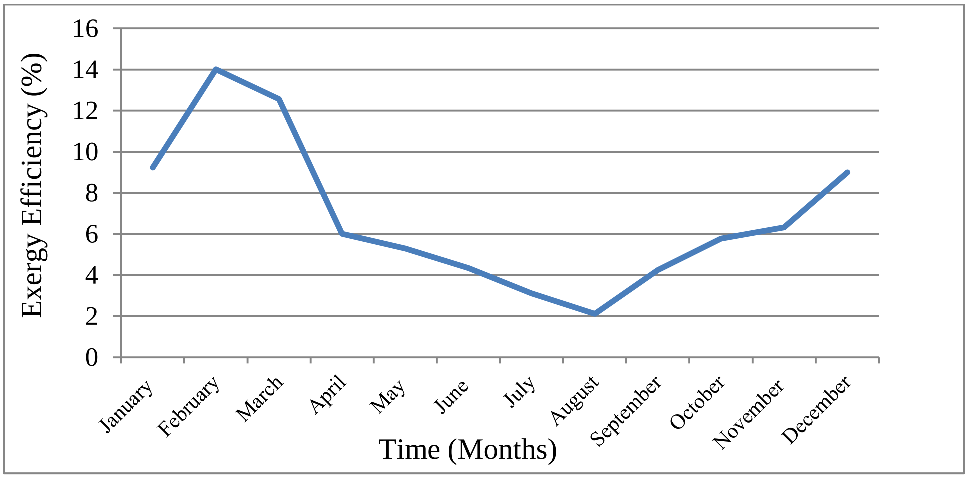


Figure 5.40. Exergy Efficiency of the Heating/Cooling System during 2012 (before retrofitting and refurbishment)

5.2.2. LowEx Results after Refurbishments

In this thesis, two different scenarios were created, which provide to calculate the useful energy value and best case scenario. First scenario includes the building retrofitting and ASHP (VRF/VRV) with COP value of 2.5 as HVAC system. Second scenario is occurred by retrofitting and GSHP with COP value of 4.1 as HVAC system.

5.2.2.1. LowEx Results after ASHP with Refurbishment

After refurbishments in the building components and HVAC system (as can be seen in Chapter 4.2), the LowEx results can be seen following table and graphs;

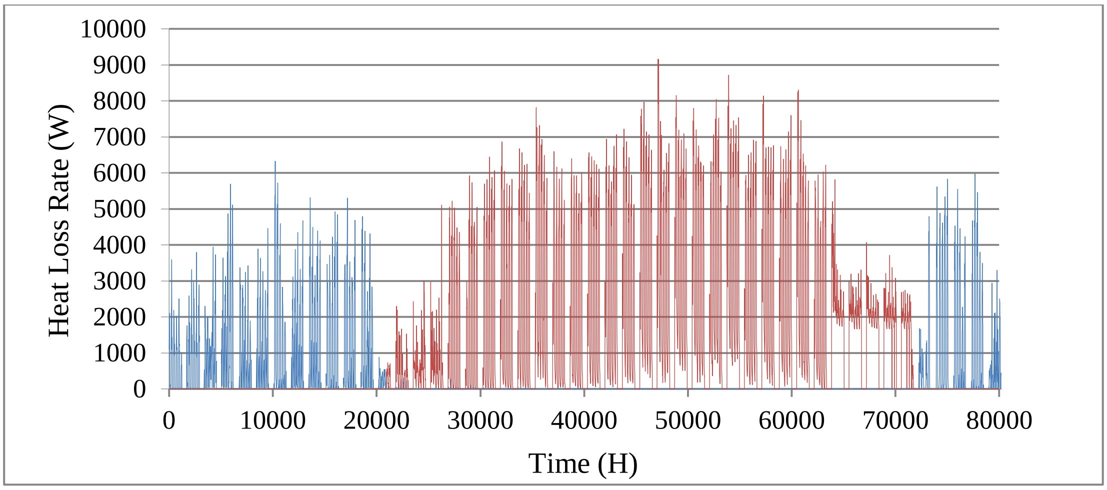


Figure 5.41. Heat loss Rate of the Heating/Cooling system

The Figure 5.41 illustrates the heat loss rate of the heating/cooling system by using the dynamic LowEx calculation expressed in Equation 2.42. In this scenario, heating/cooling system is the same and its efficiency is 2.5. Therefore; the maximum heat loss rate values were found as 6.33 kW and 9.16 kW for the heating and cooling system, respectively.

According to the LowEx results, the exergy loads of the heating/cooling system are given below in Figure 5.42. Related to the Equation 2.44, the exergy load values of the heating/cooling system were found by choosing the return dry bulb temperature of the boiler system (T_{ret}), inlet water temperature of the fan coil (T_{in}) and reference dry bulb temperature (environment temperature, T_{ref}) were chosen as 333.15 K, 353.15 K, 273.15 K for the winter, respectively. And for the summer, the return water temperature of the boiler system (T_{ret}), inlet water temperature of the fan coil (T_{in}) and reference dry bulb temperature (environment temperature, T_{ref}) were chosen as 279.15 K, 287.15 K and 309.15 K, respectively. The maximum exergy load rate of the heating season is 15.61 kW and the maximum exergy load of the cooling system is 19.89 kW.

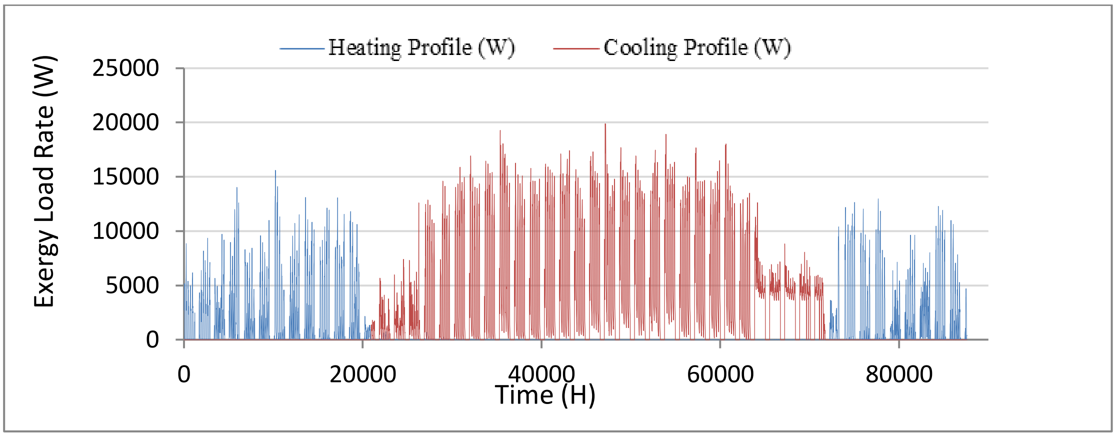


Figure 5.42. Exergy Load Rate of the Heating/Cooling System

Exergy demand rate of the heating/cooling system was defined by choosing values of the return water temperature of the boiler system (T_{ret}), inlet water temperature of the fan coil (T_{in}) and reference dry bulb temperature (environment temperature, T_{ref}) as 333.15 K, 353.15 K, 273.15 K for the winter, respectively. And for the summer, the return water temperature to the air to water chiller system (T_{ret}), inlet water temperature of the fan coil (T_{in}) and reference dry bulb temperature (environment temperature, T_{ref}) were chosen as 279.15 K, 287.15 K and 309.15 K, respectively. In this scenario, heating and cooling system is Air Source Heat Pump, and its efficiency is 2.5. In Figure 5.43, the exergy demands of the heating/cooling system are given, annually. The Solar Fraction factor was chosen as 0, and the Exergy demands of the ASHP were calculated by using Equation of 2.43. The maximum exergy demands are 12.38 kW and 17.93 kW, heating and cooling respectively.

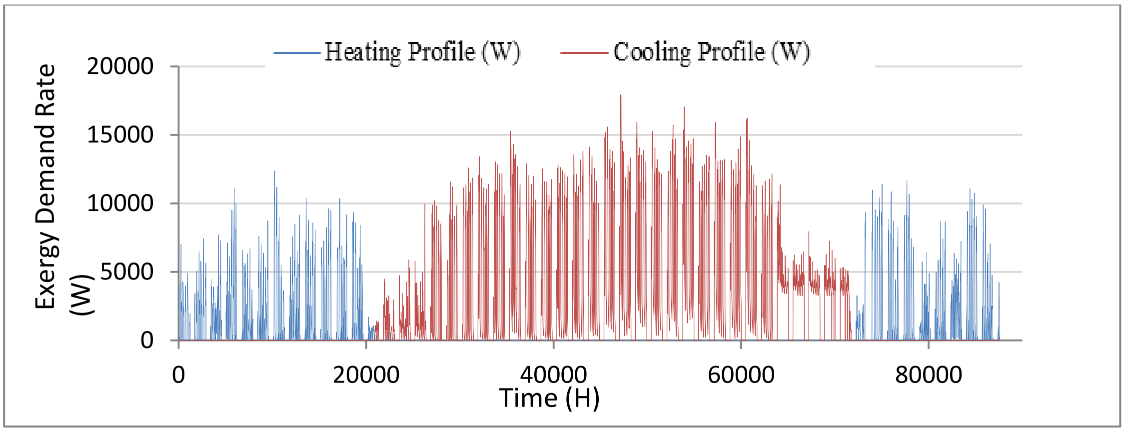


Figure 5.43. Exergy Demand Rate of the Heating/Cooling System

Figure 5.44 demonstrates the energy demand rate of the heating/cooling system during the year. The maximum heating energy demand rate is 41.91 kW and the maximum cooling energy demand rate is 56.31 kW.

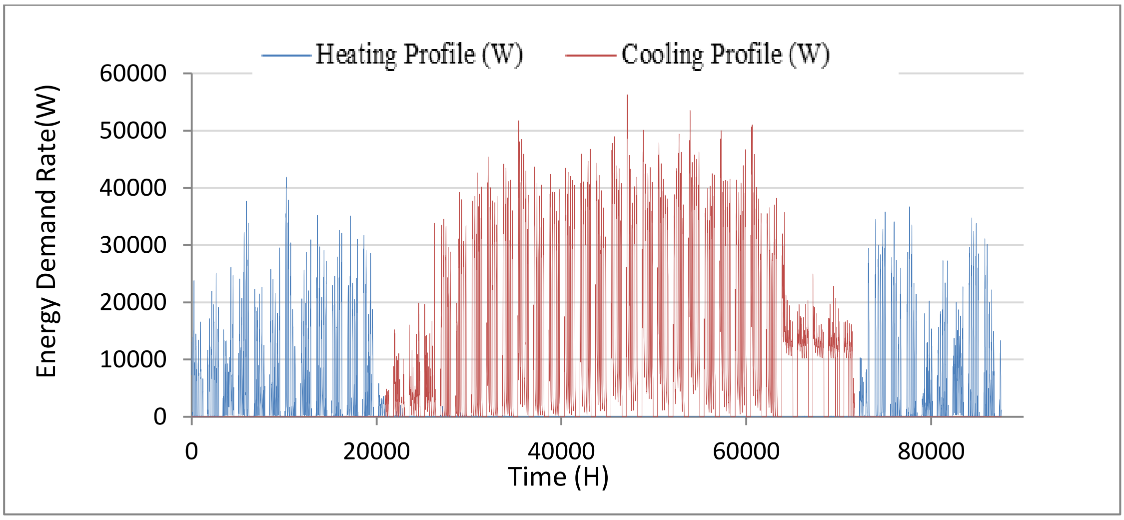


Figure 5.44. Energy Demand Rate of the Heating/Cooling System

Figure 5.45 illustrates the exergy efficiency of the ASHP system during 49th day. The maximum exergy efficiency is revealed with value of 17.99 %, whereas the minimum exergy efficiency value is 7.00 %. The difference between efficiencies is obtained because of the difference in temperatures of indoor and outdoor.

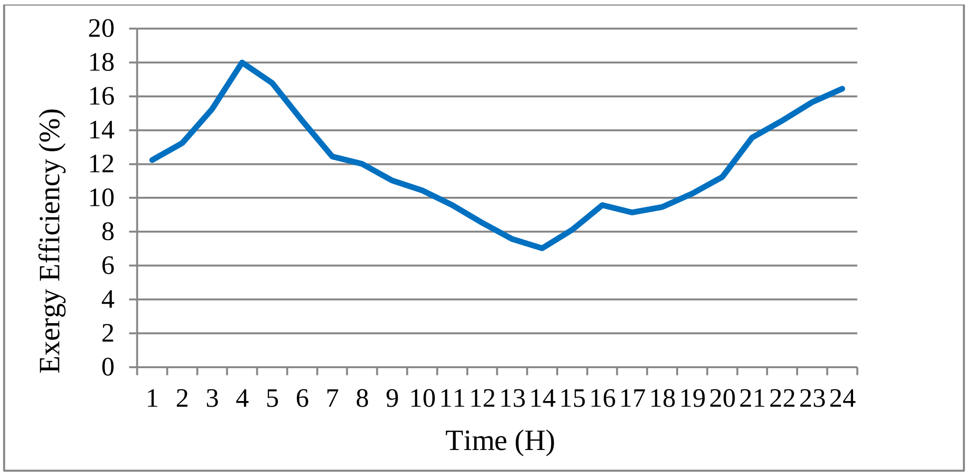


Figure 5.45. Exergy Efficiency of the ASHP System 4:00 PM on 49th day in 2012 (after retrofitting and refurbishment)

Exergy efficiency of the heating/cooling system during 2012 is demonstrated in Figure 5.48. The maximum exergy efficiency average is revealed in February with value of 17.56 %, whereas the minimum exergy efficiency average is revealed in August as 4.0 %, due to the fact that difference between environment and indoor temperatures.

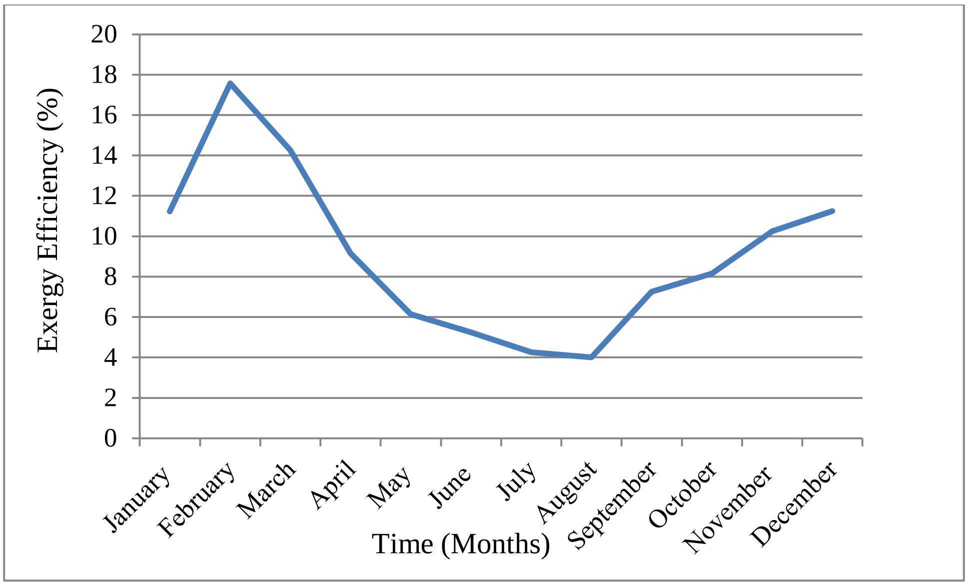


Figure 5.46. Exergy Efficiency of the ASHP System during 2012 (after retrofitting and refurbishment)

5.2.2.2. LowEx Results after GSHP with Refurbishment

In Figure 5.47, the heat loss rate of the heating/cooling system can be seen, the results were found by Equation 2.42, and efficiency of the GHSP was taken as 3.53. Maximum points are 3.45 kW for the heating season and 4.99 kW for the cooling season.

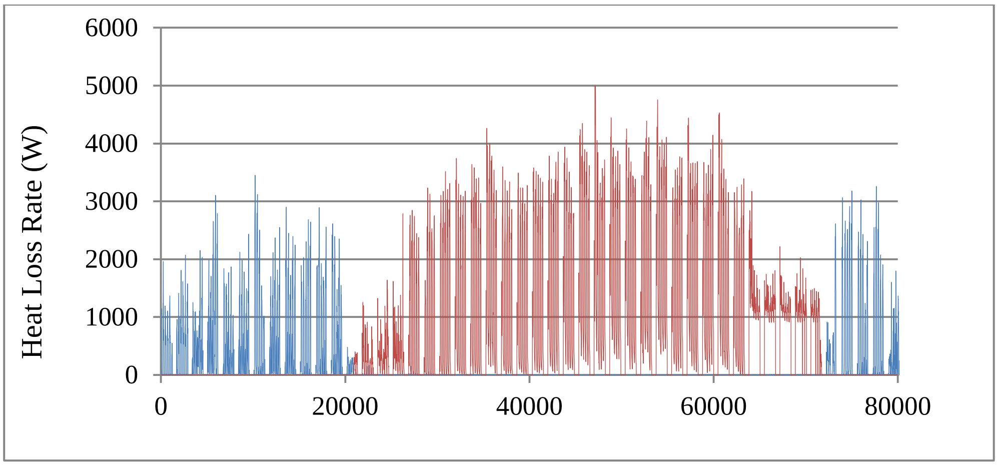


Figure 5.47. Heat Loss Rate of the GSHP System

Figure 5.48 depicts the exergy load rates of the GSHP during 2012, which were found using Equation 2.44. In order to use in the Equation, return water temperature of the boiler system (T_{ret}), inlet water temperature of the fan coil (T_{in}) and reference dry bulb temperature (environment temperature, T_{ref}) were chosen as 333.15 K, 353.15 K, 273.15 K for the winter, respectively. And for the summer, the return water temperature of the Air to water chiller system (T_{ret}), inlet water temperature of the fan coil (T_{in}) and reference dry bulb temperature (environment temperature, T_{ref}) were chosen as 279.15 K, 287.15 K and 309.15 K, respectively. The maximum exergy loads were revealed as 16.51 kW for the heating season and 21.19 kW for the cooling system.

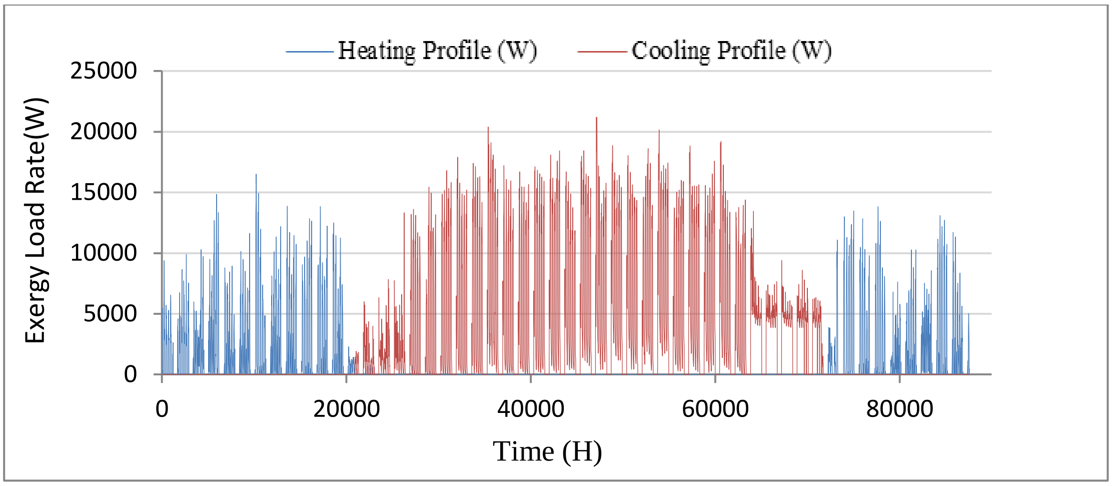


Figure 5.48. Exergy Load Rate of the GSHP System During the year

Figure 5.51 demonstrates the exergy demand rates of the GSHP system. The exergy demand results were found using Equation 2.43. Whereas 13.825 kW is appeared as the maximum exergy demand for the heating season, 19.234 kW is the maximum exergy load for the cooling season.

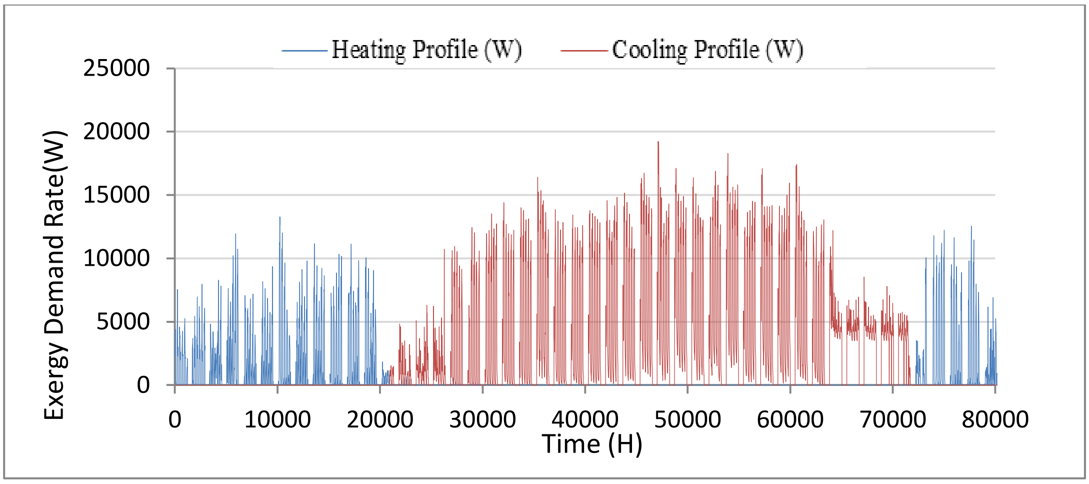


Figure 5.49. Exergy Demand Rate of the GSHP System during the year

Figure 5.50 shows the energy demand of the heating/cooling system. According to the calculations, Equation 2.49, the Solar Fraction factor is chosen 0 and efficiency is 3.53. The maximum heating energy demand point is 22.791 kW and the cooling energy demand point is 36.247 kW.

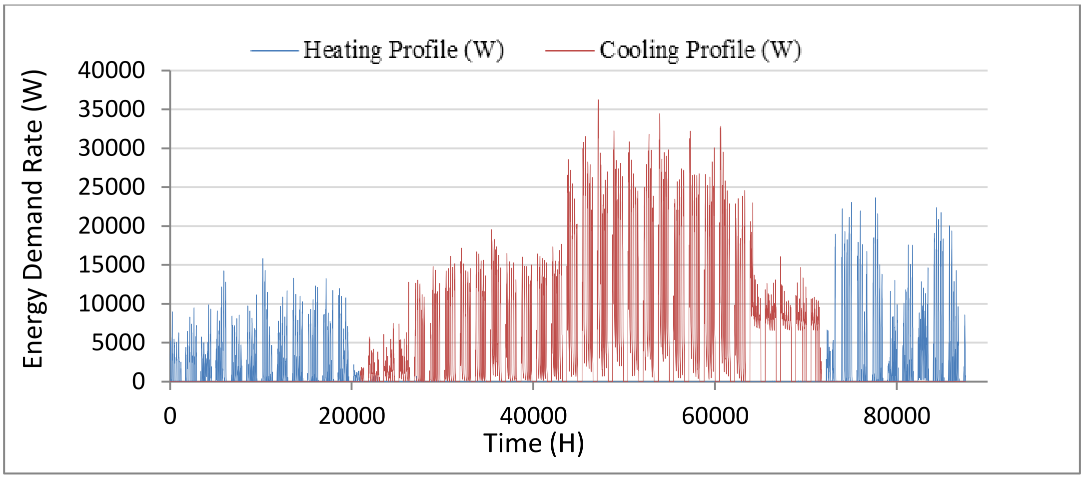


Figure 5.50. Energy Demand Rate of the Heating/Cooling system

Figure 5.51 demonstrates the exergy efficiency of the GSHP system. According to the graph, the maximum exergy efficiency value is at 4:00 PM on 49th day as 21.45 % and the minimum value of the exergy efficiency is 7,56 % at 17:00 AM on 49th day.

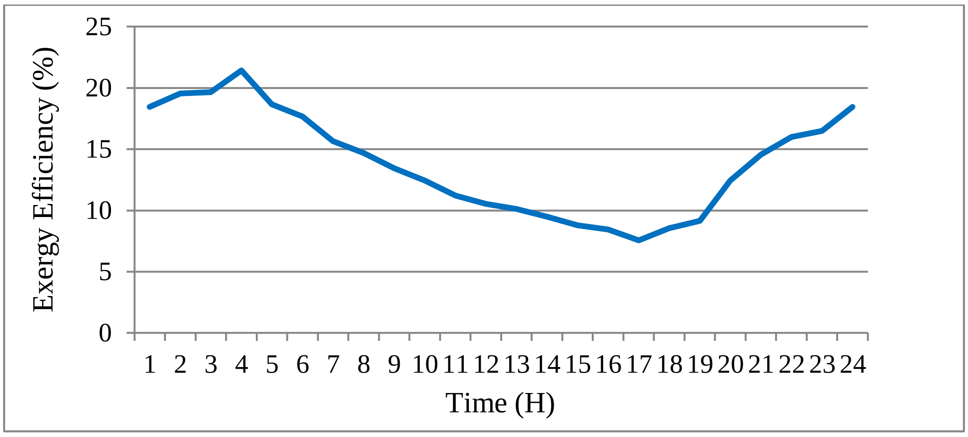


Figure 5.51. Exergy Efficiency of the GSHP system 4:00 PM on 49th day in 2012 (after retrofitting and refurbishment)

Figure 5.52 illustrates the exergy efficiency average values of the GSHP in 2012 according to the months. The maximum average value of the efficiency is 21.56 % at February and the minimum average value is 8.79 % at August.

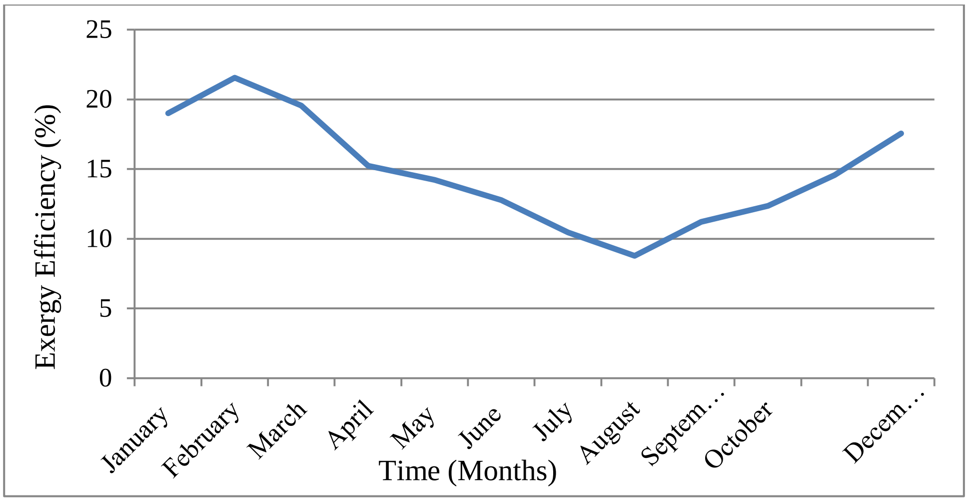


Figure 5.52. Exergy Efficiency of the GSHP system in 2012 (after retrofitting and refurbishment)

Table 5.4. Electrical Energy Demand Rates before and after Refurbishment

(kWh)	Boiler/ASHP with the Building	ASHP with the Refurbishment	GSHP with the Refurbishment
Winter	108781.38	20795.88	9892.33
Summer	68244.24	56802.49	24657.54

In Table 5.4. , electrical energy demand rates before and after refurbishment can be seen. In the real circumstance, value of 108781.38 kWh is demand for heating the building by using boiler; and value of 68244.24 kWh is demand for the cooling the building by using air to water chiller system. The values correspond to 43.16 kW for in the heating season and 27.08 kW for the cooling season as steady state condition. For the scenario including only ASHP electrical energy demand rate values are 8.25 kW and 22.52 kW for heating and cooling season as steady state condition. In the scenario of GSHP, 3.92 kW and 9.78 kW are demand rates for the heating and cooling the building in steady state condition.

CHAPTER 6

CONCLUSIONS

During the energy analysis in the EDSL-TAS, 365 days 24 hours data were entered into the program in order to analyze the building, dynamically. The obtained building summary from EDSL-TAS can be seen as extreme temperature conditions and loads are given in the Table 5.1. According to the results of the building summary, maximum heat load and maximum cooling load rate days were chosen as to be given in the thesis via EDSL-TAS. And the building loads were calculated for these days before refurbishment and after refurbishment of the building components. The results of the analysis can be seen in Chapter 5.1, explicitly.

According to the EDSL-TAS and LowEx results, the building is better level in terms of energy level after refurbishment, because the infiltration, relative humidity, heat conduction through the components and HVAC system insulation were revealed to analyze the building. In atrium, heat loss, heating/cooling loads are higher than the other parts of the building. To take some precautions, one of them is that the atrium is removed from the building and reformed as different two floors. The other precaution is that skylight removing, because heat air is accumulated in skylight space. Therefore; the heat loss is released from atrium to skylight, as well. Another precaution is that, envelope of the building is stimulated by using XPS in 0.05 m and the other building components are refurbished according to the TS-825 and region. In terms of HVAC system is insulated in order to prevent the heat loss of the components. And HVAC system is reinforced to meet the energy demand of the building, COP can be increased or ground source heat pump takes over air source heat pump.

To sum up, aforementioned precautions were taken into account in the thesis, energy level of the building is increased and exergy values are found in all scenarios. By this way, the energy demand is decreased; the energy consumption is decreased and the exergy destruction can be released.

As further studies, CFD can be carried out using Fluent as to find out temperature distribution and heat flows in the building. The results provide the heat loss and gain rate values, therefore; problematic zones and parts of the building can be defined exactly. As the other further study exergy calculation can be repeated in the relations taking some measurements related to the HVAC system. Another further study is that the analysis of the other buildings in IZTECH because the other building have some similarity with the building in the thesis as one of campus which consume the most energy per capita.

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