DESIGN AND ANALYSIS OF ENERGY SAVING BUILDINGS USING THE SOFTWARE ENERGY PLUS

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ABSTRACT

DESIGN AND ANALYSIS OF ENERGY SAVING BUILDINGS USING THE SOFTWARE ENERGY PLUS

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Being the major energy consumer of electricity and natural gas, buildings consume more than 70% of electricity and 30% of natural gas. On the way to green buildings and zero energy buildings, investigation and improvement of energy efficiency of the buildings will result in significant reductions in energy demands and CO_2 emissions; make cost savings and improve thermal comfort as well. Key steps of a successful green, energy efficient building can be summarized as whole building design, site design, building envelope design, lighting and day lighting design and HVAC system design.

Energy Plus® software is mainly developed to simulate the performance of the buildings in the view of the above listed points. The design of a building or the analysis of an existing building with the software will show how efficient the building is or will be, and also helps finding the best efficient choice of the whole building system. Thesis focuses on the effect of changes in building envelope properties.

In Turkey, topic of green buildings has recently started to be studied. Therefore, this thesis aims to present efficient technologies providing energy savings in buildings, to present green building concept and alternative energy simulation software.

In the context of this study, design, methods and material guidelines are introduced to reduce energy needs of buildings and to bring in the green building design concept. Building and system parameters to enhance building energy efficiency and energy savings together with green building principles are summarized. Moreover, whole building energy analysis methods and simulation steps are explained; year-round simulation is performed for a sample building; as a result, energy savings about 36% is achieved.

Keywords: Energy Saving, Energy Efficiency, Green Buildings, Zero Energy Buildings, Energy Plus, Open Studio, Whole Building Design

ÖZ

ENERJİ TASARRUFLU BİNALARIN ENERGY PLUS YAZILIMI KULLANILARAK TASARLANMASI VE ANALİZ EDİLMESİ

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Elektrik enerjisi ve doğal gazın başlıca tüketicisi olan binalar, toplam elektrik enerjisinin yüzde 70'inden ve toplam doğal gazın yüzde 30'undan fazlasını tüketmektedir. Enerji tüketimini ve karbondioksit emisyonunu azaltarak yeşil binalar ve sıfır enerji tüketen binalara erişmek için yapılan araştırma ve geliştirme faaliyetleri sayesinde, enerji tüketimi azaltılarak, enerji harcamaları önemli ölçüde düşürülebilir. Ayrıca bu sayede termal konfor düzeyi de bir hayli artırılabilecektir.

Yeşil, enerji verimli binalara ulaşmak için önemli adımlar; bütün bina tasarımı, çevre mahal tasarımı, bina dış yüzey tasarımı, aydınlatma ve gün ışığı tasarımları ve ısıtma soğutma havalandırma sistem tasarımları şeklinde özetlenebilir. Bu analizlerin ve simülasyonların yapılması için kullanılabilecek Energy Plus yazılımı sayesinde yukarıda bahsi geçen konularda, var olan ve henüz inşa edilmemiş binalar için performans ve verim değerlendirmeleri, en etkin ve uygun sistem, bina tasarımları yapılması mümkün olmakla beraber, tez çalışmalarında bina kabuk özellikleri üzerinde durulmuştur.

Türkiye'de yeşil bina konusu henüz yeni çalışılmaya başlanmıştır. Bu nedenle, binalarda enerji tasarrufu sağlayacak verimli metotların, yeşil bina konseptinin ve alternatif enerji simülasyonu yazılımının tanıtılması tezin önemli hedefleri arasındadır.

Tez kapsamında, bina enerji ihtiyaçlarının azaltılması, enerji tasarruflu yeşil binaların tasarlanabilmesi için tasarım, yöntem ve malzeme önerileri sunulmuştur. Enerji verimliliğini ve tasarrufu artıran bina ve sistem parametreleri ile yeşil bina ilkeleri özetlenmiştir. Energy Plus yazılımı ile sağlanabilecek bütün bina enerji analizleri metotları, simülasyon adımları açıklanmıştır. Seçilen örnek binanın yıllık bazda enerji simülasyonu yapılmış, yeni bina tasarımlarında yaklaşık %36 enerji tasarrufu sağlanmıştır.

Anahtar kelimeler: Enerji Tasarrufu, Enerji Verimliliği, Yeşil Binalar, Sıfır Enerji Tüketen Binalar, Energy Plus, Open Studio, Bütün Bina Tasarımı

To my family…

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LIST OF ABBREVIATIONS

A/C	Air Conditioning
ACH	Air Changes per Hour
AHU	Air Handling Unit
ASHRAE	American Society of Heating Refrigerating & Air Conditioning Engineers
BC	Boundary Condition
BREEAM	Building Research Establishment Environmental Assessment Method
CASBEE	Comprehensive Assessment System for Building Environmental Efficiency
DB	Dry – Bulb
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen eV (German Sustainable Building Council)
EC	Evaporative Cooler
EIFS	Exterior Insulation Finish Systems
EP	Energy Plus
EPA	U.S. Environmental Protection Agency
EPS	Expanded Polystyrene
ER	Electrical Resistance
GHG	Green House Gases
GMT	Greenwich Mean Time
GSHP	Ground Source Heat Pump
HEX	Heat Exchanger
HID	High Intensity Discharge
HOE	Holographic Optical Elements
HP	Heat Pump
HVAC	Heating Ventilating Air Conditioning
IAQ	Indoor Air Quality

IEQ	Indoor Environmental Quality
LASRS	Lightweight Aluminum Standing Steam Roofing System
LEED	Leadership in Energy & Environment Design
Low – e	Low Emissivity
LWC	Light Weight Concrete
NC	Noise Criteria
PCM	Phase Change Material
PV	Photovoltaic
RC	Room Criteria
R – Value	Thermal Resistance
SGHC	Solar Gain Heat Coefficient
SPD	Suspended Particle Devices
TSE	Türk Standartları Enstitüsü (Turkish Standards Institute)
USDOE	U.S. Department of Energy
USGBC	U.S. Green Building Council
UV	Ultraviolet
U – Value	Overall Heat Transfer Coefficient
VAV	Variable Air Volume
WB	Wet – Bulb
WGBC	World Green Building Council
WSHP	Water Source Heat Pump
XPS	Extruded Polystyrene

LIST OF SYMBOLS

Definition	Symbol	Unit
Overall Heat Transfer Coefficient	U	W/m^2K
Monthly Heating Energy Need	$Q_{\iota,month}$	J
Yearly Heating Energy Need	$Q_{\iota,year}$	J
Building Specific Heat Loss	H	W/K
Monthly Average Outside Temperature	θ_e	°C
Monthly Average Inside Temperature	θ_i	°C
Internal Gains	φ_ι	W
Solar Gains	φ_g	W
Heat Gain Usage Factor	H	-
Building Usage Area	A_n	m^2
Building Gross Volume	V_{gross}	m^3
Building Heat Losing Surface Area Total	A_{total}	m^2
Atotal/Vgross	A_{total}/V_{gross}	m^{-1}
Thickness	d	m
Thermal Conductivity	k	W/mK
Outside Convective Coefficient	α_d	W/m^2K
Inside Convective Coefficient	α_i	W/m^2K
Overall Heat Transfer Coefficient, Ceiling	U_c	W/m^2K

Overall Heat Transfer Coefficient, Roof	U_r	W/m^2K
Overall Heat Transfer Coefficient, Floor	U_f	W/m^2K
Overall Heat Transfer Coefficient, Outside Walls	U_{ow}	W/m^2K
Solar Intensity	I	W/m^2
Building Environment Property	$r_{i,month}$	-
Glazing Property	$g_{i,month}$	-
Outside Wall Area	A_{ow}	m^2
Window Area	A_{win}	m^2
Roof – Ceiling Area	A_{r-c}	m^2
Floor Area	A_f	m^2
Average Air Flow Rate (Fans)	V_f	m^3/h
Exit Air Flow Rate	V_E	m^3/h
Fresh Air Flow Rate	V_S	m^3/h
Infiltration Air Flow Rate	V_x	m^3/h
Air Flow Rate (Ventilation Closed)	V'	m^3/h
Specific Heat of Air	c	J/kgK
Ventilation and Infiltration	H_v	-
Air Change Per Hour (with 50 Pa pressure difference)	N_{50}	-

CHAPTER 1

INTRODUCTION

The aim of this preliminary chapter is to introduce the need of designing and analyzing energy saving buildings while presenting the objectives of the study and methodology applied.

1.1. Definition

Sheltering is the very basic need of human beings since first ages. People built houses to be protected from rain, harsh climatic conditions, and wild animals. In addition to the fundamental requirements, modern world buildings are expected to provide total indoor environmental satisfaction with acceptable levels of energy use.

Compared to any industry or enterprise, buildings' consumption of energy; the use of natural sources and production of CO_2 (carbondioxide) causing pollution are considerably more [1]. US Department of Energy reports that, the buildings are responsible about 50% of all energy consumption and 30% on average of GHG emissions annually [2]. Chairman of Building Technologies Program adds: "73% of electricity and 34% of natural gas are consumed by the buildings, totaling energy bills about 418$ billion" [3]. Similarly, in Europe, 40% of final energy usage and 36% of CO_2 emissions are caused by buildings remarks Mlecnik [4].

Since buildings are and will be used for all times, the need of reducing the energy consumed by the buildings becomes very important. Not only will the actions provide energy savings; but also they would diminish CO_2 emissions and provide better indoor environments for humans.

Design of the building greatly affects the total energy use. Since the direct impact is present during buildings' lifetime, both efficient building systems and its management and building characteristics are important for proper design [1].

The interface between interior and exterior environments is defined as the envelope of the building. A great portion of buildings' energy is used to correspond with heat losses (or gains) through building envelope. Achieving the necessary insulation values are critical to satisfy proper internal temperatures for thermal comfort in the building. In addition, water heating, lighting and other building processes consume energy. Besides, buildings' interactions with each other and surroundings; also HVAC system parameters and efficiencies affect the total energy use. Mlecnik, et al. presents low energy building labels all over the world as: Certified Passive Houses, LEED Buildings, Green Buildings and Sustainable Buildings [4]. Similarly, Nayar, J. presents another definition; Net Zero Energy building, such that, energy efficient construction and appliances are combined with available commercial renewable energy systems. Producing energy for water heating with solar electricity for example, the idea is to set the computation result for a building energy use and production to zero [5].

According to American Society of Heating Refrigerating & Air Conditioning Engineers (ASHRAE), a zero energy building has to have zero net energy consumption and annual carbon emissions. Therefore, buildings should use minimum natural sources with high efficiency, minimize the emissions of GHG and air quality related gases, minimize the waste and create a "green" environment while considering indoor environmental quality requirements (thermal quality, air quality, lighting quality etc.) [6].

Considering all parameters that results in heat gains and losses, energy consuming processes, quality requirements, interactions and system management affecting the design; studies presented in this thesis are defined as whole building design.

1.2. Objectives

The objectives of thesis study is to reduce the energy needs of a buildings and therefore create energy saving buildings, explaining building design parameters, green considerations and give guidelines; also present an alternative energy calculation tool via analysis and simulation.

The first objective is to create energy saving buildings by lowering the amount of energy needed, with better insulation, materials and components in compliance with green methods and higher HEX and HVAC efficiencies [7].

Secondly, design parameters that should be considered during a building design are explained throughout the thesis. These are envelope properties, building properties that affect the total energy need, indoor environmental quality considerations, green parameters and efficient HVAC system solutions.

Although energy savings focuses mainly on building envelope isolation, buildings embodied energy reduction should be considered as a green parameter. Yet, previous experience from literature will help for choosing green materials which are used for the attenuation of both embodied and operational energy need.

The last objective is to settle an understanding that energy simulations would show the daily behavior of building, total energy consumption at the very beginning of the project. American green rating system (LEED) require these calculations to be presented before the building project is signed. Therefore, the energy simulations becomes the most important part of a building project.

Architects, engineers and designers are guided and encouraged to create energy saving green buildings, use and develop green parameters and sustainable methods, creating applicable practices via simulations and satisfy both engineering and non-engineering needs [6].

1.3. Motivation

With the increasing energy demands of buildings energy savings become a major study topic in building design. The largest portion of energy is used to maintain the internal temperatures of buildings by means of heating and cooling; therefore the easiest way to reduce the need of this energy is minimizing energy losses and using energy more efficiently. It is stated that energy efficiency is the cheapest, cleanest, fastest energy source [2]. Beereport stated that building codes should be planned such that high insulation and air tightness levels, also passive strategies are to be applied which minimize the losses and provides efficient energy use [4].

In Turkey, a major portion of energy is imported. With the application of efficient thermal isolation, the resulting effect not only will be the energy reductions, but also dependence on import energy will be diminished while consequently providing a better welfare to the nation [8].

A simple green design touch such as changing the orientation of a building to make it more efficient or provide more natural lighting and natural clean air to a space, making a better outdoor environment by putting a garden on a roof and doubling outside gardens on the site, is considered as a responsible design.

Planting low maintenance plants, heating from the floor surface rather than air volume heating of a space or painting sealants that are not harmful to the environment can also mean a lot for a building. The use of such very simple design methods can bring value to a poorly designed building. Not obliged to be more costly than a poor design, the great design is the one that does respond appropriately to the environment [5].

Green and Sustainability concept motivates in order to bring in healthy buildings with limited resources, less energy usage, and pollution with new technologies and science [9, 10].

Another motivation of this thesis study is to emphasize the methods for building design. Although it is not very common even the implementation of Turkish Standard TS 825 (Insulation Rules for Buildings) in Turkey, the proposed methods of software used are very practical and provides very detailed results. The application of green methods creates a willing for designers to include these efforts into their building parameters.

Finally, in addition to other green methods, energy producing elements such as solar collectors can be used for environment and hot water heating. With the help of more efficient HVAC system technologies, net zero energy buildings can be reached at the end of the design. Mlecnik et al. also explains the aim of European Commission as reaching net zero energy buildings, and diminishing CO_2 emissions and primary energy consumption to very low or zero [4].

1.4. Methodology

Zheng defines buildings as “energy gluttons”. He remarks that energy consumption of buildings will reduce significantly by improving building envelope and adds that the development of advanced building envelope systems would reduce the energy losses is a critical research frontier [11].

Case studies show the importance of building envelope design and material choice of envelope components. For example, a poor insulated wall, floor or roof can be held responsible of 40% of the total heat loss. Similarly, inappropriate windows and doors result in 30%; also draft and other undesired air movements accounts for 25% of total heat loss [11]. Therefore, improvements of building envelopes should be brought to top priority.

Insulation attempts to keep thermal energy where it is wanted. Here the definition of overall heat transfer coefficient appears. Overall heat transfer coefficient, also known as U – value, is a measure of the flow of heat by means of conduction, convection, and radiation through a material. Thus, lowering the U – value means the insulation is better, consequently, the material transfers heat more slowly in and out of the building [12]. The methodology that is applied shall be lowering the U – value of building envelope materials, and the building itself as a result.

High energy consumptions of the building and the need of its reduction bring the attention to the calculations of U – value of the envelope, analysis of the building with all aspects.

As it is discussed, the most important design parameters are found at the building envelope elements, that consisting floor, walls, roof and glazing. While doing the whole building analysis, size and shape of building, orientation and relations to its environment should also be taken into account, including HVAC design results from the calculations of solar gains, internal loads from occupancy, lighting and equipment, with properly chosen fresh air requirements and design temperatures.

Three key steps; reducing the loads, applying systems with highest efficiencies and combining elements should be considered by designers. Lowering solar loads, lighting loads, providing daylight, and optimizing the building would reduce total load of a building. High efficiencies are aimed for energy, site, design elements and materials, thermal and air qualities as a rule of thumb. Parameters that will affect the overall building thermal definition and that can be analyzed create the synergy.

Other subjects that a designer should keep in mind during analysis are: scale of the building, environments and geographical constaints, green guidelines, regulations etc. [13]

The case study is done for a new office building with new building envelope materials. Building is assumed to be built similar to its present or existing version on the same location. First step will be analyzing the existing building with its existing properties, using the weather data provided by USDOE for Ankara, by using the software Open Studio and Energy Plus solver with the help of auxiliary programs or add-ins.

After the existing building analyses are completed, improvements for the new building will be done on the envelope and design parameters. Called the improved design (or re – design), size and shape of the building shall be kept as it is in general terms. Also considering internal IEQ concerns and green applications, total energy savings will be calculated and compared with the existing building. Additionally, the results would show daily internal temperature variations on an hourly basis which shows a better picture of lifetime temperature profile. Details are presented in the analysis chapter.

TS 825 analysis will also be performed and the capabilities and advantages of Energy Plus simulations shall be presented and compared with TS 825.

Lastly, building parameters, design considerations, green methods and green parameters will be given as guidelines. Building envelope structures, effects of green materials, indoor environmental quality considerations, green methods and applications and HVAC system suggestions will be summarized.

CHAPTER 2

DEFINITION OF WHOLE BUILDING DESIGN AND ITS COMPONENTS

This chapter introduces the definition of "Whole Building Design", explains its components in detail and their effects to the designed building. Characteristics and design properties of materials are also been presented.

2.1. Whole Building Design

Whole building design is defined as an understanding of considering all aspects of building design together to reach a high efficiency, energy-saving and green building.

Energy performance of a building is affected by the following factors: Place of the building, building form, and heat transfer characteristics (U – value or R – value) of walls, roofs, windows, floors and interior spaces, sunlight penetrating inside that influence heating or cooling load, IEQ parameters, HVAC system parameters and also sustainable material selection and other green methods [14, 15].

2.2. Site Design

Being the first component of whole building design, building site should be considered as a design parameter. Here, these parameters are the location of the building, relationship with its environment: nature, other buildings and neighborhood; orientation with respect to north and wind directions; coupled with envelope properties, general sizing and shape of building.

2.2.1. Location of a Building and Relationship with Environment

During the design, location of a building should be taken into account from different points of view. Being very important to minimize the negative effects both for the building itself and the environment, good site and location selection would lower initial, operational, maintenance and environmental costs [6].

First one is its position on the world. Geographic properties, latitude, longitude and height above sea level defines the building's position on earth; consequently, defines its climatic properties, annual solar angles, location with respect to global wind and stream routes, lakes, rivers or mountains that affects the local climate. This environment would also have a better influence on human health.

Buildings' global coordinates and elevation shall be defined in the analysis as a parameter.

On the other hand, a building's location regarding its closeness to construction materails should also be considered to fulfill a green design.

An urban project is definitely affected by city plan, other buildings and underwork. Simplest example may be shading and reflection effects of neighboring structures. These effects are considered by adding predefined constants to the equations of simulation. From a green point of view, land selection should be made considering distance to main roads, junctions and connections, water and sewage lines, even alternative public and private transportation options [16].

Being mostly valid for suburban areas, vicinity of wildlife, closeness to prime farmlands etc. becomes important while making a green design. While preparing building site, impact to natural environment, habitat, flora and land, should be kept at minimum level possible. Besides, not forcing the nature to change would result in the preservation of soil, water and air as clean as it is, which therefore have a positive effect on human health overall, wildlife and habitat.

Presence of flora and trees assist a designer to satisfy building heating and cooling requirements by helping to heat or cool the environment which is considered as a passive technique. Using native (local) plants give better results. Inspection of building site is important in order to determine possible hazardous or waste produced in the area [5]. According to these explanations, location of a building becomes a major point while defining a building as "green".

2.2.2. Size and Shape of Building

Size is the primary attribute of a building that predefines an order of magnitude for energy consumption, total gains or losses and HVAC systems used. Generally, surface areas and volume of the building are considered as major calculation parameters used with the ratio of surface area to volume which defines the useful floor area; nevertheless, floor to ceiling height, wall to window ratio or other special dimensional or non – dimensional criteria are presented in order to define size properties of a building.

Likewise, shape of a building becomes critical for building design. Shape defines angles of any surface on the envelope, which affects solar angles used in heat gain calculations, heat transfer surfaces with respect to prevailing wind directions, even application methodology for green roofs. Overhangs for blocking sunshine that is prescribing shading coefficient and also internal design and aesthetics are valued while defining the shape of the building.

Similarly, ASHRAE guides green designers to consider the importance of building form that affects energy efficiency, functionality, occupant comfort and performance. Mostly, building structure changes natural lighting properties that would change thermal and environmental comfort inside, as well as total energy consumption.

2.2.3. Orientation of Building

Orientation of a building is a parameter showing its direction with respect to north. As a main parameter for design, it affects solar gains, total heating or cooling load of building, natural light presence in spaces and its influence on occupancy.

Raised from the east, sun is heating east façade of a building during morning, even some rays may hit north oriented surfaces in early morning during summer times depending on building's latitude. Passing from south, sun goes down from the west, which results in high solar gains on south facing surfaces caused by long exposure time. In contrast to morning behavior, west surfaces gather evening sun, and similarly, close to sunset, north façade might see the sun on summer time.

Especially for highly glazed façades, avoiding solar penetration from east and west would help creating more energy efficient buildings; since east and west façades are exposed to low angle high intensity morning and evening sun that easily penetrates into the building. Besides, prevailing wind directions become very critical for total energy efficiency and natural ventilation considerations [17].

Simply shown, solar gains differ with the orientation. This input leads the designers determine total wall and window areas, reconsider envelope properties or internal room distribution such that a more efficient building is created. These parameters change the heating and cooling loads and thermal calculations.

On the other hand, for satisfaction of indoor environmental quality, natural light should be present in a space. A responsive touch of orienting a building may effectively provide daylight, better air distribution or ventilation in a space and change outdoor views of any space [15, 17].

An example design for a residential building may be placing living or dining rooms away from traffic noise and have windows facing south-east.

2.3. Building Envelope Design

Building envelope is the portion of building that separates the exterior environment (weather) from the interior with exterior walls, roof and floor. Mainly, building envelope has the functions of providing security, thermal and indoor environmental quality control. Additionally, it provides daylight, views to outside and aesthetics [18]. Building envelope components are heat transfer surfaces from hot inside from colder outside or vice versa which appears as the major portion of heating or cooling load of a building. That is, properties of the envelope dictate the loads, HVAC design, IEQ and life of the building [19].

Being the key factor of green design, primary function of the building envelope is keeping the weather out and letting the good aspects in. Construction material choice and technique dictate the life of a building, IAQ, HVAC system sizing, structural design and maintenance etc [15, 20].

The heat exchange is always present if indoor (or conditioned space) desired temperature and thermal comfort level are different than the outdoor (or unconditioned space) conditions. Therefore, there is a need of consuming energy to satisfy the requirement. The level of energy consumed through building envelope should be emphasized and design should be made by considering increase in energy efficiency and reductions in energy use.

From green design point of view, building envelope characteristics are very essential to be understood. A green envelope should be tight, energy efficient with the help of properly insulated walls, roof and floor, high efficiency windows, effective vapor and ventilation control [16].

Insulation of building envelope is very important that poorly insulated walls, roofs or foundations, draft, low quality doors and windows can result in 40%, 25%, and 30% in the total heat loss, respectively [21]. Nayar also states that, undesired air leakage from improper vents and openings for wiring or plumbing may cause a building to lose up to 30% of its energy [5].

On the other hand, a poor construction or design may result in energy inefficiencies. Misplaced shading structures, walls that are not tight or undesired heat transfer from thermal bridges bring additional thermal load to the building. Another example may be improperly chosen exhaust fans or ventilation ways that may cause moisture problems or insufficient clean air [17, 22].

Energy improvements applied via building envelope are categorized as passive techniques. Change of code standard of U – values for wall, roof, floor and window improvement applied in UK is tabulated below [23].

Table 2.1 Standard U Values for Envelope Components in UK

Envelope Element	**1995 Standard U – values [W/m²K]**	**2000 Standard U – values [W/m²K]**	**Percentage reduction in U – value [%]**
Walls	0.45	0.35	33
Roofs	0.25	0.16	36
Floors	0.45	0.25	44
Windows	3.3	2.2	33

A similar standard can also be seen in Turkish Standard Code (TS 825) for envelope components, walls, roofs, floors and windows, regarding the site zone Zone details are given in Appendix H as presented in TS 825 App. D [24].

Table 2.2 Standard U Values for Envelope Components in TS 825

Envelope Element/ Zone	Walls [W/m²K]	Roofs [W/m²K]	Floors [W/m²K]	Windows [W/m²K]
Zone 1	0.70	0.45	0.70	2.4
Zone 2	0.60	0.40	0.60	2.4
Zone 3	0.50	0.30	0.45	2.4
Zone 4	0.40	0.25	0.40	2.4

Also, strategies on thermal insulation, thermal mass, external shading etc. can be exampled as passive envelope techniques, such as including additional EPS in walls for thermal insulation, white painting external walls, reflective coated glass window glazing, overhangs and wing walls [25].

These representations explain why building envelope design and material choice are very important for a green design. Properties of roofs, walls, floors, windows and doors; insulation techniques and requirements, also their contribution to thermal and moisture control are explained in detail in the following sections.

2.3.1. Roofs

Roofs are an important component of building envelope which should be considered very carefully by a designer. Being highly affected from solar radiation and climatic effects, the influence of roofs to IEQ is critical. For buildings with large roof area, heat gains or cooling loads from roofs becomes the major element of the equation [26]. Importance of roof U – values defined by UK are presented in the Table 2.3.

Table 2.3 Roof U Values Limits

Year	U – Value [W/m^{2}K]
Before 1965	–
1965	1.42
1976	0.6
1985	0.35

Currently, 0.25 W/m^{2}K or less is required for new constructions in the UK. Decreasing trend of U – value on the table shows the importance of roofs thermal performance.

Many techniques can be applied to reduce solar gains brought to the building via roofing. These methods can be modifications of buildings' size and shape, or changing internal design, or providing mechanical / natural ventilation, changing reflective properties or insulation level on the roof.

Depending on climatic conditions and buildings' needs, types of roofs are defined below.

2.3.1.1. ***Masonry Roofs***

Preferred by South Asian and Middle Eastern climates, masonry roofs complete a masonry building. Although, masonry roofs have advantages, during tropical summers, this type's characteristics show unfavorable thermal behavior, decreasing thermal comfort and also increase in energy consumption and cost.

While masonry roof temperature rise about to 65°C, it makes indoor temperatures jump to 40°C; besides, that heating effect can last during the night because of the heat capacity of the masonry construction. This major problem can be lessened with the help of roof shading, roof coatings or co – operation of methods. It is resulted that an insulated coating system with anti – solar coating applied on a masonry roof can result on a reduction of heat gain during summer by 45 kWh/day for 208 m^2 roof area. Moreover, overall heat transfer coefficient of 3.3 W/m^2K is reduced to 0.54 W/m^2K [27].

Figure 2.1 Masonry Roof

2.3.1.2. Lightweight roofs

An economic roofing method is called Lightweight Aluminum Standing Steam Roofing System (LASRS). Lightweight roofs may have poor thermal characteristics; however, improvements can be made very easily such as adding thermal insulation or using a higher reflective light color. Han J, Lu et al states that light colors such as white, off – white, brown and green can provide reduction on thermal loads by 9.3%, 8.8%, 2.5% and 1.3% compared to black painted surface [28]. Same study results that glass fiber insulation can also be used, yet for hot and humid climates, this method is not very suitable due to interstitial condensation. On the other hand, polystyrene, polyurethane or similar thermal insulations with light colored rooftop can avoid about 50% of thermal load compared to glass wool insulation with dark outer surface. As a result, for lightweight roofs, materials with low thermal conductivity and thermal diffusivity and high reflectance provide best results [28].

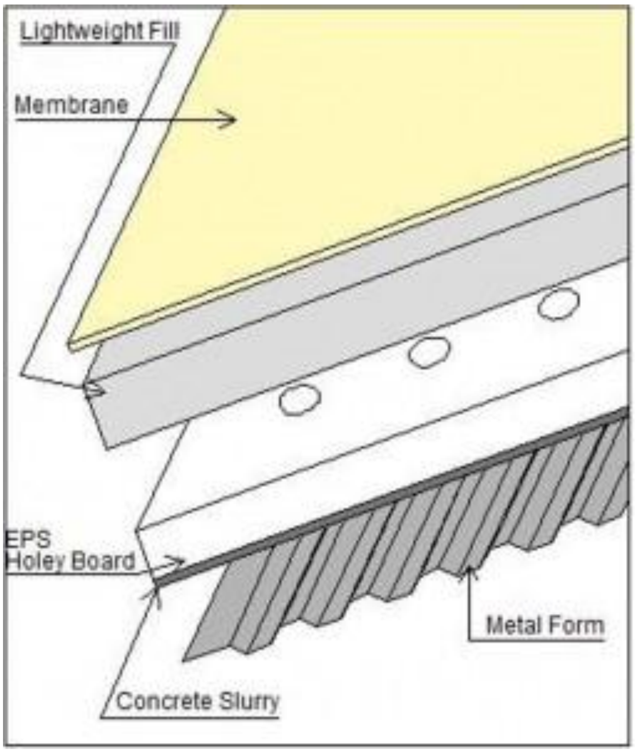

Figure 2.2 Lightweight Roof Section

2.3.1.3. Ventilated Roofs

Ventilated roof is an air path in between two slabs, which reduces the heat flow from roof to the building. Either active (forced) or passive (natural) ventilation systems are useful for hot climates and buildings having a moderate height and wide roof area. Energy savings up to 30% can be achieved for a hot summer day compared to non – ventilated roofs.

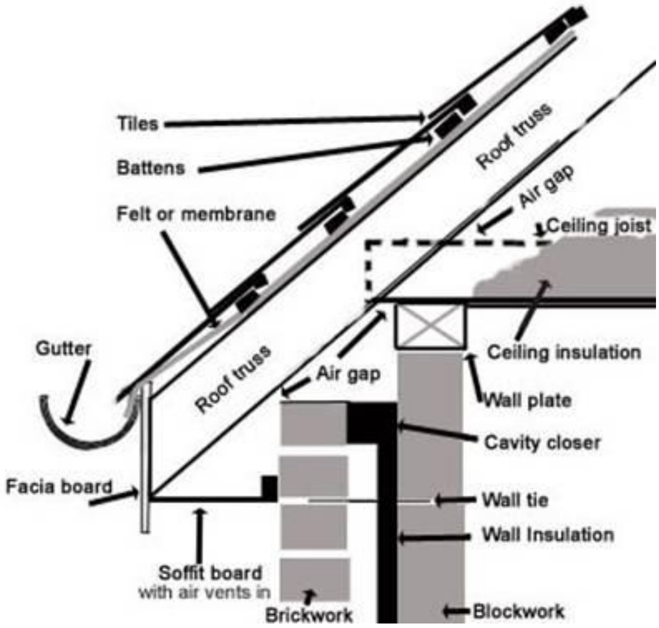

Figure 2.3 Ventilated Roof Section

2.3.1.4. Vaulted Roofs

Another method to satisfy thermal needs is changing roofs' shape. Being popular in hot climates, rim angles greater than 50° can provide quite good results for indoor thermal conditions. Solar rays are reflected from the VR, not more than flat roofs; however, dissipation of more heat through convection and re – radiation during night, make this option available for hot desert environments, but not for humid climates; since vaulted roofs are effective to reflect solar rays, however, can not reject latent heat brought with humid outdoor air.

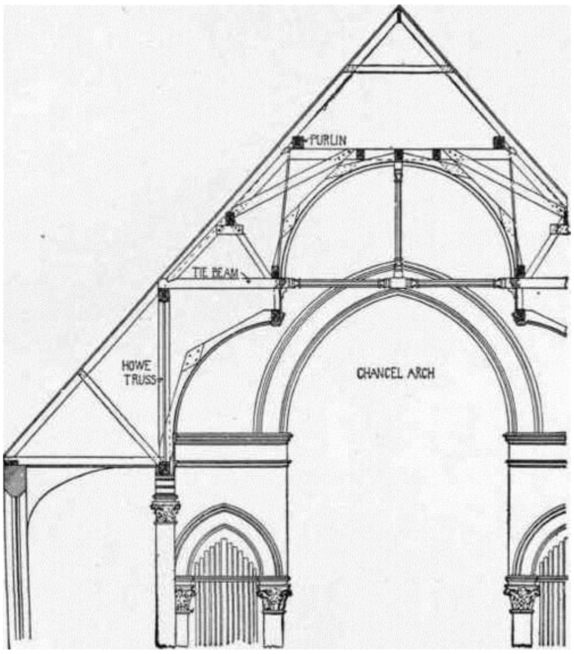

Figure 2.4 Vaulted Roof/Ceiling

2.3.1.5. ***Solar – Reflective / Cool Roofs***

This type of roofing application is based on high solar reflectance and high infrared emittance (cooling effect) properties. Here, definition of solar reflectance (SR, reflectivity or albedo [29]) appears for understanding of thermal performance of a roof. Conventional roofing materials would have a SR value of 0.05 to 0.25; whereas reflective coating have SR higher than 0.60 such that more reflectance provide a better thermal environment for roof. Solar reflectance and emittance properties of roof materials can be found on Appendix D. With high reflectance values, it is concluded that daily roof surface peak temperatures can be lowered by

33 K – 42 K. Therefore, savings of 5% to 40% for cooling loads and 5% to 10% for peak demand can be accomplished [27, 30].

*2.3.1.6. **Cool Roofs***

The technology of cool roofs is developed to reduce the amount of energy absorbed by a roof surface. New coating materials allow for the selective absorption and reflection of various spectral wavelengths. Different visual coloring enhances buildings' character still reflecting a high portion of total incident solar energy. Cool roofs reduce the cooling load on the buildings' HVAC system and significantly increase the life of roofing; also decreasing urban heat island effect by reflecting some of solar incident back to space.

Conventional roofs absorbs 40 to 70% of incident solar (heats up roof adding to cooling load and urban heat island effect) and reflecting 30 to 60% of incident solar.Cool roofs absorb only about 20% and reflect ~80% of solar incident [6].

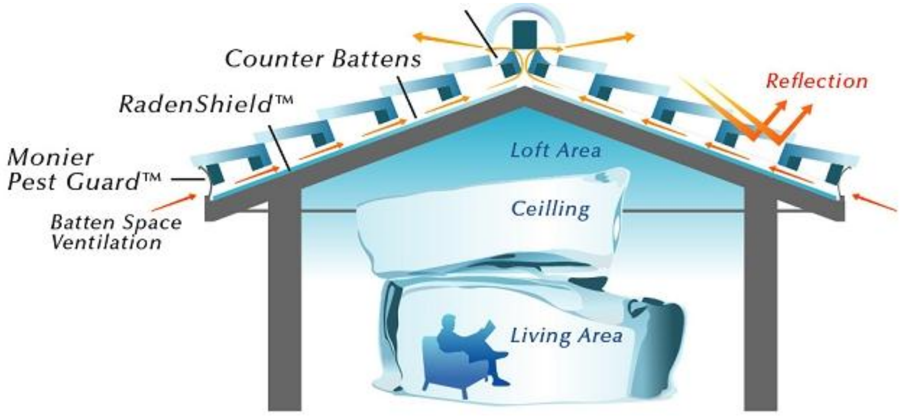

Figure 2.5 Cool Roofs

Nowadays, green roofs are commonly used passive method by designers around the world. Details are given in Chapter 4.

Sloped roofs with overhangs are preferred to flat or low – sloped roofs for residential buildings. The advantages of sloped roofs are quick shedding of water, overhangs at proper sizes provide shading for summer and permit sun penetrate inside in winter. Besides, walls and foundations are protected from water damage. For commercial buildings flat roofs are most preferred, without major shadings. Green roofs are easier to be applied to a flat roof, both with clinging to soil and water storage capacity.

2.3.1.7. ***Garden and Terrace Roofs***

Another roofing option can be applied is placing garden and terrace to rooftop. Also called as roof gardens, vegetation and terrace placings provide temperature control, captures rainwater, reduces noise, and also opens additional spaces and adds value to the building. Vegetation presence reduces solar gains affecting into the building, also creates a natural habitat that increase oxygen concentration locally. Additionally, roof gardens create additional comfortable places especially for urban environments.

2.3.1.8. ***Roofing Materials***

Different roofing materials are available regarding the building’s location and requirements. Most used ones are asphalt, metal, tile and wood.

Asphalt shingles requires fiberglass or a composition of organic felt is used as a base material. Sun and rain penetrations to asphalt shingles are very often that they should be avoided.

Metal roofing may be applied considering high reflectivity and emissivity of metals. Reflection creates a cooling effect, results in a drop of 20% to the cooling load, also helping to cool urban heat islands. Materials can be recycled from used; also roofing metals can be recycled. [30]

The application is more suitable for flat or low – sloped roofs, mostly preferred for forested and rainy areas. Although the initial cost of materials (steel, aluminum or copper) is high, with their durability, lightweight, property of being maintenance free, and reducing energy, operational costs are reducing.

Another option especially for commercial buildings with flat roofing is using clay and concrete tiles. Made from ceramic or cement concrete, they can last longer times withstanding harsh environmental conditions. From a thermal point of view, colors determine solar reflectance; they can diminish a big portion of solar radiation. These materials are energy efficient and also fire resistant, yet, they are not harmed by insects. In addition, enhancing air circulation above and below tiles makes this option a better green product. However, maintenance period and cost of this type are higher [5, 28].

As a green product, using wood for areas with low fire danger and low to moderate humidity levels can be very effective. Solar radiation absorbed by the material can easily be discharged with the help of air circulation around.

2.3.2. Walls

Generally, walls contribute the highest portion of the building envelope, providing thermal and acoustic comfort. As wall areas increase, in other words, ratio between wall and total envelope is high, and including thermal resistance value of walls, total heat transfer from walls becomes very crucial for building energy consumption. [30]

Condensation problem on wall surfaces may more possibly occur if the relative humidity of air is higher than 80 percent; which causes more important problem during cold months, for colder climates with more humidity [31].

To improve the energy efficiency and comfort levels in buildings, there are advanced wall and building design technologies. Following items describe such advanced wall technologies.

2.3.2.1. ***Passive Solar Walls***

Passive solar walls trap and transmit solar energy back into building very efficiently. Being generally appropriate to be used in cold climates, typically a 305 mm thick concrete wall is used as a south façade to absorb solar radiation. Also a glazing is present to be used as an outer cover providing greenhouse effect.

Later on, Trombe et al., improved Trombe wall system designed for colder climatic environments. This walls system has a steel panel backed with polystyrene insulation mounted on the south façade which has improved the operating efficiency by 56% [32].

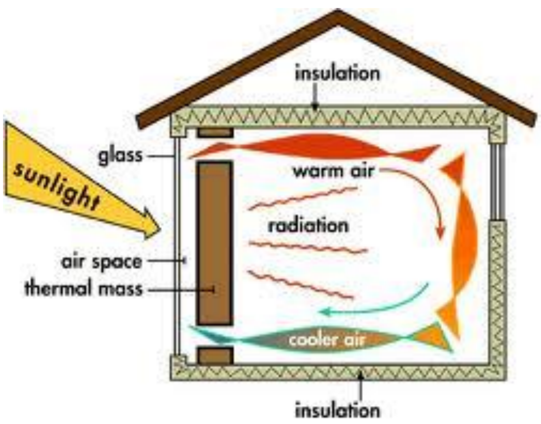

Figure 2.6 Trombe Wall Principle

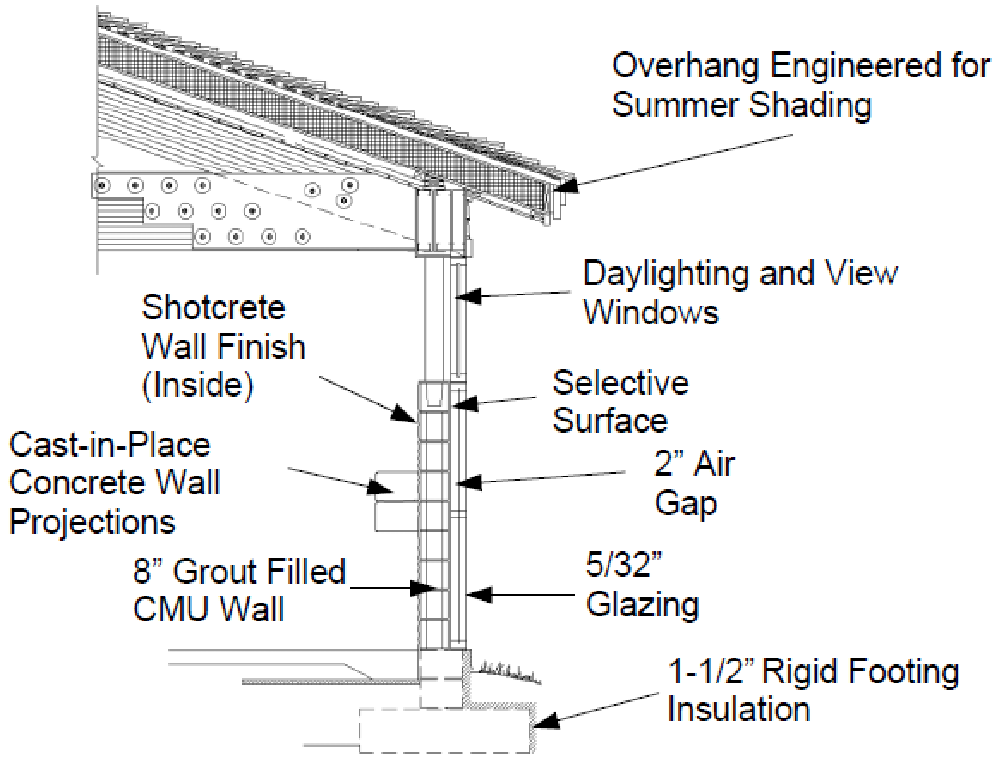

Figure 2.7 A Trombe Wall Example

Other types of passive walls are unventilated solar wall, insulated Trombe wall, and composite solar wall. For a region with shorter heating season, composite or insulated Trombe wall may be preferred in order to avoid overheating during cooling season; alternatively, solar shields can be employed. Jie et al. proposed the integration of photovoltaic units. Fixing PV panels on the back of glass cover of a standard Trombe wall, heat rejected by PV cells and absorbed by thermal mass of wall are used for space heating [33].

Phase change materials or fluidized Trombe wall systems are also present, which are thinner and have better efficiencies than concrete walls.

Panes composed from transparent and semitransparent materials enclosing water in between create the Transwall. Semitransparent glass pane and water partially absorb solar incident, and the remaining radiation is transmitted to indoors, causing both illumination and heating required.

2.3.2.2. ***Concrete Wall***

Concrete is the second mostly used material considering its versatility, strength, price and esthetic properties. Concrete is a correct sustainable material considering its production energy which is about 7 MJ/kg (Aluminum: 170 MJ/kg, Plastics: 70-80 MJ/kg). From a green point of view, higher production energy means higher embodied energy.

Concrete products with a density less than 2000 kg/m^3 are defined as LWC. For thermal insulation purposes, density can go low to 1450 kg/m^3, while for structural purposes, density range is 1600 to 2000 kg/m^3. Adding aggregates such as natural materials, polystyrene or aluminum powder, would result in improvements on thermal resistance of the wall.

Introduction of aluminum powder generates air bubbles inside, creating more thermal resistance. Additionally, density range is between 600 to 800 kg/m^3 [34].

Concrete walls are very stable and durable therefore chosen as most commonly used wall material. High thermal capacity, especially if additional insulation is applied, concrete walls are preferred in order to increase energy efficiency. Moreover, being produced locally, renewable, and having less toxic gas emissions, concrete becomes an effective choice for green designers [35].

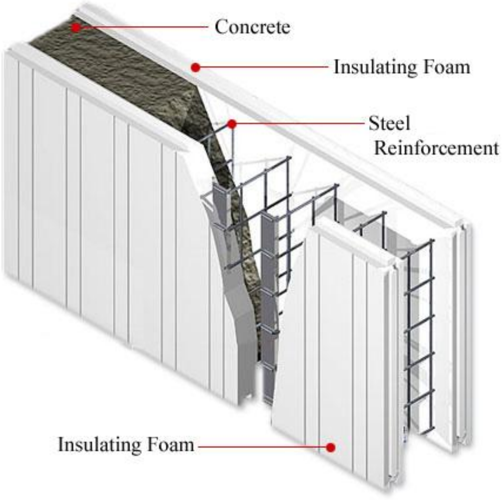

Figure 2.8 Concrete Wall

2.3.2.3. ***Ventilated or Cavity Walls***

Ventilated wall, cavity wall or double skin wall are composed of air gap between two layers of masonry wall braced with metal ties. Basically, two types of ventilated walls differ with type of convection as forced and naturally ventilated. Ventilated walls are used to enhance the passive cooling of buildings. With careful design, energy savings up to 40% can be achieved for summer cooling. On the other hand, improper construction may create thermal bridges [30, 36].

2.3.2.4. ***Walls with Latent Heat Storage***

Thermal storage capacity is enhanced by adding phase change material to a lightweight wall structure. PCM is impregnated commonly in gypsum or concrete walls. Athienitis et al. compared PCM with non-PCM based gypsum board for inside wall lining and concluded that PCM based wall lining lowered the maximum room temperature by 4°C and reduced heating demand during the night [36].

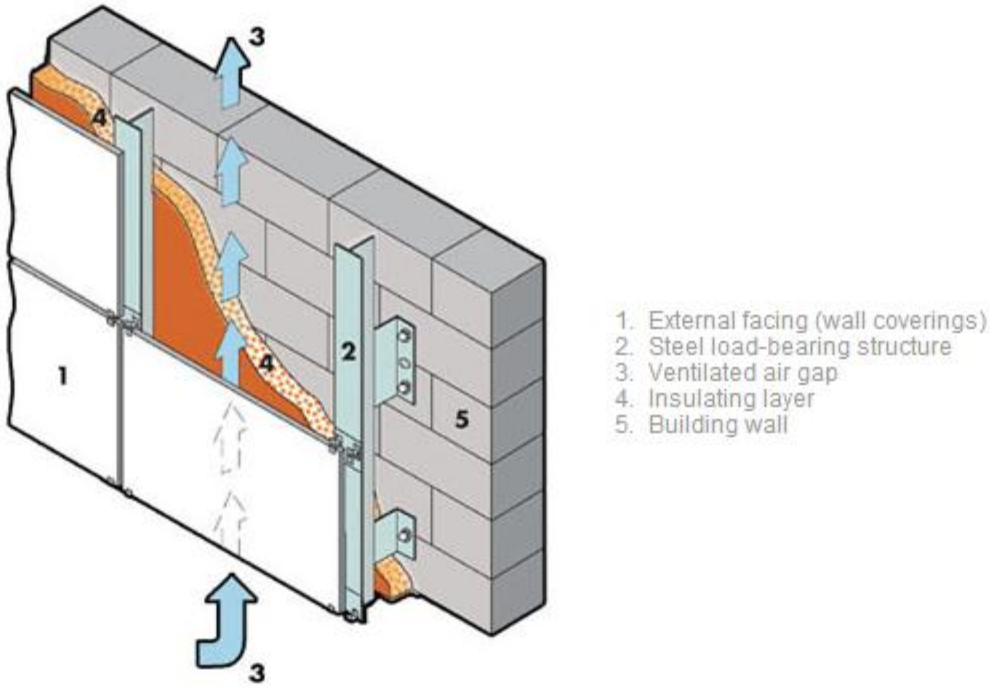

Figure 2.9 Ventilated Wall System

2.3.2.5. ***Siding Materials***

Additional to aformentioned wall types, siding options are available. Siding can be done with brick, wood, metal, plastic, or sand. Depending on climate and other requirements materials differ.

Brick is a sustainable and strong material against most of the outside forces and it has a good quality. Total energy of brick is comparably less and it has high thermal capacity. Additionally, having a long life cycle, brick is an effective green material. However, during application and operation, brick construction may require sealing against water leakage, and repair of deformed brick or cracks [37].

Wood is a construction material produced from nature used since old ages' sheltering need. As a fairly good choice for green buildings, good quality wood can provide perfect siding for years with proper maintenance. In addition to structural use and siding options, it can be used as fenestration frames. Even though reparation, replacement and installation of wood siding are easy, improper installations may cause moisture problems with high humidity absorption. From a global green point of view, wood production has to be continued with tree planting, to ensure sustainability [38].

Metals are thermally more conductive than brick, wood or other composites. Mainly, steel, aluminum, titanium, brass etc. are used for construction industry. Generally, these materials are selected for structural skeleteon. For siding options, aluminum is preferred for being light, anti-corrosive and maintenance-less; however, considering production energy and environmental effects, it is not a good green product [39].

Made as a rugged plastic material from polyvinyl chloride, vinyl may produce serious toxicity problems during manufacture and disposal. Any defects are very hard to repair. Vinyl siding needs to be installed carefully and water penetration to the wall behind should be avoided therefore a protection by a roof overhang may be necessary. For such reasons, vinyl siding is not a good green option.

Composed of sand, lime and cement, stucco is known as a common siding material for dry climates, Mediterranean or similar. Not recommended for wet climates [40].

Another siding system is Exterior Insulation Finish Systems (EIFS). “It involves the application of plasticized cement stucco product over an exterior – mounted polystyrene foam board insulation, usually top coated with an acrylic polymer sealant. It has the benefits of low cost, ease of application and good look. However, moisture can be trapped behind the siding and cause wood rot or other damage. Also, it may require a secondary shield behind, for water penetration. Failure rate of EIFS is high.”

2.3.3. *Floor*

Base of a building is called floors and floors are rather easy to handle from a thermal point of view. That is, either adjacent to the ground or an internal ceiling, floors are not exposed to sun or weather but to a more thermally controlled environment. Consequently, floors' heat load compromise about 10% of the heat loss. Although compared to other building envelope components, this heat portion looks small, cold floors are not desirable considering thermal comfort of the occupancy. Therefore, floors over unheated spaces, contacting ground or exposed to outdoor environment need insulation [41]. Additionally, vertical floor insulation, horizontal foundation wall insulation or slabs should be insulated as well.

Figure 2.10 Floor Insulation

During analysis, ground temperatures for building's location are taken as an input, which does not differ much during whole year.

On the other hand, from a green design point of view, it is important to determine correct floor materials as done for roofs or walls. Employing low-e nontoxic materials becomes important. Mineral wool is commonly used for floor insulation. Also, carpeting is considered as an internal insulation method; however, it has an effect on the indoor air quality if not properly chosen. Although moisture problems do not occur frequently with floors, a vapor barrier placed on the warmer side may be required [41].

Floor covering or finishing materials and methods would help enhancing overall heat transfer coefficients. Flooring options can be summarized as concrete, granite or polyurethane based sytems. In addition, carpeting can be applied.

From a green point point of view, wood is a sustainable finishing material. Also, wood is a good thermal insulator. On the other hand, polyurethane floor covering is applied over concrete surfaces creating high strength, waterproof surfaces. Also, green methods for floor heating and air distribution systems exist.

2.3.4. Windows and Doors

Fenestration is defined as openings of building envelope, primarily refering to windows and doors. [30] Therefore, main concerns for designers are to define the properties of windows and doors accordingly. Fenestration properties are very critical considering the level of thermal load they bring into a building, thermal comfort, lighting level of indoor environment and usability [42].

Studies and improvements brought these building envelope parts to a more significant role in improving energy efficiency. Newer buildings' designers are using high energy efficient glazing technology and frames also by considering aesthetics and cost; a green point of view would also make control of toxicity issues [43].

Window energy efficiency affects the overall energy efficiency and comfort level of a building. Using double or triple (or higher for very cold climates) glazed low–e windows with metal oxide coating would decrease cooling demand for summer by admitting visible light but not infrared heat and ultraviolet rays. Similarly, reflecting hot indoor heat back to inside, heating demand is reduced.

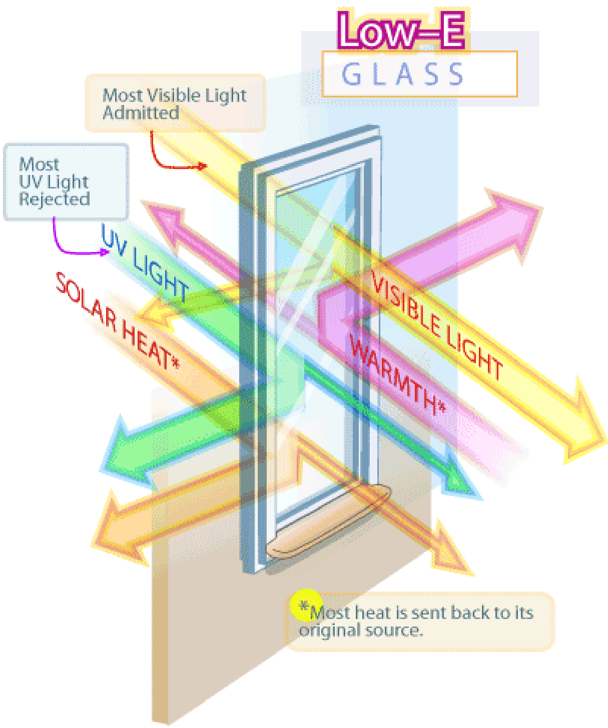

Figure 2.11 Low - e Glass

Gap(s) between panes can be in different sizes (3mm, 6mm etc.) and filled with argon or krypton or similar non – toxic gases that brings more insulation to the window. Together with coating type, window choice is done for different climatic properties [6].

Adding an UV filter can be a good option for retrofitting; avoiding 99% of UV lights and reducing the solar gain by %80, total energy saving would be increased [44].

In addition to glazing specifications itself, frame materials and finishes play an important role for energy efficiency. From a green perspective, a frame and finish will add more insulation and protection.

Different framing types can be chosen according to the requirements. Surely advantages and disadvantages would differ. Vinyl and wood frames provide more efficiency compared to metal where a higher amount of heat can travel though thermal bridges.

A combination of both wood and metal or fiberglass which are extremely durable and energy efficient, inside and outside respectively, providing UV protection and weather resistance can be chosen as a better green option [45].

Energy savings that can be provided from windows depend on thermal conductivity (U – value), solar heat gain coefficient (SHGC) of the window, as well as its orientation, environmental conditions (climatic properties) and building parameters. Technologies advance similarly for fenestration products. Solar control, insulation, low – e coatings, evacuation of air gap or filling cavities with aerogels and gases, frame improvements and spacer designs can be examples of advances glazing technologies [46].

For a passive heating application, window having a low U – value and high solar transmittance value should be preferred. Besides, to provide proper levels of illumination, spectrally selective low – e coatings are preferred to allow visible light inside and block the wavelengths that are responsible for solar heat gains.

Usage of antireflection treated low – e glazing with triple glazed windows would have desirable U – value while not decreasing the visibility.

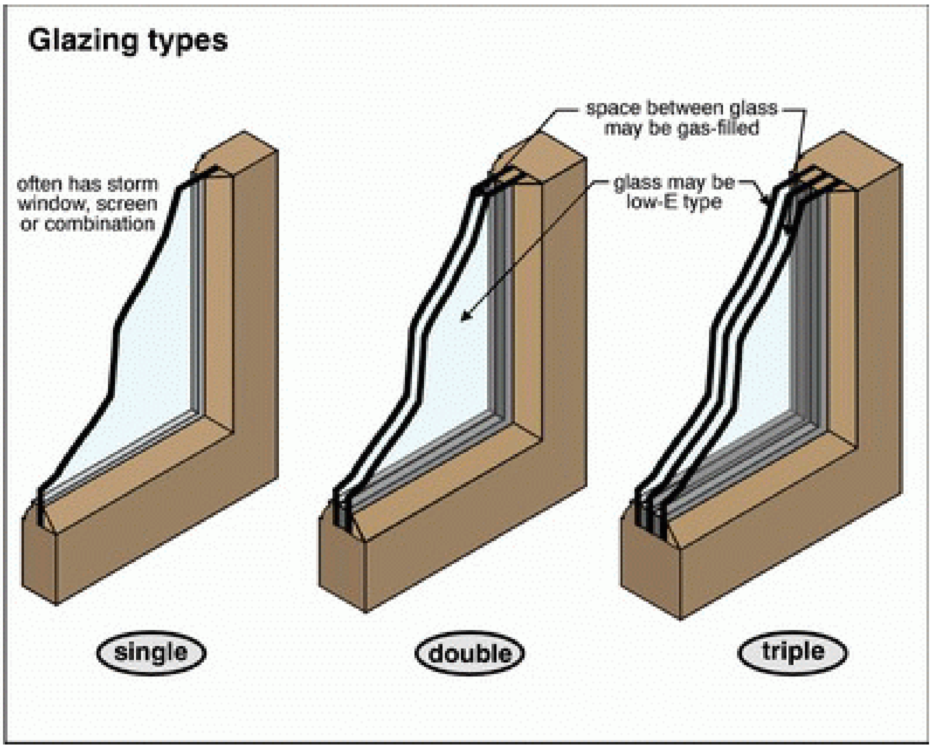

Figure 2.12 Single, Double and Triple Glazing

Sadineni et al. state that glazing should provide the best combination of high insulation performance, solar gain control and day lighting solution states. New technologies for glazing can be explained as follows [30]:

2.3.4.1. ***Aerogel Glazing***

This type is generally appropriate for roof – light applications because of their high performance, low density and exceptional light diffusing property. Density of aerogel is in the range of 1 – 150 kg/m^3 and panel thickness defines light transmission level and U – values [47].

2.3.4.2. ***Vacuum Glazing***

To eliminate conductive and convective heat transfer effect of air between panes, a vacuum space is created. Therefore, U – value fenestration (considered as glazing and frame including indoor and outdoor film coefficients) is reduced to 1 W/m^2K.

Application of low – e coating on one or both of glass panes provide a reduction of re – radiation, making it a widely used energy efficient glazing option.

Analysis resulted that triple glazed windows with vacuumed space in between can provide thermal transmittance values less than 0.2 W/m^2K [48].

2.3.4.3. ***Switchable Reflective Glazing***

Mainly, switchable reflating glazing type has a variable tint glazing. In some types, optical properties of glazing change depending on incident solar radiation, with applying DC voltage or using hydrogen. It’s mostly suitable for buildings that have high solar gains and so cooling loads. Life cycle analysis results show that it can provide about 50% reduction of energy consumption [47].

Other types of new technology fenestration are Suspended Particle Devices (SPD) film and Holographic Optical Elements (HOE).

SPD film, which contains light absorbing particles inside, is suspended between glass panes. Alignments of these particles change to create a transparent glass; random distribution provides an opaque solar barrier in the normal state.

HOE guides the solar incident usually onto the ceiling of internal space, which can be used as a day lighting option [47].

The most energy efficient doors available in market are: wood cladding, fiberglass and steel doors with polyurethane foam cores. Doors with new frames may also include magnetic strips to create tighter seals that reduce air and water leakage and noise. This makes the building more efficient.

Fenestration frames play an important role in order to minimize thermal bridges and infiltration heat losses (or gains). Usually frame effects are considered in the definition of total U – value of glazing [30].

2.3.5. Thermal Control via Building Envelope

2.3.5.1. ***Thermal Insulation***

Baysal defines thermal insulation as a material that retards the heat flow, and a barrier between two mediums having a temperature difference. Material type and its application method greatly affects the level of insulation. In addition, air or gas gaps inside the insulaton materials greatly enhances the level of insulation. As a consequence, thermal insulation is the primary element that changes overall heat transfer properties of a building envelope component. In order to create a thermally comfortable environment, the presence of thermal insulation is inevitable [41]. In the following sections, general types and methods of insulation are presented.

2.3.5.1.1. Batt and Blanket Insulation

This type of insulation is the most commonly used one because of its low cost and ease of production/maintenance. Generally, the compositions of fibers, mineral fibers or wools, are prepared as their shape tells, in the form of batt and blankets. These types are applied made to floors, ceiling and walls. The shape would also bring some disadvantages if a building has irregular portions. Also, it may seal some air in between the envelope components, which may not be desired [6].

2.3.5.1.2. Loose Fill Insulation

Loose fill insulation firstly differs with preparation of the insulation. While batt, blanket or rigid boards are prepared as the final products, loose fill insulation materials are applied on site. Loose fibers of wool, fiberglass or cellulose are blown to the space that will be insulated with the special application equipment. Therefore, it brings out a higher cost compared to mass production insulation types. Proper densities of loose fill insulation provide less air leakages and better noise cancelling [5].

2.3.5.1.3. Rigid Board Insulation

This type of insulation is generally used for maintenance of flat roofs, walls of basements, around concrete slabs and cathedral ceilings. Material types of rigid board insulation can be fiberglass, polystyrene and polyurethane.

Inside usage should be supported with 300 mm gypsum board or similar building – code – approved material for fire safety. Unlike waterproof covering for exterior use, insulation of the interior of masonry walls does not require vapor – retarding treatment [5, 21].

2.3.5.1.4. Spray Foam Insulation

Composed of two – part liquid containing a polymer such as polyurethane or modified urethane, and foaming agent; spray foam insulation expands into a solid cellular plastic that fills every cavity and crack. The effectiveness of spray foam is higher such that it acts as an insulation material and air barrier, therefore securing air tightness of the building. Also, spray foam in small containers may be appropriate when replacing windows or doors. Material and operation costs increase the overall value compared to other methods [5].

2.3.5.2. ***Selection of Insulation***

Insulation type and materials are selected considering very different properties of the project. Whole building design approach examines these properties and lets designers decide the right selections for any component of the building.

Insulation type and material decisions are made based on the whole building desing decision parameters. To summarize, buildings' location is considerable while not all insulation material would work for any kind of climate. More, climate changes thermal needs of building. Need for overall heat transfer coefficient directly affects the selection of insulation [19, 21, 43].

On the other hand, green considerations and design rules such as being materials low-e, non-toxic or resistance against water or humidity, leads designers towards the final touch to create the building. A green whole building design is made by analyzing the materials thermally and also greenwise.

2.3.6. Moisture Control via Building Envelope

Building envelope has the property of being the interface for mass transfer of moisture between outside and inside. Moisture (water) intrusion can happen as rainwater intrusion which can be easily avoided, with vapor intrusion or infiltration. However, envelope material choice becomes important for vapor intrusion. Water vapor intrusion increases the latent heat to be removed from the system which requires a larger and costly A/C system; on the other hand IAQ problems or health problems may occur because of mold or mildew creation.

Similar to the thermal control, building envelope components may also be employed with moisture control. The need of moisture control and usage of internal air barriers in buildings arises from preventing mold and other moisture damage and block the fumes of unhealthy building materials [43].

Air tightness and better insulations may create problems for the transfer of water vapor through building envelope. Especially in cavity walls of buildings with frame construction, addition of thermal insulation may cause moisture problems in the insulation, since water vapor may not flow through the wall to evaporate and dry out, therefore mold and rot can damage the assembly [16].

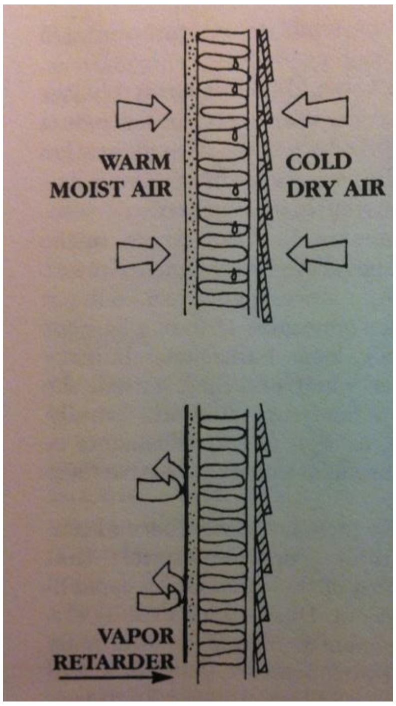

Figure 2.13 Moisture Migration

Four basic approaches to water penetration control in buildings can be listed as follows [5]:

2.3.6.1. ***Mass***

This method implies traditional structures such as solid concrete, masonry and wood, shedding most surface water, and subsequently release absorbed moisture as water.

2.3.6.2. ***Barrier***

Moisture barriers are designed to completely shed surface water with no moisture penetration. Barrier types are exterior insulation finish system (EIFS) and stucco or clapboard walls built without a drainage plane.

2.3.6.3. ***Internal Drainage Plane***

"Structures using this approach include typical stucco and clapboard walls built with a drainage plane or moisture barrier located between the exterior cladding and the supporting wall that provides extra moisture resistance."

2.3.6.4. ***Rain Screen***

Rain screens can be applied to brick veneer cavity walls, furned out clapboard walls, and drainable EIFS. It involves a moisture management system incorporating the exterior cladding, air cavity, drainage plane and airtight support wall that offers a number of shedding pathways.

2.4. Internal Concerns and Indoor Environmental Quality (IEQ)

Although building design primarily concerns about energy consumption, envelope properties etc., a green whole building design would include IEQ considerations as well.

Every occupant ought to have different preferences, behaviors, and satisfaction and thermal comfort levels, relation with the thermal environment and therefore, it would result in different reactions.

While an internal temperature is sufficient for one, very naturally another may feel warm or cold or uncomfortable in the same room.

Aim of a designer is to satisfy the indoor environmental quality for whole occupancy. However, due to these differences, the object is likely to become to provide the highest common satisfaction level.

For that purpose, international associations or communities define some offering levels. Considering temperature, summer and winter design or set temperatures may be taken as 23°C ± 2°C and 21°C ± 2°C respectively, in accordance with the standards based on previous experience, studies and observations. Similarly, some values are defined for humidity level, ACH, or contamination ratio etc., for different design criterions.

Details in IEQ considerations that determine the general well – being of occupancy, are given in the following sections as: Thermal comfort, IAQ, lighting and daylighting quality, and noise and acoustical concerns.

2.4.1 Thermal Comfort

Providing a thermally comfortable enviroment is one of the key factors to satisfy overall IEQ of a building. A thermally comfortable environment would increase the performance and productivity of the occupancy.

Thermal comfort introduces a design challenge since it needs control of air movements and velocity, thermal radiation, air temperature distribution, humidity floor temperatures etc. In addition to that clothing, metabolism rate, and personal preferences affect thermal comfort levels. [37]

ASHRAE defines thermal comfort as “that condition of mind which expresses satisfaction with the thermal environment”. [6]

Although satisfying thermal comfort for each occupant should be considered as ideal design requirement; individual factors, activity and clothing level or personal expectations leads the designers to provide comfort for the majority of the occupancy.

Between summer and winter design or set temperatures, 23°C ± 2°C and 21°C ± 2°C respectively, thermal comfort is satisfied; the range may affect total energy consumed for heating or cooling.

On the other hand, there are some rules that need to be applied as a rule of thumb, not proposed as a temperature or humidity range. Diffuser discharge temperatures and air velocities may create uncomfortable environments. Highly deflected exit temperatures resulted in discomfort for occupancy on air discharge direction. Generally, for large enclosures or offices, these problems occur more frequently. Coupled with high air velocities, discomfort level increases thermally and acoustically, which starts after 4m/s.

Therefore, a designer considers thermal comfort goals as supplying homogenous temperatures with homogenous temperature changes in the space.

A very intelligent design example is applied in The University of British Columbia Life Sciences Center in Vancouver, B.C using thermal mass property of envelope materials; such that daily heat gains are absorbed by the envelope material, which has a thermal lag (about 12 hours, may be less or more depending on latitude). The resulting application is to cool the building during the night, off hours, and let building live the cooler night temperatures during the day with a small help of ventilation. Therefore, a thermally comfortable environment is created since occupancy would never feel colder discharge temperatures and high velocities at all.

Another point is to avoid the feeling of cold coming from cool walls or windows, which actually is a radiative heat transfer. For a warm feeling, temperature difference between internal wall or window surface and environment should be less than 3°C. Otherwise, the radiative heat transfer from human body to surface (or vice versa) creates a cooling or heating effect and feeling [16, 49].

2.4.2 Indoor Air Quality

Indoor air quality (IAQ) is a subtopic of indoor environmental quality, which studies about air and air movement properties and considerations for a space, a building and the outside environment itself.

IAQ focuses on reducing the pollutant contamination of indoor air, providing fresh air for every occupant homogenously. Direct mixing of indoor and outdoor air should be avoided if the fresh air shall be distributed to an occupied space. Therefore, air intakes and exhaust openings are to be placed considerably such that outside air contamination would not bring any negative effect to inside; moreover, environment, occupancy outside or building intakes are secured of exhaust air [49].

IAQ requirements can be satisfied via the application of the sample suggestions presented.

Prefer low-e, non-toxic green materials such that a material itself does not produce a contaminant that pollutes the indoor air. Combustion equipments creating hazardous gases should not be installed without any ventilation. Occupancy and air distribution or ventilation system must be prevented from smoke. Moisture and humidity control systems shall be used such that mold or mildew production is avoided. IAQ performance is valued with well-being of the occupants. Therefore, ducting installation and maintenance, leakages of air considering air quality and thermal quality to occupied spaces are to be done carefully. Locations of air intakes away from pollutant generation and VAV controls that help providing better airflows to each space are effective methods to maintain IAQ [17, 51].

2.4.2.1. Ventilating and Cleaning Indoor Air

First step to keep fresh indoor air is to provide proper ventilation. For older buildings, since constructions are loose, not only from windows and doors; but also from leakages the ventilation happens and sufficient outside air is allowed inside. About a rate of 3 to 4 air exchanges per hour, inside air is kept fresh; nevertheless, loose construction avoids the building from being energy efficient. ASHRAE standardized 0.35 ACH for residential buildings. Yeang K. summarizes clean and fresh air requirements of buildings according to their purpose [52].

Table 2.4 Clean and Fresh Air Requirements

Intented Use of Building or Space	**Min. Clean Air Requirement (m^3/h/person)**	**Min. Fresh Air Requirement (m^3/h/person)**
Restaurant, Dance Hall etc.	17	10
Offices	13	1.2
Shop, Shopping Mall	13	2.3
Foyer, Lobby, Corridors	13	0.9
Classroom, Theater, Movie Theater	8.5	6.0
Factory, Plant or Production Centers	13	1.8
Residential, Housing Spaces	13	-

Studies of Prof. Bulut results fresh air requirements in buildings, classes and offices as presented in Table 2.5 [53].

Table 2.5 Fresh Air Requirements

Building Type		**Fresh Air Requirement (m^3/h/person)**
Houses	Average	3.13
	Minimum	1
	Maximum	6
Classes	Average	23.9
	Minimum	1
	Maximum	49
Offices	Average	3.3
	Minimum	1
	Maximum	45

Buildings are constructed more tightly to achieve these values. Besides, alternative strategies for ventilation and indoor air cleaning are necessary.

Firstly, a designer should consider allowing optimum amount of fresh air into the building. However, outdoor air often contains pollutants. Methods that can be applied to reduce pollutant contamination are source control, air cleaning and ventilation.

Gaseous and radon related pollutants can be controlled during construction or upgrades, exhaust fans of heating/cooling systems or bathroom should be directed properly in order to prevent mold or mildew production.

Mechanical ventilation, air-air heat recovery or energy recovery ventilation, or fresh air intake systems can help ventilation via windows. Additional air filters or cleaning systems can also be applicable to minimize indoor air pollution.

General types can be listed as: mechanical air filtering, electronic air cleaning and ion generators. One or combination of these types can be used. Auxiliary devices such as smoke alarms, CO_2 or natural gas detectors should be installed as well [54].

2.4.2.2. ***Designing Healthy Buildings***

2.4.2.2.1. ***Ventilation Air Cleaning***

To satisfy good indoor air quality, not only the air filters, but also air cleaning systems would provide higher quality air. For a green building, natural ventilation can also be an option since it consumes less energy; however, outdoor air should be properly guided through the building.
Envelope materials on the other hand should be selected accordingly, such that microbial growth is avoided [6].

2.4.2.2.2. ***Passive Solar Disinfection***

Among other great benefits, natural light provides natural disinfection to building air and surfaces. Even for northern latitudes, proper indoor lighting levels with more fenestration or skylights enhance self-disinfection property of building and air [55].

2.4.2.2.3. ***Vegetation Air Cleaning***

As a green application, living vegetation layers act as a natural bio filter, therefore reduce some microbial species and help oxygen generation. Gardens and vegetation may have a positive effect on occupancy. Building materials, envelope, furniture, paints, flooring have an effect on IAQ that should be considered [51].

2.4.2.2.4. ***Natural Ventilation Strategies***

Natural ventilation strategies are applied within whole building design approach. Some examples to these strategies are placing buildings' longer façades with high glazing towards summer prevailing wind direction; not blocking openings or fenestrations with aesthetic components; placing window openings perpendicular to pressure areas; placing air intakes below the walls and exhaust to upper portions; designing the building such that chimney effect is avoided; or having spaces at least 3m between floor and ceiling. Each one of them can be used for a specific project, considering the requirements.

Besides, natural ventilation can help internal cooling. However, solar effects should be avoided and solar gains should be minimized. For this purpose, fenestration surfaces should be limited and protected with shading devices; bare ceilings should be designed with high thermal capacity for night cooling; precautions should be taken at the envelope such that walls solar transfer should be minimized. Plants and trees also help ventilation and blocks reflections [56].

2.4.3 Lighting and Day Lighting Quality

Either artificial or natural, light is essential for any space in any building. Providing necessary amounts of lighting with quality is a design requirement.

The purpose of space or zone differs the lighting level required. Also, lighting level is influenced by outdoor environment, other buildings or landscape.

Lighting comfort level of the occupancy is determined by both presence of light and quality. Providing natural light would definitely have a positive effect on the occupancy. If possible, daylighting with windows that also provide outdoor views is the best lighting option.

2.4.3.1. ***Lighting***

Health, comfort and productivity of the occupancy in a building space are affected by the quality and quantity of lighting. Lighting sources as natural and artificial may be provided to each space; however, artificial lightings would consume the largest portion of building's electricity and also produce heat which may or may not be desired.

Accorging to a research done by a lighting company, lighting strategies inside and outside of a space should be applied, for example new fixtures, sources and lighting controls can reduce lighting use up to 75% [5].

Energy used for lighting is compared to other mains for offices, commercial buildings and schools. The results show that lighting is the major one among the others, which shows the importance of lighting from a green design point of view [57].

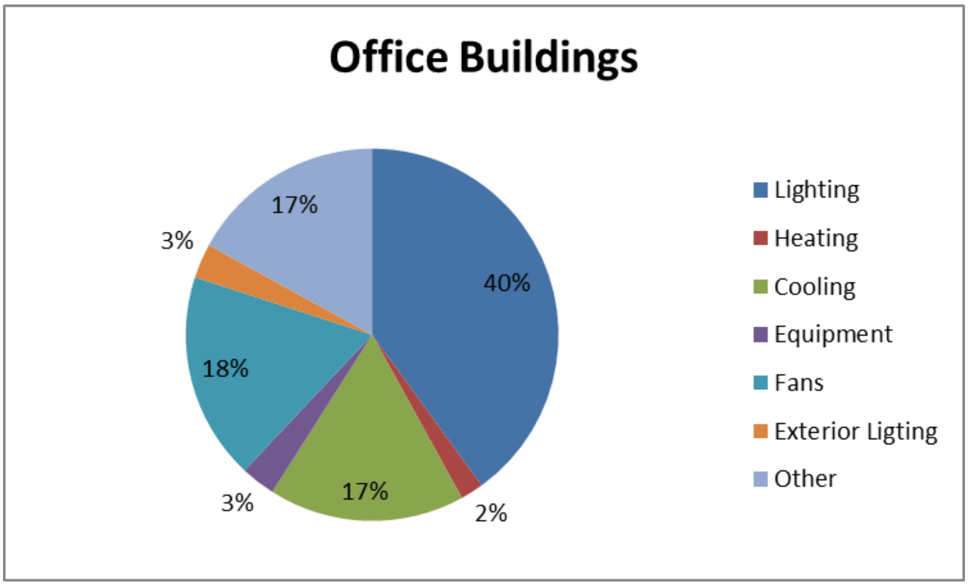

Figure 2.14 Office Buildings' Energy Usage Percentage

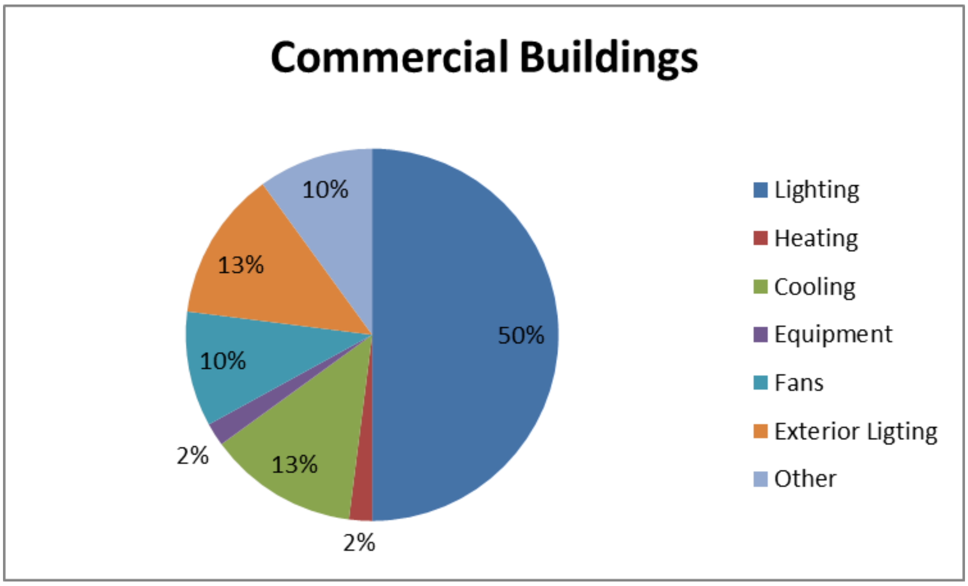

Figure 2.15 Commercial Buildings' Energy Usage Percentage

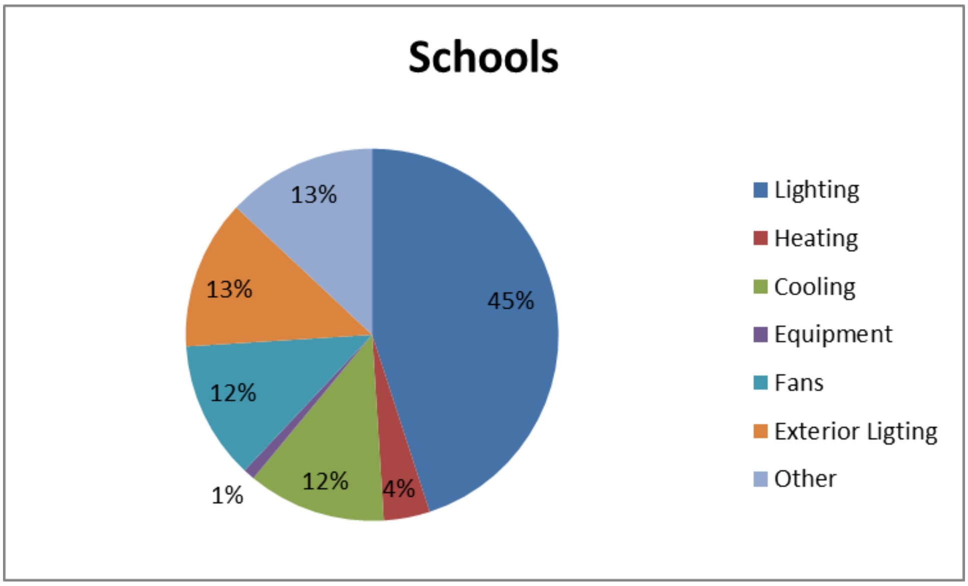

Figure 2.16 Schools' Energy Usage Percentage

2.4.3.1.1. ***Indoors***

A very high portion of indoor artificial lighting is satisfied by incandescent or fluorescent light bulbs. Comparing these, fluorescent lighting is very efficient compared to incandescent. For fluorescent lighting, the best option to be preferred mostly is ceiling or wall mounting. Also, for non – frequently used spaces, occupancy sensors should be added.

Another consideration in order to choose energy efficient light sources might be checking color temperatures; proper option is to choose cooler lights than incandescent bulbs [5].

Since color of light is important for space type, new technology efficient light bulbs generating cooler colors but very similar to daylight should be chosen. For example, for more visual working style, cooler lights are preferred to satisfy a better contrast. Or for living areas, warm lighting would be better considering closeness to skin tones and clothing colors.

Switching to compact fluorescent bulbs would reduce power requirement, is considered as a green method [58].

2.4.3.1.2. ***Outdoors***

Outdoor lighting is important for buildings' environment and landscape; also it provides security and helps navigation. Generally, efficient low-wattage lighting would suffice for security and utilities areas, not necessarily to be bright.

Fluorescent High Intensity Discharge (HID) or sodium lights, with motion sensors are chosen as the best system solution. Including reflective fixtures help increasing the efficiency of the light source. Timers and solar powered lights are used to create more green and efficient environment lightings [58].

2.4.3.2. ***Daylighting***

It is undeniable that daylighting has a positive effect on occupancy. For a building, artificial lights are wanted to be kept at minimum level. Also, considering energy efficiency, lighting accounts for the highest portion energy used. Therefore, daylighting usage would reduce energy consumption at high levels [56].

However, daylighting would not be possible at all times; therefore the most effective solution is to use artificial lighting and daylighting together in a building. Coming from windows and skylights, daylighting decreases the dependence to artificial lighting during daytimes.

Daylight harvesting analysis helps optimizing building geometry, define glazing properties and orientation, also energy performance analysis.

For a green design, buildings' size and location of buildings, also climatic effects play important role for window placement to maximize daylighting [16, 37, 58].

South facing windows would be best daylighting solution if seasonal temperatures are moderate, which avoids extreme cooling loads for the building. If necessary, during summer, high angle solar rays can be avoided by using proper shading. On the other hand, south faces provide the maximum daylighting for winter sunlight.

Northern directions usually admit no direct sunlight for northern hemisphere. These windows admit evenly distributed natural light and bring no unwanted heat gain.

East and west façades are exposed to sun and windows receive good daylight in the morning and evening respectively. However, this direct sunlight should be limited as during summer time mostly, unwanted heat gains may occur; and for winter times, low angle solar rays contribute to heating.

Providing natural light from windows also presents outdoor view for the occupancy. If this method is not possible by any means, redirecting natural light via interior ceilings is a good application.

2.4.3.3. ***Avoiding the Lights***

Especially for incandescent light bulbs, control becomes important. On average, 10 – 15% of the electricity is turned into light, which means 85 – 90% discharged as heat. Therefore, incandescent light bulbs should be turned off when not used.

For fluorescent light bulbs, it is not very easy to decide turning on and off considering cost effectiveness. Turninng of the lights when occupancy is out more than 15 minutes is a common application of green design. Fluorescent light bulbs are more expensive and operation time depends on the number of times that they are switched on and off [5].

2.4.4 Noise and Acoustic Concerns

Sound and vibration contribution to environmental quality, productivity and health should not be forgotten in the design.

Three basic criteria are widely used for indoor noise: Noise Criteria (NC), room criteria (RC) and A-weighting (dBA); as the latter used for outdoor noise too.

Sound sources are classified as indoor and outdoor sound sources. Indoor sources are equipments (fans, pumps, compressors etc.), high flow velocities or pressure losses in duct systems, vibrations or high flow rates in piping systems.

Indoor sounds travel though two paths. Airborne sound travels through air and windows, while structureborne sounds are transferred via solid envelope, floor or wall. Some examples can be people walking on the floor above or elevator noise

Outdoor sound sources are mostly the equipment that discharges the excess heat from the building. Cooling towers, expansion coolers, dry coolers and exhaust fans are mechanically creates noise. Also, environmental noises and sound reflections from the environment are considered as an outdoor source.

Some suggestions or tips for green design acoustical concerns can be as adjusting fan/pump speeds and air velocities inside ducting/piping system respectively provide reductions from 5 to 10 dB. On the other hand, selection of insulation materials with noise reduction properties helps diminishing structureborne noise. Also, double or triple glazed windows with proper frames reduce outdoor noise. Lastly, locating sound sources near reflective sources can increase noise levels; therefore one should keep a minimum of 3 m distance from sound sources [6].

2.5. HVAC System Design

The satisfaction of thermal comfort levels, indoor air quality and other design parameters are affecting the HVAC system choice to be present in the building. Calculations of HVAC system design are done mainly by considering heat gains and losses. Fresh air requirements also make an input to system design.

Heat gains or losses for a building are resulted from outside conditions, by conduction, convection and solar or space radiation. Internally, occupancy present, lighting and equipment such as computers, TV's, other home appliances or office and laboratory devices, and other miscellaneous heat rejecting units add heat loads to the building.

Moreover, other environmental effects are to be considered as a heat gain or loss, affecting total heating or cooling load of the building, meaning the HVAC system design.

Building designs affect HVAC system design, performance and energy efficiency. Building layout optimization helps daylighting considerations or space grouping determines the selection of AHU and ducting; in order to provide a more energy efficient HVAC system.

Climatic conditions or human expectations are the features that effect HVAC system design. Main climatic properties taken into consideration are ambient temperature, humidity, solar intensity, wind patterns and directions, ground temperatures. On the other hand, side properties are air quality and pollution properties, freshwater availability and quality, site drainage can be considered for a green HVAC system design.

Regional (local) climates, also known as local climate, change the design. Knowing local properties of the weather and environment would lead the designer to a better overall result.

2.5.1 Key Considerations in the HVAC Design Process

First of all, design intent should be cleared. Performance goals for energy, environment, comfort level, costs are to be set; and methods to achieve these goals should be determined.

For a building, design is integrated with other disciplines. Therefore, HVAC system design also integrates with other disciplines, architectural and structural disciplines, lighting, and daylighting, air distribution, functional and interior design etc. Resulting performance of the HVAC system provide thermal comfort IEQ and energy efficiency [16].

A good HVAC system design considering the requirements has highly energy efficient equipment, fast response to partial loads, efficient cooling or heating, and necessary indoor air quality.

Verifying design intent with design and construction results the “good” design. Goals, discipline coordination, equipment selection, installation, testing and operating show how good the design and production is made.

Challenge of load reduction for HVAC system reveals reducing envelope loads, internal loads, power loads and A/C loads.

Reduction of solar loads with shading, glass selection and ratio; internal loads with lighting power, equipment occupancy controls; and proper selection of system to reduce the power and A/C loads determine the quality of the design.

Energy simulations should be developed and applied such that the selection of both the building envelope properties and HVAC systems also the operations settings (schedule, thermostat, flow rate etc.) are determined properly.

Together with HVAC system properties such as type, efficiency, operation settings which are significantly affected by design parameters including building envelope features size, shape, orientation, construction sets for walls, roof and window types and sizes; total heating or cooling load of a building can be determined by this co-operating design approach.

The best combination of above mentioned design parameters would minimize energy use and provide the desired indoor environmental comfort. This results that envelope and HVAC systems should be improved together for whole building analysis and better designs.

In recent studies, optimizations on building shapes, construction insulations and other design features are started to be investigated [59]. Bichiou used a model including building envelope features, HVAC system properties and schedules for a residential building in his approach; which can be a prototype method for other designers to apply to any commercial or residential building [60].

Heating only systems include furnace and electrical resistance (ER). Cooling only systems consist of evaporative cooler (EC) and air conditioner (A/C). Systems providing both heating and cooling are also considered in the optimization simulation environment and include ground source heat pump (GSHP) and the air-to-air heat pump (HP). Several GSHP configurations are considered in the simulation environment including vertical and horizontal wells. It should be remembered that for humid climates, evaporative cooling is not suitable.

A whole building energy simulation engine is employed in Bichiou's studies.

2.5.2 HVAC System Selection

HVAC system selection depends on size of the building, types and levels of loads, set temperatures and environmental effects. Supporting equipment controls such as thermostats are also selected with the system.

Thermal comfort affects HVAC system selection and size as well. Therefore, thermal comfort requirements, 22±2 °C, 21-23°C, 21±3 °C or 18 ↔ 24 °C etc. should be analyzed in detail for system selection [61].

Analysis, envelope and system choosing help decreasing life cycle costs of buildings. Some basic HVAC related methods that can reduce thermal load on a building can be listed as follows:

Turn off or turn down air conditioning when occupancy is out of the building. For a commercial building, this method can be applied by re-arranging the A/C schedules [5]. As an example, for a building that has a total thermal time lag about 10 – 12 hours, daily A/C conditioning schedule can be reversed; meaning that high temperatures of daytime would be felt inside during night and vice versa. Therefore, running the HVAC systems at full power while nighttime, when the occupancy is close to zero, would satisfy a quieter working environment during the day (only ventilation fans working).

Adjustment of thermostat values would definitely affect total energy consumption. Studies show that adjusting thermostats (does not mean inside temperature) for winter period to 20°C at home and 16°C when away and 25°C for summer would provide resting times to HVAC system and helps saving about 10 – 15% energy savings [6].

In a typical building, heating and cooling loads constitute more than half of the energy use. The first step to decrease the cost of heating and cooling loads is to maximize the buildings' efficiency. These methods are explained in detail in this thesis; as using higher levels of insulation, energy efficient windows and doors, etc. A green building aims maximization of passive heating or cooling and creation of a tight and efficient envelope.

Other HVAC upgrade and retrofitting tips can be considering the usage of hot water heating instead of electrical system, usage of central A/C systems, switching to a heat pump based system or switching to a baseboard hot water heating system instead of ducting required system. These methods can be applied regarding building type and needs.

2.5.3 Cooling Systems

Passive or active, simple or complicated cooling systems can be applied the on building. Most common cooling applications are listed below.

2.5.3.1. ***Ventilation***

Natural ventilation is cheapest and most energy efficient way to cool a building except in very hot and humid climates. It may or may not require additional fans; also supply fans might be necessary for large buildings. Especially for attics, ventilation can significantly reduce the use of air conditioning.

2.5.3.2. ***Evaporative Coolers***

A technique that can be applied in low – humidity environments, evaporating water putted into air provides a natural energy – efficient cooling. Operation cost is about quarter of a central A/C and installation cost is about half of central A/C.

2.5.3.3. ***Air Conditioner***

Generally, most buildings commercial or residential are equipped with air conditioning systems depending on the requirements. Nayar states a resulting of 20 to 50% cost reductions with higher efficiency A/C units [5].

2.5.4 Heating Systems

In heating systems, addition to building requirements, fuel type and energy related issues defines the decisions.

2.5.4.1. ***Furnaces and Boilers***

Being ideally similar, furnaces and boilers differ with as they heat air and water respectively. A furnace heats the air and providing hot air into the spaces via air ducts; while boilers heat water and provide hot water or steam. Increasing efficiency can reduce about 30% of energy and cause less pollution.

Another option to be applied to increase the efficiency of the system can be programmable thermostats, ducting for forced air system and space control. For colder climates such systems with highest efficiency should be selected and installed.

2.5.4.2. ***Electric Resistance Heating***

Although electric resistance heating method seems very efficient since electricity is to heat almost perfectly via resistances; electricity production with gas or coal generator with about efficiency of 30% makes electricity expensive. Therefore, usage of a heat pump would decrease half of the operation cost. Types of electric resistance heaters can be classified as baseboard heating, wall heating, furnace and thermal storage heating systems.

2.5.4.3. ***Active Solar Heating***

Solar receptors collect and absorb solar rays and transfer the collected energy directly into the building or indirectly by using a reservoir to be supplied later. Basically, two types as liquid and air based systems exist as active solar heating systems. Liquid based system heats water or a liquid solution in a hydraulic collector, while air based ones heat air in an air collector. If storage is necessary, a liquid based system is often more suitable.

This method becomes very cost effective if used throughout the year, and for colder climates with good solar resources. Choosing active solar heating for a building's heating system (or supplementary heating system) would significantly reduce the energy cost, air pollution and greenhouse gas emissions which arises from burning of fossil fuels.

System sizing and selection is defined by mostly on site which determines solar presence, building design and heating needs. In addition, local environmental conditions, climate, collector selection as type and area etc. determines total energy that can be provided by the active solar heating system [5].

2.5.4.4. ***Radiant Heating***

Radiant heating panels supply heat directly to building's floor, wall or ceiling. Compared to baseboard and forced air heating, radiant heating is more energy efficient, since no energy is lost through ducting.

2.5.4.4.1. *Radiant Floor Heating*

Three types exist as radiant floor heating. First one is radiant air floors. Air cannot hold large amounts of heat, is not very cost effective, therefore seldom used.

Second one is electric radiant floors. Consisting electric cables and mats and conductive materials on bottom, it covers the floor as a tile. Due to high electric prices, usage with a thermal storage mass around creates a more efficient system since this mass is heated during day off peak hours.

Most popular system is the hot water radiant heating system being cost effective mostly for climates that require more heating. Water heated by boilers is pumped through patterned tubes underneath. Another advantage of these systems is that they use less electricity and water can be heated via various sources.

For floor covering, ceramic appears as a good choice considering its conductivity and thermal storage capacity. On the other hand, insulation options would help the system efficiency; however, less carpeting shall be used to enhance heat transfer for wood flooring.

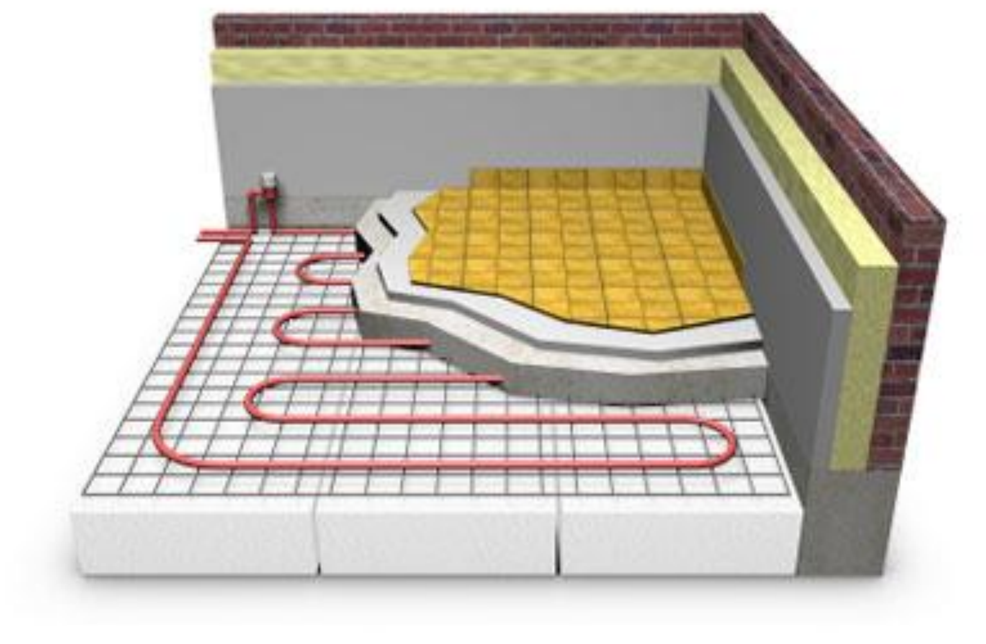

Figure 2.17 Radiant Floor Heating

2.5.4.4.2. Radiant Panel Heating

Radiant heat panels are used in walls or ceilings, usually made from aluminum, these panels are heated with electricity or tubing where hot water flows inside although latter one may cause leakage problems. That is why mostly electrical heating is employed for radiant panel heating in buildings. Operation cost would be higher however; radiant panels can be used as an auxiliary heating option for some spaces. To save more energy, thermostat values of heaters can differ and control of individual systems would be helpful.

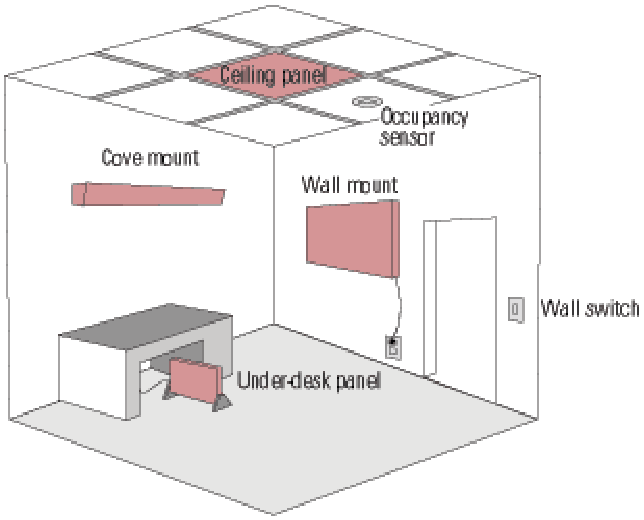

Figure 2.18 Radiant Panel Heating

2.5.4.5. ***Heat Pump Systems***

As an alternative to furnaces and air conditioners, heat pumps offer an energy-efficient solution for climates with moderate heating and cooling loads. Main advantage of heat pumps is that delivery of more useful energy than consumed.

Heat pumps move the heat in the reverse direction of natural heat flow, making cold space cooler and warmer spaces warmer; providing up to 4 times energy than consumed.

2.5.4.5.1. Air Source HP

Air source heat pumps realize the heat transfer between indoor space and outdoor air. High efficiency heat pumps can also make dehumidification better than the standard A/C unit; besides, provide less energy and more cooling comfort during cooling season. Although being the most preferred system, for harsh cold climates, most heat pumps are not preferable.

2.5.4.5.2. Geothermal HP

Although installation cost of geothermal heat pumps are high, achieving high efficiency by transferring heat from ground or a water source makes geothermal heat pumps quite preferable and decreases operational costs. Another advantage is relatively constant source temperatures.

2.5.4.5.3. Absorption HP

Absorption heat pump is a new technology gas fired heat pump for residential systems which uses heat as its energy source and can be driven by various energy sources.

2.5.4.5.4. Water Source HP (WSHP)

Water source heat pump uses a flowing water sink as source of heat. Single pass and recirculation systems are available. Heating loop is a closed loop which transfers heat from the medium to the central boilers; while cooling loop it transfers to cooling towers or chillers.

2.5.4.5.5. Ground Source HP (GSHP)

Ground source heat pump is a more general definition. This type of heat pump systems may use ground air, soil heat, rock heat or body of water (lake or groundwater etc.) as a heat source.

Typically ground source heat pumps have higher efficiencies than air sourced ones; since the ground heat sources have relatively constant temperatures compared to air sources. Therefore, lower difference in temperatures allow higher system efficiencies.

Ground source heat pumps have higher installation costs because of excavation works.

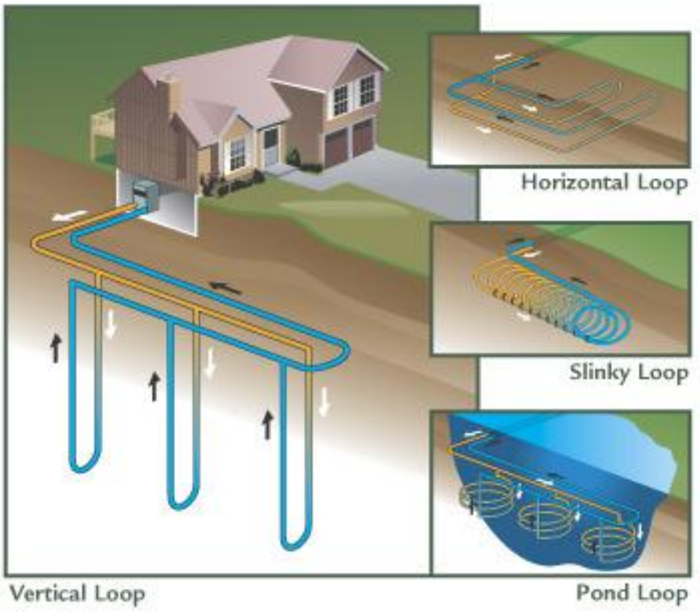

Figure 2.19 Water and Ground Heat Pump Systems

2.5.5 Water Conservation, Filtration and Heating

With increasing energy prices, the world changes fossil fuels to environmentally friendly products. Also water demand rise parallel to population creates the concern to conserve water used commercially and residentially.

Efforts should be focused both on more efficient water usage and pollution reduction. Considerable amounts of energy are used for hot water production, water treatment, preparation and supply.

Some basic tips to save water in commercial or residential buildings are listed below (from Water Sense Program of EPA):

- Fixing the leaks can avoid unused water to flow away.
- Switching to a shower rather than a bath, can reduce water usage by 60% to 80%.
- Turning off the tap while brushing teeth or saving would also add water saving. Also motion sensors may be added to taps to cut water while not used.
- Irrigation water usage accounts for 30% of household water use on average. Change to drop irrigation to avoid 50% of water evaporation help a saving about 20% to 50%.
- Use high efficiency washing machines working with full load can result water savings about 30% to 40%.
- Especially for office or commercial buildings, flushing accounts for a considerable portion of water usage. Toilets made before ’92, was using 3.5 gallons of water per flush, new models drop the usage to 1.3 gallons.
- Insulation of hot water pipes with foam pipe insulation would decrease the heat loss.
- Use dishwasher to diminish water use rather than washing by hand.

2.5.5.1. ***Water Heating***

Water heating applications cover 14 – 25% of energy used in buildings. Selection of highly efficient proper models would help cost reductions.

In conventional water heaters, fuel sources (natural gas, fuel oil, propane etc.) or electricity is used to heat the water inside the reservoir. Since this reservoir is continuously heated and loses water to ambient, storage tanks should be insulated. A high level of insulation about R-12 to R-25 would be sufficient.

As another option, instantaneous water heaters can also be used. This type of heaters is known as demand and tankless water heaters since they only provide hot water when it is needed and therefore save energy.

Although hot water flow rates may not be as much as the reservoir types, gas-fired ones may supply higher flow rates compared to electrically heated ones.

2.5.5.1.1. Heat Pump Water Heaters

As described, heat pumps move the heat from one place to another by using electricity. Water heating system can be integral to a space conditioning system. Initial costs are higher for heat pump water heating system where operational costs balance the total cost.

2.5.5.1.2. Solar Water Heaters

Also known as solar domestic hot water heating system, solar water heaters can be quite cost effective for buildings’ hot water generation. As the heating source is sun, which is free, these systems can be used in any climate.

System includes solar collectors and highly insulated storage tanks. Active systems include circulation pumps and controls. All these advantages make solar water heating a frequently used option for green(ing) buildings. Nevertheless, a backup heating system is also required for cloudy days.

2.5.6 Appliances and Electronics

In a typical commercial or residential building, appliances such as electronics equipment, computers, TV’s, washers, dryers, water heaters, and other equipment use electricity, and also generate heat. Consideration of appliances and electronics is a must for a building design. Especially for a green design, green labeled or A+, A++ labeled products would absolutely be more suitable regarding energy consumption values.

Energy Star rated appliances are reducing carbon pollutions and have a very considerable positive effect on energy cost. A sensitive designer (or customer) should check energy values of an appliance (heater, air conditioner, water heater or refrigerator etc.); where heating or cooling uses 50% of total energy of an average residential building. For example, switching to warm water reduce 50% of energy while cold mode of washing machine uses 90% less energy compared to hot washing [5, 16].

CHAPTER 3

SOFTWARE ENERGY PLUS AND ANALYSIS

This chapter is devoted to overview of software "Energy Plus" and its auxiliary application software "Open Studio" and "Google Sketchup" used in this thesis study, and the analysis performed using the software.

3.1. Energy Plus® Overview

Energy Plus is a simulation tool developed by U.S. Department of Energy (USDOE) and used by engineers and architects. It simulates building performances, retrofitting studies, helps HVAC system selection and optimizes energy performance.

Energy Plus is a thermal load and energy analysis simulation software. Based on user inputs for building itself and operational properties, it calculates heating and cooling loads to maintain temperature set points year round.

Energy Plus provides a simultaneous solution coupling building response with thermal system. Thermal interface between building spaces and environment can be resulted with user-definable thermal steps. Weather files are also available and used for many locations in a text file format (See Appendix E for example file).

Heat transfer algorithms are defined such that heat balance based solution, where thermal loads are calculated simulatenously, on an hourly basis including radiant and convective effects of both interior and exterior. Envelope conduction heat transfer function is transient since programs runs with time steps. Using third degree heat transfer finite element models, ground effects are also brought into the equation.

Moreover, for more detailed analysis daylighting controls and pollution sensors are available.

Being a simulation engine, but not a user interface, Energy Plus needs some auxiliary programs. Although text based input file import is available, Google Sketch-up and integrated Open Studio provide Graphical User Interface for a more user friendly view and simplified input definitions. For building drawings and envelope details as windows, doors or shading, Google Sketch-up tools are used.

All parameters can be defined to the program via Open Studio interface, and analysis is performed for user defined schedule with desired time steps. Parameters defined for accomplishment of Whole Building Analysis are illustrated in the following analysis chapters.

Figure 3.1 Energy Plus, Open Studio and Google Sketchup

3.2. Analysis Steps

Analysis are performed using the software Energy Plus as the thermal solver, and two auxiliaries Open Studio and Google Sketchup. Open Studio is used as a user interface and all definitions, also it understands thermal properties of any component. Meanwhile, Google Sketchup is a drawing tool used to draw building geometry.

Analysis procedure are explained briefly, detailed instructions are presented in the Appendix B.

Analysis requires an Open Studio model and the user starts to develop its own requirements inside that model. The model contains building details, envelope details, materials database, load definitions, schedules, HVAC systems and so on.

Building parameters such as location (latitude, longitude), orientation are entered at the very beginning. Building envelope details (walls, roofs, floor, fenestration etc.) are drawn with Google Sketchup and building geometry is constructed. Thermally, it is sufficient to use a single layer interface between indoor and outdoor, or indoor spaces. Later on material layers will be defined for each building envelope element.

Assinging space relations is important in order to define boundary conditions. A space component can be exposed to outdoor conditions, sun and wind, or ground; but an internal space may be adjacent to another internal space, that is, exposed to indoor conditions.

Material properties can be defined manually in the software. Thermal properties of the materials, as well as thickness is necessary in order to create an envelope component composed of material layers.

Loads and schedules are to be defined in order to simulate building's behavior throughout the desired time period. Internal loads (occupancy, lighting, equipment etc.) that differ as per building shall be inputted by the user; although solar loads and conduction loads are calculated by the program itself regarding the location, orientation and time of day, also outdoor weather properties.

After all input data is entered, last step is to run a whole year simulation using the available weather data file.

3.3. Analysis of the Existing Building

3.3.1 Inputs, Properties and Explanations for Existing Building Analysis

This section is devoted to studies of the results of building analysis before for the existing building.

Existing building located in Ankara, an office building with given details below.

Table 3.1 Energy Plus Analysis General Properties

	Value
Program Version and Build	EnergyPlus-64 7.0.0.036, 12.05.2012 14:15
Weather	OS:RUNPERIOD 1
Latitude [deg]	40.12
Longitude [deg]	32.98
Elevation [m]	949.00
Time Zone	2.00
North Axis Angle [deg]	90.00
Rotation for Appendix G [deg]	0.00
Hours Simulated [hrs]	8760.00

3.3.1.1. Template, Building Envelope and Constructions

Open a new Open Studio model from template, “ase……...osm” template is prepared for analysis including building components, schedules, load definitions etc. Although saved .osm file includes previous building envelope drawings, new geometries can be created and used.

Building plan is taken from the architectural drawing with exact dimensions. The building consists four offices (two offices - double floors) and hall (single floor) types enclosures, as open offices. Therefore, all spaces would have similar characteristics and homogenous thermal conditions, so it is logical to define the spaces as such from an analysis and engineering point of view.

Table 3.2 Building Dimensions

Space	Length [m]	Width [m]	Height [m]
Office – 1	34	16	4.5
Office – 2	49	16	4.5
Office – 3	34	16	4.5
Office – 4	49	16	4.5
Hall – 1	34	49	9
Hall – 2	49	49	9

Table 3.3 Building Area

	Area [m^2]
Total Building Area	5395.00
Net Conditioned Building Area	5395.00
Unconditioned Building Area	0.00

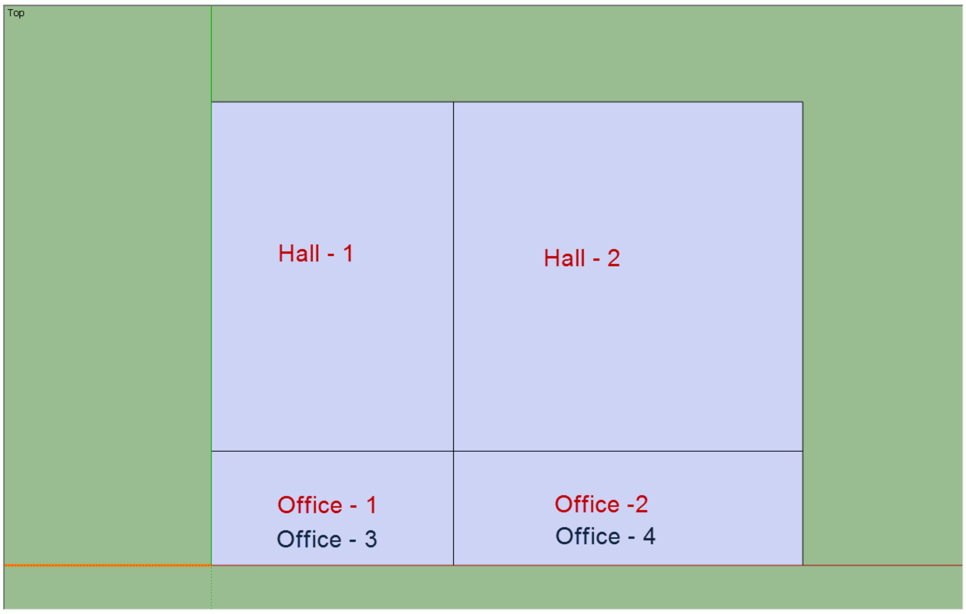

Figure 3.2 Building Space Diagram

Figure 3.3 Location of Case Study Building

After building is drawn, 6 spaces are created with desired dimensions. All space properties can be defined separately, or construction sets can be employed.

Fenestration and door details are drawn on the envelope with dimensions given in Table 3.4. Building total window and wall areas and window to ratios are given in Table 3.5.

Table 3.4 Fenestration Dimensions

Item	Length [m]	Height [m]
Windows	3.5	1.1
Door – 1	3	3
Door – 2	4	4
Door – 3	4	4

The surface type rendering view shows the roof as red, and walls are yellow. Fenestration and doors will be shown as blue and brown, respectively in the Figures 3.4 and 3.5.

Properties of the envelope components, walls, roof, floor and fenestration are presented as envelope layer details given in Figures 3.6 and 3.7.

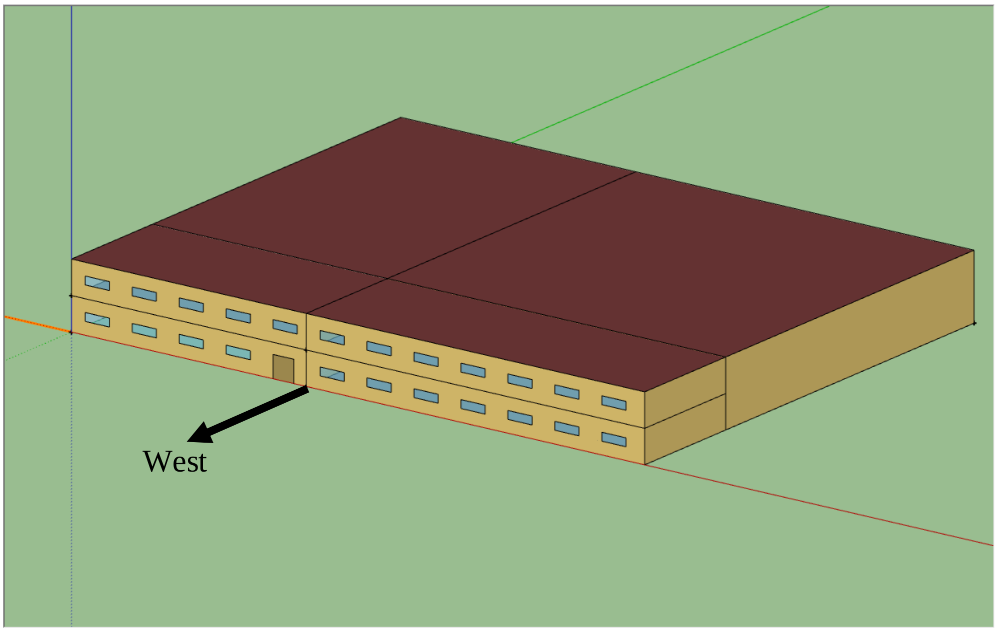

Figure 3.4 General View of Analysis Building (Isometric View Front Side)

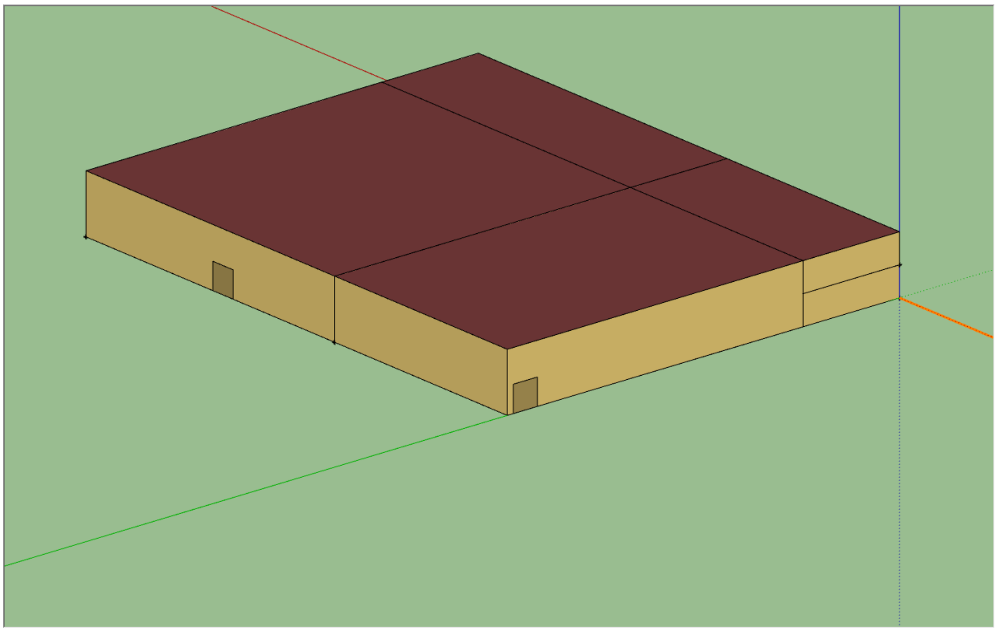

Figure 3.5 General View of Analysis Building (Isometric View Back Side)

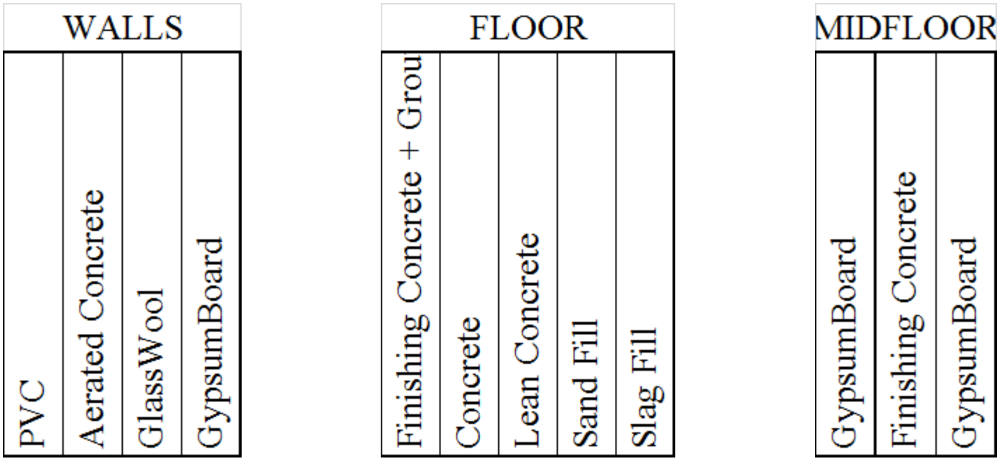

Figure 3.6 Walls and Floor Material Layers

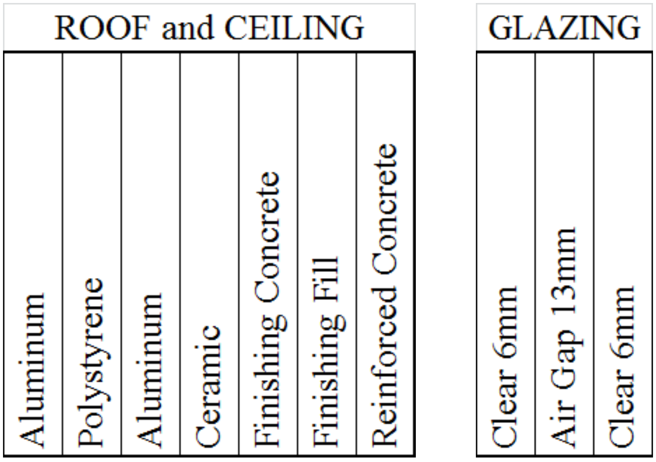

Figure 3.7 Roof-Ceiling and Glazing Material Layers

Table 3.5 Window-Wall Ratio (General)

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m^2]	2664.00	585.00	747.00	585.00	747.00
Window Opening Area [m^2]	88.55	0.00	0.00	0.00	88.55
Window-Wall Ratio [%]	3.32	0.00	0.00	0.00	11.85

Therefore, envelope overall heat transfer coefficients for existing building envelope are presented in Table 3.1, Table 3.2 and Table 3.3.

Table 3.6 Opaque Exterior Details

	Construction	Reflectance	U-Factor with Film [W/m²K]	U-Factor no Film [W/m²K]
OS:SURFACE 35	0000_DUVAR_DIS	0.30	0.309	0.324
OS:SURFACE 38	0000_TABAN	0.30	0.387	0.427
OS:SURFACE 36	0000_CATI_TAVAN	0.30	0.276	0.291
	Azimuth [deg]	**Tilt [deg]**	**Cardinal Direction**	
OS:SURFACE 35	270.00	90.00	W	
OS:SURFACE 38	90.00	180.00		
OS:SURFACE 36	90.00	0.00		

Table 3.7 Fenestation Details

	Construction	Glass Area [m²]	Area of One Opening [m²]	Glass U-Factor [W/m²K]	Glass SHGC
OS:SUBSURFACE 19	0000_PENCERE	3.85	3.85	2.670	0.764
	Parent Surface	**Shade Control**	**Glass Visible Transmittance**	**Azimuth [deg]**	**Cardinal Direction**
OS:SUBSURFACE 19	OS:SURFACE 35	No	0.812	270.00	W

Table 3.8 Exterior Door Details

	Construction	U-Factor with Film [W/m²K]	U-Factor no Film [W/m²K]	Gross Area [m²]	Parent Surface
OS:SUBSURFACE 10	000_EXTERIOR DOOR	1.181	1.181	9.00	OS:SURFACE 37
OS:SUBSURFACE 1	000_EXTERIOR DOOR	1.181	1.181	16.00	OS:SURFACE 5
OS:SUBSURFACE 2	000_EXTERIOR DOOR	1.181	1.181	16.00	OS:SURFACE 10

Internal spaces and boundaries of the building are shown in the Figure 3.8.

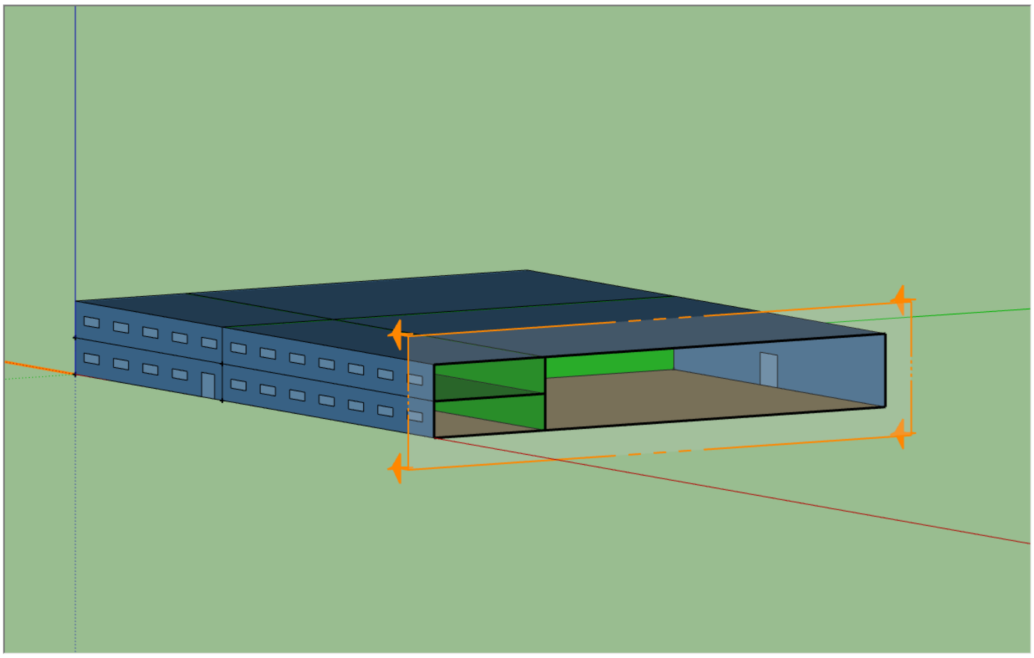

Figure 3.8 Internal Spaces and Boundaries

All spaces are defined to be "ASE SPACE" regarding their head construction sets. Figure 3.9 shows space types of 6 spaces defined for the building.

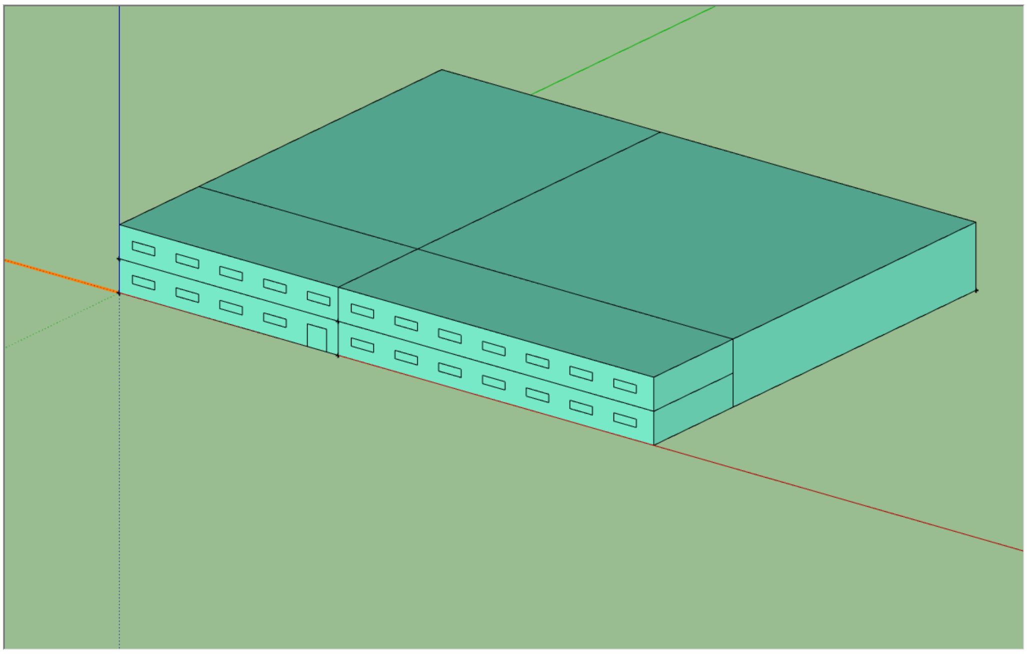

Figure 3.9 Analysis Building View (Space Type)

The building is divided into two thermal zones as halls and offices. Loads for occupancy, lighting and equipments are calculated and presented in the Table 3.9. Regarding thermal zones, Table 3.10 presents the zone summary. Equipment loads consist workstations, personal computers, electrical and electronical test setups and other equipment. Floor plans of the buildings are presented in Figures 3.10 and 3.11.

Table 3.9 Occupancy, Lighting and Equipment Load Distributions

	Occupancy	Lighting	Equipment Load
Offices	0.095 people/m^2	12.08 W/m^2	56.81 W/m^2
Hall – 1	0.140 people/m^2	12.08 W/m^2	48.33 W/m^2
Hall – 2	0.103 people/m^2	12.08 W/m^2	19.07 W/m^2

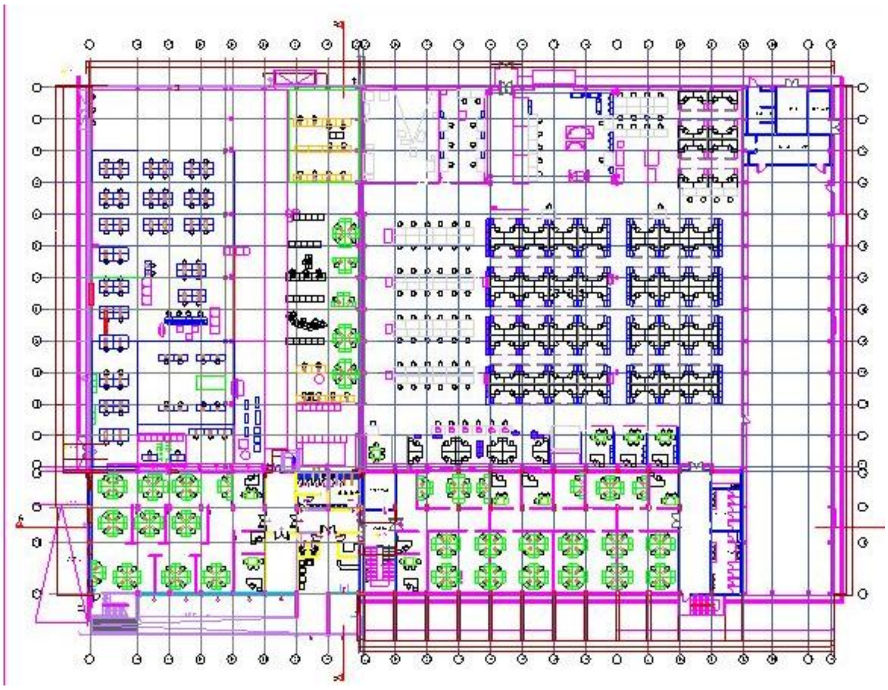

Figure 3.10: Building Plan (Ground Floor)

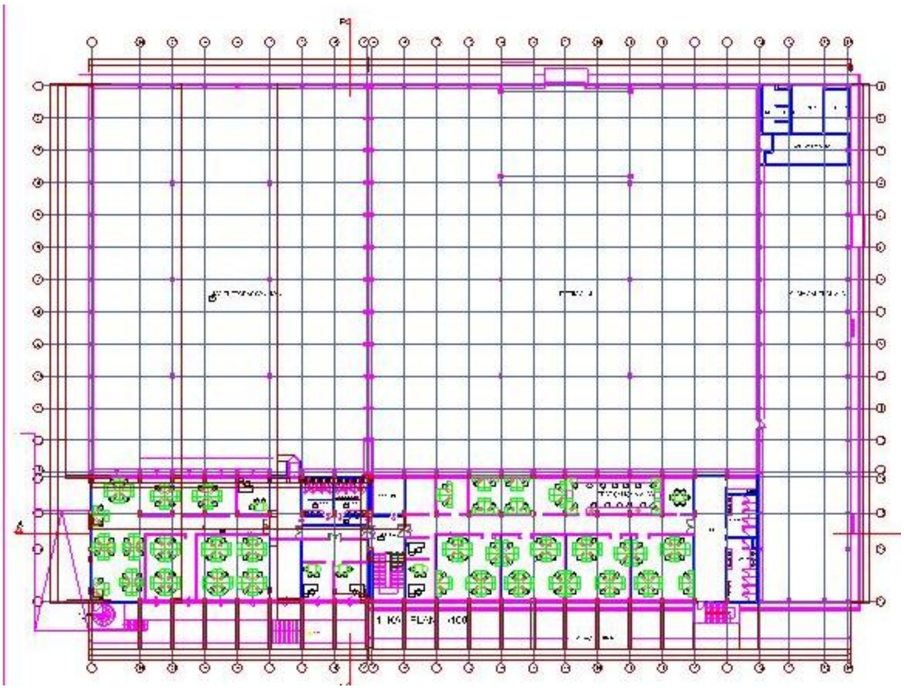

Figure 3.11: Building Plan (First Floor)

Table 3.10 Zone Summary

	Area [m²]	**Conditioned (Y/N)**	**Volume [m³]**	**Gross Wall Area [m²]**
OS:THERMALZONE 4	1328.00	Yes	11952.00	1035.00
OS:THERMALZONE 3	4067.00	Yes	36603.00	1629.00
Total	5395.00		48555.00	2664.00
Conditioned Total	5395.00		48555.00	2664.00
Unconditioned Total	0.00		0.00	0.00
	Window Glass Area [m²]	**Lighting [W/m²]**	**People [m²/person]**	**Plug and Process [W/m²]**
OS:THERMALZONE 4	88.55	12.0800	2.96	124.7100
OS:THERMALZONE 3	0.00	12.0800	2.96	124.7100
Total	88.55	12.0800	2.96	124.7100
Conditioned Total	88.55	12.0800	2.96	124.7100
Unconditioned Total	0.00			

Weather data file is available for Ankara as **TUR_Ankara_171280_IWEC.epw** in USDOE website. The simulation details are summarized in Table 3.11 and Figure 3.12. More information are presented in Appendix E.

Table 3.11: Simulation Details

Weather File	**TUR_Ankara_171280_IWEC.epw**
Location	ANKARA_TUR Design_Conditions
Lattitude	39.96 N
Longitude	32.76 E
Time Zone	+2.0
Elevation	949.0m

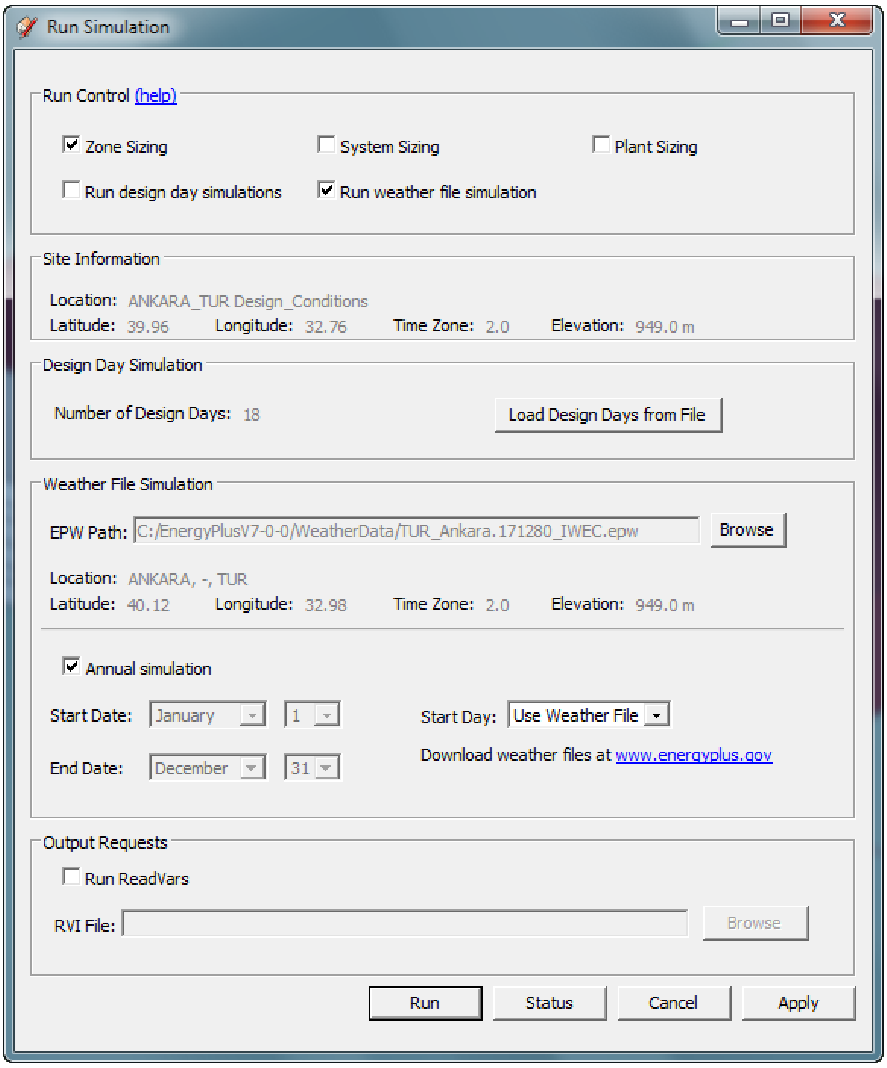

Figure 3.12: Simulation Details

In the analysis weather file for Ankara is used and the annual simulations are made for ideal air loads regarding weather file by Energy Plus. Ideal air loads means that performance of the HVAC system is idealized such that the thermostat values are perfectly supplied by the HVAC system.

An example thermostat definition with schedules is given in the Figure 3.13, detailed schedules are presented in Appendix F.

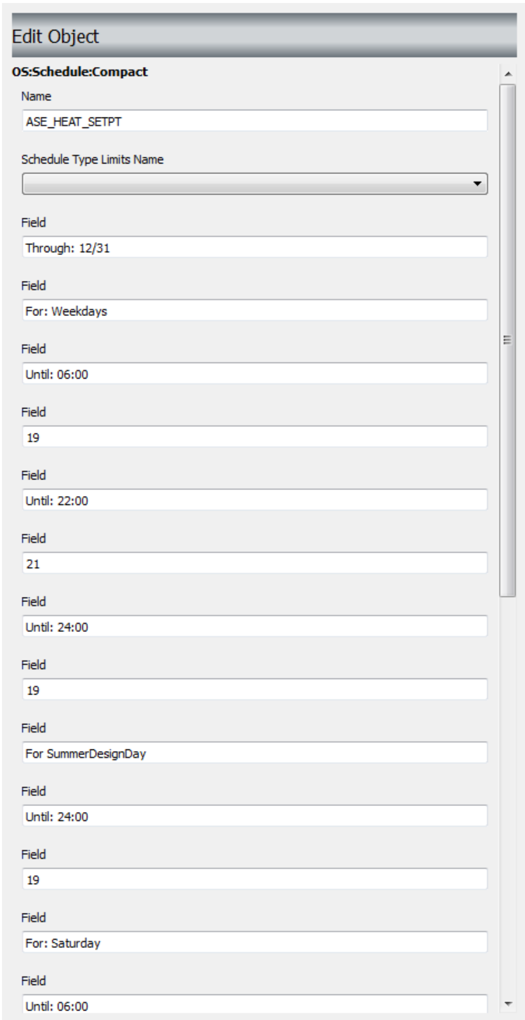

Figure 3.13: Thermostat Definitions and Schedules

Results of existing building analysis are presented in Section 3.3.2, as Site and Source Energy, Zone Cooling and Heating, Average and Minimum Outdoor Air, and Heat Gains.

3.3.2 Existing Building Analysis Results

Existing building analysis results are presented in the following tables.

Table 3.12: Site and Source Energy

	Total Energy [GJ]	Energy Per Total Building Area [MJ/m^2]	Energy Per Conditioned Building Area [MJ/m^2]
Total Site Energy	39798.69	7376.96	7376.96
Net Site Energy	39798.69	7376.96	7376.96
Total Source Energy	122656.36	22735.19	22735.19
Net Source Energy	122656.36	22735.19	22735.19

Table 3.13: Zone Cooling (Cooling Design Days)

	Calculated Design Load [W]	User Design Load [W]	Calculated Design Air Flow [m^3/s]	User Design Air Flow [m^3/s]
OS:THERMALZONE 4	727331.47	727331.47	73.642	73.642
OS:THERMALZONE 3	2180358.78	2180358.78	220.755	220.755
	Design Day Name	**Date/Time Of Peak**	**Temperature at Peak [°C]**	**Humidity Ratio at Peak [kgWater/kgAir]**
OS:THERMALZONE 4	ANKARA ANN CLG .4% CONDNS DB=>MWB	8/21 15:00:00	33.00	0.00781
OS:THERMALZONE 3	ANKARA ANN CLG .4% CONDNS DB=>MWB	8/21 15:00:00	33.00	0.00781

Table 3.14: Zone Heating (Heating Design Day)

	Calculated Design Load [W]	User Design Load [W]	Calculated Design Air Flow [m^3/s]	User Design Air Flow [m^3/s]
OS:THERMALZONE 4	359116.57	359116.57	15.651	15.651
OS:THERMALZONE 3	1154654.00	1154654.00	50.322	50.322
	Design Day Name	**Date/Time Of Peak**	**Temperature at Peak [°C]**	**Humidity Ratio at Peak [kgWater/kgAir]**
OS:THERMALZONE 4	ANKARA ANN CLG 2% CONDNS DP=>MDB	8/21 07:00:00	7.99	0.00746
OS:THERMALZONE 3	ANKARA ANN CLG 2% CONDNS DP=>MDB	8/21 07:00:00	7.99	0.00746

Table 3.15: Average Outdoor Air During Occupied Hours

	Average Number of Occupants	Zone Volume [m^3]	Infiltration [ACH]	Simple Ventilation [ACH]
OS:THERMALZONE 4	95.72	11952.00	0.051	4.896
OS:THERMALZONE 3	293.14	36603.00	0.051	4.895

Table 3.16: Minimum Outdoor Air During Occupied Hours

	Average Number of Occupants	Zone Volume [m^3]	Infiltration [ACH]	Simple Ventilation [ACH]
OS:THERMALZONE 4	95.72	11952.00	0.001	0.000
OS:THERMALZONE 3	293.14	36603.00	0.001	0.000

Table 3.17: Surfaces by Class

	Total	Outdoors
Wall	20	12
Floor	4	4
Roof	4	4
Building Detached Shading	0	0
Fixed Detached Shading	0	0
Window	23	23
Door	3	3
Glass Door	0	0
Shading	0	0
Overhang	0	0
Fin	0	0
Tubular Daylighting Device Dome	0	0
Tubular Daylighting Device Diffuser	0	0

Table 3.18: HVAC Summary

	Count
HVAC Air Loops	0
Conditioned Zones	2
Unconditioned Zones	0
Supply Plenums	0
Return Plenums	0

Table 3.19: Annual Building Sensible Heat Gain Components

	HVAC Input Sensible Air Heating [GJ]	HVAC Input Sensible Air Cooling [GJ]	People Sensible Heat Addition [GJ]	Lights Sensible Heat Addition [GJ]	Equipment Sensible Heat Addition [GJ]
OS:THERMALZONE 4	4219.142	-1480.062	366.500	195.508	2782.171
OS:THERMALZONE 3	13004.628	-4563.049	1123.004	598.743	8520.399
Total Facility	17223.769	-6043.112	1489.504	794.252	11302.570
	Window Heat Addition [GJ]	**Infiltration Heat Addition [GJ]**	**Window Heat Removal [GJ]**	**Infiltration Heat Removal [GJ]**	**Opaque Surface Conduction and Other Heat Removal [GJ]**
OS:THERMALZONE 4	141.996	300.604	-62.354	-6188.107	-275.398
OS:THERMALZONE 3	0.000	920.600	0.000	-18935.298	-669.027
Total Facility	141.996	1221.204	-62.354	-25123.404	-944.425

Table 3.20: Peak Cooling Sensible Heat Gain Components

	Time of Peak	HVAC Input Sensible Air Cooling [W]	People Sensible Heat Addition [W]	Lights Sensible Heat Addition [W]
OS:THERMALZONE 4	26-AUG-14:00	-710259.50	31607.68	14438.02
OS:THERMALZONE 3	26-AUG-14:00	-2137866.95	96798.53	44216.42
Total Facility	26-AUG-14:00	-2848126.45	128406.22	58654.44
	Equipment Sensible Heat Addition [W]	**Window Heat Addition [W]**	**Infiltration Heat Addition [W]**	**Opaque Surface Conduction and Other Heat Removal [W]**
OS:THERMALZONE 4	149053.39	38379.13	508692.92	-31911.65
OS:THERMALZONE 3	456476.01	0.00	1557872.08	-17496.10
Total Facility	605529.41	38379.13	2066565.00	-49407.75

Table 3.21: Peak Heating Sensible Heat Gain Components

	Time of Peak	HVAC Input Sensible Air Heating [W]	People Sensible Heat Addition [W]	Lights Sensible Heat Addition [W]
OS:THERMALZONE 4	28-JAN-08:00	1656969.96	33391.97	14438.02
OS:THERMALZONE 3	28-JAN-08:00	5068409.63	102262.91	44216.42
Total Facility	28-JAN-08:00	6725379.59	135654.88	58654.44
	Equipment Sensible Heat Addition [W]	**Window Heat Removal [W]**	**Infiltration Heat Removal [W]**	**Opaque Surface Conduction and Other Heat Removal [W]**
OS:THERMALZONE 4	66245.95	-4693.51	-1756608.49	-9743.90
OS:THERMALZONE 3	202878.23	0.00	-5379613.50	-38153.69
Total Facility	269124.18	-4693.51	-7136221.99	-47897.59

3.4. Analysis of New Design Building

3.4.1 Inputs, Properties and Explanations for New Building Analysis

This section is intended to analyze the improved building regarding the items described in the chapter "whole building design".

Improved analysis is done for the same building at the same location. Building shape, orientation and fenerstation openings are kept as it is. Loads and schedules have not been changed. Building envelope parameters are improved and thermal analysis is repeated. Differences are tabulated in the following section. Building envelope components are imporved as presented in Figures 3.14 and 3.15..

WALLS
Termojet Board Grout
Shapemate
Styrofoam
Finishing Concrete

FLOOR
Floormate
Concrete
Lean Concrete (Green)
Sand Fill
Slag Fill

MIDFLOOR
Termojet Board Grout
Lean Concrete
Floormate

Figure 3.14: Walls and Floor Material Layers (New)

ROOF and CEILING
Aluminum
Phenolic Foam
Roofmate
Aerated Concrete
Lean Concrete
Finishing Fill
Hekimboard

GLAZING
Clear 4mm
Argon Gap 12mm
Clear 4mm
Argon Gap 12mm
Clear 4mm

Figure 3.15: Roof-Ceiling and Glazing Materials (New)

Table 3.22: Opaque Exterior New Building

	Construction	Reflectance	U-Factor with Film [W/m²K]	U-Factor no Film [W/m²K]
OS:SURFACE 10	0000_GREEN_DIS	0.30	0.147	0.151
OS:SURFACE 7	0000_GREEN_FLOOR	0.30	0.360	0.395
OS:SURFACE 36	0000_GREEN_ROOF	0.30	0.261	0.275
	Azimuth [deg]	**Tilt [deg]**	**Cardinal Direction**	
OS:SURFACE 10	0.00	90.00	N	
OS:SURFACE 7	90.00	180.00		
OS:SURFACE 36	90.00	0.00		

Table 3.23: Fenestation Details New Building

	Construction	Glass Area [m²]	Area of One Opening [m²]	Glass U-Factor [W/m²K]	Glass SHGC
OS:SUBSURFACE 6	0000_GREEN_ WINDOW	3.85	3.85	1.628	0.685
	Parent Surface	**Shade Control**	**Glass Visible Transmittance**	**Azimuth [deg]**	**Cardinal Direction**
OS:SUBSURFACE 6	OS:SURFACE 17	No	0.738	270.00	W

3.4.2 New Building Analysis Results

New building analysis results are presented in the following tables.

Table 3.24: Site and Source Energy New Building

	Total Energy [GJ]	Energy Per Total Building Area [MJ/m²]	Energy Per Conditioned Building Area [MJ/m²]
Total Site Energy	25298.49	4689.25	4689.25
Net Site Energy	25298.49	4689.25	4689.25
Total Source Energy	51891.10	9618.37	9618.37
Net Source Energy	51891.10	9618.37	9618.37

Table 3.25: Zone Cooling New Building

	Calculated Design Load [W]	User Design Load [W]	Calculated Design Air Flow [m^3/s]	User Design Air Flow [m^3/s]
OS:THERMALZONE 1	663781.70	663781.70	65.695	65.695
OS:THERMALZONE 2	238599.81	238599.81	24.176	24.176
	Design Day Name	**Date/Time Of Peak**	**Temperature at Peak [°C]**	**Humidity Ratio at Peak [kgWater/kgAir]**
OS:THERMALZONE 1	ANKARA ANN CLG .4% CONDNS DB=>MWB	8/21 07:00:00	18.99	0.00781
OS:THERMALZONE 2	ANKARA ANN CLG .4% CONDNS DB=>MWB	8/21 17:00:00	30.84	0.00781

Table 3.26: Zone Heating New Building

	Calculated Design Load [W]	User Design Load [W]	Calculated Design Air Flow [m^3/s]	User Design Air Flow [m^3/s]
OS:THERMALZONE 1	56464.43	56464.43	2.711	17.183
OS:THERMALZONE 2	25588.63	25588.63	1.229	5.611
	Design Day Name	**Date/Time Of Peak**	**Temperature at Peak [°C]**	**Humidity Ratio at Peak [kgWater/kgAir]**
OS:THERMALZONE 1	ANKARA ANN HTG 99.6% CONDNS DB	1/21 24:00:00	-15.70	0.00107
OS:THERMALZONE 2	ANKARA ANN HTG 99.6% CONDNS DB	1/21 24:00:00	-15.70	0.00107

Table 3.27: Annual Building Sensible Heat Gain Components

	HVAC Input Sensible Air Heating [GJ]	HVAC Input Sensible Air Cooling [GJ]	People Sensible Heat Addition [GJ]	Lights Sensible Heat Addition [GJ]
OS:THERMALZONE 1	0.000	-9396.938	1042.039	597.634
OS:THERMALZONE 2	0.000	-3114.465	340.258	195.146
Total Facility	0.000	-12511.403	1382.296	792.779
	Equipment Sensible Heat Addition [GJ]	**Window Heat Addition [GJ]**	**Window Heat Removal [GJ]**	**Opaque Surface Conduction and Other Heat Removal [GJ]**
OS:THERMALZONE 1	8394.366	0.000	0.000	-637.101
OS:THERMALZONE 2	2741.017	127.716	-43.025	-246.647
Total Facility	11135.383	127.716	-43.025	-883.747

Table 3.28: Peak Cooling Sensible Heat Gain Components

	Time of Peak	HVAC Input Sensible Air Heating [W]	HVAC Input Sensible Air Cooling [W]	People Sensible Heat Addition [W]
OS:THERMALZONE 1	17-JUL-11:00	0.00	-595945.19	96798.53
OS:THERMALZONE 2	15-JUL-16:30	0.00	-211129.78	23289.87
Total Facility	17-JUL-11:00	0.00	-798360.02	128406.22
	Lights Sensible Heat Addition [W]	**Equipment Sensible Heat Addition [W]**	**Window Heat Addition [W]**	**Opaque Surface Conduction and Other Heat Removal [W]**
OS:THERMALZONE 1	44216.42	456476.01	0.00	-1545.78
OS:THERMALZONE 2	14438.02	149053.39	44347.54	-19999.04
Total Facility	58654.44	605529.41	9938.34	-4168.38

3.5. Analysis with TS 825

TS 825 “Thermal Insulation Requirements for Buildings” is a standard of Turkish Standards Institute last revised on May 2008. TS 825 covers rules to calculate annual energy requirement for space heating, maximum allowable heat loss values and other calculation methods for new buildings; and modifications of existing buildings more than 15% of floor area. meanwhile, the standard introduces maximum U – values for building envelope components. Therefore, it does not cover other design needs for energy calculation. The fundamental objective to introduce this standard was increasing energy savings by reducing the amount of energy used for space heating [41].

Unlike Energy Plus software, buildings’ properties such as orientation, relationship with environment, shape that affects shading, are not detailed as design parameters on TS 825 analysis.

On the other hand, solar gain calculations are made using monthly averages, which may not bring out the real results, but maxima. Solar intensity values are present for main directions, for directions in between, main values are taken.

Using a weather file brings hourly, daily values which show more the real case.

Also internal loads are defined considering building types as a constant wattage/area, with a usage factor. A schedule is missing therefore not showing the real situation. Scheduled, transient calculation is done with EP software.

If whole building is heated to the same temperature, and temperature difference between spaces is less than 4K, define the building as single space and use single space building definition method defined in TS 825 Item 2.2 [24].

Baysal presented a Visual Basic based software BuildMATE, that performes annual heating energy requirement calculation, total heat requirement calculation, heating system design and economical analysis in 2001. The software applies TS 825 calculation methods by inputting building design information, and using embedded material properties [41]. Nonetheless, TS 825 analysis presented in the following section are performed by Microsoft Excel macros developed for this thesis study.

Table 3.29: TS 825 Nomenclature

TS 825		
Definitions	**Symbols**	**Unit**
Monthly Heating Energy Need	$Q_{ı,month}$	J
Yearly Heating Energy Need	$Q_{ı,year}$	J
Building Specific Heat Loss	H	W/K
Monthly Average Outside Temperature	θ_e	°C
Monthly Average Inside Temperature	θ_i	°C
Internal Gains	$\varphi_ı$	W
Solar Gains	φ_g	W
Heat Gain Usage Factor	H	-
Building Usage Area	A_n	m^2
Building Gross Volume	V_{gross}	m^3
Building Heat Losing Surface Area Total	A_{total}	m^2
Atotal/Vgross	A_{total}/V_{gross}	m^{-1}

3.5.1 TS 825 Design and Calculation Methods

Monthly average outside temperature to be used in the calculations ($T_{o,monthly}$). is gathered by zoning definitions. Design building is located in ANKARA, which is in ZONE 3) in the TS 825 standard. See Appendix H for zone details.

Table 3.30 and Figure 3.16 shows Monthly Average Outside Temperature to be used for Daily Zone Temperatures for ANKARA. (TS 825 Appendix – B.2)

Table 3.30: Monthly Average Temperatures for ANKARA

Month	$\theta_{e,month}$ [°C]	Month	$\theta_{e,month}$ [°C]
January	-0.3	July	21.7
February	0.1	August	21.2
March	4.1	September	17.2
April	10.1	October	11.6
May	14.4	November	5.6
June	18.5	December	1.3

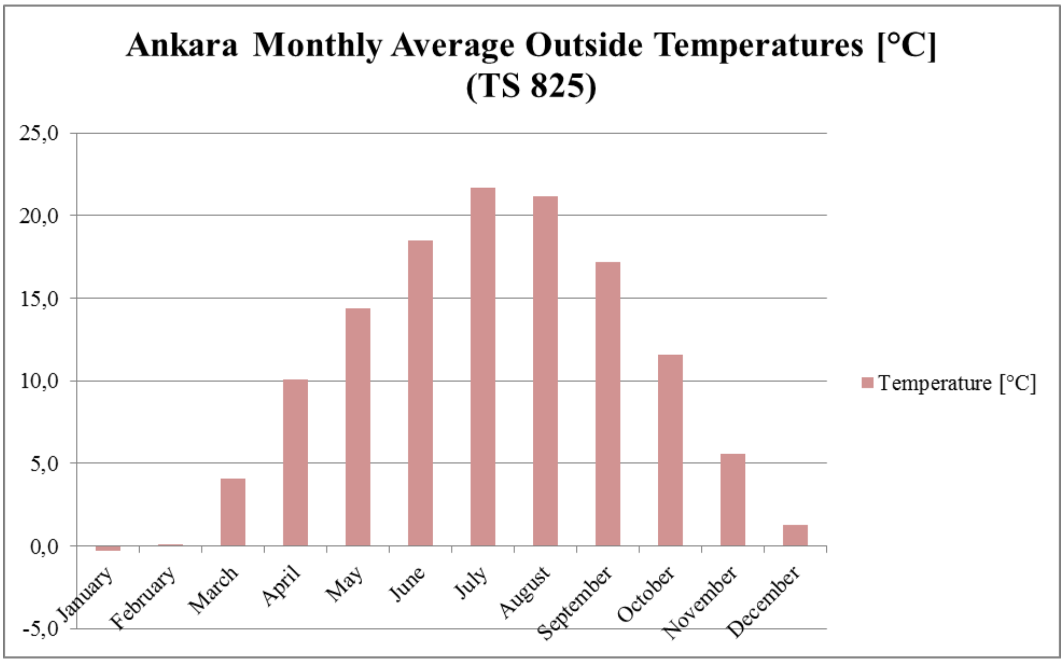

Figure 3.16: Monthly Temperature Distribution of ANKARA

Building size and calculation method should be defined considering inside thermal spacing. Wall, floor, ceiling and glazing areas are calculated and presented in Table 3.31.

Table 3.31: Building Dimensions TS 825

		Area [m²]	a (x) [m]	b (y) [m]	h (z) [m]	Space
Outside Wall	Aow	2005.85	83	65	9	Hall + Ground Floor
Glazing Inc. Windows & Doors	Awin	88.55	83	16	4.5	First Floor
Roof - Ceiling	Ar-c	5395.00				
Floor	At	6723.00				
Total	Atotal	14197.00				
Vgross	Vgross	48555.00				
	Atotal/Vgross	0.29				

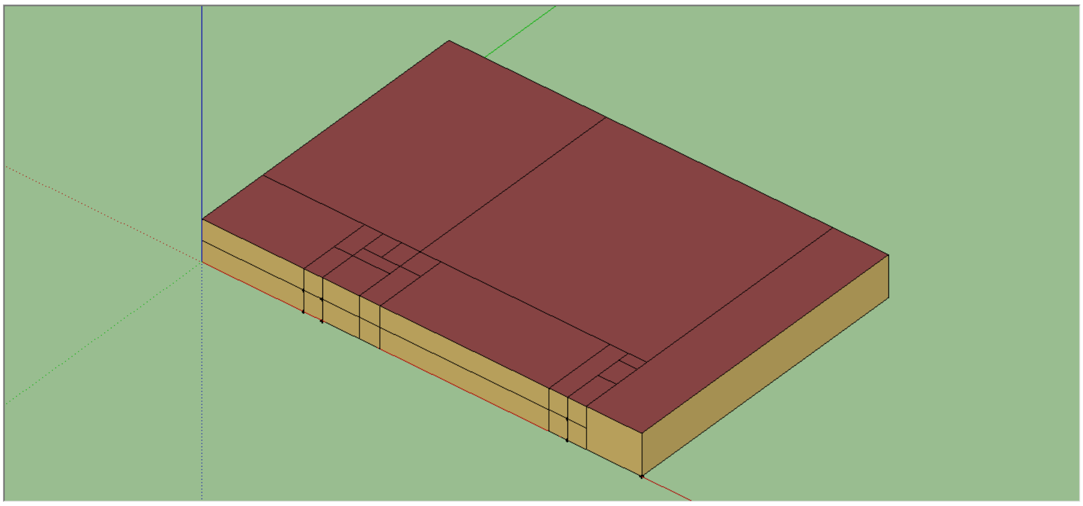

Figure 3.17: Building Isometric View

Although design temperatures for offices (commercial buildings) are to be chosen as 19°C, for analysis similarity, and to be more consistent with the real case, design temperature is selected as 22°C, chosen from TS 825 standard [24]. Envelope U – values are calculated and details are presented in Table 3.32.

Table 3.32: Calculated U Values TS 825

		d [m]	k [W/mK]	d/k, 1/α [m^2K/W]	U [W/m^2K]
Outside Walls (U_{ow})	$1/\alpha_i$			0.143	
	GypsumBoard	0.011	0.180	0.061	
	GlassWool	0.050	0.034	1.471	
	Aerated Concrete	0.200	0.100	2.000	
	PVC	0.010	0.200	0.050	
	$1/\alpha_d$			0.050	
	Total			**3.775**	**0.265**
Floor (U_f)	$1/\alpha_i$			0.200	
	Finishing Concrete + Grout	0.050	1.200	0.042	
	Concrete	0.200	1.800	0.111	
	Lean Concrete	0.100	1.500	0.067	
	Sand Fill	0.300	0.600	0.500	
	Slag Fill	0.400	0.200	2.000	
	$1/\alpha_d$			0.000	
	Total			**2.919**	**0.343**
Roof (U_r)	$1/\alpha_i$			0.143	
	Aluminum			0.000	
	Polystyrene	0.080	0.024	3.333	
	Aluminum			0.000	
	$1/\alpha_d$			0.050	
	Total			**3.526**	
Ceiling (U_c)	$1/\alpha_i$			0.143	
	Ceramic	0.020	0.850	0.024	
	Finishing Fill			0.000	
	Finishing Concrete	0.030	1.200	0.025	
	Reinforced Concrete	0.150	1.800	0.083	
	$1/\alpha_i$			0.143	
	Total			**0.418**	
	Total (U_r+U_c)			**3.944**	**0.254**

Monthly average solar radiation values are entered as given in TS 825 (Monthly Average Solar Intensities [W/m^2]) for each direction North, South, West and East, respectively [24].

Table 3.33: Monthly Solar Intensities

	I South [W/m²]	I North [W/m²]	I West [W/m²]	I East [W/m²]
January	72	26	43	43
February	84	37	57	57
March	87	52	77	77
April	90	66	90	90
May	92	79	114	114
June	95	83	122	122
July	93	81	118	118
August	93	73	106	106
September	89	57	81	81
October	82	40	59	59
November	67	27	41	41
December	64	22	37	37

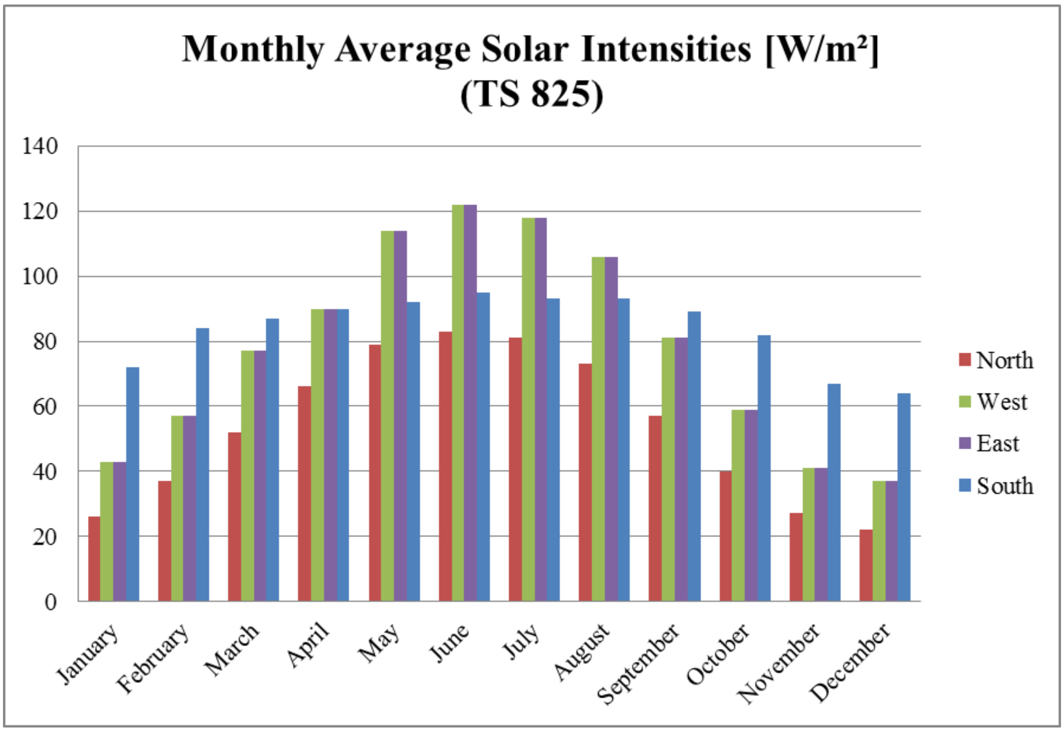

Figure 3.18: Monthly Average Solar Intensity Distribution

Based on total glazing area, Solar Gains are calculate and presented in Table 3.34. Factors and directional variables;

- ri,month: Building environment property, Ref:TS 825 Chart 5
- gi,month: Glazing property, Ref: TS 825 Chart 6
- Windows are placed on south surfaces (Ii,month is taken as southern intensities)
- A_i: Glazing area

Table 3.34: Solar Gains TS 825

	Solar Gain [W]	$r_{i,month}$	$g_{i,month}$	$I_{i,month}$ [W/m^2]	A_i [m^2]
January	1509.816	0.80	0.60	43.00	88.55
February	2001.384	0.80	0.60	57.00	88.55
March	2703.624	0.80	0.60	77.00	88.55
April	3160.080	0.80	0.60	90.00	88.55
May	4002.768	0.80	0.60	114.00	88.55
June	4283.664	0.80	0.60	122.00	88.55
July	4143.216	0.80	0.60	118.00	88.55
August	3721.872	0.80	0.60	106.00	88.55
September	2844.072	0.80	0.60	81.00	88.55
October	2071.608	0.80	0.60	59.00	88.55
November	1439.592	0.80	0.60	41.00	88.55
December	1299.144	0.80	0.60	37.00	88.55

Conduction and convection heat loss is calculated. Convective portionncan be neglected if no thermal bridge existence is assumed. U values for windows are taken as stated by the method considering window properties. For ventilation, TS Item 2.2.1.1.2 definitions is used.

Table 3.35: TS 825 Calculations

			Conduction					Ventilation & Infiltration	
Specific Heat Loss	H	12391.2	U		A		UxA		
Conduction &Convection	Hi	3025.9	U_{ow}	0.265	A_{ow}	2005.85	531.413	n_h	0.8
Vent. & Inf.	Hh	9365.3	U_{win}	3.400	A_{win}	88.55	248.710	V_h	38844
			U_{r-c}	0.254	A_{r-c}	5395.00	1367.981	e	0.1
			U_f	0.343	A_f	6723.00	2302.835	f	20
				V_f	20300				
				V_E	3900				
				V_S	20300				
				V_x	8005.66				
				V'	28305.66				
				r_o	1.184				
				C	1006				
				H_v	9365.273				
				N_{50}	5				

Constant internal gain values are defined considering building usage type (office, house, hospital etc.) as stated in TS 825.

Table 3.36: Internal Gains

	Month	**Gain [W]**
Average internal gains can be taken as a constant. For buildings that have electric components above average and most lighting with electricity; max. 10 W/m^2 (per floor area)	January	67230
	February	67230
	March	67230
	April	67230
	May	67230
	June	67230
	July	67230
	August	67230
	September	67230
	October	67230
	November	67230
	December	67230

Monthly and yearly heating needs are calculated (for some summer months, heating need may not exist) and compared to standard constraints to check whether the building design correct. Maximum allowable overall heat transfer coefficients should also be checked for envelope components.

3.6. Differences Between Energy Plus and TS 825

Thesis study provides building thermal solutions with Energy Plus and also TS 825. The differences between two methods have began to be examined started with inputing, and to resulting stages.

Basic differences observed between Energy Plus and TS 825 can be listed and summarized in Section 3.6.1.

3.6.1 Inputs

3.6.1.1. Daily Inputs

Energy Plus gather daily inputs and solutions to present the year round energy simulation of a building, while TS 825 standard has monthly averages to find the results. Meanwhile, EP is able to divide days into timesteps, to be defined by the user.

3.6.1.2. Inputting Schedules and Load Definitions

Scheduling and manual load definitions are available for Energy Plus software. For example, an occupancy schedule can be inputted considering subdaily timesteps, i.e. using daily frequencies of the occupancy, as well as weekly, and year round schedules, in order to put holidays etc. into the timetable. Moreover, schedules for lighting, equipment works, HVAC thermostat values, ventilation and infiltration are also available.

Similarly, loads can be defined by user, regarding the real case will or would happen in the building, in the format of W/m^2, W/person or $person/m^2$.

On the other hand, TS 825 standard provides constant tabulated values for building loads, as an overall for all load components.

Furthermore, solar loads are to be calculated in TS 825 solution by using monthly solar intensity averages. However, EP calculates solar gains daily, regarding time, solar angles and shadings.

3.6.1.3. HVAC System Definitions

HVAC systems designed can be defined in Open Studio. Supply – Demand sides, heaters, chillers, fans, pumps etc., are inputs of this Open Studio feature. In TS 825 definition an HVAC system input does not exist.

3.6.1.4. Weather Files

Weather files are the essential input file for Energy Plus simulation. These data are available for more than 2100 countries and available for downloading from USGBC website.

3.6.2 Outputs

Given the inputs to both Energy Plus and TS 825, year round solutions are gathered. However, while Energy Plus shows the real behavior of the building whole year and also daily, TS 825 solution compares the heating needed with design standards. Having mentioned that only heating need is calculated with TS 825 (e.g. for July month, heating will not be necessary for Ankara, since outdoor average temperature is higher than indoor design temperature); Energy Plus shows results for both heating and cooling, regarding building needs.

CHAPTER 4

GREEN METHODS

This chapter is devoted to a thorough presentation of all the aspects of the green (or passive) design methods available. According to Nayar.J, a green method is intelligent, rational and cost – effective [5].

Therefore, a green method can be an introduction of a highly efficient building envelope component, providing more natural ventilation, changing a schedule or application and realization of a green system.

4.1. Re – Introducing "Green"

The concept of green means acting similar or parallel to nature in general. A green application, material or product happens to be sensitive to human, nature, environment, and planet earth. It saves energy and money as well.

In case of a building, a green application cares about human health might satisfy better indoor air quality by providing natural ventilation or improving mechanical ventilation; avoid air pollution with the usage of non-toxic materials; or bring more natural light to rooms.

Using renewable natural sources, less energy and water, being cost – effective with high quality building materials and processes and less maintenance; a green building minimizes its environmental impact, wastes fewer sources at all times, recycles and conserves materials, reduces GHG emissions, ensures good IAQ and IEQ, aims producing more than it consumes.

4.2. Green Materials

Green building materials should be chosen among renewable sources, considering a lifetime environmental effect. A designer, arhitecht or engineer would have the word to specify durable, non-toxic, high-performance, and low waste materials for minimum energy consumption in the building. Misselection of materials causes pollution and threatens health and productivity of occupancy that spends 70% of time inside closures. [52]

Quality of green, sustainable materials are determined regarding the following factors. Energy required for production, resulting carbondioxide emission, environmental impact, toxicity of material, total energy consumed to transport and supply, and pollution level for materials’ life cycle. [37]

Green materials reduce environmental impacts, heed ecology and society also conserves people health. Green materials are harvested such that resources are used wisely by renewable methods, and also the product becomes renewable.
IAQ is preserved for built spaces since chemical emissions and toxic waste of green materials are very limited. By avoiding GHG emissions ozone layer is protected. , Even, procurement from local resources reduces transportation costs, which brings another burden to the environment if transportation distances are higher [62].

4.3. Green Roofs

As a passive, green method, green roofs are employed to stop the direct radiation effect of incoming solar rays to the building [26]. Either partly or fully covered with a layer of vegetation defines Sadineni [30] for green roofs.

Green roofs are classified as a green cooling technique. Providing reduction of the proportion of solar radiation that reaches to roof structure and beneath; also offering an additional insulation value and lesser environment temperature, green roofs helps cooling the building. The total improvement effect of green roofs can be presented with “albedo” number which is the ratio of total reflected incident to total incident. Higher albedo means higher reflection of solar incident. A green roof can have an equivalent albedo of 0.75 – 0.80 which is very close to the brightest possible white roof; on the other hand, bitumen, tar or gravel roofs have typically 0.1 – 0.2 albedo numbers [63].

Green roofs are reducing heat gains (or thermal load) to the building by means of conduction, radiation, evaporation and its thermal mass and insulation properties. Roof temperatures play an important role for heat exchange from exterior surface to interior especially in hot summer days. For example for a flat black roof which is covered with asphalt on its outmost layer, temperatures can go up to 80°C; whereas a green roof can reduce its outdoor temperature around 27°C which is closer to indoor design temperatures. Nichaou et al.presented a study for internal air temperatures of a building with existing insulation in the presence of green roofs. For a design day in July, internal air temperatures exceeded 30°C for 68% of period, but with a green roof, this was only for 15% of the period. Daily mean, maximum and minimum temperatures were found to be 2°C, 3°C and 1°C lower respectively [64].

Additionally, for a green roof, since heat accumulation during the day is less; therefore, less heat is released from the building to environment during the night. Consequently, ambient air temperature on top of vegetation layer decreases after sunset that cools the roof. On the contrary, heat accumulated by a black roof radiates back and heats the environment [26].

Outdoor temperatures coupled with solar gains bring the heaviest load that should be rejected (cooled) to a building. A green roof may reduce heat gains by 70% to 90% in summer as well as heat loss by 10% to 30% in winter [64].

Concept of evaporative cooling is also present for a green roof case. Green vegetation layer does photosynthesis which uses energy and water (vapor) acts a passive cooler by removing heat from the building.

Green roof components, soil, vegetation layer and auxiliary components present a thermal mass and insulation on top of the roof structure. Thermal mass helps stabilizing indoor air temperatures year round that provides better thermal comfort and creates a delay on peak load. Besides, additional effect of insulation improves the overall heat transfer coefficient that reduces heat transfer, and hence energy consumption. For a planted roof with thermal insulation and U – value of 0.4 W/m^2K, temperature difference across roof construction overall drops down to 2.5°C levels for a wide range of outdoor temperatures between -10°C and +40°C.

The effect of green roofs can be seen from U – value of roof construction with and without green roofs are preseted in Table 4.1 [26].

Table 4.1: U values for Roofs

Roof Construction	U – Value Without Green Roof [W/m^2K]	U – Value With Green Roof [W/m^2K]
Well Insulated	0.26 – 0.40	0.24 – 0.34
Moderately Insulated	0.74 – 0.80	0.55 – 0.59
Non Insulated	7.76 – 18.18	1.73 – 1.99

As can be resulted from the table, green roofs have an energy saving potential for all buildings, but more for non – insulated or moderately insulated constructions. Therefore, green roofs are a good option not only for new buildings obeying present building regulations that points high levels of insulation, but also will it give the most benefit to older buildings with poor insulation [26].

4.3.1. Green Roof Techniques

Green roofs firstly reduce the buildings' HVAC energy consumption by diminishing heat flowing into the building in summer and out from roof during winter due to insulation properties of added soil. In addition, green roofs act as an active cooling system to remove the heat from the roof through evapotranspiration (which also requires irrigation).

Recommended soil absorptivity values are given in the Table 4.2; compare it to a normal soil surface absorptivity of ~0.7 [26].

Table 4.2: Absorptivity Constants

City	Absorptivity
Atlanta	0.46
Denver	0.58
Honolulu	0.56
Los Angeles	0.62
New York	0.39
Phoenix	0.67
Seattle	0.36

With rapid growth of our cities, our environment is mostly covered with concrete and asphalt. Green fields left their spaces to housing and commercial buildings. Air pollution became a major problem for urban environment.

Large, tall buildings heat the environmental air by blocking air circulation. Urban and industrial areas increase water usage; besides, urbanization decreased natural soil content for rain water absorption, resulting in overloading sewer systems. Moreover, a lot of cities faced flood. Most efficient solution to these problems is to re – create green environments on top of buildings that destroy them, greening building roofs.

Figure 4.1: Green Roof Examples

*4.3.1.1. **Why Green Roofs?***

4.3.1.1.1. Decreasing Waste Water

A saving up to 90% of waste water coming from roofs can be reached depending on green roof design and chosen system properties. This way lightens sewer system loads of the city, alternatively, increase the possibility of providing more services with same material, or provide material savings by the reduction of system.

4.3.1.1.2. Create Environment with Lesser Dust

Green roofs help filtration of dust particles in atmosphere. Environmentally harmful elements such as nitrate inside air or rain water are absorbed and transmitted to soil.

4.3.1.1.3. Reducing Environmental Noise

Surfaces covered with green layers would provide a 3dB decrease on acoustic noise compared to other roof surfaces. In addition, noise passing to indoor environment can be reduced up to 8dB. This matter is particularly important for buildings close to airports or highways.

4.3.1.1.4. Acquiring New Utilization Areas

Outside environments covered with vegetation can be acquired instead of gravel roofs. For urban environment, where natural environment and life do not exist, green roofs may satisfy the need for gardens.

4.3.1.1.5. Changing Climatic Properties of the Environment

Amount of oxygen is increasing while plants breathe. Air cleanliness is procured especially for high construction of traffic areas, with green roofs. More rainy, livable environments, and cooler summers happens.

4.3.1.1.6. Increasing Roof Insulation

Green roofs insulate. Supported with polystyrene insulation, green roofs can achieve up to 50% increase on total insulation value. Better insulation means saving energy use for heating and cooling.

4.3.1.1.7. Increase the Life of Water Insulation

Green roofs prevent harsh effects of climate reaching to building structure. Therefore water insulation materials are secured from high temperature differences, dangerous UV rays, and mechanical damage.

4.3.1.1.8. Nature Means Beauty

Lack of natural environment in urban areas can easily be filled with greening roofs. The most positive assistance for urban buildings is bringing aesthetically beauties, natural beauties with green roofs.

Lastly, advantages and disadvantages of green roofs are tablulated in Table 4.3.

Table 4.3: Advantages and Disadvantages of Green Roofs

Advantages	Disadvantages
Storm water runoff reduction	Additional structural load
Reduced heat gains (in summer) and heat loss (in winter) to building envelope	Cost
Longer life for the base roofing system (may not apply to an intensive green roof)	Additional maintenance, ranging from limited for an extensive green roof with low – maintenance plants for high for a manicured landscape intensive roof
Reduced noise transmission	Optimal roof type, plant materials, and soil depths, will vary depending on climate
Aesthetic benefits to people in or around the building with the additional green space	Documentation of benefits such as reduction in heat island effect has not been proven
Other general environmental benefits, such as reduced nitrogen runoff (source: bird droppings), air pollutant absorption, potential carbon sink, bird habitat	

4.3.2. Types of Green Roofs

There exist two types of green roofs, as intensive and extensive. An intensive green roof means deeper layers for deep plants such as shrubs and trees. On the other hand, extensive green roofs have thinner layers for lower planting for grass [30].

Green roof systems are classified as intensive and extensive. An intensive green roof is a miniature of an ecosystem having a minimum of 30 cm soil thickness giving a burden to the building structure from 300 to 750 kg/m^2. On the other hand, extensive green roofs have a smaller soil thickness up to 15 cm. Commonly installed in modular plots, typical load of extensive systems is about 50 to 100 kg/m^2 [6].

Intensive method means the usage of bounteous amounts of soil, even letting tree planting on the roof. Intensive green roofs bring a burden of 300-750 kg/m^2 to roof structure, therefore static system should be designed accordingly. Besides, plants used with intensive green roofs need more maintenance and irrigation. These effects should also be considered while choosing the method of greening.

Extensive green roofs on the other hand are the appropriate choice for light roof gardens. Thanks to special materials and techniques, a load about of 50-100 kg/m^2 is added to the roof structure. In other words, greening roofs by removing gravel, concrete or ceramic, from a flat roof with or tile from an inclined one, would not bring much burden to the building. Moreover, extensive green roofs would need at most one or two times maintenance per year.

4.3.3. Green Roof Components and Their Properties

Green roofs are composed of several layers: Mainly, a waterproofing membrane, growing medium and vegetation layer. Also, a root barrier layer, drainage layer or an irrigation system can be added [30].

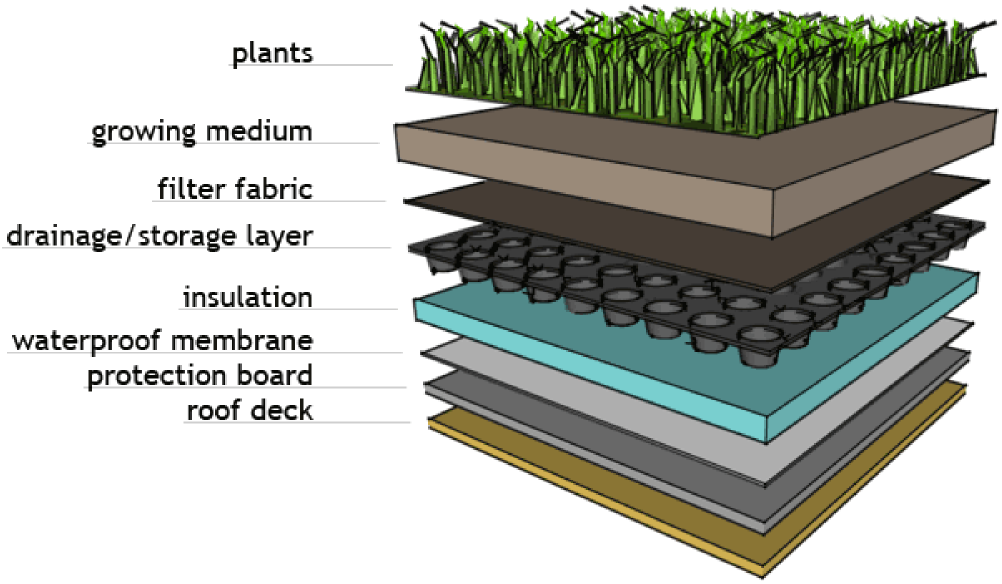

Figure 4.2: Green Roof Layers

4.3.3.1. ***Basic Layers***

4.3.3.1.1. Vegetation Layer

Vegetation layer should be in consistence with local climates, if applied systematically, will provide best results for the green roofs.

4.3.3.1.2. Vegetation Carrier Layer

Base soil meeting nutrition needs of vegetation, secures long life and properties desired for green roofs.

4.3.3.1.3. Filters and Drainage Layer

This layer is needed to collect filtered rain water for rainless days, at the same time, if accumulation of rain water is too much; drainage layer should discharge the excess amount in order to prevent rot/molding inside vegetation, and other layers.

4.3.3.1.4. Protection Layer Against Mechanical Effects and Humidity

Special carpets are resistive to rot/molding protect root holding layers and water insulation layer against mechanical effects.

4.3.3.1.5. Rot Holding Layer

Damage can be done by roots to water insulation layers should definitely be avoided. For this purpose, either special root holding layers or self-protective water insulation layers are employed.

4.3.3.1.6. Water Insulation and Roof Construction

The most important requirement for green roof application is to supply a water insulation layer and a statically stiff construction.

4.3.4. Roofs Types That Green Roofs Can Be Applied

Green roofs usually applied on roofs constructed considering reverse roofing rules, that have an inclination angle of 2°, and good insulated flat roofs. However, inclined roofs can be greened with proper methods. On the other hand, for special methods roofs without any inclination exist.

In addition to geometrical properties, roofs differ in material used and construction system. On principle, there is one greening method for any kind of roofs. For thermally non-insulated roofs such as garage, depot, car park, shading, etc. the only concern can be structural load carrying capacity. For insulated roofs, different types and application methods can be discussed.

4.3.4.1. ***Single Shell Non-Ventilating Roofs***

Also known as conventional roofs are used very frequently. For greening applications, one should take attention that a vapor resistive material of sd=100 m below insulation layer. Any kind of green roof application can be applied on conventional roofs.

*4.3.4.2. **Single Shell, Reverse Roofs***

Reverse roofs are the ones that have thermal insulation layer on top and water insulation layer on bottom. Materials that will be used for reverse roofs shall avoid drying of thermal insulation layer. Therefore, root holding layer should not be placed on top of thermal insulation layer.

*4.3.4.3. **Double Shell Ventilating Roofs***

Also known as cold roofs, this type presents a ventilation cavity on top of thermal insulation layer. Water insulation is applied on a secondary roof plane above this cavity. The only concern shall be the preparation of a strong layer for the secondary roof plane, which carries the green roof [65, 66, 67].

4.4. Green Walls (Vertical Systems)

In addition to green roof applications; being also a green method, green façade systems provide energy savings passively with climbing trees and plants. These systems help energy savings by shadow produced by living vegetation, additional insulation, evaporative cooling and wind barrier action. It has also ecological and environmental advantages [69].

Considering buildings to be responsible about 40% of emissions, CO_2 and GHG reductions that shall be made can be supplied vertical greening systems as it is done by green roofs.

Green façades also have effect on IEQ; influences comfort and well being. Improving air quality by reducing pollution (less dust levels), reduction of the heat island effect by avoiding re-radiation and humidity affected by evapotranspiration can be benefits of green living systems.

On the other hand, green façades had the problems such as damaging the façade materials, animal attraction, and maintenance costs. To avoid these problems, vegetation layers are hanged to modular trellises, wires or mesh structures in developed green façade systems.

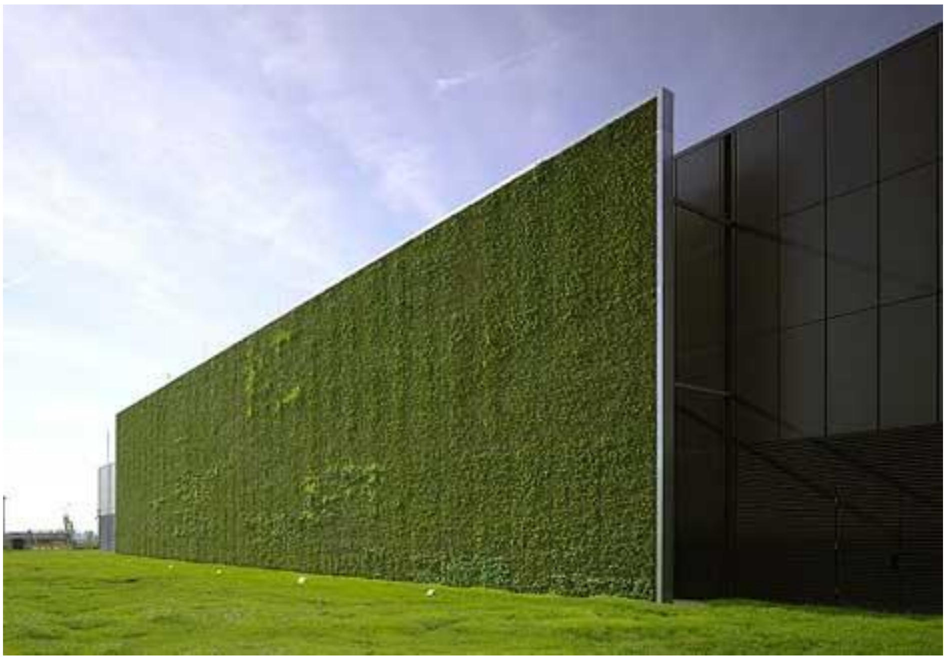

Figure 4.3: A Green Wall Application

Similar to green roofs, intensive and extensive systems exist for green façade applications.

Different mechanisms are considered for green vertical system usage. Solar radiation effect and shadow produced by the green layer; thermal insulation provided; evaporative cooling effect, wind blockage and others.

Akbari et. al resulted that trees’ shading provide about 30% energy savings on average and up to 42% peak loads for cooling season [13].

Previous studies showed that solar radiation reaching to a building is reduced to one sixth by shadow produced by trees. Also planting reduces internal temperature more than curtain blinds. Leaf surfaces goes up to 35°C while blind surfaces can heat up to 55°C [15].

With these positive effects of green façades, air conditioning system load is reduced by 20%.

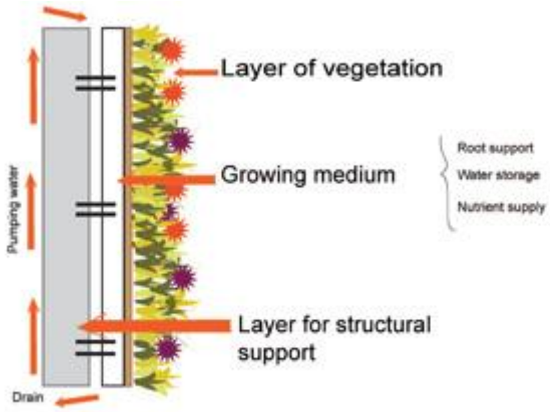

Figure 4.4: Green Wall System

In another application, 3.5 to 5.6 ° C indoor temperature reductions are achieved for cooling seasons and 3 °C increase for heating season. Perrini showed that urban heat island effect is reduced by 2-4°C with radiation reduction provided by solar radiation absorption of green layers, and 2-6°C with evapotranspiration effect, shading and humidity brings reduces A/C energy needed [70].

Solar radiation is stopped by 37% with one layer of leaves and 86% with five layers.

Shading effect and UV light reduction, green layers protect materials, coatings and paints; suitable both for new buildings and retrofitting projects.

Insulation properties of the building are also affected by green façades. A local climate is produced by green walls in between the building wall itself and green vegetation layer. Thickness of green layer creates a stagnant air layer and shading, water content changes insulation properties. Air layers between produces a very effective insulation. Best insulation results are obtained for southern façades, which reduces the highest solar radiation. Similarly, on west surfaces solar radiation is reduced by 28% on cooling season. Additionally, during heating season, heat loss is reduced up to 25% [71].

Moreover, enhanced with wind effect an evaporative cooling effect is created by evapotranspiration.

Vegetated wall surfaces protects the envelope component from wind flow, snow and rain; protects the building against the harsh environment, sun and also changes the visual.

Green façades improves visual, aesthetic and social aspects of the environment, economically influences the neighborhood and enhances human health. For example, green views help patients to recover more quickly.

“The system design can take into account many aspects, such as the integration with the building envelope, a sustainable material choice considering environmental impact but also symbiosis between the growing medium and the vegetation, which is a key element for the success of the greening system. Also the economical aspects, related costs savings due to possible reduction of energy needed for heating and cooling, have to be taken into account for avoiding a larger use of green envelopes in the urban area.” [70].

4.5. Other Green Methods and Applications

For energy production on site, locally harvested renewable wood for winter heating can be used.

4.5.1. Low – Energy Design Process

An integrated design procedure including extensive simulations should be used to minimize a building’s energy consumption. Passive solar applications, better thermally envelopes, day lighting and natural ventilation can be used. Passive downdraft cooling towers may provide cooling, and Trombe walls provide a significant amount of heat to the building. 67% savings are achieved in 2 years.

For large scale residential or commercial buildings, electricity generation can be done with renewable methods, with high quality and efficiency.

Usually, hydropower is the first renewable production method comes to mind. Being the least expensive method for large scales, electricity generation is done with the power of the water. In Turkey, the power of rivers is a good advantage.

Biopower or biomass mostly uses waste from wood-processes or agriculture, generating energy from combustion of such materials.

If high solar gains are present, a solar power generator can be employed. Solar power focused at a specific point is used to heat a fluid while the fluid transfers its energy to a conventional steam generator to boil the water.

Geothermal energy uses Earth's heated underground water and uses it to produce electricity.

Photovoltaic panels or solar cells are used in many areas to get power economically. A PV panel directly generates electricity from the sunlight with a solar cell.

Wind turbines are also widely used by power providers. Wind energy can be harvested anywhere in the world if a stable strong wind exists.

4.5.2. Solar Power

One of the green methods is to let the power of sun for some parts of buildings' energy (electricity) needs. Previously, solar power was mostly used for water heating or providing small amounts of electricity for some appliances. Today, developing technologies let gathering energy even to heat a pool for a residential building. Solar power depends highly on building and site properties, for example roof's orientation, size, shading and other factors [46].

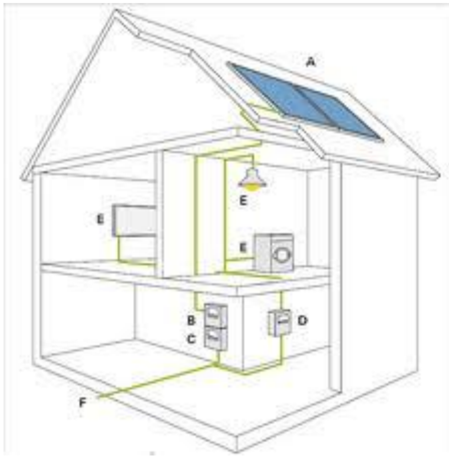

Figure 4.5: Solar Energy Chart of a House

4.5.2.1. ***Photovoltaics***

Photovoltaic panels are an array of solar modules to gather sun rays and turn it to electricity that a building needs. Mounted on roofs, PV panels electricity output is connected to building's electric distribution panel. Photovoltaics or Solar Batteries are square or circular devices about 100 cm^2, and 0.2 to 0.4 mm thickness [5, 37].

Some PV examples used in buildings are: A 5kW system of sleek polycrystalline of PV modules might cover several hundreds of sq. ft. of roof at an installation cost of 40 to 50k$ and generate 5.5 kWh per year. Another example can be Aldo Leopold Legacy Center in Wisconsin. The building has 39.6 kW rooftop photovoltaic arrays to produce about 10% more electricity than it needs [6].

Figure 4.6: A Building Roof Covered with PV Panels

*4.5.2.2. **Solar Powered Water Heater***

Solar power helps heating the domestic water before the delivery to the showers, sinks, and laundry etc. where the hot water is needed. A system with collectors mounted on the roof and storage tank provides the energy needed for an average scale residential house.

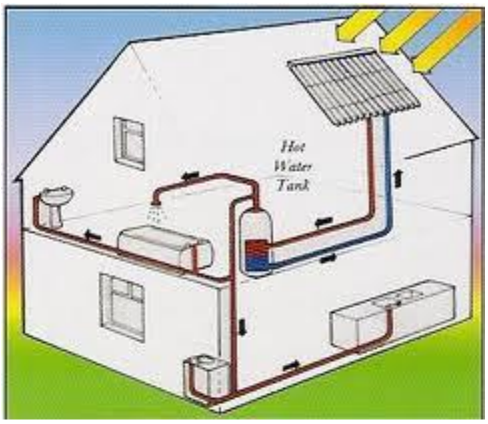

Figure 4.7: Solar Powered Water Heater System

4.6. Green Building Rating Systems

82 nations over the world are involved into WGBC (World Green Building Council) taking up green building initiatives above some level [30]. Most commonly used green building rating systems are LEED (USA), BREEAM (UK), R-2000 (Canada), DGNB (Germany), Green Star (Australia) and CASBEE (Japan).

4.6.1. LEED (www.usgbc.org/LEED)

Provided by USGBC, LEED is a worldwide green building rating system that evaluates green buildings over its lifecycle. LEED rating system has different categories that include detailed control lists. The system is used by engineers, architects, investors, service managers, landscape architects, builders and contractors. Having an integrated approach, LEED system evaluates buildings' performance regarding sustainable lands, water efficiency, energy and atmosphere, materials and resources, indoor and environmental quality, innovation and design process [72].

LEED has a number of categories that are applied and also some pilot applications.

Figure 4.8: LEED

LEED – NC (New Constructions) aims influencing green considerations and evaluates sustainability for office buildings, high-rise residential buildings, government buildings, commercial facilities, production facilities which are an in project phase. Since June 2006, Version 2.2 Rating System and Credit Checklist and LEED – NC Version 3.0 are applied. Percentage distribution of LEED – NC, Version 3.0 is presented as follows [37].

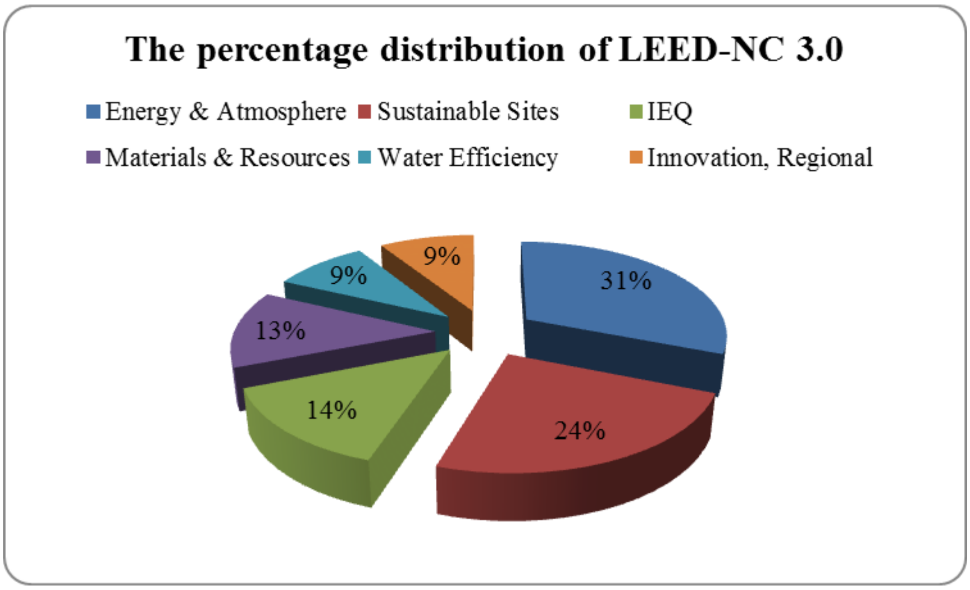

Figure 4.9: Percentage Distribution of LEED – NC 3.0

LEED – EB (Exiting Buildings) rating system on the other hand, helps building owners, administrators, or builders consider green methods that increase operation efficiency and reduce environmental impancts during maintenance and repair. This category covers maintenance, repair, cleaning chemicals, renewation programs and many other topics.

Being mostly used for rental office buildings, LEED – CI (Commercial Interiors) supports productive, healthy environments as well as aims reducing operational and maintenance costs.

LEED – S (Schools) is prepared considering K-12 schools' design and buildings bases. In addition to LEED – NC, it considers architectural planning, classroom acoustics, natural lighting, structural phyiscs, and mildew and fungus formation. Especially developed for school environments, LEED – S gives attention to children, professor and management health and sustainable schools.

Meanwhile, LEED – H (Hospitals) has special requirements of hospitals aiming long term sustainability. LEED – H (Houses) is developed for high performance green houses which draw attention to sustailability principles. On the other hand, LEED – CS (Core & Shell) for envelope and HVAC design; LEED – ND (Neighbour Development) for urbanization projects exist [72].

4.6.2. BREEAM (www.bre.co.uk)

Developed in UK since 1990, BREEAM is one of the most commonly used rating systems on an international level; especially influences environmental performances of commercial buildings. BREEAM approach supports most advanced sustainable technologies and environmental performance of buildings.

Figure 4.10: BREEAM

Over 115.000 buildings are certified with BREEAM which aims reduced energy consumptions, and highest environmental quality and indoor air qualities. Nine performance categories are graded at design, operation or maintenance basis. These are, building management, health and comfort, energy, transportation, water, materials, land, ecology and pollution.

BREEAM evaluates the performance for new or existing buildings and other building types. Ecohomes and Code for Sustainable Homes grades existing buildings and new buildings respectively. On the other hand, BREEAM Multi-Residential covers new or existing student hall residences, dormitories, or dispensaries. Yet, BREEAM Industrial, Offices, Retail, Healthcare, Schools, Prisons covers the related buildings. On an international level, BREEAM serves for the assessment of buildings according to their purposes [73].

4.6.3. R – 2000 (www.chba.ca)

Created by Natural Sources Canada, R – 2000 is a standard that aims building environmentally sensitive and energy efficient houses. The standard involves many technical conditions as well as national building codes. Designed by educated experts, over 10.000 R – 2000 houses cares about insulation, air tightness, fenestration performance, HVAC sizing and ventilation levels. In addition, R – 2000 standards lead buildings owners to apply some additional methods. These are low-e carpeting, air filtration systems, low-e paints, adhesives, coatings and floorings [74].

Environmentally, the buildings should contain renewable materials for insulation, coatings, plasterboards etc. have drainage plates, consist energy efficient equipment and high efficiency heating / cooling systems. Considering abovementioned standards and methods, sustainability and performance issues are solved according to building requirements, priorities and performance [74].

Figure 4.11: R - 2000

4.6.4. DGNB (www.dgnb.de)

Launched in 2008, the newest green building rating system is German Sustainable Building Council’s (DGNB) certification system. Although German Building Certificate has similar applications as LEED or BREEAM, it focuses more on Life Cycle Analysis of materials and costs.

Figure 4.12: DGNB

Six topic points are available in the system; Ecological Quality, Economical Qualiy, Socio – cultural and Functional Quality, Technical Quality and Quality of the Process. Meanwhile, Location Quality is considered separately, which does not count with overall building grade.

51 credit categories exist in the rating system, graded from one through ten points; also each category has a weighting value between 1 and 3 accoding to their importance.

DGNB have developed rating system for New Construction, Office and Administrative Buildings, Retail, Residential (Multifamily Residential Buildings with more than ten apartments), Industrial, Institutional, Existing Buildings, and Office and Administrative Buildings.

German Green Building Rating System is available for international projects since October 2010. Moreover, an international certification system for countries that are not represented in any system is prepared based on European building standards, regulations and datasets [75, 76].

CHAPTER 5

CONCLUSION and FUTURE WORK

5.1. Conclusion

This thesis study presented an alternative year-round energy performance simulation software, Energy Plus, its auxiliaries Open Studio and Google Sketchup; analyzed the case study building energy performance with existing properties and new properties. Moreover, same building analysis are performed by using Microsoft Excel macros with TS 825 standard; and two approaches are compared.

Whole building design concept with its components are presented, green methods and guidelines of are summarized in the thesis study. Whole building design concept covers and explains the following topics: Site design that includes location, size, shape and orientation of a building; envelope design with enveople properties of roofs, walls, floor and fenestration, also thermal and moisture control; indoor environmental quality considerations; efficient HVAC system suggestions; green methods, applications accompanied with tips and guidelines. Lastly, most widely-known green building rating systems are presented.

Firstly, EP software and auxiliaries is presented and analysis steps are explained. The capabilities of the software and the reason that it is chosen, can be summarized and compared with TS 825 as follows:

Being a freeware with its auxiliaries, EP is capable of running a whole year simulation with subdaily timesteps defined by user. Therefore, year-round real behavior of building is resulted. TS 825 checks whether the building is designed according to the code; however the real case would be different. These differences are caused by several calculation assumptions and approximations. Therefore, EP analysis shows a more approximated results to the real case.

Parameters of TS 825 are presented in averages. For example solar heat gains are provided as monthly averages, while the analysis of EP calculates the actual solar gains (considering shading from outdoors and building itself) and puts into the transient equation. In addition, indoor heat gains are taken into consideration as a constant value defined with respect to building or space type and includes heat gains from occupancy, lighting and equipment. Moreover, building heat load lacks also the daily schedule, which becomes very critical for a transient calculation.

On the other hand, EP analysis creates the chance to input the heat load variables one by one (different inputs for occupancy, lighting, equipment etc.) also scheduling these variables to simulate the buildings daily routines. Therefore, the transient solution takes on meaning.

Furthermore, calculation methods of TS 825 and EP's transient method create another difference to see the total building load. TS 825 standard applies if heating load exists, that is, if the building heat gains are more than heat discharge (no heating is necessary) for a monthly calculation, the equation results in zero for the specific month. Although it may also occur for year round analysis of EP, this excess heat is considered as cooling load to be discharged.

Another major difference is that the indoor design temperature is defined to be constant and specified for the building in TS 825, while indoor design temperatures are defined and scheduled by the designer for specific building requirements or parameters. Again the analysis becomes more realistic and accurate.

Although both calculation methods gets the input of envelope thermal properties and used the electrical resistance approach to calculate the overall heat transfer coefficient (may differ while including convective effects of indoor and outdoor air), specific heat values of materials are taken into consideration with EP that is necessary for the transient calculation. The designer or analyzer may also desire to input the HVAC system into the transient equation, which is also not possible with TS 825.

As a first step, existing building analysis are performed. Simulation done for 24 hours and 365 days by inputting building envelope properties, loads, schedules, thermostat values (with idealized HVAC system approach) and provided weather data has resulted in an energy consumption of **7376.96 MJ/m^2** for the existing building.

The second simulation is applied to see the difference if the envelope components are chosen to be high performance and green. Changing the materials used in walls, roof and floor, and also selecting of triple glazed windows reduced the energy consumption to **4689.25 MJ/m^2**.

A reduction about 36% is achieved only with envelope material changes (36% reduction means 13 points out of 19 in LEED certification system).

Later on, methods and parameters presented in TS 825 standard are applied and used, which results in 16.71 kWh/m^3 of total heating load for year round calculation and compared to standard limit 18.80 kWh/m^3 which approves the design.

Here, after the materials are selected, building shape and/or orientation, thermal schedules and set points may be changed and compared with the current energy consumption. Moreover, HVAC system properties can be included to the solution. Lastly, green methods can be applied and more energy consumption reductions can be achieved. Green roof applications would be easy for the flat roof of the building, expected to achieve a reduction about 30% to 40% roof heat gains.

Building orientation effect is examined in the study. Fenestration is on one side of building, and its area is very small compared to floor area. That is, indoor loads are greatly higher than solar effect. The analysis showed that, orientation change affects case study building's total energy consumption not more than one percent.

It would be easy to result that selective decisions on the design, materials or construction increase the cost of the building. However, energy conservation achieved, or added values of conserving the environment, balances the initial cost of the building. Especially during architectural design, right decisions and principles would increase the building's value; besides total material and construction cost can always be optimized. In the near future, green buildings would be more preferable by becoming more important and common. Specialists from architecture or building sector comment that investment cost of the construction increases by 4% – 8% by applying green considerations; whereas green building's energy conservation can go up to 50% – 70%. Therefore, it is concluded that energy saving green buildings have the advantage of decreasing operational costs in acceptable time periods.

5.2. Future Work

It is resulted that year round whole building energy analysis simulates total energy consumption easily. Changing the values (designing) of building site, envelopes, thermal loads, schedules, thermostats or any other parameter gets fast responses which are the very important for a project.

By using Energy Plus software and the auxiliaries Open Studio and Google Sketch-up, whole building design analysis can be performed for any building by any designer or project shareholder; as well as academic researchers or students. Thesis presents the usage of the above mentioned software and design guidelines to realize an energy saving building. In addition, green methods are suggested such that a green building is designed.

At the next step, if a project aims to have LEED or BREEAM or any other green building certificate, proposed and suggested methods are used and energy simulations must be done therefore Energy Plus is used. On the other hand, if any other design parameters or requirements exists for such guideline of certification systems; these can easily be implemented.

Whole building analysis is explained in detail. Yet, the example case is presented to show how the system work and what should be taken into consideration. Analysis are made by using all building parameters except HVAC system details (thermal conditions are assumed to be ideally satisfied regarding the input schedules and thermostats). Envelope parameters are changed and an energy saving about 30% is resulted. Therefore, other whole building design variables such as orientation, shape changes (if necessary), HVAC system detail inputting are left to future studies.

On the other hand, detailed indoor environmental quality analysis is not included; yet, IAQ analysis, visual analysis or noise analysis can be added to future projects.

New and innovative designs and materials are introduced to the marketplace daily therefore a careful designer should follow new technologies and products for projects.

Lastly, from an economical point of view, whole building analysis requires a detailed study for project cost and economy. Buildings site selection, closeness to urban life, ease of material finding and gathering; operational and maintenance costs should be considered for a project. Therefore, an economical study is suggested as future work, the expected values are an increase of 2% to 8% of initial costs, that recovers within 2 years; and reduction of operational costs about 30% to 40%.

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APPENDIX A

GREEN ROOF APPLICATION SYSTEMS

A.1 Extensive Green Roofing on Conventional Roofs up to %2 Inclination

For greening conventional roofs up to %2 inclination, and inclined roofs up to %10, water holding and drainage layers plays the important role.

Total System thickness: ~9cm
Water storage capacity: ~20-30l/m^2
System weight including vegetation: ~80-100 kg/m^2
Layers:

Extensive vegetation
Vegetation carrying layer
Filter
Water holding layer
Humidity holding and protective layer
Root holding layer and water insulation
Carrier system

A.2 Extensive Green Roofing on Conventional Flat Roof

Vegetation layer should be lifted adequately since standing water may cause vegetation to putrefy. In addition to this function, EPS layers also provide drainage function. Weight of polystyrene is less therefore total weight would not ascend.

Total System thickness: ~14cm
Water storage capacity: ~10-20l/m^2
System weight including vegetation: ~65-90 kg/m^2
Layers:

Extensive vegetation
Vegetation carrying layer
Filter
Water set layer
Humidity holding and protective layer
Root holding layer and water insulation
Carrier system

A.3 Extensive Green Roofing on Roof with Inclination Between 20% and 40%

Precautions should be taken to avoid slipping of system with inclined roofs. To achieve this goal, polystyrene layers that are strong against slippage can be employed. Additionally, for roofs higher that 30% inclination a jute mesh can be used under vegetation.

Total System thickness: ~13cm
Water storage capacity: ~20-30l/m^2
System weight including vegetation: ~80-100 kg/m^2
Layers:

Extensive vegetation
Jute mesh
Vegetation carrying layer
Water set layer
Humidity holding and protective layer
Root holding layer and water insulation
Carrier system

A.4 Extensive Green Roofing on Roof with Inclination Between 40% and 100%

For steeper roofs, it is very important to avoid slippage of vegetation and soil. This need can be achieved with a special anti-slippage layer. While the special layer is applied, no roof holding is used. However, if water insulation is necessary, this layer should be chosen tough against root forces and should be fixed mechanically.

Total System thickness: ~12cm
Water storage capacity: ~68l/m^2
System weight including vegetation: ~155 kg/m^2
Layers:

Extensive vegetation
Jute mesh (if vegetation carpet is not used)
Anti-slippage layer
Vegetation carrying layer
Root holding layer and water insulation
Thermal Insulation (XPS)
Vapor preventive layer
Carrier system

A.5 Extensive Green Roofing on Reversed Roofs

For reverse roof systems which are widely used on thermally insulated flat roofs, XPS sheets are exposed to rainwater, where evaporation must be avoided. Therefore, a separator layer rather than a thicker protective layer should be employed. Additionally, if root holding layer is necessary, this layer should be under thermal insulation layer.

Total System thickness: XPS + ~9cm
Water storage capacity: ~20-30l/m^2
System weight including vegetation: ~80-100 kg/m^2
Layers:

Extensive vegetation
Vegetation carrying layer
Filter
Water set layer
Separator layer (high vapor tranmission)
Thermal Insulation (XPS)
Root holding layer and water insulation
Carrier system

A.6 Intensive Green Roofing on Conventional Roofs up to %2 Inclination

Special water set layers for intensive vegetation has sufficient water storaage and drainage capacity with high mechanical strength. Water holding layer and protective layers should be chosen considering vegetation type.

Total System thickness: 16-20cm
Water storage capacity: 68l/m^2
System weight including vegetation: 180 kg/m^2
Layers:

Intensive vegetation
Vegetation carrying layer
Filter
Water set layer
Thermal Insulation layer
Root holding layer and water insulation
Carrier system

A.7 Intensive Green Roofing for Automatically Irrigated Vegetation

A special soil and water set layer allows automatic irrigation of vegetation layer from bottom. The level of water is controlled by buoys and valves.

Total System thickness: min. 27 cm

Water storage capacity: 113l/m^2

System weight including vegetation: min. 360 kg/m^2

Layers:

Intensive vegetation
Vegetation carrying layer
Filter
Soil appropriate for automatic irrigaiton
Water set layer
Humidity holding and protective layer
Root holding layer and water insulation
Carrier system

APPENDIX B

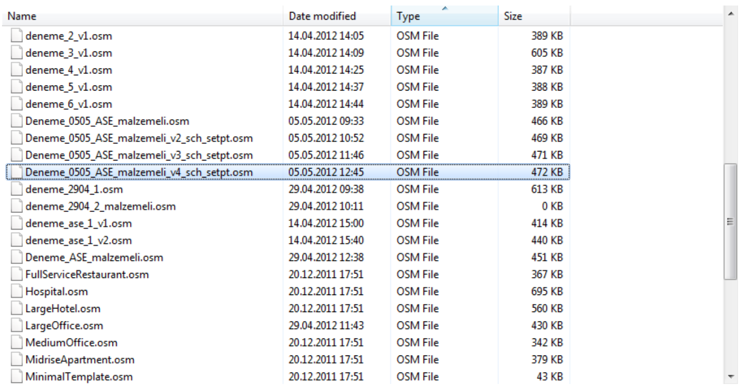
ANALYSIS STEPS

B.1 Preliminary Analysis Steps and Methods - Application

B.1.1 Template, Building Envelope and Constructions

1. Open a new Open Studio model from template
    a. Default templates provide a provision
    b. User may define his/her own template and/or modify any item on the pre-defined template model

Figure B.1 Open Studio Top Bar



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deneme_3_v1.osm	14.04.2012 14:09	OSM File	605 KB
deneme_4_v1.osm	14.04.2012 14:25	OSM File	387 KB
deneme_5_v1.osm	14.04.2012 14:37	OSM File	388 KB
deneme_6_v1.osm	14.04.2012 14:44	OSM File	389 KB
Deneme_0505_ASE_malzemeli.osm	05.05.2012 09:33	OSM File	466 KB
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Deneme_0505_ASE_malzemeli_v3_sch_setpt.osm	05.05.2012 11:46	OSM File	471 KB
Deneme_0505_ASE_malzemeli_v4_sch_setpt.osm	05.05.2012 12:45	OSM File	472 KB
deneme_2904_1.osm	29.04.2012 09:38	OSM File	613 KB
deneme_2904_2_malzemeli.osm	29.04.2012 10:11	OSM File	0 KB
deneme_ase_1_v1.osm	14.04.2012 15:00	OSM File	414 KB
deneme_ase_1_v2.osm	14.04.2012 15:40	OSM File	440 KB
Deneme_ASE_malzemeli.osm	29.04.2012 12:38	OSM File	451 KB
FullServiceRestaurant.osm	20.12.2011 17:51	OSM File	367 KB
Hospital.osm	20.12.2011 17:51	OSM File	695 KB
LargeHotel.osm	20.12.2011 17:51	OSM File	560 KB
LargeOffice.osm	29.04.2012 11:43	OSM File	430 KB
MediumOffice.osm	20.12.2011 17:51	OSM File	342 KB
MidriseApartment.osm	20.12.2011 17:51	OSM File	379 KB
MinimalTemplate.osm	20.12.2011 17:51	OSM File	43 KB

Figure B.2: OSM files

Above .osm template is prepared for trial analysis including building components, schedules, load definitions etc. Although saved .osm file includes previous building envelope drawings, new geometries can be created and used.

2. Draw the building plan using Google Sketch-up tools

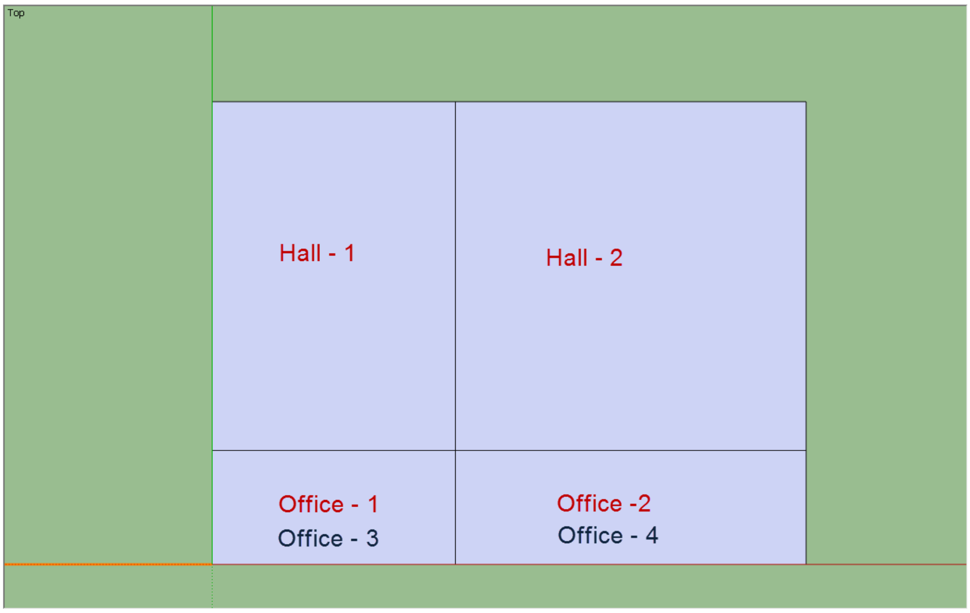


Figure B.3: Space Distribution of Building

The building consist four offices (two offices - double floors) and hall (single floor) types enclosures, as open offices. Therefore, all spaces would have similar characteristics and homogenous thermal conditions, so it is logical to define the spaces as such from an analysis and engineering point of view.

3. Use the tool “Create Spaces From Diagram” to create the building

Figure B.4: Create Spaces Tool

After the application, 6 spaces are created with desired dimensions. All space properties can be defined separately, or construction sets can be employed. The first view type is “Render by Surface Type” here, one can see the roof as red, and walls are yellow. Fenestration and doors will be shown as blue and brown, respectively.

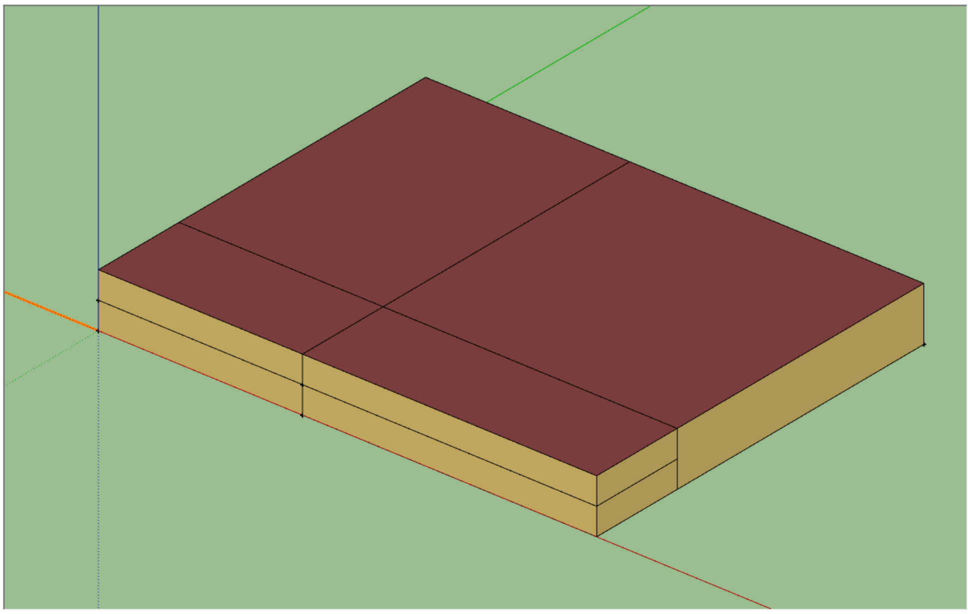


Figure B.5: Isometric View of Sample Building

4. Draw fenestration and door details on the envelope
    a. Then use the tool "Project Loose Geometry" to make the software that there is another surface on the related wall.

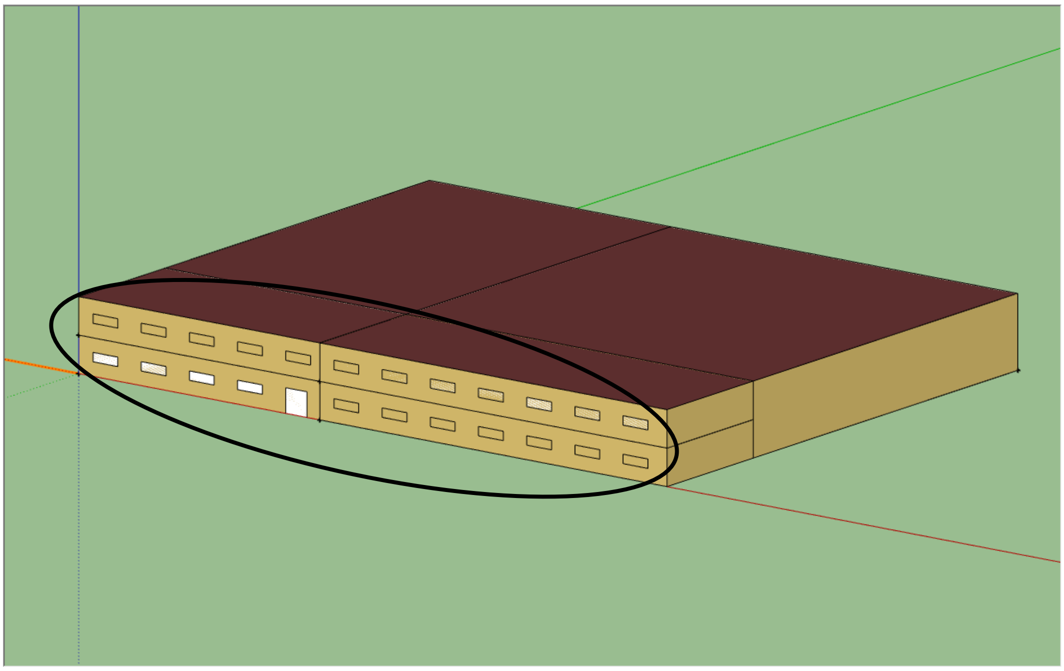


Figure B.6: Fenestration Drawing To Be Projected

Figure B.7: Project Loose Geometry Tool

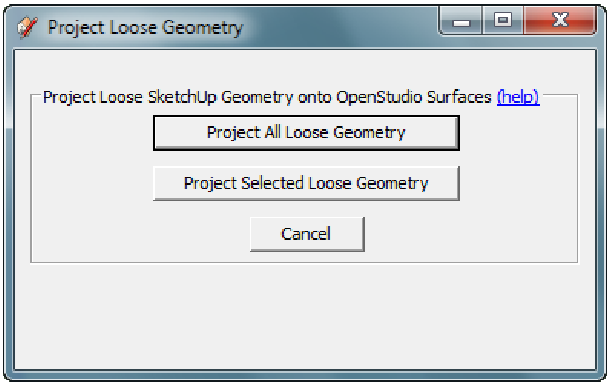


Figure B.8: Project Loose Geometry Interface

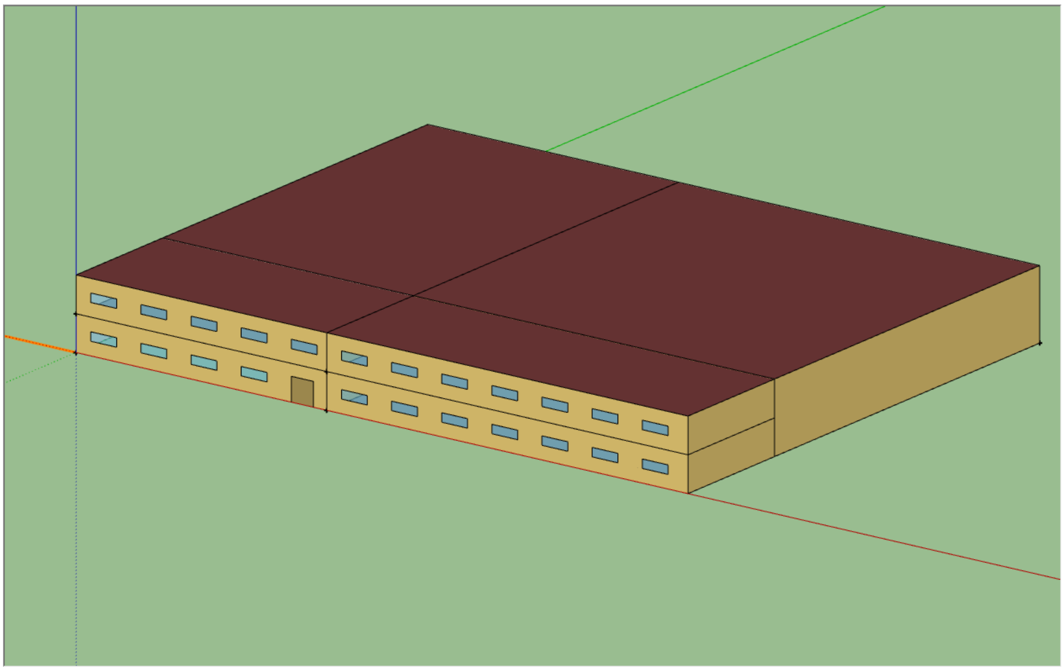


Figure B.9: Building View (Isometric View Front Side)

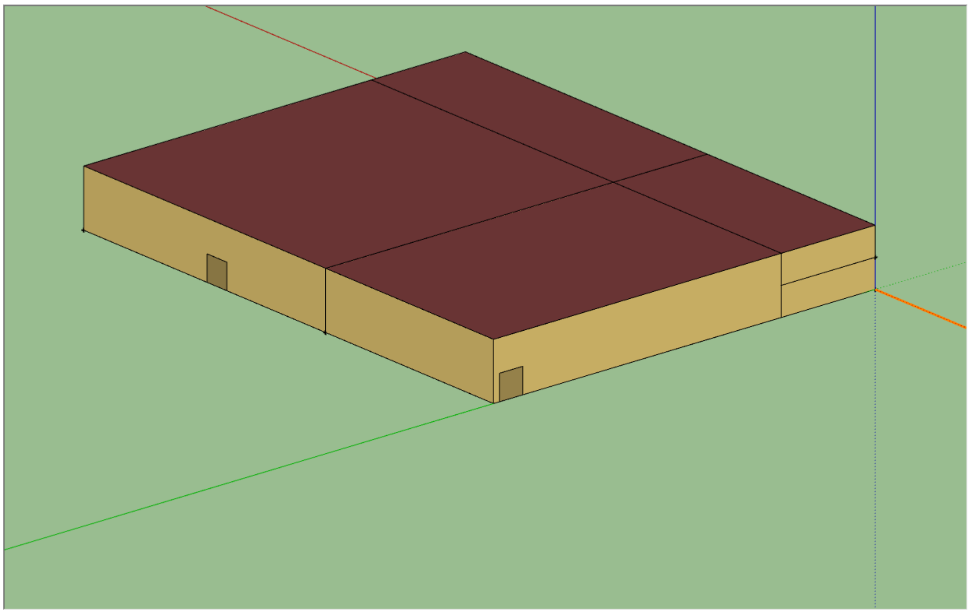


Figure B.10: Building View (Isometric View Back Side)

5. Switch to view "Render By Boundary Condition"

Figure B.11: Render By Boundary Condition Tool

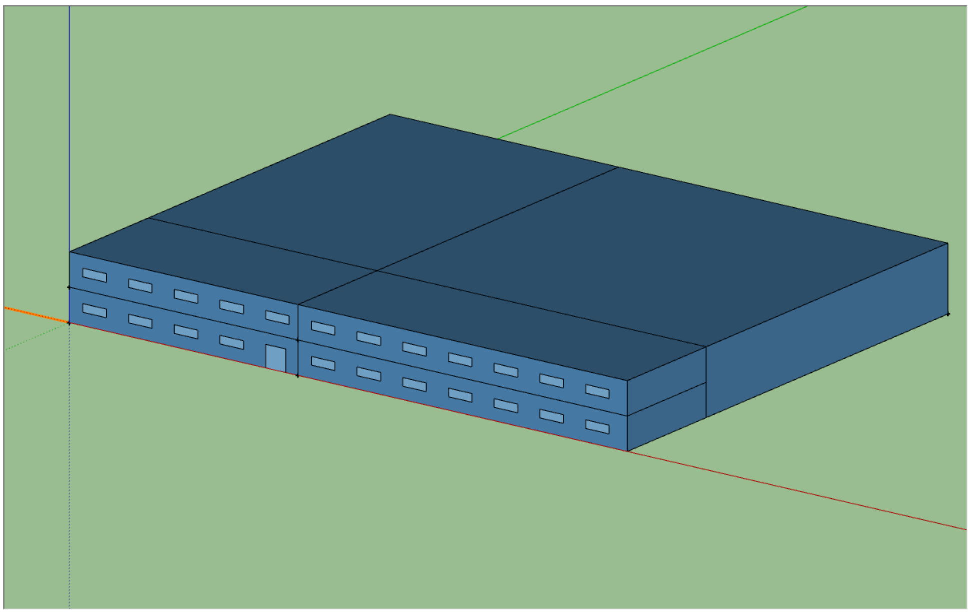


Figure B.12: Building Rendered by Boundary Conditions

6. Use "Surface Matching" tool to create adjacent surfaces such as internal walls, floors etc.
    a. If a surface which must be an internal surface and not presented as such,
        i. Either use "Intersect the Model" tool
        ii. Or manually match surfaces

Figure B.13: Match Tool

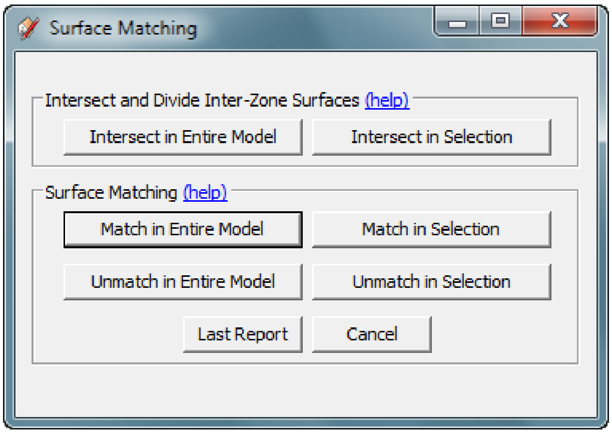


Figure B.14: Match Tool Interface

After intersection and matching, blue surfaces show outside BC, green surfaces show inside BC. Inside BC means a wall of a space has the adjacent space as its outside boundary. Therefore thermal equation would have the values of that space, not the outside weather data.

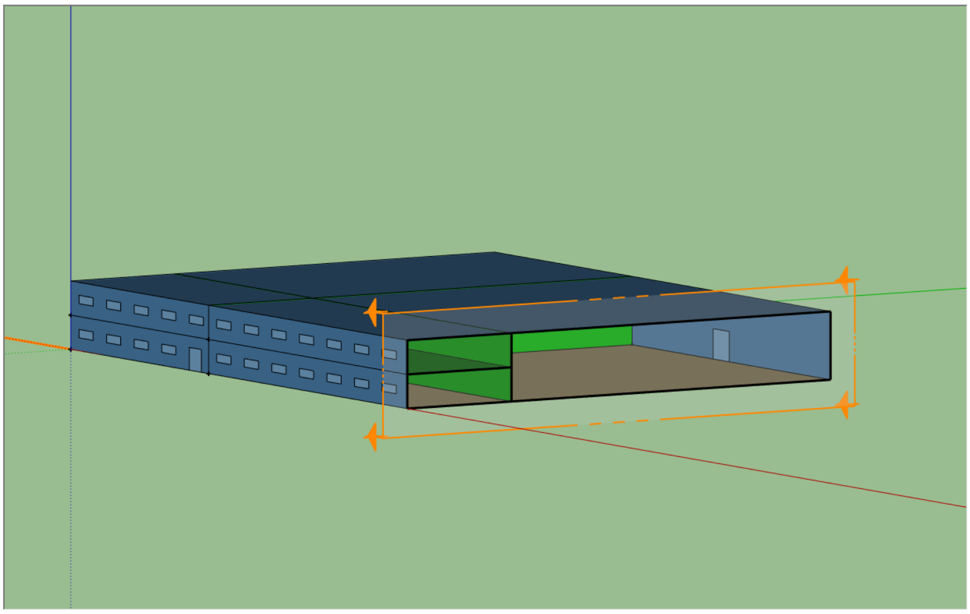


Figure B.15: Indoor Boundary Conditions and Section View

7. Open “Inspector” to build construction sets and change template variables etc.

Figure B.16: Inspector Tool

Besides the Inspector, “Set Attributes for Selected Spaces” can change space properties.

Figure B.17: Set Attributes Tool

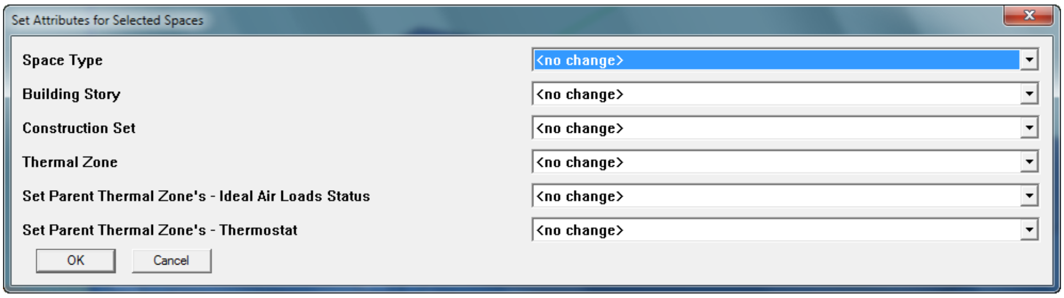


Figure B.18: Set Attributes Tool Interface

B.1.2 Building Activity, Thermal Zones and Weather

8. Switch to view "Render By Space Type"

Figure B.19: Render By Space Type Tool

9. Use "Set Attributes" tool to select predefined space types for building spaces. (or select from "Inspector")

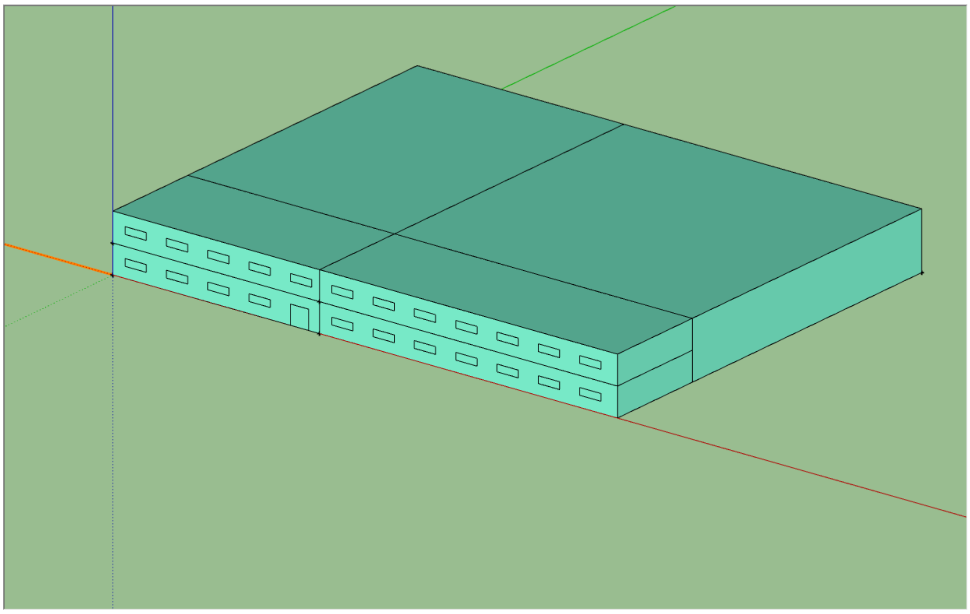


Figure B.20: Space Rendered By Space Type

All spaces are defined regarding their head construction sets. Therefore colors of the spaces are the same. Envelope material details shall be prepared inside construction sets.

10. Using “Inspector” define,
    a. Number of occupancy
    b. Schedules
    c. Lighting, equipment loads
    d. Fresh air requirements
    e. Any other attribute as an input to the analysis

11. Use “Set Attributes” tool to select thermal zones for each space
    a. Select “New Thermal Zone” if different properties exist for spaces

Figure B.21: Render By Thermal Zone Tool

Thermal zones for the offices are separated from the ones created for hall spaces.

12. Use “Set Attributes” tool to select thermostat values for each space

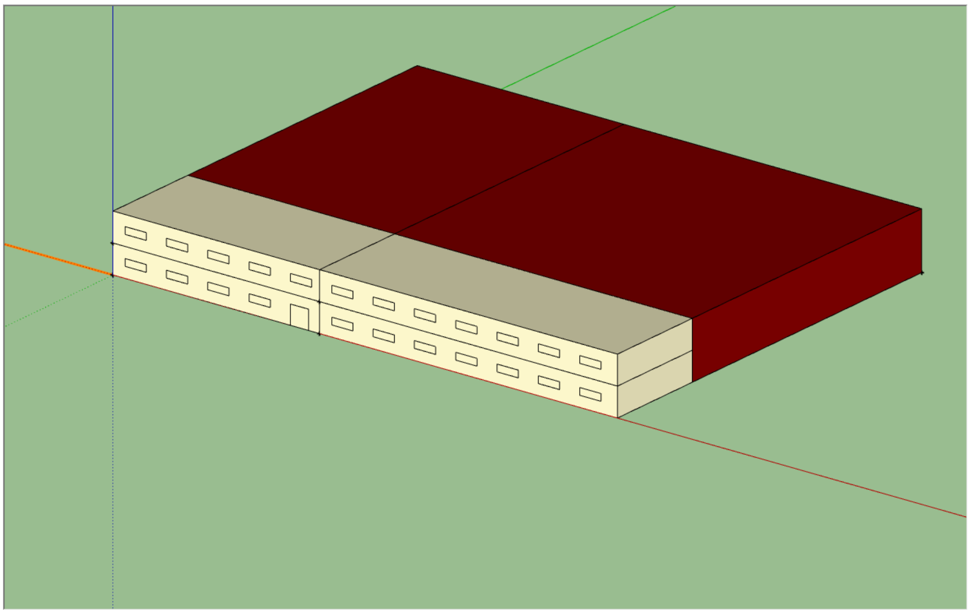


Figure B.22: Building Rendered By Thermal Zone

13. Use “Run Simulation” tool to include the weather file

Figure B.23: Run Simulation Tool

In the analysis weather file for available cities is used and the annual simulations are made for ideal air loads regarding weather file by Energy Plus. Ideal air loads means that performance of the HVAC system is idealized such that the thermostat values are perfectly supplied by the HVAC system.

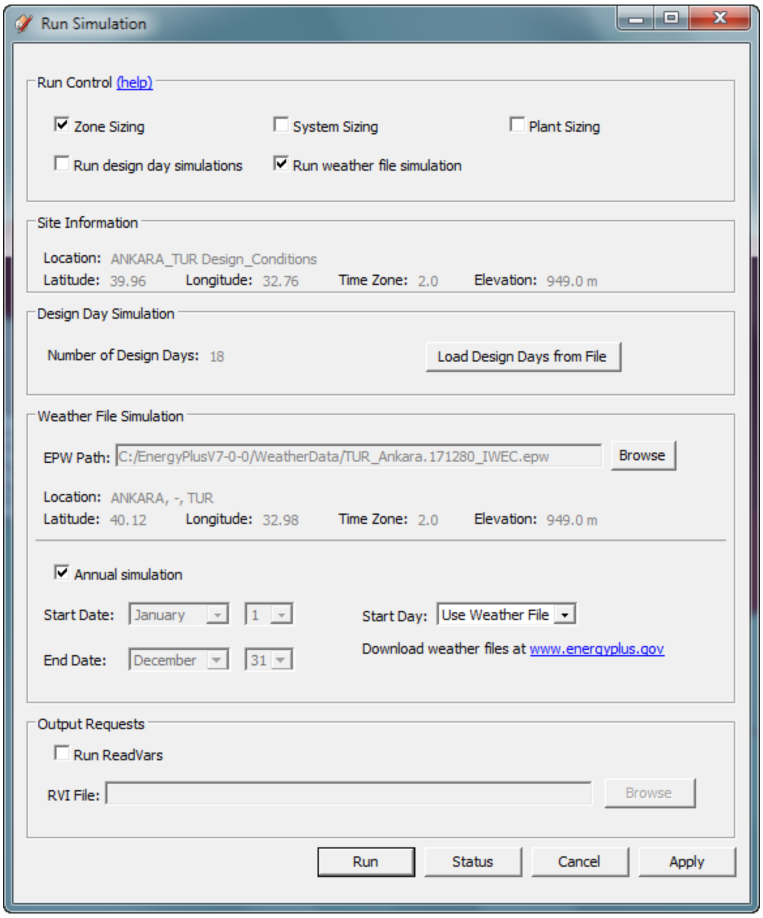


Figure B.24: Run Simulation Tool Interface

B.2 Example Roof / Wall / Floor / Fenestration Definitions as Materials In the Form of Layers.

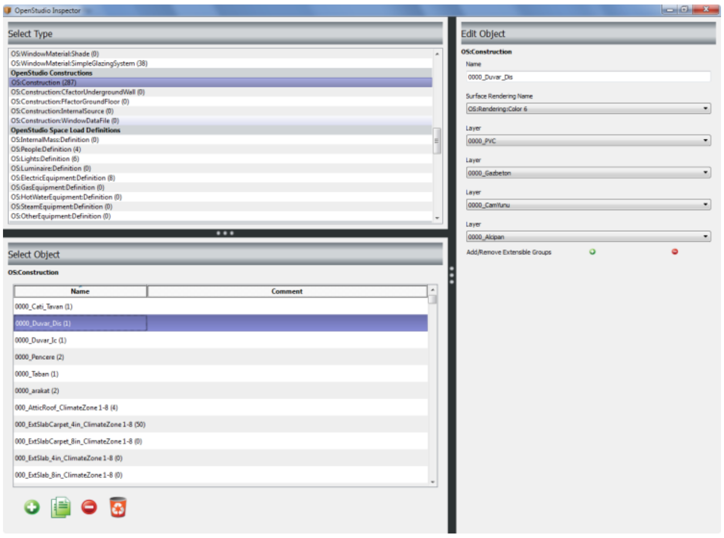


Figure B.25: Envelope Detail Interface

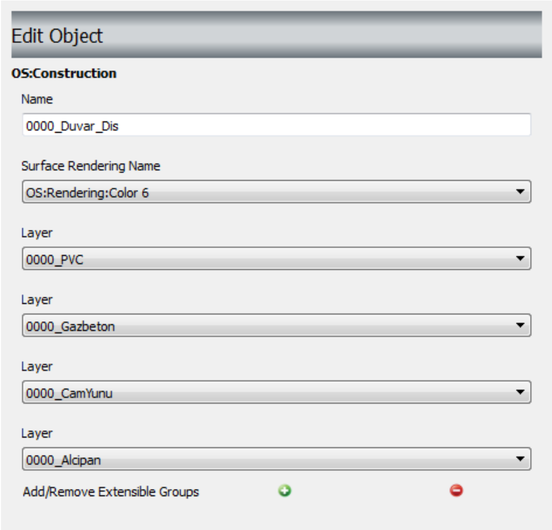


Figure B.26: Constuction Detail Interface

Material definitions are made such that,

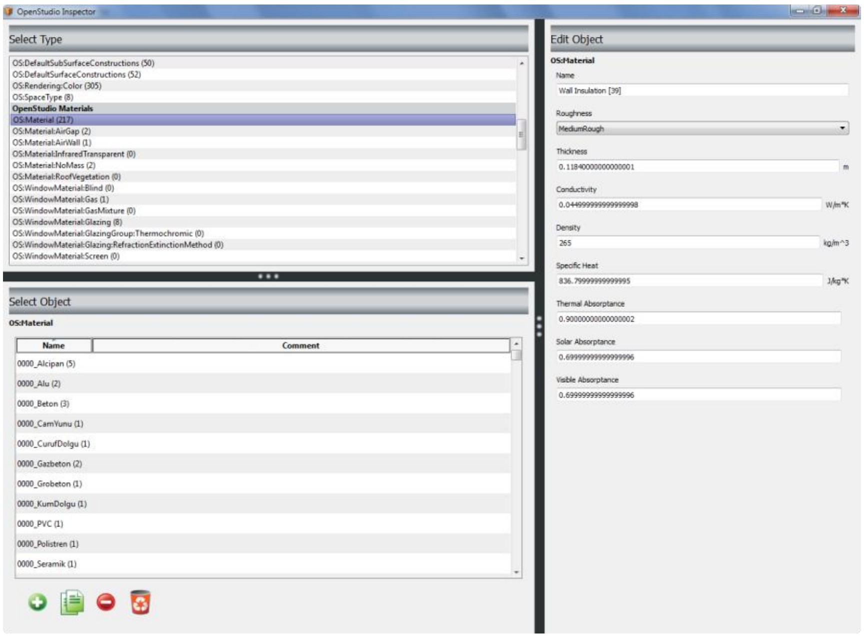


Figure B.27: Material Properties Interface – 1

For each material, it is possible to define;

- Roughness
- Thickness
- Thermal Conductivity
- Density
- Specific Heat
- Thermal, Solar and Visible Absorptance

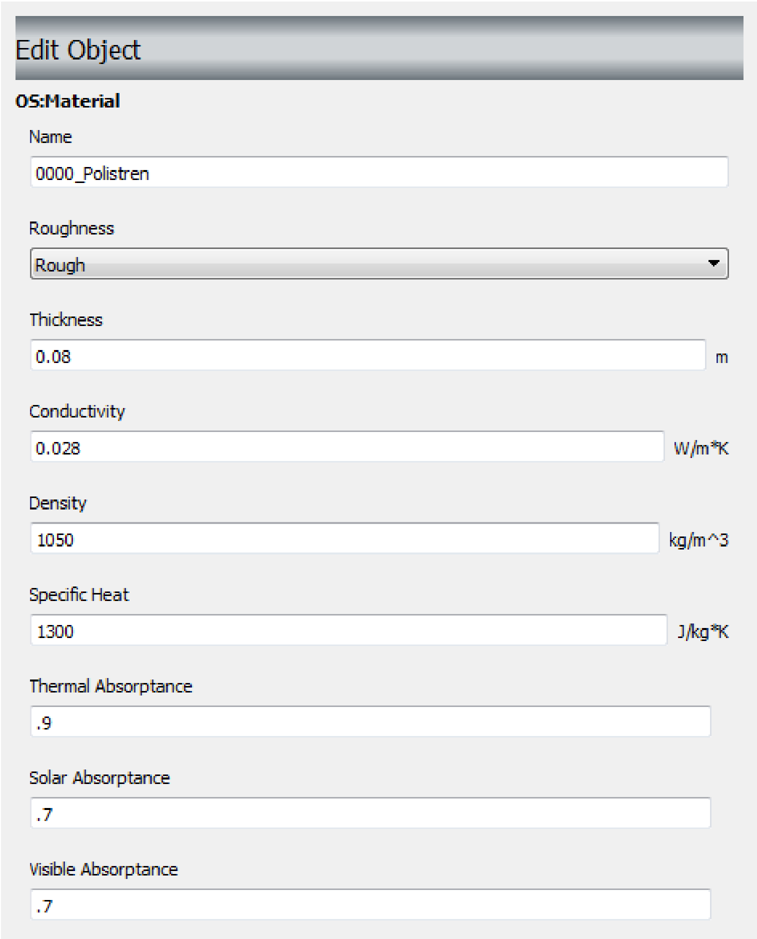


Figure B.28: Material Properties Interface – 2

B.3 Load Definitions

B.3.1 Occupancy

Defined as People / Area

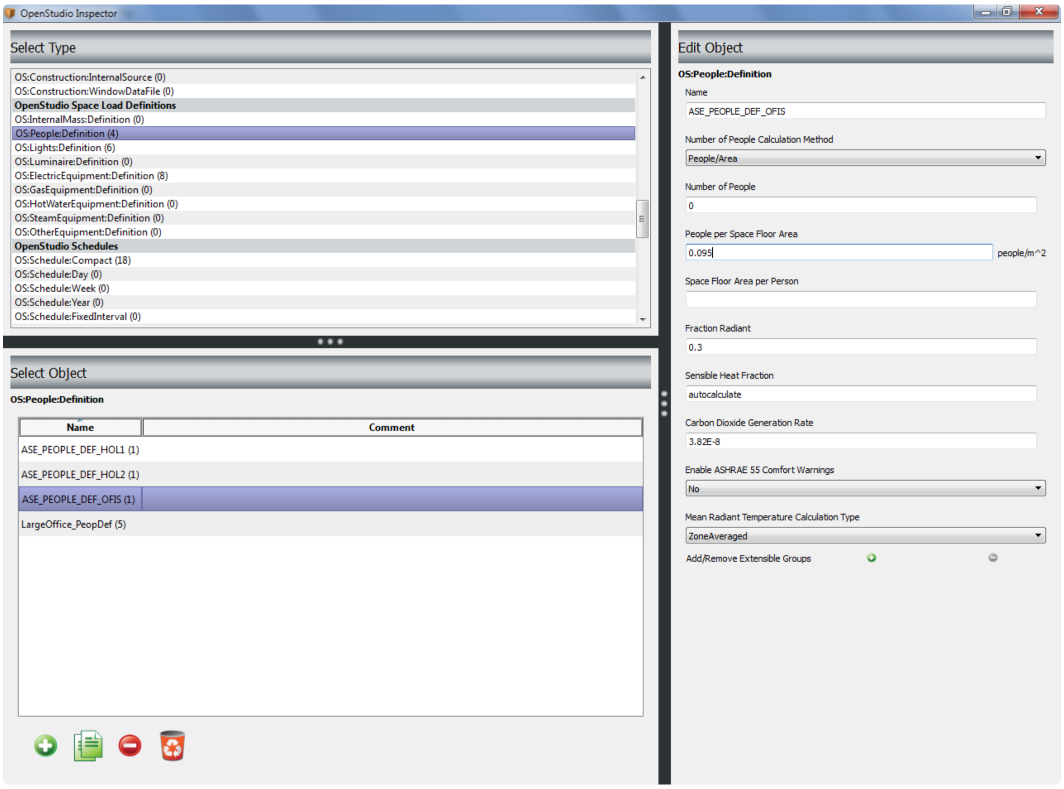


Figure B.29: Occupancy Definition Interface

B.3.2 Schedules

Define Schedules for

- Occupancy
- Activity
- Lighting
- Equipment
- Heating / Cooling Set Points
- Ventilation & Infiltration

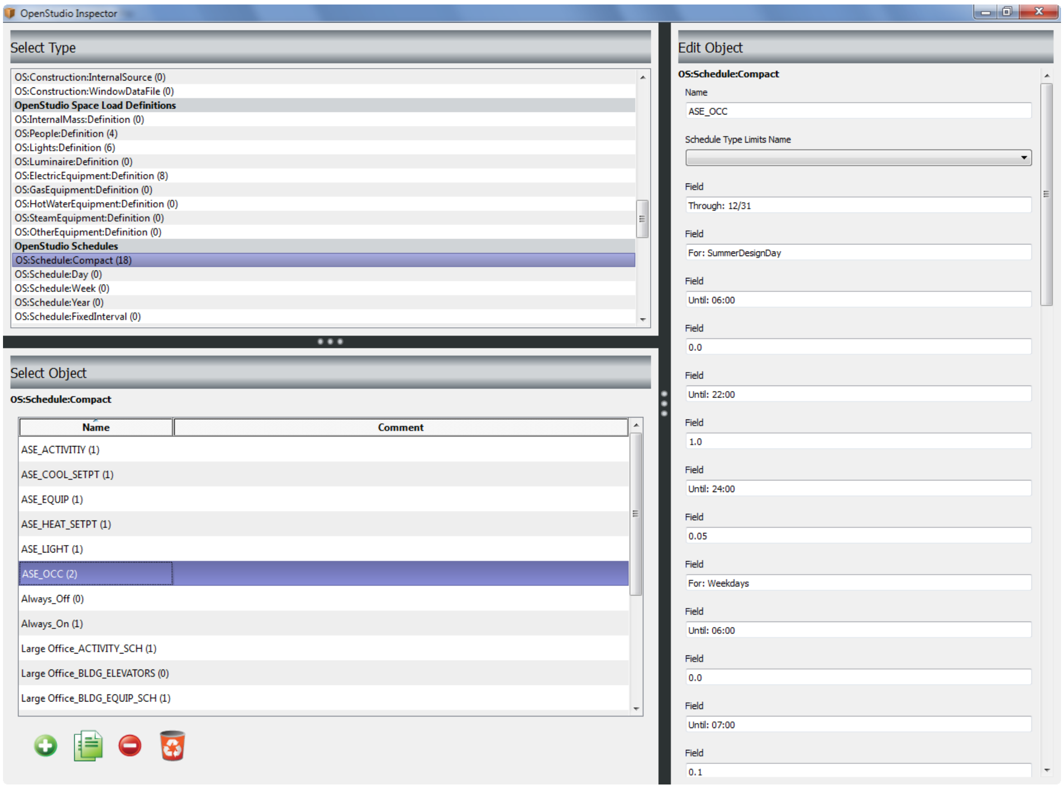


Figure B.30: Schedules Interface

B.3.3 Lighting

Defined as Watts per Space Floor Area,

Lighting calculation (averaged):

$$Lighting\ Level\ (\frac{W}{m^2}) = \frac{No.of\ fixtures\ (\#) \times Wattage\ per\ fixture\ (W)}{Total\ building\ area\ (m^2)}$$

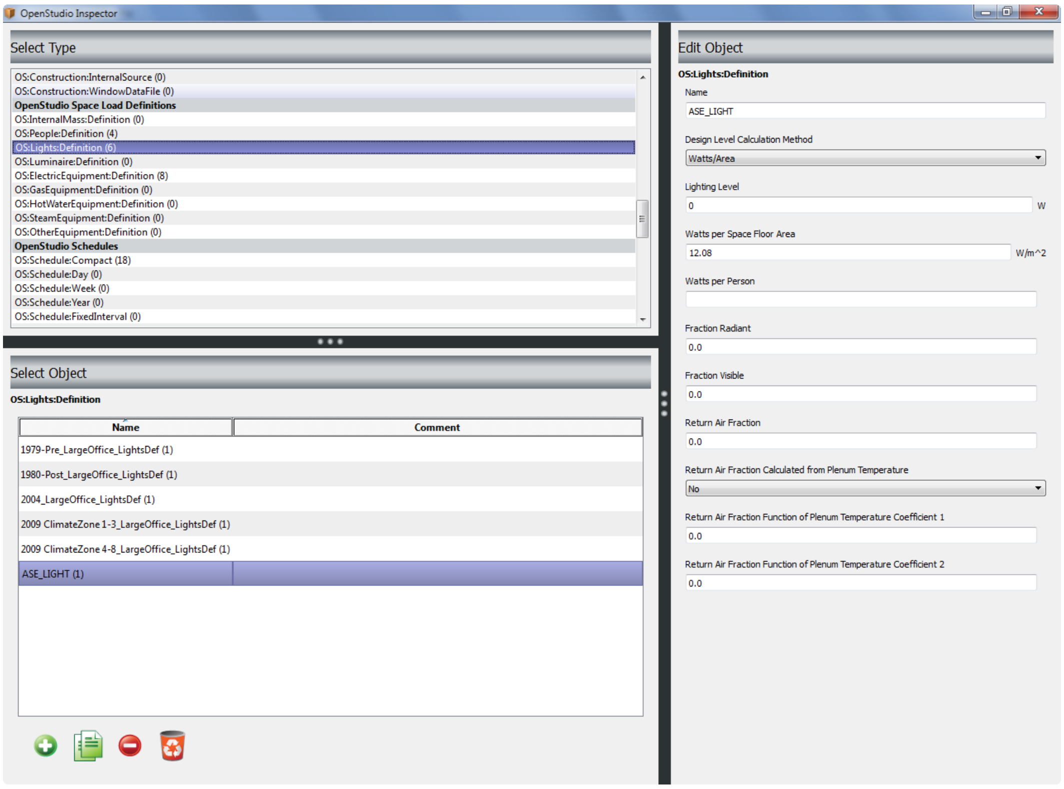


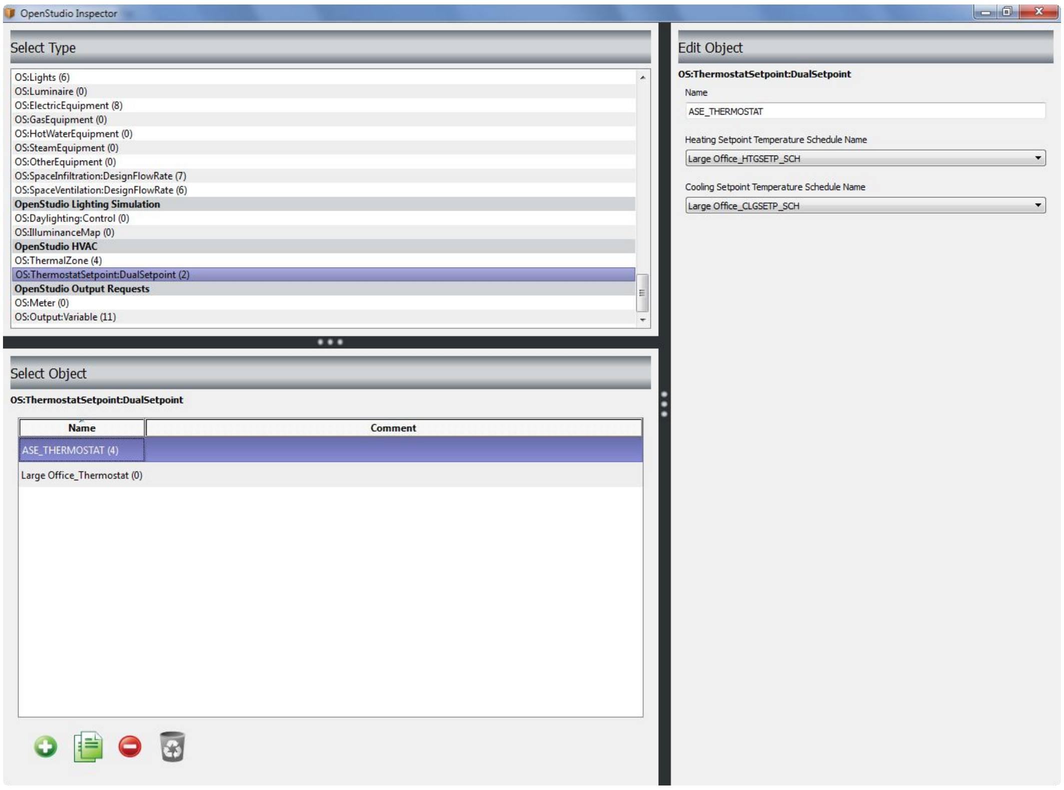
Figure B.31: Lighting Definition Interface

B.3.4 Equipment

Equipment present in the offices and halls are workstations, personal computers and electronic setups and other equipments. Please find the related wattages in the thesis. Resulting values are shown below.

$$Eqpt.Level\,(\frac{W}{m^2}) = \frac{\sum No.of\ eqpt\ (\#) \times Wattage\ per\ eqpt.(W)}{Total\ building\ area\ (m^2)}$$

B.4 Thermostat Definitions



,

Figure B.32: Thermostat Definition Interface

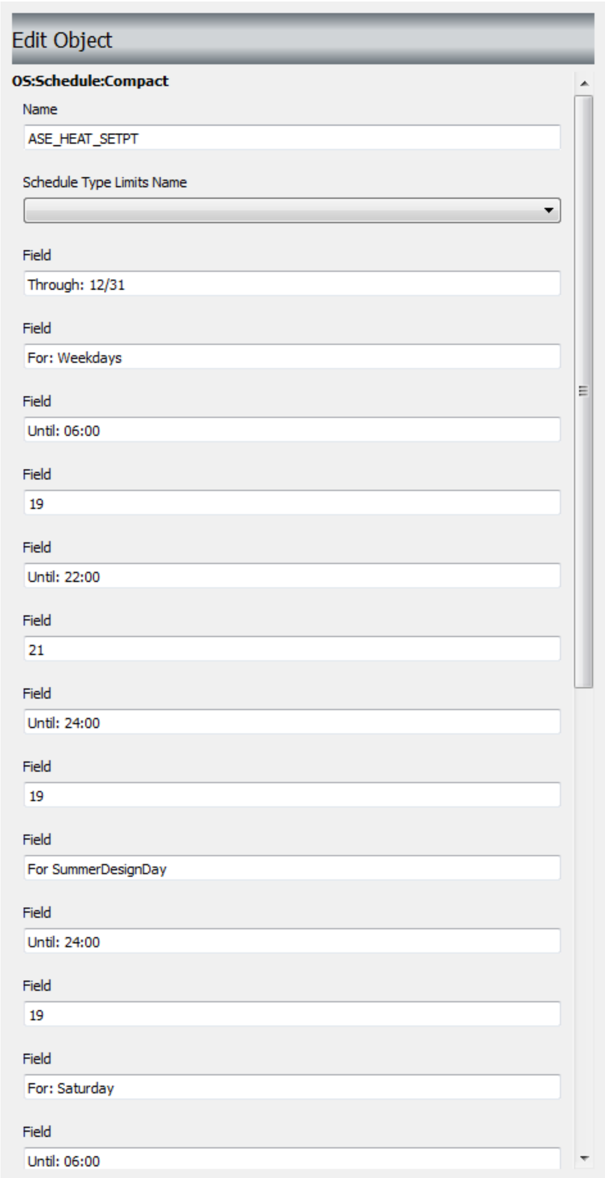


Figure B.33: Heating Set Points

APPENDIX C

RESULTS OF TS 825 ANALYSIS

Table C.1 Results of TS 825 Analysis

				H	Ti,month	Td,month	Ti,month-Td,month	ηmonth	φi,month	φg,month	t [s]	KKO month
Qmonth	**January**	543247728	kJ	12391.20	22.0	-0.3	22.3	0.98	67230.00	1509.82	2592000	0.25
	February	529198531	kJ	12391.20	22.0	0.1	21.9	0.98	67230.00	2001.38	2592000	0.26
	March	402175236	kJ	12391.20	22.0	4.1	17.9	0,96	67230.00	2703.62	2592000	0.32
	April	222450989	kJ	12391.20	22.0	10.1	11.9	0.88	67230.00	3160.08	2592000	0.48
	May	108551194	kJ	12391.20	22.0	14.4	7.6	0.73	67230.00	4002.77	2592000	0.76
	June	28036112	kJ	12391.20	22.0	18.5	3.5	0.45	67230.00	4283.66	2592000	1.65
	July	245581	kJ	12391.20	22.0	21.7	0.3	0.05	67230.00	4143.22	2592000	19.20
	August	1709243	kJ	12391.20	22.0	21.2	0.8	0.13	67230.00	3721.87	2592000	7.16
	September	50281147	kJ	12391.20	22.0	17.2	4.8	0.57	67230.00	2844.07	2592000	1.18
	October	182845945	kJ	12391.20	22.0	11.6	10.4	0.84	67230.00	2071.61	2592000	0.54
	November	359294631	kJ	12391.20	22.0	5.6	16.4	0.95	67230.00	1439.59	2592000	0.34
	December	493321792	kJ	12391.20	22.0	1.3	20.7	0.98	67230.00	1299.14	2592000	0.27
Qyear	**Total**	**2921358130**	kJ									
Qyear/Vgross		16.71	kWh/m3									
Table A.2 Zone.3	Vgross Q3DG	18.80	O.K									

APPENDIX D

DESIGN PARAMETERS FROM LITERATURE

Solar reflectance and infrared emittance properties of typical roof types along with temperature rise [68].

Table D.1: Solar Properties of Roof Surfaces

Roof Surface Type	Solar Reflectance	Infrared Emittance	Roof Surface Temperature Rise [°C]
Ethylene propylene diene monomer (EPDM) – black	0.06	0.86	46.1
EPDM – white	0.69	0.87	13.9
Thermoplastic polyolefin (TPO) – white	0.83	0.92	6.11
Bitumen – smooth surface	0.06	0.86	46.1
Bitumen – white granules	0.26	0.92	35
Built – up roof (BUR) – dark gravel	0.12	0.90	42.2
BUR – light gravel	0.34	0.90	31.7
Asphalt shingles – generic black granules	0.05	0.91	45.6
Asphalt shingles – generic white granules	0.25	0.91	35.6
Shingles – white elastomeric coating	0.71	0.91	12.2
Shingles – aluminum coating	0.54	0.42	28.3
Steel – new, bare, galvanized	0.61	0.04	30.6
Aluminum	0.61	0.25	26.7
Siliconized polyester – white	0.59	0.85	20.6

Some envelope and system parameters that can be chosen for building analysis are presented in Table D.2 [60].

Table D.2: A Sample Set of Building Parameters

Parameter Name	Parameter Specification	Possible Values
Azimuth	Orientation of building relative to north	0 – 360 : with 22.5° steps
Aspect Ratio	Size ratio of bounding rectangle	1 – 1.25 – 1.33 – 1.5 – 2
Shape	General Building Shapes	Rectangle, cross, trapezoid L, T, E
Foundation Insulation	Foundation type Slab-on-grade-floor	Uninsulated, 0.6m R-5 perimeter and R-5 gap 1.2m R-5 perimeter and R-5 gap 0.6m R-10 perimeter and R-5 gap 1.2m R-10 perimeter and R-5 gap 4.5m R-10 perimeter and R-5 gap
Wall Construction	Insulation location and R-value Wall Insulation	R-13 fiberglass batt R-15 fiberglass batt R-19 fiberglass batt R-21 fiberglass batt R-13 fiberglass batt + 2.5 cm foam R-19 fiberglass batt + 2.5 cm foam R-21 fiberglass batt + 2.5 cm foam R-19 fiberglass batt + 5 cm foam
Roof Construction	Roof Insulation	R-30 fiberglass R-40 fiberglass R-50 fiberglass R-60 fiberglass
Infiltration	Air infiltration level	Typical, tight, tighter, tightest
Window Type	Glazing Types for windows	Double clear Low-e low SHGC argon Low-e high SHGC argon 3 pane 1 heat mirror 4 pane 2 heat mirror krypton
WWR	Window to Wall Ratios	0.1 – 0.15 – 0.2 – 0.25 – 0.3 – 0.35 – 0.4
Mass	Thermal Mass	Light, medium, heavy
Shading	Overhangs and fins on windows	None, short, long
Heating Set Point	T [°C] set point for heating	19°C 20°C 21°C
Cooling Set Point	T [°C] set point for cooling	24°C 25.5°C 26.5°C
HVAC System	HVAC System Type	AC with furnace AC with electrical resistance EVAP-cooler with furnace EVAP-cooler with electric resistance Direct EVAP-cooler with furnace GSHP vertical (rectangle 3x5, 6x3, 8x2) GSHP vertical (line 10, single 15) GSHP horizontal (VX8) GSHP horizontal (HOO 8) GSHP horizontal (H-XO-XO 8)

Some properties of bulbs are listed as follows:

Table D.3: Lightbulb Properites

Type	**Property.**	**Price**	**Last Hour**	**Color Temp.**
Traditional Incandescent	Most frequently used type for residential, provides a warm consistent diffuse light	75ç	750 – 2000h	2700 – 2800K
Compact Fluorescent	1/5 to 1/3 electricity of incandescent, provide cool and diffuse light. New technologies provide warmer lights, resembles to incandescent or natural light.	$2.5	10000h	Warm – white 2700 – 3000K Cool white Bright white 4000 – 4200K Daylight CFL >5000K
Tungsten Halogen	Bright warm incandescent, longer life and more efficient than traditional incandescent not as efficient as CFL	$4	2000 – 4000h	2900 – 3200K
Xenon, Krypton	Also incandescent, clear, warm white light, very efficient	$4	10000h	3000 – 12000K
LED	Bright, clear light, will replace TI and CFL with new technology, highly energy efficient	$15-$100	30000 – 100000h	2700K

Heat generation values of the equipment and appliances:

Table D.4: Heat generation values of the equipment and appliances

Appliance	**Common Wattage**
Clock Radio	10 W
Clothes Washer	350 – 500 W
Clothes Dryer	1800 – 5000 W
Coffee Maker	900 – 1200 W
Dehumidifier	785 W
Ceiling Fan	65 – 175 W
Whole House Fan	240 – 750 W
Hair Dryer	1200 – 1875 W
Iron	1000 – 1800 W
Microwave	750 – 1100 W
CPU (Awake)	120 W
CPU (Sleep)	30 W
Monitor (Awake)	180 W
Monitor (Sleep)	30 W
Laptop	50 W
Workstation	325 – 425 W
Radio	70 – 400 W
Refrigerator	725 W
TV (19'')	65 – 110 W
TV (36'')	133 W
TV (Flat)	120
Toaster	800 – 1400 W
DVD	25 W
Vacuum Cleaner	1000 – 1440 W
Water Heater	4500 – 5500 W
Water Dispenser	250 W
Tea Maker (Office Type)	2000 W

Example Design Variables and Schedules for a Residential Building

Table D.5: Example Design Variables and Schedules for a Residential Building

	Material	**U – Value [W/m²K]**
External Walls	125-150 mm reinforced concrete with ceramic tile finish (external surface absorption coefficient = 0.5, 0.8 and 0.9)	2.1 – 2.9
Windows	6mm clear glass (shading coefficient = 0.95) 6mm tinted glass (shading coefficient = 0.7) (WWR=4 – 56%)	5.6
Roof	Reinforced concrete with 40mm insulation (extruded polystyrene foam)	0.64
Indoor Condition	22.3°C	
Occupancy Schedule	Living Room	Bedroom
Mon – Fri	6pm-11pm	11pm-7am
Sat	2pm-11pm	11pm-7am
Sun	9am-12noon	11pm-9am
Lighting Load	60W for bedrooms (small), 120W for bedrooms (large), 200W for living and dining rooms	
Lighting Schedule	Corresponds to occupancy except bedrooms where an nominal lighting load of 10% was applied	
Equipment load	118W for bedrooms, 150W for living and dining rooms	
Equipment schedule	Corresponds to occupancy except bedrooms where an nominal equipment load of 10% was applied	
A/C Schedule	Corresponds to occupancy	
Infiltration	0.6 air changes per hour (ACH)	
Period of cooling analysis	6-month (May- October)	

APPENDIX E

ENERGY PLUS INPUT INFORMATION

Statistical Weather Data Available for Energy Plus Analysis

Weather Data, Design Days and Statistical Weather Data are accessible from

- http://apps1.eere.energy.gov/buildings/energyplus/
- http://apps1.eere.energy.gov/buildings/energyplus/weatherdata/6_europe_wmo_region_6/TUR_Ankara.171280_IWEC.stat

Statistics for TUR_Ankara.171280_IWEC

Location -- ANKARA - TUR

{N 40° 7'} {E 32° 58'} {GMT +2.0 Hours}

Elevation -- 949m above sea level

Standard Pressure at Elevation -- 90432Pa

Data Source -- IWEC Data

APPENDIX F

ENERGY PLUS SCHEDULES

Table F.1 Cooling and Heating Set Points

Cooling Set Points (Temperature)			**Heating Set Points (Temperature)**	
Through:	12/31		Through:	12/31
For:	Weekdays SummerDesignDay		For:	Weekdays
Until:	06:00		Until:	06:00
Field	24		Field	19
Until:	22:00		Until:	22:00
Field	23		Field	21
For:	Saturday		Until:	24:00
Until:	06:00		Field	19
Field	24		For:	SummerDesignDay
Until:	18:00		Until:	24:00
Field	23		Field	19
Until:	24:00		For:	Saturday
Field	24		Until:	06:00
For:	WinterDesignDay		Field	19
Until:	24:00		Until:	18:00
Field	24		Field	21
For:	AllOtherDays		For:	WinterDesignDay
Until:	24:00		Until:	24:00
Field	24		Field	21
			For:	AllOtherDays
			Until:	24:00
			Field	19

Table F.2 Schedules for Lighting, Occupancy and Equipment

Lighting		Occupancy		Equipment	
Fraction		**Fraction**		**Fraction**	
Through:	12/31	Through:	12/31	Through:	12/31
For:	Weekdays	For:	Summer Design Day	For:	Weekdays
Until:	05:00	Until:	06:00	Until:	08:00
Field	0.05	Field	0.0	Field	0.4
Until:	07:00	Until:	22:00	Until:	12:00
Field	0.2	Field	1.0	Field	0.9
Until:	08:00	Until:	24:00	Until:	13:00
Field	0.9	Field	0.05	Field	0.8
Until:	17:00	For:	Weekdays	Until:	17:00
Field	0.9	Until:	06:00	Field	0.9
Until:	18:00	Field	0.0	Until:	18:00
Field	0.9	Until:	07:00	Field	0.8
Until:	20:00	Field	0.1	Until:	20:00
Field	0.5	Until:	08:00	Field	0.6
Until:	22:00	Field	0.9	Until:	22:00
Field	0.3	Until:	12:00	Field	0.5
Until:	23:00	Field	0.95	Until:	24:00
Field	0.1	Until:	13:00	Field	0.4
Until:	24:00	Field	0.2	For:	Saturday
Field	0.05	Until:	17:00	Until:	06:00
For:	Saturday	Field	0.95	Field	0.30
Until:	06:00	Until:	18:00	Until:	08:00
Field	0.05	Field	0.7	Field	0.4
Until:	08:00	Until:	20:00	Until:	14:00
Field	0.1	Field	0.4	Field	0.5
Until:	14:00	Until:	22:00	Until:	17:00
Field	0.5	Field	0.1	Field	0.35
Until:	17:00	Until:	24:00	Until:	24:00
Field	0.15	Field	0.05	Field	0.3
Until:	24:00	For:	Saturday	For:	Summer Design Day
Field	0.05	Until:	06:00	Until:	24:00
For:	Summer Design Day	Field	0.0	Field	1
Until:	24:00	Until:	08:00		
Field	1	Field	0.1		

Table F.2 Schedules for Lighting, Occupancy and Equipment (Cont'd)

Lighting		Occupancy		Equipment	
Fraction		Fraction		Fraction	
For:	WinterDesignDay	Until:	14:00	For:	WinterDesignDay
Until:	24:00	Field	0.5	Until:	24:00
Field	0	Until:	17:00	Field	0
For:	All Other Days	Field	0.1	For:	AllOtherDays
Until:	24:00	Until:	24:00	Until:	24:00
Field	0.05	Field	0.0	Field	0.30
		For:	All Other Days		
		Until:	24:00		
		Field	0.0		

APPENDIX G

MATERIAL CATALOGUE

Table G.1 Material Catalogue

Material Type and Property	Material Name	Roughness	Thickness (d) [m]	Thermal Conductivity (k) [W/mK]	Specific Heat (Cp) [J/kgK]	Density [kg/m^3]
Envelope	Gypsum board	Medium Smooth	0.011	0.210	4473	835
Insulation	Glass Wool	Rough	0.050	0.116	670	60
Wall	Aerated Concrete	Medium Rough	0.200	0.116	920	400
Envelope	PVC	Smooth	0.010	0.232	900	1400
Floor	Finishing Concrete + Grout	Rough	0.050	1.400	960	2200
Floor / Wall	Concrete	Medium Rough	0.200	2.092	750	2300
Floor / Wall	Lean Concrete	Medium Rough	0.100	1.743	750	2300
Floor	Sand Fill	Very Rough	0.300	0.697	630	1600
Floor	Slag Fill	Very Rough	0.400	0.232	1089	800
Envelope	Aluminum	Smooth	0.050	0.250	910	2700
Isolation	Polystyrene	Rough	0.080	0.028	1300	1050
Envelope	Ceramic	Smooth	0.020	0.987	1090	2600
Wall / Roof	Finishing Concrete	Rough	0.050	1.394	960	2200
Envelope	Plaster	Smooth	0.020	0.870		
Envelope	Plaster	Smooth		0.192	800	
Envelope (Indoor Plaster)	Plaster With PCM	Smooth		0.104	1200	600
Envelope	Inner Plaster	Smooth	0.01 - 0.02	0.870		1800
Wall	Horizontal Perforated Brick		0.190	0.450		
Insulation	Thermal Insulation		0.060	0.040		
Envelope	Outer Plaster		0.005	0.870		

Table G.1 Material Catalogue (Cont'd)

Material Type and Property	Material Name	Roughness	Thickness (d) [m]	Thermal Conductivity (k) [W/mK]	Specific Heat (Cp) [J/kgK]	Density [kg/m^3]
Floor	Grout		0.030	1.400		
Insulation	Thermal Insulation		0.080	0.040		
Floor	Finishing Grout		0.020	1.400		
Wall	Light Concrete		0.100	1.100		
Floor	Blockage		0.150	1.740		
Floor / Wall	Reinforced Concrete		0.150	1.300		
Insulation	Thermal Insulation		0.120	0.040		
Envelope	Termojet Plaster			0.060		300
Envelope	Gypsum			0.350		1100
Wall	Brick		0.190	0.340		700
Wall	BİMS		0.190	0.180		600
Wall	LightBlock		0.190	0.140		500
Insulation (R=1.25 m^{2}K/W)	Megawool Rock Wool Sheet	Very Rough	0.050	0.040		110
Insulation (R=1.25 m^{2}K/W)	Dynafoam Board	Rough	0.040	0.032		28
Isolation	Thermo Shield					
Adhesive	Seratut Construction Element					
Insulation (R = 0.113 W/m^{2}K)	RLU			0.044		180
Insulation (R = 0.065 W/m^{2}K)	RLU			0.077		600
Window	Regal					
Wall / Roof	Fıbrecement	Smooth	0.006 - 0.020	0.180		1350
Window	S700 glass			U_f = 2.8 W/m^{2}K		
Insulation	Manto Therm EPS					
Insulation	Manto Therm XPS					

Table G.1 Material Catalogue (Cont'd)

Material Type and Property	Material Name	Roughness	Thickness (d) [m]	Thermal Conductivity (k) [W/mK]	Specific Heat (Cp) [J/kgK]	Density [kg/m^3]
Insulation (Cellulose cement board)	Hekımboard		0.006 - 0.020	0.180		1350
Insulation	Thermo Hooder EPS			0.032		
Insulation	Thermo Hooder EPS			0.036		
Insulation	Rockwool			0.040		150
Insulation with Noise reduction: 60 dB	ISO Duo		0.140 0.195	U = 0.29 W/m^{2}K U = 0.48 W/m^{2}K		531
	ISO Duo Tekno Bims Cavity Wall					
Wall				0.190		850
Wall Wall	Tekno Bims Cavity Wall Tekno Bims Cavity Wall Multi Line			0.210		850
				0.230		850
			0.190	0.147		705
Wall Floor	Tekno Bims Cavity Wall Multi Line Pumice Tekno Bims		0.190 0.000 - 0.003	0.147 U = 0.185 W/m^{2}K		705 875 2315
Insulation	Shapemate IB	Rough	0.030 - 0.080	0.029		> 30
Insulation	Styrofoam	Rough	0.025 - 0.060	0.033		> 30
Roof	Roofmate		0.030 - 0.100			
Roof Floor	Roofmate Floormate		0.030 - 0.100 0.030 - 0.100	0.029		> 32
				0.029		> 32
				0.035		> 30
Insulation	Extruded Polystrene			0.030		
Insulation	Glass Fibre Quilt			0.040		
Insulation	Phenolic Foam			0.020		

Table G.1 Material Catalogue (Cont'd)

Material Type and Property	Material Name	Roughness	Thickness (d) [m]	Thermal Conductivity (k) [W/mK]	Specific Heat (Cp) [J/kgK]	Density [kg/m^3]
Insulation	Polyurethane Board			0.025		
Insulation	Cellulose Fibre			0.035		
Green Roof Component	PV		2.25cmx 50mx10cm		350 g/m^2	System filter for heavy constuction
Green Roof Component	Floradrain FD40		1mx2m			2.2 kg/m^2
Green Roof Component	Floradrain FD60		1mx2m			2.3 kg/m^2
Green Roof Component	Stabilodrain SD30		0.94mx2m			3 kg/m^2
Green Roof Component	WSB 80-PO		2mx20m x10cm		1.25 kg/m^2	Root holding layer
Green Roof Component	Zincolit					
Green Roof Component	SF (System Filter)		2x100m x20cm		100 g/m^2	
Green Roof Component	Floradrain FD 25		1mx2m			1.5 kg/m^2
Green Roof Component	Floraset FS75		1mx1xm			1.9 kg/m^2
Green Roof Component	SSM 45		2mx50m x 10cm		470 g/m^2	Humidity holder and protective mattress
Green Roof Component	TGV 21		1.6mx250m x10cm			80g/m^2
Green Roof Component	WSF 40		8mx25m x 1.5m			380g/m^2

Table G.1 Material Catalogue (Cont'd)

Material Type and Property	Material Name	Roughness	Thickness (d) [m]	Thermal Conductivity (k) [W/mK]	Specific Heat (Cp) [J/kgK]	Density [kg/m^3]
Green Roof Component	BSM 64		2mx25mx 10cm			650g/m^2
Green Roof Component	WSM 150		1mx15m x10cm			1500g/m^2
Green Roof Component	Georaster		54cmx54cm x62.5cm			1.8 kg/pc
Green Roof Component	JEG		1.22mx70m x10cm			500g/m^2
Thermal Insulation	EPS		2cm-10cm		0.039	
Thermal Insulation	EPS		2cm-10cm	0.034		16
Thermal Insulation	XPS		2cm-10cm	0.031		28-32
Thermal Insulation	Rockwool		3cm-10cm	0.034		150
Sandwich Panel top: 0.5mm Al bottom: 0.4mm Al	Polystyrene filled 5 layer panel EPS		0.045-0.050	0.034		18-20
Sandwich Panel Rock wool or Glass wool	Rockwool filled 5 layer panel		0.05-0.06-0.075-0.100	0.035		

APPENDIX H

ZONES DEGREE DAYS ACCORDING TO CITIES

Zone – 1:

ADANA	AYDIN	MERSİN	OSMANİYE	ANTALYA
HATAY	İZMİR			
Ayvalık	Dalaman	Fethiye	Marmaris	Bodrum
Datça	Köyceğiz	Milas	Gökova	

Zone – 2:

SAKARYA	ÇANAKKALE	K. MARAŞ	RİZE	TRABZON
ADIYAMAN	DENİZLİ	KİLİS	SAMSUN	YALOVA
AMASYA	DİYARBAKIR	KOCAELİ	SİİRT	ZONGULDAK
BALIKESİR	EDİRNE	MANİSA	SİNOP	DÜZCE
BARTIN	GAZİANTEP	MARDİN	BATMAN	GİRESUN
ŞANLIURFA	MUĞLA	ŞIRNAK	BURSA	İSTANBUL
ORDU	TEKİRDAĞ			
Hopa	Arhavi	Abana	Bozkurt	Çatalzeytin
İnebolu	Cide	Doğanyurt		

Zone – 3:

AFYON	BURDUR	KARABÜK	MALATYA	AKSARAY
ÇANKIRI	KARAMAN	NEVŞEHİR	ANKARA	ÇORUM
KIRIKKALE	NİĞDE	ARTVİN	ELAZIĞ	KIRKLARELİ
TOKAT	BİLECİK	ESKİŞEHİR	KIRŞEHİR	TUNCELİ
BİNGÖL	IĞDIR	KONYA	UŞAK	BOLU
ISPARTA	KÜTAHYA			
Pozantı	Korkuteli	Merzifon	Dursunbey	Ulus
Tosya				

Zone – 4:

AĞRI	ERZURUM	KAYSERİ	ARDAHAN	GÜMÜŞHANE
MUŞ	BAYBURT	HAKKARİ	SİVAS	BİTLİS
KARS	VAN	ERZİNCAN	YOZGAT	KASTAMONU
Keles	Elbistan	Mesudiye	Uludağ	Afşin
Göksun	Kığı	Pülümür	Solhan	Şebinkarahisar