THERMAL BRIDGE DETAILING IN TUNNEL FORM BUILDINGS WITH PASSIVE HOUSE PRINCIPLES

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ABSTRACT

THERMAL BRIDGE DETAILING IN TUNNEL FORM BUILDINGS WITH PASSIVE HOUSE PRINCIPLES

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As a result of depleting fossil fuels, increased energy prices and global warming, the growing importance of energy efficiency given birth to spread construction of energy saving buildings and use of new technologies around the world. Since thermal bridges in buildings may cause excessive heat loss, mold growth and deterioration of indoor air quality; to eliminate thermal bridges becomes very crucial both in existing buildings and in energy efficient buildings.

In this thesis, energy demand of a six storey tunnel form social housing unit in Ankara is calculated using Passive House Planning Package. Later on, the energy demand of the building is reduced applying Passive House Principles. The impacts of thermal bridges on energy demand of the baseline building and Passive House building are compared by evaluating six construction details including balcony, basement wall, roof, floor slab, interior wall and corner detail. Thermal bridge calculations are carried using Therm 6.3 Software. Since the results indicate that the fraction of the transmission heat losses is highest in the balcony, balcony detail is studied in more detail to show the impacts of improved detailing on annual heating demand.

Application of Passive House principles results in up to 82% reduction in annual heating demand and up to 57% reduction in primary energy demand. In the baseline building, the impact of thermal bridges, as the percentage of the total annual heating demand, is small (5%). As properties of the thermal envelope are improved, the impact of thermal bridges is also increased (up to 14%). The amount of heat losses through thermal bridges is highest at the balcony, unheated basement wall and roof detail respectively for the both cases. Floor slabs and interior walls are the places where most of the total fabric conduction heat losses occur in the building. To insulate the balcony floor slab above and below the slab can reduce the thermal bridge heat losses by 32%. To use a thermal break element can reduce the thermal bridge heat losses by 84% and increase the minimum surface temperature significantly ensuring a detail without the risk of structural damage.

Keywords: Passive House, Tunnel Form Buildings, Thermal Bridges, Heat Loss, PHPP, Therm 6.3

ÖZ

TÜNEL KALIP BİNALARDA PASİF EV PRENSİPLERİ İLE YAPILAN ISI KÖPRÜSÜ DETAYLANDIRMALARI

Yılmaz, Derya

Yüksek Lisans, Yapı Bilimleri, Mimarlık Bölümü

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Fosil yakıtların tükenmesi, artan enerji fiyatları ve küresel ısınma sonucunda, enerji verimliliğine verilen önemin artması ile enerji etkin bina tasarımlarının ve yeni teknolojilerin kullanımı dünya genelinde artmıştır. Isı köprüleri binalarda aşırı ısı kaybı, küf oluşumu ve iç ortam hava koşullarının kötüleşmesine sebep olabileceği için, hem mevcut hem enerji etkin bina tasarımında ısı köprülerine karşı önlem alınması büyük önem taşımaktadır.

Bu tezde, Ankara'daki 6 katlı bir tünel kalıp apartman dairesinin enerji tüketimi Passive House Planning Package programı kullanılarak hesaplanmıştır. Daha sonra, binanın enerji tüketimi Pasif Ev prensipleri uygulanarak düşürülmüştür. Isı köprülerinin mevcut binadaki ve Pasif Ev'deki etkileri balkon, bodrum duvarı, çatı, ara kat döşemesi, iç duvar ve köşe detaylarını içeren 6 bina detayı incelenerek karşılaştırılmıştır. Isı köprüsü hesaplamaları Therm 6.3 programıyla yapılmıştır. Sonuçlara göre, mevcut binada balkonda iletim yoluyla meydana gelen ısı kayıpları en yüksek orana sahip olduğu için, detay geliştirmenin ısı kayıplarına etkilerini göstermek açısından balkon detayı daha kapsamlı çalışılmıştır.

Pasif Ev prensiplerinin uygulanması yıllık ısıtma tüketiminde %82 ve primer enerji tüketiminde %57'ye varan bir azalma sağlamıştır. Mevcut binada ısı köprülerinin toplam yıllık ısıtma talebindeki payı daha azdır (%5). Binanın dış katmanının özellikleri iyileştirildiğinde, ısı köprülerinin etkileri de belirgin şekilde artmıştır (%14). Isı köprülerinden meydana gelen ısı kayıpları sırasıyla balkon, bodrum duvarı ve çatıda hem mevcut bina hem Pasif Ev için en fazladır. Isı iletim yoluyla meydana gelen toplam ısı kayıpları en fazla döşemelerde ve iç duvarın dış duvara birleşimlerinde meydana gelmektedir. Balkon döşemesini alttan ve üstten yalıtmak ısı köprülerinden meydana gelen ısı kaybını %32 azaltmaktadır. Isı kırıcı bir elemanın balkon döşemelerinde kullanımı ısı köprülerinden meydana gelen ısı kayıplarını %84 azaltmış ve minimum yüzey sıcaklığını büyük ölçüde arttırmıştır.

Anahtar Kelimeler: Pasif Ev, Tünel Kalıp Binalar, Isı Köprüleri, Isı Kaybı, PHPP, Therm 6.3

To my beloved mother…

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LIST OF ABREVIATIONS

ABBREVIATIONS

BEP: Building Energy Performance

BRE: British Research Establishment

CHP: Combined Heat and Power

CFOs: Chlorofluorocarbons

COP: Coefficient of Performance

DHW: Domestic Hot Water

EnerPHit: Quality-Approved Energy Retrofit with Passive House Components

EPDB: Energy Performance of Buildings Directive

EPS: Expanded Polystyrene

GHE: Ground Heat Exchanger

GWP: Global Warming Potential

HCFCs: Hydro chlorofluorocarbons

HDD: Heating Degree Days

HP: Heat Pump

HVAC: Heating Ventilating Air Conditioning

IPHA: International Passive House Association

LEED: Leadership in Energy and Environmental Design

MATPUM: Middle East Technical University Research and Implementation Center for Built Environment and Design

MVHR: Mechanical Ventilation with Heat Recovery

NRE: Non-renewable Energy

PIR: Polyisocyanurate

PE: Primary Energy

PHI: Passive House Institute

PHPP: Passive House Planning Package

PO: Potential Oxidation

TRNSYS: Transient System Design Tool

SH: Space Heating

SHGC: Solar Heat Gain Coefficient

TS 825: Turkish Thermal Insulation Standard

TOKİ: Housing Development Administration of Turkey

VT: Visible Transmittance

WRS: Water Resistive Barriers

XPS: Extruded Polystyrene

LIST OF SYMBOLS

SYMBOLS

A Area of each element, m^2

λ Thermal conductivity, W/mK

d Thickness of the material, m

H_{TB} Additional heat loss through thermal bridges, W/K

H_T Total fabric conduction heat loss, W/K

Ψ Linear thermal transmittance, W/mK

χ Point thermal transmittance, W/K

U Thermal transmittance of the building element, W/m^2K

U_g Thermal transmittance of the window frame, W/m^2K

U_i Thermal transmittance of the glazing, W/m^2K

l Length of the building element, m

f_{Rsi} Temperature factor, -

g Solar energy transmittance coefficient, %

P Fraction of transmission heat loss, %

R Thermal resistance, m^2K/W

Θ_{si} Temperature of the internal surface, °C

Θ_i Internal temperature, °C

Θ_e External temperature, °C

L_{2D} Thermal coupling coefficient, W/mK

U_j Thermal transmittance of the 1D component, W/ m^2 K

l_j Length over which the U value applies, m

Nj Number of 1D components.

CHAPTER 1

INTRODUCTION

In this chapter, the argument, objectives of the thesis and general procedure are proposed respectively. Moreover, the disposition of the report is given at the end of this chapter.

1.1 Argument

Cases like energy crisis and global warming has become one of the most important items of the agenda within the range of disciplines as politics and architecture in 21st Century. As a result of depleting fossil fuels, increased energy prices and global warming, the growing importance of energy, given birth to spread construction of energy saving buildings and use of new technologies around the world.

Many countries developed methods for the definition of houses with a very low energy use in the past years, among which the Passive House is a widespread concept that is seen as a long-term political ambition to reduce energy consumption in the building sector by many countries (Mlecnik *et al.,* 2010). In order to achieve energy reduction targets, various directives and plans were issued by the European Commission. According to one of those directives, namely the Energy Performance of Buildings Directive, all new buildings have to be nearly zero-energy buildings by 31 December 2020. In addition to that, the development of a pathway for moving the building stock towards very low energy or Passive House Standard was suggested by the European Commission in "Action Plan for Energy Efficiency: Realizing the Potential" in 2006.

The term Passive House, represents a dwelling with very good thermal insulation, good air tightness and highly efficient ventilation heat recovery. The low heat losses, together with the passive use of solar and internal gains, enables a heating load which is so low that it can be covered exclusively by heating the supply air that is required for good indoor air quality (Schnieders,, 2009). While the first Passive House is designed to be suitable for a Central European Climate in Germany, numerous Passive House buildings can be seen in different climate conditions around the world today. Although the Passive House solutions for each location, climate, and geographic conditions can differ, to achieve very low heating demands and primary energy consumption to meet Passive House Standard, careful attention should be given firstly on application of a complete and continuous insulation. After that selection of window glazing and frame, creating an airtight building envelope, avoiding thermal bridges and using a comfort ventilation system with heat recovery are the other principles of Passive Houses. Since Passive House Standard does not dictate any particular methods of construction, passive houses can be designed as masonry, timber or composite considering local building traditions and national building regulations.

A thermal bridge free design, as previously stated, is one of the pillars of Passive Houses. An irregularity in the building envelope resulting with a significant increase of heat transfer in comparison to the surrounding elements is referred to as a thermal bridge. For instance, partial penetration of the building envelope by materials with a different thermal conductivity. A critical amount of heat loss, mold growth, deterioration of indoor air quality, and defects in the building itself may occur because of thermal bridges in the buildings. According to Ge *et al.* (2013), up to 30% of heating energy can be lost through thermal bridges for highly insulated residential buildings. The increase in the levels of insulation of buildings also increases the contribution of thermal bridges in the overall heat consumption (Déqué *et al*., 2000).

Building sector in Turkey, which is the second largest energy consumer and responsible 32% of the total national related CO_2 emissions in 2008, uses the largest amount of this energy to meet residential buildings‟ heating demand (UNDP, 2013).Although the concept and technology of energy efficient buildings become widespread especially in the US and European Union, energy efficiency and environmental issues are not the main issues in social housing design and operation both in the Housing Development Administration of Turkey (TOKİ), and in general in Turkey (MATPUM, 2010). Yüksek & Esin (2013) explicate the reasons for this situation with the inefficiencies in regulations, implementations and examinations on energy efficiency.

According to the TOKİ, the total number of buildings is approximately 20 million in Turkey and 46% of these housing stocks will be demolished and rebuilt within an average period of 20 years against disaster risk. In Turkey, TOKİ is the leader official institution meeting 5-10% of the housing needs. “Tunnel form construction” which allows fast and quality production with an earthquake resistant construction, is being used in many TOKİ houses (TOKİ, 2013). The thermal efficiency of structures produced using tunnel form is specified mostly by the items of the infill structure, which is not typically classified as part of the system and is generally commissioned separately. These constructions have the potential to be very airtight, and the comprehensive use of concrete will yield structures of high thermal mass (EST, 2005). Tunnel form construction projects bring speed and quality production with. However MESA contractor firm, which constructs large-scale tunnel form housing developments in Turkey and abroad, faced with complaints from the building occupants related to the mold growth in some of their projects in the past (MESA MESKEN,1996). Therefore, various detailing variations were tried in order to find the best option to eliminate thermal bridges during many years by the firm.

This study is carried out to see if it is possible to design tunnel-form structures as Passive House buildings. Secondly, the study puts emphasis on the importance of construction details in tunnel form typology in terms of eliminating thermal bridges. In this study, a six storey tunnel formwork mass housing project unit is studied to meet Passive House Standard. Using Therm 6.3 software, various construction details representing geometric and structural thermal bridges are evaluated in terms of numerical results to show the impacts of thermal bridges on overall heat loss and energy demand both of the baseline building and the Passive House building. Since the results indicate that the fraction of the transmission heat losses is highest in the balcony, balcony detail is studied in more detail to show the impacts of improved detailing on heat loss. Throughout the study, Ankara, which is determined by the Turkish Thermal Insulation Standard in 3^{rd} zone (cold region), was selected for the analyses.

1.2 Aim and Objectives

The primary aim of this study is to check whether it is possible and viable to create tunnel form housing in Passive House Standard. The secondary aim of this study is to check the standard tunnel form projects from construction detailing perspective against Passive House Standard.

The objectives of the thesis are:

- to evaluate and indicate the effects of thermal bridges on annual heating demand of a selected case study building and the Passive House building.
- to examine the geometry and details of the case study building in order to identify the implementations that can be problem when designing Passive Houses.
- to give guidance for construction sector professionals involved with the construction of Passive Houses.

1.3 Procedure

The first stage of the study is composed of a literature survey which is based on articles, books, and journals related with the research field. In the second stage of the study, the energy demand of the baseline building is calculated using Passive House Planning Package (PHPP) that is developed by Passive House Institute. Following that, the baseline building geometry is analyzed in terms of thermal bridges and six construction details are selected to carry out thermal bridge simulations using Therm 6.3 software. The proportion of the overall heat loss due to thermal bridges, total fabric conduction heat losses, minimum surface temperature of the walls and fraction of transmission heat losses are found for the baseline building. The detail which shows highest fraction transmission heat losses is chosen to be studied in more detail to indicate the impacts of improved detailing on annual heating demand in Passive House Building. After that, Passive House principles are applied to the baseline building to reduce the energy demand. The construction details evaluated formerly are improved considering PHPP results. To validate the constructability of the thick insulation and proposed details, a face to face interview is made with the Project Manager of a tunnel-form construction project. Interview results are presented after the simulation results. In addition to the interview, a simple payback period calculation is made comparing the first initial cost and operating cost of the various cases. At the last phase, the simulation results of six different building junctions and two different cases are compared across each other.

1.4 Disposition

This report is composed of five chapters, of which "Introduction" is the first and it covers the argument, aim and objectives of the thesis, as well as the general procedure of this report and disposition.

In the second chapter, the literature survey on the subject domain is presented. Literature survey consists of information on Introduction to Passive Houses, Passive House basics, thermal envelope design, and aspects related to Passive Houses such as ventilation, heating, and Passive House economics. The chapter is concluded with a critical review of the literature to summarize accumulated knowledge.

The third chapter is dedicated to the material and method of the study. As the material, first of all, the case study building, the details tested and the selected climate are presented. Afterwards, the energy simulation program PHPP and thermal bridge calculation tool Therm are introduced. In pursuit of defining the material of the study, the method of the study is given in the second section. Calculation of the energy demands of the baseline building and thermal bridge assumptions are explained both for the baseline and Passive House building.

In the fourth chapter, the results of the study, together with the interview and interpretations are given.

In the final chapter a brief outline of the study and the findings are presented.

CHAPTER 2

LITERATURE REVIEW

This chapter comprises of the issues searched from the literature that are presented in five main sections. The first section holds qualification of an introduction to Passive Houses. In the second section, description and requirements of Passive Houses, studies related to Passive Houses, energy efficient building design in Turkey and a comparison of Passive House Standard with TS 825 Standard is given under Passive House Basics heading. In the third section, the four principles of Passive House are explained. In the fourth section various ventilation and heating systems suitable for Passive Houses are compared, and Passive House economics are discussed. In the end, a critical review of the literature is presented to summarize the accumulated knowledge and to view the whole frame.

2.1 Introduction to Passive Houses

In this section, first of all, the Energy Performance of Buildings Directive, the certification of buildings and, energy efficient components are explained. Following that, definitions of various energy efficient building schemes are made.

2.1.1 Energy Performance of Buildings Directive

The Energy Performance of Buildings Directive, which was originally adopted in 2002 and revised in 2010, is issued by the European Commission. It requires member states to introduce energy certification schemes for buildings. In order to advance in the compliance of international agreements such as Kyoto protocol and forthcoming negotiations, as well as to reduce its energy dependency and greenhouse gas emissions in the European Union, the directive promotes improving the energy performance of both new and existing buildings by taking into account climatic and local conditions. Figure 2.1 presents the scope of the directive.

According to EPBD (2010), by 31 December 2020, all new buildings must be nearly zero-energy buildings; and after 31 December 2018, new buildings occupied and owned by public authorities must be nearly zero-energy buildings. A nearly zero-energy building is defined as a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby (namely wind, solar, etc.).

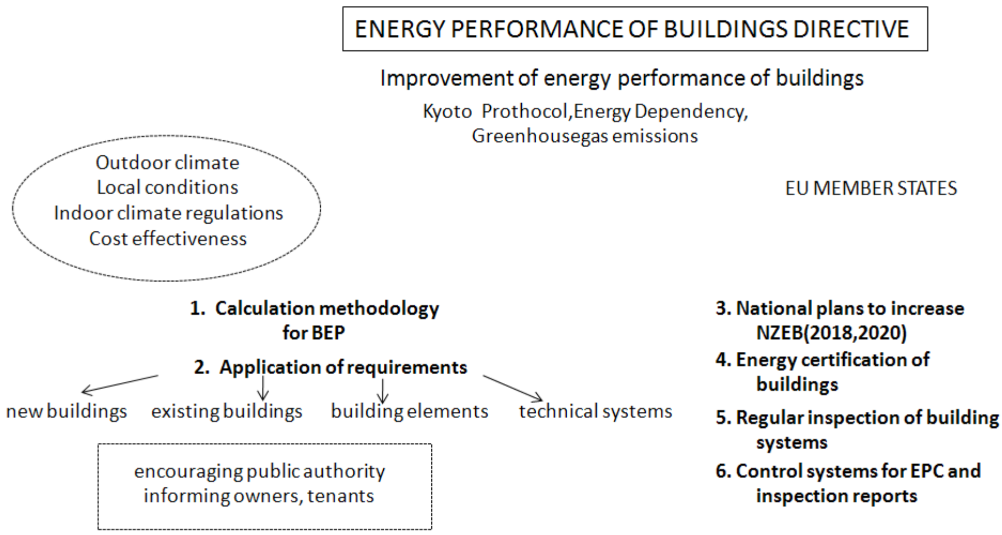


Figure 2.1 Scope of Energy Performance of Buildings Directive

In addition to a requirement for introducing a methodology for calculating the integrated energy performance of buildings and certificating buildings; briefly, the following requirements are stated in the Directive:

- to apply minimum requirements also to the energy performance of building elements and technical building systems (such as heating, cooling units),
- to create national plans to increase the number of nearly zero- energy buildings,
- to inspect heating and air-conditioning systems in buildings regularly,
- to develop independent control systems for energy performance certificates and inspection reports.

Encouragement of public authorities for a leading role in the field of energy performance of buildings and the importance of reaching cost optimal levels is highlighted by the Directive.

In addition to EPBD, a comprehensive "Action Plan for Energy Efficiency: Realizing the Potential" is presented also by the European Commission in late 2006. The development of a pathway for moving the building stock towards very low energy or Passive House Standard was suggested there (EuroACE, 2013).

According to Williams (2012), although introduction of energy certificates for all properties has had very limited effect on purchase or rental decisions in Europe, higher resale values for low energy homes were reported in the USA. Thus, to generate future market demand, sharing the positive experience of living in a low energy home is essential.

2.1.2 Certification of Buildings and Energy Efficient Components

Energy certification for buildings which is mainly a market mechanism whose main goal is to support higher energy performance standards than the regulated ones, emerged in the early 1990s (Casals, 2005; Lombard *et al.*, 2008). Cotterell & Dadeby (2012) state that certification of a building is a way to avoid the tendency to make unproven claims about environmental or energy performance. The authors emphasize the importance of certification in countries where the standard is not widely understood or recognized.

According to Casals (2005), a well implemented energy certification plan must consider a clear quantification of design concepts with the potential for building energy consumption reduction, such as bioclimatic architecture, passive heating, passive cooling, passive ventilation, integration of renewable energies.

Numerous initiatives have arisen throughout Europe as an essential method to encourage demand and to ensure the quality of demonstration projects with excellent energy performance. There are many different kinds of low energy building labels such as „Certified“ Passive Houses, LEED buildings, Green Buildings, Sustainable Buildings and Zero Carbon Buildings (Mlecnik *et al.,* 2010).

Table 2.1 Building Standards around the world (Wegner, 2010).

Country	Name of body	Independent / Government	Name of standard	Further Details
Canada	Canadian Home Builders' Association and Natural Resources Canada	Government	R-2000	Has been exported to many countries around the world including mainland Europe
Denmark	Solar Aktivhaus	Independent	Solar Aktivhaus	This is more of a product than an actual certification, but it does highlight the variation available
England	Building Research Establishment (BRE)	Government	BREEAM	British Research Establishment Environmental Assessment Method
Germany	Passiv Haus Institut	Independent	Passiv Haus Standard	Is now widely accepted by Europe; that even the European Parliament are commenting on its effectiveness
Germany	Plus Energy	Independent		Rolf Disch was the pioneering architect. These buildings produce more energy than they consume, and so sell it back to the grid.
Germany	DGNB	Government		German Sustainable Building Council
Germany	CasaClima Agency	Independent	KlimaHaus Casaclima (A,B, Gold, +)	
Ireland	SEI	Government	BER Rating	
Scotland	Scottish Passivhaus Institut Centre (SPHC)	Independent	Passiv Haus Standard	Passivhaus certification is authorised by the German Passivhaus Institut
Netherlands	Dutch Green Building Council (DGBC)	Independent	BREEAM Netherlands	
Switzerland	MINERGIE	Independent	Minergie-P; Minergie-P-Eco	
UK	AECB	Independent	The AECB Silver Standard, Passivhaus Standard and Gold Standard	Passivhaus certification is authorised by the German Passivhaus Institut
USA	Energy Star	Independent	Energy Star	
USA	Green Globes	Independent	Green Globes, via third part assessment	Certified by ANSI since 2005. The genesis of the system was the Building Research Establishment's Environmental Assessment Method (BREEAM). In 1996, the Canadian Standards Association (CSA) published BREEAM Canada for Existing Buildings
USA	US Green Building Council (USGBC)	Independent	Leadership in Energy and Environmental Design (LEED)	LEED is a third-party certification program and the nationally accepted benchmark for the design, construction and operation of high performance green buildings

In Table 2.1, some of the building energy standards are listed by country. Among those standards, Passive House Standard is developed by an independent research institute called Passive House Institute (PHI) in Germany. The Certification of Passive Houses and EnerPHit retrofits can be made by PHI or by the accredited Passive House Certifiers worldwide.

In addition to the building certification, certification systems for individual building components also play an important role to ensure energy efficiency. Williams (2012) clarifies the importance of certification on the promotion of low zero carbon technologies such as solar panels, ground source heat pumps, heat recovery systems. But the author highlights the importance for whole system certification rather than component certification. According to the author, the use of an individual certified component cannot always ensure an effective result, because it is seen that to combine two certified low zero carbon technologies may lead to problems sometimes.

2.1.3 Definition of Various Energy Efficient Building Schemes

World energy crises, such as the 1979 oil shortage or the drastic increase in the oil prices in the early 1990s, led to governmental concerns over the supply of and path to worldwide energy resources. European nations that are highly dependent on energy resources from politically unstable areas were especially affected. Concurrently, the energy consumption of buildings was steadily increasing in developed countries and exceeding the other major sectors, industry and transportation. Under such circumstances new concepts related to energy efficiency in buildings emerged (Lombard *et al.*, 2008). Nowadays, it is possible to see several examples of energy efficient buildings such as low-energy houses, zero energy houses, plus energy houses and Passive Houses.

Low Energy House

Williams (2012) states that there is a growing interest in low energy housing among the European and American consumers currently. According to Mumovic *et al.* (2008), low-energy houses are buildings with annual thermal loads below 80 kWh/m^2a. There are special standards for low energy buildings in Germany (DE), Austria (AT), Denmark (DK) and Switzerland (CH). Niedrigenergihäuser (DE, AT) requires 30 W/m^2 per year, Minergie® (CH) requires 42 W/m^2 per year of heat demand for space heating and sanitary hot water (IEA, 2008).

Zero Energy House

There is no agreement on the use of the term zero energy house. According to Cotterell & Dadeby (2012), any emissions created in a zero carbon house are balanced by the energy generated on-site via renewable methods. According to Williams (2012), a zero energy building is a building from which there are zero-net CO_2 emissions during operation and only the zero carbon standards implies the use of low carbon energy sources. Cotterell & Dadeby (2012) state that since a Passive House standard leads to the extremely low energy requirement for space heating and encourages efficient energy use across all electrical appliances, it should be easier and cheaper to meet zero carbon standard in a Passive House.

Plus Energy House

A plus energy building is defined as a building which delivers more energy to the supply systems than they use (IEA, 2008). Mumovic *et al.* (2008) state that a plus energy house generates energy for heating, cooking, water heating and the operation of home appliances through active utilization of solar energy. They are not connected to the public electrical grid and they use all available measures of energy conservation.

Passive House

Passive House is a concept which was originated in Germany, by collaboration between German and Swedish researchers. The first Passive House dwelling was built in 1991 in Darmstadt as indicated in Figure 2.2. Since its inception in 1988, the Standard has been adopted in many countries (Wegner, 2010). The standard is applicable to all building types including schools, hospitals, offices etc. The tallest Passive House is constructed in 2003 in Hamburg with 8 floors above ground and 3 levels of basement (PHI, 2012). The term Passive House, represents a dwelling with very good thermal insulation, good air tightness and highly efficient ventilation heat recovery. The low heat losses, together with the passive use of solar and internal gains, enables a heating load which is so low that it can be covered exclusively by heating the supply air that is required for good indoor air quality. Such buildings perform very low heating demands around 15kWh/m^{2}a. By increasing the efficiency of household devices and the DHW system, the total primary energy demand can be significantly reduced, too (Schnieders, 2009).

Figure 2.2 First Passive House Project: in Darmstadt, Kranichstein

Mumovic *et al*. (2008) state that zero energy buildings, energy self-sufficient buildings and plus energy buildings require additional improvements that are not economically feasible considering current prices. Williams (2012) states that Passive House is the most energy efficient form of housing currently being built. To apply Passive House Standard on new build housing in Europe could as much as cut in half the current energy losses. Many countries see a „Passive House" level already as a long-term political ambition to reduce energy consumption in the building sector (Mlecnik *et al*., 2010).

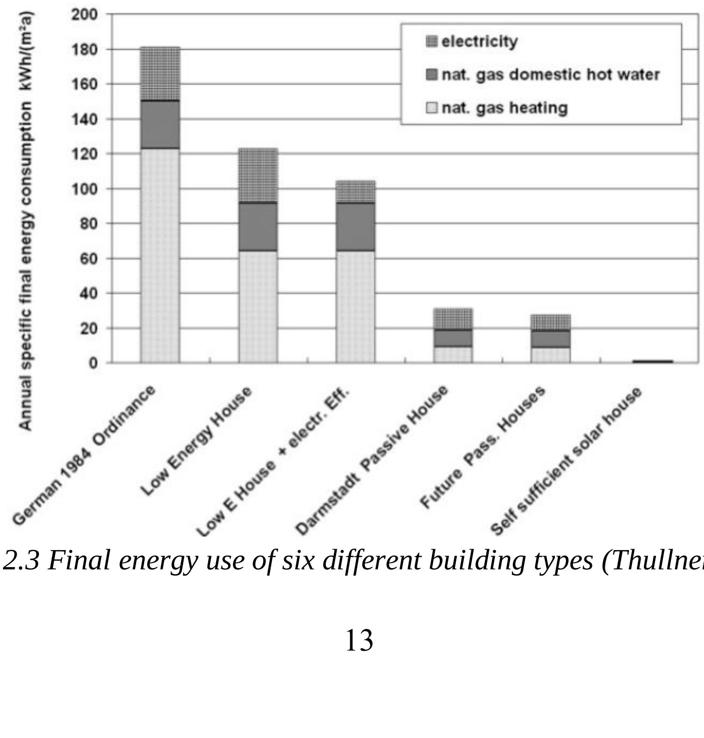


Figure 2.3 Final energy use of six different building types (Thullner, 2010).

A comparison of the final energy use of various building types is indicated in Figure 2.3. Buildings that comply with the “German 1984 Ordinance” are poorly insulated buildings, while “low energy houses + electric efficiency” are defined by an efficient use of electricity and “future Passive Houses” are even slightly better performing as the ones of the Passive House Institute (Thullner, 2010).

According to Monteiro & Freire (2012), a Swiss standard house, a low-energy house which meets the Minergie standard, a Passive House (with a ventilation heat recovery system, solar collectors and photovoltaic panels) were compared concerning life cycle impact assessment. Results were calculated based on global warming potential (GWP), acidification, and photochemical oxidation (PO)) as well as non-renewable energy (NRE) requirements. Considering the Swiss electrical mix, the results showed that in comparison to the standard house, NRE was reduced by 33% in the Minergie house and 66% in the Passive House. Concerning other impacts, the two low-energy houses presented a similar performance with significant reductions (e.g. 62% for GWP, 29% for PO, and 10% for acidification) relative to the Swiss standard house.

2.2 Passive House Basics

In this section, description and requirements of Passive Houses, studies related to Passive Houses, energy efficient building design in Turkey and a comparison of Passive House Standard with the Turkish insulation standard, namely TS 825 Standard is given.

2.2.1 Passive House Description and Requirements

There are sometimes common misunderstandings about Passive Houses concerning the design, heating system or their use. Passive House design is sometimes also referred to as passive solar design. According to Feist (2001), the Standard has been named “Passive House” because the passive use of free heat gains provided externally by solar irradiation through the windows and internally by the heat emissions of appliances and occupants-basically suffices to keep the building at comfortable indoor temperatures throughout the heating period. According to PHI, thermal insulation, Passive House windows, air tightness, thermal bridge free design and comfort ventilation with highly heat recovery are the five principles of Passive Houses as it is indicated in Figure 2.4.

With a passive solar design, the use of the sun‟s energy for the heating and cooling of a living space is pointed. The building itself or some element of it profits natural energy characteristics in materials and air created by exposure to the sun in this approach (Passive Solar Design, 2013). Despite the useful concept of the passive solar design, it is very dependent on building orientation (Wegner, 2010).

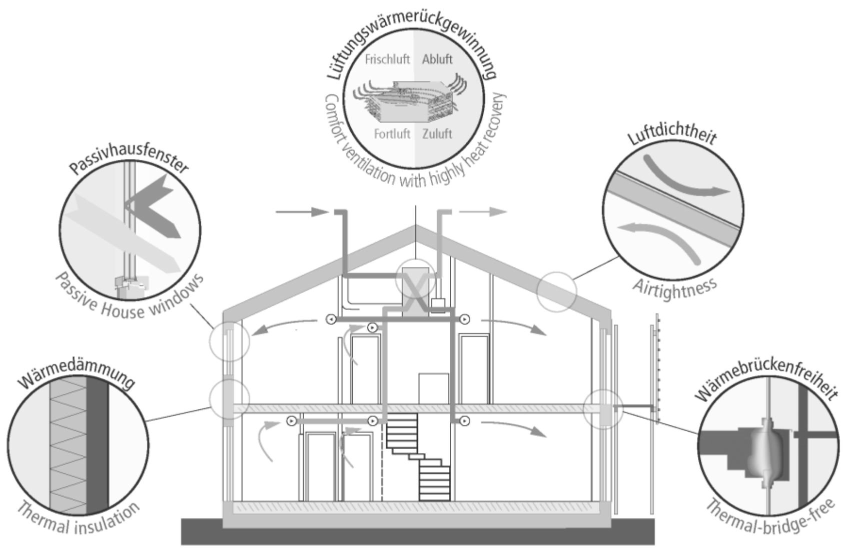


Figure 2.4 Principles of Passive Houses (PHI, 2013)

Passive House also requires a heat generator for the small remaining heat energy. Therefore "House without heating" isn„t exactly accurate, but conventional radiators are not needed for heat distribution. The requirements for Passive Houses in Cool-Temperate climate can be seen in Table 2.2.According to the Passive House Institute (PHI) to define a building as a Passive House the following criteria must be met (Feist *et al.*, 2012):

1. Annual heating demand may not exceed 15 kWh/ (m^2a) and the heating load accounts for around 10W/m^2.

2. It is also essential to provide the following requirements:

- U-values of exterior building elements must be less than 0.15 W/ (m^2K) in Germany (cool- temperate climate).
- U-values of windows and all glazing must be less than 0.8 W/ (m^2K) in Germany (cool- temperate climate).
- The external envelope must be thermal bridge free in Germany (cool- temperate climate).
- For both under and over-pressurization, the measured air leakage must not exceed 0,6 h^{-1} at a pressure differential of 50 pa.
- The ventilation system must be designed with the highest energy recovery efficiency (nHR≥75% complying with PHI certification) and the minimal electricity consumption (≤ 0.45 Wh/m^3 supply air volume)
- Domestic hot water generation and distribution systems with minimal heat losses must be used.
- Highly efficient use of household electricity is essential.

3. The use of specific primary energy for all domestic applications (heating, hot water and domestic electricity) must not exceed 120 kWh/ (m^2a) in total.

Table 2.2 Passive House Requirements in Cool-Temperate Climate

Annual heating demand	≤15kWh/(m^2a)
Heating load	≤10 W/m^2
Pressuration test result n50	≤0.6 h^{-1}
Entire Specific Primary Energy Demand	≤120kWh/(m^2a)
Annual cooling demand	≤15kWh/(m^2a)
U values of exterior components	≤0.15 W/(m^2K)
U values of windows	≤0.8 W/(m^2K)
Effective heat recovery rate of ventilation System	≥%75
Noise emission of ventilation system	< 25 dBA

Not only new buildings, but also existing buildings can be certified as a Passive House. EnerPHit for certified energy retrofits with Passive House Components criteria has been developed by the PHI for such buildings (PHI, 2012).

2.2.2 Studies related to Passive Houses

Kuzman *et al.* (2013) compare different constructions types for passive houses, such as solid wood, wood-frame, aerated concrete, and brick with each other in order to determine the advantages and disadvantages of the most common construction materials. The results show that the application results of analytic hierarchy process method can be used for analyzing the decision criteria related to a Passive House. Furthermore, the highest ranking criteria in decision-making were health and psychological aspects, functionality and end-of-life disposal, emissions, and aesthetics, apart from load capacity, fire safety and energy efficiency. And, wood as a renewable raw material is one of the best choices for energy-efficient construction.

Mlakar & Strancar (2011) analyzed data from a single family Slovenian passive house to investigate overheating in hot summer periods and to estimate the general house response under real conditions. Results indicate that strict shading during the day and excessive ventilation through opened windows during the night can keep the internal temperatures within the comfort level during hot periods in a hot continental climate of northern Slovenia.

According to Kaklauskas *et al.* (2012), social, cultural, ethic, psychological, emotional and ethnic aspects over the process of the existence of the Passive House have generally been ignored or discussed minimally. In their study, the socio-cultural aspect of how self-expression values influence the spread of the Passive House in different countries was discussed.

Georges *et al.* (2013) state that power over sizing of the current stoves and their long operating time may lead to unacceptable overheating. Therefore the authors studied the integration of wood stoves applied to a detached house in Belgium using detailed dynamic simulations (TRNSYS). The results show that in order to prevent overheating, a large power modulation is important. A high building thermal mass, to open the internal doors, and a heat emission dominated by radiation also reduce the overheating, but a smaller extent.

Salman (2010) applies Passive House Standard to a TOKİ social housing unit in Istanbul in order to reach zero carbon home. The author claims that PHPP gives more accurate results on space heating than electricity and hot water heating. Therefore primary energy (PE) demand was not calculated by PHPP. However, the PHPP results are not compared with an estimation using exact numbers of PE consumption of the building at the end. The author stated that the simulations carried out with the lack of information such as electricity consumption of households in Turkey and the cooking demand was not taken into account. Apart from those, thermal bridges are not mentioned and calculated in this study. According to the author, further studies are necessary to investigate average water heating, electricity and space heating demands of buildings in Turkey.

2.2.3 Energy Efficient Design in Turkey

According to Karasu (2010), the connection of architecture and energy was realized at the end of the 20th century in Turkey. Energy efficiency awareness has not reached the desired level in Turkey since the regulations, implementations and examinations on energy efficiency have not reached a sufficient level yet (Yüksek & Esin, 2013). Considering the integration of technology to energy efficiency of buildings, Turkey is one of the countries presenting the lowest national shares of high-tech sectors in total employment below 2% (Eurostat, 2013).

According to Yılmaz (2008), the advantages of architectural design to create energy efficient designs by passive ways using renewable sources are ignored in Turkey and intelligent buildings are usually granted as the buildings where HVAC and electrical systems of the building are automatically controlled by building energy management system (Yılmaz, 2008).

The author continues that the energy systems of buildings are generally designed based on the average meteorological variables in Turkey. Most of the time, only outdoor temperature is considered for HVAC system design and there is not enough effort during the design process to use the renewable sources. Consequently, energy efficiency can‟t be provided at the expected level even in the buildings equipped with high-tech and expensive building energy management systems. Therefore, starting intelligent building design from the beginning of the design stage by the integration of different disciplines is essential (Yılmaz, 2008).

Yüksek & Esin (2013) studied the energy efficiency methods applied in traditional rural houses in the rural Thrace region of Turkey. The energy-efficient characteristics of the sample structures built using timber, stone and adobe construction methods were determined by investigating various aspects such as site layout, form, and material specifications. According to the authors the ecological characteristics of these houses can be applied to current buildings by estimating and repeating these characteristics.

High quality of workmanship is required in energy efficient houses as well as in Passive Houses. The constructed poor quality of housing for low-income families is one of the criticisms against TOKİ. Although a large majority of homeowners satisfied with the conditions, experts and technicians think differently on the quality of the work done and they require the activation of an effective control mechanism (Eşkinat, 2012).

In February 2007, a research in order to improve the quality of TOKİ housing projects in terms of universal and sustainable design by Middle East Technical University Research and Implementation Centre for Built Environment and Design (MATPUM) and TOKİ was made. Several design strategies were offered to TOKİ can be seen in Table 2.3 (Sezer, 2009). According to another research made by MATPUM (2010), by applying renewable energy and energy efficient design strategies to TOKİ mass housing projects; TOKİ can be a forerunner so as to obtain energy savings and protect environment in Turkey. The advantages of this vision can be summarized as follow:

- to help reducing global warming and carbon tax obligation of the country.
- to reduce homeowners‟ energy consumption and the dependency on foreign energy sources
- to speed up research and development, as well as scientific and technological activities
- to generate national energy, environment and efficiency standards
- to settle new employment and investment sectors
- to reduce prices of energy efficient technologies in the country

Table 2.3 Design strategies offered to TOKİ for a universal and sustainable design

Taking into account the Climate		
Open Areas	**Building Envelope**	**Building System**
Open green areas (a minimum of %10)	Insulation	Energy efficient HVAC and central systems, motors, transformers
Plants requiring minimum water	Low-e glasses	Solar Collectors for a minimum of %50 DHW
Wide green parks considering local heat island effects	Natural and regional materials	Utilizing renewable energy
	Maximum natural light	PV cells use for a minimum %5 electricity
Reducing heat absorbing reflective pavements	Grass roof (if possible)	Heat Pumps
Caring the ecological features of the site		Energy efficient lighting fixtures
Water		
Collecting rain water		**Waste Management**
Filtering grey water		Measuring indoor air quality
Water Storage		Landscape designers and ecologists

2.2.4 Comparison of Passive House Standard with TS 825 Standard

The TS 825 standard is the insulation standard must be applied to the buildings in Turkey. It covers a method for estimating annual heating energy demand of buildings, specifies U factors for the building components and restricts maximum annual energy consumption per square meter in new buildings. Turkey is divided into four climatic regions in TS 825, where Region 1 symbolizes the areas which demand the least energy for heating, and Region 4 symbolizes the areas which demand the most energy for heating. A comparison of air tightness levels for TS 825 Standard, Passive House Standard and EnEV Standard can be seen in Table 2.4.

Table 2.4 Comparison of air tightness

TS 825 Standard		Passive House		EnEV 2009(Germany)	
multi dwelling	One dwelling	new buildings	retrofits	with ventilation	without ventilation
$n_{50}<2$	$n_{50}<4$	$0.6 \le n_{50}$	$1 \le n_{50}$	$n_{50} \le 1.5$	$n_{50} \le 3$
$2 \le n_{50} \le 5$	$4 \le n_{50} \le 10$				
$5<n_{50}$	$10<n_{50}$				

A comparison of the required U values for the building elements as walls, roofs, floors and windows for the three different standards is presented in Table 2.5. When U value requirements of 3rd region and Passive House Standard are compared, it is seen that Passive House Standard requires three times better U values for wall, floor and window and requires two times better windows.

According to TS 825 Standard, to have a linear thermal transmission coefficient (Ψi,e) less than 0,1 W/(mK), is satisfactory to omit thermal bridges in the related equation. If this assumption is compared with Passive House Standard, considering that a thermal bridge free design is one of the pillars of Passive House, in order to fulfill Thermal Bridge Free definition linear heat coefficient should be less than 0.01 W/ (mK). Janssens *et al*. (2007) emphasize the importance of the geometrical factors in the value of the linear thermal transmittance. According to the authors, it is quite easy to obtain a value smaller than 0.10 W/mK junctions at exterior corners, even when the thermal insulation is interrupted. However, junctions at interior corners may have a Ψ value larger than 0.10 W/mK, even with perfectly continuous insulation.

Table 2.5 Comparison of U Values for the related standards

		U wall (W/m²K)	U roof (W/m²K)	U floor (W/m²K)	U Window (W/m²K)
TS 825 Standard	1st region	0,7	0,45	0,7	2,4
	2nd region	0,6	0,4	0,6	2,4
	3rd region	0,5	0,3	0,45	2,4
	4th region	0,4	0,25	0,4	2,4
Passive House		0,15	0,15	0,15	0,8
EnEV 2009		0,28	0,2	0,2	1,3

Interior comfort temperatures are different in the TS 825 and Passive House Standard. A comparison of indoor temperatures for the related standard can be seen in Table 2.6.

Table 2.6 Comparison of indoor temperatures for the related standards

	TS 825	Passive House
Residents Offices	19ºC	20ºC
Hotels, Schools Museums	20ºC	

In TS 825 standard, to calculate ventilation heat losses, air change rate (n_h) is assumed 0.8 h^{-1} in naturally ventilated buildings. In PHPP, in case of using natural ventilation air change rate through specific window opening configurations can be calculated through the software. Comparison of internal heat gains can be seen in Figure 2.7.

Table 2.7 Comparison of internal heat gains

TS 825 Standard		Passive House	
Buildings with low internal heat gains	5W/m²	Residential	2,1W/m²
Buildings with high internal heat gains	10W/m²	Non-residential	3,5 W/m²
			Manual calculation

To use the method of temperature factor to assess thermal bridges has proposed by International Energy Agency. To establish the design values of the temperature factor is the responsibility of each country. On the basis of the indoor temperature 20°C and relative humidity 50%, outdoor temperature – 5 °C, and the highest relative humidity at the surface of the building envelope 80%, the lowest value of the temperature factor 0.7 is determined in the German DIN standard (Kalamees, 2006).
If the minimum temperature factor fRsi≥0.7, mold growth and condensation will be avoided also in Passive Houses.

It is essential to limit the difference between indoor temperature and the temperature in individual surfaces surrounding rooms. When the operative indoor temperature is within a comfortable range, there won"t be uncomfortable radiation losses. By limiting the temperature differences, cold air circulation, draughts and cold feet can be avoided. (Krick, 2010). TS 825 standard, the difference between the minimum surface temperatures and the interior temperature should not be more than 3ºC in order to prevent mold growth and ensure internal comfort. Also, if the relative humidity of the surface exceeds 80% for a short time, there is a risk of mold growth on the surfaces. Since lower temperatures will result in higher relative humidity, it is essential to control the difference between the surface temperatures and the interior air temperatures.

2.3 Thermal Envelope Design

In this section, first of all, the importance of thermal insulation and application of super insulation with the studies on optimum insulation thickness in Turkey are explained. Secondly, the effects of window components such as frame, glazing and spacer selection, as well as window installation on heat losses are explored. Following that the description and impacts of thermal bridges are described and thermal bridge free construction details are presented. Finally, issues related to air tightness of buildings with blower door testing are introduced and strategies for an airtight construction are presented.

2.3.1 Thermal Insulation

The thermal energy of a heated building is lost by conduction, convection and radiation. Controlling heat transfer through the exterior assemblies of a house is the primary purpose of thermal insulation. To ensure the comfort of the occupants, the energy efficiency and durability of the home, insulation and the air barrier should form a continuous envelope around the house (Richard & Bynum, 2001).

Lechner (2001) states that the thermal resistance expressed as R value is one of the most important characteristics of insulation materials since that will determine the necessary insulation thickness. Moisture resistance, fire resistance, potential for generating toxic smoke, physical strength, and stability over time is the other important characteristics of insulation materials. Thermal resistance is expressed in square meter Kelvin per Watt and calculated by using the equation 1 given below:

$$R = d/\lambda \quad m^2K/W \qquad (1)$$

Where;

d: the thickness of the material, m

λ: the thermal conductivity of the material, W/mK.

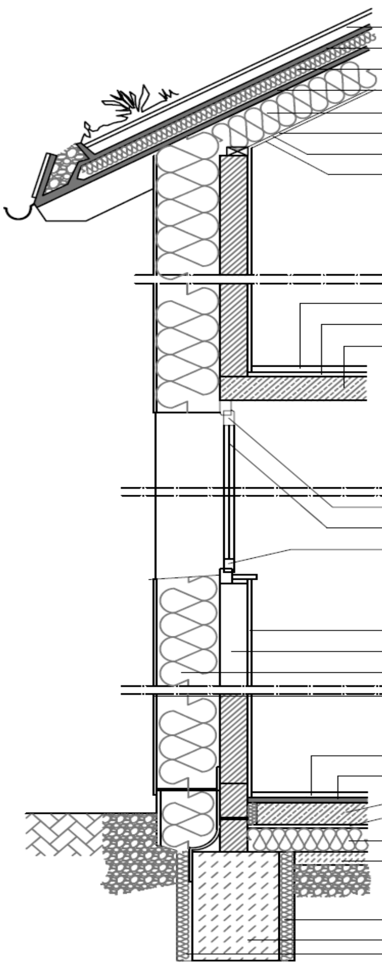
The larger a material‟s R value, the more it resists the movement of heat from one side to the other. Therefore the higher the R value, the better the insulation (Edminster, 2009).To be effective, thermal insulation must also be relatively free of interruptions by construction elements with high conductivity, i.e., thermal bridges. Air interruption, moisture interruption, and thermal bridging can weaken the effectiveness of a wall or roof.

The U value, which is also referred as an overall heat transfer coefficient, is a heat transfer rate through a specific component over a given area if the temperature difference is one degree (1 Kelvin). The unit of the U-value is W/ (m^2K). A lower U-value indicates a high level of insulation and U value is the inverse of R value.

Around 1980, a new approach called *super insulation,* like it is used in a Passive House, reducing fuel consumption by 75 to 95 percent relative to conventional houses came to the attention of architects. A super insulated house is tolerant of less favorable sites and orientations, because of its main reliance on heat conservation rather than on solar radiation (Bynum, 2001).The typical characteristic of a super insulated house is thick and widely applied insulation. Also a moderate amount of insulation is provided at the sills, headers, eaves, window and door frames. Interior heat is generated by systems and appliances typically functioning within the home as stoves for cooking, DHW systems, human bodies, lighting equipment and electric appliances (Bynum, 2001).

Required U values of the Passive House building elements are not dependent on the construction method but on the climate. When building Passive Houses, various construction methods such as solid, timber or steel construction, prefabricated components cladding element technology, mixed technology systems, etc. can be used (Waltjen *et al*., 2009).

Figure 2.5 indicates construction details of a super insulated house in Germany. The exterior wall construction of the building has a U value of 0.11W/ m²K with 40 cm external insulation, where U value roof is 0.12 W/m²K with 34 cm insulation. U value of windows is 0.75 W/m²K complying with the Passive House Standard for a Central European Climate. Foundation footing is covered with 10 cm insulation on both sides to prevent heat loss. 20 cm insulation is installed on the basement floor slab in addition to 3 cm insulation below the floor screed. It is seen that the insulations are not standardized considering their R values and thicknesses.



Layer	Description	Width cm	Thermal conductivity W/mK	U value W/m²K
Roof				
1	Earth+vegetation	11,50		0,12
2	Water proofing	0,02		
3	Insulation	10,00	0,035	
4	Wood	2,00	0,130	
5	Insulation+wood	24,00	0,049	
6	Vapour barrier	0,02		
7	Lattice	2,40		
8	Gypsum board	1,50	0,700	
Ceiling				
9	Screedfloor	4,00	1,400	0,83
10	Insulation	3,00	0,040	
11	Concrete	18,00	2,100	
Window				
12	Sealed Frame			1,40
13	Glazing			0,50
14	Glazing and Frame			0,75
Exterior wall				
15	Plaster	1,50	0,700	0,11
16	Limestone	17,50	0,990	
17	Insulation	40,00	0,045	
18	Plaster	2,00	0,870	
Basement Slab				
19	Screedfloor	4,00	1,400	0,13
20	Insulation	3,00	0,040	
21	Concrete	18,00	2,100	
22	Water Proofing	0,02		
23	Insulation	20,00	0,030	
24	Concrete	10,00	2,100	
Foundation				
25	Insulation	10,00	0,035	
26	Concrete	60,00	2,100	
27	Insulation	10,00	0,035	

Figure 2.5 Construction details of a super insulated house (Harvey, 2006).

Since it eliminates thermal bridging, to place the insulation on the outside of the assembly is more effective in reducing energy consumption than to place in the middle of the envelope section or toward the interior of the building (Mehta *et al.*, 2009 & Sezer, 2005). Kolaitis *et al*. (2013) state that external thermal insulation system offers a range of significant advantages, such as prevention of moisture condensation, straightforward tackling of thermal bridges and utilization of the building‟s thermal mass, but it is also associated with higher installation costs, especially when installed on higher floors and it can be damaged due to weather or accidents. In contrast to external thermal insulation, the internal thermal insulation exhibits significantly lower installation costs, but it results in an important loss of indoor space and is associated with high risk of moisture condensation.

According to Harvey (2006), externally applied insulation will be most effective in hot-dry climates, where the best strategy will often be to rely on night ventilation and thermal mass to keep the building comfortable during the day time. In hot and humid regions, where high-mass buildings are required because of structural integrity, it is better to apply the insulation internally. Because when ventilated these buildings behave as buildings with low thermal mass. According to Özel & Pıhtılı (2007), recent developments in research have indicated that better thermal performance can also be obtained if the insulation is placed as two pieces of the same total thickness of insulation instead of placing as one piece. To determine optimum location and distribution of insulation in a wall, Özel&Pıhtılı (2007) made an analysis of 12 different wall configurations with different configurations of insulation layers during typical summer and winter days in Elazığ, Turkey. Results indicated that the best result is obtained in the case where three layer insulation being each one 2 cm are placed on the indoor surface, on the outdoor surface and in middle of wall. In addition, it was found that equal thicknesses of insulation layers placed in the indoor and outdoor surface of wall was better than different thicknesses from the point of view of maximum time lag and minimum decrement factor.

Kolaitis *et al*. (2013) compare internal and external thermal insulation systems for energy efficient retrofitting of residential buildings. Both external and internal thermal insulation configurations have reduced significantly the annual total HVAC energy consumption. On average, external insulation results in approximately 8% higher energy savings than internal insulation on an annual basis (when compared to the no insulation case), independent of climatic zone and occupant behavior. Also the authors find out that installation of thermal insulation may result in higher cooling energy requirements. However this adverse effect can be compensated with “active” occupant behavior (e.g. utilization of dynamic shading and night ventilation).

Cotterell & Dadeby (2012) state that buildings with an efficient form factor require less insulation. As a result, it is cheaper to construct. BRE (n.d.) also emphasizes the impact of the ratio between the external surface area (A) and the internal volume (V) of a building, which indicates the compactness, on the overall energy demand. According to BRE (n.d.), the amount of additional insulation thickness required to keep the same heating demand is influenced by the A/V ratio. And, an efficient compactness ratio is considered to be one were the A/V ratio ≤ $0.7 m^2/m^3$. Figure 2.6 shows the impacts of surface area increase for the same useful floor area on insulation thickness.

Figure 2.6 Impact of surface area increase on insulation thickness (BRE, n.d.)

Kruger, *et al*. (2013) state that the cost of insulating a house which is one of the primary factors that should be taken into account when selecting insulation can be divided into several parts: materials, installation, secondary costs (e.g., air sealing and waste disposal), and cumulative energy costs through the lifetime of the structure. And the best judgments can be made by taking into account all of these factors.

Mehta *et al*. (2009) divide insulating materials into the three categories which are fibrous insulation, granular insulation and foamed insulation as it is indicated in

Table 2.8. Fibrous insulating materials such as fiberglass, rock wool and slag wool insulations are fire, moisture and vermin resistant. Fiberglass as the most commonly used fibrous insulation can be found in the form of batts, blankets and semi rigid boards. Expanded perlite granules, expanded vermiculite granules and expanded polystyrene (EPS) granules are the three types of granules are in common use. And the most commonly used insulating foams are synthetic (plastic) foams, such as extruded polystyrene and polyisocyanurate which are used as rigid boards.

Cotterell & Dadeby (2012) states that to use insulation quick to install on-site or pre-installed should help reducing cost. Board based insulation has to be cut very precisely to avoid thermal bridging, which adds more cost by taking more skill and time. Blown-in insulation such as cellulose can also be cost-effective, since it requires very little labor to install.

Table 2.8 Commonly used Insulating Materials (Mehta et al., 2009).

Physical Structure	Configuration	Insulating material
Fibrous insulation	Batts, blankets and semi rigid boards	Fiberglass, Rockwool, Slag wool
	Loose-fill	Cellulosic fibers, fiberglass, rock wool
Granular insulation	Loose fill	Expanded perlite and vermiculite granules
	Rigid boards	Perlite board, Expanded polystyrene(EPS)
	Masonry inserts	EPS masonry inserts
	Insulating concrete	Perlite concrete, Vermiculite concrete
Foamed insulation	Rigid boards	Plastic foams,(Extruded polystyrene(XPS), isoboard),cellular glass
	Insulating concrete	Foamed concrete
	Foamed-in-place insulation	Foamed-in-place polyurethane

Sadineni *et al.* (2011) state that the chlorofluorocarbons (CFCs) and hydro chlorofluorocarbons (HCFCs) slowly emitted over the life cycle of some foam type insulation materials such as extruded polystyrene (XPS) and polyisocyanurate (PIR) verify harmful to the environment due to their large ozone depletion and global warming potentials. Insulating foam containing isocyanides acts as a powerful irritant on eyes and skin. And glass-fiber batt type insulation material is known to cause health related problems often times, especially respiratory ailments, to the personnel handling it.

Florides *et al*. (2002) examine various measures such as ventilation, thermal mass and shape of building for a typical house model in Cyprus. The results show that for a house that is constructed from single walls with no roof insulation, about7% of the annual cooling load can be saved, whereas these savings are about 19% for a house constructed from walls and roof with 50 mm insulation. To maintain the house at 25ºC in summer, ventilation leads to a maximum reduction of annual cooling load of 7.7%. And with better insulated house, depending on the construction type, better savings can be obtained.

- **Studies on Optimum Insulation Thickness in Turkey**

The insulation of buildings was not a common occurrence in Turkey until it became obligatory after the publication of the TS 825 Turkish Thermal Insulation Standard (Ekici *et al*., 2012). According to Bolattürk (2006), in Turkey heat loss from buildings is one of the primary sources of energy waste, since no or little insulation is used in existing and new buildings. Kürekçi *et al*. (2012) state that low density, cheap insulation materials with 3 or 4 cm thickness is applied to the buildings that are insulated. Therefore, considerable energy savings can be obtained by using proper thickness of insulation in buildings. Lechner (2001) states that optimum insulation thickness is mainly a function of climate and the value of energy saved. There are various studies which focus on the selection of the exterior wall system or the optimum insulation thickness. Here some of those studies are mentioned briefly.

Sezer (2005) notes that wall insulation is implemented with four different systems in Turkey, which are the external wall insulation system, the internal insulation system, cavity wall insulation system and curtain wall insulation system. The author also states that the exterior insulation system, used commonly in Europe and America, has also been used more often in Turkey in recent years.

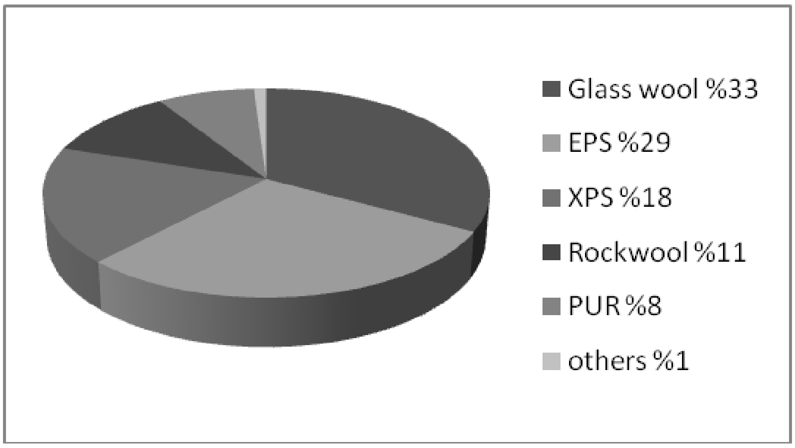


Figure 2.7 Insulation materials used in Turkey (Alkaya et al., 2012)

Selection of materials used to construct buildings is a complex process that is influenced by numerous considerations as material properties, economics and environmental effects. Today, most common insulation materials in use are glass wool, EPS and XPS in Turkey (Alkaya *et al.*, 2012). Figure 2.7 indicates the share of insulation materials in Turkey.

Bolattürk (2006) studied the optimum insulation thicknesses, energy savings, and payback periods in 16 cities from four climate zones of Turkey. The results show that optimum insulation thicknesses vary between 2 and 17 cm, energy savings between 22% and 79%, and payback periods between 1.3 and 4.5 years depending on the city and the type of fuel.

Ekici *et al.* (2012) calculated the optimum insulation thicknesses, energy savings and payback periods for the different wall types; using stone, brick and concrete. Antalya (1st zone), _Istanbul (2nd zone), Elazığ (3rd zone) and Kayseri (4th zone) were selected for analysis. The results show that the optimum insulation thickness varies between 0.2 cm and 18.6 cm, energy savings vary between 0.038 $/m^2 and 250.415 $/m^2, and payback periods vary between 0.714 and 9.104 years depending on the city, the type of wall, the insulation material and the cost of fuel.

Kürekçi *et al.* (2012) studied optimum insulation thickness for two different fuels (natural gas, coal) and five different insulation material (rock-wool, glass-wool, XPS, EPS, polyurethane) in 81 provinces in Turkey using lifetime cost analysis method.

The results show that optimum insulation thickness vary between 3 cm to 12 cm depending on the insulation type in Ankara. The results indicate that when the insulation thickness is increased, the amount of cost savings is increased in case of installing rock wool, glass wool, XPS and EPS.

2.3.2 Windows

Mumovic & Santamouris (2008) state that windows which provide natural light, ventilation and weather protection are very important component of buildings. The energy balance of a building shows that, when non-transparent parts of a building are well insulated, the most energy loss occurs through windows. Kruger & Seville (2013) cite that decisions in the selection of windows like its size, location, shading elements, glazing and frame materials, as well as installation method are critical to creating a sustainable home.

Krigger & Dorsi (2009) state that energy efficient windows use three strategies to improve the R value of glass, which are multiple panes, gas fillings, and special coatings. Triple glazed windows which are usually more energy efficient than double-glazed windows, can achieve a U-value as low as 0.6 W/m^2K. But triple-glazed windows are usually much more expensive than double-glazed windows (SEAI, 2013). Currently, there is a wide variety of window glass assemblies available, featuring from one to four glazing layers. Table 2.9 indicates energy characteristics of typical window glass options.

Table 2.9 Energy characteristics of various glazing (Krigger & Dorsi, 2009).

Glazing assembly	U-factor	R-value	SHGC	VT
Single glass	1.1	0.9	0.87	0.9
Standard insulated glass	0.5	2	0.76	0.81
High-SHGC, low-e insulated glass	0.3	3.3	0.74	0.76
Medium-SHGC, low-e insulated glass	0.26	3.8	0.58	0.78
Low-SHGC, low-e insulated glass	0.29	3.4	0.35	0.65
Triple glazed 2 low-e insulated coatings	0.12	8.3	0.5	0.65

According to Jankovic (2012), gasses such as krypton, argon and xenon have lower conductivity than air. Therefore, they improve the thermal insulation properties of glazing while not reducing light and radiation transmission properties. Table 2.10 indicates the thermal conductivity (W/mK) and other properties of different gases that can be used in windows, as well as the optimal thickness of the gas layer is for an average inside to outside temperature difference of 20K. Kruger & Seville (2013) states that southern low-e glass in warmer climates, has the coating on the inside surface of the outside pane of glass to allow less heat penetration, whereas northern low-e glass in colder climates, has the coating on the outside surface of the inner pane to increase solar gain. Jankovic (2012) states that amount of reflected, transmitted and absorbed solar radiation vary between different types of glass. Tinted glass will absorb more, where reflective glass will reflect more than clear glass.

According to Harvey (2006), a layer of motionless air created between the two glazing, increases the thermal resistance in a double glazed window. If the thickness (L) of the gap between two panels of glass increases, the thermal resistance to molecular heat conduction increases. If L is large enough for convective motions to begin, which is more easily triggered the greater the temperature difference between the inside and outside panes of glass, the thermal resistance will abruptly drop. The heavier the enclosed gas, the optimum size of the gap between the two panes of glass is smaller.

Table 2.10 Properties of different gases (Harvey, 2006).

Gas	Conductivity	Percentage in air	Optimal thickness of gas layer	Gas-separation energy for a 1,1 m^2 glazed area
Air	0.025		20mm	
Argon	0.0161	0.9	16mm	12kJ
Krypton	0.0096	0.000114	12mm	508MJ
Xenon	0.0055	0.0000087	8mm	4.5GJ

> "Low energy houses use two layer insulated windows with U=1.1 to 1.3 W/m^2K, while the Passive Houses have three layer insulated windows with U< 0.7 W/m^2K. This reduces the temperature difference between the room air and the window surfaces and thus ensures higher comfort. Room air temperature can be lowered by several degrees. Every 1ºC of room temperature reduction means 6 per cent savings in fuel consumption „ (Mumovic&Santamouris, 2008).

The impact of three different glazing types on the cooling load for a typical house model in Cyprus is studied by Florides *et al*. (2002). The authors compared the clear double glazing, reflective double glazing and low emissivity double glazing. The results showed that, a saving in the annual cooling load of between 3100 and 7300 kWh can be seen when compared to the construction with clear double-glazing windows. Window glazing will also reduce solar radiation transmission into the house, which will be beneficial in cold days leading to an increase of the annual heating load.

The frame as one of the parts of thermal resistance of a window, are made of mostly wood, plastic, aluminum, or a combination of these materials. Harvey (2006) states that aluminum frames cause the greatest heat loss of any framing material, followed by aluminum frames with a thermal break, aluminum-clad wood frames, and wood and vinyl frames, with the lowest heat loss from insulated fiberglass frames. Although, the heat loss through the glazed area is very small in high performance windows, heat loss from the window frame and spacers can be crucial if insulated frames and spacers are not used.

Kruger & Seville (2013) state that if insulated glass spacers are made of metal, they can create thermal bridge reduces the efficiency of the entire unit. Warm edge spacers (stainless steel, plastic spacers, and foam spacers) improve both the U factor and the condensation rating. Consequently, they reduce the amount of heat conducted through them. Ψ values for an aluminum spacer is approx. 0.08 W/mK, whereas a "warm edge "spacer is approx. 0.04 W/mK (INOUTIC, 2013).

The ultimate performance of a window unit depends on not only how advanced the glazing and frame materials are, but also the quality of its installation. Inaccurate installation can lead to air leakage, unnecessary heat loss, condensation, and water leakage. As a result, diminished energy performance, deterioration of walls, insulation and the window unit itself might be seen (Carmody, 2000).Cotterell & Dadeby (2012) list the four basic principles of a good installation as follow:

- to sit the window in the same line as the insulation, not staggered to it
- to wrap the outside of the window frame with at least 60-70 mm of insulation
- to use a tape on to the window frame
- the window is wind-tight along outside edges and waterproof against driving rain

Most important energy considerations for windows are thermal transmittance (U-factor) and solar heat gain (Krigger & Dorsi, 2009).According to PHI (2012), the g-value of the glazing, reflecting the potential solar heat gains, should be as high as possible with common values around 0.5. Since different climate regions will require different target window U values and different glazing types to meet Passive House standard, the average U values required for windows relating to seven different climate regions, are published by Passive House Institute. Table 2.11 shows the average required U values of windows for seven different climate regions (PHI, 2012).

Table 2.11 The average required U values for windows

Region	Name	Recommended glazing	U_W
1	Arctic	Vacuum low-e	0,40
2	Cold	Quadruple glazed low-e	0,60
3	Cool-temperate	Triple glazed low-e	0,80
4	Warm-temperate	Double glazed low-e	1,25
5	Warm	Double glazed	2,85
6	Hot	Double glazed anti-sun	1,55
7	Extremely hot, often humid	Triple glazed anti-sun	1,25

According to Persson & Werner (2011), when building a Passive House, to use large windows facing south and to use small windows facing north to minimize the heat losses through the windows is a common technique. The authors studied terraced houses in Sweden to investigate how the window size based on orientation influence the energy consumption and maximum power in low energy houses. The study shows that it is not so important to keep down the window area facing north for the investigated buildings. By decreasing the window size facing south, it is possible to decrease the risk of excessive temperatures or energy needed for cooling.

2.3.3 Thermal Bridges

A thermal bridge is a part of the building envelope where the otherwise uniform thermal resistance is critically changed by (1) a full or partial penetration of the building envelope by materials with a different thermal conductivity, (2) a change in thickness of the material, or (3) a difference between internal and external areas, such as appears at wall, floor, and ceiling junctions (Janssens *et al.*, 2007).

According to Hens (2007), thermal bridges experience not only larger heat losses and gains than the adjacent elements, but also the inside surface temperatures are lower there than on the adjacent elements during the heating season. Figure 2.8 indicates the temperature difference in an insulated and non-insulated corner. According to Ge *et al*. (2013), in some buildings up to 30% of heating energy can be lost through thermal bridges for highly-insulated residential buildings adopting high performance windows. According to a research on Turkish buildings, there is about %95 increase in U-value of walls owing to thermal bridges (Dilmaç & Kesen, 2003)

Harvey (2006) explains that precautions to eliminate thermal bridges as places where there are gaps in the insulation or highly conductive materials bridging from indoors to outdoors, reduce the likelihood of condensation and all the problems associated with condensation.

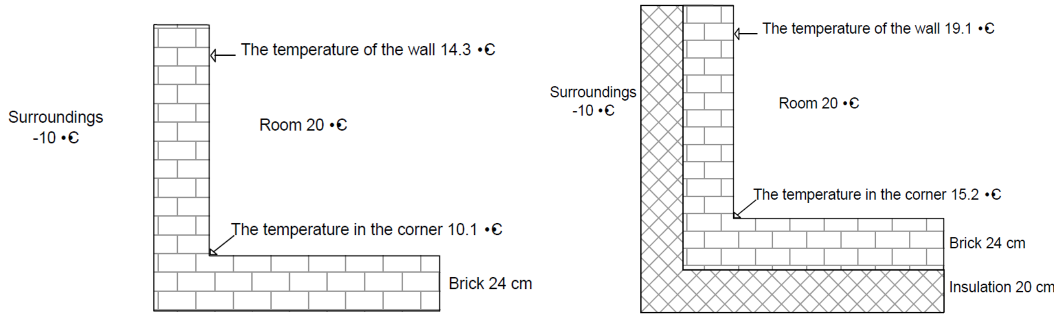


Figure 2.8 Temperature in non-insulated and insulated corners (Mumovic&Santamouris, 2008).

According to Hens (2007), there are two types of thermal bridges, which are geometric thermal bridges and structural thermal bridges. Geometric thermal bridges, as a result of the three dimensional character of a building occur at angles, corners, inner and outer reveals around windows, etc. Geometrical thermal bridges are so small as long as the exterior insulation is sufficiently dimensioned and continuous (Isover, 2008). Structural thermal bridges, as a result of structural decisions, occur at steel or concrete girders and columns that penetrate the envelope, as well as at discontinuities in the thermal insulation. Figure 2.9 shows examples of structural and geometric thermal bridge.

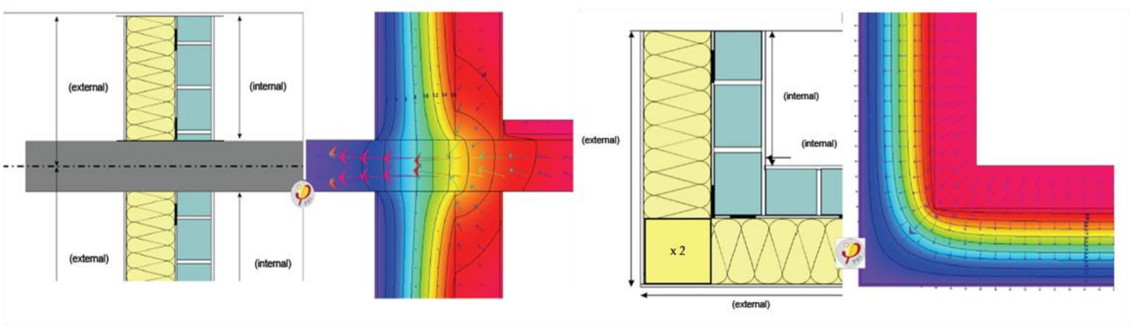


Figure 2.9 A structural and geometric thermal bridge (PHI, 2012).

Thermal bridges are quantified by a linear or local thermal transmittance. According to ISO 10211 (2007), a linear thermal transmittance is a heat flow rate in the steady state divided by length and by the temperature difference between the environments on either side of a thermal bridge. A linear thermal bridge is represented by Ψ value in W/mK and used as a correction term for the linear influence of a thermal bridge. A point thermal transmittance is a heat flow rate in the steady state divided by the temperature difference between the environments on either side of a thermal bridge and it is represented by χ value in W/K. It is used as a correction term for the influence of a point thermal bridge. Point thermal bridges are not considered as they generally form a very small proportion of total heat loss. Therefore, only linear thermal bridges (both geometric and structural) are calculated independently and entered into the heat loss calculation (Jacobson, 2012).According to Janssens *et al.* (2007), a linear thermal transmittance value depends on several factors:

- Continuity of the thermal insulation layer
- U-factor of adjoining building elements
- Geometrical conditions: position of the thermal insulation, difference between internal and exterior areas (exterior or interior corners), etc.

Janssens *et al.* (2007) emphasize the impact of the position of the thermal insulation on the linear thermal transmittance. If thermal insulation is positioned closer to the interior, the assumption that the heat loss surface is defined by the exterior dimensions deviates more from the physical reality. Figure 2.10 shows results for masonry wall corners continuously insulated with exterior, interior, or cavity insulation. The figure relates the U-factor to the Ψ -value of corner junctions. It is seen that the Ψ -value deviates more from zero when the wall is poorly insulated.

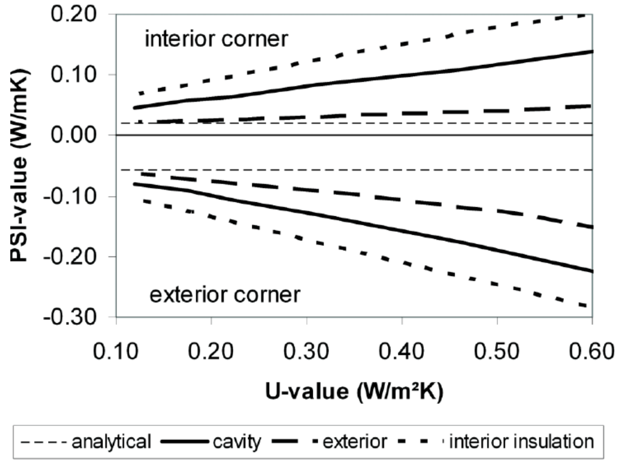


Figure 2.10 Psi values of various wall corners (Jansens et al., 2007).

- **Mold growth and condensation**

Deterioration of indoor air quality parameters and mold growth, as well as defects in the building after a certain period of time may occur as a result of thermal bridges (Mumovic & Santamouris, 2008). Surface condensation appears when the surface temperature is lower than the dew point of surrounding air. Surface condensation is one of the main reasons of mold growth due to the presence of the moisture within the wall section encouraging the biological practice. The thermal defects such as thermal bridges, surface condensation or interstitial condensation may result in lower surface temperatures below the dew point temperatures can suffer from the mold growth. The outdoor temperature, the indoor temperature and the thermal properties, configuration of the different materials and the inside surface conductance impact the inside surface temperature on a building component (Standaert, a1984).

When the outside temperature is colder than the inside temperature, the thermal bridges are colder than the interior surrounding wall and room air. Thus, they make the adjacent wall and air to cool quickly. Since cooler air can hold less moisture than warm air, moisture condenses out on the surface of the cooler wall. This moisture can provide a matter for the mold growth (Roaf *et al*., 2007).

According to SHC (2011), various mold species grow when the relative humidity at the component surface is ≥80%. Regarding the surface temperature, the building component‟s surface temperature must be ≥ 12.6 °C. Figure 2.11 presents relative humidity at the surface of the building component, given for different component surface temperatures (indoor air humidity 50%, indoor air temperature 20 °C). According to TS 825 Standard, relative humidity of interior environment is taken 65% in naturally ventilated buildings and 55% in buildings with mechanical ventilation when doing condensation calculations. Relative humidity of outside air in December, January and February is taken 78%, 76% and 71% respectively in Ankara.

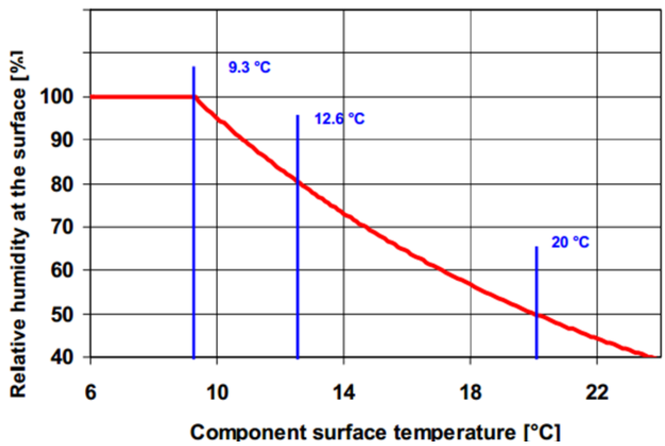


Figure 2.11 Relative humidity at the surface of the building component (SHC, 2011).

- **Thermal Bridge Free Construction Details**

Thermal bridge free design is one of the pillars of Passive House concept and if the sum of all thermal bridges of a building is ≤ 0, the construction is regarded as thermal bridge free. Constructive thermal bridges which achieve the value Ψa≤ 0, 01 W (mK) are regarded as being thermal bridge free (PHI, 2012). Cotterell & Dadeby (2012) state that careful design and „architectural detailing‟ of building junctions are very necessary to deal with thermal bridges. Figure 2.12 presents the crucial points to avoid thermal bridges in building envelope.

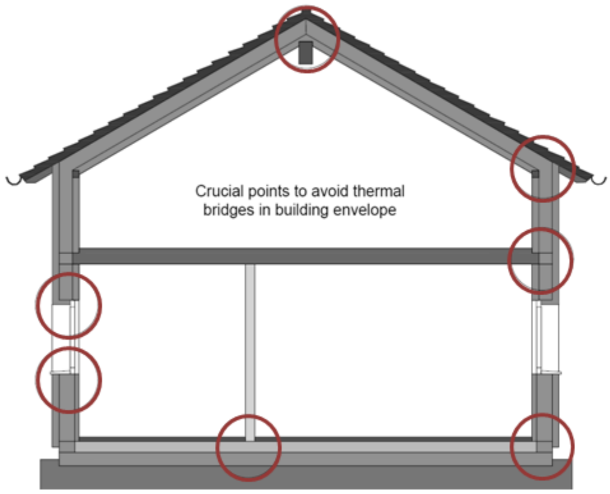


Figure 2.12 Crucial points to avoid thermal bridges in building envelope (PHI, 2006).

In order to avoid thermal bridges, the following rules should be followed: (Schild & Blom, 2010)

- The thermal insulation envelope should not be interrupted around the entire building.
- If an interrupted insulation layer is unavoidable (e.g. balcony or wall /foundation), the thermal resistance of the insulation layer should be as high as possible.
- The insulation layer should not have any gaps at building element junctions and they should be installed without misalignment.
- Design edges should have as obtuse angles as possible.

The balcony which is framed or built continuous with the interior floor passes through the thermal barrier and creates a "heat fin" to the exterior of the building. Regardless of climate, heat loss and gain can occur through this bridge. There are two methods which can be used to eliminate the effect of a wall to balcony slab thermal bridge (Totten *et al.*,n.d):

- To provide separate structure to build the balconies or to use branded systems that are comprised of insulation and low conductance material post-tensioning cables that can tie the exterior structure to the interior structure as indicated in Figure 2.13.

- To use insulation carefully above and below the slab for a certain distance into the building to reduce the effect of the thermal bridge.

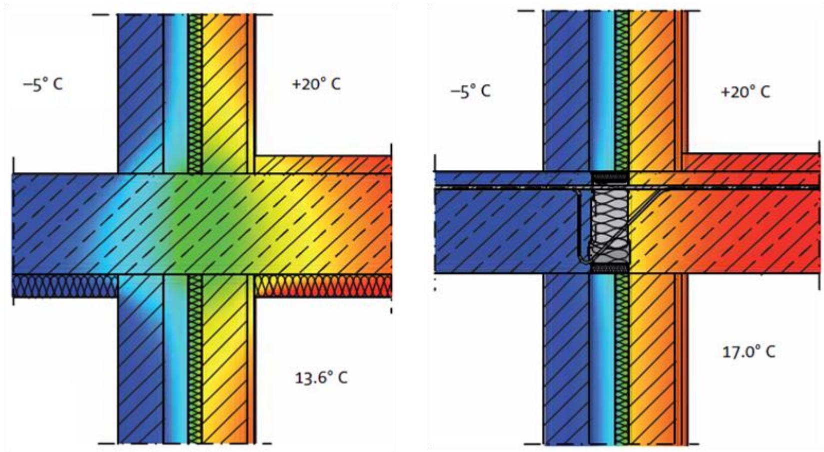


Figure 2.13 Balcony connection without and with thermal break element (SchöckIsokorb, 2009).

Significant thermal bridges can occur if a window is not installed correctly in the wall. To minimize thermal bridges, installing the windows in the insulation layer of the external wall has a great importance since additional insulation that covers the window frames reduces heat losses (IPHA, 2010). Figure 2.14 shows an example of a Passive House window installation without thermal bridges.

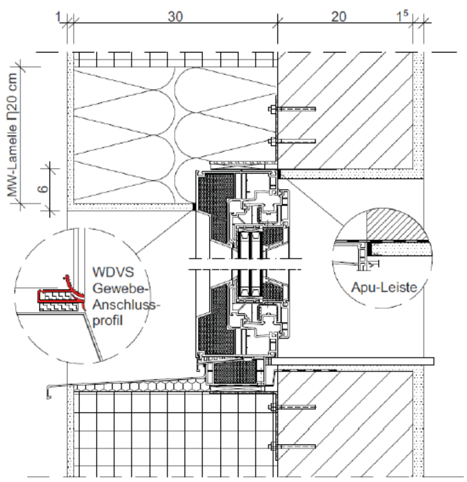


Figure 2.14 Passive House Window installation without thermal bridges (Vetter, 2012).

A thermal bridge free ceiling connection with the unheated basement is showed in Figure 2.15.According to manufacturer's instructions, the ceiling design has a U-value of 0, 27 W /(m^2K).In an unheated basement, the concrete cores of the outer walls have to be thermally separated from both sides of the ceiling. This is done by a foam glass block as shown in the drawing. This results in Ψa = -0.027 W / (mK), based on the temperature difference with the outside air (Feist *et al.*, 2010).

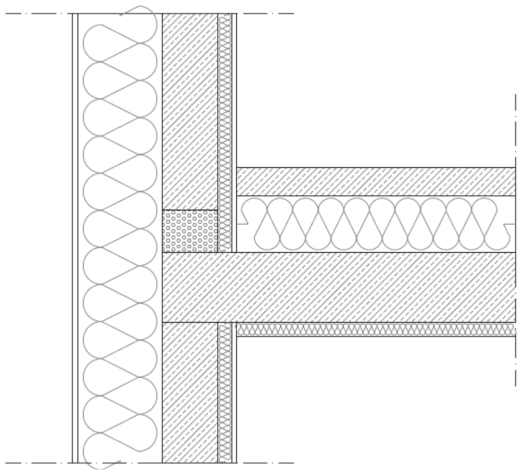


Figure 2.15 Ceiling connection with the unheated basement (Feist et al., 2010).

A thermal bridge free ground connection with strip foundation is detailed as it is demonstrated in Figure 2.16. In this detail, foundation strips are made of cellular lightweight concrete. The authors also suggests a connection detail using foam glass block, but it is stated that the carrying capacity of this construction is much higher than in the variant with the foam glass block: Cellular lightweight concrete (λ= 0.5 W/ mK), has a compressive strength of up to 9 N/ (mm^2) whereas foam glass (λ= 0.055 W/ mK) of about 1 N/ (mm^2). With the use of cellular lightweight concrete, the insulation layers cannot be effectively connected to each other, however: Ψa = 0.035 W/ mK can be reached, whereas = -0.015 W/ mK can be reached with the use of foam glass block (Feist *et al.*, 2010).

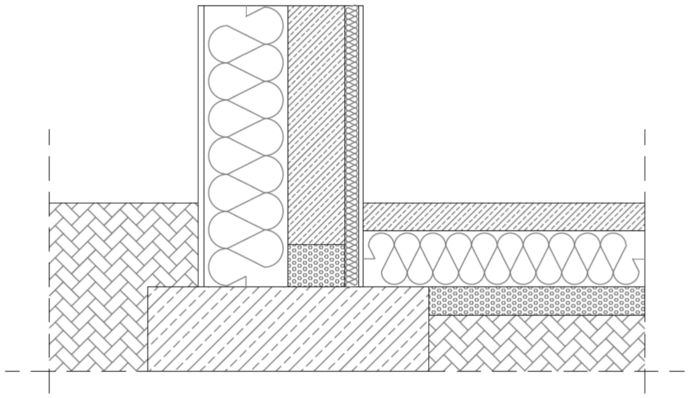


Figure 2.16 Ground connection with strip foundation (Feist et al., 2010).

Figure 2.17 indicates an example for an eaves detail of a pitched roof to reduce thermal bridges. According to the authors, to limit thermal bridging and air leakage for the illustrated detail, a minimum of 50mm layer of compressible mineral wool or similar should be applied. It is crucial to be sure that loft insulation meets wall insulation. And to ensure a minimum of 25 mm air gap is necessary (TSO, 2001).

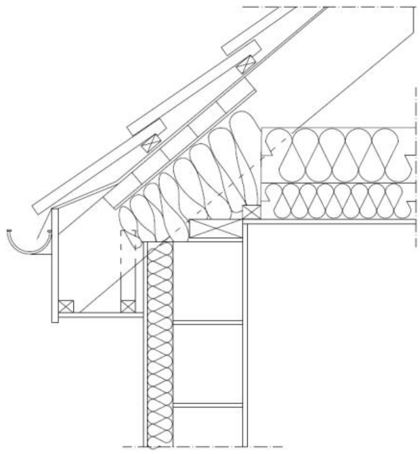


Figure 2.17 Pitched roof, ventilated loft, eaves detail (TSO, 2001).

- **Studies on thermal bridges**

Comiskey (a.2009) compares and evaluates numerical results of construction details of a dwelling to show how lower psi values affect the overall loss and energy consumption in SAP 2005. The study showed that a considerable reduction in heat loss can be achieved by modeling individual dwelling specific details rather than using non-accredited details.

Déqué *et al.* (2001) model the heat transfers in the intersections of walls using Sisley software and then integrated in Clim 2000.The aim is to describe the modeling approach used to evaluate the effect of thermal bridges on the energy performance of buildings accurately. The authors use T and L shaped structures in this study. The results showed that the accuracy of heat losses is increased by about 5-7% by taking 2D models of thermal bridges into account.

Cappelletti *et al.* (2011) evaluate the heat losses due to the frame installation in terms of linear thermal transmittance using THERM 5.2. The impact of window installation of a wooden frame window on thermal losses is estimated. The results showed that regarding the position of the frame, the consistent reduction up to 70-75% of linear thermal transmittances moving the window from internal to external position can be achieved.

Ge *et al.* (2013) evaluate the impact of thermal bridges, particularly concrete balcony slabs, on the energy efficiency of a typical multi-unit residential building built in Canada. According to the study, by introducing thermal break in the balcony, the overall U-value of the balcony is reduced by 72–85%. By reducing the heat transfer through balcony slabs, the space heating energy consumption may be reduced by 5–13% and space cooling energy consumption by less than 1%.

Ascione *et al.* (2013) state that in most cases, building energy simulation programs solve heat conduction through walls by considering one-dimensional heat flows and neglecting thermal bridges. Therefore, the authors study a new method to implement bi-dimensional and three-dimensional heat transfer in dynamic energy simulation software. In this study, the authors investigate the accuracy of the methodology by means of comparisons with experimental measurements.

Larbi (2005) develops analytical formulas for the thermal transmittance of three different 2D thermal bridges which are a slab on grade floor-wall junction, a floor-wall junction and a roof-wall junction. According to the results, the presented models can be used by practitioners, provided that both boundary conditions and material characteristics are similar to the ones used in this study.

Nyberg (2011) studied thermal bridges at foundations and evaluated heat calculation methods using HEAT 2 and HEAT 3. The results indicated that the thickness and thermal conductivity of the ground insulation and the size of the floor slab both have greatly importance to the Ψ_g value. The amount of soil in the detail has some too little importance while the soil‟s thermal conductivity has some importance. The verification indicates that the shape of the floor slab has little importance for the heat transfer coefficients H_g for ground and H_{wall} for the wall together.

Sezer & Yeşilyurt (2011) studied a residential area in Bursa where cavity walls system is used. U values of thermal bridges in three different cavity wall examples of the building blocks are calculated and heat losses through these thermal bridges are compared. To eliminate thermal bridges in cavity walls system or interior insulation system is possible with additional insulation applications. To apply insulation externally is the best solution to eliminate thermal bridges.

Kalpak & Dilmaç (2003) analyzed the cavity walls system applications in abroad and Turkey and gave application proposals to eliminate thermal bridges in cavity walls system. Karabulut, Buyruk & Fertelli (2011) study the impacts of intermediate floor slab thermal bridges where a cavity wall system is used. Also the authors study balcony thermal bridges that are extensions of a reinforced concrete beam and insulated internally. According to the results, most of the heat losses occur through concrete beam surfaces and to insulate the beams reduces thermal bridges.

İZODER TS 825 calculation software is a free of charge software written by İZODER which enables to evaluate energy efficiency of a building considering national regulations in Turkey. The software also includes linear thermal transmittance calculations for various details and variations taking into account TS EN ISO 10211-1, TS EN ISO 10211-2, TS EN ISO 14683 and TS 8441 standards. Thermal bridge calculations for various balcony, roof, floor slab, interior wall, column, corner, window options are carried using exterior or interior dimensions.

According to MESA MESKEN (1996), speed and quality production of tunnel formwork system brought joy at the first applications. But later on, there were complaints from the building occupants. Therefore condensation and mold problems in tunnel formwork constructions were studied by the research group of the firm. To inhibit mold growth totally, it is not enough to avoid thermal bridges and use the best insulation material. If ventilation is not provided effectively, water vapor is not ejected from the building and relative humidity is not lower than 60%, mold growth can occur at any building. Therefore, applying the whole house approach such as Passive House concept is recommended rather than separated measures without an overall plan.

2.3.4 Air Tightness

Mehta *et al.* (2009) explain that the loss of heated or cooled air through cracks and unsealed joints in the building envelope is called exfiltration, and its replacement by the outside air is called infiltration. Collectively, this air migration is called as air leakage. Air leakage increases the energy consumption of a building since the infiltrating air must be heated, cooled, humidified, or dehumidified to the required levels.

Cotterell & Dadeby (2012) states that the advantages of reducing air leakage are:

- savings of heat energy
- improved insulation performance
- better comfort levels
- durability of the building fabric by minimizing vapor moisture entering it.

Even with the smallest of air leakages into the insulation layer, the insulation`s thermal performance is significantly reduced. In one experiment, for example,

performance altered from a U-value of 0,3W/m^{2}K to a U value of 1,44W/m^{2}K-a factor of nearly five (Cotterell & Dadeby, 2012).
Montoya *et al*. (2010) study the most influential building characteristics related to air tightness in single family Catalan dwellings. And the authors found out that in addition to year of construction and number of stories, the structure type, the floor area and insulation type are the most significant variables influencing air tightness.

Since materials and workmanship used in constructing buildings influence the air infiltration rate in buildings, properties determined for Germany by DIN 4701, don‟t give reliable results when applied in Turkey, which has different meteorological conditions than Germany (Tanrıbilir *et al*., 1990). The authors have measured air tightness of 18 rooms and air infiltration rate of 34 rooms using two blower doors and decaying tracer gas technique with nitrous oxide (N_2O). Canadian and ASTM standards were used for measurements. The test rooms were selected from new, unoccupied multi-storey apartment buildings and two or three story dwellings. Air tightness of the rooms was about 2.64 to 20.54 ACH (Air changes per hour) at 50 Pa indoor outdoor air pressure differences, while air infiltration rates were in the range of 0.16 to 1.99 ACH.

- **Blower Door Testing**

Air tightness testing is an important tool to evaluate the effectiveness of air barrier assemblies. Today, air tightness testing can be made in quantitative and qualitative ways. Quantitative air tightness testing gives values for comparison with specified targets, standards, industry averages, whilst qualitative testing gives a useful tool for visually determining the location, direction, and importance of airflows. Today, using a blower door is the most common quantitative test method to measure the air leakage of the building enclosure (RHD Building Engineering Ltd., 2013).A large fan is sealed into a door or window that creates excess pressure or negative pressure in the entire building as it is indicated in Figure 2.18.

The pressure test should only be carried out for the heated building volume. Basement, porches, conservatories etc. that are not integrated into the thermal envelope of the building should not be included in the pressure test (Feist *et al*., 2012). It is necessary to close primary windows and storm windows, to open interior doors, to disable heaters and water heaters before blower door testing (Krigger *et al*., 2009). Also it is essential to ensure that any intended leakage paths are sealed. For instance, ventilation units can be sealed off with tapes. The air tightness test result will be affected by high winds. Therefore, the test should be carried on when the wind speed is below 6m/s or 21.6 km/h on the day (Cotterell & Dadeby, 2012).

Figure 2.18 Illustration of blower door test

According to Krigger *et al*. (2009), the blower door apparatus includes:

- A frame and flexible panel to plug an open doorway
- A variable speed fan to create pressure and air flow
- A pressure gauge to measure the pressure difference between the home and outdoors
- One or two airflow manometers to measure a large range of airflow values
- Hoses to attach the pressure manometer to outdoors and the airflow manometer to the fan

- **Strategies for an airtight construction**

The air tightness of a building can be outlined using the "red pencil method" which is made by tracing the whole building envelope with a pencil without any breaks in each sectional drawing as it is presented in Figure 2.19. Waltjen *et al.* (2009) state that armored building boards, interior plaster; concrete, wood-based panels are the four material groups that can be used to complete an airtight layer. Table 2.12 indicates materials suitable and unsuitable for air tightness layer.

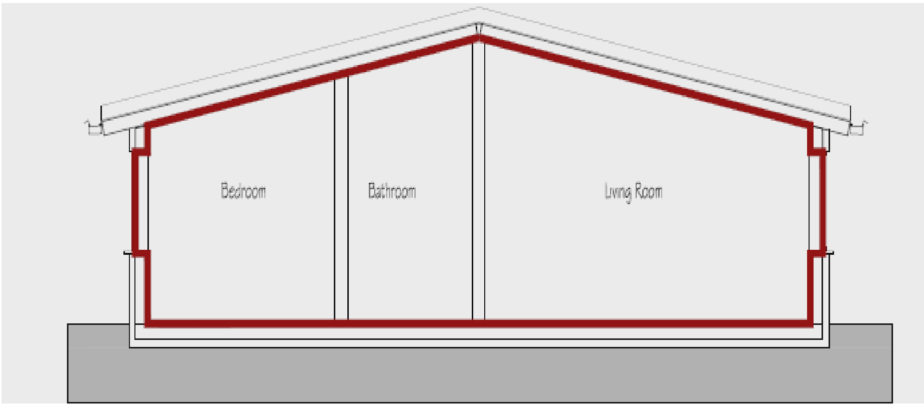


Figure 2.19 Defining air tightness of a building with Red pencil method

Harvey (2006) states that the building envelope must contain four barriers: a thermal barrier, an air barrier, a vapor barrier and a moisture barrier. An air barrier is any material on a building preventing the movement of air through exfiltration and infiltration (Bynum, 2001).The use of an air-impermeable insulation (spray foam) usually eliminates the need for a separate air barrier but if air permeable insulation is installed (mineral or glass wool) a separate air barrier must be installed (Kruger *et al.*, 2013).Figure 2.20 indicates an example of an exterior air barrier approach in a Multi-Family Residential Building which is utilized to either seal the joints in the exterior sheathing or seal the exterior sheathing membrane.

Figure 2.20 An exterior air barrier approach in a Multi-Family Residential Buildings (RHD Building Engineering Ltd., 2013).

A vapor barrier, which is now called vapor retarders, reduces the rate and volume of vapor diffusion through a building‟s ceilings, walls, and floors. They are commonly made of polyethylene sheets, treated papers, and metallic foils (Bynum, 2001).

Vapor barriers aren‟t necessary in all climates since they trap moisture. Buildings that are either heated or air conditioned for most of the year typically remain drier without vapor barriers (Krigger *et al*., 2009).According to Mumovic *et al*. (2008), moisture that is responsible for 70 to 80 per cent of all damage in buildings, relates to water in its three states (vapor, liquid and solid) with inclusion of all substances such as salts. To keep bulk moisture out of the structure and to prevent structural damage and mold growth, Water Resistive Barriers (WRBs) must be installed on all non-reservoir walls. The most common WRB is house wrap. Liquid-applied WRBs are popularly used in multifamily projects. Water-resistant wall sheathing and foam sheathing can also serve as the WRB (Kruger *et al*., 2013).

Table 2.12 Materials suitable/unsuitable for air tightness layer (Cotterell & Dadeby, 2012).

Airtight materials	Non-airtight materials
Air tightness tapes and grommets	Cement
Concrete (quality-dependent)	Chipboard
Glass	General-purpose sealants and foams
Good-quality OSB (18 mm or thicker)	Insulation
Gypsum plaster	Masonry (bricks or blocks)
Intelligent breather membrane (vapor-open)	Plasterboard
Lime Plaster (to suitable specification)	Tiling and grout
Steel	Unprocessed wood
Vapor barrier membranes (vapor-closed)	Wood fiber boards

According to Kruger & Seville (2013) there are three types of air sealing materials: caulks and adhesives, liquid (spray foam), and air barriers. Various types of air sealing materials can be seen in Table 2.13.To complete the thermal envelope and reduce air infiltration; the following parts in a building must be fully sealed:

- Every pipe, wire duct, and chase
- All transition points between materials in walls; including between double and triple studs, along the lines where the wall plates meets floors and ceilings, around windows and doors, between masonry or concrete and wood, along rim joists
- Attic accesses, such as pull-down stairs, ceiling hatches, knee wall doors
- Light fixtures and registers for HVAC

Figure 2.21 Window installation in concrete masonry wall (Kruger & Seville, 2013).

Figure 2.21 indicates a window installation in concrete masonry wall. According to Kruger *et al*. (2013), the following five steps should be carried for the illustrated window installation:

- To install precast tiered sill or cast in place sill and sealing to sill with a liquid applied waterproof sealant.
- To install wood bucks over sealant.

- To apply sealant at the jambs and head.
- To install window and apply sealant over exposed wood bucks
- To install exterior finish with continuous bead of sealant at jambs and head.
- Seal window to the stucco.

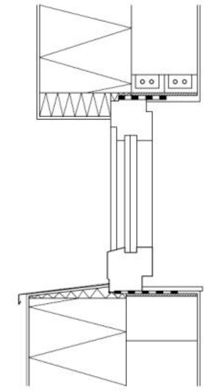
Table 2.13 Type of air sealing materials (Kruger & Seville, 2013).

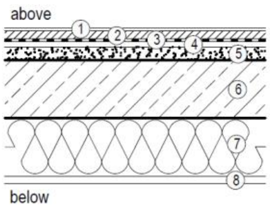
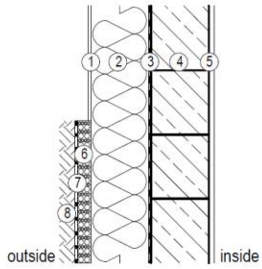
Caulking and Adhesives	Liquid Foam	Air barrier materials
Water based caulks	One-part foam	Plywood
Silicone caulk	Two-part foam	Sheet metal
Polyurethane caulk		Foam board
Acoustical sealant		House wrap
Water-soluble duct mastic		Drywall
Stove cement		
Fire-rated caulk		
Construction adhesives		

Firlag (2012) claims that in buildings with traditional brick or precast concrete construction, achieving the assumed level of air tightness is easier than in those with wood-frame construction since wood frame constructions have a more complicated construction details. Developing a guide book that includes examples of properly solved construction details, as well as education and promotion of air tightness aspects are very important.

> "A classically masoned outside wall is sufficiently airtight if it has a continuous, uninterrupted layer of interior plaster and force-fitted joints. But the interior plaster has to be applied over the entire surface (before applying the screed layer) to the uncovered ceiling layer. Even "invisible areas„ behind steps and bathroom separating walls have to be plastered accurately. It has proven to be practicable to apply a "preliminary layer" in the form of a smooth mortar in the preliminary construction phase. Force-fitted inter connected concrete elements are the only load bearing components that are airtight on their own„ (Waltjen *et al.*, 2009).

Pan (2010) studied the relationship between air tightness and its influencing factors based on new build houses in the UK. Results showed that houses built using precast concrete panels were significantly more airtight than those built using timber frame. The masonry and reinforced concrete frame dwellings were most leaky. The use of „self-build" procurement route and innovative building practice led to performing better air tightness of houses. In Figure 2.22, various construction details suitable for Passive Houses are presented.

<table>
<tr><th>CONSTRUCTION DETAILS</th><th>TECHNICAL DESCRIPTION</th></tr>
<tr><td></td><td>HONEYCOMB BRICK OUTSIDE WALL, WOODEN WINDOW

Half of the window frame is on the solid wall, ths side is screwed to the masonry
Use a smooth screed layer on all sides
Bond a fleece-laminated butyl rubber strip to seal the smooth screed on all sides
Connect the interior plaster with the window frame plastering bead if needed.
Ensure driving rain sealing and windtightness by means of suitable completion.</td></tr>
<tr><td>
</td><td>SOLID BASEMENT CEILING SLAB
1.Floor surface
2.Cement screed (5 cm)
3.Building paper
4.Wood fiberboard for sound insulation (3,6 cm)
5.Gravel filler,bonded (5 cm)
6.Reinforced concrete (20 cm)
7.Mineral wool (20 cm)
8.Lightweight wood wool acoustic panel (2,5 cm)</td></tr>
<tr><td>
</td><td>SEALED CONCRETE OPEN BLOCK OUTSIDE WALL
IN CONTACT WITH GROUND

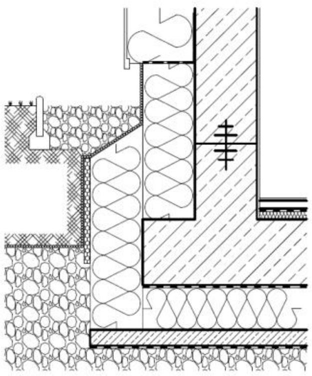
1.Base course plaster or cladding
2.XPS CO_2 foamed (32 cm)
3.Two layer polymer bitumen seal (1 cm)
4.Concrete insulation blocks (25 cm)
5.Loam rendering (1,5 cm)
6.Subsoil
7.PP Filter fleece
8.Concrete drainage blocks (8 cm)</td></tr>
<tr><td></td><td>WATER RESISTANT CONCRETE SLAB FOUNDATION
The drainage pipes should be laid below the lower edge of the floor slab, but above the upper edge of the natural ground
Use washed drainage gravel
Line drainage gravel bed with PP filter fleece on all sides, and avoid mixing the gravel with soil during construction
Seal the polymer bitumen sheet stripe visible between the base insution and insulation of the rising wall tightlyon the wall surface, cover the joint with a long lasting elastic seal
The combination of a water resistant concrete floor slab and a rising wall with a bituminous seal is techically possible, but not recomended.</td></tr>
</table>

Figure 2.22 Construction details for Passive Houses (Waltjen et al., 2009)

2.4 Ventilating, Heating and Economics of Passive Houses

In this section, first of all, three different ventilation strategies are explained and the application of these strategies in Passive Houses is compared. Following that, various heating systems with a comparison are described. Finally, economics of Passive Houses are discussed.

2.4.1 Passive House Ventilation

Due to the fact that humans in developed parts of the world spend most of their time indoors, indoor environmental quality plays an important role for human health, comfort and performance. Furthermore, a balanced ventilation concept is considered as a proxy of the indoor air quality.

The choice of ventilation type can differentiate correspondingly different countries, climates, boundary conditions, occupant behavior and choice of consumer. While natural ventilation is accepted widely in Southern Europe, simple exhaust systems are more popular in the moderate climate region. In Scandinavia, balanced mechanical heat recovery ventilation is the most common system. (Laverge & Janssens, 2013).

- **Natural Ventilation**

Mumovic *et al*. (2008) state that single sided ventilation which can be made with single opening or with double opening generally serving single rooms, submits the least attractive natural ventilation solution. Wind effect and stack effect as the two other mechanisms generating natural ventilation. Wind effect occurs as a result of the difference of pressure including positive pressure on the windward side and negative pressure on the leeward side of the building. Jankovic (2012) states that stack effect occur as a result of buoyancy of air. Volume of warm air which has lower density than cold air has a tendency to rise above volume of cold air. If there are openings at the base and top of a tall space (which is called a stack or chimney), the warm air escapes from the top openings. The higher the temperature differences between the top of the stack and the outside air, the more intensive the stack effect.

The design and type of windows affect both the direction and the quantity of the air flow. According to Lechner (2001), double hung and siding windows lock at least 50 percent of the air flow. And casement windows allow nearly all full airflow, but they can change the direction of the airflow. Horizontal strip or ribbon windows are often very good at providing good ventilation over large areas of a room.

According to Harvey (2006), the acceptable air temperature increases with natural ventilation as a result of enhanced psychological adaptation to warmer conditions compared to buildings with mechanical ventilation. Mumovic *et al.* (2008) claim that lower sick building symptom prevalence is reported in naturally ventilated buildings in comparison to the mechanically and air conditioned buildings. According to the authors, carefully designed naturally ventilated buildings can cost less to construct and maintain more than heavily mechanically serviced correspondents. But according to Feist (2006), to achieve an air exchange of about 0.33 air change per hour (which is necessary for hygienic conditions), the windows have to be opened wide for 5 to 10 minutes every three hours, and this is hardly ever done in practice. Kruger & Seville (2013) state that natural ventilation is not a certain way to provide a measurable amount of air exchanges, since this method is subject to significant variations with temperature, wind direction, and wind speed.

According to Jankovic (2012), if natural ventilation cannot provide one or more of the following, mechanical ventilation is used:

- consistency of supply and control
- quantity and quality of required air
- isolation from external environment to avoid pollution, noise or increased security

- **Mechanical Exhaust Ventilation**

Air is exhausted from the rooms with higher pollutant generation and lower air quality in mechanical exhaust ventilation systems. Air penetration through the building envelope or special air intakes brings outdoor air for ventilation into the building. If the pressure drop in the exhaust grille is high enough to stop airflow from floor to floor, exhaust from the different floors can be connected to the same duct in apartment buildings (Mumovic & Santamoris, 2008). Figure 2.23 indicates a mechanical exhaust ventilation system serving several apartments.

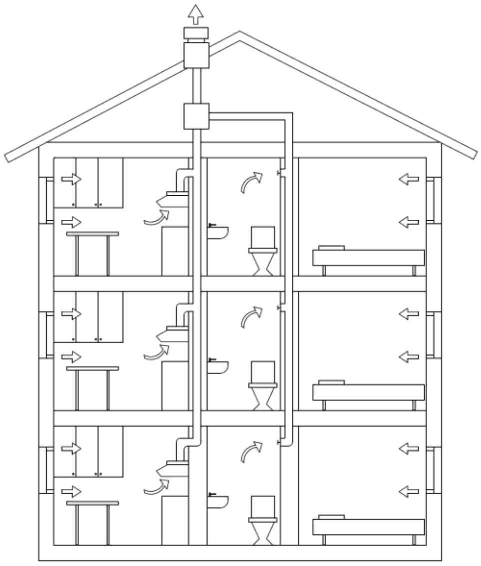


Figure 2.23 Mechanical exhaust ventilation system serving several apartments (Mumovic & Santamoris, 2008).

According to Krigger *et al*. (2009), exhaust ventilation systems are inexpensive and easy to install. And they create negative pressure within the home, which helps reducing the likelihood of moisture accumulation in cold climates. However, this depressurization can draw outdoor moisture into the home in hot and humid climates. Simple exhaust ventilation has the drawback that no widely available technology allows for heat recovery on it, since it still needs electricity for fan operation. However, it gives more stable flow conditions than natural ventilation and some of the energy in the exhaust air can be recovered by the implementation of heat pump technology for domestic hot water production or for low temperature heating systems (Laverge &Janssens, 2012).

Mumovic & Santamoris (2008) list the further drawbacks of the mechanical exhaust system as follows:

- Draughts during the winter in cold climates.
- Inadequate airflow in bedrooms and living rooms.
- Dependence on leakage in the building envelope for the distribution of outdoor air in the building.
- Low sound weakness of typical air intakes for outdoor noise.

- **Mechanical Heat Recovery Ventilation**

Jankovic (2012) cites that in order to reduce energy consumption and carbon emissions of buildings, heat recovery systems are absolutely necessary if mechanical ventilation is specified in a building. Installing ventilation systems with heat recovery is becoming widespread especially in the high latitude countries such as Germany and Sweden. For instance, in Germany the building code for the year 2000 contains prescripts for well insulated and tight buildings so the energy demand for heating from ventilation air tends to reach about 60% of the total annual energy demand for the building. Therefore new buildings must install ventilation systems with heat recovery (Zhou *et al.*, 2007).

Depending on air tightness and insulation of buildings, ventilation heat losses can be typically 35–40 kWh/m^2a in residential buildings, and up to 90% of this can be recovered with mechanical ventilation with heat recovery (Tommerup & Svendsen, 2006).

Highly efficient MVHR unit is one of the main components of a central European Passive House. To guarantee a high indoor air quality, the need to install mechanical ventilation becomes apparent in airtight buildings (Feist *et al.*, 2005). While airtight buildings are effective for energy savings, infiltration rates are reduced, and as a result indoor air quality deteriorates. To solve this problems caused by the tightly sealed building envelopes, heat recovery ventilators are used as an effective way of saving energy and maintaining necessary ventilation rates (Kim *et al.*, 2012). The general rule of thumb is that an MVHR should only be installed in buildings achieving an air tightness of 3 ach at 50 Pa or better. One recommendation is that a maximum rate of 1.5 ach at 50 Pa should be the target to ensure efficient performance (Cotterell & Dadeby, 2012).

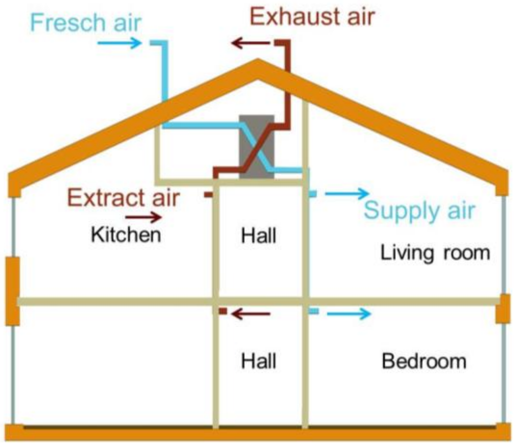


Figure 2.24 Ventilation in a Passive House (PHI)

In MVHR units, used air is continuously being removed from the rooms with high levels of pollution and humidity such as kitchen, bathroom, WC, utility room, while fresh air is supplied to the living areas such as living room, bedroom or study room as it is presented in Figure 2.24.

As it is shown in Figure 2.25, a typical heat recovery system in building includes ducts for incoming fresh air and outgoing stale air, a heat exchanger core, where heat or energy is transferred from one stream to the other and two blower fans; one is to exhaust stale air and supply fresh air via the heat exchanger core (Idayu & Riffat, 2012).

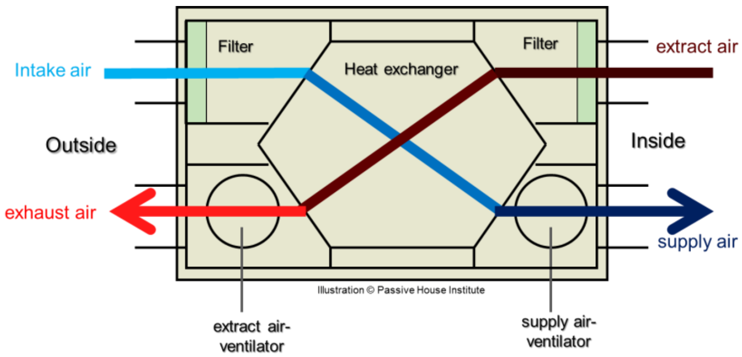


Figure 2.25 Mechanical heat recovery ventilation system (PHI)

The fresh air is automatically preheated or pre-cooled in the core (depending on the season) by the exhausted air and distributed to the interior part of the buildings. The outgoing and incoming air passes next to each other but do not mix in the heat exchanger. Heat is recovered from the internal air before it is discharged to the outside and warms the incoming air. In an advance design of this system, sometimes the incoming air is filtered to reduce the incidence of pollen and dust while the outgoing air is filtered to protect the heat exchanger and internal components (Idayu & Riffat, 2012).

According to Laverge &Janssens (2012), MVHR effectiveness is affected by a number of factors such as temperature and humidity conditions and flow rate through the unit. Moreover, frost and afterwards required defrosting cycles can have a significant impact on the seasonal effectiveness.

Table 2.14 Advantages and disadvantages of MVHR systems

Advantages	**Disadvantages**
Warmed supply air possible	Capital cost
Energy Recovery	Complex installation
Draught free design	Regular maintenance requirement
Control of humidity	Necessity of an airtight dwelling
Reduction of pollutants and condensation	Increased electricity bills related to specific fan power
Effective distribution of air	
Reduction of external noise	

Mark & Gillott (2000) specify that MVHR systems have various advantages such as warmed supply air, recovered exhaust air, draught free design and reduction of pollutants as well as condensation, control of humidity, effective distribution of air, reduction of external noise can be obtained by installing MVHR. The authors classify also the disadvantages of MVHR systems as their capital cost, complex installation, regular maintenance requirement and necessity of an airtight dwelling for effective operation. Table 2.14 indicates a summary of advantages and disadvantages of MVHR systems.

According to Idayu *et al.* (2012), mechanical ventilation in some cases increases a household‟s electrical power consumption by up to 50%. The total electric power use of all fans in the ventilation system of a building is taken into account by specific fan power, and it can play an important role to reduce the electricity use for MVHR. Proper design and installation are also critical to achieve the designed specific fan power in practice (Railio & Mäkinen, 2007). Laverge & Janssens (2012) highlight the effects of fan power consumption in heat recovery units for the different countries of the EU in their study. According to the authors, fan power will typically increase with higher heat recovery unit effectiveness. And unless low specific fan power is achieved, for the moderate climate region of middle Europe, natural ventilation, simple exhaust mechanical ventilation and heat recovery ventilation have no clear advantage over each other considering operating energy and associated ecologic (CO_2) and economic effects.

Ventilation systems of new buildings that have an air flow of more than 500 m^3/h, a minimum of 50% efficiency in summer as well as in winter is required in Turkey. Taking into account investment and operation costs, if the energy economy is advantageous, to use heat recovery systems are an obligatory since 2010 (MPWS, 2010).

- **Comparison of Ventilation Strategies**

Hasselaar (2008) states that the development of energy efficient building is technology driven. The author claims that the feedback from the consumers is not enough and there are complaints by occupants about perceived health effects of mechanical heat recovery ventilation. The author classifies the potential problems as overheating, noise from installations, legionella contamination of domestic water buffers, low ventilation volumes, complex control mechanisms and lack of flexibility of ventilation services.

Kah (2011) compares outdoor air exchange in winter in two structurally identical buildings, one of which had been renovated as a low energy house with window ventilation and the other as a Passive House with controlled ventilation. Air exchange was recorded for about two months in five apartments with only window ventilation and six apartments with controlled ventilation. According to results, in the apartments with controlled ventilation, air quality showed much better conditions. The apartments with only window ventilation had poor air quality 70 percent of the time during the study`s time frame, whilst the apartments with controlled ventilation had poor air quality 34 percent of the time.

Maier *et al.* (2009) perform comprehensive experimental investigations in 22 identical low energy residential houses in Germany which is equipped with four different ventilation systems: natural ventilation, mechanical ventilation with single ventilators, mechanical ventilation with heat recovery and system of air heating. The results show that the mechanical ventilation systems with a function of heat recovery had lower heat consumption by about 10–30% than the systems with the mechanical ventilation with single ventilators and the window ventilation. In the event of the air quality with respect to the CO_2 concentration, the mechanical ventilation systems showed by 40–50% better results than the systems with the window ventilation. Respectively, the mechanical ventilation system with single ventilators show by about 30% better results than the system of the mechanical ventilation with in- and out-leading air elements and by about 10% than the system of air heating.

Table 2.15 Classification of indoor air quality based on EN 13779

CO_2 content of indoor air (ppm)	< 400	400-800	800-1000	>1000
Description	high	medium	moderate	low
Category	IDA1	IDA2	IDA3	IDA4

Peper (2012) carried an extended monitoring to determine the air quality and air exchange rates via the ventilation systems in 15 apartments in Frankfurt. The study is also carried to evaluate the influence of user behavior on air quality. According to the author, no general trend was detected for the use of ventilation units. And air quality classes IDA 1 to 3 were met 95.4% of the time during the winter heating season. The CO_2 concentrations therefore show that the indoor air quality was good to very good in the apartments and was only rarely moderate. Table 2.15 indicates classification of indoor air quality based on EN 13779.

Laverge & Janssens (2012) compare the mechanical heat recovery ventilation with simple exhaust mechanical ventilation in terms of primary energy, carbon dioxide emission, household consumer energy price and exergy for the different climates in Europe including Turkey. According to their study, higher gas prices (compared to electricity prices) in North-West Europe allows for economic benefits from running heat recovery ventilation effectiveness as low as 50%, whereas lower gas prices advance natural and mechanical exhaust ventilation for instance in Turkey. In the countries where nuclear power like in France or renewable energy dominates the electricity production, usage of MVHR will result in low carbon dioxide emissions. Respectively, in countries like Turkey where the share of renewable in total electricity generation is not that much, installation of MVHR would not be strongly promoted compared to other countries by the carbon dioxide metric. The authors also state that heat recovery ventilation can only be operated profitably in low pressure drop and low fan power systems in the Mediterranean basin (Laverge & Janssens, 2012).

2.4.2 Passive House Heating

The selection of the ideal heating system for a building hinges on a number of factors: the type of the building, the number of people and their clothing, the period of utilization, the type of the energy supply, the environmental pollution, the costs as well as regional regulations (Ringer, 2011).

So as to reduce overdependence on particular types of energy supply, diversification is the most usual suggestion. Nevertheless, with regard to climate change this diversification should result with the least possible impact on CO_2 emissions. Thus, a combination of different techniques can be useful: (Sopha & Klöckner, 2011)

- to extend and diversify the production of sustainable electricity
- to increase energy efficiency on the user side and reduce energy demand
- to implement heating sources using available alternative sources of energy

According to Feist (2000), in general the whole range of conventional heat supply technologies can be applied in Passive Houses. Figure 2.26 shows the implemented supply variants in Passive Houses. For instance, the frequency of existence of the energy source in the Passive House varies notably from the average frequency of use in many countries such as Germany. The reason is that the suitability of the respective energy sources for smaller outputs, the availability of relevant heat generators and the basic costs for grid-based systems.

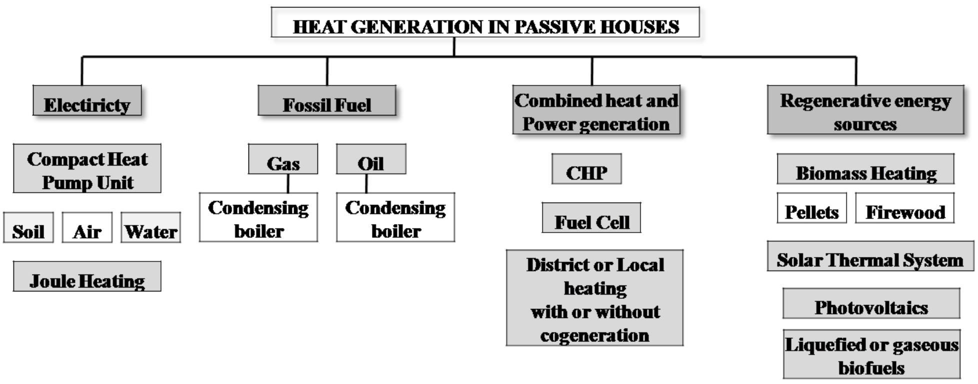


Figure 2.26 Heat Generation in Passive Houses (Feist, 2000)

Georges *et al.* (2012) analyze the cost-effectiveness and environmental performance of heating systems considering the Belgian context for Passive House or low energy houses. The authors state that some solutions that are optimal at higher net energy needs (e.g. for 120 kWh/m2 year), like the standard HP and the wood-pellet boilers, will involve too high investments to be cost optimal for very low net SH needs. Among the systems, the compact HP with the best seasonal performance factor, the wood-log boilers, the wood hydro-stoves and the standard stoves supplied with solar thermal panels for the DHW production (using electric backup) are essentially the most appropriate solutions.

Even though the burning of biomass is considered to be carbon neutral, this does not mean that biomass performs better than other types of fuels considering the impacts on human health and ecosystem quality. Several studies showed that the health impact arising from biomass combustion or pellet gasification in district and residential heating is many times higher than natural gas combustion (Pa *et al.*, 2013).

- **Wood Pellets**

According to Magelli *et al.* (2009), pelletization creates a clean burning, convenient and energy-concentrated fuel from bulky fibrous waste such as sawdust and wood shavings. High prices on fossil fuels and government support for renewable energy have significantly increased the demand for wood pellets in Europe. Wood pellets are predominantly used in residential applications such as boilers and stoves especially countries like Austria, Germany and Italy (Olsson *et al.*, 2011). According to Magelli *et al.* (2009), the greatest amount of pellets used in Europe is produced in British Columbia (BC), and more than 80% of those wood pellets are exported to Europe.

One of the evaluations of wood pellets usage based on a streamlined life cycle analysis in BC indicates that the replacement of firewood by wood pellets in BC residential heating will considerably lower the impacts on human health, ecosystem quality, and climate change and primary energy consumption (Pa *et al.*, 2013). But related to wood pellets exportation, it should be noted that the marine transportation of wood pellets are responsible for the most air pollutant emissions (Magelli *et al.*, 2009).

Fiedler & Persson (2009) analyzed the potential of carbon monoxide emission reduction when the pellet heater is combined with a solar heating system. In the study, the authors compared 4 different types of systems with a reference system which is based on a pellet boiler and is not combined with solar heating. As a result, the authors find out that reducing almost 50% of the CO emissions is possible by combining the pellet heater with a solar heating system.

The authors also compared the average annual emissions of those 5 systems with the limit values of two eco labels. Consequently, the average emissions under these realistic annual conditions of the existing systems were greater than the limit values of two eco-labels.

- **District Heating**

Since the 14th century, district energy systems have been used in Europe and Northern European countries are the main users in district energy systems (Rezaie & Rosen, 2012). District energy systems connect public, domestic and commercial sector buildings to several energy sources through a piping network using environmentally optimum fuel sources such as combined heat and power, industrial waste heat, energy from waste, biomass and geothermal (Ross, 2008). Harvey(2006) states that the connection of building to a district heating system provides large energy savings if the district heating system is waste heat but district energy projects are typically complex and include a large number of issues such as institutional, technological, legal and financial. They are capital intensive, with a large upfront investment that is paid back over a long period of time.

According to Williams (2012), Passive Houses are compatible with district heating systems, because of the reason that district heating systems provide an oversupply of heat. However, Passive Houses are a suitable technical option where there are no district heating systems, particularly in lower density areas.

> “District energy systems are categorized based on different aspects. One grouping is derived from the heat transport fluid: low-pressure steam, hot water and hot air. Another classification is based on the thermal energy transported: heating, cooling, and cooling and heating. A further categorization of district heating system can be based on the type of heat resources: using a separate source of energy for heat or using recycled energy/heat. The most practical example of the latter type of thermal network is one using combined heat and power (CHP), as cogenerated heat from generating electricity can then be utilized for heating nearby buildings.„ (Rezaie *et al*, 2012).

Persson& Werner (2011) studied the future competitiveness of district heating also in areas where no district heating exists today by an in depth analysis of the distribution capital cost at various city characteristics, city sizes, and heat demands. The authors state that the future competitiveness of district heating will always depend on the combination of distribution cost and the cost difference between district heat supply and alternative local heat supply. The study indicates that compact cities have better conditions for district heating (and cooling) than sparse cities, since the plot ratios are higher.

Lund *et al*. (2010) calculate the consequences in relation to fuel demand, CO_2 emissions and cost various heating options, including district heating as well as individual heat pumps and micro CHPs based on the case of Denmark. The authors state that, the best solution would be to combine a gradual expansion of district heating with individual heat pumps in the remaining houses in case of a system which are mainly based on fossil fuels, as well as in a potential future system based 100 per cent on renewable energy.

Spaeth (2006) investigates the specific heat costs in a district in Freiburg, Germany where the majority of the buildings were highly energy efficient houses and heat is provided by a district heating network. Because of the obligation to connect all houses to the grid and the tariff structure, specifically for the Passive House dwellers, higher specific heat prices were seen. Consequently, the case study indicates, that such systems might only be economically viable, where a high density of the population, and/ or additional demand for heat or cooling due to commercial activities is given.

- **Heat Pump**

Heat pumps draw heat from an outdoor source, such as the air, the ground, or a body of water, and transport it to an indoor space for heating purposes or, conversely, for cooling purposes (Kruger & Seville, 2013). Heat pumps can also be used for the production of hot water (Harvey, 2006). A statistical evaluation made by PHI shows that heat pump is one of the most common building services systems to be used in the Passive House nowadays.

The coefficient of performance (COP) is the crucial parameter to measure the performance of a heat pump. Performance of the compression-expansion cycle and the performance of the heat exchangers also affect the performance of a heat pump (Harvey, 2006). The author states that the COP of a heat pump relies on the difference between the inside and outside air temperature. And the average COP over the heating season relies on the climate and therefore it will rely on location. According to Mumovic *et al.*(2008), subject to the selected energy source and heating system temperature, modern electrical heat pumps can achieve a COP between 3,5 and 5,5 which means that for every kWh power consumed, 3,5 kWh to 5,5 kWh heating energy can be created. Lechner (2001) claims that the efficiency of heat pumps drops with the outside temperature, therefore they are not suitable in very cold climates.

There are three types of heat pumps in general which are air source heat pumps, ground source heat pumps and mini splits. Air source heat pumps provide a specific amount of heat at a specific outside temperature. If the outside temperature decreases, the efficiency goes down. Ground source heat pumps exchange heat between the ground or water and the home inside and the house is heated or cooled with forced air or hydraulic distribution systems (Kruger& Seville, 2013). According to Edminster (2009), mini splits allow heating or cooling individual rooms, they can be used when occupants are there and this allows reduction on operating cost. They have no ducts, therefore they simplify installation.

- **Comparison of the Systems**

Badescu (2007) studied the economic feasibility of different active space heating systems based on ground thermal energy utilization. Ground heat exchanger (GHE), a ground source heat pump (GSHP) and the case of not using renewable energy was studied. As a result, GSHP configuration proves to be the best economical solution on medium- and long-time operation (i.e. longer than 3–10 years). The configuration based on a ground heat exchanger is also a better solution than conventional heating in case the operation time is longer than 20–30 years. Comparison to the GSHP configuration, GHE has the advantage of a much lower investment cost.

Badescu & Staicovici (2006) studied the active heating system of a Passive House in Germany including solar thermal collectors, a water storage tank, a secondary water circuit, a domestic hot water preparation system and air ventilation and heating system. The authors have seen that the active solar heating system produces a smaller amount of heat than the heat provided by the passive solar heating system. Almost the entire solar energy collected is not used for space heating but contributes to DHW preparation which makes the water- to-water heat exchanger of the DHW system to operate at a higher efficiency than the water-to-air heat exchanger of the air heating system.

2.4.3 Passive House Economics

According to Schnieders & Hermelink (2006), sustainable building has a social, an ecological and an economic component in general. The very low energy consumption also leads to the minimum life cycle cost of Passive Houses which is a major economic argument. Swiss calculations of „allowable environmental loads"" for a house provide first evidence that the allowable limits for building energy Standard has to be much better than „low-energy"" and may be situated in the range of Passive Houses.

William (2011) states that although the additional capital cost of Passive Houses has been highlighted as a concern, Passive Houses can be constructed for costs that are no longer significantly higher than a normal house in Germany and Sweden (in the range of 4-6% more than standard house). But the build cost for Passive Houses varies significantly across Europe. The author also states that as building code requirements, energy prices, labor cost, and skills differ significantly from one country to another, to transfer the price estimations from countries where the market is better developed to other countries where low energy buildings are less common, seems misleading.

Stanford (2012) compared the cost of two certified Passive Houses with typical construction projects in Santa Fe, New Mexico, USA using RS-Means software. The results indicate that both Passive House Projects were built for less than the model house presenting a typical single family construction. The author also indicated the distribution of the project costs among the projects. Among all projects, thermal envelope costs had the highest cost proportion compare to the cost of other building systems such as mechanical, electrical system or cost of finishes.

Georges *et al.* (2013) claim that generally, reducing the space heating needs by improving the thermal performance of the building envelope is combined with efficient heating systems minimizes the delivered energy and greenhouse gas emissions. Nevertheless, these better systems are often more expensive so that the extra- investment could be hardly recovered for small-scale energy consumption. According to the same author, the Passive House can become a global optimum if severe assumptions are considered: a longer lifespan of architectonic measures combined with a low discount rate or a high increase in energy prices.

Audenaert *et al.* (2008) make a comparison on specific additional cost of the standard house (3), low energy house (3) and Passive House (5) in their study. The authors find out that the extra cost of the low-energy house is 4% and of the Passive House is 16% in comparison with the standard house where the main difference caused by the isolation and ventilation. According to the authors, the impact of the Passive House is highly dependent on the evolution of the energy prices. And the Passive House becomes very profitable, in case of an annual growth of 15% in energy prices. The authors conclude that since the energy price growth rate is unpredictable, because of its less dependency on future energy prices, a low- energy house is the safest choice at this moment.

Newman (2012) compared a small detached Passive House on a single plot, with an equivalent house built to UK 2010 Building Regulation Standards. The results showed that for a 25 year 3.9% annual percentage rate repayment mortgage, the Passive House investment in the study presented a more economically viable solution than a house built to current UK building regulations.

2.4.4 Embodied Energy and Energy Efficient Buildings

Embodied energy is the amount of energy used to produce an object, such as a brick or a window. To calculate the embodied energy of a material, all stages such as extraction of raw materials, transportation, energy used in factories, energy used on site to install the product should be taken into account (Roaf *et al.*, 2007).

Improving the insulation of the building envelope can reduce the energy needed during the operational use of buildings greatly. But studies showed that embodied energy can account for up to 50% of total energy use. Thus, it is very important not only to reduce operational energy in the design process but also to consider the choice of building materials or components and aspects of reuse/recycling (Thormark, 2007).

The option which reduces operating energy use also reduces total life cycle use in most circumstances. In some examples, the high embodied energy in high-performance building elements (such as krypton filled double or triple glazed windows) can be mainly offset from savings in the embodied energy of heating and/or cooling equipment (IPCC,2013). Due to the energy intensive conditions applied for the manufacturing of insulation materials or the high embodied energies of the oil-based raw materials, the embodied energy of most widely used insulation materials is portrayed by very high values (LEEMA, 2012). The embodied energy of various insulation materials can be seen in Figure 2.27.

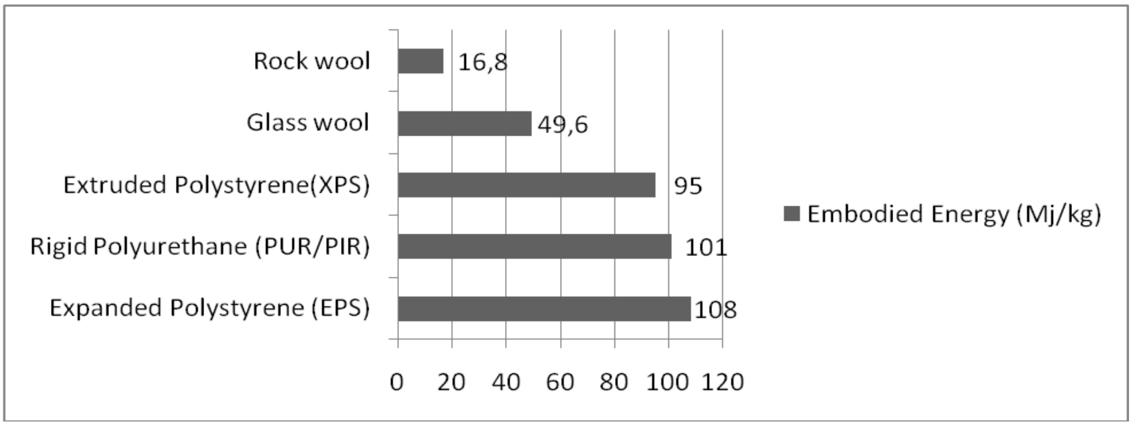


Figure 2.27 Embodied Energy of various insulation materials (LEEMA, 2012)

Materials that have the lowest embodied energy intensities such as concrete and timber are consumed in very large quantities; whereas the materials such as stainless steel with high energy content are used in much lesser amounts. Therefore the greatest amount of embodied energy in a building is often in concrete and steel (EPA VICTORIA, 2011). Hammond & Jones (2008) estimated the energy and carbon requirement of external works of several case studies. In Figure 2.28 the contribution of different materials to the embodied energy and embodied carbon of a case study building is shown.

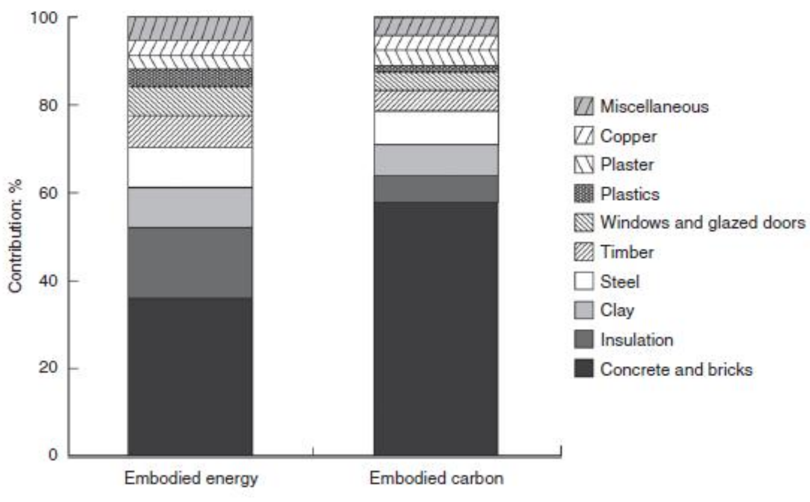


Figure 2.28 Breakdown of embodied energy and carbon by material (Hammond & Jones, 2008)

Stephan *et al.* (2013) state that studies on Passive Houses do not take into consideration the embodied energy required to manufacture the building materials. Thus the authors analyzed the total life cycle energy consumption of a typical Belgian passive house, comprising embodied, operational and transport energy. It is stated that current building energy efficiency certifications might not ensure lower energy consumption and can, paradoxically result in increased energy consumption because of their limited scope.

Proietti *et al.* (2013) studied also LCA of a Passive House located in Italy using SimaPro software. All life cycle phases were analyzed from raw material to controlled de-construction, waste handling and treatment. The results indicate that to apply energy saving measures could importantly reduce the impact of modern dwellings.

2.5 Critical Review of the Literature

A significant amount of heat loss, mold growth, deterioration of indoor air quality, and defects in the building itself may occur because of thermal bridges in the buildings. It is frequently stated in former studies that the weight of thermal bridges in the overall heat consumption of the energy efficient buildings is higher compared to the poorly insulated buildings. But this information is not clearly explained with calculations in a comparison using both a poorly insulated building and well insulated building.

TOKİ is the leader official institution meeting a crucial amount of housing needs in Turkey and tunnel formwork construction system is being used in many TOKİ houses. Tunnel formwork projects bring with speed and quality production, however the MESA MESKEN Firm, which construct large-scale housing developments in Turkey and abroad, faced with complaints from the building occupants related to the mold growth in some of their projects in the past. Therefore, various detailing variations were tried in order to find the best option to eliminate thermal bridges during many years. The earlier researches made by the Research and Development group of the Firm verify a need for thermal bridge studies in tunnel form work projects.

The studies related to thermal bridges in Literature are mainly divided into two sections. A group of researchers study just one specific building component, such as window frame installation, foundation, balcony or different shaped walls to show the impact of thermal bridges on heating energy consumption or heat losses. Another group of researchers study new methods to estimate the effects of thermal bridges or implement bi-dimensional and three-dimensional heat transfer to building energy simulation programs which only consider one dimensional heat flows.

It was seen that the studies related to thermal bridges in Turkey are limited with the studies on cavity walls system or considering only intermediate floor slab details. The most comprehensive data related to thermal bridges in Turkey currently is made by İZODER. In the İZODER TS 825 Calculation software, linear thermal transmittance values of various balcony, roof, floor slab, interior wall, column, corner, window options can be found. However, foundation and unheated basement wall details are not included in the software.

It is seen from the literature that there is a lack of a studies that compare the impact of thermal bridges in an existing and energy efficient building at the same time. Also there is not any study comparing the weight of heat loss through thermal bridges of various building components in a building itself. Since tunnel formwork system is widely applied in Turkey, these studies are carried out using a tunnel formwork building designed by TOKİ.

CHAPTER 3

MATERIAL AND METHOD

In this chapter, the details of the material and methodology used in the study are presented. The first section covers the selection criteria of the subject material. The second section describes the methodology.

3.1 MATERIAL

In this section, case study building and computer simulation programs which are used in the research methodology are presented.

3.1.1 Case Study Building

The case study building consists of a tunnel form work social housing unit that is designed by TOKİ. Figure 3.1 indicates the three different TOKİ social housing typologies, F1 type, L5 type and C type respectively. Since buildings with a compact form require less insulation, therefore they are cheaper to construct. As previously mentioned, an efficient compactness ratio (area/volume) is considered to be less than 0.7 m^2/m^3 (BRE, n.d.). In this respect, three TOKİ social housing typologies, namely F1, L5 and C are compared in terms of their compactness as it is indicated in Table 3.1. The results demonstrate that all typologies have an efficient compactness ratio that is under 0.7 m^2/m^3, but typology C has the most efficient ratio among them. Hence, building typology C is selected as a case study.

Table 3.1 Compactness of TOKİ social housing typologies

Compactness Ratio			
	F1	L5	C
Surface Area(m^2)	2530,2	2920,8	3146,1
Volume(m^3)	5581,2	7070,2	8281,7
A/V (m^2/m^3)	**0,45**	**0,41**	**0,37**

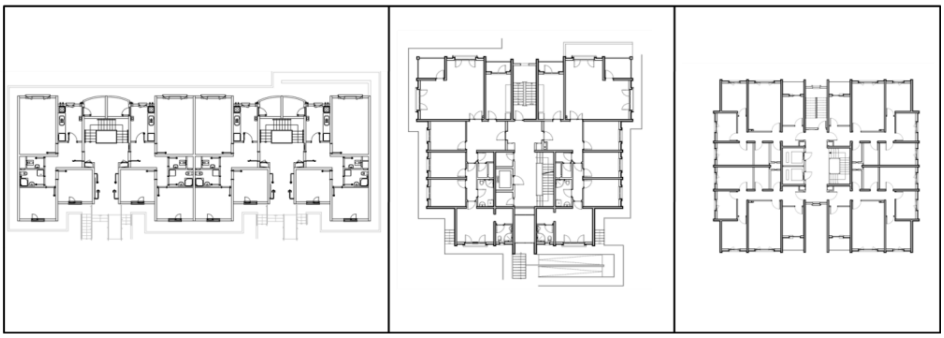


Figure 3.1 TOKİ Social Housing Typologies, F1 type, L5 type and C type

The case building has 6 floors and a basement floor with 25 numbers of dwellings inside. The building deviates from north 20º. Location of the existing building and the photo of the case study can be seen in Figure 3.2 and 3.3.

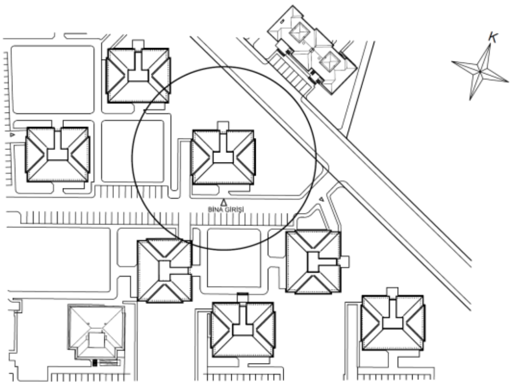


Figure 3.2 Location of the case building on the site plan


Figure 3.3 Photo of the case study: Building type C, block 10

In the TOKİ social housing unit, one apartment and auxiliary rooms such as installation rooms and storage rooms are located on the basement floor and four identical apartments on the other floors. Each main hall and apartment is designed inside the heated area. Therefore the apartment and main hall on the basement floor are included in the thermal envelope. Table 3.2 highlights general information on the existing TOKİ social housing unit.

Table 3.2 Existing Building Information

Treated Floor Area	2189.5 m^2
Window Percentage	19.70%
Deviation from North	20º
Number of Dwellings	25
Number of Floors	6+basement
Number of Occupants	100

3.1.2 Construction Details modeled to evaluate Ψ values

Firstly, the baseline building geometry is analyzed in terms of thermal bridges. Figure 3.4 presents the thermal bridges in the entire building. It is seen that, there are more than 20 thermal bridges in the building. These thermal bridges represent the cases where the continuity of the insulation is interrupted or there is a change in the geometry of the junctions. In this study, six thermal bridges are studied.

PLAN	1	**Corner 1 (Convex)**
	7	Corner 2 (Concave)
	8	Corner 3 (Concave)
	2	**Penetration of interior wall to exterior wall**
	9	Kitchen wall to firestairwell connection
	10	Window jamb
	11	Fire escape door jamb
	12	Entrance door jamb
SECTION	13	Window lintel
	14	Window sill
	15	Fire escape door lintel
	16	Fire escape door sill
	17	Entrance door lintel
	18	Entrance door sill
	3	**Roof overhang**
	4	**Intermediate floor slab detail**
	5	**Balcony detail (with connection to the wall)**
	19	Balcony detail (with connection to the door)
	20	Foundation detail
	21	Corner ceiling at the basement floor
	22	Elevator shaft wall at the roof 1
	23	Elevator shaft wall at the roof 2
	6	**Unheated basement wall 1**
	24	Unheated basement wall 2
	25	Unheated basement wall 3

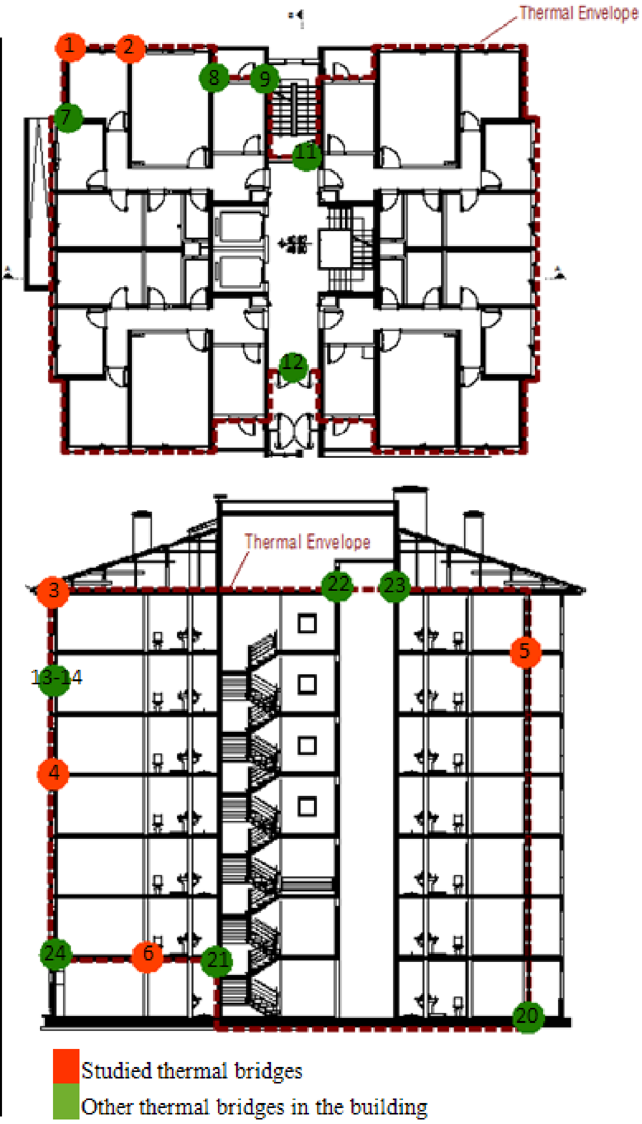


Figure 3.4 Thermal bridges in the entire building

Three of the thermal bridges represent cases where an interruption of a thermal insulation can be seen. Those are at the roof, unheated basement wall and balcony. The other three thermal bridges represent cases where the insulation is continuous. However, the geometry of the detail such as at the corner and the penetration of materials with different thermal conductivities can also cause thermal bridges.

Therefore penetration of interior wall to exterior wall and intermediate floor slab details are also studied. Since the calculation method of psi values for wall to floor functions in contact with ground and window installation thermal bridges differs, the heat loss through these details are not evaluated in this study. Construction details modeled for the existing building are presented in Figure 3.5.

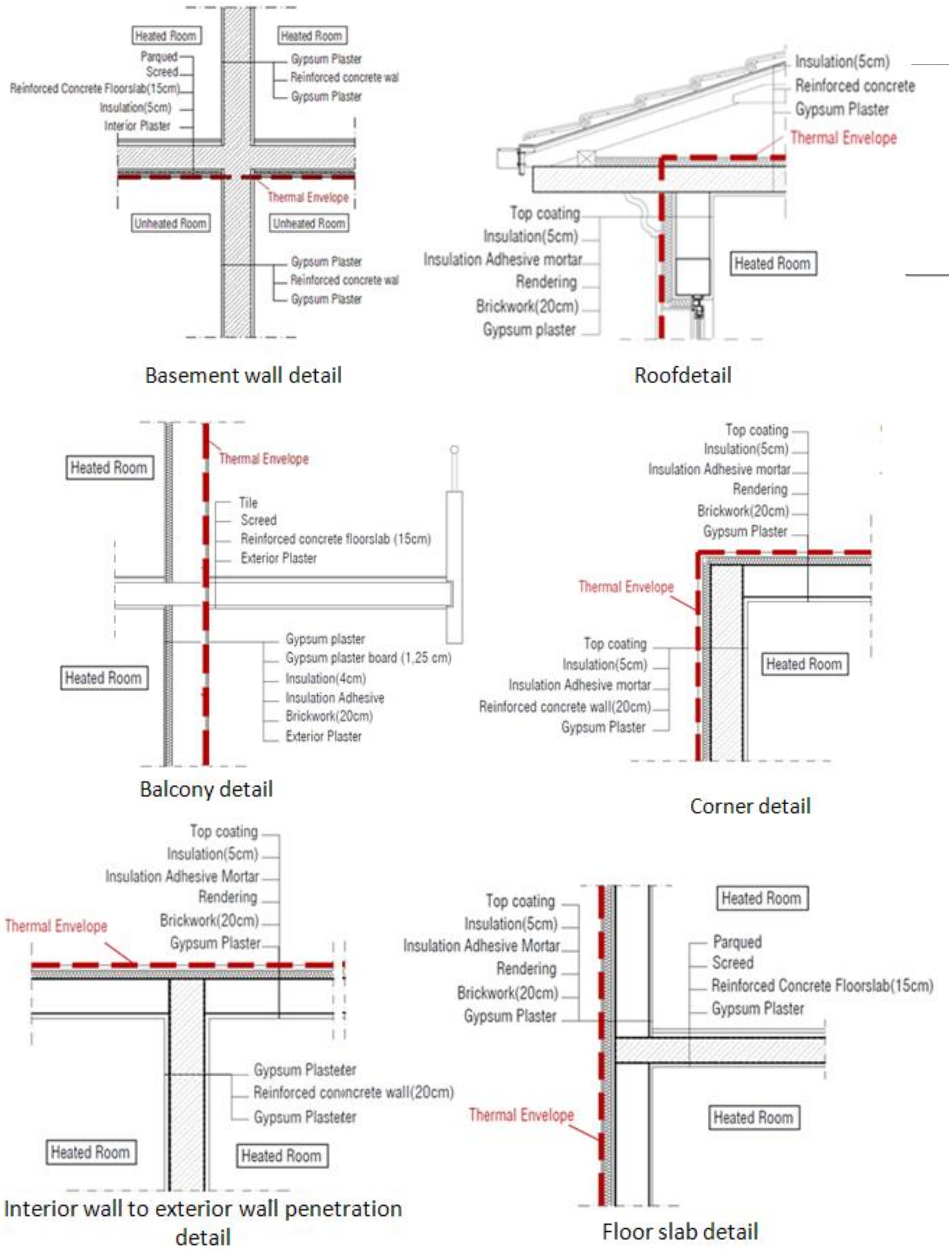


Figure 3.5 Construction details modeled for the existing building

3.1.3 Climate

The case study building is located in Ankara, which is classified in Climate Region III in TS 825 standard. Ankara features a semi-arid climate that designated with BSk under Köppen's climate classification. BSk climate is a cold dry climate which has small enough amounts of precipitation to be classified as dry climates. Ankara has a continental climate, with cold, snowy winters due to its elevation and inland location, and hot, dry summers (KHO, 2013).Weather data of Ankara (Latitude 39.92° and Longitude East 32.83 °) is obtained from the database included in the Meteonorm software. Meteonorm provides also a worst case scenario of the weather data. In this study, the standard case scenario is used. Figure 3.6 indicates the solar radiation on different orientations and the ambient temperature in Ankara using Meteonorm Data.

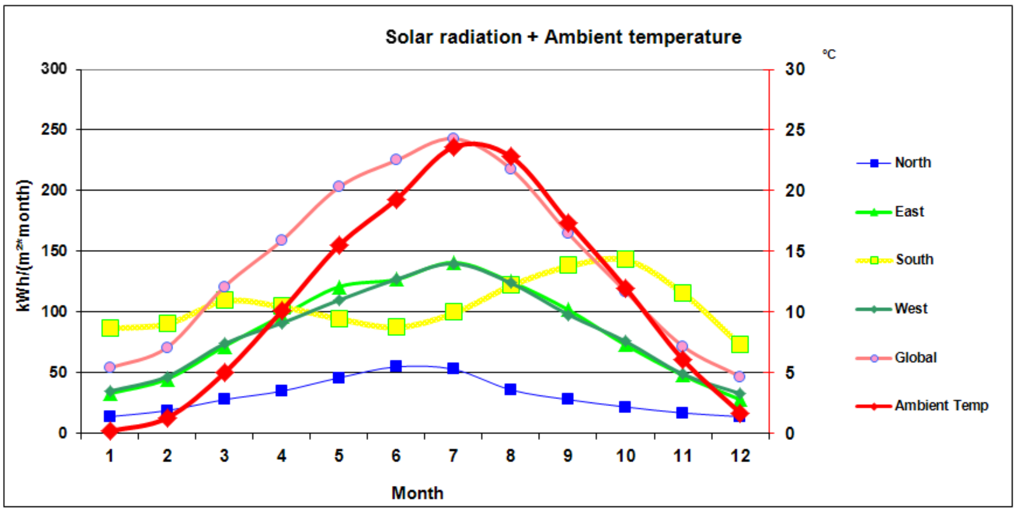


Figure 3.6 Solar Radiation and Ambient temperature of Ankara

3.1.4 Passive House Planning Package Version 7

To estimate the specific building demands as space heating, cooling and primary energy demand of the existing building and Passive House building, a spreadsheet based design tool called The Passive House Planning Package Version 7 (2012) which was developed by Passive House Institute in Germany, has been used.

The Passive House Planning Package (PHPP) mainly assists architects and specialist planners in designing Passive Houses and simplifies the Passive House design process. The Passive House criteria have to be verified using PHPP in order to get a building certification.

The PHPP Version 7 design tool contains 36 Excel worksheets where the user can enter the required inputs to dimension windows, the ventilation system and building services. Figure 3.7 indicates PHPP inputs sequence for Residential Buildings.

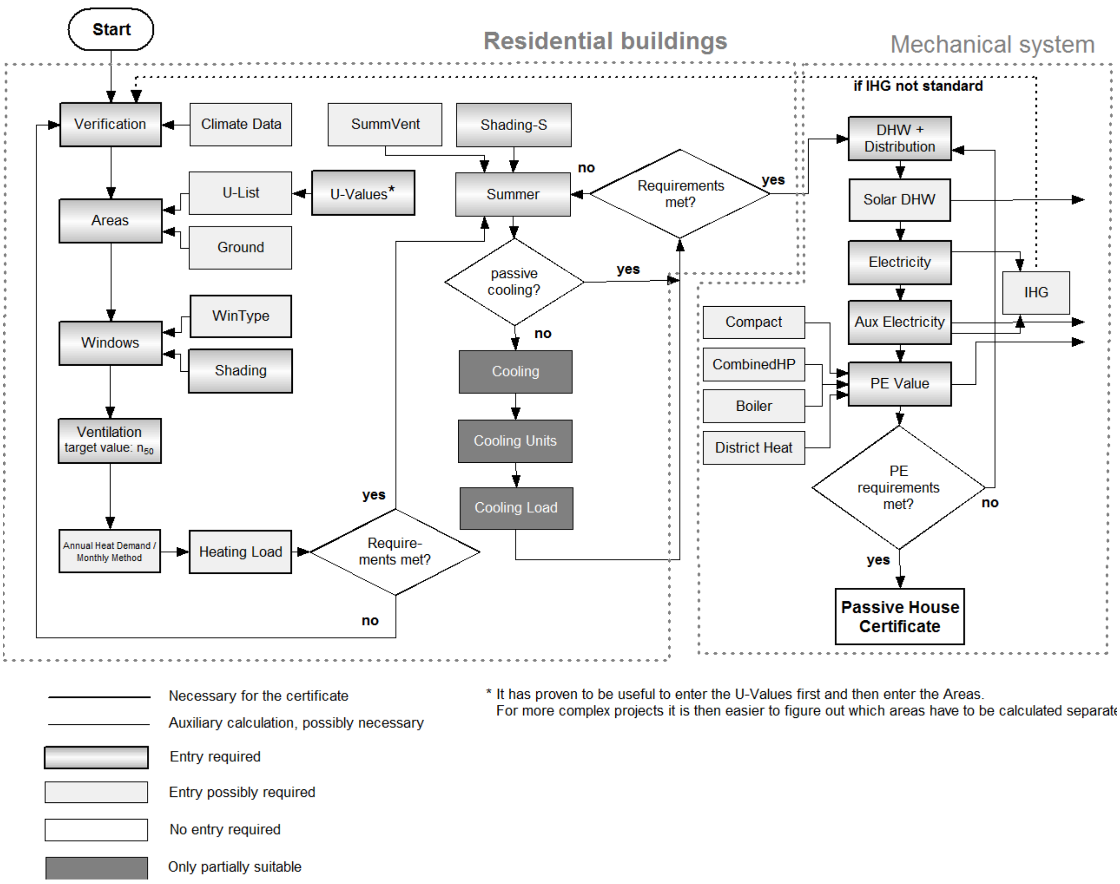


Figure 3.7 PHPP input sequence for residential buildings (Feist et al., 2012).

In the PHPP graphical user interface, yellow cells with blue text require user inputs to be applied in additional calculations (Such as treated floor area, window dimensions, shading objects, ventilation unit specifications, etc.). It should be avoided to enter new data to white and green cells. Green cells signify important calculation results.

Table 3.3 Calculation method, standard references in the PHPP (Feist et al., 2012).

Climate Data	Regional Data set or individual climate data
Design indoor temperature	20°C without night set back
Thermal comfort criteria	in Accordance with ISO 7720
Internal Heat Gains	2,1 W/m²
Occupancy rates*	35 m²/per person
Domestic hot water demand	25 lt per person per day at 60°C
Average ventilation volumetric flow	20-30 m3/h per person in the household
Electricity Demand*	Standard values according to PHPP
Thermal envelope	Exterior Dimention reference without exception
U-value of opaque building components*	PHPP Procedure on the basis of EN 6946
U-values of windows and doors	PHPP Procedure with computed values for the Uf and Ψg in accordance with EN 10077, Ψinst in accordance with EN ISO 10211
Glazing	Ug in accordance with EN 673, and g value in accordance with EN 410
Heat Recovery Efficiency	Testing Method in accordance with PHI.
Energy Performance Indicator of the heat generator	PHPP Method or separete verification
Primary energy factors	PHPP Dataset

The boundary conditions used in PHPP is significantly different from the calculation process used for German Energy Conservation Ordinance. For instance, internal heat gains, the average indoor design temperature, calculation of solar gains, temperature correction factors, and additional air exchange rate are different. (Feist *et al*., 2007).Table 3.3 indicates the calculation method, conditions and standard references used in PHPP.

3.1.5 THERM 6.3

To calculate two dimensional heat transfer coefficients, Therm 6.3 program developed by Lawrence Berkeley National Laboratory (LBNL) is used. Therm is a

Microsoft Windows ™ based free of charge computer program which enables to model two dimensional heat transfer through building products such as windows, walls, foundations; appliances; and other products where thermal bridges are of concern. By using Therm, a product‟s energy efficiency and local temperature patterns which may relate directly to problems with condensation, moisture damage, and structural integrity can be evaluated.

Cross sections of building products or fenestrations can be drawn using the program‟s graphic interface. It is also possible to import files as DXF or bitmap to create the cross sections. Then the results can be viewed as U factors, isotherms, heat-flux vectors, and local temperatures (Finlayson *et al*., 1998).

3.2 METHOD

Firstly, the energy consumption of the tunnel formwork social housing unit is estimated using PHPP software. Following that, the existing building geometry and the construction details are evaluated. After the selection of the studied thermal bridges, thermal bridge simulations are carried out. The detail, whose fraction of the transmission heat losses is highest, is studied in more detail to show the impacts of improved detailing on annual heating demand in the next level. After that, the energy demand of the unit is reduced by applying Passive House principles and construction details from various building junctions that can simply to meet the Passive House Standard are proposed. Using PHPP and Therm 6.3 software, the proportion of the overall heat loss due to thermal bridges is evaluated. To test the applicability of the details, an interview is made with the Project Manager of a tunnel formwork construction firm. In addition to that, a simple cost comparison is made between the proposed systems.

Calculation of the energy demand of the existing building is carried with the guidelines stated in Passive House Planning Package 2012 manual. Monthly method is selected as the calculation method, since the annual method can deliver results that are too low for certain building types (Feist *et al*., 2012). Although the interior temperature is defined as 19 ºC in TS 825 in residential buildings, according to Feist *et al.* (2012), the interior design temperature used for planning and verification is 20 ºC. The upper limit of summer comfort temperature is 25 ºC in the PHPP; however different temperatures may be specified. According to a survey made by MESA Research and Development Group in 1997, interior comfort temperature is also found 20-22 ºC in low-rise buildings in Ankara. In general, 50% for relative humidity and 20-25 ºC for indoor temperature are accepted as ideal thermal comfort condition (Coşkun *et al.*, 2010). Therefore, minimum and maximum interior temperature is set to 20 ºC and 25 ºC respectively. There are 25 dwellings in the existing building. It is assumed that one dwelling has 4 occupants and in the calculations planned number of occupants is entered as 100. For the calculation of internal heat gains, standard internal heat gain values delivered by PHPP software are used since it is recommended for the Passive House Certifications.

The effective thermal storage capacity of the building is entered as 204 Wh/m^2K which is a default value for massive constructions. The specific energy demands of the existing building are estimated without any modifications.

3.2.1 Calculation of the Energy Demand of the Baseline Building

Calculation of the energy demand of the baseline building is carried mainly on two steps. In the first step, all necessary data such as architectural, mechanical, sanitation and construction drawings of the baseline building are collected from the TOKİ Administration. Figure 3.8 indicates the steps carried to calculate the energy demand of the building. A site inspection is made at the building plot with photographing surrounding buildings. To have more accurate results, the models of mechanical units such as gas boiler, circulation pumps, *etc.* are recorded by visiting mechanical room. Technical specifications are outlined in Table A.2 of Appendix A. DHW consumption of the each dwelling is recorded to have more realistic results on DHW energy demand. The DHW consumption of the each dwelling can be found in Table A.1 of Appendix A. Thermal conductivity of some materials differs depending on the manufacturer and country. The materials specified in the construction drawings do not give detailed information such as thermal conductivity of the materials. Therefore short interviews with building contractor are made on the phone to clarify the type of the materials. Corresponding to these interviews, the thermal conductivity of the materials is taken from TS 825 Standard.

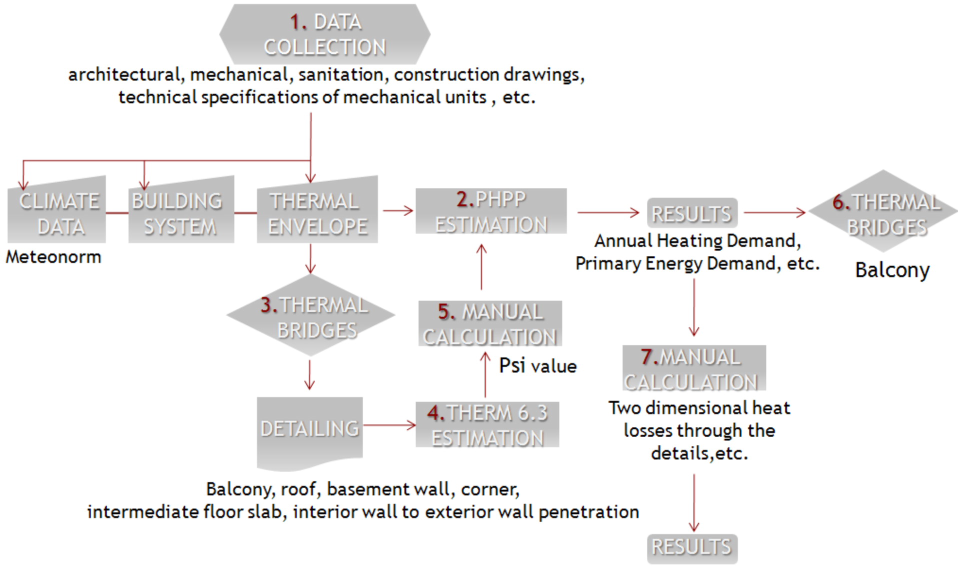


Figure 3.8 Steps carried to calculate the energy demand of the buildings

In the second step, to start calculation of the energy demand of the baseline building using PHPP 2012, firstly the thermal envelope of the existing building is determined. Figure 3.9 indicates the thermal envelope of the existing building. Following that, all the necessary data is entered to the PHPP step by step. This order is defined according to the PHPP software‟s own worksheet sequence.

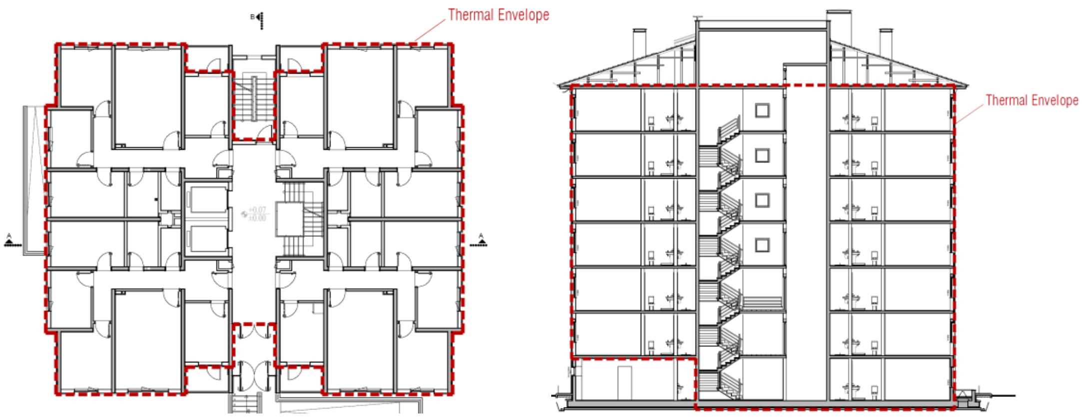


Figure 3.9 Thermal envelope boundaries of the existing building

The simulation process of this study using PHPP can be explained in four sub-sections. In the first section, considering the calculation methods defined by PHPP 2012, all necessary input related to the building‟ thermal envelope is measured and estimated. The first section covers the calculation of the areas such as treated floor area, areas of the facades, floor slab, roof; estimation of external volume, etc. In addition to that, additional inputs for radiation balance are made. U Values of the opaque components‟ of the building are calculated in U-Values worksheet considering the construction details of the existing building. PHPP Inputs related to the thermal envelope of the baseline building is given in Figure A.2 to A.5 of Appendix A. Window dimensions of the building are entered as it is indicated in the project drawings considering the PHPP method. The window dimensions entered to the PHPP can be found in Figure A.1 of Appendix A.

The data of technical specifications that is used for window glazing and frames in the existing building is entered to PHPP considering Table 3.4. In addition to that, the dimensions related to shading elements such as surrounding buildings, overhangs, etc. are entered. The shading inputs can be found in Figure A.6 of Appendix A.

Table 3.4 Window glazing and frame types of the existing building.

Description	g value	U_g value
Window Glazing (Double glazing_16mm air)	0.77	2.7
Balcony Door Glazing (Double glazing_12 mm air)	0.77	2.9
	U_f	
Plastic Window Frame	1.6	
Metal Entrance Door Frame	2.4	

In the third section, the energy demand of the building system is calculated. Calculation of the length of the DHW and heating pipes are calculated considering sanitation and mechanical drawings. Technical specifications of the related units that are gathered from the manufacturer are entered to PHPP. Since there is no mechanical ventilation, no ventilation unit is entered to the software.

There is not any blower door test carried to measure air tightness of existing TOKİ houses in literature. Therefore, air exchange rate @50pa is assumed to be 5 (1/h), which corresponds to a medium air tightness level for the buildings with multiple apartments according to TS 825. And air change rate by natural ventilation in summer is entered as 0.8(1/h) which is a standard value in TS 825. It is planned that 2 windows in the bedroom and one window in living room are open for 6 hours (a fraction opening %50) on each apartment during the summer at night. Assumed summer ventilation sheet is presented in Figure 3.10.

Description	Night 1	Night 2	
Fraction of Opening Duration	50%	50%	
Climate Boundary Conditions			
Temperature Diff Interior - Exterior	1	1	
Wind Velocity	0	0	
Note: for summer night ventilation please set a temperature difference otherwise the cooling effects of the night ventilation wi			
Window Group 1			
Quantity	25	50	
Clear Width	0,44	0,44	
Clear Height	1,12	1,12	
Tilting Windows?			
Opening Width (for tilting windows)			
Window Group 2 (Cross Ventilation)			
Quantity	25	25	
Clear Width	0,44	0,74	
Clear Height	1,12	1,12	
Tilting Windows?			
Opening Width (for Tilting Windows)			
Difference in Height to Window 1			
Single-Sided Ventilation 1 - Airflow Volume	1732	3463	0
Single-Sided Ventilation 2 - Airflow Volume	1732	2912	0
Cross Ventilation Airflow Volume	3463	6376	0
Contribution to Air Change Rate	0,32	0,58	0,00

Figure 3.10 Assumed summer night ventilation concept

Table 3.5 Properties of existing household appliances for domestic electricity demand

Dishwashing	Cold water connection
Clothes washing	Cold water connection
Clothes drying with	Clothes line
Refrigerator	Combined(freezing, refrigerating)
Cooking with	Gas

To calculate domestic electricity demand, properties indicated in Table 3.5 are applied considering Sanitation Drawings. For the baseline building, electricity demand of dishwasher, wash machine, refrigerator, cooker, television, small appliances and lighting are calculated. The electricity consumption values of the household appliances for the both cases can be found in Table A.3 of Appendix A.

A central heating system is installed in the existing building as the specifications are entered in Figure A.8 of Appendix A. The hot water is generated by a gas boiler in the boiler room and heat is distributed through hot water radiators to the dwellings and main apartment halls. For DHW generation, a gas water heater is installed in each dwelling.

Table 3.6 DHW system pipe lengths

Space Heat Distribution	Warm Region	Cold Region
Length of distribution pipes	2037.53	24.54
Pipe width	50	
Pipe insulation thickness	40	
Insulation thermal conductivity	0.04	
DHW consumption per Person and Day (lt)	76	
DHW distribution and storage	Warm Region	Cold Region
Length of circulation pipes(flow return)	103.7	30.8
Total length of individual pipes	727.15	84
Storage losses	2.5 W/K	

The total length of space heating distribution pipes, circulation pipes and individual pipes that are inside and outside of the thermal envelope is entered using the sanitary installation projects delivered by the TOKİ as it is presented in Table 3.6.

The heat loss through the pipes acts as an internal heat source and a part of this emitted heat is supposed to reduce the annual heating demand in PHPP. According to PHPP, the standard value of DHW consumption is 25lt/p/d. To get more realistic values, water consumption of 24 dwelling is measured. It was seen that the water consumptions differentiates too much from one apartment to another. The highest five value is taken as sample and the average value that is 76 lt per person per day is used in the calculations. The current result is much higher than the standard values. Thus, it is important to use water saving appliances when designing sustainable buildings in order to save resources. In the fourth section, the weather data of Ankara which is obtained from Meteonorm in PHPP format is entered. A set of various countries‟ climate data can be obtained from PHPP 7 database. However, PHPP 7 does not include climate data of Ankara. The climate input is presented in Figure A.9 of Appendix A.

- **Thermal Bridge Assumptions of the Existing Building**

Since two dimensional heat flows are not calculated by PHPP, Therm 6.3 software is used to provide realistic values for two dimensional heat flows. This section can be regarded as a sub section of the thermal envelope calculations.

Firstly, details of the critical points are drawn taking into account this definition: When modeling the construction, location of cut-off planes should be at least d_{min} from the central element in a 2D geometrical model as it is presented in Figure 3.11. d_{min} is the greater of 1 m and three times the thickness of the flanking element concerned (EN ISO 10211(2007). Using the dxf drawings as an underlay as it is presented in Figure 3.12, the below presented construction details of existing buildings are simulated.

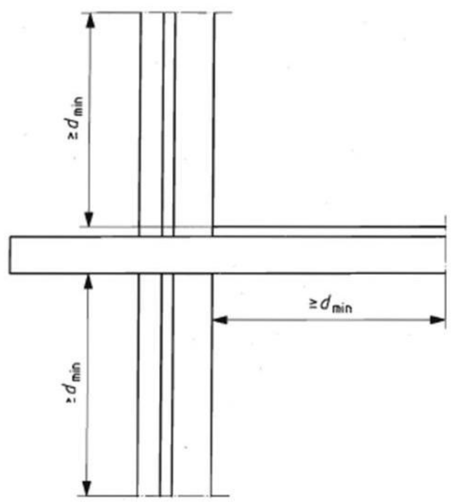


Figure 3.11 Location of the cut-off planes in a 2D geometrical model (EN ISO 10211, 2007).

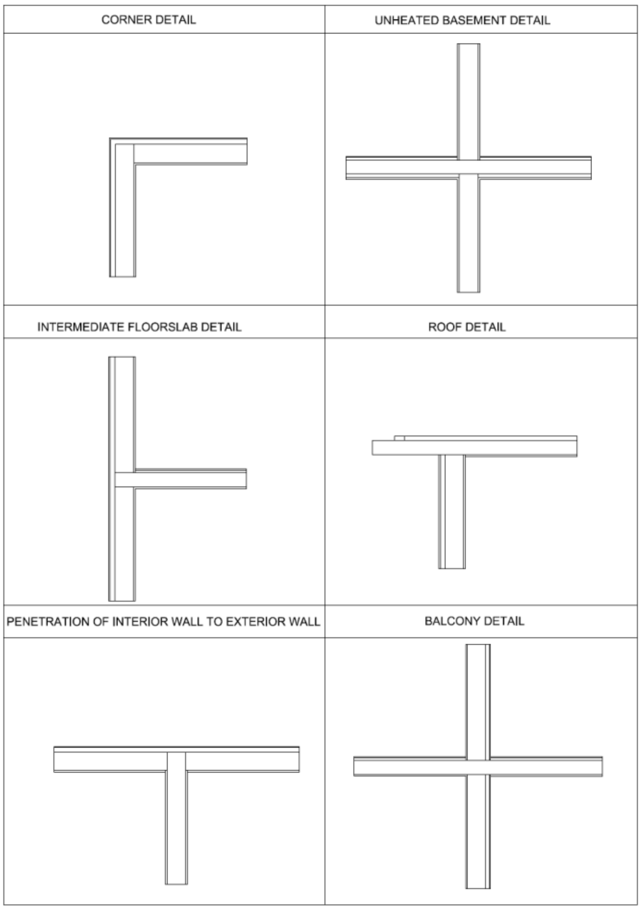


Figure 3.12 Existing Building Drawings used in Therm 6.3

Table 3.7 Material properties used in the existing building

	Thermal Conductivity (W/mK)
Reinforced Concrete	2,5
Brick Masonry (600 kg/m³)	0,36
EPS Insulation	0,04
Gypsum plaster	0,51
Exterior Plaster	1
Interior Plaster	1
Screed	1,4
Tile	1
Parquet	0,13
Gypsum plaster board	0,25

The materials and thermal conductivities used in the software are presented in Table 3.7. In this study, to calculate the heat loss through thermal bridges, firstly linear thermal transmittance value (psi value) of each detail is calculated. Equation 2 gives the calculation formula of the psi value (ISO 10211, 2007):

$$\Psi = L_{2D} - \sum_{j=1}^{N_j} U_j \cdot l_j \quad \text{W/mK} \qquad (2)$$

Where;

L_{2D}: Thermal coupling coefficient, W/mK

U_j : Thermal transmittance of the 1D component, W/ m^2 K

l_j : Length over which the U value applies, m

Nj: Number of 1D components.

Thermal coupling coefficient is obtained from a 2D calculation of the component. Since Therm 6.3 does not provide psi value automatically, a manual calculation is made with respect to the exterior dimensions of the each detail. Figure 3.13 indicates the calculation of ψ value, using U-factor from Therm 6.3.

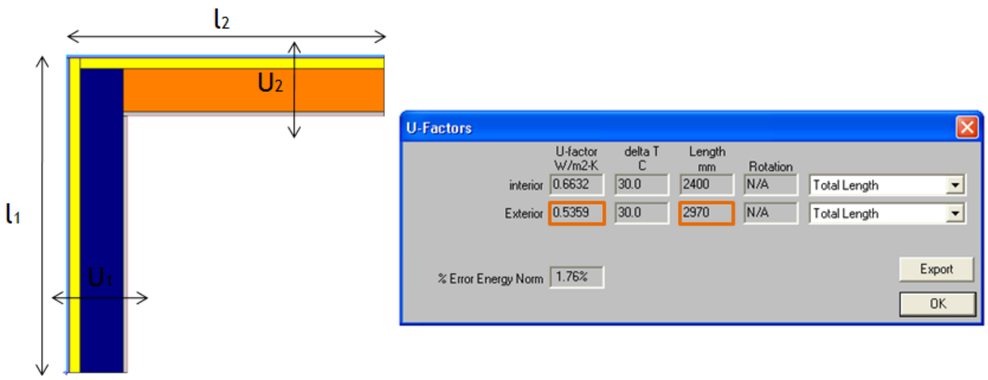


Figure 3.13 Illustration of the calculation of psi values using Therm 6.3

Psi value in W/mK using Therm 6.3, calculated by the Equation 3 given below (Samuel, 2010):

$$\Psi = (U_t . l_t) - (U_1 . l_1) - (U_2 . l_2) \quad \text{W/mK} \tag{3}$$

Where:

U_t: U factor of the building element using Therm, W/m^2K

l_t: Total length of the building element using exterior dimensions using Therm, m

U_1: U value of the building component 1, W/m^2K

L_1: Total length of the building component using exterior dimensions, m

U_2: U value of the building component 2, W/m^2K

l_2: Total length of the building component using exterior dimensions, m.

For opaque components, maximum % error is set to 2% and maximum iterations are set to 10 during calculations. Table 3.8 and Table 3.9 indicate the boundary conditions used in Therm 6.3 Software.

Table 3.8 Boundary Temperatures used in Therm 6.3

Exterior Temperature (ºC)	-10
Interior Temperature(ºC)	20
Unheated Basement Temperature(ºC)	5

Table 3.9 Heat transfer Resistances and Film Coefficients used in Therm 6.3

	Direction of heat flow		
	Upwards	Downwards	Horizontal
Rsi (m^2K/W)	0,1	0,17	0,13
Film coefficient (W/m^2K)	10	5,88	7,69
Rse (m^2K/W)	0,04		
Film coefficient (W/m^2K)	25		

A psi value (ψ) is in some degree similar to a U value. Just as a U value is multiplied by the area of the surface to calculate total heat loss, a ψ value is multiplied by the length of the thermal bridge to calculate total heat loss (Jacobson, 2012). The additional heat loss through each thermal bridge (H_{TB}), which is expressed in Watt per Kelvin, can be calculated by using the Equation 4 given below LCHLZ (2013):

$$H_{TB} = (l \times \Psi) \quad \text{W/K} \quad (4)$$

Where;

Ψ: Linear thermal transmittance of the thermal bridge, W/mK

l: Length of the thermal bridge in the building, m.

Since the energy performance of a building is highly dependent on the total heat loss through the building envelope, the total fabric conduction heat loss (H_T) of each detail that is also expressed in Watt per Kelvin is also calculated. To obtain total heat fabric conduction heat loss, the Equation 5 given below is used:

$$H_T = \sum H_{TB} + \sum U \times A \quad \text{W/K} \quad (5)$$

Where;

H_{TB}: Additional heat loss through thermal bridge, W/K

U: U value of each element, W/m^2K

A: Area of each element, m^2.

Condensation and mold growth is very serious aspect of thermal bridges. Low internal surface temperatures can lead to surface condensation and temperature factor is used as an indicator of condensation risk. In Germany and in various countries, dimensionless temperature factor *fRsi* is used to evaluate the condensation and mold growth risk of thermal bridges. If the minimum surface factor $f_{Rsi} \geq 0.7$ condensation and mold growth will be avoided in Passive Houses. If the internal humidity is higher, the critical temperature factor will be higher to reduce the possibility of condensation (Way, 2009). *fRsi* factor can be calculated by using the Equation 6 given below (ISO 20211, 2007):

$$f_{Rsi} = \frac{\Theta_{si} - \Theta_e}{\Theta_i - \Theta_e} \quad (6)$$

Where;

f_{Rsi}: the temperature factor for the internal surface, °C

Θ_{si}: the temperature for the internal surface, °C

Θ_i: the internal temperature, °C

Θ_e: the external temperature, °C.

3.2.2 Calculation of the Energy Demand of the Passive House Building

Table 3.10 indicates the properties applied to the case study building in order to meet Passive House Standard. The inputs of Passive House entered to PHPP can be found in Appendix B.

Table 3.10 Properties applied to the existing building to meet Passive House Standard

PASSIVE HOUSE CASE	
Wall insulation	150 mm, λ=0.035W/mK
Roof insulation	150 mm, λ=0.035W/mK
Foundation insulation	150 mm, λ=0.035W/mK
Glazing	Triple glazing,16mm, Argon, Ug=0,6, g=0.55
Frame	PH PVC Frame, U_f=0.79 W/m²K
External wall	Masonry, 200mm, λ=0.33
Ventilation	MVHR Unit,%85 Efficiency
Heating	Air Source Heat Pump
DHW Generation	Solar collectors+Air Source Heat Pump
Air tightness(assumed)	0.6(1/h)

Achieving Passive House Standard was possible with installing triple window glazing with Argon filling. The technical specifications of the glazing are selected from one of the leading companies of the flat glass market in Turkey as it is indicated in Table 3.11.

Table 3.11 Technical Specifications of one of the leading flat glass company in Turkey

	U value W/m^{2}K		Solar Energy	
Product	Air	Argon	Total transmittance	SC
C 4(*)+9+4+9+4(*)	1.2	0.9		
D 4(*)+12+4+12+4(*)	0.9	0.7		
E 4(*)+16+4+16+4(*)	0.7	0.6	0.48	0.55

To ensure indoor comfort, Mechanical Ventilation with Heat Recovery is applied. Living room and bedrooms are included in supply air zone, where kitchen, bathroom and WC are included in extract air zone. And the hall is included in transferred air zone. The ventilation concept proposed for the existing building is presented in Figure 3.14.

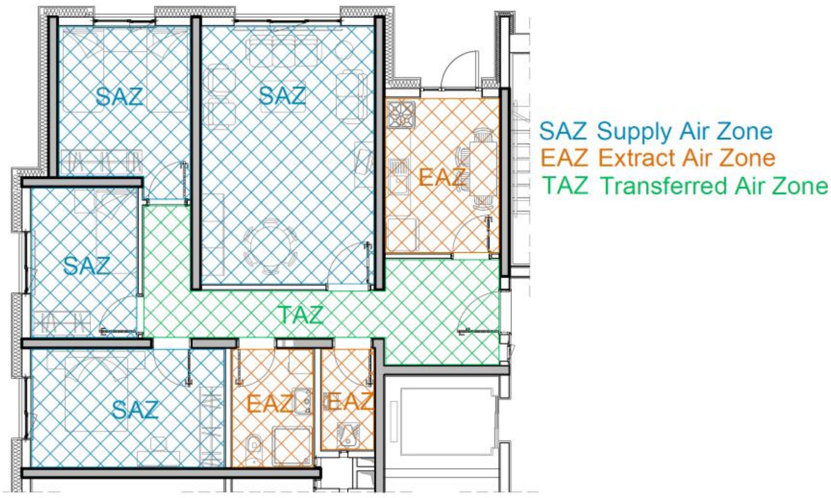


Figure 3.14 Planned Supply, Extract and Transferred Air Zones for one dwelling

According to PHI, a ventilation system where supply air is 20 to 30 m^3/h per person within the whole apartment is enough to provide sufficient air quality in residential buildings. It is assumed that the number of occupants is 4 in a dwelling. The required supply air can be found as follow using PHPP for the whole dwelling as it is indicated in Figure 3.15:

Occupancy	m^2/P	22			
Number of occupants	P	100.0			
Supply air per person	m^3/(P*h)	30			
Supply air requirement	m^3/h	**3000**		Bathroom	
Extract air rooms		Kitchen	Bathroom	(shower only)	WC
Quantity		25	25		25
Extract air requirement per room	m^3/h	60	40	20	20
Total Extract Air Requirement	m^3/h	**3000**			

Figure 3.15 Calculation of supply air and extract air requirement for the whole apartment

The ventilation system must have efficiency more than %75, complying with PHI certification and the results from standard testing procedures have to be subtracted 12 percentage points (Feist *et al*., 2012). There are no Turkish manufacturers of Passive House Certified Ventilation Units yet. Therefore ventilation unit is selected from the single distributor of PH certified ventilation unit currently in Turkey.
Two solar collectors are proposed for the each dwelling with an efficiency of %77 to generate domestic hot water. According to PHPP, %34 of the DHW generation can be delivered from the solar collectors.

Heating with air source heat pumps can deliver energy savings up to 20 percent compare to condensing boiler gas with an efficiency of %107 (Denizalp & Onan, 2013).A comparison of air source heat pump‟ savings with other energy sources to heat a house in Istanbul can be seen in Table 3.12. For the rest DHW demand, as well as to heat the dwellings in winter, an air source heat pump with a COP of 4 is used.

Table 3.12 Percentage of savings in Istanbul when installing air source heat pumps (Denizalp & Onan, 2013).

Fuel type	Heating Savings by using air source heat pump in Istanbul			
	COP			
	3	3,5	4	4,5
Natural gas (condensing boiler, %107 efficiency)	19%	2%	-11%	-20%
Natural gas (conventional boiler)	4%	-11%	-22%	-31%
Coal	-17%	-29%	-38%	-45%
Electric	-67%	-71%	-75%	-78%

- **Thermal Bridge Assumptions of the Passive House Building**

Using the dxf drawings indicated in Figure 3.16 as an underlay, the construction details are simulated in Therm 6.3. The materials and thermal conductivities used in Therm 6.3 are presented in Table 3.13.

Table 3.13 Material properties used in the Passive House Case

	Thermal Conductivity (W/(mK))
Reinforced Concrete	2,5
Brick Masonry (600 kg/m³)	0,33
Rock wool Insulation	0,035
Gypsum plaster	0,51
Exterior Plaster (Insulated)	0,07
Interior Plaster	1
Screed	1,4
Tile	1
Parquet	0,13
Isokorb	0,099

15 cm external wall insulation is proposed continuously on all of the external wall surfaces. The standard thickness for the accompanying insulation of interior basement walls will usually be around somewhere between 5 and 10 cm. (PHI, 2013). Thus in the unheated basement wall, 5 cm thick insulation is extended 100 cm from the top of the basement ceiling to bottom. 5 cm thick insulation is proposed along with the concrete roof overhang.

To show the impacts of improved detailing on heat loss, balcony detail is studied in more detail. Only 15 cm external wall insulation is proposed in the first balcony detail. 3 cm of insulation is proposed above and below the slab in the second balcony detail not to create elevation difference between the kitchen and balcony. Lastly, a thermal break element is proposed in the third balcony detail. An example of a thermal break element can be seen in Figure B.9 of Appendix B.

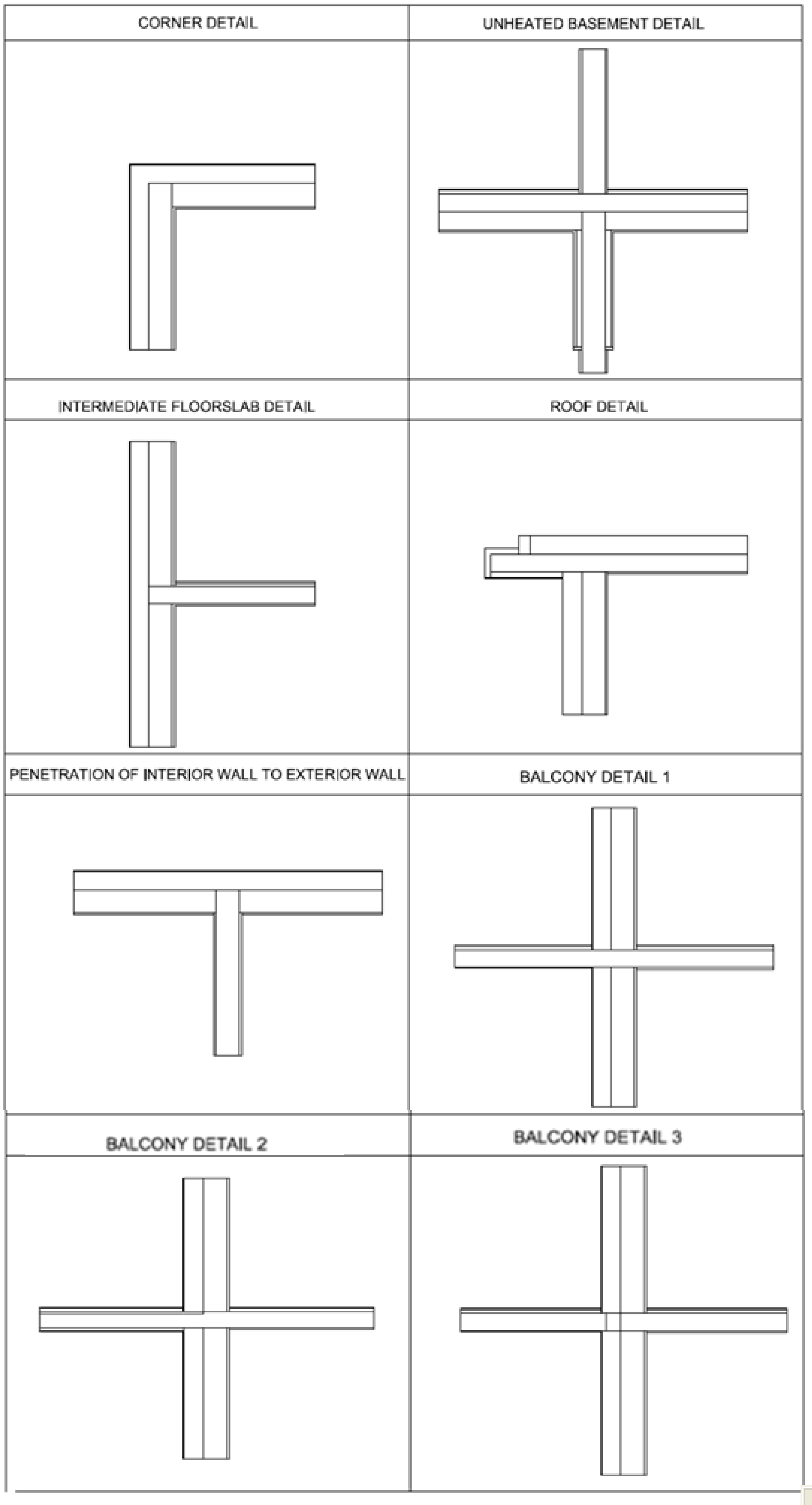


Figure 3.16 Passive House Case Drawings used in Therm 6.3

CHAPTER 4

RESULTS AND DISCUSSION

This chapter presents results and discussion of the energy demand and thermal bridge simulations of the case study building. As mentioned in the previous chapter, a six storey tunnel form social housing unit is studied in this study. Firstly, the annual heating demand, heating load, primary energy demand and CO_2 emissions are compared in graphs and tabulated data.

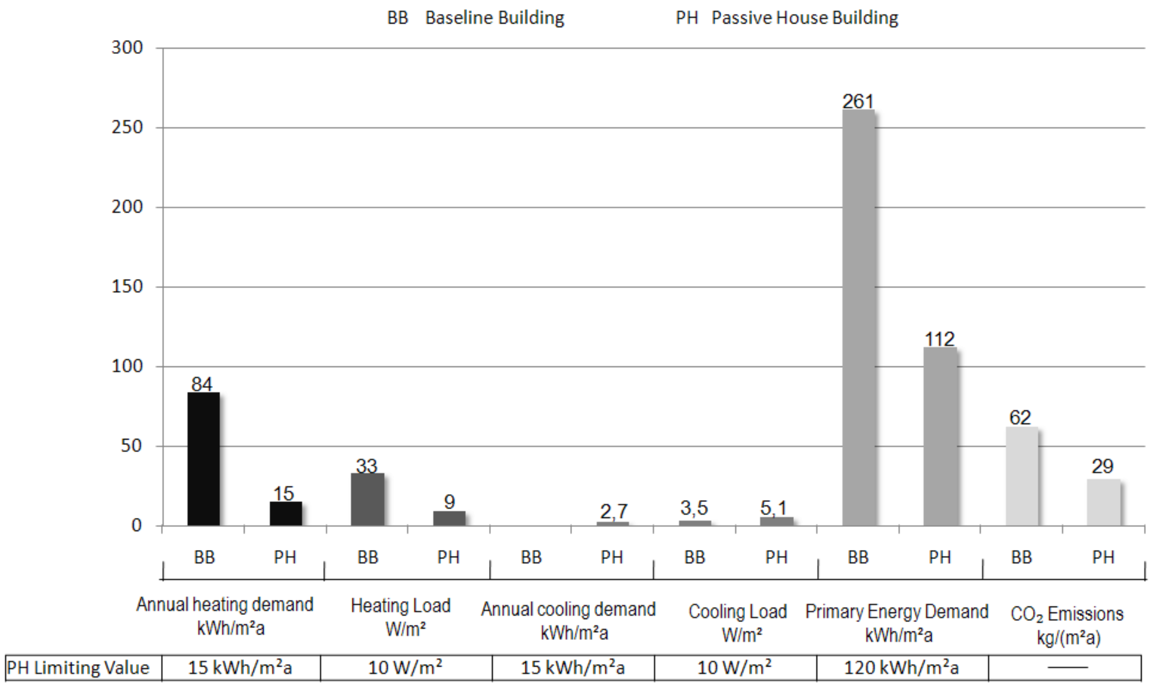


Figure 4.1 Comparison of the specific building demands

The results indicate that it is possible to achieve Passive House Standard in the tunnel form housing unit. By applying Passive House Standard 82% and 73%

reductions can be achieved respectively in annual heating demand and in heating load of the case building in Ankara. In addition to that 57% reduction in primary energy demand which covers the space heating, cooling, DHW and household electricity and 53% reduction in the CO_2 emissions are obtained as it is indicated in Figure 4.1. According to the results, the primary energy demand of the baseline tunnel formwork housing unit is 261 kWh/(m^2a). Whereas 112 kWh/(m^2a) primary energy demand (including space heating, cooling, dehumidification and household electricity demand) can be reached by applying Passive House Principles.

As the Passive House principles are applied, the cooling load of the building is increased from 3,5 W/m^2 to 5,1 W/m^2 which is 46%. Cooling demand of the building is increased from 0 to 2,7 kWh/m^2a. According to the Standard, if the frequency over 25ºC exceeds 10%, additional passive measures such as shading or the natural ventilation is necessary. If the comfort limit cannot be provided by passive ways, active cooling would be obligatory. However, in the case study building, to use temporary shading devices (such as blinds, vertical lamellas, etc.) and increase the natural ventilation rate was enough to meet the comfort level. Temporary shading input is presented in Figure B.8 of Appendix B and summer ventilation input is presented in Figure B.4 of Appendix B. In this study minimum and maximum interior temperature are set to 20 ºC and 25 ºC respectively. It should be noted that thermal comfort level of people differs due to many reasons such as climate, activity, clothing, age, etc. If the upper limit of thermal comfort of occupants is higher than that of 25 ºC, the cooling demand and cooling load will be lower in the Passive House case. If the minimum interior temperature is set to 19 ºC as it is in TS 825 Standard, the heating demand and heating load of the two cases will be lower.

Table 4.1 Applied systems in baseline building and in Passive House

	BASELINE HOUSING UNIT	PASSIVE HOUSE CASE
Wall insulation	EPS 5cm, λ=0.040 W/(mK)	Rock wool 15cm, λ=0.035 W/(mK)
Roof insulation	EPS 5cm, λ=0.040 W/(mK)	Rock wool 15cm, λ=0.035 W/(mK)
Basement insulation	EPS 5cm, λ=0.040 W/(mK)	Rock wool 15cm, λ=0.035 W/(mK)
Foundation insulation	-, 6mm Water Proofing Membrane	Rock wool 15cm, λ=0.035 W/(mK)
Glazing	Double(16-4-16), Air, Ug=2,7,g=0.77	Triple (16-4-16-4-16), Argon Ug=0,6, g=0.55
Window Frame	PVC, U_f=1.60 W/(m²K)	PH Frame, U_f=0.79 W/(m²K)
Brick Masonry	20cm,λ=0.36	20cm, λ=0.33
Ventilation type	Natural Ventilation	MVHR Unit,%85 Efficiency
Heating	Central Heating with Gas Boiler	Air Source Heat Pump, COP:4
DHW	Gas Water Heater for DHW	Solar collectors+Air Source Heat Pump
Air tightness (1/h)	5 (assumed)	0.6 (assumed)

Not only reducing the operational energy of buildings, but also the choice of the building materials and components are important factors since these decisions effect the life cycle energy consumption of buildings. The embodied energy of various insulation materials was presented in previous sections. In the Passive House case, rock wool insulation is proposed due to the high embodied energy of EPS insulation that is used in the baseline building as a comparison was presented in Figure 2.27. Table 4.1 indicates the applied systems of the baseline building and the Passive House. In the case study building, 15 cm thick rock wool insulation is proposed. Passive House Standard is achieved using triple glazed windows that are manufactured by a Turkish flat glass company in Turkey. Currently there is not a Turkish company that manufactures a certified Passive House window frame in Turkey. Therefore the frame type is chosen from one of the foreign offices that distributes Passive House Certified Frame. The MVHR unit applied in this study is selected from a foreign manufacturer of PH certified ventilation unit currently in Turkey. According to the manufacturer, the ventilation units are not distributed in Turkey. Therefore the ventilation units will have to be imported in the current situation which could result in a higher embodied energy due to the transportation.

4.1 Evaluation of the Baseline Building Energy Demand

Figure 4.2 and Figure 4.3 indicates the specific building demands of the baseline building without thermal bridges and with thermal bridges. It should be noted that in the under presented results only the thermal bridge calculations are carried for six details. If the whole building details were taken into account, the results would differ.

Specific building demands with reference to the treated floor area				use: Monthly method	
	Treated floor area	2189,5	m^2	Requirements	Fulfilled?*
Space heating	Annual heating demand	81	kWh/(m^2a)	15 kWh/(m^2a)	no
	Heating load	32	W/m^2	10 W/m^2	no
Space cooling	Overall specific space cooling demand		kWh/(m^2a)	-	-
	Cooling load		W/m^2	-	-
	Frequency of overheating (> 25 °C)	0,0	%	-	-
Primary Energy	Space heating and cooling, dehumidification, DHW, household electricity.	257	kWh/(m^2a)	120 kWh/(m^2a)	no
	DHW, space heating and auxiliary electricity	180	kWh/(m^2a)	-	-
	Specific primary energy reduction through solar electricity		kWh/(m^2a)	-	-
Airtightness	Pressurization test result n_{50}	5,0	1/h	0,6 1/h	no

Figure 4.2 Energy demand of the Baseline Building without Thermal Bridges

Specific building demands with reference to the treated floor area				use: Monthly method	
	Treated floor area	2189,5	m^2	Requirements	Fulfilled?*
Space heating	Annual heating demand	84	kWh/(m^2a)	15 kWh/(m^2a)	no
	Heating load	33	W/m^2	10 W/m^2	no
Space cooling	Overall specific space cooling demand		kWh/(m^2a)	-	-
	Cooling load		W/m^2	-	-
	Frequency of overheating (> 25 °C)	0,0	%	-	-
Primary Energy	Space heating and cooling, dehumidification, DHW, household electricity.	261	kWh/(m^2a)	120 kWh/(m^2a)	no
	DHW, space heating and auxiliary electricity	184	kWh/(m^2a)	-	-
	Specific primary energy reduction through solar electricity		kWh/(m^2a)	-	-
Airtightness	Pressurization test result n_{50}	5,0	1/h	0,6 1/h	no

Figure 4.3 Energy demand of the Baseline Building with Thermal Bridges

The share of the heat losses occurs in the studied thermal bridges can be seen in Figure 4.4. According to the results, the impact of thermal bridges is 3.94 kWh/ (m^2a) which corresponds 5 % of the annual heating demand that is 84.2 kWh/ (m^2a).

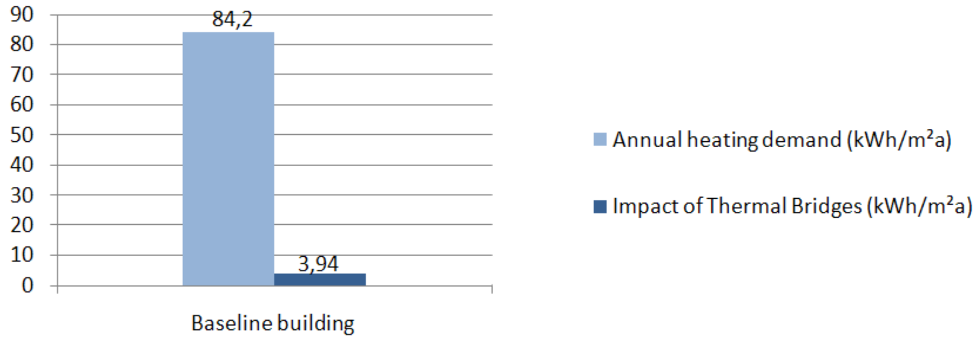


Figure 4.4 Transmission heat losses through thermal bridges in the baseline building

The results indicate that the annual heating demand and primary energy demand of the baseline building is 84kWh/(m^2a) and 261 kWh/(m^2a) respectively. According to a research the average natural gas consumption of a family is 1500 m^3/a and the average electricity consumption of a family is 1800kWh/a in Turkey (Çakar, a.2007). Taking this information account, the average energy demand of a family is 18120 kWh/a in Turkey. Calculation of the average energy demand can be found in Table B.1 of Appendix B. Comparing this data with PHPP results, it is seen that a similar result which is 20880 kWh/a is achieved with PHPP calculations.

4.1.1 Evaluation of the Thermal Bridges of the Baseline Building

In this part, details of the baseline building are evaluated in terms of the psi values, heat losses through thermal bridges and minimum surface temperatures. The data used to calculate the baseline and Passive House thermal bridges are presented in Table A.4 of Appendix A. The calculation of the length of the thermal bridges is also presented in Appendix A.

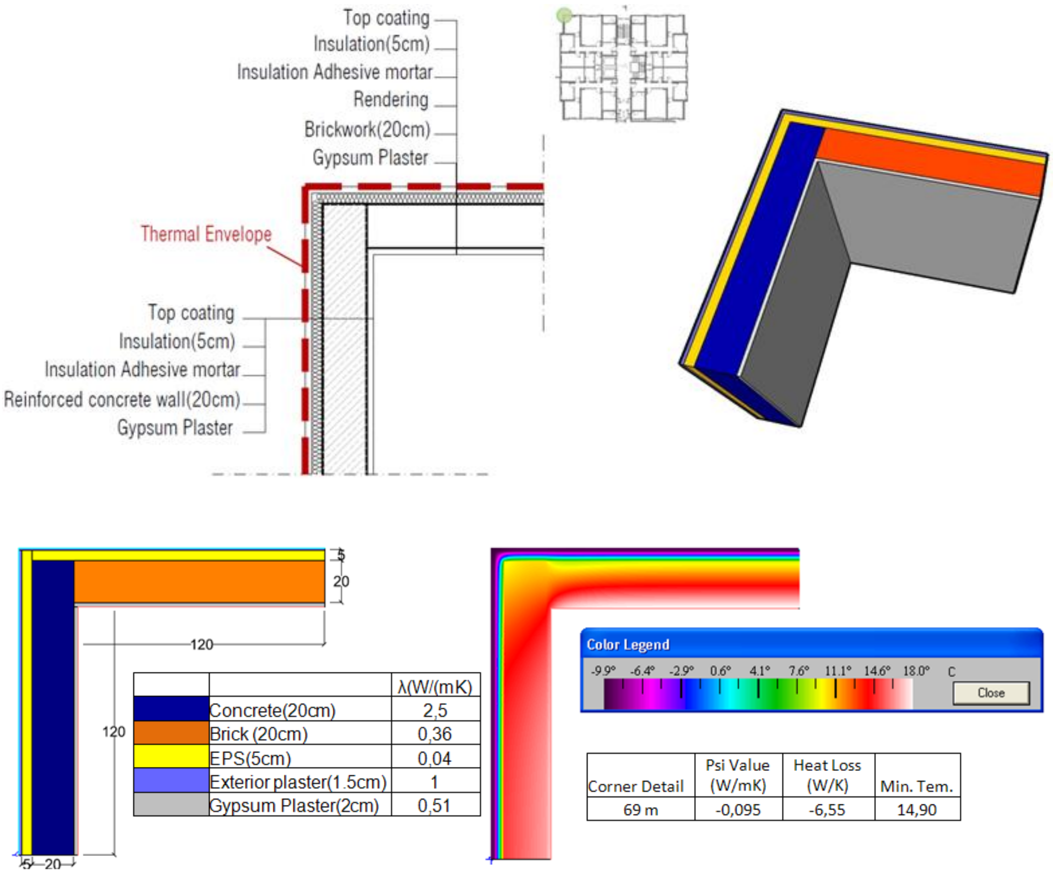
Calculations are made considering that the interior air temperature is 20ºC and the exterior air temperature is -10ºC. Calculation method of condensation risk in building components is different in TS 825 Standard. Since the results of the baseline building will be compared with the energy efficient case, the boundary conditions are chosen considering Passive House Standard.

Low minimum surface temperatures around the thermal bridges cause surface condensation. According to TS 825 regulation, the difference between the minimum surface temperature and the interior temperature should not be more than 3ºC. Therefore 17ºC is the target minimum surface temperature in terms of mold growth and indoor quality concerns in the standard. The relative humidity of naturally ventilated buildings is assumed to be 65% in Turkey. And if the relative humidity of surfaces reaches 80% even for a short time, there is a risk of mold growth.

As previously stated, surface condensation appears when the surface temperature is lower than the dew point of surrounding air and mold growth is a coincidence of surface condensation. It it is assumed that the interior room air temperature is 20 ºC at 65% relative humidity, the dew point temperature will be around 14 ºC. The relationship between relative humidity, interior air temperature and dew point temperature is presented in Table B.2 of Appendix B. If the surface temperature is lower than 14 ºC, condensation will appear on the surfaces which may later cause mold growth.

Corner Detail

Figure 4.5 indicates an example of a potential geometric thermal bridge. 5 cm EPS insulation is applied continuously at the building corners in the baseline building.



		λ(W/(mK)
	Concrete(20cm)	2,5
	Brick (20cm)	0,36
	EPS(5cm)	0,04
	Exterior plaster(1.5cm)	1
	Gypsum Plaster(2cm)	0,51

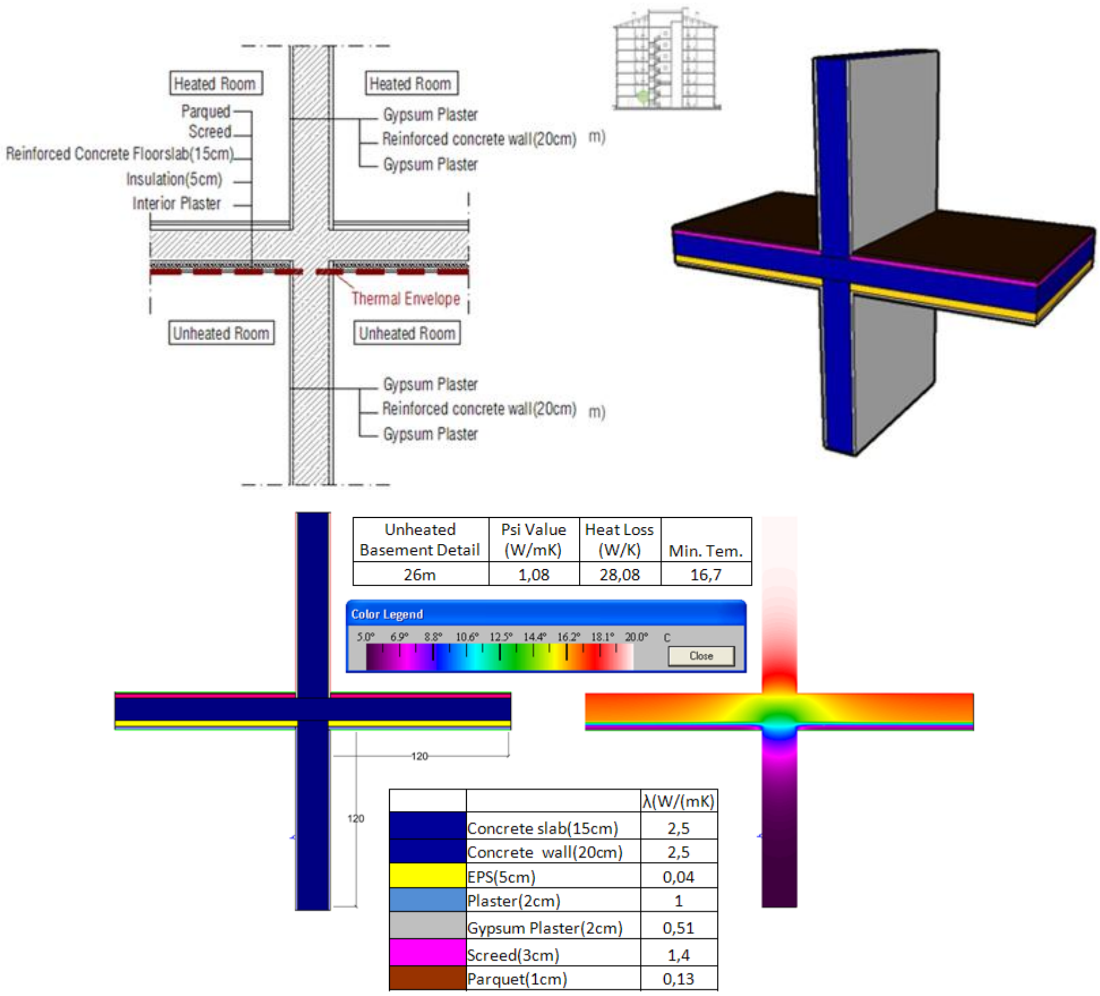
Corner Detail	Psi Value (W/mK)	Heat Loss (W/K)	Min. Tem.
69 m	-0,095	-6,55	14,90

Figure 4.5 Corner detail of the TOKİ social housing unit

According to the results, the psi value of the corner detail is -0.09 W/mK. It means that the detail is thermal bridge free and the negative prefix results a credit for the energy balance. To multiply the length with psi value gives the heat loss which is 6.55 W/K. Most heat loss occurs in the inside corner of the walls where the minimum surface temperature of the wall is 14.90 ºC. Lower surface temperatures have higher relative humidity which causes a risk of mold growth. However the minimum surface temperature is higher than 14 ºC, thus it can be said that there is not a risk of condensation.

Unheated Basement Wall Detail

In Figure 4.6, the basement wall detail of the baseline building can be seen. 5cm of insulation below the reinforced concrete floor slab is applied continuously.



Unheated Basement Detail	Psi Value (W/mK)	Heat Loss (W/K)	Min. Tem.
26m	1,08	28,08	16,7

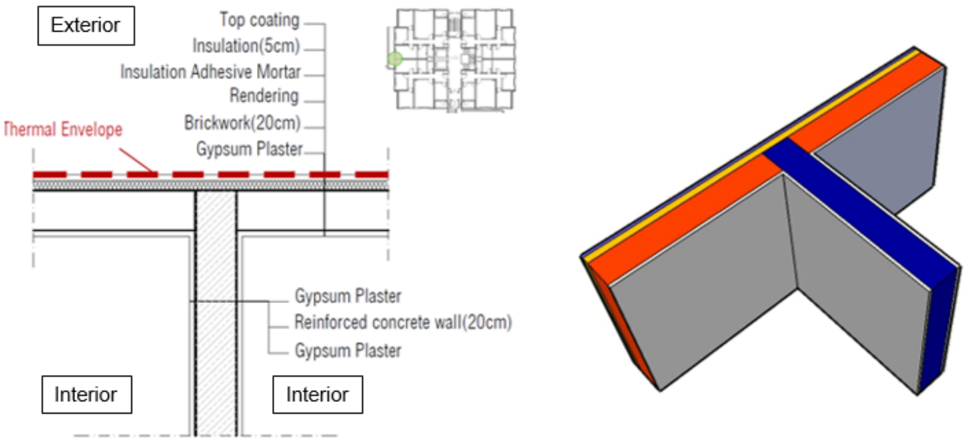
		λ(W/(mK))
	Concrete slab(15cm)	2,5
	Concrete wall(20cm)	2,5
	EPS(5cm)	0,04
	Plaster(2cm)	1
	Gypsum Plaster(2cm)	0,51
	Screed(3cm)	1,4
	Parquet(1cm)	0,13

Figure 4.6 Unheated basement wall detail of the TOKİ social housing unit

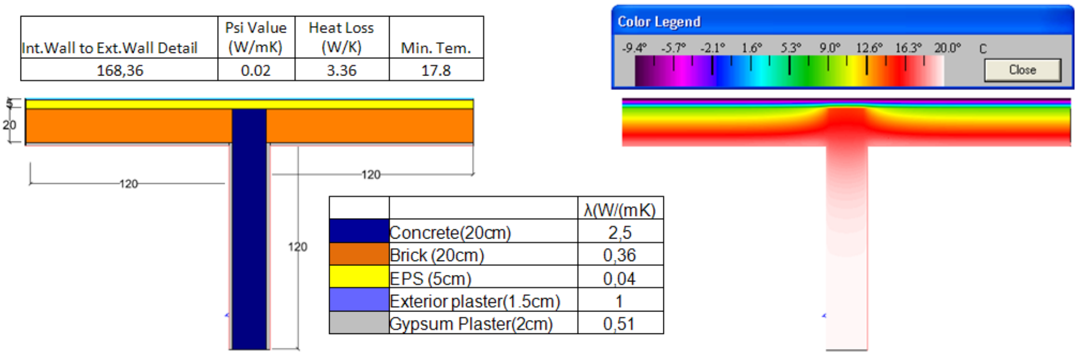
A psi value of 1.08 W/mK which is quiet high is found for the above mentioned detail. 28.08 W/K heat losses occur through the thermal bridges. Again, most heat loss occurs in the inside corner of the walls where the minimum surface temperature is 16.70 ºC.

Interior Wall to Exterior Wall Detail

A structural thermal bridge can be seen in Figure 4.7. A psi value of 0.02 W/mK is found for the detail. The length of the thermal bridge is 168.36 m. It is found that 3.36 W/K heat losses occur because of thermal bridges. Minimum surface temperature is 17.8 ºC on the inside corner of the wall which provides a good indoor air condition. The minimum surface temperature is higher than 14 ºC, thus it can be said that there is not a risk of condensation.



Int.Wall to Ext.Wall Detail	Psi Value (W/mK)	Heat Loss (W/K)	Min. Tem.
168,36	0.02	3.36	17.8

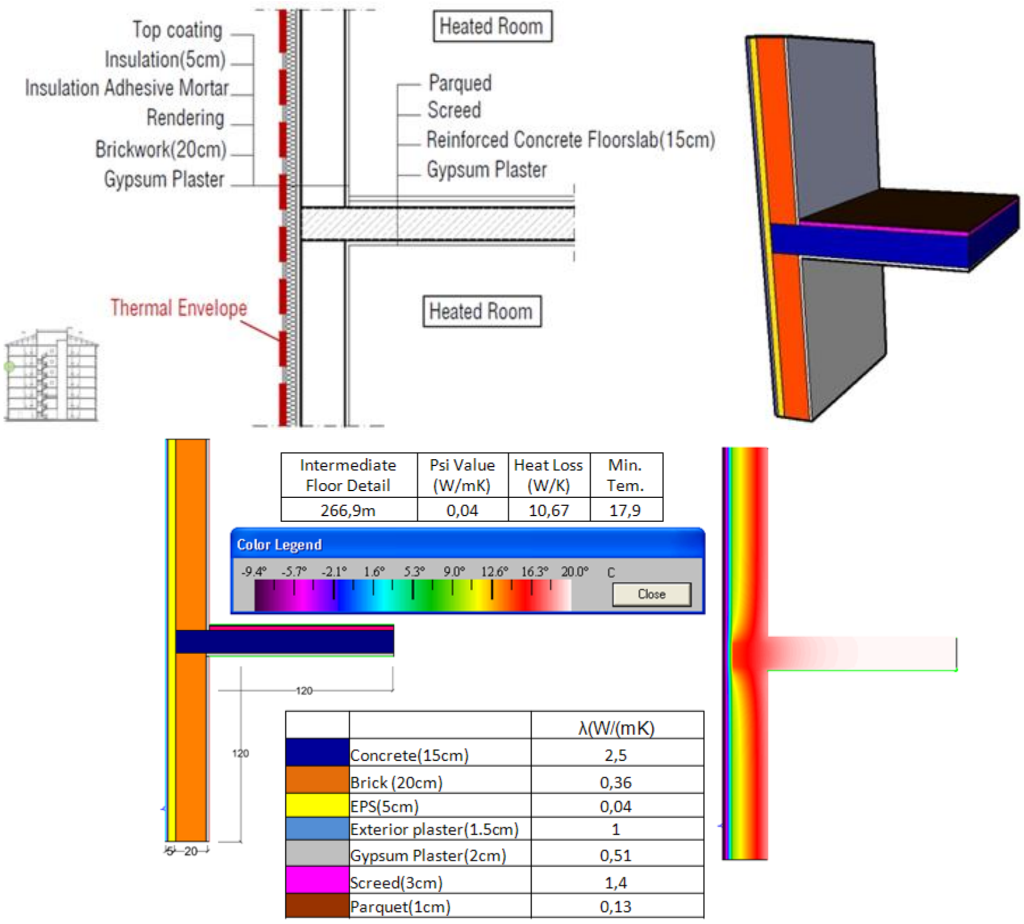


	λ(W/(mK)
Concrete(20cm)	2,5
Brick (20cm)	0,36
EPS (5cm)	0,04
Exterior plaster(1.5cm)	1
Gypsum Plaster(2cm)	0,51

Figure 4.7 Penetration of internal wall to exterior in baseline building

Intermediate Floor Detail

Another example of a structural thermal bridge, where reinforced concrete floor slab penetrate thermal envelope can be seen in Figure 4.8. A psi value of 0.04 W/mK is found for the detail. The length of the thermal bridge is 266.9 m. 10.67 W/K heat losses occur through thermal bridges. Minimum surface temperature is 17.9 ºC on the inside corner of the wall surface which is enough for a good indoor air condition.



Intermediate Floor Detail	Psi Value (W/mK)	Heat Loss (W/K)	Min. Tem.
266,9m	0,04	10,67	17,9

	λ(W/(mK)
Concrete(15cm)	2,5
Brick (20cm)	0,36
EPS(5cm)	0,04
Exterior plaster(1.5cm)	1
Gypsum Plaster(2cm)	0,51
Screed(3cm)	1,4
Parquet(1cm)	0,13

Figure 4.8 Intermediate floor junction in the baseline TOKİ social housing unit

Roof Detail

Roof overhang detail of the social housing unit is indicated in Figure 4.9. 5cm insulation is applied on the external wall and on the roof in the detail. However, discontinuity can be seen in the thermal insulation through the overhang. A psi value of 0.22 W/mK is found for the detail. The length of the thermal bridge is 32,1m. 7.06 W/K heat losses occur through the thermal bridges. The largest heat loss in the roof overhang detail is in the corner where the minimum surface temperature is 11.9ºC. It is too low to ensure good air quality. The minimum surface temperature is lower than the dew point temperature (14 ºC), thus there is a risk of condensation and mold growth in this detail.

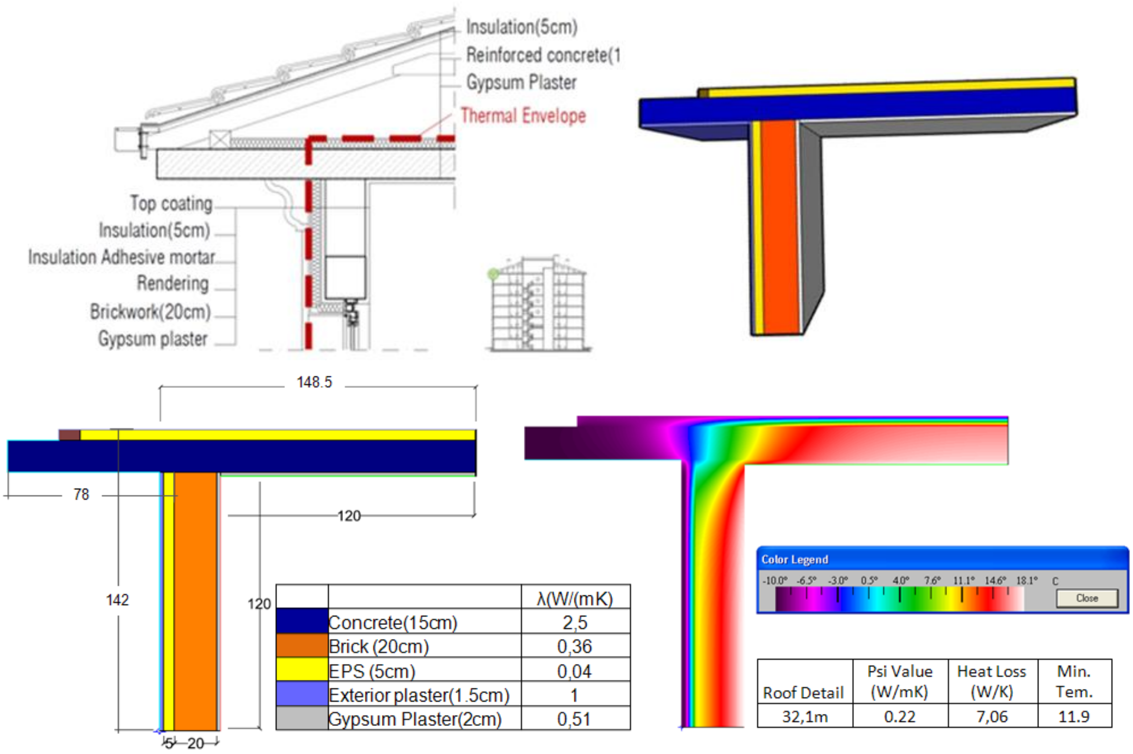
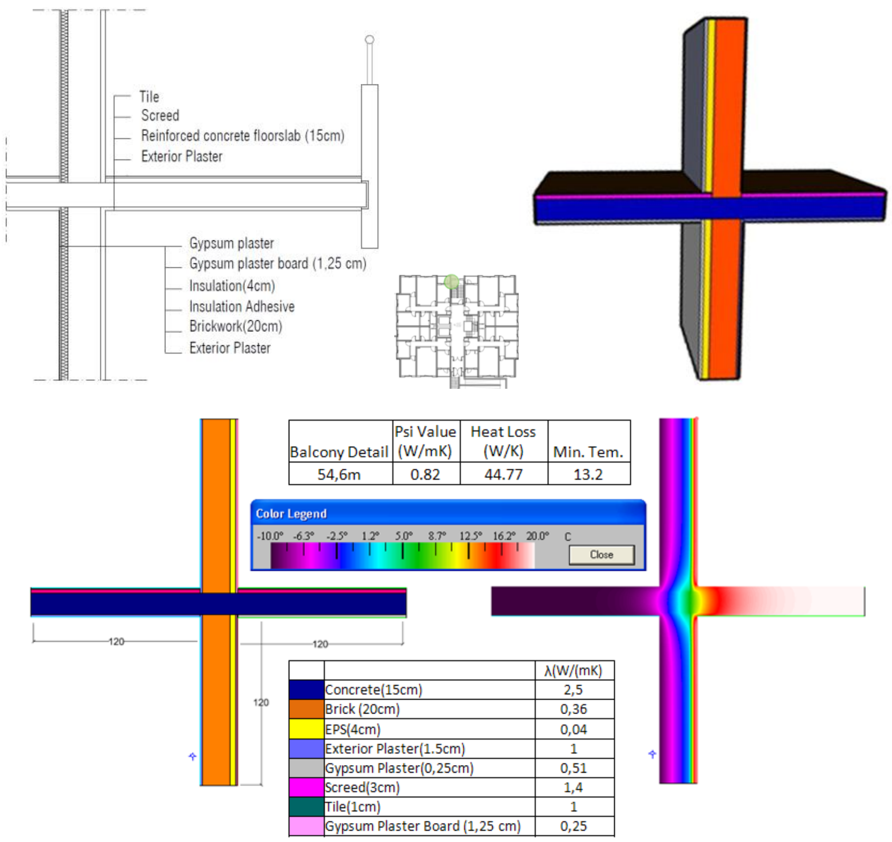


Figure 4.9 Roof Detail in the baseline building

Balcony Detail

In the baseline building, also in Turkey in general the balconies are framed continuous with the interior floor which creates wall to balcony slab thermal bridge. Figure 4.10 indicates the balcony detail in the baseline building. The external wall is insulated internally with 4 cm insulation. A psi value of 0.82W/mK is estimated for the above mentioned detail. The length of the thermal bridge is 54.6 m. It is found that 44.77 W/K heat losses occur through the thermal bridges. After roof detail, the lowest minimum surface temperature is seen on the balcony detail which is 13.2 ºC. There is a risk of surface condensation due to the low minimum surface temperature. Heat losses through thermal bridges represent the highest amount in the balcony detail compare to the other details.



Balcony Detail	Psi Value (W/mK)	Heat Loss (W/K)	Min. Tem.
54,6m	0.82	44.77	13.2

	λ(W/(mK)
Concrete(15cm)	2,5
Brick (20cm)	0,36
EPS(4cm)	0,04
Exterior Plaster(1.5cm)	1
Gypsum Plaster(0,25cm)	0,51
Screed(3cm)	1,4
Tile(1cm)	1
Gypsum Plaster Board (1,25 cm)	0,25

Figure 4.10 Balcony detail in the baseline building

4.2 Evaluation of the Passive House Building Energy Demand

Figure 4.11 and Figure 4.12 indicate the specific building demands of the Passive House building without thermal bridges and with thermal bridges. It should be also noted that in the under presented results only six details are estimated. If the whole building details were taken into account, the results would differ.

Specific building demands with reference to the treated floor area				use: Monthly method	
	Treated floor area	2189,5	m²	Requirements	Fulfilled?*
Space heating	Annual heating demand	14	kWh/(m²a)	15 kWh/(m²a)	yes
	Heating load	9	W/m²	10 W/m²	yes
Space cooling	Overall specific space cooling demand	3	kWh/(m²a)	15 kWh/(m²a)	yes
	Cooling load	5	W/m²	-	-
	Frequency of overheating (> 25 °C)		%	-	-
Primary Energy	Space heating and cooling, dehumidification, household electricity.	113	kWh/(m²a)	120 kWh/(m²a)	yes
	DHW, space heating and auxiliary electricity	63	kWh/(m²a)	-	-
	Specific primary energy reduction through solar electricity		kWh/(m²a)	-	-
Airtightness	Pressurization test result n_{50}	0,6	1/h	0,6 1/h	yes

Figure 4.11 Energy demand of the Passive House Building without Thermal Bridges

Specific building demands with reference to the treated floor area				use: Monthly method	
	Treated floor area	2189,5	m²	Requirements	Fulfilled?*
Space heating	Annual heating demand	16	kWh/(m²a)	15 kWh/(m²a)	-
	Heating load	9	W/m²	10 W/m²	yes
Space cooling	Overall specific space cooling demand	3	kWh/(m²a)	15 kWh/(m²a)	yes
	Cooling load	5	W/m²	-	-
	Frequency of overheating (> 25 °C)		%	-	-
Primary Energy	Space heating and cooling, dehumidification, household electricity.	114	kWh/(m²a)	120 kWh/(m²a)	yes
	DHW, space heating and auxiliary electricity	64	kWh/(m²a)	-	-
	Specific primary energy reduction through solar electricity		kWh/(m²a)	-	-
Airtightness	Pressurization test result n_{50}	0,6	1/h	0,6 1/h	yes

Figure 4.12 Energy demand of the Passive House Building with Thermal Bridges

The share of the heat losses occurs in the studied thermal bridges can be seen in Figure 4.13. According to the results, the impact of thermal bridges is 2.29 kWh/ (m^2a) which corresponds 14% of the total heating demand that is 15.9 kWh/ (m^2a).

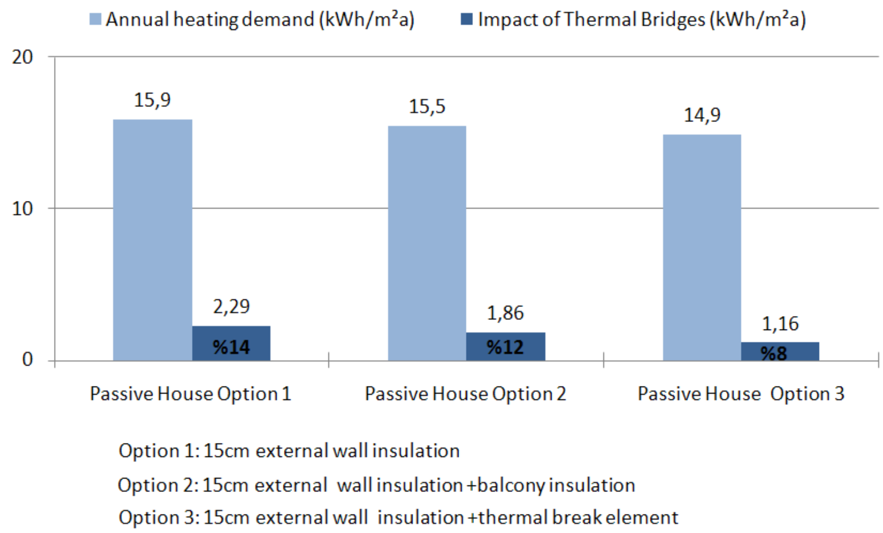


Figure 4.13 Transmission heat losses through thermal bridges in the Passive House Building

Option 1 represents the balcony detail, where there is no additional measure taken for reducing thermal bridges. Only the external wall insulation thickness is increased. Option 2 represents the balcony detail, where the floor slab is insulated above and below the slab. Option 3 represents the balcony detail, where a thermal break element is used. The results indicate that to insulate balcony floor slab above and below the slab, reduce the annual heating demand 2% from 15,9 kWh/m^{2}a to 15,5 kWh/m^{2}a.Whereas to use a thermal break element reduce the annual heating demand % 6, from 15,9 kWh/m^{2}a to 14,9 kWh/m^{2}a.

4.2.1 Impact of Ventilation System Efficiency on Insulation Thickness

It is required to use a MVHR system with more than 75% efficiency in Passive Houses. Nevertheless, BEP Standard requires using of MVHR systems more than 50% efficiency in Turkey in buildings that have an air flow more than 500 m^3/h. The efficiency level of the selected ventilation system effects the heating load of the system, so the required insulation thickness to achieve target efficiency levels. The graph presented in Figure 4.14 indicates that on each case; how the insulation thickness changes depending on the efficiency level of the ventilation system assuming that the heating load of the building will be lower than 10W/m^2 threshold. It is seen that lower the efficiency level of MVHR, thicker the insulation. To use a MVHR with 50%, requires a 30cm thick insulation thickness in the Passive House building whereas to use a MVHR with 85% efficiency, requires a 15 cm thick insulation in order to have heating loads below 10W/m^2.

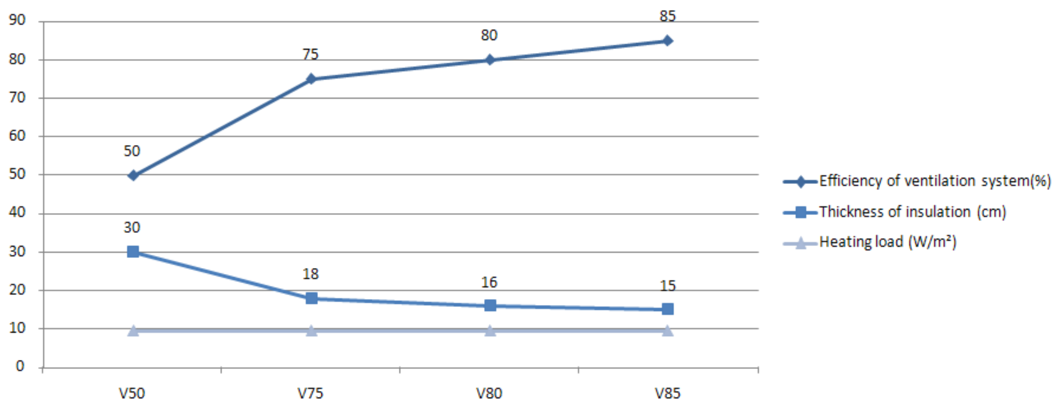
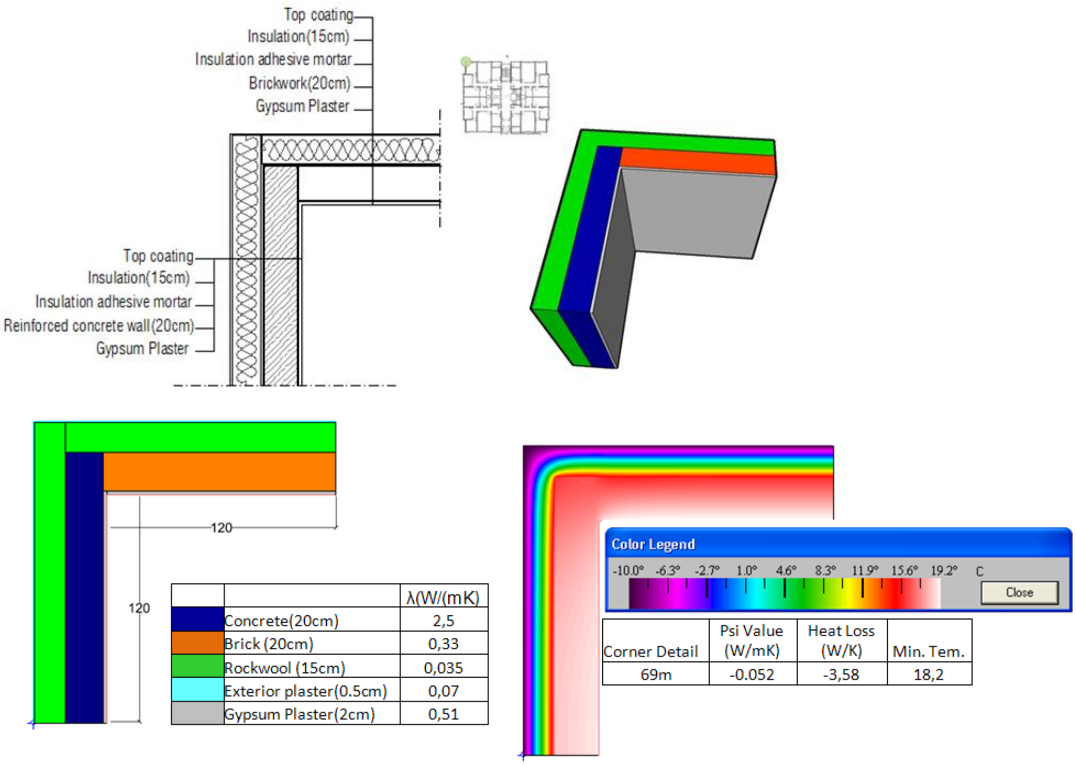


Figure 4.14 Correlation of ventilation system efficiency and insulation thickness

4.2.2 Evaluation of the Thermal Bridges of the Passive House Building

In this part, details proposed for the Passive House building are evaluated in terms of psi values, heat loss through thermal bridges, minimum surface temperatures and f_{Rsi} factors. If the minimum temperature factor $f_{Rsi} \geq 0.7$, mold growth and condensation will be avoided in Passive Houses. If the temperature factor is larger than 0.7, it means that the results are better.

Corner Detail



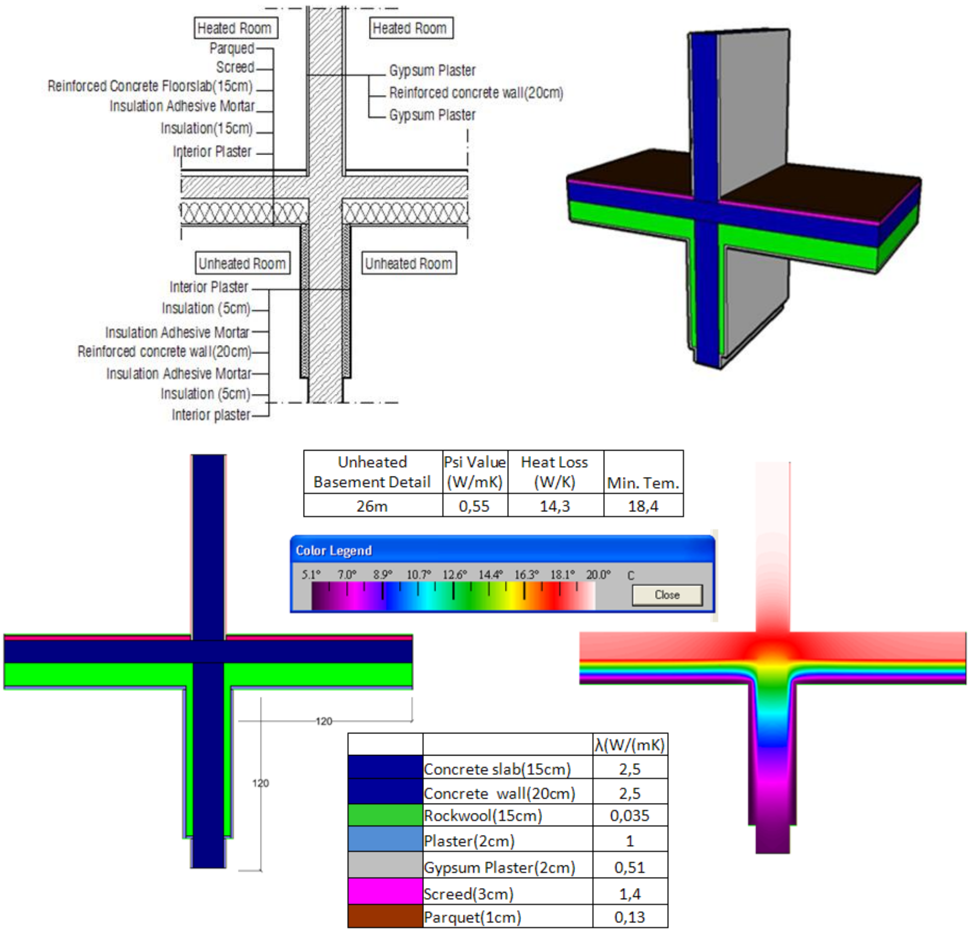
		λ(W/(mK)
	Concrete(20cm)	2,5
	Brick (20cm)	0,33
	Rockwool (15cm)	0,035
	Exterior plaster(0.5cm)	0,07
	Gypsum Plaster(2cm)	0,51

Corner Detail	Psi Value (W/mK)	Heat Loss (W/K)	Min. Tem.
69m	-0.052	-3,58	18,2

Figure 4.15 Corner detail in the Passive House Building

The external wall corner of the Passive House building is presented in Figure 4.15. The calculated psi value of the corner detail is -0.05W/mK. When external dimensions are used in the calculations, the negative psi value at a corner represents a subtraction in heat loss to help to correct for overestimation of heat loss. 3.58 W/K heat loss occurs through thermal bridges. Minimum surface temperature is 18.2ºC on the internal wall surface. More heat loss occurs in the inside corner of the walls. Assuming that indoor air temperature is 20 ºC at 50% relative indoor air humidity, since the minimum surface temperature is higher than 12.6 ºC, there is not a risk of mold growth. f_{Rsi} is 0.94.

Unheated Basement Wall Detail



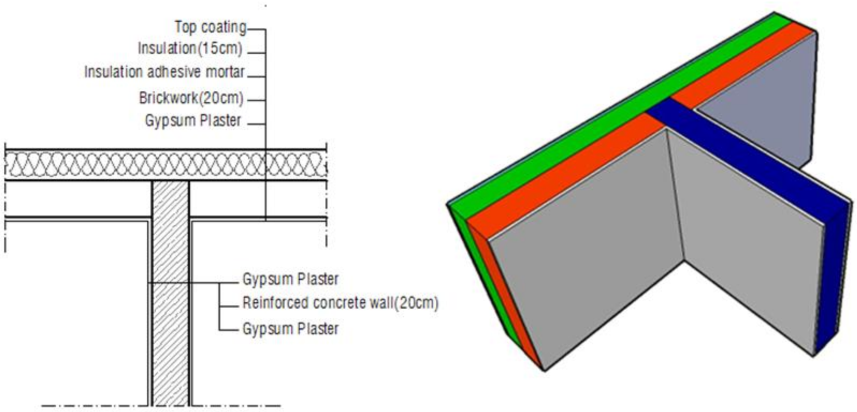
Unheated Basement Detail	Psi Value (W/mK)	Heat Loss (W/K)	Min. Tem.
26m	0,55	14,3	18,4

		λ(W/(mK))
	Concrete slab(15cm)	2,5
	Concrete wall(20cm)	2,5
	Rockwool(15cm)	0,035
	Plaster(2cm)	1
	Gypsum Plaster(2cm)	0,51
	Screed(3cm)	1,4
	Parquet(1cm)	0,13

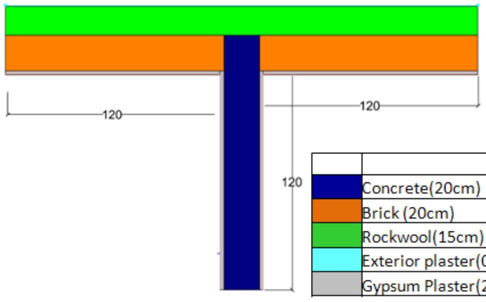
Figure 4.16 Unheated basement wall detail in the Passive House Building

In this detail, 5 cm thick insulation is extended 100 cm from the top of the ceiling to the bottom on the unheated basement wall as it is presented in Figure 4.16. A psi value of 0.55 W/mK is found for the above mentioned detail. Since the continuity of the insulation is still disrupted, a thermal bridge free design is not achieved in this detail. The length of the thermal bridge is 26m. It is found that 14.3 W/K heat losses occur through the thermal bridges. Minimum surface temperature is 18.4ºC on the internal wall surface. f_{Rsi} is 0.94. Since the minimum surface temperature is higher than 12.6 ºC, there is not a risk of mold growth.

Interior Wall to Exterior Wall Detail



Int.Wall to Ext.Wall Detail	Psi Value (W/mK)	Heat Loss (W/K)	Min. Tem.
168,36	0.005	0.84	18.6



		λ(W/(mK))
	Concrete(20cm)	2,5
	Brick (20cm)	0,33
	Rockwool(15cm)	0,035
	Exterior plaster(0.5cm)	0,07
	Gypsum Plaster(2cm)	0,51

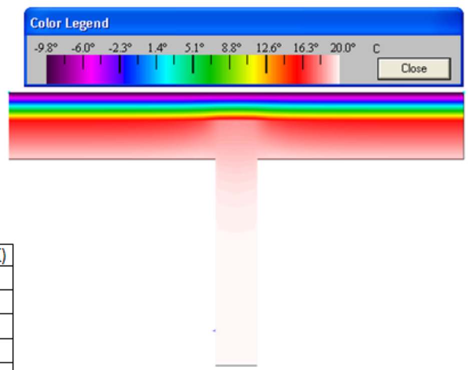
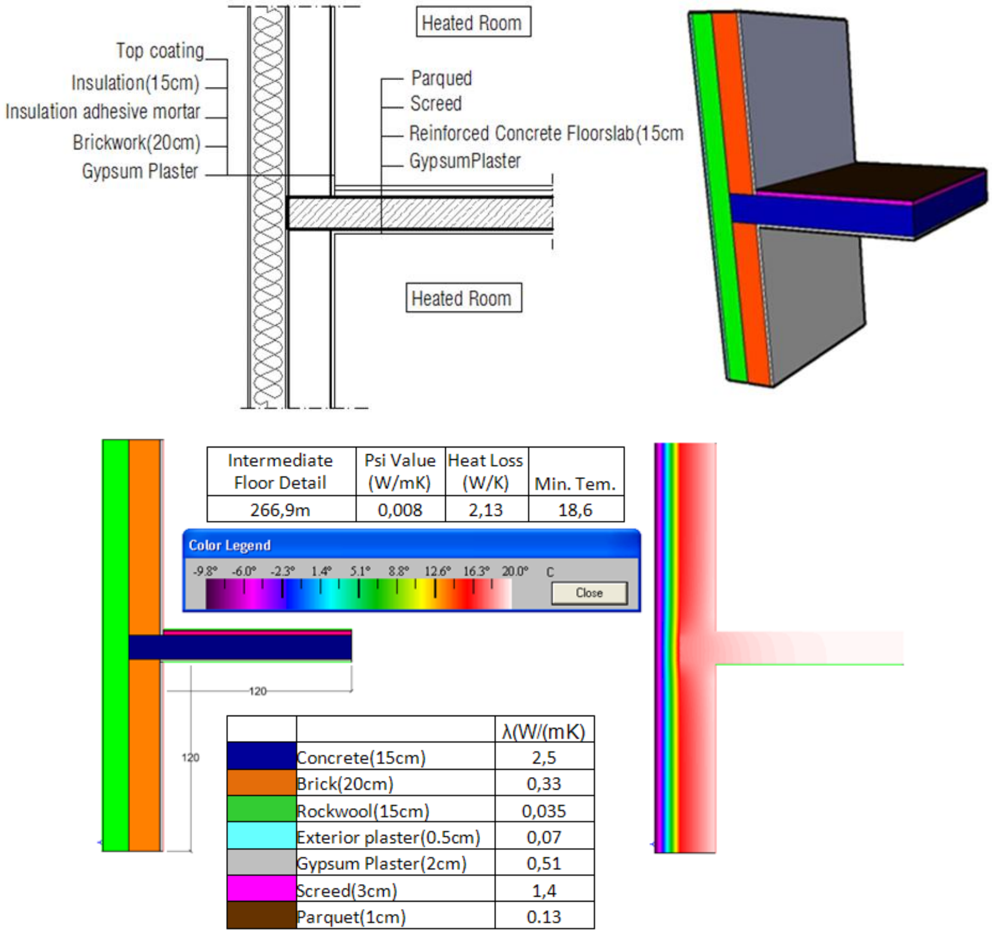


Figure 4.17 Exterior wall to interior wall detail in the Passive House Building

Penetration of structural wall to the insulation in the Passive House building is presented in Figure 4.17. A psi value of 0.005 W/mK is calculated for the above mentioned detail. The detail is regarded as thermal bridge since the psi value is lower than 0.01 W/mK. The length of the thermal bridge is 168.36 m. It is found that 0.84 W/K heat losses occur because of thermal bridges. Minimum surface temperature is 18.6ºC on the internal wall surface. *f* Rsi is 0.95. Since the minimum surface temperature is higher than 12.6 ºC, there is not a risk of mold growth.

Intermediate Floor Slab Detail



Intermediate Floor Detail	Psi Value (W/mK)	Heat Loss (W/K)	Min. Tem.
266,9m	0,008	2,13	18,6

		λ(W/(mK)
	Concrete(15cm)	2,5
	Brick(20cm)	0,33
	Rockwool(15cm)	0,035
	Exterior plaster(0.5cm)	0,07
	Gypsum Plaster(2cm)	0,51
	Screed(3cm)	1,4
	Parquet(1cm)	0.13

Figure 4.18 Intermediate floor slab detail in the Passive House Building

Intermediate floor junction of the Passive House building is presented in Figure 4.18. A psi value of 0,008 W/mK is found for the above mentioned detail. The detail is regarded as thermal bridge since the psi value is lower than 0.01 W/mK. The length of the thermal bridge is 266.9 m. It is found that 2.13 W/K heat losses occur through this detail. Minimum surface temperature is 18.6ºC on the internal wall surface. f_{Rsi} is 0.95. Since the minimum surface temperature is higher than 12.6 ºC, there is not a risk of mold growth.

Roof Detail

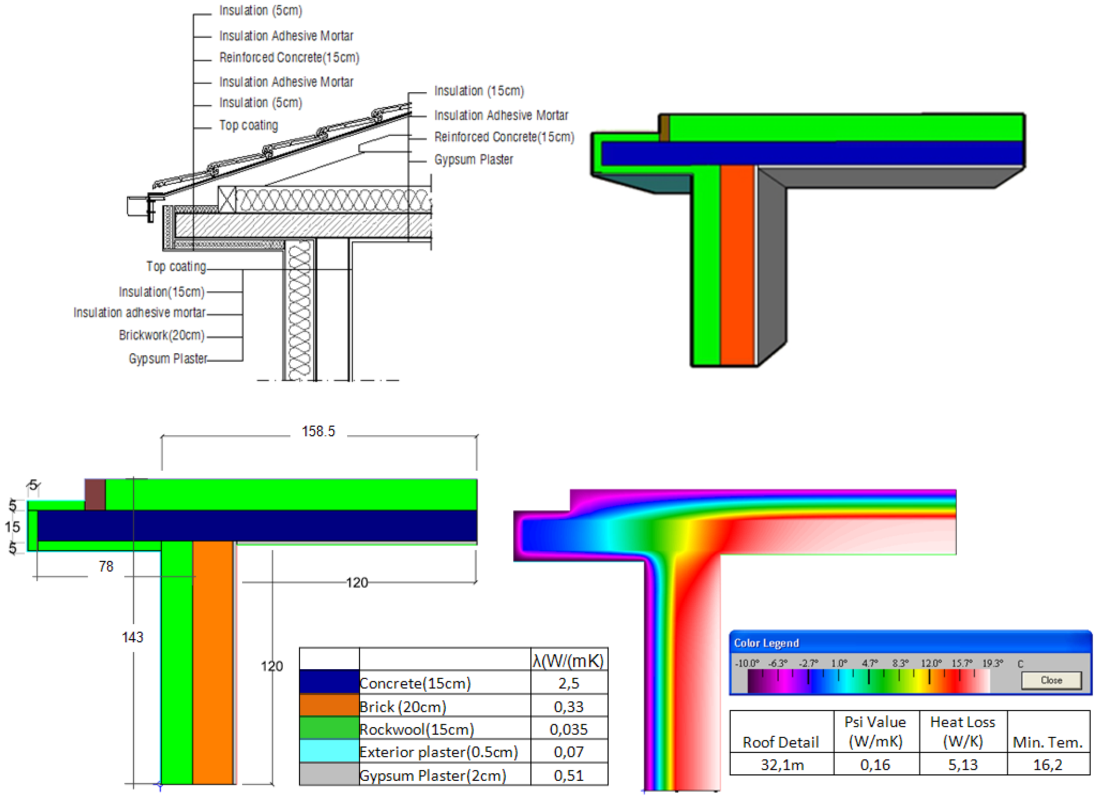
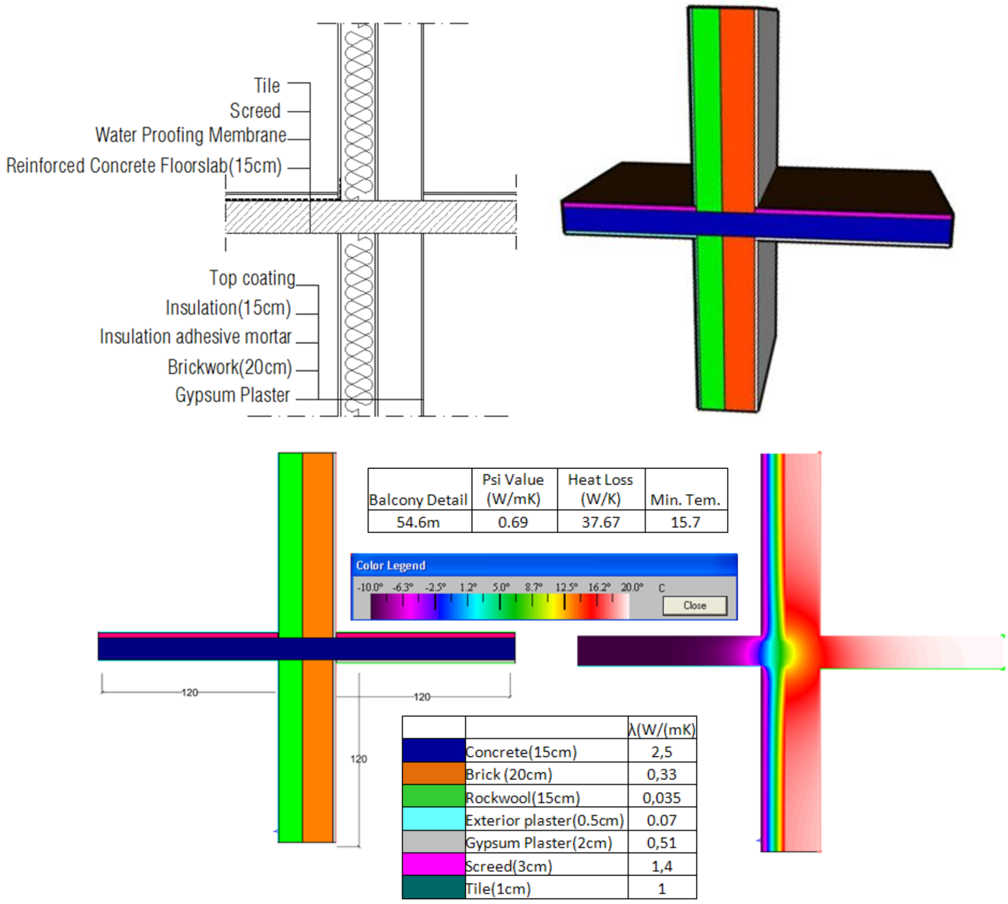


Figure 4.19 Roof detail in the Passive House Building

Roof detail of the baseline building is presented in Figure 4.19. A psi value of 0.16 W/mK is found for the above mentioned detail. Since the continuity of the thermal envelope is disrupted by concrete ceiling, a thermal bridge free design is not achieved. The length of the thermal bridge is 32.1m. It is found that 5.13 W/K heat losses occur through the thermal bridges. Minimum surface temperature is 16.2ºC on the internal wall surface. f Rsi is 0.87. Since the minimum surface temperature is higher than 12.6 ºC, there is not a risk of mold growth.

Balcony Details

To reduce the effects of the thermal bridges, various methods can be applied such as using insulation above and below the slab for a certain distance or thermal break elements that are comprised of insulation can be a solution.

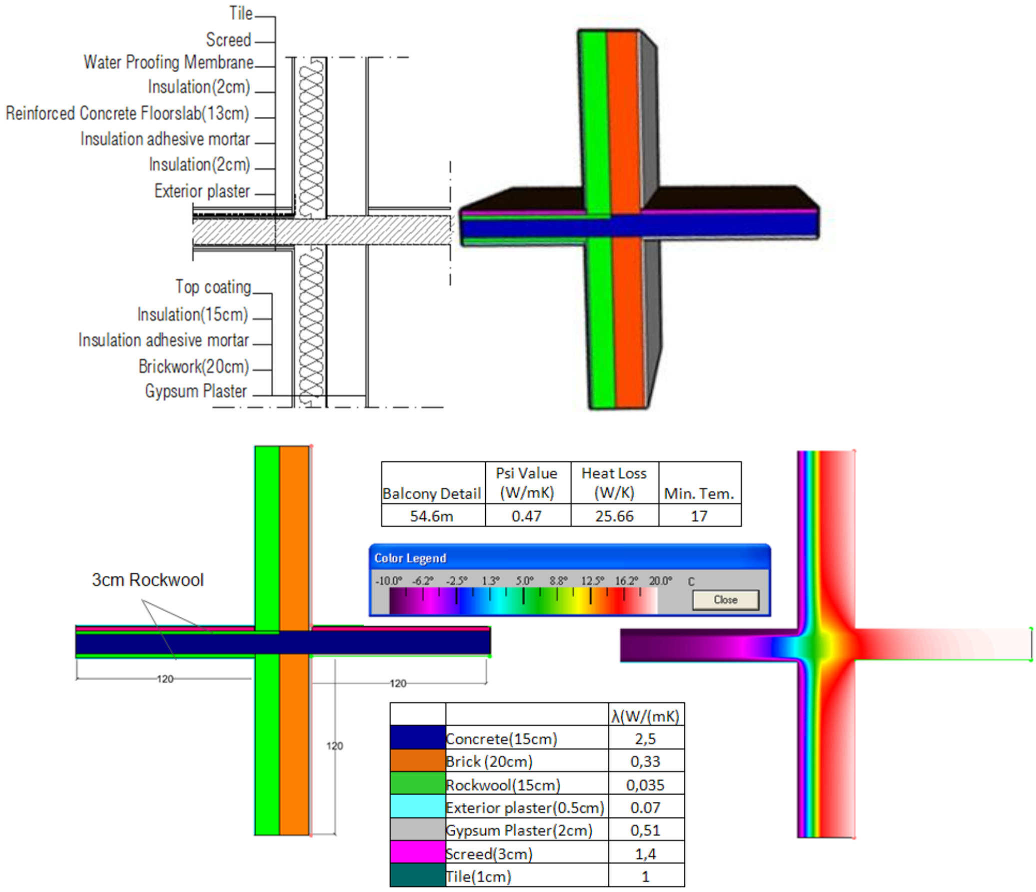


Balcony Detail	Psi Value (W/mK)	Heat Loss (W/K)	Min. Tem.
54.6m	0.69	37.67	15.7

		λ(W/(mK)
	Concrete(15cm)	2,5
	Brick (20cm)	0,33
	Rockwool(15cm)	0,035
	Exterior plaster(0.5cm)	0.07
	Gypsum Plaster(2cm)	0,51
	Screed(3cm)	1,4
	Tile(1cm)	1

Figure 4.20 Balcony Detail Variation 1

First variation of balcony for the Passive House Building is presented in Figure 4.20. Not any additional measures are applied to the balcony in this detail except from using 15 cm thick external wall insulation. A psi value of 0.69 W/mK is found for the above mentioned detail. The length of the thermal bridge is 54.6 m. It is found that 37.67 W/K heat losses occur through the thermal bridges. Minimum surface temperature is 15.7ºC on the internal wall surface. f_{Rsi} is 0.83.



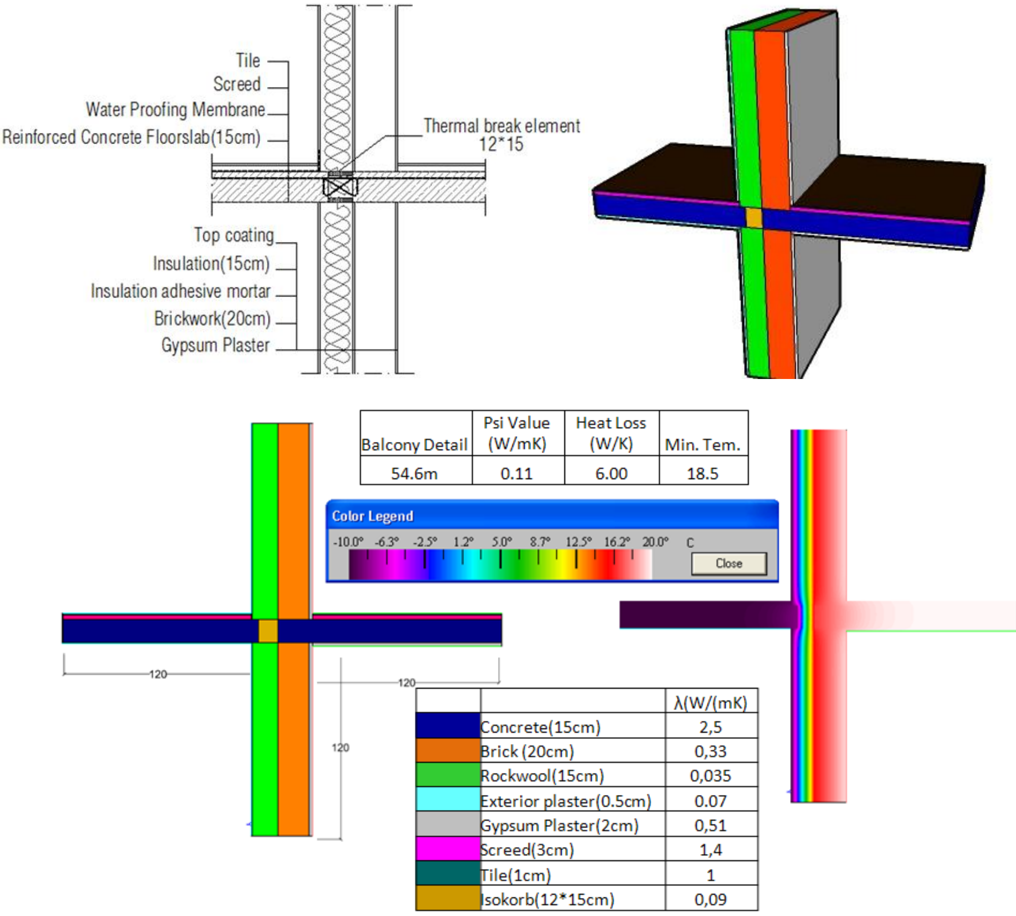
Balcony Detail	Psi Value (W/mK)	Heat Loss (W/K)	Min. Tem.
54.6m	0.47	25.66	17

		λ(W/(mK)
	Concrete(15cm)	2,5
	Brick (20cm)	0,33
	Rockwool(15cm)	0,035
	Exterior plaster(0.5cm)	0.07
	Gypsum Plaster(2cm)	0,51
	Screed(3cm)	1,4
	Tile(1cm)	1

Figure 4.21 Balcony Detail Variation 2 (below and above slab insulated)

Second variation of balcony for the Passive House Building is presented in Figure 4.21. In this detail, the balcony is insulated above and below the slab. It is proposed to reduce the balcony thickness to an acceptable amount to apply insulation. A psi value of 0.47 W/mK is found for the above mentioned detail. The length of the thermal bridge is 54.6 m. It is found that 25.66 W/K heat losses occur through the thermal bridges. Minimum surface temperature is 17ºC on the internal wall surface.

f_{Rsi} is 0.88.



Balcony Detail	Psi Value (W/mK)	Heat Loss (W/K)	Min. Tem.
54.6m	0.11	6.00	18.5

	λ(W/(mK)
Concrete(15cm)	2,5
Brick (20cm)	0,33
Rockwool(15cm)	0,035
Exterior plaster(0.5cm)	0.07
Gypsum Plaster(2cm)	0,51
Screed(3cm)	1,4
Tile(1cm)	1
Isokorb(12*15cm)	0,09

Figure 4.22 Balcony Detail Variation 3(with thermal break element)

Third variation of balcony for the Passive House Building is presented in Figure 4.22. In this detail, a thermal break element which is comprised insulation and low conductance material post-tensioning cables that can tie the exterior structure to the interior structure is used. Various branded systems are developed to reduce the impacts of thermal bridges. A psi value of 0.11 W/mK is found for the above mentioned detail. The length of the thermal bridge is 54.6 m. It is found that 6 W/K heat losses occur through the thermal bridges. Minimum surface temperature is 18.5ºC on the internal wall surface. f_{Rsi} is 0.94.

Results for the heat loss through thermal bridges and minimum surface temperatures can be seen in Figure 4.23. According to the results, to reduce thermal bridge heat losses, it is crucial to develop a detail presenting continuity of the insulation. At floor slab and interior wall detail, since the continuity of the insulation is provided and because of the geometry, thermal bridge heat losses are reduced easily.

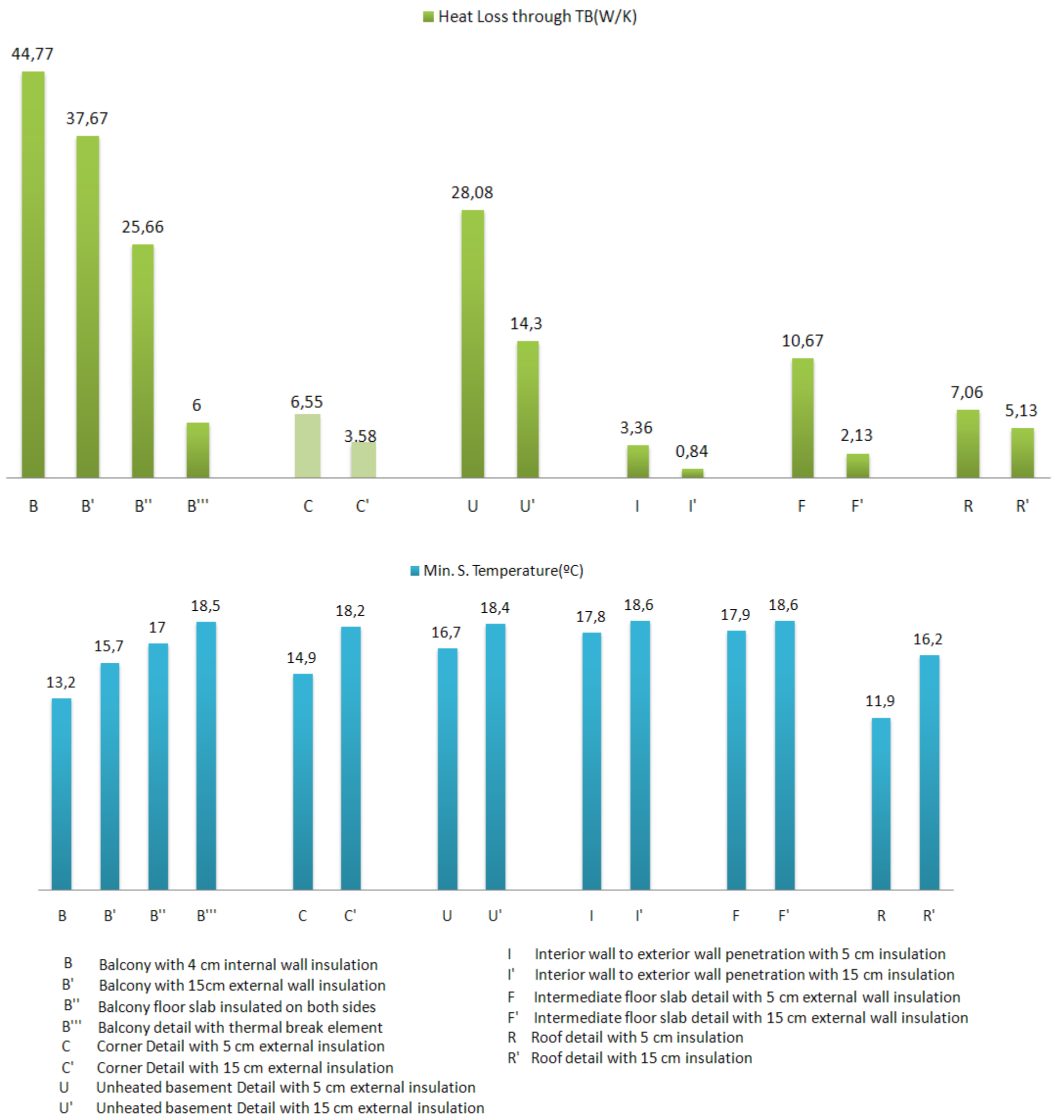


Figure 4.23 Evaluation of Heat Loss through Thermal Bridges and Minimum Surface Temperatures

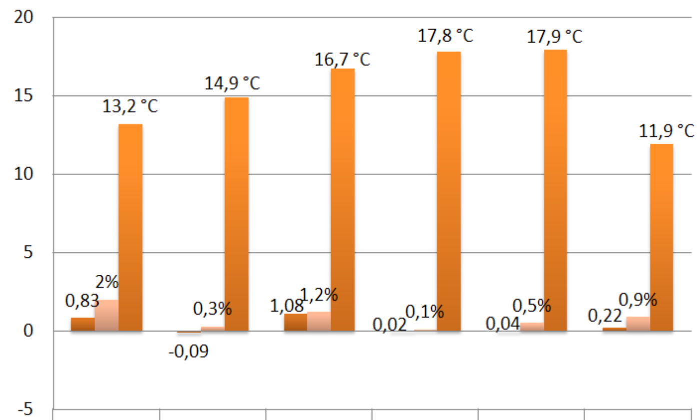
However, details such as balcony, unheated basement wall, roof overhang details require special attention to obtain thermal bridge free design. In these details, the insulation is disrupted by the concrete floor slabs. The results indicate that, improving thermal envelope has a positive impact on increasing minimum surface temperatures of walls.

4.3 Comparison of the Results

The results of the psi values, minimum surface temperatures of the walls and the fraction of transmission heat losses (P1) of the baseline building can be seen in Figure 4.24 and the same results for the Passive House case can be seen in Figure 4.25. Large positive psi values represent the worst performance.

It is seen that in the baseline building details which are insulated poorly, the psi values are higher than Passive House building details. Lower minimum surface temperatures can be seen in all of the baseline building details compare to the Passive House details. Fraction of the transmission heat losses is highest in the balcony (except the detail with thermal break element), unheated basement wall and roof detail both for the baseline building and the Passive House building.

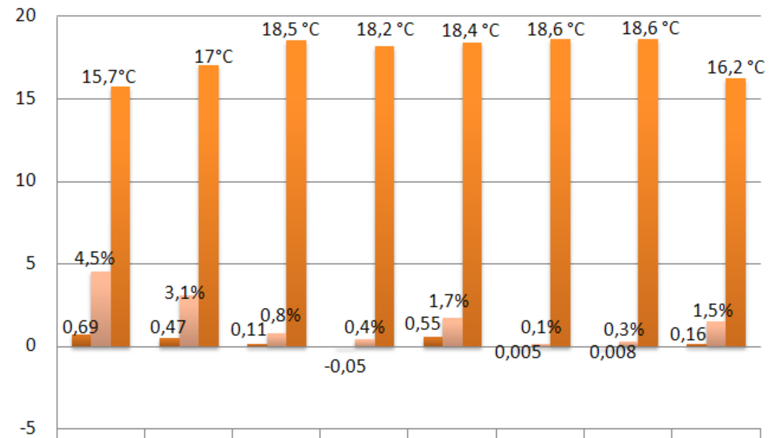
In the baseline building details, thermal bridge free design criteria of PHI is achieved only in the corner detail. Low minimum surface temperatures are observed especially in the balcony, corner and roof detail. Assuming that interior air temperature is 20 ºC at 65% relative humidity, mold growth may occur in the balcony and roof details since the minimum surface temperatures are relatively low which may lead to higher relative humidity on these surfaces. Moisture condenses out on the surface of the coldest wall surfaces in these places and this moisture provides a matter for the mold growth. Compare to the other evaluated details, balcony is the place where the weight of transmission heat losses is the highest.



	B	C	U	I	F	R
Psi value (W/mK)	0,83	-0,09	1,08	0,02	0,04	0,22
P1(%)	2	0,3	1,2	0,1	0,5	0,9
Min. S. Temperature(ºC)	13,2	14,9	16,7	17,8	17,9	11,9

B Balcony with 4 cm internal wall insulation
C Corner Detail with 5 cm insulation
U Unheated basement Detail with 5 cm insulation
I Interior wall to exterior wall penetration with 5 cm insulation
F Floor slab detail with 5 cm insulation
R Roof detail with 5 cm insulation
P1 Fraction of transmission heat losses

Figure 4.24 Evaluation of the Psi values, minimum surface temperatures and the fraction of transmission heat losses of the baseline building details



	B'	B''	B'''	C'	U'	I'	F'	R'
Psi value (W/mK)	0,69	0,47	0,11	-0,05	0,55	0,005	0,008	0,16
P1(%)	4,5	3,1	0,8	0,4	1,7	0,1	0,3	1,5
Min. S. Temperature(ºC)	15,7	17	18,5	18,2	18,4	18,6	18,6	16,2

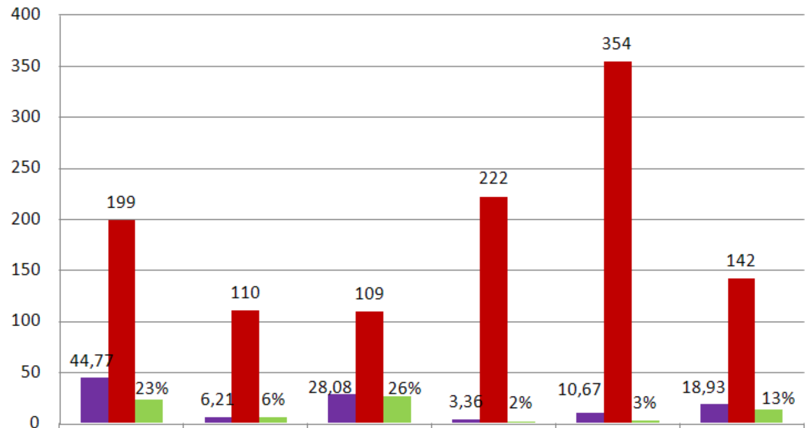
B' Balcony with 15 cm external wall insulation
B'' Balcony floorslab insulated on both sides
B''' Balcony detail with thermal break element
C' Corner Detail with 15 cm external insulation
U' Unheated basement Detail with 15 cm external insulation
I' Interior wall to exterior wall penetration with 15 cm insulation
F' Intermediate floor slab detail with 15 cm external wall insulation
R' Roof detail with 15 cm insulation
P1 Fraction of transmission heat losses

Figure 4.25 Evaluation of the Psi values, minimum surface temperatures and the fraction of transmission heat losses of the Passive House details

In the Passive House building details, thermal bridge free design criteria of PHI is fulfilled in the corner detail, as well as in the interior wall to exterior wall penetration detail and in the intermediate floor slab detail. The additional measures are not enough to fulfill thermal bridge free design criteria in balcony details. On the other hand, the psi value is greatly reduced with the use of a thermal break element in the balcony. In addition to that, the minimum surface temperature of the wall was increased significantly. By applying an accompanying insulation at the unheated basement wall, a thermal bridge free design is not achieved, however the psi value of the detail is reduced 49% by improving the thermal envelope. By using an insulation layer along the roof overhang, a thermal bridge free design is not achieved, but the psi value of the detail is reduced 27%.With the improvement of the details, the minimum surface temperatures of the walls are significantly increased especially in the balcony, corner and roof (more than 3ºC). The minimum surface temperature is increased on the unheated basement walls from 16.7ºC to 18.4ºC. On the other two details, 0.7 ºC minimum surface temperature increase is seen. If there are not any additional measures taken to reduce balcony thermal bridges, the fraction of the transmission heat losses becomes the highest in the balcony.

The results of heat loss through thermal bridges, total fabric conduction heat losses through the details and percentage of the thermal bridge heat losses of the baseline building and the Passive House can be seen in Figure 4.26 and Figure 4.27 respectively.

The results indicate that heat loss through the thermal bridges is higher in the entire baseline building details than the Passive House building details. If the thermal properties of the thermal envelope is improved and a thermal break element is used; total fabric conduction heat losses through the balcony is reduced 70 % in the Passive House building. In addition to that, the heat loss through thermal bridges share higher percentage in the Passive House building than in the baseline building details except intermediate floor slab detail and interior wall to exterior wall penetration and balcony with thermal break element. It means that disruption of thermal insulation results in higher percentage of thermal bridge losses.

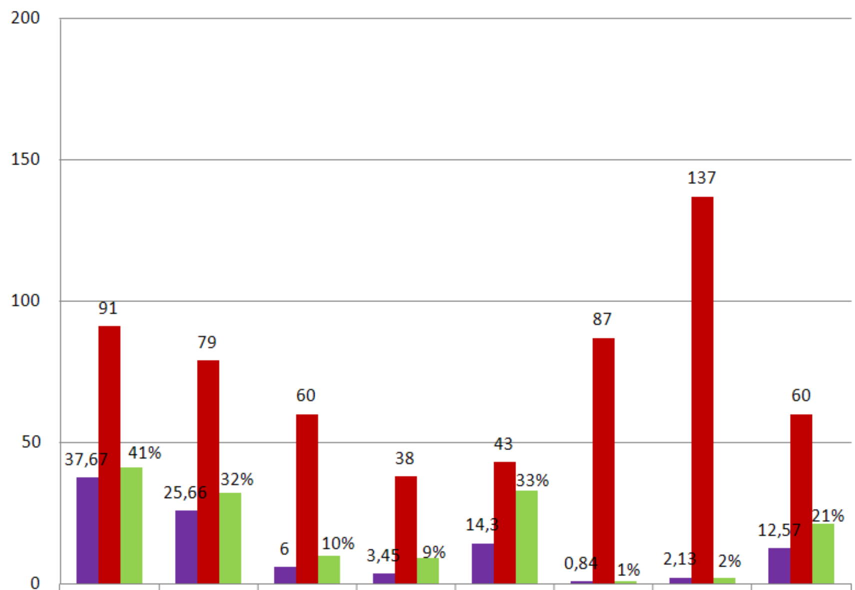


	B	C	U	I	F	R
■ Heat Loss through TB(W/K)	44,77	6,21	28,08	3,36	10,67	18,93
■ H_T(W/K)	199	110	109	222	354	142
■ P2(%)	23	6	26	2	3	13

B Balcony with 4 cm internal wall insulation
C Corner Detail with 5 cm external insulation
U Unheated basement Detail with 5 cm external insulation
I Interior wall to exterior wall penetration with 5 cm insulation
F Intermediate floor slab detail with 5 cm external wall insulation
R Roof detail with 5 cm insulation

*Ht: Total fabric conduction heat loss, P2: Percentage of heat loss through thermal bridges

Figure 4.26 Additional factors studied in the baseline building



	B'	B''	B'''	C'	U'	I'	F'	R'
■ Heat Loss through TB(W/K)	37,67	25,66	6	3,45	14,3	0,84	2,13	12,57
■ H_T(W/K)	91	79	60	38	43	87	137	60
■ P2(%)	41	32	10	9	33	1	2	21

B' Balcony with 15 cm external wall insulation
B'' Balcony floorslab insulated on both sides
B''' Balcony detail with thermal break element
C' Corner Detail with 15 cm external insulation
U' Unheated basement Detail with 15 cm external insulation
I' Interior wall to exterior wall penetration with 15 cm insulation
F' Intermediate floor slab detail with 15 cm external wall insulation
R' Roof detail with 15 cm insulation

*Ht: Total fabric conduction heat loss, P2: Percentage of heat loss through thermal bridges

Figure 4.27 Additional factors studied in the Passive House building

In the baseline building, balcony, unheated basement wall and roof detail are the details respectively where the most of the heat losses through thermal bridges occur. Intermediate floor slabs, interior wall to exterior wall penetrations and balconies are the places where total fabric conduction heat losses mostly occur respectively. 26% of the total fabric conduction heat losses in the unheated basement wall occur due to the thermal bridges. This rate is 23% for the balcony and 13% for the roof detail.

In the Passive House building, if there is no additional measure taken to reduce balcony thermal bridges, the heat losses through that thermal bridge becomes the highest compare to the other details. If a thermal break element is used to reduce balcony thermal bridges, the highest heat losses due to the thermal bridges occur in the unheated basement wall and roof respectively. Intermediate floor slab details, interior wall to exterior wall penetrations are the places where the highest total fabric conduction heat losses occur respectively compare to the other tested building parts. 41% of the total fabric conduction heat losses in the balconies occur due to the thermal bridges if there is no measure taken to reduce thermal bridges. This rate is 33% for the unheated basement wall and 32% for the balcony variation in which the floor slab is insulated above and below the slab to reduce thermal bridges. 21% of the total fabric conduction heat losses in the roof occur due to the thermal bridges. All of the details had higher minimum temperature factors than 0.7, which means that the mold growth and condensation would not occur.

4.4 Constructability of the Proposed Case

To test the constructability of the proposed case (a tunnel formwork social housing unit with 15cm external wall insulation), a face to face interview was conducted with the Project Manager of MESA Group. MESA is a construction company which was established in 1969 in order to construct large-scale housing developments in Turkey and abroad.

The interview was structured in two parts. Firstly, six questions were asked about the insulation applications and thermal bridges. Secondly, the interviewee was asked to evaluate the proposed details one by one in terms of their constructability. The interview can be viewed in more detail in Appendix C.

4.4.1 Thick Insulation in Tunnel Formwork Constructions

The interviewee told that the external walls of one of the tunnel formwork social housing projects in Ankara that was completed by the firm in 2011 had 10cm thick rock wool insulation. Also external walls of Turkish Contractors Association Building in Ankara which was completed in 2013 had 10 cm thick rock wool insulation. This building is an example of an energy efficient building and candidate of LEED Gold Certificate. Since the anchors installed in the concrete and the masonry walls were different in this project (type and size), they had difficulty finding necessary products and had to import some of the products from abroad. There was a delay in the transportation of their order.

There were problems sometimes to ensure the perpendicularity of the external wall surfaces. Therefore the interviewee said that to check the accuracy of the applications at the construction site was very necessary especially in high rise buildings. The interviewee was involved with in a tunnel formwork project abroad, where external walls had 15cm thick insulation. Considering this work experience abroad, the interviewee did not think that to install thicker insulations would be a problem in terms of constructability and structural point of views.

Since the insulation is heavier, in addition to the cost of insulation, the cost of the anchors and the cost of labor (25%) would also increase.

4.4.2 Precautions Taken to Reduce Thermal Bridges in Tunnel Formwork Projects

The interviewee explained that most of the time they take measures in their projects to eliminate thermal bridges. But there are also times that they ignore it. The company had a Research and Development Group until 2002, which was working on the thermal insulation applications with cost comparison, condensation problems and the occupant comfort in tunnel formwork buildings constructed by them.

The interviewee gave some examples of the measures that they had taken to eliminate thermal bridges before. In the first tunnel formwork projects, the company installed 5cm Herapor on the concrete and precast walls internally which is an insulation board made of expanded polystyrene and coated with wood wool cement boards. But it was seen that the material was broken into pieces during the installation and the thermal bridges were not eliminated. Therefore they stopped using it. Later 5 cm foamed polystyrene was installed internally. Although this method produced much better results, there were still thermal bridges at the floor slabs and the leakage problems. After that, it was seen that the installation of the insulation externally eliminated thermal bridges and leakages. Therefore to install insulation externally was a method which had been used for a long time to eliminate thermal bridges, reduce condensation problems, leakages and operating costs by the company.

4.4.3 Evaluation of the Constructability of the Proposed System

The interviewee thought that all the details were constructable. However, use of a thermal break element to reduce balcony thermal bridges was open to discussion. He said that, firstly, an opinion of a structural engineer was necessary. After that, economics of scale was an important factor. He had concerns about whether the installation of a thermal break element can be fast at the construction site.

It was seen that this technology had been suggested a solution for thermal bridges in tunnel formwork projects by the former research group of MESA MESKEN in 1996. But it was cited that a cost comparison for the various applications was crucial.

The interviewee proposed to install different anchor elements in the concrete and the brick during insulation installations. The interviewee told that the insulation is extended 60 cm from the top of the ceiling to the bottom on the unheated basement walls in their projects (In the detail, the insulation is extended 100 cm). As a result of the noise complaints from the occupants, 3 cm rock wool was installed on the reinforced concrete floor slab for sound insulation for the last 4 or 5 years. To eliminate thermal bridges at roof overhang, they did not install insulation at the front of the concrete slab, but it was installed at a certain distance (60cm) at the bottom of the slab. And then the detail was completed with another material (but not with the insulation, since it is more expensive). At the balcony, they installed only at the bottom of the floor slab to reduce thermal bridges. But sometimes they ignored balcony thermal bridges and did not take any measure.

4.5 Cost Evaluation of the Proposed Case

Since cost is one of the most important factors in determining the selection of the applied system, a cost comparison is made between the proposed cases and the baseline case. Payback period is calculated simply assuming that the annual cash flows are equal. The initial investment cost of the external wall insulation and annual operating savings of the heating system are calculated for each of the cases as it can be seen in Figure 4.28. Initial investment cost of the baseline building‟s external wall insulation is lower, which is 4,265 TL per dwelling. Option 1 represents the case where there were no additional measure taken to reduce balcony thermal bridges. In this case, the installation of 15 cm external wall insulation on the external walls cost 12,594 TL per dwelling. Option 2 represents the case, where balcony floor slabs are insulated above and below the slab. In this case, the investment cost for external wall insulation is 13,025 TL per dwelling. Option 3 is the case, where in addition to the insulation; thermal break element is installed. In this case, the initial investment cost is 13,771 TL. However, when the annual operating savings are taken into account, it can be seen that the expenses of baseline building for first investment and operation costs in 50 years are much more expensive than other options. Option 1 and 2 start to payback after 13 years and 14 years respectively, and Option 3 starts to payback after 15 years.

The difference in annual heating demands, minimum surface temperatures of the walls at balcony details, first investment costs and annual operation costs per dwelling can be seen in Table 4.2. The unit prices of electricity and natural gas are 0.35 TL/kWh and 0.10 TL/kWh respectively (TUIK, 2013). To calculate the investment cost of insulation, the unit prices are taken from Izocam. The unit price of the thermal break element is taken from Schöck Isokorb. The unit prices used in the calculations as well as quantity of the proposed materials can be found in Table D.1 of Appendix D. Although applying less insulation thickness gives cheaper initial investment cost, increasing the insulation thickness results in a cost effective reduction in the heating energy demand. Therefore, increasing insulation thickness is more advantageous in the long term. To insulate the balcony floor slabs above and below the slab ensures better indoor conditions and the initial investment cost does not differ much from the non-insulated case. Thus it can be seen as an optimal solution to eliminate thermal bridges. To use a thermal break element gives the best results in terms of improvement of thermal properties of the envelope and indoor air conditions. However it is the most expensive solution.

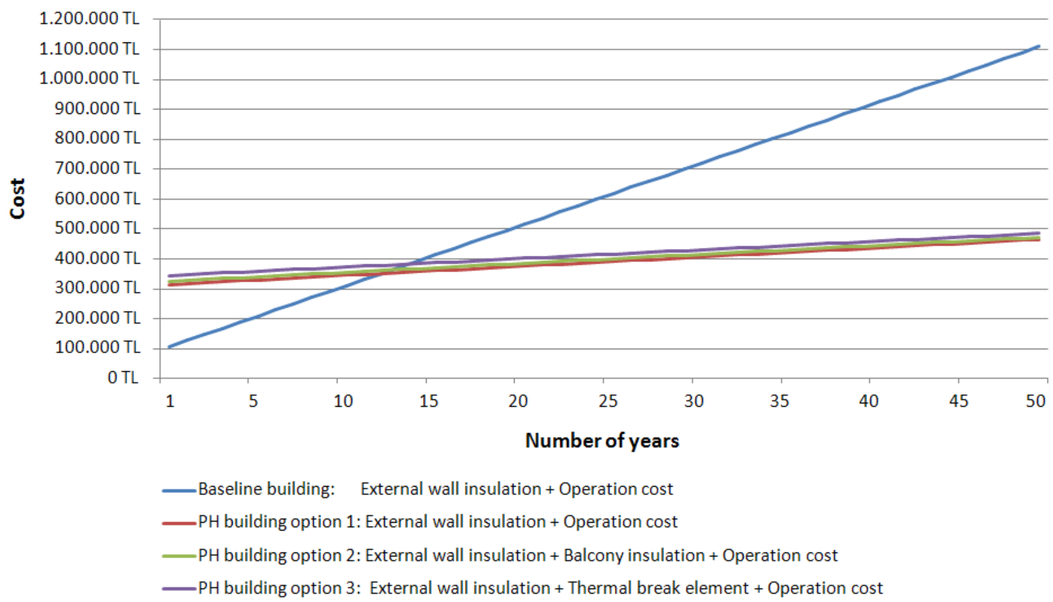


Figure 4.28 Cost comparison of building variations

Table 4.2 Evaluation of the various options

Building	Detailing	Annual Heating Demand kWh/(m²a)	Min. Surface Temperature at wall on balcony detail	Initial Investment Cost per dwelling (TL)	Annual Heating Operation cost per dwelling (TL)
Option 1	15 cm external wall insulation	15,9	15,7ºC	12.594 TL	123
Option 2	15 cm external wall insulation+3 cm insulation above and below the balcony slab	15,5	17ºC	13.025 TL	120
Option 3	15 cm external wall insulation+ thermal break element	14,9	18,5ºC	13.771 TL	115
Baseline	5 cm external wall insulation	84,2	13,2ºC	4.265 TL	819

CHAPTER 5

CONCLUSION

In this study, firstly, energy demand of a 6 storey tunnel formwork social housing unit in Ankara was estimated using PHPP (2012). The effect of various thermal bridges, on the energy efficiency of the baseline building was evaluated through Therm 6.3 Simulations. Later on, Passive House principles were applied to the building also to see if it was possible to reach one of the leading standards in energy efficiency. According to the PHPP simulations, 15 cm insulation thickness was found and various details were proposed for the formerly studied thermal bridges. Six thermal bridges, including balcony, roof, corner, unheated basement wall, intermediate floor slab and penetration of interior wall to exterior wall were tested for the baseline building case and Passive House case. To test the constructability of the details in a tunnel formwork social housing unit, a face to face interview was conducted with the Project Manager of the MESA Group that was a company constructing large-scale housing developments in Turkey and abroad. A simple cost comparison was made considering the external wall insulations, operating costs, and various applications to eliminate balcony thermal bridges in Passive House building. At the end, the impacts of thermal bridges in the baseline building and in the Passive House building were compared.

5.1 Savings through applying Passive House Standard

In this study, 15cm Rockwool external wall insulation, triple glazed windows with Argon filling, super insulated window frames, highly efficient MVHR unit, heating with air-source heat pump (COP:4) were applied to the baseline building. Assuming that the building is thermal bridge free, the Passive House Standard could be met in the tunnel form housing unit in Ankara. 82% and 73% reductions could be achieved respectively in annual heating demand and in heating load of the case building. In addition to that 57% reduction in primary energy demand which covers the space heating, cooling, DHW and household electricity and 53% reduction in the CO_2 emissions could be obtained. Applying Passive House principles to the case building, the cooling load, cooling demand and the frequency of overheating were increased. However, use of passive measures such as temporary shading and night time cooling was enough to meet the comfort requirement of the Standard. Since the space heating and cooling requirements are extremely low in Passive House Standard and energy efficiency is encouraged across all systems and appliances, to achieve net zero energy buildings with help from on site renewable energy sources could be easier.

Evaluating only six thermal bridges in the building, it was possible to achieve Passive House Standard for each three cases. However, if the entire thermal bridges in the building were taken into account, some changes in the passive design or the other components of the building could be necessary. Because the heating demand of the building slightly increased depending on the selected details. Therefore architectural detailing has an important impact to reach the target values of Passive House Standard.

5.2 Construction of a Passive House in Turkey

Due to the inefficiencies in regulations, implementations and examinations on energy efficiency, energy efficient building design is not a main issue as it is in European Union in Turkey. Public authorities have a key role in increasing the energy performance of buildings in this respect. Considering international examples, Turkish government can create future targets to cut excessive energy demand of buildings by working on a national energy efficient building standard. In order to do that, firstly the energy demand of the existing buildings should be studied in depth. This would require a comprehensive research on various topics such as Turkish building traditions, culture, and current energy performance of households or HVAC system, etc. To strengthen the reliability of the results, developing software based on the life style of Turkish culture and energy performance of building components, HVAC systems and households in Turkey is highly essential.

To test the real amount of savings by applying energy efficiency standards such as Passive Houses, pilot projects should be delivered taking into account the local climate and traditions. After completing such projects, monitoring is highly crucial in terms of sharing positive experience of living in the energy efficient buildings. If the adaptation of an international standard to Turkish climate or region is not successful in terms of intended amount of energy savings, internal comfort or cost optimization, to record all experiences learned from the project is important to prevent future application failures. This study shows that Passive House Standard can be met in a TOKİ social housing unit in Ankara and this would significantly reduce especially the heating demand of the buildings. However, to reach the target efficiency levels mentioned previously is possible if all the parties involved in the project including contractor, architect, engineer, manufacturer and tradesperson have the right skills.

While reducing the operational energy demand of buildings, it is very important to put emphasis on the embodied energy of the proposed building construction. Selection of the building materials such as insulation type and construction system, building systems such as heating type have direct impact on the life cycle energy of the buildings. Materials of the structural system such as concrete, wall filling such as brick and insulation materials are consumed in very large quantities. Thus to prefer natural materials to heavily processed ones, would have less environmental impacts and lower embodied energy. In this study, when selecting the exterior insulation material, the embodied energy of the materials was taken into account regarding a previous research. However, a much more comprehensive study is necessary to show the environmental impacts of the whole selected system.

Turkey is one of the countries presenting the lowest national shares of high-tech sectors in total employment. Construction of energy efficient buildings such as Passive Houses introduces modern technologies and innovative solutions in practice especially to the countries where these technologies are not widely used. Especially in countries where energy efficiency is a new issue such as in Turkey, to ensure predicted energy savings, using certificated building components becomes crucial. During this study, there were no local products providing the high thermal performance specifications of Passive House suitable equipments such as window frames and ventilation units. Therefore production of those components is highly essential. By inciting the local companies manufacturing the aforementioned products, new employment and investment sectors can be settled and the public awareness of the energy efficiency can be increased.

To prove the air tightness level of the building with an air tightness test is one of the principles of the Passive House Standard. Currently there are no obligatory regulations for air tightness levels of buildings in Turkey. There are also no studies addressed the air tightness levels of existing buildings in the country. In this study, the air tightness level is assumed to reach the required level. However, quality of workmanship is a factor effecting the air tightness of the buildings necessarily. Poor quality workmanship is one of the problems of the construction industry in Turkey, causing great spending of money, time and resources. Since construction of Passive Houses requires high quality workmanship, to achieve the required energy efficiency and comfort levels, it is very important to put effort on this issue.

This study indicated that to meet Passive House Standard in the case study building was possible with a minimum of 15 cm insulation (lambda value of 0,035 W/mK) based on PHPP calculations. At first sight there might be concerns about the excessive insulation thickness in terms of constructability also between construction professionals. Thus, it is important to increase the awareness about energy efficiency targeting the lack of specialized knowledge among construction professionals and public by delivering catalogues including various details with their construction process.

Moreover, selecting thicker insulations will require new insulation accessories such as longer size anchors and plinth profiles. To apply those thicker insulations on a tunnel formwork building would demand different anchor types for concrete surfaces. Since the applied insulation thickness to the buildings in Turkey currently is much lower than the Passive House Buildings, to find suitable equipment and technologies for Passive House construction can be difficult at the first stage in terms of supply of those products. However with the wider acceptance of the new construction approaches, to reach those products will be possible.

5.3 Evaluation of the detailing of the Baseline Building

Considering the whole existing building design, the baseline building can be regarded as positive in terms of its compactness ratio. The thermal insulation system was applied externally in the majority of the building, which is an important factor to avoid thermal bridges. However, it was seen that the continuity of the insulation was disrupted at various parts in the building such as at the roof, balcony, unheated basement wall and foundation which will cause thermal bridges. If the building regulations include methods in order to avoid thermal bridges in terms of construction detailing, thermal bridges can be avoided much more easily in the design stage of buildings.

As long as the passive design principles such as building orientation, form, thermal properties exterior building envelope, shading etc. are not taking into account considering the climate, the capacity needed for the active systems such as heating, cooling or ventilation would increase. Therefore, to give importance to the passive design strategies in order to reduce the energy consumption of active systems is necessary in general in Turkey. In that sense, traditional architecture can give good examples in the guidance of sustainable building design, material selection, and construction techniques.

In the baseline building, where the insulation was poorer than Passive House building, the impact of thermal bridges, as the percentage of the total annual heating demand, was small (5%). In this study, only six thermal bridges were studied. Once the construction of a building is completed, the elimination of thermal bridges is very difficult. Thermal bridge simulations enable to detect the problematic areas where mold growth or condensation might occur in the building junctions. Therefore to support the detailing process of building junctions by dynamic simulation tools can help to avoid the unintended consequences such as deterioration of indoor air quality, additional cost and waste of time.

Considering the thermal bridges, it was seen that poorly insulated details, had higher psi values. Unheated basement wall had the highest psi value in the baseline building. As previously stated, İZODER TS 825 Calculation Software includes default values for thermal bridges. Detailed analysis in construction design can be removed by using those default values for thermal bridges. Therefore, using a list of thermal bridges would save time. Nevertheless, if a thermal bridge has different properties, it can result in an over or under estimate of the thermal bridge. Accordingly, to prevent wrong calculations, technical guides explaining how to deal with thermal bridge calculations would be useful. Since the heat losses through thermal bridges at the unheated basement wall was very crucial, to study unheated basement wall thermal bridges and calculate a default value for this detail is important.

Balconies, unheated basement walls and roof were some of the junctions where the continuity of the insulation was disrupted. Consequently, heat losses through thermal bridges were highest in these parts. Lower minimum surface temperatures were seen in all of the baseline building details compare to the Passive House details which would be uncomfortable to the building occupants. Roof, balcony and corner details were the places where minimum internal surface temperatures were lowest respectively. Except internal wall and floor slab detail, the difference between the minimum surface temperatures and the interior temperature was more than 3ºC in all of the details. This result implies that the current condition of the baseline building does not meet the TS 825 Regulation requirement in terms of mold growth and internal comfort point of view. When the results compared taking into account dew point temperature, the minimum surface temperatures are lower than the dew point in the balcony and roof detail which cause condensation.

Highest linear thermal transmittance values were found for unheated basement wall, balcony and roof respectively. Total fabric conduction heat losses were highest at the floor slab and interior exterior wall penetrations, since these details were repeated quiet often. 23% of the total fabric conduction heat losses in the balconies occurred due to the thermal bridges. This rate was 26% for the unheated basement wall and 13% for the intermediate floor slab detail.

5.4 Evaluation of the detailing of Passive House Building

As properties of the thermal envelope were improved, the impact of thermal bridges was also increased obviously (14%). Therefore, in energy efficient building design such as Passive Houses, on which the interest is increasing day by day, to address thermal bridging, will become more crucial in the future. As a result, architectural detailing will be more important in order to deal with thermal bridges, to reach the required efficiency levels, to improve thermal comfort of occupants and to avoid moisture issues. Applying the systems mentioned in previous sections, the details were made using in general 15 cm insulation thickness in the Passive House case. The thermal bridge calculations are carried out assuming that the indoor temperature is 20°C and the outdoor temperature is -10°C. It is seen that, to reduce the heat loss through thermal bridges until it becomes negligible in the Passive House, it is necessary to develop new construction details especially for the balcony, roof and unheated basement wall.

5.4.1 Balcony floor slab without any thermal bridge measures

By increasing only the external wall insulation thickness at the balconies, minimum surface temperature of the walls increased only 2.5 ºC, from 13.2ºC to15.7ºC. Heat losses through thermal bridges accounted 41% of the total fabric conduction heat losses if there were no additional measures taken to reduce balcony thermal bridges. Just with an improvement on the thermal performance of the external wall, heat losses through thermal bridges reduced 16%.

5.4.2 Balcony floor slab insulated above and below the slab

To insulate balcony floor slab above and below the slab increased minimum surface temperature of the walls from 13.2ºC to 17ºC. Heat losses through thermal bridges account 32% of the total fabric conduction heat losses in this detail. The impact of thermal bridges on annual heating demand could be reduced 2% compare to the first option. Heat losses through thermal bridges reduced 32% compare to the first option.

5.4.3 Balcony floor slab with Thermal break element

Using a thermal break element in balcony made clear benefits on improving the minimum surface temperature of the walls significantly and reducing the heat loss through thermal bridges. The minimum surface temperature was increased from 13.2ºC to 18.5ºC. Heat losses through thermal bridges account 10% of the total fabric conduction heat losses. The impact of thermal bridges on annual heating demand could be reduced to an important extend 6% by using a thermal break element. Heat losses through thermal bridges reduced 84% compare to the first option. However thermal bridge free design criteria of Passive House Standard could not achieved. To construct pre-fabricated steel balconies in case of framing the balcony continuous with the interior floor is a method used to eliminate thermal bridges abroad as it is shown in Figure 5.1. Use of thermal break element is the most expensive solution and it takes two years more to payback compare to the other two cases.

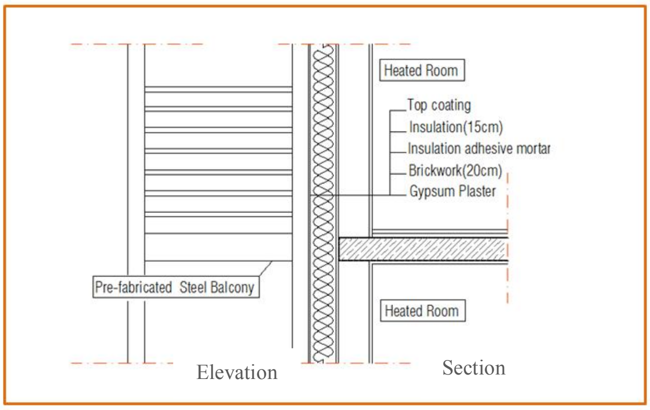


Table 5.1 Pre-fabricated steel balcony

5.4.4 Unheated basement wall detail

To install 15 cm thick insulation on the ceiling and to extend 5 cm thick insulation from top of the ceiling 100 cm to the bottom on both sides of an unheated basement wall would increase the minimum surface temperature from 16.7 ºC to 18.4 ºC. With the improvement of the thermal envelope the heat losses through thermal bridges reduced 50%. However the thermal bridge free designs criteria of Passive House Standard could not achieved. As it was shown in literature in Figure 2.15 and 2.16, foam glass block or cellular lightweight concrete is proposed in connection details to reach thermal bridge free design criteria for such cases.

5.4.5 Corner detail

With the improvement of the thermal envelope, a significant minimum surface temperature could be seen at the corner of the building. The minimum surface temperature was increased from 14.9ºC to 18.2ºC. With the improvement of the thermal envelope the heat losses through thermal bridges are reduced 45% compare to the baseline building. Corner details both in the baseline building and Passive House building represents a thermal bridge free design with a negative prefix.

5.4.6 Roof detail

In addition to the 15cm insulation applied on the roof, 5cm insulation was applied along with the roof overhang. The minimum surface temperature was increased greatly, from 11.9ºC to 16.2ºC. However heat losses through thermal bridges did not reduce very much, only 27%. Thermal bridge free design criteria were not achieved since the insulation was disrupted by the concrete floor slab in the proposed detail. In case of insulating the outside overhang of the roof, to use a detail without an exposed section of the roof overhang as it is presented in Figure 5.2 can be applied.

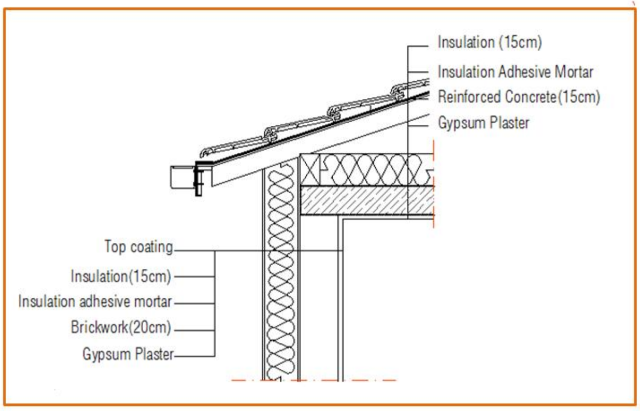


Table 5.2 Roof overhang detail

5.4.7 Intermediate floor slab detail

Application of 15cm thermal insulation on the external wall was enough to reach thermal bridge free design. The minimum surface temperature increased less than 1 ºC, from 17.9ºC to 18.6ºC. However, the heat loss through thermal bridges reduced 80%.

5.4.8 Interior wall to exterior wall detail

Application of 15cm thermal insulation along the external wall was enough to reach thermal bridge free design. The minimum surface temperature also increased less than 1 ºC, from 17.8ºC to 18.6ºC. Meanwhile, the heat loss through thermal bridges reduced 75%.

5.5 Further Research

In this thesis, the impact of thermal bridges on the energy demand of an existing building and Passive House building is investigated using six thermal bridges. Since PHPP only calculate one dimensional heat flows ignoring thermal bridging, additional software is needed to estimate the linear thermal transmittance values. However, Therm 6.3 does not provide the linear thermal transmittance value which is required to calculate thermal bridge heat losses by PHPP. Thus the calculation of linear thermal transmittance of each thermal bridge becomes a time consuming assessment which is not practical in this case. To carry out as accurate analysis as possible, further studies can be done on additional tools or pragmatic approaches to simplify thermal bridge calculations of buildings.

Thermal bridges in the case study building are not limited with the above studied six details. Considering the entire building, more than twenty thermal bridges can be found to compare the effects of the thermal bridges on building energy demand. In the baseline building, thermal insulation was not installed to the foundation and window installations represent a case which is not recommended for energy efficiency. Therefore heat losses through these parts become crucial. Since the calculation methods for foundation and window thermal bridges are different, they are not studied in this thesis. The impacts of foundation and window thermal bridges can be investigated with further studies.

When improving the energy performance of buildings, the importance of reaching cost optimal levels is highlighted in EPBD. In this study, since the main objective of the thesis is different, a simple cost comparison is made considering external wall insulation systems and operating costs. A comprehensive life cycle assessment study can be done in future studies comparing an existing social housing unit and a Passive House social housing unit in Turkey.

In addition to the reducing the operational energy demand of buildings, the embodied energy of the proposed building construction is very important. Studies showing the environmental impacts of applied systems in highly energy efficient buildings should be carried out in future studies.

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APPENDIX A

BASELINE BUILDING INPUTS

Table A.1 DHW consumption of the each dwelling in case study building

House no	Water(m3)
1	235
2	231
3	225
4	252
5	112
6	110
7	99
8	
9	424
10	294
11	366
12	210
13	230
14	202
15	166
16	276
17	25
18	313
19	357
20	423
21	408
22	398
23	82
24	149
Total (for 44 months)	2.010
Average	402
	76lt

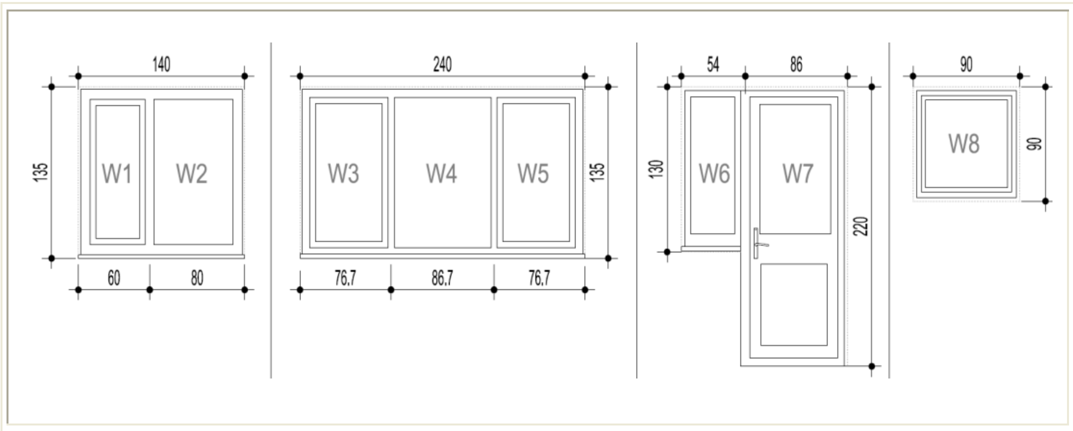


Figure A.1 Window dimensions and types of the case building

Table A.2 Technical specifications of the Heating and DHW system of the baseline building

		Type	Electricity Consumption	Efficiency
Heating System	Central Heating, Boiler(natural gas)	TR 250	350W	94.20%
	Circulation Pump	ALF 40.2A FR	85-550W	
DHW System	Gas Water Heater in each dwelling	C 275 F	73W	84%

Table A.3 Household Electricity Consumptions (Mutlu M. et al.(a.2010)

Baseline Building Household Electricity	**Electricity Consumption**	**Class**
Refrigerator	2,01 kWh/d	C
Dish Washer	1,34 kWh/use	C
Wash Machine	1,01 kWh/use	C
Passive House Household Electricity	**Electricity Consumption**	**Class**
Refrigerator	1,23 kWh/d	A
Dish Washer	1,05 kWh/use	A
Wash Machine	0,95 kWh/use	A

Table A.4 Used values in Thermal Bridge Calculations

Baseline Building Thermal Bridges						İZODER TS 825
	U_{2D}	l_1	l_2	f_{Rsi}	psi	psi
Corner	0,5359	1,485	1,485	0,83	-0,09	-0,05
Unheated basement	1	1,32	1,32	0,87	1,08	-
Interior wall	0,5143	1,32		0,93	0,02	0
Floor slab	0,5098	1,305	1,305	0,93	0,04	0
Roof	0,6596	1,485	1,44	0,73	0,22	0,55
Balcony	0,8712	1,305	1,305	0,13	0,82	0,75
Passive House Building Thermal Bridges						Used value in Therm File
	U_{2D}	l_1	l_2	f_{Rsi}	psi	
Corner	0,1874	1,57	1,57	0,94	-0,05	* total length
Unheated basement	0,4131	1,37	1,37	0,94	0,55	*projected x
Interior wall	0,1965	1,32		0,95	0,005	* total length
Floor slab	0,196	1,305	1,305	0,95	0,008	* total length
Roof	0,2591	1,575	1,52	0,87	0,16	*custom lenght
Balcony'	0,4583	1,305	1,305	0,83	0,692	*projected y
Balcony ''	0,3734	1,305	1,305	0,88	0,47	*projected y
Balcony '''	0,2387	1,305	1,305	0,94	0,118	*projected y

Table A.5 Calculation of lengths of the thermal bridges

Name	Lenght	Height	Number of repeated details	Additional	Total (m)
Balcony	2,6		20		52
Corner		2,77	25		69,25
Unheated basement wall	26		1		26
Interior wall to exterior wall penetration		2,77	61		168,97
Intermediate floor slab	52		5	6,9	266,9
Roof (with brick wall)	7,6		4		32,1
Roof (with concrete wall)	5,8		4		39,2

Figure A.2 Lengths of the thermal bridges

Area input												
Area Nr.	Building element description	Group Nr.	Assigned to group	Quan-tity	x (	a [m]	x	b [m]	+	User-Deter-mined [m²]	-	User Sub-traction [m²]
	Treated Floor Area	1	Treated Floor Area	1	x (		x		+	2189,52	-	
	North Windows	2	North Windows									
	East Windows	3	East Windows									
	South Windows	4	South Windows	Please complete in Windows worksheet								
	West Windows	5	West Windows									
	Horizontal Windows	6	Horizontal Windows									
	Exterior Door	7	Exterior Door	6	x (	1,00	x	2,20	+		-	
1	East Wall to Ambient Air	8	Exterior Wall - Ambient	1	x (		x		+	463,84	-	
2	West Wall to Ambient Air	8	Exterior Wall - Ambient	1	x (		x		+	463,84	-	
3	North Wall to Ambient Air	8	Exterior Wall - Ambient	1	x (		x		+	390,41	-	
4	South Wall to Ambient Air	8	Exterior Wall - Ambient	1	x (		x		+	433,48	-	
5	East Basement Wall to Ambi	8	Exterior Wall - Ambient	1	x (		x		+	5,71	-	
6	West Basement Wall to Ambi	8	Exterior Wall - Ambient	1	x (		x		+	37,16	-	
7	North Basement Wall to Amb	8	Exterior Wall - Ambient	1	x (		x		+	33,95	-	
8	North Basement wall to gro	9	Exterior Wall - Ground	1	x (		x		+	5,53	-	
9	East Basement Wall to unhe	12	Exterior Wall/Floor to Unheated B	1	x (		x		+	41,37	-	2,20
10	West Basement Wall to unhe	12	Exterior Wall/Floor to Unheated B	1	x (		x		+	24,27	-	4,18
11	North Basement Wall to unh	12	Exterior Wall/Floor to Unheated B	1	x (		x		+	9,96	-	
12	South Basement Wall to unh	12	Exterior Wall/Floor to Unheated B	1	x (		x		+	59,26	-	2,20
13	North Wall to unheated sta	14	Exterior Wall to Unheated Stairwe	1	x (		x		+	52,88	-	15,40
14	East Wall to unheated stai	14	Exterior Wall to Unheated Stairwe	1	x (		x		+	84,88	-	
15	West Wall to unheated stai	14	Exterior Wall to Unheated Stairwe	1	x (		x		+	70,60	-	
16	Roof	10	Roof/Ceiling - Ambient	1	x (		x		+	422,28	-	
17	Roof lift	10	Roof/Ceiling - Ambient	1	x (		x		+	28,76	-	
18	Floor slab basement	11	Floor slab / basement ceiling	1	x (		x		+	143,21	-	
19	Floor slab above unheated	12	Exterior Wall/Floor to Unheated B	1	x (		x		+	311,45	-	
20	Exterior Door Basement_90	7	Exterior Door	3	x (	2,20	x	1,00	+		-	
21	Exterior Door Basement_100	7	Exterior Door	1	x (	2,20	x	0,90	+		-	
22	Roof entrance	10	Roof/Ceiling - Ambient	1	x (		x		+	3,61	-	
23					x (		x		+		-	

Figure A.3 Area input of baseline building in PHPP

Length ℓ [m]	Input of thermal bridge heat loss coefficient W/(mK)	Ψ W/(mK)
69,00	Corner 5cm	-0,090
26,00	Unheated basement 5cm	1,080
266,90	Intermediate floor 5cm	0,040
32,10	Roof 5cm_brick	0,220
39,20	Roof 5cm_concrete	0,373
168,36	Interior to exterior 5cm	0,020
54,60	Balcony	0,828

Additional inputs for radiation balance

These columns serve for considering the radiation balance of exterior, opaque surfaces. Inputs only for those surfaces which are adjacent to ambient air! For consideration of heating in Central European climates no input is required.

Exterior absorptivity	Exterior emissivity	Deviation from north	Angle of inclination from the horizontal	Reduction factor shading
0,20	0,90	110	90	0,70
0,20	0,90	290	90	0,70
0,20	0,90	20	90	0,70
0,20	0,90	200	90	0,70
0,20	0,90	110	90	0,70
0,20	0,90	290	90	0,70
0,20	0,90	20	90	0,70
0,00	0,90	20	90	0,70
0,40	0,90	110	90	0,70
0,40	0,90	290	90	0,70
0,40	0,90	20	90	0,70
0,40	0,90	200	90	0,70
0,20	0,90	20	90	0,70
0,20	0,90	110	90	0,70
0,20	0,90	290	90	0,70
0,80	0,90		0	0,70
0,80	0,90		0	0,70
0,00	0,00		0	0,70
0,00	0,00		0	0,70
0,00	0,00		90	0,70
0,00	0,15		90	0,70
0,40	0,90		0	0,40

Figure A.4 Thermal Bridge and radiation balance inputs for baseline building

Wedge shaped building element layers and still air spaces -> Secondary calculation to the right

Building: Toki C Blok

Assembly No. 1 — Building assembly description: Exterior Wall East West — Interior insulation?

Heat transfer resistance [m²K/W] — interior Rsi: 0,13 — exterior R_{se}: 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Gypsum plaster	0,510					20
2.	Brick Masonry	0,360	Concrete	2,500			200
3.	EPS Insulation	0,040					50
4.	Exterior plaster	1,000					15
5.							
6.							
7.							
8.							

Percentage of Sec. 2: 52,1% — Percentage of Sec. 3: — Total: 28,5 cm

U-Value: 0,595 W/(m²K)

Assembly No. 2 — Building assembly description: Exterior Wall South — Interior insulation?

Heat transfer resistance [m²K/W] — interior Rsi: 0,13 — exterior R_{se}: 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Gypsum plaster	0,510					20
2.	Brick Masonry	0,360	Concrete	2,500			200
3.	EPS Insulation	0,040					50
4.	Exterior plaster	1,000					15
5.							
6.							
7.							
8.							

Percentage of Sec. 2: 7,3% — Percentage of Sec. 3: — Total: 28,5 cm

U-Value: 0,520 W/(m²K)

Assembly No. 3 — Building assembly description: Exterior Wall North — Interior insulation?

Heat transfer resistance [m²K/W] — interior Rsi: 0,13 — exterior Rse: 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Gypsum plaster	0,510					20
2.	Brick Masonry	0,360	Concrete	2,500			200
3.	EPS Insulation	0,040					50
4.	Exterior plaster	1,000					15
5.							
6.							
7.							
8.							

Percentage of Sec. 2: 8,1% — Percentage of Sec. 3: — Total: 28,5 cm

U-Value: 0,522 W/(m²K)

Figure A.5 U Value inputs for baseline building in PHPP

Quan-tity	Description	Deviation from north	Angle of inclination from the horizontal	Orientation	Window rough openings	
					Width	Height
		Degrees	Degrees		m	m
2	1FSouthW1	200	90	South	0,600	1,350
2	1FSouthW2	200	90	South	0,800	1,350
2	1FSouthW3	200	90	South	0,767	1,350
2	1FSouthW4	200	90	South	0,867	1,350
2	1FSouthW5	200	90	South	0,767	1,350
2	1FSouthW6	200	90	South	0,540	1,300
2	1FSouthW7	200	90	South	0,860	2,200
2	2FSouthW1	200	90	South	0,600	1,350
2	2FSouthW2	200	90	South	0,800	1,350
2	2FSouthW3	200	90	South	0,767	1,350
2	2FSouthW4	200	90	South	0,867	1,350
2	2FSouthW5	200	90	South	0,767	1,350
2	2FSouthW6	200	90	South	0,540	1,300
2	2FSouthW7	200	90	South	0,860	2,200
2	3FSouthW1	200	90	South	0,600	1,350
2	3FSouthW2	200	90	South	0,800	1,350
2	3FSouthW3	200	90	South	0,767	1,350
2	3FSouthW4	200	90	South	0,867	1,350
2	3FSouthW5	200	90	South	0,767	1,350
2	3FSouthW6	200	90	South	0,540	1,300
2	3FSouthW7	200	90	South	0,860	2,200
1	3FSouthW7	200	90	South	0,900	0,900
2	4FSouthW1	200	90	South	0,600	1,350
2	4FSouthW2	200	90	South	0,800	1,350
2	4FSouthW3	200	90	South	0,767	1,350
2	4FSouthW4	200	90	South	0,867	1,350
2	4FSouthW5	200	90	South	0,767	1,350
2	4FSouthW6	200	90	South	0,540	1,300
2	4FSouthW7	200	90	South	0,860	2,200
1	4FSouthW7	200	90	South	0,900	0,900
2	5FSouthW1	200	90	South	0,600	1,350
2	5FSouthW2	200	90	South	0,800	1,350
2	5FSouthW3	200	90	South	0,767	1,350
2	5FSouthW4	200	90	South	0,867	1,350
2	5FSouthW5	200	90	South	0,767	1,350
2	5FSouthW6	200	90	South	0,540	1,300

Figure A.6 Window inputs for baseline building in PHPP

Height of the shading object	Horizontal distance	Window reveal depth	Distance from glazing edge to reveal	Overhang depth	Distance from upper glazing edge to overhang	Additional shading reduction factor
m	m	m	m	m	m	%
h_{Hori}	d_{Hori}	o_{Reveal}	d_{Reveal}	o_{over}	d_{over}	r_{other}
20,46	46,03	0,18	0,070	0,96	15,190	
20,46	46,03	0,16	0,020	0,98	15,140	
20,46	46,03	0,22	0,060	0,96	15,180	
20,46	46,03	0,21	0,730	0,98	15,193	
20,46	46,03	0,22	0,060	0,96	15,180	
20,46	46,03	0,15	0,050	2,62	15,170	
20,46	46,03	0,11	0,130	2,58	15,250	50%
17,55	46,03	0,18	0,070	0,96	12,280	
17,55	46,03	0,16	0,020	0,98	12,230	
17,55	46,03	0,22	0,060	0,96	12,270	
17,55	46,03	0,21	0,730	0,98	12,283	
17,55	46,03	0,22	0,060	0,96	12,270	
17,55	46,03	0,15	0,050	2,62	12,260	
17,55	46,03	0,11	0,130	2,58	12,340	50%
14,61	46,03	0,18	0,070	0,96	9,370	
14,61	46,03	0,16	0,020	0,98	9,320	
14,61	46,03	0,22	0,060	0,96	9,360	
14,61	46,03	0,21	0,730	0,98	9,373	
14,61	46,03	0,22	0,060	0,96	9,360	
14,61	46,03	0,15	0,050	2,62	9,350	
14,61	46,03	0,11	0,130	2,58	9,430	50%
14,61	46,03	0,32	0,080	6,85	9,850	
11,73	46,03	0,18	0,070	0,96	6,460	
11,73	46,03	0,16	0,020	0,98	6,410	
11,73	46,03	0,22	0,060	0,96	6,450	
11,73	46,03	0,21	0,730	0,98	6,463	
11,73	46,03	0,22	0,060	0,96	6,450	
11,73	46,03	0,15	0,050	2,62	6,440	
11,73	46,03	0,11	0,130	2,58	6,520	50%
11,73	46,03	0,32	0,080	6,85	6,940	
8,82	46,03	0,18	0,070	0,96	3,550	
8,82	46,03	0,16	0,020	0,98	3,500	
8,82	46,03	0,22	0,060	0,96	3,540	
8,82	46,03	0,21	0,730	0,98	3,553	
8,82	46,03	0,22	0,060	0,96	3,540	
8,82	46,03	0,15	0,050	2,62	3,530	
8,82	46,03	0,11	0,130	2,58	3,610	50%
8,82	46,03	0,32	0,080	6,85	4,030	
5,91	46,03	0,18	0,070	0,96	0,645	

Figure A.7 Shading inputs for baseline building in PHPP

Passive House verification

PRIMARY ENERGY VALUE

Building: Toki C Blok

Building Type/Use:	Multi family house	
Treated Floor Area A_{TFA}:	2190	m²
Space Heating Demand incl. Distribution	85	kWh/(m²a)
Useful Cooling Demand:	0	kWh/(m²a)

	PE Value
100%	kWh/kWh
0%	1,1

Condensing boiler gas	
101%	
86,5	95,2
0,0	0,0
86,5	95,2

	PE Value
0%	kWh/kWh
0%	0,7

0%	
0,0	0,0
0,0	0,0
0,0	0,0

	PE Value
0%	kWh/kWh
100%	1,1

water heater gas	
84%	
0,0	0,0
69,3	76,3
0,0	0,0
5,7	6,3
75,0	82,5

Figure A.8 Primary Energy inputs for baseline building in PHPP

		Project Data		Standard Values		Input field
$P_{nominal}$	*(Rating Plate)*	74	kW	74	kW	250
		0		0		
		Project Data		Standard Values		Input field
$\eta_{30\%}$	*(Manufacturer)*	100%		100%		94%
$\eta_{100\%}$	*(Manufacturer)*	94%		94%		95%
$q_{B,70}$	*(Manufacturer)*	0,8%		0,8%		1,4%
$\vartheta_{30\%}$	*(Manufacturer)*	30	°C	30		46
		Project Data		Standard Values		Input field
η_{GZ}	*(Manufacturer)*			60%		
η_{SO}	*(Manufacturer)*			70%		
$z_{HC,m}$	*(Manufacturer)*			0,4		
$\Delta\vartheta$	*(Manufacturer)*		K	30	K	
$A_{install}$	*(Project)*		m²	0	m²	
$Q_{N,GZ}$	*(Manufacturer)*		kWh	111,0	kWh	
$Q_{N,m}$	*(Manufacturer)*		kW	74,0	kW	350,0
$Q_{HE,GZ}$	*(Manufacturer)*		kWh		kWh	
$P_{el,SB}$	*(Manufacturer)*		W		W	

Figure A.9 Heat Generator input for baseline building in PHPP

Month	1	2	3	4	5	6	7	8	9	10	11	12	Heating Load		Cooling Load
Days	31	28	31	30	31	30	31	31	30	31	30	31	Weather 1	Weather 2	Radiation
Ankara	Latitude:	39,9	Longitude ° East	32,8	Altitude m	872		Daily Temperature Swing Summer (K)		13,0	Radiation Data:	kWh/(m²*month)	Radiation: W/m²		W/m²
Ambient Temp	0,2	1,3	5,0	10,1	15,5	19,3	23,6	22,8	17,4	12,0	6,1	1,7	-6,7	-1,4	26,1
North	14	19	28	35	46	55	53	36	28	22	17	14	19	14	71
East	33	45	72	97	121	127	141	125	102	73	48	28	38	20	197
South	87	91	110	105	95	88	100	123	139	144	116	73	95	44	137
West	35	47	74	91	110	127	140	124	98	76	49	33	43	30	189
Global	54	71	121	159	203	225	243	218	165	117	72	47	64	38	328
Dew Point	-3,5	-3,8	-2,4	2,6	6,8	9,0	9,9	9,9	6,9	3,9	0,8	-1,7			
Sky Temp	-11,4	-12,8	-10,1	-4,5	0,5	3,2	4,3	5,4	1,0	-2,9	-7,3	-10,0			17,3
Ground Temp	17,8	17,7	17,8	18,1	22,5	22,9	23,2	23,3	23,1	18,8	18,4	18,1	17,7	17,7	23,3

Figure A.10 Baseline Building & Passive House Climate Input

APPENDIX B

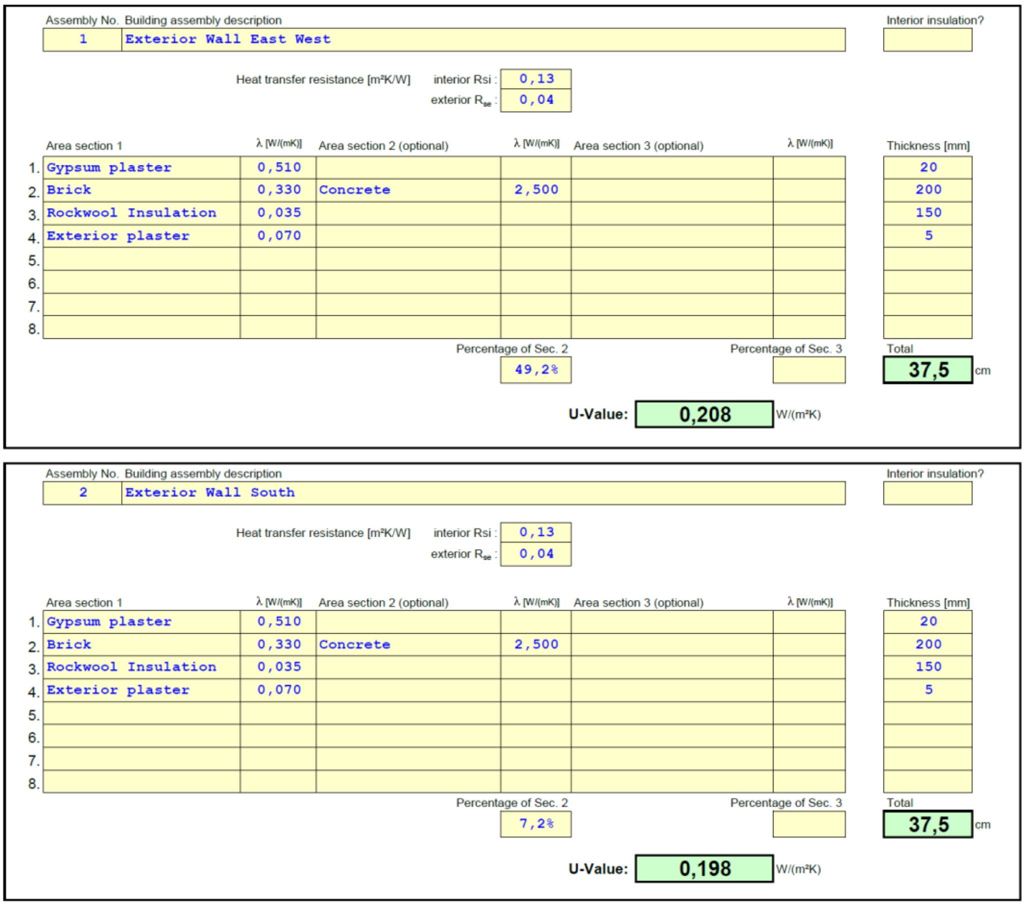
PASSIVE HOUSE BUILDING INPUTS

						Area input						
Area Nr.	Building element description	Group Nr.	Assigned to group	Quan-tity	x (	a [m]	x	b [m]	+	User-Deter-mined [m²]	-	User Sub-traction [m²]
	Treated Floor Area	1	Treated Floor Area	1	x (		x		+	2189,52	-	
	North Windows	2	North Windows	Please complete in Windows worksheet								
	East Windows	3	East Windows									
	South Windows	4	South Windows									
	West Windows	5	West Windows									
	Horizontal Windows	6	Horizontal Windows									
	Exterior Door	7	Exterior Door	6	x (	1,00	x	2,20	+		-	
1	East Wall to Ambient Air	8	Exterior Wall - Ambient	1	x (		x		+	491,09	-	
2	West Wall to Ambient Air	8	Exterior Wall - Ambient	1	x (		x		+	491,09	-	
3	North Wall to Ambient Air	8	Exterior Wall - Ambient	1	x (		x		+	397,74	-	
4	South Wall to Ambient Air	8	Exterior Wall - Ambient	1	x (		x		+	443,00	-	
5	East Basement Wall to Ambi	8	Exterior Wall - Ambient	1	x (		x		+	5,95	-	
6	West Basement Wall to Ambi	8	Exterior Wall - Ambient	1	x (		x		+	40,02	-	
7	North Basement Wall to Amb	8	Exterior Wall - Ambient	1	x (		x		+	35,93	-	
8	North Basement wall to gro	9	Exterior Wall - Ground	1	x (		x		+	5,58	-	
9	East Basement Wall to unhe	12	Exterior Wall/Floor to Unheated B	1	x (		x		+	35,19	-	2,20
10	West Basement Wall to unhe	12	Exterior Wall/Floor to Unheated B	1	x (		x		+	16,06	-	4,18
11	North Basement Wall to unh	12	Exterior Wall/Floor to Unheated B	1	x (		x		+	10,41	-	
12	South Basement Wall to unh	12	Exterior Wall/Floor to Unheated B	1	x (		x		+	63,09	-	2,20
13	North Wall to Unheated Sta	14	Exterior Wall to Unheated Stairwe	1	x (		x		+	56,42	-	15,40
14	East Wall to Unheated Stai	14	Exterior Wall to Unheated Stairwe	1	x (		x		+	90,46	-	
15	West Wall to Unheated Stai	14	Exterior Wall to Unheated Stairwe	1	x (		x		+	74,84	-	
16	Roof	10	Roof/Ceiling - Ambient	1	x (		x		+	436,28	-	
17	Roof lift	10	Roof/Ceiling - Ambient	1	x (		x		+	28,76	-	
18	Floor slab basement	11	Floor slab / basement ceiling	1	x (		x		+	165,37	-	
19	Floor slab above unheated	12	Exterior Wall/Floor to Unheated B	1	x (		x		+	303,27	-	
20	Roof entrance	10	Roof/Ceiling - Ambient	1	x (		x		+	3,59	-	
21					x (		x		+		-	
22					x (		x		+		-	

Figure B.1 Passive House building area input

Length ℓ [m]	Input of thermal bridge heat loss coefficient W/(mK)	Ψ W/(mK)
69,00	Corner 15cm	-0,052
26,00	Unheated basement 15cm	0,550
266,90	Floor slab 15cm	0,008
32,10	Roof 15cm_brick	0,160
39,20	Roof 15cm_concrete	0,197
168,36	Interior to exterior 15cm	0,005
54,60	Balcony	0,690

Figure B.2 Passive House building thermal bridge input



Assembly No. Building assembly description: 1 Exterior Wall East West
Interior insulation?

Heat transfer resistance [m²K/W] interior Rsi : 0,13 exterior R_{se} : 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Gypsum plaster	0,510					20
2.	Brick	0,330	Concrete	2,500			200
3.	Rockwool Insulation	0,035					150
4.	Exterior plaster	0,070					5
5.							
6.							
7.							
8.							

Percentage of Sec. 2: 49,2% Percentage of Sec. 3: Total: 37,5 cm

U-Value: 0,208 W/(m²K)

Assembly No. Building assembly description: 2 Exterior Wall South
Interior insulation?

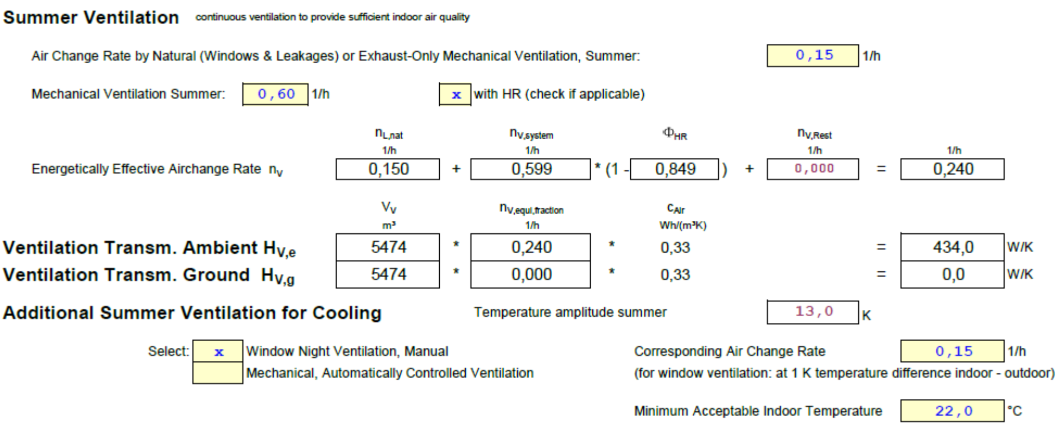
Heat transfer resistance [m²K/W] interior Rsi : 0,13 exterior R_{se} : 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Gypsum plaster	0,510					20
2.	Brick	0,330	Concrete	2,500			200
3.	Rockwool Insulation	0,035					150
4.	Exterior plaster	0,070					5
5.							
6.							
7.							
8.							

Percentage of Sec. 2: 7,2% Percentage of Sec. 3: Total: 37,5 cm

U-Value: 0,198 W/(m²K)

Figure B.3 Passive House building U value input



Summer Ventilation continuous ventilation to provide sufficient indoor air quality

Air Change Rate by Natural (Windows & Leakages) or Exhaust-Only Mechanical Ventilation, Summer: 0,15 1/h

Mechanical Ventilation Summer: 0,60 1/h   x with HR (check if applicable)

	$n_{L,nat}$ 1/h		$n_{V,system}$ 1/h		Φ_{HR}			$n_{V,Rest}$ 1/h		1/h
Energetically Effective Airchange Rate n_V	0,150	+	0,599	* (1 -	0,849	)	+	0,000	=	0,240

	V_V m³		$n_{V,equi,fraction}$ 1/h		c_{Air} Wh/(m³K)	=		
Ventilation Transm. Ambient $H_{V,e}$	5474	*	0,240	*	0,33	=	434,0	W/K
Ventilation Transm. Ground $H_{V,g}$	5474	*	0,000	*	0,33	=	0,0	W/K

Additional Summer Ventilation for Cooling   Temperature amplitude summer 13,0 K

Select: x Window Night Ventilation, Manual
Mechanical, Automatically Controlled Ventilation

Corresponding Air Change Rate 0,15 1/h
(for window ventilation: at 1 K temperature difference indoor - outdoor)

Minimum Acceptable Indoor Temperature 22,0 °C

Figure B.4 Passive House Summer Ventilation input

Type of ventilation system

x	Balanced PH ventilation	*Please Check*
	Pure extract air	

Infiltration air change rate

Wind protection coefficients e and f		
Coefficient e for screening class	Several sides exposed	One side exposed
No screening	0,10	0,03
Moderate screening	0,07	0,02
High screening	0,04	0,01
Coefficient f	15	20

			for Annual Demand:	for Heating Load:					
Wind protection coefficient, e			0,07	0,18					
Wind protection coefficient, f			15	15	Net Air Volume for Press. Test	V_{n50}		Air permeability	q_{50}
Air Change Rate at Press. Test	n_{50}	1/h	0,60	0,60	2014	m³		0,38	m³/(hm²)

			for Annual Demand:	for Heating Load:
Excess extract air		1/h	0,00	0,00
Infiltration air change rate	$n_{V,Res}$	1/h	0,015	0,039

Selection of ventilation data input - Results

The PHPP offers two methods for dimensioning the air quantities and choosing the ventilation unit. Fresh air or extract air quantities for residential buildings and parameters for ventilation can be determined using the standard planning option in the 'Ventilation' sheet. The 'Additional Vent' sheet has been created for more complex ventilation systems and allows up to 10 diff Furthermore, air quantities can be determined on a room-by-room or zone-by-zone basis. Please select your design method here.

	Ventilation unit / Heat recovery efficiency design		Mean Air exchange m³/h	Mean Air Change Rate 1/h	Extract air excess (Extract air system) 1/h	Effective heat recovery efficiency Unit [-]	Specific power input Wh/m³	Heat recovery efficiency SHX
x	Sheet Ventilation (Standard design)	*(Sheet Ventilation see below)*	2021	0,37	0,00	84,9%	0,42	0,0%
	Sheet Extended ventilation	*(Sheet Additional Vent)*						
	(Multiple ventilation units, non-residential buildings)							

SHX efficiency η^*_{SHX} 0%

Occupancy	m²/P	22				
Number of occupants	P	100,0				
Supply air per person	m³/(P*h)	30				
Supply air requirement	m³/h	3000		Bathroom		
Extract air rooms		Kitchen	Bathroom	(shower only)	WC	
Quantity		25	25		25	
Extract air requirement per room	m³/h	60	40	20	20	
Total Extract Air Requirement	m³/h	3000				

Design air flow rate (maximum) m³/h 3000

Average air change rate calculation

Type of operation	Daily operation duration h/d	Factors referenced to maximum	Air flow rate m³/h	Air change rate 1/h
Maximum		1,00	3000	0,55
Standard	14,0	0,77	2310	0,42
Basic	10,0	0,54	1615	0,30
Minimum		0,40	1200	0,22
	Average value	0,67	Average air flow rate (m³/h) 2021	Average air change rate (1/h) 0,37

Selection of ventilation unit with heat recovery

	Central unit within the thermal envelope.
x	Central unit outside of the thermal envelope.

	Heat recovery efficiency Unit η_{HR}	Specific power input [Wh/m³]	Application range [m³/h]	Frost protection required	Unit noise level < 35dB(A)
Ventilation unit selection: Zehnder Comfoair XL 6000	0,85	0,42	2000 - 4000	yes	n.s.

Conductance value of supply air duct Ψ	W/(mK)	0,518	See calculation below		
Length of supply air duct	m	0,5			
Conductance value of extract air duct Ψ	W/(mK)	0,518	See calculation below		
Length of extract air duct	m	0,5		Room Temperature (°C)	20
Temperature of mechanical services room	°C	5,1		Av. Ambient Temp. Heating P. (°C)	5,1
(Enter only if the central unit is outside of the thermal envelope.)				Av. Ground Temp (°C)	12,3

Effective heat recovery efficiency $\eta_{HR,eff}$ 84,9%

Figure B.5 Passive House building ventilation input

Passive House verification

SOLAR HOT WATER GENERATION

Building:	Toki C Blok Passive House		Building Type/Use:	Multi family house	
			Treated Floor Area A_{TFA}:	2189,5	m²

Solar Fraction with DHW demand including washing and dish-washing

Heating Demand DHW	q_{gDHW}	182806	kWh/a	from DHW+Distribution worksheet
Latitude:		39,9	°	from Climate Data worksheet
Selection of collector from list (see below):		1	Selection:	Standard Flat Plate Collector
Solar Collector Area		100,00	m²	
Deviation from North		135	°	
Angle of Inclination from the Horizontal		30	°	
Height of the Collector Field		2	m	
Height of Horizon	h_{Hori}	3,45	m	
Horizontal Distance	a_{Hori}	38,45	m	
Additional Reduction Factor Shading	r_{other}	100%	%	
Occupancy		100,0	Persons	
Specific Collector Area		1,0	m²/Pers	

Estimated Solar Fraction of DHW Production	**34%**			
Solar Contribution to Useful Heat	**62036**	kWh/a	**28**	kWh/(m²a)

Secondary Calculation of Storage Losses

Selection of DHW storage from list (see below):	1	Selection:	Solar Storage
Total Storage Volume	2000	litre	
Volume Standby Part (above)	600	litre	
Volume Solar Part (below)	1400	litre	
Specific Heat Losses Storage (total)	4,5	W/K	
Typical Temperature DHW	60	°C	
Room Temperature	20	°C	
Storage Heat Losses (Standby Part Only)	**48**	W	
Total Storage Heat Losses	**180**	W	

Figure B.6 Passive House solar hot water input

Heat Pump				PE Value	CO_2-Emission Factor (CO_2-Equivalent)
Covered Fraction of Space Heating Demand		*(Project)*	100%	kWh/kWh	g/kWh
Covered Fraction of DHW Demand		*(Project)*	66%	2,6	680
Energy Carrier - Supplementary Heating			Electricity	2,6	680
Annual Coefficient of Performance - Heat Pump		*Separate Calculation*	4,0		
Total System Performance Ratio of Heat Generator		*Separate Calculation*	0,3		
Electricity Demand Heat Pump (without DHW Wash&Dish)	Q_{HP}		18,0	46,7	12,2
Non-Electric Demand, DHW Wash&Dish		*(Electricity worksheet)*	0,0	0,0	0,0
Total Electricity Demand Heat Pump			**18,0**	**46,7**	**12,2**

Other			PE Value	CO_2-Emission Factor (CO_2-Equivalent)
Covered Fraction of Space Heating Demand	*(Project)*	0%	kWh/kWh	g/kWh
Covered Fraction of DHW Demand	*(Project)*	34%	0,2	55
Heat Source	*(Project)*	solar		
Performance Ratio of Heat Generator	*(Project)*	77%		
Annual Energy Demand, Space Heating		0,0	0,0	0,0
Annual Energy Demand, DHW (without DHW Wash&Dish)		14,4	2,9	0,8
Non-Electric Demand, DHW Wash&Dish	*(Blatt Strom)*	0,0	0,0	0,0
Non-Electric Demand Cooking/Drying (Gas)	*(Blatt Strom)*	4,6	5,0	1,1
Total - Other		**19,0**	**7,9**	**1,9**

Figure B.7 Passive House primary energy input

			Summer		
hang Depth	Distance from Upper Glazing Edge to Overhang	Additional Shading Reduction Factor (Summer)	Reduction factor z for temporary sun protection	Horizontal Shading Reduction Factor	Re Re
m	m	%	%	%	
o_{over}	d_{over}	r_{other}	z	r_H	
0,84	15,26		50%	87%	
0,82	15,22		50%	87%	
0,84	15,26		50%	87%	
0,82	15,22		50%	87%	
0,84	15,26		50%	87%	
2,42	15,22		50%	87%	
2,44	15,26	50%	50%	87%	
0,84	12,35		50%	89%	
0,82	12,31		50%	89%	
0,84	12,35		50%	89%	
0,82	12,31		50%	89%	
0,84	12,35		50%	89%	
2,42	12,31		50%	89%	
2,44	12,35	50%	50%	89%	
0,84	9,44		50%	91%	
0,82	9,40		50%	91%	
0,84	9,44		50%	91%	
0,82	9,40		50%	91%	
0,84	9,44		50%	91%	
2,42	9,40		50%	91%	
2,44	9,40	50%	50%	91%	
6,62	9,88		50%	91%	
0,84	6,53		50%	92%	
0,82	6,49		50%	92%	
0,84	6,53		50%	92%	
0,82	6,49		50%	92%	
0,84	6,53		50%	92%	
2,42	6,49		50%	92%	
2,44	6,53	50%	50%	92%	
6,62	6,97		50%	92%	
0,84	3,62		50%	94%	
0,82	3,58		50%	94%	
0,84	3,62		50%	94%	
0,82	3,58		50%	94%	
0,84	3,62		50%	94%	
2,42	3,58		50%	94%	
2,44	3,62	50%	50%	94%	
6,62	4,06		50%	94%	
0,84	0,71		50%	96%	
0,82	0,67		50%	96%	
0,84	0,71		50%	96%	
0,82	0,67		50%	96%	
0,84	0,71		50%	96%	

Figure B.8 Temporary Summer Shading Input

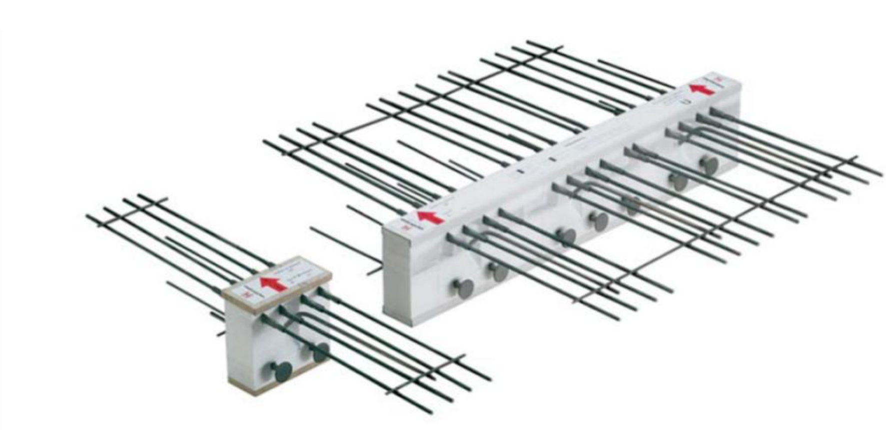


Figure B.9 Insulated balcony connection Detail (Halfen HIT, 2004).

Table B.1 Calculation of the average energy consumption

		Conversion of m³ to kWh		Resource
	Usage (m³)		1500	
	Correction factor		1,02264	*Energylinx
	Calorific Value	9155 kcal/m³	38,3 Mj/m³	* Baskent Doğalgaz
Natural gas	Result		16320	
Electricity(kWh)			1800	
Total (kWh)			18120	

Table B.2 Dew point temperature for different relative humidity and interior air temperature (LAMTEC,2014)

Air Temp °C	% Relative Humidity																		
	100	95	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10
43	43	42	41	40	39	38	37	35	34	32	31	29	27	24	22	18	16	11	5
41	41	39	38	37	36	35	34	33	32	29	28	27	24	22	19	17	13	8	3
38	38	37	36	35	34	33	32	30	29	27	26	24	22	19	17	14	11	7	0
35	35	34	33	32	31	30	29	27	26	24	23	21	19	17	15	12	9	4	0
32	32	31	31	29	28	27	26	24	23	22	20	18	17	15	12	9	6	2	0
29	29	28	27	27	26	24	23	22	21	19	18	16	14	12	10	7	3	0	
27	27	26	25	24	23	22	21	19	18	17	15	13	12	10	7	4	2	0	
24	24	23	22	21	20	19	18	17	16	14	13	11	9	7	5	2	0		
21	21	20	19	18	17	16	15	14	13	12	10	8	7	4	3	0			
18	18	17	17	16	15	14	13	12	10	9	7	6	4	2	0				

APPENDIX C

INTERVIEW QUESTIONS

17.12.2013

Thesis Topic: Thermal Bridge Detailing in Tunnel Formwork Housing with Passive House Principles

Abstract: In the scope of this thesis, the energy demand of 6 storey tunnel formwork housing unit is estimated. Various details are evaluated in order to determine the impacts of thermal bridges on energy demand. Later on, Passive House principles, which is a high energy efficiency building standard are applied. According to the simulations, 15 cm insulation thickness is found and various details are proposed for the former studied junctions. At the end, the impacts of thermal bridges in the baseline building and in the Passive House building are compared.

Aim of the interview: Evaluation of the application of 15 cm insulation in a Passive House tunnel form work social housing unit

Questions:

1. How much insulation have the tunnel form work social housing units constructed by your Firm in Ankara?
2. Have your Firm ever constructed a building which requires thicker insulations than current applications in Turkey? (e.g. Energy efficient building)
3. If yes, did you deal with any problems during the application?
4. What kind of the difficulties can create application of 15 cm insulation thickness?

a. Structural
b. Economics
c. Applicability

5. Do you take precautions to reduce thermal bridging in the detailing of your projects?
6. If yes, what are these precautions?
7. Considering 6 storey tunnel formwork building, please evaluate the proposed details.

Answers:

1. How much insulation have the tunnel form work social housing units constructed by your Firm in Ankara?

Park Oran Project in Ankara has 10 cm external wall insulation (completed in 2011).

2. Do you take precautions to reduce thermal bridging in the detailing of your tunnel formwork projects?

Most of the time, we do. But there are also times we ignore it. The company had a Research and Development Group until 2002, which was working on the topics related to the thermal insulation applications with cost, condensation problems and the occupant comfort in tunnel formwork buildings. *(The Project Manager later delivered these reports. It was seen that the research group also worked with thermal image camera to detect heat loss in the single family houses but not in tunnel formwork projects)*

3. If yes, what are these precautions?

In the first tunnel formwork projects, 5cm Herapor was installed internally on the concrete and precast walls. But it was seen that the material was broken into pieces during the application and the thermal bridges was not reduced. Therefore they stopped using this application. Later, 5 cm foamed polystyrene was installed internally on the both surfaces. Although this method gave much better results, there were still thermal bridges at the floor slabs and the leakage problems continued. After that, it was seen that the application of insulation externally eliminates thermal bridges and leakages. Therefore the application of insulation externally is a method which is used for a long time to eliminate thermal bridges, reduce condensation problems, leakages and operating costs by the company.

4. Have your Firm ever constructed a building which requires thicker insulations than current applications in Turkey? (E.g. Energy efficient building)

Yes, Turkish Contractors Association Building in Ankara which was completed in 2013 has 10 cm external rock wool insulation and is a candidate of LEED Gold Certificate.*(Also the Project Manager worked for a tunnel formwork Project abroad, where 15cm external insulation was applied.)*

5. If yes, have you dealed with any problems during the application?

Since the anchor elements used on the surface of the concrete and the brick differ and the size of the anchors were longer, there were difficulties about supply and they had to import some of the products from abroad. There were problems sometimes to ensure the perpendicularity of the external wall surfaces. Therefore to check the accuracy of the applications at the construction site is very necessary especially in high rise buildings.

6. **What kind of the difficulties can create application of 15 cm insulation thickness?**

a. Structural

Depending on the selection of the insulation materials (e.g. properties, density), the load of the insulation might increase .But it is not seen as a problem.

b. Cost

Since the insulation is heavier, in addition to the cost of insulation, the cost of the anchors and the cost of labor (25%) would also increase.

c. Constructability

In general, an increase in the insulation thickness is not seen as a problem in terms of constructability.

7. Considering a 6 storey tunnel formwork building, please evaluate the proposed details:

Detail 1. Corner Detail
Comment:
Constructable. Different anchor elements can be used for the concrete and the masonry surface.

Detail 2. Unheated Basement Wall Detail
Comment: Constructable. This method is also used by Mesa. The insulation extends 60cm from the top of the ceiling to the bottom on unheated basement walls (In the detail, the insulation extends 1 m).

Detail 3. Penetration of internal wall to exterior wall
Constructable.

Detail 4. Intermediate Floor Slab Detail
Constructable. There were complaints from the occupants related to the noise, therefore since last 4-5 years, 3 cm rock wool is applied for sound insulation on the reinforced concrete floor slab in their projects.

Detail 5. Roof Detail
Constructable. They do not install it at the front of the floor slab, but it is installed until a certain distance (60cm) at the bottom of the floor slab. And then the detail is completed with another material (but not with the insulation, since it is more expensive)

Detail 6. Balcony Detail A (Only the insulation thickness is increased)
He agrees that thermal bridges cannot be eliminated in this detail.

Detail 7. Balcony Detail B (Insulation of floor slab above and below the slab)
In their projects, they install just at the bottom of the floor slab to reduce thermal bridges. But sometimes they ignore balcony thermal bridges and do not take any measure.
He thinks the detail is constructable. The thickness can be reduced in the balcony floor slab as it is proposed.

Detail 8. Balcony Detail C (Thermal Break Element)

The constructability of a thermal break element is open to discussion. Firstly, an opinion of a structural engineer is needed. After that, economics of scale is a very important factor. He had concerns about whether the installation of a thermal break element can be fast at the construction site. It was seen that this technology had been proposed as a solution for the thermal bridge problems in tunnel formwork projects of MESA MESKEN by the former research group in 1996. But it was cited that a cost comparison for the various application is crucial.

APPENDIX D

QUANTITY CALCULATION

Table D.1 Unit Prices of materials and quantity estimations

Material	Package	Unit	Unit price (TL)	Source
Rock wool insulation board (3cm)	1	m²	11,7	Izocam
EPS insulation board (5cm)	1	m²	9,1	
Rock wool insulation board (5cm)	1	m²	19,5	
Rock wool insulation board (10cm)	1	m²	39	
Insulation adhesive mortar *strong	5kg	kg	0,56	
Insulation adhesive mortar	5kg	kg	0,5	
Insulation base coating * strong	5kg	kg	0,64	
Insulation base coating	5kg	kg	0,56	
Cementitious plaster	3kg	kg	0,92	
Insulation smoothing and leveling layer	0,1lt	lt	8,7	
Insulation top coating	0,2lt	lt	13,65	
Insulation mesh	1,1 m2	m²	1,62	
Corner profile	0,25 m	0,25 m	1	
Standard Anchor for 5-6 cm insulation	6	1	0,15	
Anchor for 3-4 cm insulation board	6	1	0,52	
Anchor for 5-6 cm insulation board	6	1	0,54	
Anchor for 14 cm insulation board	6	1	1,42	
Thermal break element K30-CV 35 (* 1 euro=2,85 TL)		m	158,84 euro	Schöck Isokorb
Baseline Building External Wall Area	2302,7 m²			
Passive House Building External Wall Area	2396,1 m²			
Thermal break element	65m (2,6 m per dwelling)			
Balcony floor slab insulation area	220 m²			
Material		**Labor cost**	**VAT**	**Cost per m²**
5cm external wall insulation (EPS)	23,69	16	18%	46,3
15 cm external wall insulation (Rock wool)	81,41	30	18%	131,4
3 cm balcony floor slab insulation (Rock wool)	21,48	20	18%	48,94