ENERGY EFFICIENT RETROFITTING OF HISTORICAL BUILDINGS: A CASE STUDY ON THE BUILDING OF BASMANE SEMT MERKEZİ – İZMİR

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ABSTRACT

ENERGY EFFICIENT RETROFITTING OF HISTORICAL BUILDINGS: A CASE STUDY ON THE BUILDING OF BASMANE SEMT MERKEZİ – İZMİR

Buildings account for 40% of total energy consumption in the European Union yet at the same time it is foreseen that they have a considerable energy saving potentials. Along with the issued energy efficiency related laws and regulations, energy efficient retrofitting applications of the existing buildings are getting increased and the new buildings are built considering the energy efficiency issues. At this point, historical buildings should be treated different than contemporary ones when energy efficient improvements matter. Therefore the specifications adding value to the historical buildings require attention and well-preservation while saving energy. The purpose of this study is to denote how the energy efficient retrofitting in historical buildings should be managed in a transdisciplinary way with a case study conducted on a historical building, *Basmane Semt Merkezi-İzmir*. A detailed building energy simulation tool, DesignBuilder, was used to determine the impacts of the energy efficient retrofits. The actual energy consumption of the case building was calculated obtaining the utility bills regarding electricity and heating fuel consumption. Building energy simulation tool was calibrated by comparing of the measured and simulated indoor air temperatures and total energy consumptions. The inappropriate retrofits, which contradict to the heritage and cultural values, were eliminated with an interdisciplinary approach. Later appropriates retrofits were gathered into three packages to evaluate their effects on the energy consumption. The results show that energy saving up to 41% can be obtained without damaging the heritage values. Besides, the results of combined and aggregated effects of single retrofits show considerable alterations that might cause errors in economical calculations.

ÖZET

TARİHİ BİNALARIN ENERJİ VERİMLİ İYİLEŞTİRİLMESİ: BASMANE SEMT MERKEZİ BİNASI – İZMİR ÖRNEK ÇALIŞMASI

Binaların enerji kullanımındaki payı dikkate alındığında, enerji tasarruf potansiyelinin yüksek olduğu ve bu alanda yapılacak olan verimlilik çalışmalarının enerji tüketimini azaltacağı belirtilmektedir. Yeni yapılacak olan binalarda, enerji verimliliği hususu dikkate alınırken, mevcut binalarda ise enerji verimli iyileştirme çalışmalarına hız verilmiştir. Tarihi binalara bu kapsamda yapılacak olan enerji verimliliği çalışmalarında mevcut binalara yapılan uygulamalarla müdahalede edilmemesi gerektiği vurgulanmaktadır. Bu nedenle, enerjinin korunmasının yanında tarihi binaların kültürel ve mimari miraslarının korunması da önem kazanmaktadır. Bu çalışmanın öncelikli amacı, tarihi, mimari ve kültürel değeri olan binalarda yapılabilecek enerji vermliliği çalışmalarında nasıl bir yol izlenmesi gerektiğini disiplinlerarası yaklaşımla belirtilmek, örnek bir çalışma ile uygulamalı olarak göstermektir. Çalışmada, İzmir'in Basmane semtinde bulunan tarihi *Basmane Semt Merkezi* binası incelenmiştir. Yapılacak olan enerji verimli iyileştirmelerin etkisinin hesaplanması için detaylı bina enerji simülasyonu (DesignBuilder) kullanılmıştır. Binanın geçmiş dönem enerji tüketim değerleri, elektrik faturaları ve yakıt tüketiminden yola çıkarak hesaplanmıştır. Bina enerji simülasyonu, iç ortam sıcaklıkları ve enerji tüketimi simülasyon sonuçlarının gerçek verilerle karşılaştırılması ile kalibre edilmiştir. Yapılacak olan enerji verimli iyileştirmelerin, binanın tarihi, mimari ve kültürel miras değerleri üzerindeki riskleri disiplinlerarası bir yaklaşım ile değerlendirilmiş, bu değerlere uygun olmayan iyileştirmeler elenmiş ve uygun olanlar üç iyileştirme paketi altında toplanarak enerji tüketimi üzerindeki etkileri incelenmiştir. Sonuçlar, bu yaklaşımla binanın mimari ve kültürel miras değerlerine zarar vermeden %41'lik bir enerji tasarrufu sağlanabileceğini göstermiştir. Ayrıca iyileştirmelerin bileşik etkileri, tekil etkilerinin toplamı ile karşılaştırılmış ve sonuçlarda oluşabilecek farklılıkların ekonomik hesaplamalarda hatalara yol açabileceği görülmüştür.

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Mtoe	Million tonnes of oil equivalent
HVAC	Heating, ventilation and air-conditioning
q	Heating rate of the radiator per metre
q_s	Catalogue heating rate of the radiator per metre
ΔT_s	Difference between indoor air temperature and average water temperature at standard conditions
ΔT	Difference between indoor air temperature and average water temperature out of standard conditions
p_h	The air pressure different than standard conditions,
s	Radiant fraction of the radiator
y	Coefficient obtained from heat power experiment
Z	Elevation
MBE	Mean bias error
RMSE	Root-mean-squared error
CV(RMSE)	Coefficient of variables root-mean-squared-error
t	Measured dry-bulb temperature
o	Simulated dry-bulb temperature
n	Number of observations
A_{period}	Mean of the measured values
COP	Coefficient of performance

CHAPTER 1

INTRODUCTION

Total primary energy consumption in the World has risen with developing technology and increasing population. Figures from 1992 to 2012 indicate that total primary energy consumption in the World sharply rose by 52%, from 8196.1 Mtoe to 12476.6 Mtoe, in last two decades (BP 2013). Therefore finding an alternative way has become an essential issue to overcome this increasing energy demand. Developed countries have been seeking and investing on the alternative energy sources, such as wind, solar, bio fuels, to substitute the share of fossil-fuel-driven energy sector while working on the efficient use of energy.

Figure 1.1 shows the renewable energy consumption trend in the World from 2002 to 2012. The renewable energy usage has risen almost three times to 237,4Mtoe compared with 2002 data. According to 2012 figures, the U.S.A. has the largest share with 21.4 % while is followed by China, Germany, Spain and Brazil with 13.4%, 10.9%, 6.3% and 4.7%, respectively. The trend obviously denotes that countries have been gradually investing on renewable energy technologies.

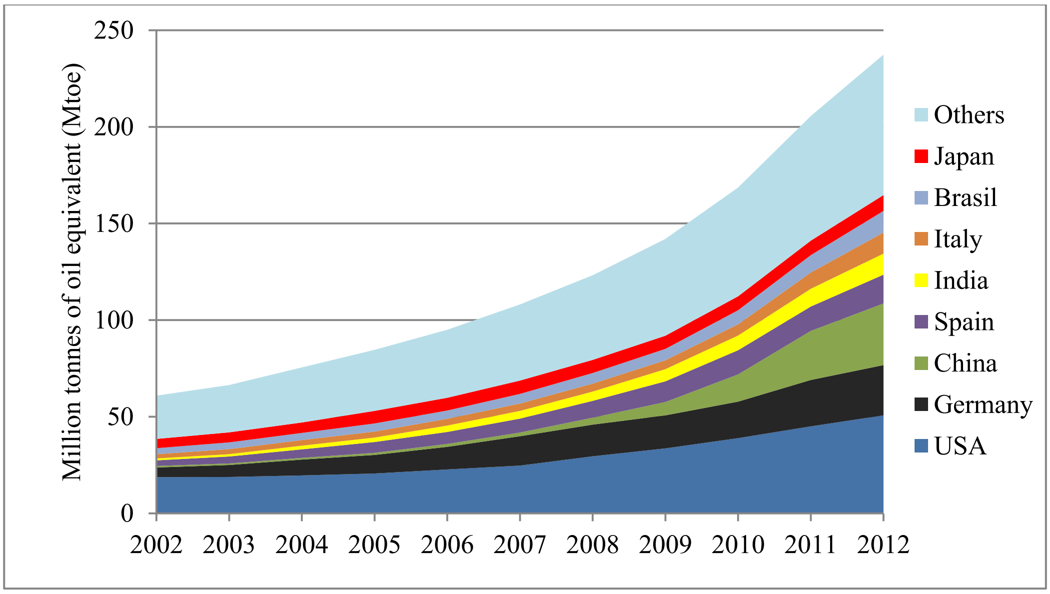


Figure 1.1. Renewable energy consumption trend in the world (2002 -2012)
(Source: BP 2013)

Another option to reduce the use of non-renewable energy sources is to stimulate the efficient use of energy. According to the report published by International Energy Agency (IEA), major energy-consuming countries have new energy consumption targets (IEA 2012). The report indicates that the United States declared new fuel economy standards. China is aiming 16% cut by 2015 in terms of energy intensity. The European Union (EU) stated 20% reduction in its energy demand up to 2020 (EPBD 2002). Japan has the target of cutting its electricity consumption by 10% until 2030. Turkey's target on reduction in energy consumption by 2020 is 10% which is relatively conservative (EEL 2007). Even though these targets are counted to be hope-inspiring policies, a huge proportion of energy efficiency potential in the World, of which are 80% of building sector and more than half in industry, still remains intact (IEA 2012).

Figure 1.2 illustrates that Turkey's total final energy consumption is mainly shared by three sectors, industry (36%), buildings [34% (48% residential and 52% non-residential)] and transport (18%) (MENR 2011). The remaining 12% energy consumption caused by commercial and public services, agricultural and other non-specified sectors.

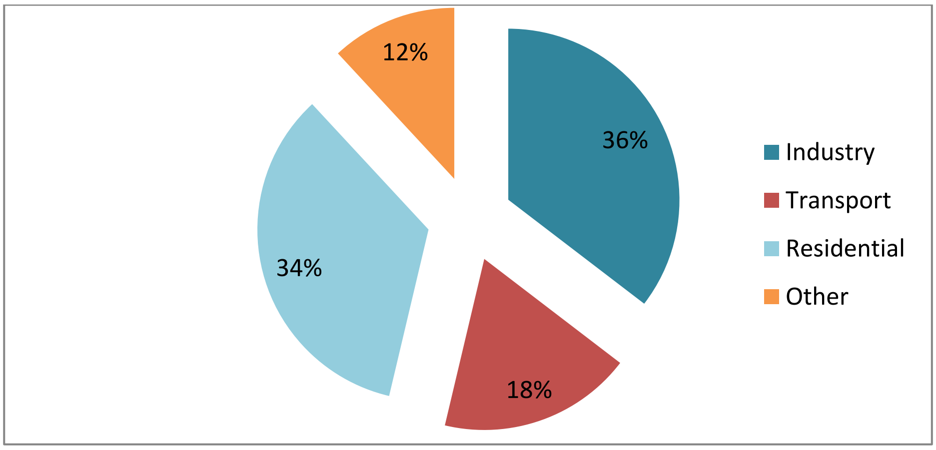


Figure 1.2. Turkey's total final energy consumption by sector
(Source: MENR 2011)

This breakdown (Figure 1.2) is the prominent indicator of possible energy saving scenarios and precautions. The residential share of the whole is worthwhile to perform energy efficiency studies in buildings. In other words, the total energy consumption indicates that a great energy saving potential is available in residential energy sector. For this reason, various energy laws were legislated, directives and regulations supporting the efficient use of energy in buildings went into power in the member states of the EU (CA 2013).

In Europe, efficient use of energy in buildings has become an important issue since buildings are responsible about 40% of primary energy consumption. To reduce this share, EU legislated Directive on the Energy Performance of Buildings (EPBD) (2002/91/EC) basically states that each member state should develop a methodology to predict and certificate the energy performance of buildings (EPBD 2002).

Turkey officially began to pay more attention to energy efficiency with a standard “Thermal Insulation Requirements for Buildings” (TS825 2008) which was legislated first in 2000 and revised later in 2008. Then, the Energy Efficiency Law aiming for a 10% reduction in energy consumption by 2020, went into force in 2007. The purposes of the law are mainly to use energy more efficiently, to reduce wasted energy, to lighten the energy expenditures on economy and to increase efficient use of energy and energy resources for saving the environment (EEL 2007). The most regulatory legislation associated with efficient use of energy in buildings is “Directive of Building Energy Performance”. The directive, which in accordance with EPBD, basically aims to define a methodology to calculate the whole energy use of the buildings, to label the primary energy consumption and CO_2 emissions level of the buildings, to determine the viability of using renewable energy sources, to inspect the heating and cooling systems in the buildings and to restrict the CO_2 emissions, went into force in 2008.

The term building in the directive refers to existing buildings and buildings that will be built. However, almost no specific definition on historical buildings is given. The clause (2/ç) in the directive (BEP 2008) simply denotes that energy efficient retrofits and interventions in buildings having historical heritage value ought to be done in cooperation with authorised official authorities and without affecting the historical heritage value of the buildings, of which is mentioned as a similar statement in the EPBD (BEP 2008). Therefore, energy efficiency applications in historical buildings require special interest. In Turkey, almost no special interest has been given to historical buildings regarding the efficient use of energy.

The building stock in the World has range from the monumental ones to the contemporary buildings. The key step is to give a definition of the historical building in order to identify those buildings that should be treated separately.

> The significance of historical buildings clearly encompasses the more obvious architectural and aesthetic values, but it also includes less tangible elements such as associations with historic people and events, examples of technological innovations, aspects of social history and links with a building's setting and other heritage assets (EH 2008).

At this point, giving an answer to the question "What is the heritage value?" can clarify and enlighten the possible misunderstandings behind it. Basically, any tangible and intangible element giving identity and character to the building can be counted as a heritage value, which is primarily categorised as evidential, historical, aesthetic and communal value (EH 2008).

Considering immense number of historical buildings in use and those to be restored in Turkey, it is not difficult to estimate enery saving potential to reduce energy consumption figures.

The general aim of this study is to investigate energy efficient retrofitting interventions in historical buildings taking into account of the heritage values. The building that was chosen as case study is *Basmane Semt Merkezi (Basmane Neighbourhood Centre)*, which is located at Basmane district in İzmir, Turkey. The building was built by Tabak Family in İzmir by the end of the 19th century. Later it was donated to the Prime Ministry General Directorate of Social Services and Child Protection to serve as a dormitory for the orphans. Konak Municipality financially undertook a restoration project which was prepared and supervised by İzmir Institute of Technology, Department of Architectural Restoration. The restoration work was completed in 2007.[1] Currently, *Basmane Semt Merkezi* is used to educate illiterate women and deliver training courses of handcrafts, embroidery, marbling etc.

The thesis includes six chapters. The second chapter presents the studies related to energy efficient retrofits in both contemporary and historical buildings. The third chapter includes information related with the case building. In chapter four, the methodology of this thesis will be given. Later, case study and the results will be introduced. Finally, the last chapter gives the conclusions of this study.

"[1] *The restoration project of historic house in Basmane/İZMİR"* is prepared as a First Semester Project in 2004 in the scope of RES 501 Design in Architectural Restoration (I) supervised by Assist. Prof. Dr. Selim Sarp Tunçoku. Implementation work was consulted together with Prof Dr. Başak İpekoğlu and sponsored by Konak Municipality of İzmir. Restoration work was completed in February, 2007.

CHAPTER 2

LITERATURE SURVEY

In this chapter scientific studies related with the research area will be presented. The main purpose of the literature review is to highlight the associated studies in literature and make them the source of inspiration for the framework of the thesis. First, literature survey was conducted under two main categories such as energy efficient retrofitting in contemporary and historical buildings. Later, contemporary buildings were investigated under two sub-categories, namely commercial and residential, owing to the general pattern of the studies. Similarly, studies regarding historical buildings were gathered in two groups due to whether they consider the heritage value or not.

Furthermore, some other parameters**,** that are highly connected to the framework of the thesis, such as validation and calibration of the building energy simulation (BES) tools, significance of the weather data in BES calculations, economical analysis of retrofitting applications, directives and guidelines about the energy performance of the buildings were used to spot some prominent studies in the literature. Table 2.1 shows the general view of the literature survey.

Retrofitting applications in contemporary buildings were gathered in two sub-headings as residential and commercial buildings. Although they are used for different purposes retrofitting in contemporary buildings are generally applied from the quantitative point of view. Qualitative specifications are not of interest in general and are not considered when retrofits are decided. For example, irreversibility of the interventions is not taken into account since energy saving in contemporary buildings, either it is commercial or residential, is the most important criterion (Eskin and Türkmen 2008; Koranteng and Mahdavi 2011; Güçyeter and Günaydın 2012; Chidiac et al. 2011; (Tronchin and Fabbri 2008; Al-Ragom 2003; Nabinger and Persily 2011; Desogus et al. 2013; Balaras et al. 2000; YILDIZ 2008).

In historical buildings, literature survey was conducted considering and not the heritage value. Primary aim of the studies on not considering the heritage value is to reduce the energy consumption of the building via energy efficient retrofits. Despite the

Table 2.1. Categorisation of the literature survey

	Contemporary Buildings		Historical Buildings	
Categories	Commercial	Residential	Heritage Value	No Heritage Value
Building Energy Simulation (BES), Energy consumption & Retrofitting	(Eskin and Türkmen 2008) (Koranteng and Mahdavi 2011) (Güçyeter and Günaydın 2012) (Chidiac et al. 2011)	(Tronchin and Fabbri 2008) (Al-Ragom 2003) (Nabinger and Persily 2011) (Desogus et al. 2013) (Balaras et al. 2000) (YILDIZ 2008)	(Curtis 2013) (Norrström 2013) (Brostrom et al. 2012) (Cluver and Randall 2012) (Gyritli 2011) (Broström et al. 2013) (Eriksson et al. 2012) (Kikira and Gigliarelli) (Broström and Svahnström 2011)	(Bojić et al. 2012) (Ascione, de Rossi, and Vanoli 2011) (Pérez Gálvez et al. 2013)
BES validation	(Melo et al. 2012) , (Ryan and Sanquist 2012) (Judkoff and Neymark 1995), (DBV 2011), (ASHRAE140-2007 2010)			
BES calibraiton	(Eskin and Türkmen 2008)(Güçyeter and Günaydın 2012) (Koranteng and Mahdavi 2011), (O'Neill et al. 2011), (ASHRAE 2002), (Kandil and Love 2013)			
Importance of weather data in BES calculations	(Bhandari, Shrestha, and New 2012), (Dombaycı 2009), (Radhi 2009), (Chan 2011), (Pérez Gálvez et al. 2013)			
Economic analysis	(Koranteng and Mahdavi 2011)	(Desogus et al. 2013)	(Broström et al. 2013) (Cluver and Randall 2012)	(Bojić et al. 2012)
Guidelines, directives	(EPBD 2002),(BEP 2008) , (CA 2013)		(ENH 2008), (BURRA 1999), (EH 2008), (CEN) (Curtis 2013)	-
Projects			(SECHURBA), (3ENCULT), (EFFESUS 2013), (SOB 2013), (CFC 2013)	-

historical character of the buildings, they were treated as contemporary buildings (Ascione, de Rossi, and Vanoli 2011; Pérez Gálvez et al. 2013; Bojić et al. 2012).

On the other hand, studies (Table 2.1.) taken into account of the heritage value specifically emphasise that historical buildings are part of our history and community so that should be conserved and re-integrated into our life without changing and damaging their architectural, cultural and historical values. Therefore those studies primarily aim to conserve the heritage value of the buildings when energy conservation is of interest. In other words, building elements carrying heritage values like walls, floors, roof, windows, doors etc, are suggested to change as small as necessary but preserved as much as possible in order to conduct an energy efficient intervention in historical buildings. A deep qualitative assessment is also required to point out the risks and benefits of the energy efficient retrofits on heritage and cultural values Thus, any intervention having unacceptable effect on heritage value of the building is assumed to be inappropriate (Curtis 2013; Norrström 2013; Broström et al. 2012; Cluver and Randall 2012; Gyritli 2011; Broström et al. 2013; Eriksson et al. 2012; Kikira and Gigliarelli; Broström and Svahnström 2011).

It has been seen that retrofitting studies in the literature utilised two methods to evaluate the effects of the interventions on the building energy consumption. One of which is to collect energy billing data or measure the consumption figures after the retrofitting. Other is to use BES tools to design the retrofits, simulate the building and evaluate the energy consumption. While the number of the BES tools is increasing, utilisation of them in retrofitting studies became popular. Their primary usages in research area are to design a new building, renovate the existing ones and building energy certification.

Nevertheless, outputs of the BES tools are questioned even though their input capabilities are detailed. Validation of any BES tool is, therefore, required to be sure from the accuracy of the results. Thus studies, which use BES tool in their calculations, also included and proved the validation of the BES tool. One of the important outcomes of the validation studies is the ANSI/ASHRAE Standard 140, Building Thermal Envelope and Thermal Load Test, which is comparative validation method for building energy simulation tools (ASHRAE140-2007 2010). Some of the significant studies in the literature regarding the validation are categorised and given in Table 2.1.

It does not mean that a validated BES tool reflects the accurate or the closest results when compared to the actual energy consumption. The output of BES tool can change mainly due to the expert level of the users. For this reason, calibration is required to prove whether if the accuracy of the simulation results in the acceptable limits. In the selected papers (Table 2.1) retrofitting studies in the buildings were done using calibrated BES tools of which is made generally via two ways (Eskin and Türkmen 2008; Güçyeter and Günaydın 2012; Koranteng and Mahdavi 2011; O'Neill et al. 2011; ASHRAE 2002; Kandil and Love 2013). One of those is to compare the simulated and measured energy consumption figures (Kandil and Love 2013). Second method is to compare the simulated and measured indoor climate parameters such as dry-bulb temperature, relative humidity, illumincance levels (Koranteng and Mahdavi 2011). In order to make simulation results to converge the actual ones and obtain a better model, a method including four steps was commonly used. The method includes the steps below:

1. Measuring the indoor and outdoor climate (usually dry-bulb temperature, relative humidity for both, solar radiation for outdoor only) for the time period whose actual building energy consumption figures are known.
2. Integrating the outdoor climate data into the simulation weather data for the desired time period.
3. Simulating the building model.
4. Tuning the parameters like thermo-physical properties of the construction materials, internal gains, heating system efficiency, up until the simulated and measured values converge.

Some studies point out the significance of the weather data used in BES calculations. It is highlighted in the papers that accuracy of the BES results highly associated with the weather data. The results show that weather data might cause considerably high discrepancies on building energy consumption figures (Bhandari, Shrestha, and New 2012; Dombaycı 2009; Radhi 2009; Chan 2011; Pérez Gálvez et al. 2013).

Moreover, the studies including economic analysis were also categorised in Table 2.1. General aim of the economical analysis in retrofitting studies is to determine whether the energy efficient interventions are economically viable or not. The prominent conclusion of the papers is that replacing the windows with the more efficient ones is the retrofit having the longest pay-back period and is not cost effective

(Koranteng and Mahdavi 2011; Desogus et al. 2013; Broström et al. 2013; Cluver and Randall 2012; Bojić et al. 2012).

With the EPBD, efficient use of energy in buildings is accelerated and supported by the member states in the EU. In Turkey, Building Energy Performance Directive, which is in accordance with the EPBD, was legislated in 2008 through the EU accession process. However, neither of the directives have obvious statements about the historical buildings. In the literature, it was observed that the majority of the energy efficient retrofitting studies were conducted in the countries such as England, Scotland, Sweden, Italy, Greece, etc. whose building stock is relatively older. As a result, England and Scotland separately published a guideline (ENH 2008; EH 2008; Curtis 2013) about how energy efficient retrofits in historical buildings should be applied and managed without damaging their heritage values. Eventually, the EU started to develop a standard namely, "Guidelines for improving energy performance of architecturally, culturally or historically valuable buildings (CEN)".

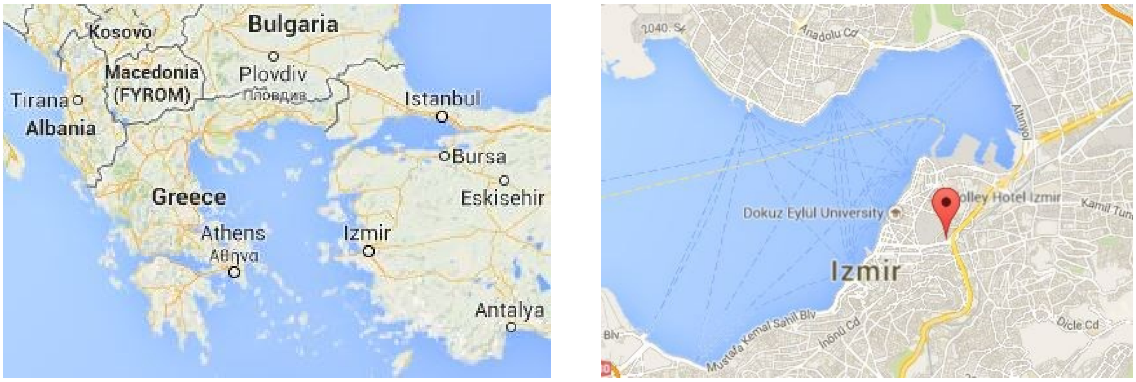
Additionally, projects aiming conservation of historical buildings were conducted and co-operated internationally. Common aims of the projects are to conserve the historical buildings, obtain energy saving, re-integrate their usage into our life, make them sustainable for the future generations and improve the retrofitting scientific knowledge in historical buildings. Some of the relevant projects supported by the states, organisations and energy agencies are given in Table 2.1.

What this study primarily contributes to the current literature is that how the energy efficient retrofitting in historical buildings should be managed using a validated and calibrated building energy simulation tool, in a systematic and transdisciplinary way. Furthermore, the proposed method will be applied in a case study and interpreted from the perspective of energy saving, heritage value and Turkish Standards (TS825). At this point out that it is also significant to point out that this study will be the first in Turkey which considers energy efficient retrofitting in historical buildings via interdisciplinary approach.

CHAPTER 3

BASMANE SEMT MERKEZİ BUILDING

The *Basmane Semt Merkezi* building is placed in Basmane district of İzmir which is the third largest city of Turkey. The Basmane district was the commercial centre of the İzmir during the Levantine Period from the beginning of the 17th up to the end of 19th century. Therefore, the area reflects representative example of the 19th century residential architecture in İzmir (Yardım and Tunçoku 2008). The Figure 3.1(a) illustrates the position of *İzmir* while that of (b) shows the approximate position of *Basmane Semt Merkezi.*



(a) (b)

Figure 3.1. (a) İzmir, (b) Basmane District
(Source: Google Maps)

Basmane District was an important commercial area located closeby the train station in the 19th century. After the majority of the hotels around İzmir Kordon was demolished by the 1922 fire, Hotels Street in Basmane gained significance since the hotels were the only examples reflecting the characteristics of an important period (Zeren 2011).

In the early 19th century, the buildings on the street were designed as hotels but used as accommodation for middle and low income people in the last few decades. Due to insufficient maintenance and inappropriate interventions over time, the street lost it’s architectural importance while facing with some security and social problems. For this reason İzmir-Konak Municipality took a series of decisions and conducted projects to make Hotels Street to vitalise it’s importance and heritage value (Zeren 2011).

Through the renovative interventions, Konak Municipality improved the infrastructure and street pavements. Business owners also took part on the task of the façade renovation while the inhabitants and some other people participated as volunteers for implementation works (Zeren 2011).

The west façade of *Basmane Semt Merkezi* faces to the street numbered 1299 which is connected to the one numbered 1296 and named as *“Oteller Sokağı”* referring to the Hotels Street. As seen in Figure 3.2, street numbered 1299 is quite narrow (not more than 3 meters) and historical buildings are located on both sides.

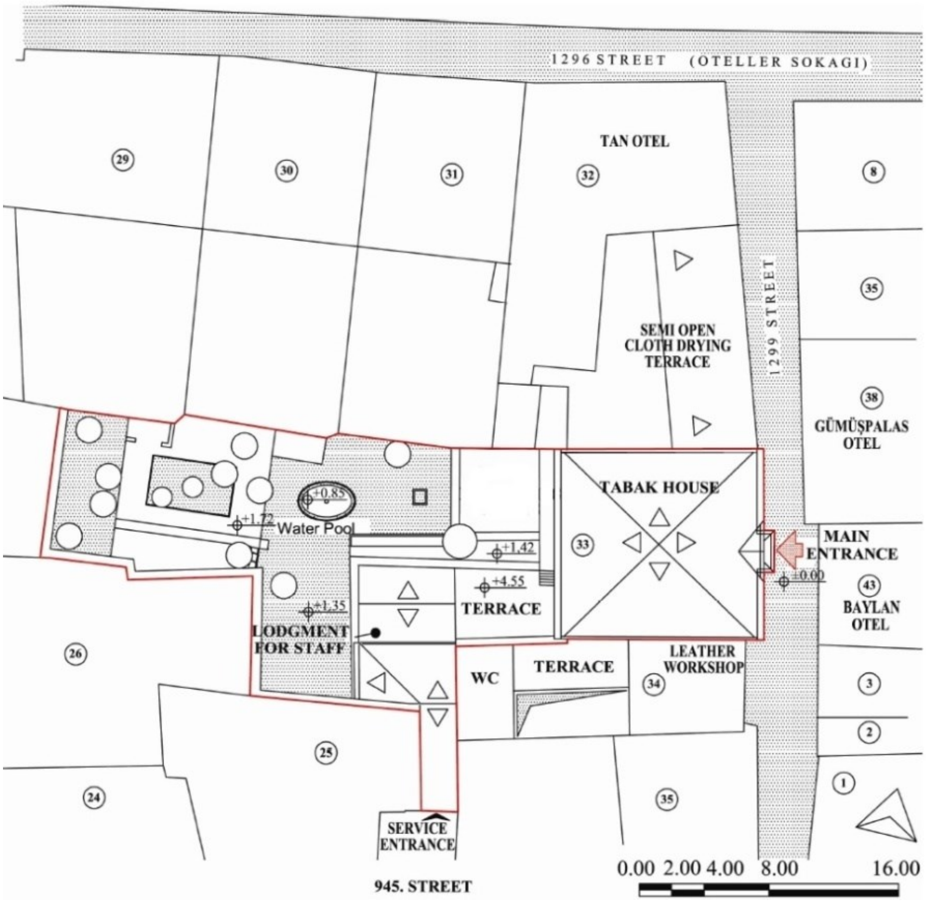


Figure 3.2. The site plan of *Basmane Semt Merkezi*
(Modified from the drawings of Dept. of Architectural Restoration – IZTECH)

Basmane Semt Merkezi is a three-storey building including the basement. It was built on the East – West direction. The west façade faces to the garden. Also, there is a service building adjacent to the house at the southeastern part of the garden. The connection between the house and the service building is provided only at the ground floor level (Figure 3.3).

Figure 3.3.Adjacency to the service building

The rooms are symmetrically located at the either sides of a longitudinal corridor, at both floors. The wooden stairs on the southwestern end of the house is the only connection between the ground and the first floor. Entrance to the basement is provided by the stairs (Figure 3.4). Besides, there is a bay window (called *cumba*) on the east and a balcony on the west edge of the first floor (Figure 3.5).

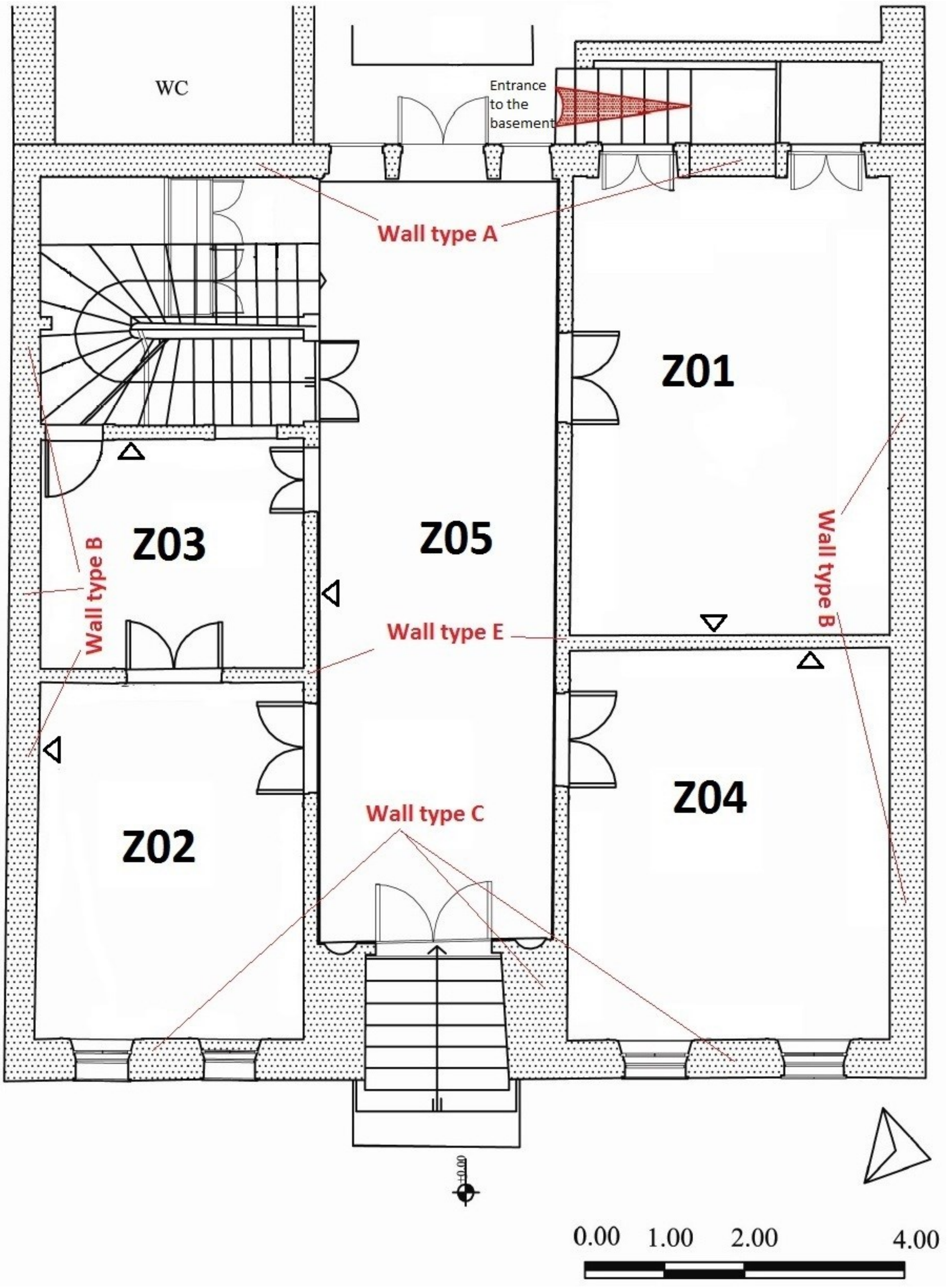


Figure 3.4. Ground floor plan
(Modified from the drawings provided by Dept. of Architectural Restoration - IZTECH)

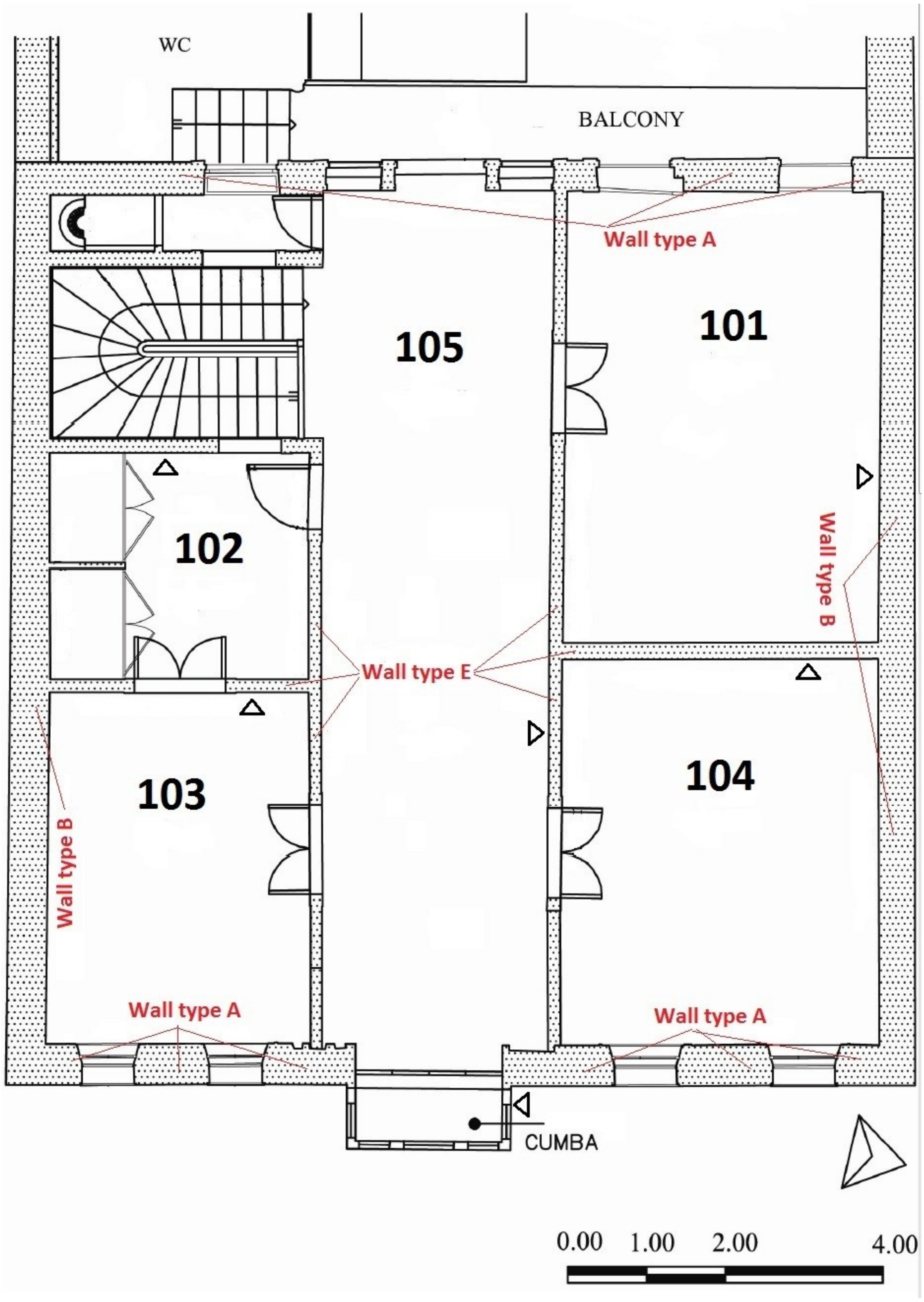


Figure 3.5. First floor plan
(Modified from the drawings provided by Dept. of Architectural Restoration - IZTECH)

3.1. Structure of the Building

The general aim of restoration applications is to improve the original fabric with compatible materials and techniques in the light of restoration principles.

In this section, the present situation of the building components such as; interior and exterior walls, roof, first and ground floors, windows, doors and shutters will be described.

3.1.1. Walls

The building envelope has an exterior wall structure, which is not homogenously distributed, and shows different characteristics from façade to façade. Thus, five different wall structures and their overall heat transfer coefficients (U-values) were defined and given in Table 3.1.

Table 3.1. Wall types and corresponding overall heat transfer coefficients

	Wall Type	Façade	U-values (W/m^{2}K)
External	A	First floor east and west Ground floor west	1.2
	B	First floor north and south Ground floor south Ground floor north (with brick)	1.1
		Ground floor north (with andesite)	0.96
	C	Ground floor east	1.2
	D	Basement	1.1
Internal	E	Partitions (first and ground floor)	1.3

Construction materials of each wall were obtained via both field investigation and architectural projects. Basically, the structure of the building is a typical form of composite system that includes wood construction techniques and stone/brick masonry (Yardım and Sarp Tunçoku 2008). The structure of each wall will be described in the next section.

3.1.1.1. Structure of Wall Type A

The structure of the east and west wallsof the first floor is composed of four layers. Each wall is 45 cm in total and labelled as the wall type A. The layers are; lime plaster, andesite rubble with lime mortar, *hımış* frame and lime plaster from outer to inner face None of exterior walls has an insulation layer. Figure 3.6 illustrates the cross-section of the wall with construction materials.

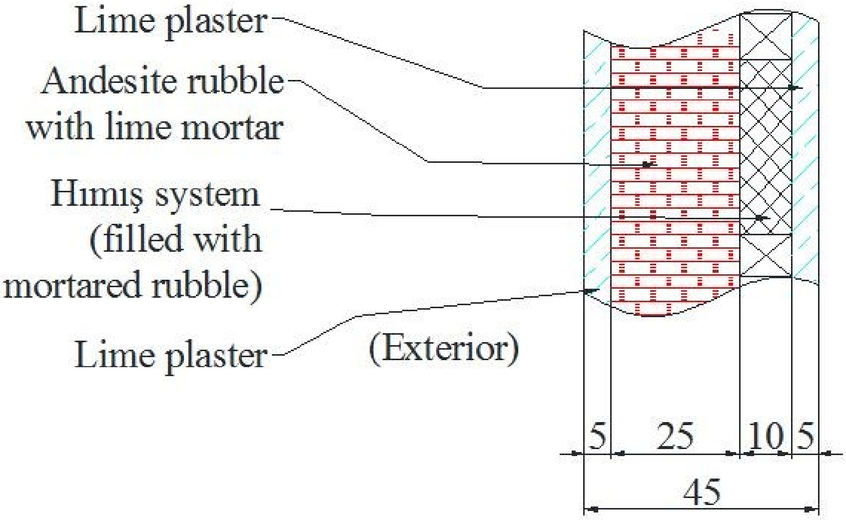


Figure 3.6. Cross-section of the wall type A (cm)

“Hımış” system forms the timber skeleton and composed of posts, beams and bracings. The compartments of this frame are usually filled with rubble or brick with mortar. Plaster can be applied on the surface directly. If these compartments are left empty (as the case in the separation walls between rooms in this house) plaster is applied on wood laths (of 2.5 cm wide 1 cm thick) nailed on the *“hımış” frame* which is called *“bağdadi”* plastering technique as seen at the right side of Figure 3.7. It was preserved with partial reinforcements according to the decisions taken in the restoration project.

Using the information related to the construction materials, overall heat transfer coefficient of the wall type A is calculated as 1.2 W/m^2.K.

Figure 3.7. The traditional hımış system and structure of partition walls (Source: Archives of Architectural Restoration Department IZTECH)

3.1.1.2. Structure of Wall Type B

A view of the wall type B is illustrated in Figure 3.8.

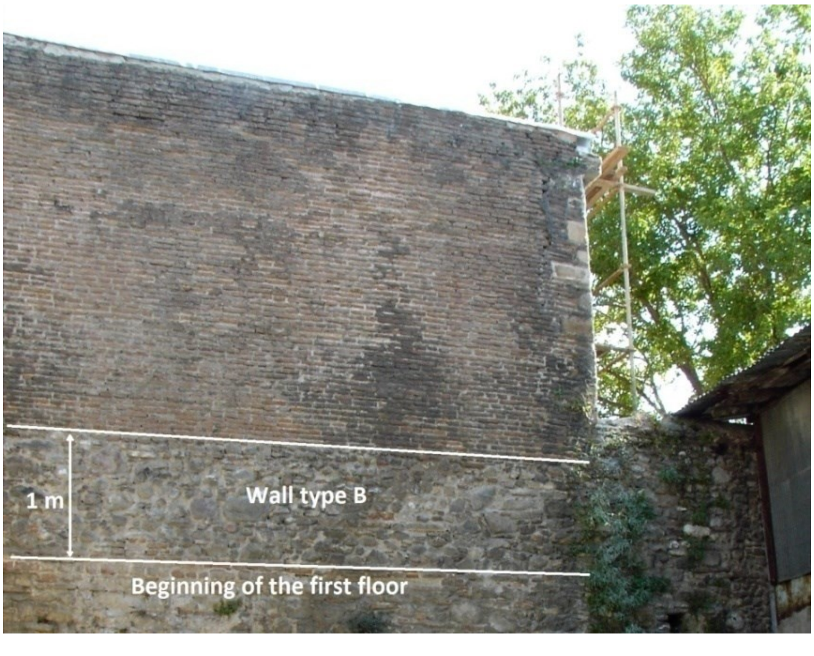


Figure 3.8. Constructional variation on first floor north exterior wall (Source: Archives of Architectural Restoration Department IZTECH)

First floor north façade, which has a 45 cm width, has two different wall structures because of the restoration based interventions. The first meter of the wall, from the end of ground floor external wall, is composed of andesite, *hımış system* and lime plaster while the rest of the wall includes brick instead of andesite. The area between the white lines (Figure 3.8) refers to the structural variance on the wall.

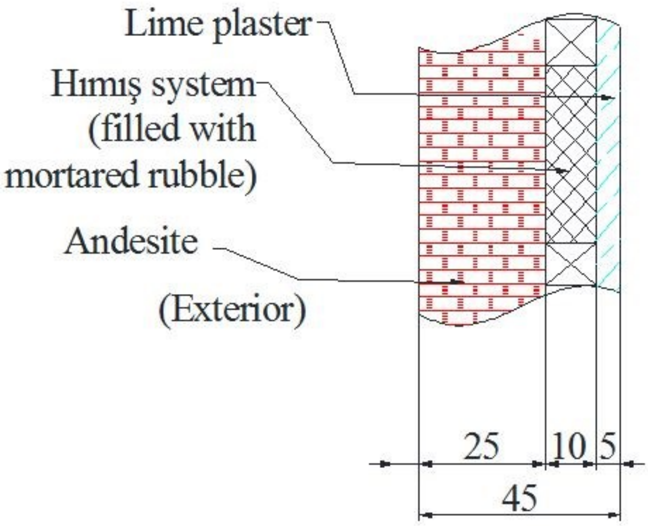


Figure 3.9. Cross-section of wall type B (with andesite)

Overall heat transfer coefficient of the wall including andesite is calculated as 0.96 W/m^{2}K while that of including brick is 1.1 W/m^{2}K. Cross section of the walls and dimension of each element (in cm) including andesite and brick can be seen on Figure 3.9 and Figure 3.10, respectively.

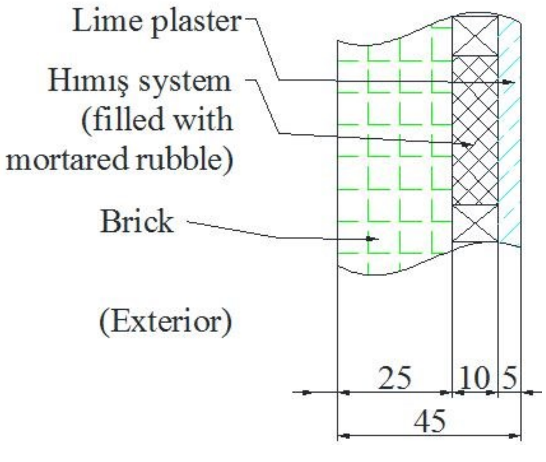


Figure 3.10. Cross-section of wall type B (with brick)

3.1.1.3. Structure of Wall Type C

Ground floor east wall is constructed with the wall type C. Similar to the wall type A, type C consists of 4 layers. However, the outermost layer of the wall type C, which is shown in Figure 3.11, is cladded with tuff plates instead of covering lime plaster.

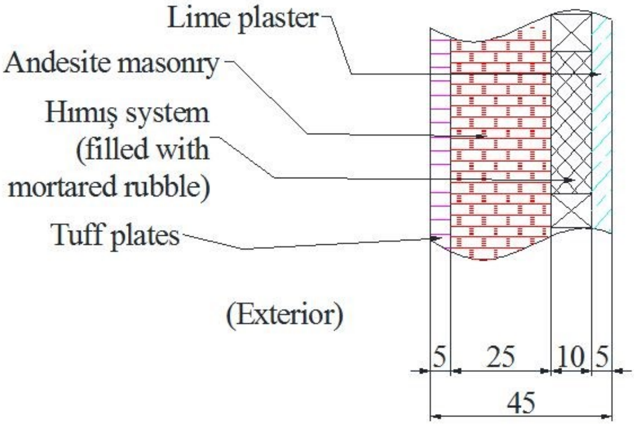


Figure 3.11. Cross-section of wall type C (cm)

The difference in structure does not considerably affect the overal heat transfer coefficient when comparing two wall types. Hence, the U-value of wall type C was calculated as 1.2 W/m^{2}K.

3.1.1.4. Structure of Wall Type D

Wall type D wraps up the whole basement and has the structure basically composed of andesite stone masonry. Wall thickness shows variations (45 –50 cm) from façade to façade. Overall heat transfer coefficient of the wall type D is calculated as 1.1 W/m^{2}K.

3.1.1.5. Structure of Wall Type E

Basically, two different internal wall structures have been detected. The wall structure, which is constructed with "*bağdadi*" plastering technique, is simply composed of 5 layers as seen on Figure 3.12. The difference occurs due to the air gap thickness between wood layers. The reason of the air gap thickness difference is thought to be workmanship based during the restoration project.

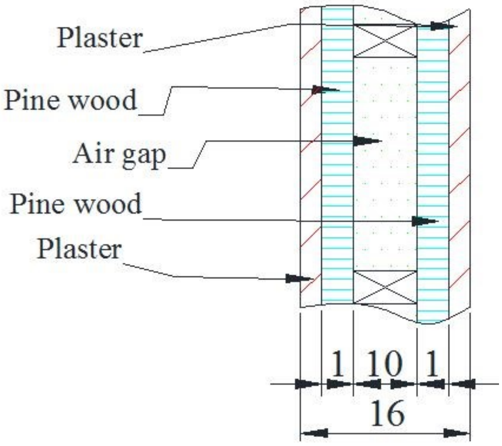


Figure 3.12. Cross section of the wall type E (cm)

Despite the fact that small variations in the thickness of air gaps in the wall compositions, U-value does not change considerably. Therefore overal heat transfer coefficient is assumed as the same for the first and ground floors.

3.1.2. Floors

The building shows different floor patterns form level to level. For this reason, structure and properties of each floor construction will be defined seperately. Floor patterns and corresponding overall heat transfer coefficients are given in Table 3.2.

Table 3.2. Floor types and corresponding U-values

Floors	U-value (W/m^2K)
Ground floor (marble cover)	3.6
Ground floor (timber)	1.4
First floor	1.1
Basement floor	1.5
Attic floor	1.1

3.1.2.1. Ground Floor

Ground floor shows two different patterns throughout the level. First pattern is available on the longitudinal hall, which is covered with marble plates on the leveling mortar and compacted earth. Second one, that is similar to the floor on the first level, constructed of pinewood planks nailed on timber beams.

Overal heat transfer coefficient of the floor with marble is calculated as 3.6 W/m^2K while the timber construction has the U-value of 1.4 W/m^2K.

3.1.2.2. First Floor

On the contrary to the ground level, first level shows a unique pattern throughout the whole floor. Despite the minor differences in thickness, the floor pattern, in general, can be assumed as the same. Floor thickness is 33 cm and it is composed of, from top to bottom, pinewood floor planks, air gap and pinewood ceiling cover. Actually, the layer which is stated as air gap refers to the timber beams that are set with the approximate spans of 1 m. Since the air gap occupies the majority of the layer composition, the component was assumed to be only air gap. The cross-section of the floor can be seen on Figure 3.13. U-value of the floor was calculated as 1.1 W/m^2K.

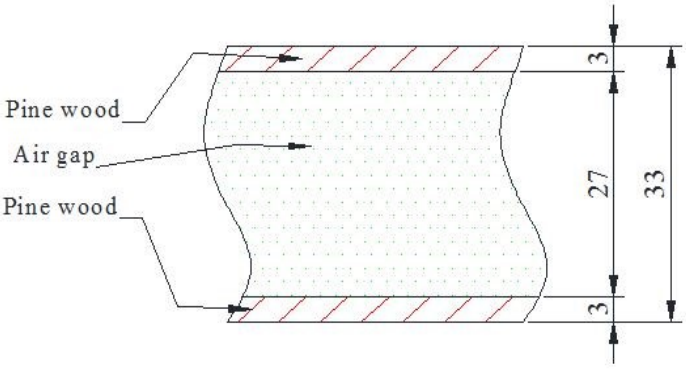


Figure 3.13. Cross-section of first floor

3.1.2.3. Basement Floor

Simply, the basement floor is compacted earth. This situation is presented as an assumption which considers the basement is composed of earth with 50 cm thickness so has the overal heat transfer coefficient of 1.5 W/m^{2}K.

3.1.2.4. Attic Floor

Attic floor has the similar composition to the one on the first floor. The only difference between them is the air gap thickness. Total attic floor thickness is 16 cm included the air gap thickness of 10 cm. Figure 3.14 illustrates the cross section of the floor.

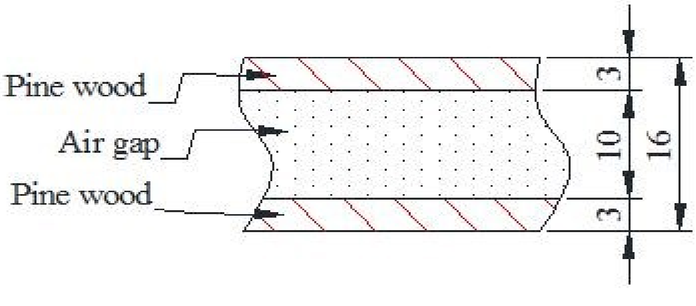


Figure 3.14. The cross section of the attic floor

As stated earlier, timber construction is assumed as air gap since the majority of the layer occupied by the air. Therefore the U-value of the floor is calculated as 1.1W/m^{2}K.

3.1.3. Pitched Roof

The building has a traditional pitched roof, which is presented in Figure 3.15. Constructional composition of the roof (from outermost to innermost layer) is clay tile, roofing felt and the pine wood planks nailed on the timber rafters. Construction elements, their thicknesses and U-value of the pitched roof are given on Table 3.3. Hence, U-value of the roof is calculated as 2.5 W/m^{2}K which is rather high regarding energy efficiency.

Table 3.3. U-value and the thickness of the construction elements of the roof

Layer	Material	Thickness (cm)
Outermost	Clay tile	3
1	Roofing felt	0.3
Innermost	Pine wood	3
U Value (W/m^2.K)	2.5	

Figure 3.15. Pitched roof before restoration
(Source: Dept. of Architectural Restoration - IZTECH)

3.1.4. Doors, Windows and Shutters

The glazing system of the building is a simply single pane vertical sliding sash window with wood frame. The windows are generally rectangular and have a 50% openable area with horizontal and vertical dividers. The windows can be open only vertical direction by sliding up and down. Two small windows are also available on the west façade of the building. Materials and overall heat transfer coefficients of the windows are presented in the Table 3.4.

Table 3.4. Window components and their overal heat transfer coefficient

Window Component	Material	U-value (W/m^2K)
Frame	Pine wood	3.2
Glazing	Glass (3mm)	3.2

Window components and their thermo-physical properties were selected from the library of the building energy simulation software DesignBuilder and the overall heat transfer coefficient of the frame and glazing were calculated as 3.2 W/m^2K for both.

Other openable components of the buildings are the doors. Four door patterns were observed throughout the building, which are presented on Table 3.5.

Table 3.5. Door types, materials and their overal heat transfer coefficient

Door Type	Material	U-value (W/m^2K)
External door	Iron	3.8
Basement doors	Iron	3.8
Wooden doors (frame)	Pine wood	3.6
Wooden doors (glazing)	Glass	3.2
Internal doors	Pine wood	2.3

External door which provides access to the house from the street (Figure 3.16) is composed of iron through its whole area and has a U-value of 3.8 W/m^2K. Similarly, basement doors have the same materials and thermo physical properties with the external door.

Wooden doors, which open to the garden at the ground floor and to the balcony at the first floor, have also rectangular shape and crowned with an arch. The difference in this door type is the glazing ratio which is less than 50%. Wooden internal doors of the building have overall heat transfer coefficient of 2.2 W/m^2K.

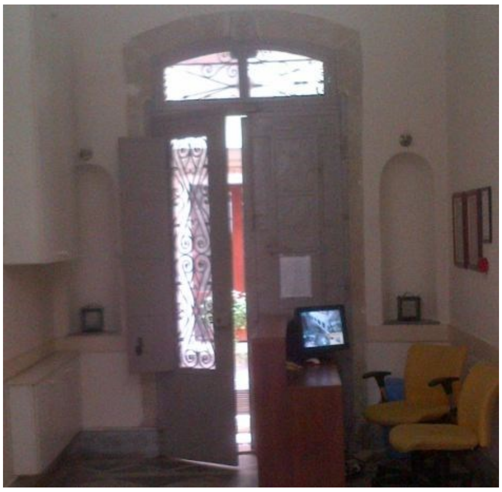


Figure 3.16. The external door

Shutters of the building are the simple, iron ones which can be seen from Figure 3.17. There are no shutters on the windows of the west end of longitudinal hall and on the *cumba*.

Figure 3.17. Shutters on the west façade

According to the observations done throughout the building, shutters are used for several purposes other than shading such as to keep the windows of unoccupied rooms clean and safe. Shutters of the first level rooms are kept closed out of the work hours.

3.2. Heating System of the Building

The building is heated by a hot water boiler with a capacity of 22 – 29 kW, which is located in the basement. The hot water in the boiler is distributed in the building through a hydronic system with radiators.

Radiators are located in each room and all have the same dimensions of 60 cm x 120 cm. The heating rate of the radiators, for 90/70°C(supply/return) temperature and 1 m length, were obtained from the manufacturer's catalogue (Baymak 2013). Nevertheless, heating rate of each radiator varies basically depending on the indoor air and the boiler hot water supply temperatures (MMO/2004/352). Table 3.6 shows the heating rate of the radiators calculated using Equations (3.1) and (3.2) for various indoor air and average supply/return temperatures.

$$\frac{q_s}{q} = \left[\frac{\Delta T_s}{\Delta T}\right]^n \left[s + (1-s)\left(\frac{101{,}325}{p_h}\right)^{4{,}67y-5{,}25)}\right] \quad (3.1)$$

Standard conditions are defined as 80°C for average supply/return temperature and 20°C indoor air temperature.

$$p_h = 101{,}325(1 - 2{,}25577 * 10^{-5}Z)^{5{,}2559} \quad (3.2)$$

Where Z is the elevation and is obtained as 19 m for the case building using Google Earth (GoogleEarth 2013).

Table 3.6. Heating rate (W) of the radiators for variousoperating conditions

		Indoor Air Temperature (°C)							
		17	18	19	20	21	22	23	24
Average Supply/Return Temperature (°C)	80	2406	2360	2315	2269	2224	2179	2134	2089
	75	2179	2134	2089	2044	2000	1955	1911	1867
	70	1955	1911	1867	1823	1780	1736	1693	1650
	65	1736	1693	1650	1607	1564	1522	1479	1437
	60	1522	1479	1437	1395	1353	1312	1270	1229

Under standard conditions, heating rate of the radiators is 2.3 kW while it is 1.5 kW at actual operating conditions which are 22^{0}C indoor air temperature and 65^{0}C average supply/return temperature. Figure 3.17 shows one of the radiators in the building.

Figure 3.18. A hot water radiator in the building

Heating system is operated manually by the administrator of the building during the working hours (09:00 – 17:00). For 2012 – 13 heating season, it was operated from November 1 to April 11th.

Figure 3.19 shows the radiant electric heaters used as auxiliary heating sources in the building. The working schedule of the electric heaters depends on the course schedule and occupant behaviour.

Figure 3.19. Radiant electric heaters

3.3. Lighting System of the Building

The building has the lighting system which is manually operated by the occupants depending on the luminance level in the space. Lighting is operated simply controlling two levels on/off button. First level turns on the half of the light bulbs while the second level does the whole. The light bulb used in the building is spiral shape, white colour and energy efficient. Due to the specifications obtained from the manufacturer's catalogue (Osram 2013), one light bulb provides 800 lumen illuminance flux consuming 13 W electricity. Figure 3.20 shows the light bulb used in the building.

Figure 3.20. The light bulb used in the building

Sufficient luminance level may vary according to the activity done in the space. In a study, the sufficient luminance level for the office work requiring the computer usage was found to be between 100 and 300 lux while the ones requiring less computer usage is between 300 and 600 lux (Galasiu and Veitch 2006). In this study, sufficient luminance level is assumed as 600 lux per space.

CHAPTER 4

METHODOLOGY

In this chapter, the methodology describing the process, in order to conduct an energy efficient retrofitting in historical buildings, will be explained step by step. First, the building energy simulation (BES) tools will be introduced and their significance in the methodology will be pointed out. Then,the validation techniques of the BES tools will be described.Later, both the significance of the simulation calibration and how the calibration work should be done will be given. Finally, the energy efficient retrofitting scenarios in accordance with the historical heritage values of the building will be defined. For a better understanding, a flow chart of the methodology is shown in Figure 4.1.

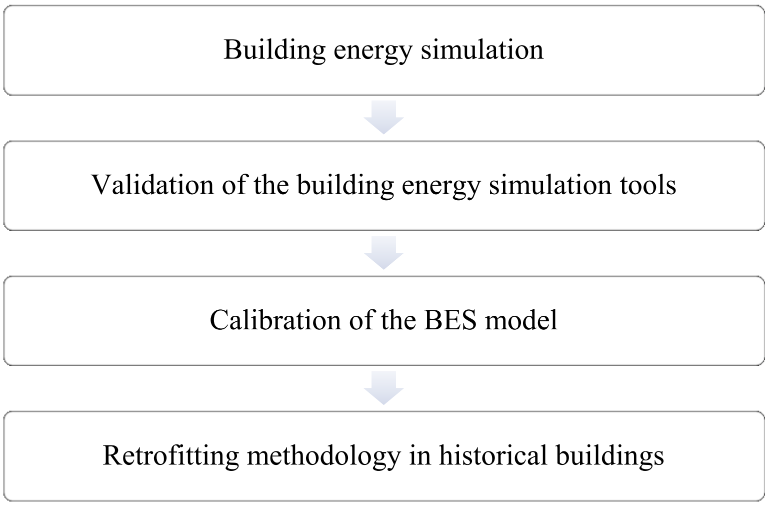


Figure 4.1. Flow diagram of the methodology

4.1. Building Energy Simulation Tools

Building energy simulation is a tool used to estimate the energy performance and thermal loads of the buildings. The typical use of the building energy simulation tools are to predict the energy use of the new buildings and that of in renovation regarding the heating, cooling, ventilation, air conditioning and architecture. After the first appearance of the BES tools around 1980s, they have been developed and improved to model and simulate complex and detailed systems (Ryan and Sanquist 2012).

Nowadays, there exists considerable number of BES tools around the world, which are mainly divided into two categories as simplified and detailed (EERE 2013). State-of-the-art BES tools such as EnergyPlus (EP 2013), DesignBuilder (DB 2013), ESP-r (ESP-r 2013), EDSL-Tas (EDSL 2013), provide detailed simulation while the simplified tools use less input for calculation due to the user's priorities (Melo et al. 2012). In spite of the presence of a large number of the simulation tools, their primary use is to meet the requirements for green building certification (Hoque 2012).

Possible variations in the simulation results might occur even though the BES tools are selected carefully and the users are highly expert on using them. According to comparative study results on the accuracy of the tools, there can be significant deviation between modelled results and actual design from 18% to 225%. This may be due to occupant behaviour, climate or meteorological data for the simulation period and impression in the energy model inputs (Hoque 2012).

Thus, the building's architecture, dynamic parameters such as occupancy, lighting and heating period, meteorological data and other inputs depending on the availability and ability of the BES tools should be well defined due to minimise the related uncertainties. The BES tools having ability to input the parameters in detail will increase the accuracy of the results and let the users make reliable calculations. In this study DesignBuilder (DB 2013) will be used as a BES tool in simulation calculations.

4.1.1. DesignBuilder BES Tool

DesignBuilder (DB 2013) is a dynamic building energy simulation software that has 3D modelling interface and uses the EnergyPlus (EP 2013) as calculation methodology in simulations. The software has different modelling features as well as lighting and energy modelling, CFD analysis, heating and cooling system design. It is possible to obtain and assess the results based on annually, monthly, daily, hourly and sub-hourly time intervals.

The software allows users to input variety of parameters that can be in detailed or simple concept. In other words, DesignBuilder does calculations in two basic methods which are simple or detailed. Simple method is used to simulate the building performance in situations requiring minimum parameters to be input while the detailed method asks users to enter as much as variables that have considerable impact on the results. In this thesis, both methods are used due to the input availibility.

One of the important parameters affecting energy simulation results is weather data. DesignBuilder has widespread weather data sets which make it possible to do building energy simulation worldwide. ASHRAE worldwide weather data (ASHRAE 2013)(4429 data sets) and locations are embeded in the software and also wide range of EnergyPlus weather data can be downloaded.

4.2. Validation of the BES Tools

The methodologies are reliable as long as they are validated. There are three validation methods which are, analytical, empirical and comparative (Judkoff and Neymark 1995). The advantages and disadvantages of these three validation methodologies are given in the Table 4.1.

Table 4.1. Validation techniques
(Source: Judkoff and Neymark 1995)

Validation Technique	Advantages	Disadvantages
Comparative	- No input uncertainty -Any level of complexity -Inexpensive -Quick	-No truth standard
Analytical	-No input uncertainty -Exact truth standard given the simplicity of the model Inexpensive	-No test of the model -Limited to cases for which analtical solutions can be derived
Empirical	-Approximate truth standard within experimental accuracy	-Measurement involves some degree of uncertainty -Detailed measurements of high quality are expensive and time-consuming -A limited number of data series are economically practical

Basically, each validation technique has its own advantages and disadvantages. Analytical validation technique is used to validate the BES tools or algorithm comparing to the results from a known analytical solution under simple boundary conditions. The advantageous sides of the technique are low cost, no input uncertainty and exact truth standard. On the other hand it is limited to the cases which analytical solutions can be derived (Judkoff and Neymark 1995).

Empirical validation is a technique which compares the calculated results with measured data from laboratory experiment or a real construction. Therefore the method is approximate truth and highly dependent of the experimental accuracy. However, the disadvantages are uncertainties and high cost due to detailed measurements (Judkoff and Neymark 1995).

Last, comparative validation is an approach which compares a methodology with itself or to other methodologies. Basically, the comparative technique includes sensitivity testing and inter-model comparisons. The prominent advantages of this technique is to be inexpensive and quick whilst it has no truth standard (Judkoff and Neymark 1995).

The BES tool that is intended to be used throughout the calculation should be validated using one of these techniques for the reliability of the results. Nowadays, several program developers started to pay attention and interest to publish the validation results (CA 2013).

4.3. Calibration of the BES Tools

Building energy simulations should be calibrated in order to better reflect the energy consumption of the building. In the literature, the most common ways to make a calibration are either to compare the utility bills with the consumption results of the simulation or to make a comparison between the indoor air temperature of measured and simulated data. A suggested way to conduct a simulation calibration is to tune the model by changing the thermal properties, internal gains, air-exchange rate and the other inputs of the models (Koranteng and Mahdavi 2011).

4.4. Energy Efficient Retrofitting Methodology in Historical Buildings

Energy efficient retrofitting in historical buildings requires an interdisciplinary approach of sustainable management based on both quantitative and qualitative values. In other words, the building having the heritage values can be assumed to be irreplaceable which requires special interest and cautious management (Eriksson et al. 2012). Thus, a method considering both heritage values and energy savings should be followed to obtain better solutions. Figure 4.2 illustrates the steps to be followed in this study, which was inspired from the standard (CEN).

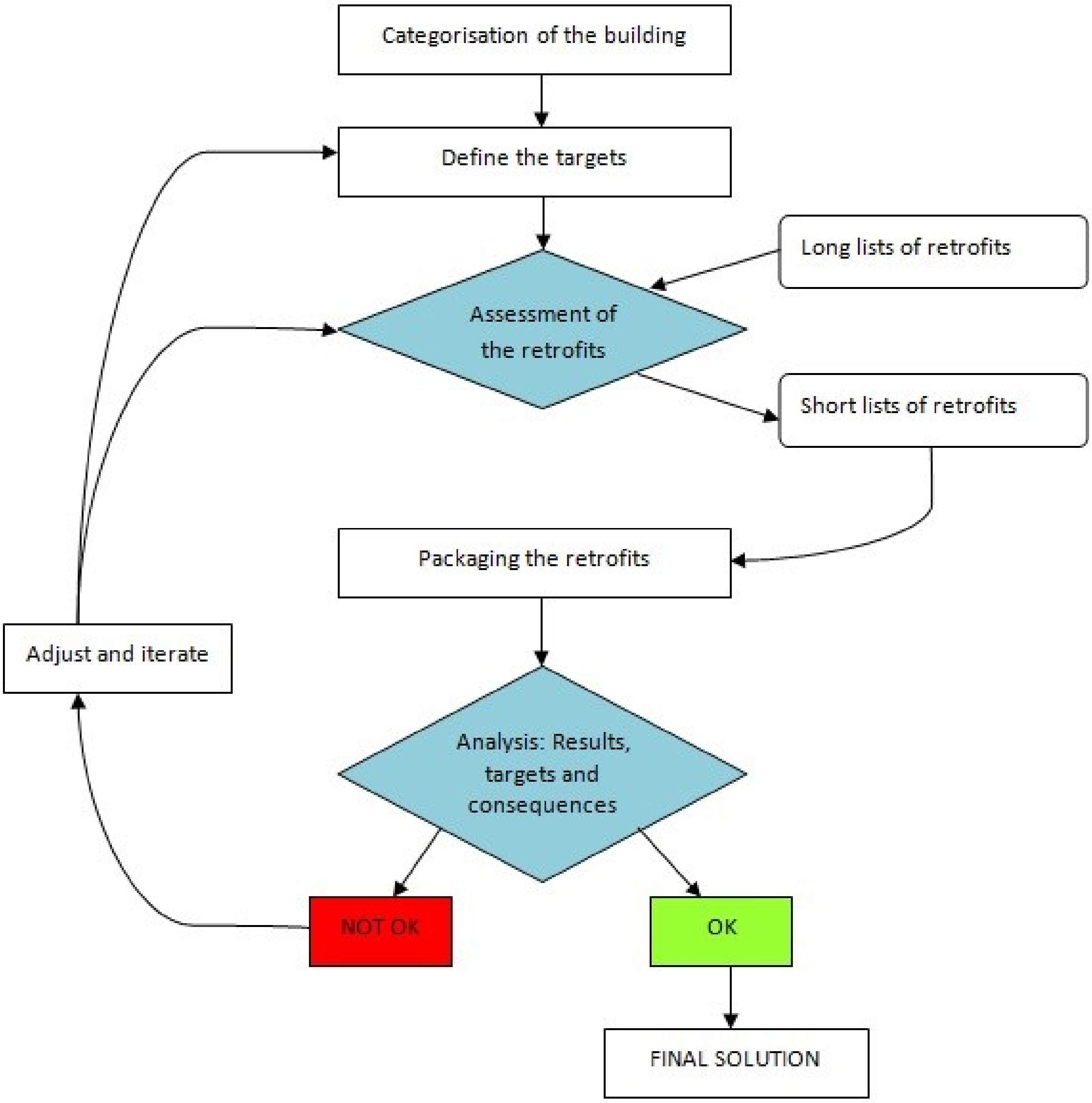


Figure 4.2. Flow chart illustrating the steps of the retrofitting methodology

Mainly, Figure 4.2 illustrates the following steps:

1. Building categorisation should be done based on available data.
2. Targets should be well defined.
3. The first assessment is done to select the better retrofits and eliminate the inappropriate ones.

4. Appropriate measures are gathered into groups to see their combined effect.
5. Results are interpreted according to the targets, cultural heritage values and building physics.

4.4.1. Building Characterisation

In order to assess energy efficient retrofits, their compatibility and potential, one must first try to comprehend what the term cultural heritage means to address. The buildings which possess cultural heritage value in the sense that they connect the present day to the past. They are, therefore, tangible records that enrich the lives, define the national identity, and express the diversity of our communities. Since they are unique and irreplaceable in terms of cultural significance, they must be well conserved and sustained for the next generations (BURRA 1999).

The principle behind building conservation requires a sensitive approach in adapting them to contemporary use as much as necessary with minimum interventions. Before taking decisions, heritage values of a place, a building or anythingelse should be well understood by the sequence of gathering and evaluating the information. The management policy, therefore, must include the understanding and characterisation of cultural and heritage significance (BURRA 1999). Thus, characterisation of the building is an initial and big step for the rest of the assessment.

The visual character of the building is highly associated with the architectural proportions, construction and materials. Hence, the building components such as walls, floors, roof, windows and doors might be counted as the significant features from the perspective of cultural heritage value. Replacement of those components with incompatible ones will thereby have negative impact on cultural heritage value of the building. After the character definition of the building, this will be used as the main criterion to weigh the risks and benefits of the energy efficient retrofits (Eriksson et al. 2012).

4.4.2. Targets

Retrofitting targets should be defined clearly before the analysis. In addition to the energy saving, cost saving, CO_2 emission reduction and preservation of the building can be defined as other targets within the analysis. Targets can be either single or multiple. Since the multiple targets might be problematic for decision making, the priority of the targets must be defined in relation to each other.

Quantitative targets can be defined based on the national policies, the international targets or user dependent decisions. As an example, the 2020 reduction target in energy consumption of Turkey and the EU is 10% and 20%, respectively (EEL 2007). For some cases, indoor environmental quality might be an issue to control. Other quantitative targets can similarly be defined. However, qualitative targets, which are highly related with the building characteristics, can vary due to a specific building or type of the building and the interpretation of national and regional policies.

4.4.3. Evaluation and Elimination of the Retrofits

Energy efficient retrofitting of historical building is a final product of interdisciplinary approach so that should be evaluated taking into account several criteria given below (Broström et al. 2013):

- Energy saving
- Cultural heritage values
- Durability
- Economic return
- Moisture
- Indoor environment

The first step for the retrofitting assessment is to introduce long list of interventions. In the second step, a risk-benefit analysis should be done to identify better solutions and eliminate the inappropriate ones. The scale of the risk-benefit analysis consists of five levels, which is shown on Table 4.2. Each level is coloured and will be used later in the analysis to better illustrate the assessment.

Table 4.2. Levels of risk-benefit analysis
(Source: CEN)

High risk	Low risk	Neutral	Low benefit	High benefit

4.4.4. Grouping the Retrofits

After the elimination of the inappropriate retrofits, a short list of possible interventions is obtained. The principle behind the combination of the retrofits is not only to meet the multiple targets but also see their combined effects. One should not forget that in order to conserve the building fabric at maximum level, the retrofits and works should be kept to the minimum necessity. Moreover, the changes on the building fabric should be reversible so that it can be returned to its original without damage (EH 2008).

4.4.5. Results and Their Assessment According to the Targets

Assessment of the retrofit packages is done in relation to the targets as specified in section 4.2.2. A package which does not meet the targets should be adjusted and iterated to obtain the desired results (Figure 4.2). At this point, one must realise that target definition and retrofit packaging play a significant role in the iterative progress.

CHAPTER 5

CASE STUDY

In this chapter, the methodology mentioned in the Chapter 4 will be applied to the case building, Basmane Semt Merkezi.

5.1. Energy Simulation of the Case Building

In order to run a building energy simulation, a series of inputs are required depending on the capabilities of the BES tool. The better the BES model the more accurate the results. Possible inputs and outputs of a BES tool are roughly illustrated in Figure 5.1.

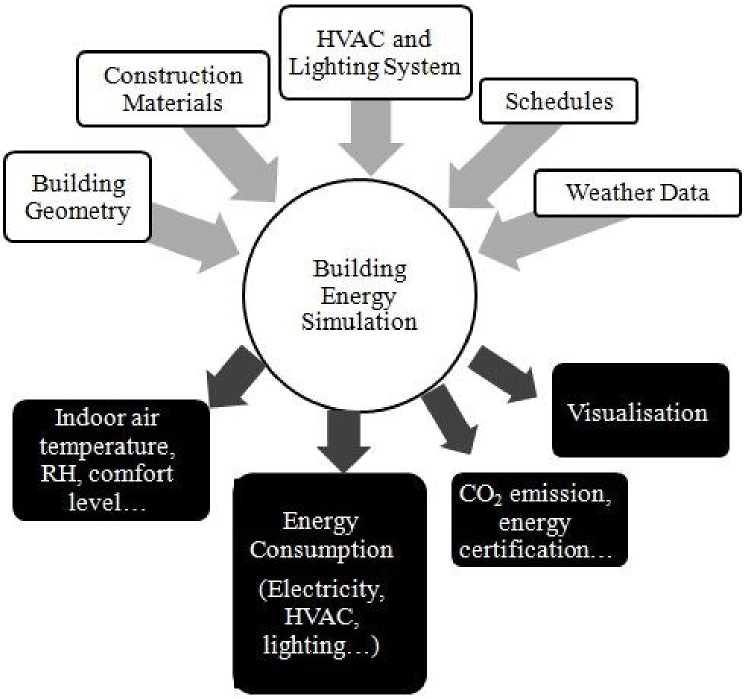


Figure 5.1. Inputs and outputs of the BES tool

Thus, the building geometry should, at first, be well-defined including the construction materials. Then, the inputs regarding the HVAC and lighting system of the building is computed. Later, occupancy related variables, such as heating system operation, window and door operation, are scheduled. Finally, weather data, which reflects the climate of the environment where of the building is located, is taken from the software library or measurements of the closest Meteorological Station.

Possible outputs that can be obtained via the BES tools are energy consumption (electricity, HVAC system fuel, lighting, etc.), indoor air temperature, relative humidity, comfort levels, a building energy certificate, and visualisation.

Inputs for the case study BES model will be given in the following sections.

5.1.1. Building Geometry

The Basmane Semt Merkezi was modeled along with neighbourhood to observe the shading effects on solar gain calculations, in 3D drawing interface of DesignBuilder (DB 2013). Architectural plans and dimensions were obtained from the Architectural Restoration Department of İzmir Institute of Technology and through field investigations.

As a traditional building, the house has a relatively regular geometry when compared to many others with irregular shapes and masses. However, some assumptions were unavoidable to simplify the building geometry to fit well for the building energy simulation model. Assumptions made on modelling the geometry of the case building are as below:

1. Since DesignBuilder has no ability to model stairs, it was modeled as a whole considering the volume it occupied in total.
2. In the DesignBuilder, partitions are assumed as a part of zones. Thus, halves of the partitions were assumed within the affiliated zone.
3. Storey height is the total height between the ceiling surface of a given storey and the ceiling surface of the storey below.
4. Adjacent buildings were assumed as adiabatic.

Figure 5.2 shows the building and its surroundings drawn on 3D user interface of DesignBuilder. Gray coloured items illustrate the neighbour buildings, of which indicated via A,B and C are assumed as adiabatic. The reasons to assume the buildings as adiabatic are to reduce the run time of the simulation and those buildings A and B are also occupied and conditioned.

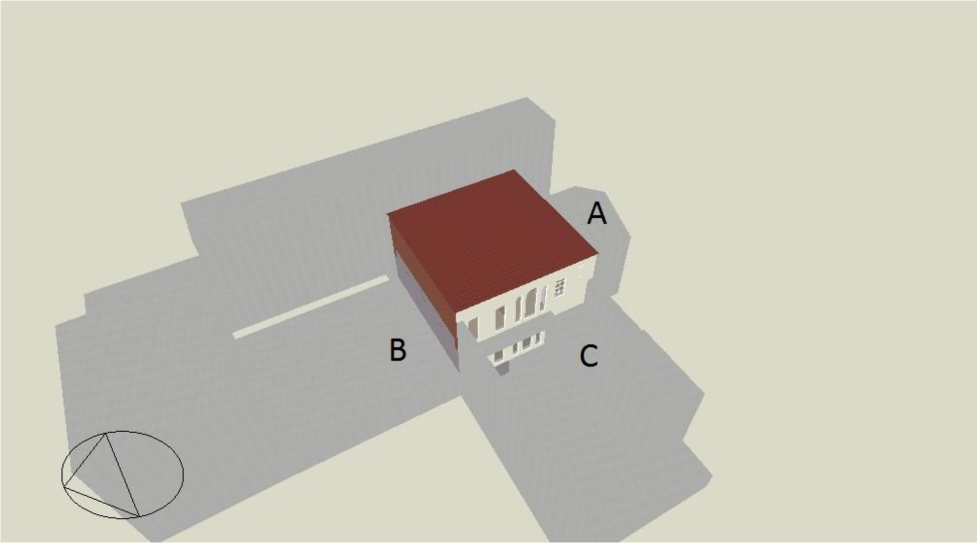


Figure 5.2. Basmane Semt Merkezi and the neighbour buildings

5.1.2. Schedules

One of the advantages of dynamic building energy simulation is to be able to define time dependent variables such as occupancy density, HVAC operation, internal gains and lighting operation.

DesignBuilder allows users to define the schedules which indicate the operational and occupancy dependant variations during a day, week, month and year. In this study, compact schedule format was used to minimise the operational and occupancy dependant errors in building energy simulation calculations.

5.1.3. Occupancy Schedule

Since the spaces in the building are used for different purposes at different times, occupancy pattern of each space shows variances accordingly. Table 5.1 denotes the weekly occupancy schedule for each room in the building.

Grey coloured squares in the table denote that the space is occupied between the specified hours by the number of occupantsspecified. Unless otherwise stated, this weekly occupancy schedule will be used.

Table 5.1. Occupancy schedule of the spaces

Space	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Starts at	Ends at	Number of Occupants
Administrator Room (Z01)	▨	▨	▨	▨	▨	▨		08:30	17:30	1
Classroom (Z02)	Unoccupied									
The Scout Room(Z03)	Unoccupied									
Guest Room (Z04)	Unoccupied									
Corridor (Z05)	▨	▨	▨	▨	▨	▨	▨	08:30	17:30	1
Administrator Room (101)	Unoccupied									
Ironing Room (102)	▨	▨	▨	▨	▨			09:30	15:30	1
Sewing Room (103)	▨	▨	▨	▨	▨			09:30	15:30	5
Marbling room (104)	▨	▨	▨	▨				09:30	15:30	5
Corridor (105)	▨	▨	▨		▨	▨		16:00	17:30	6

However, there exist some exceptions in regular weekly occupancy schedule due to several reasons. The space Z01, which used for administrative purpose, is also occupied at Saturday up to 12:30. The spaces 101, Z02, Z03 and Z04 are assumed as unioccupied because of the irregular and rare use. The zones 102, 103, 104, which are used for various courses, are unoccupied between the July 15 and October 1 because of the end of the course programs. The longitudinal corridor (105) at first level, which is also used as a classroom, is also occupied on Saturday between hours 11:30 and 13:00.

Moreover, because of the official holidays the occupancy schedule is not the same every week throughout a year. Therefore, the days, in which the building does not serve, ought to be defined. Table 5.2 gives the official holiday schedule that will be used in simulations.

Table 5.2. Official Holiday Schedule of Turkey 2013

Name	Start Day	Number of Days
New Years' Day	January 1	1
National Sovereignty and Children's Day	April 23	1
Workers' Day	May 1	1
Commemoration of Atatürk, Youth and Sports Day	May 19	1
Ramadan Bayram	August 8	4
Victory Day	August 30	1
Sacrifice Bayram	October 15	3
Republic Day	October 29	1

5.1.4. Heating Operation Schedule

The building is heated on weekdays between November 1 and April 11. The heating system is manually switched on at 08:30 and off at 17:30, which are the working hours, by the administrator of the building.

5.1.5. Auxiliary Heating Schedule

Although the heating system is in operation, auxilary heating sources are also used to meet the occupants’ comfort requirements. Thus, radiant electrical heaters are used in the spaces which are Z01, Z05, 103, 104, and 105. Operation of the electrical heaters is in accordance with the specified occupancy schedule and heating operation schedule.

5.1.6. Equipment Schedule

Other heat sources that ought to be taken into account in energy simulations are equipment such as, computer, printer, fax machine, television and iron. In the building, three computers, one printer and one iron are used. The usage of each equipment depends on the occupancy schedule of the specified room.

Moreover, the heat gain of each equipment needs to be defined clearly. A study on the heat gain data for the office equipment denotes that the heat gain from any office equipment is not the value given in the nameplate (Hosni and Beck 2011). Therefore the actual heat gains from the office equipments were obtained. Hence, desktop computer in the spaces Z01 and Z05 are assumed to give off 65W heat to indoor environment. Also, the heat gains from the small multifunctional printer and iron are 15 W and 2400 W for the spaces indicated, respectively.

5.1.7. Lighting Schedule

Lighting is manually operated in the building when the occupants feel the luminance level in any space is not sufficient.As stated earlier in Chapter 3, 600 lux will be assumed as a minimum threshold luminance level to switch the lights on. Table 5.3 indicates the number of lighting fixture and supplied luminance level.

Table 5.3. Lighting fixtures and supplied luminance level per space

	The Space	Floor Area (m^2)	Number of Fixtures	Lux
Ground level	Administrator Room (Z01)	23.2	5	172
	Classroom (Z02)	15.99	4	200
	The Scout Room (Z03)	10.17	2	157
	Guest Room (Z04)	20.23	4	158
	Corridor (Z05)	30.98	5	129
First level	Administrator Room (101)	23.34	2	68
	Ironing Room (102)	10.13	3	237
	Sewing Room (103)	15.51	4	206
	Marbling Room (104)	20.26	4	158
	Corridor (105)	42.64	10	187

In lighting calculations, a two step operation pattern was used, which models the lighting operation switching on the whole or half of the lighting fixtures according to the minimum threshold level. Even though the lighting is operated by occupants, the simulation model is expected to reflect the similar pattern with the operation. Lighting simulations were modeled taking into consideration of occupancy schedule specified for each space.

5.1.8. Internal and External Door Schedule

Internal doors are the significant components if the spaces in the building are conditioned independently. Therefore, taking into consideration of the duration of opening the internal door is an important issue for heat loss calculations. DesignBuilder allows users to model the situation defining the parameter “time door is open” in percentage, which means that the door is kept open during occupancy period.

In the study, internal doors were assumed to be open 5% of their occupancy period. In other words, if the space is occupied for 100 minutes, the internal door is assumed to be open for 5 minutes in total. External doors, on the other hand, show different pattern depending on the season. The main door opening to the street is observed to be fully open on working hours between the months May and October while it is assumed to be open 5% out of that time period. The door opening to the garden has similar pattern as the main door.

5.1.9. Shading Schedule

Shading operation of the building is rather complicated because of the irregular use. For this reason, assumptions were made to simplify the operation schedule. Thus, the shadings except than the ones on first level east façade are modeled always on. The reason why the shadings on the ground floor are kept closed is due to safety and cleaning issues.

5.1.10. Window Schedule

According to the observations and comments of the occupants it was determined that the windows had been close majority of the occupancy period. Also, service staff in the building stated that they did care of keeping the windows shut down because of the cleaning and security purposes. Thus, windows were modelled and scheduled as closed in order to reduce the occupancy related uncertainties.

5.2. Validation of DesignBuilder BES Tool

The following section will introduce the validation results of DesignBuilder obtained applying a comparative validation technique.

5.2.1. Building Energy Simulation Test (BESTEST)

BESTEST is a procedure, which was developed by International Energy Agency (IEA) in 1995, to test and diagnose the building energy simulation programs. Later, ASHRAE Standard 140 (ASHRAE140-2007 2010) was developed using the BESTEST procedure (Melo et al. 2012). The procedure contains several tests assessing the effect of physical properties on the results of building energy simulations. The purpose of this procedure is to create obvious, well-defined test series for software-to-software comparisons and program diagnostics. Not every simulation program requires the same input to do calculations. Hence, test series defined in BESTEST are designed to test different building simulation programs (Judkoff and Neymark 1995).

There are 36 BESTEST cases in all, plus 4 free-floating cases (no heating or cooling). These cases are classified as either qualification or diagnostic cases. A recommended way to apply the procedure is to run the qualification test first. The remaining cases are designed for diagnostic purposes (Judkoff and Neymark 1995). In this Thesis, 11 qualification tests for heating are considered since the building is neither cooled nor mechanically ventilated.

The procedure was designed to observe the effect of one parameter being changed case by case on the simulation results. According to the procedure, a program is assumed to pass the qualification cases when the results are favourable with the results of both qualification and sensitivity cases of reference programs (acceptance range) (Judkoff and Neymark 1995). Sensitivity cases test the increment or decrement magnitude of the methodology according to the parameter changed every case.

Qualification cases are divided into two categories, which are lightweight (600 series) and heavyweight (900 series) thermal mass cases. The Case 600 is the base case which takes into consideration of the test construction illustrated on Figure 5.3. Other test cases are variations of the base construction.

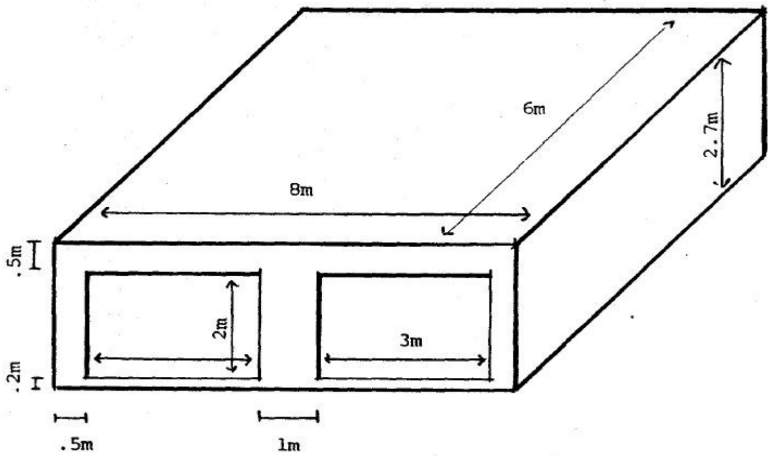


Figure 5.3 Isometric view of test case 600
(Source: Judkoff and Neymark 1995)

Table 5.4 shows 11 qualification cases. Accordingly, the Case 610 includes 1 moverhang on south facade different from Case 600. The Case 620 considers 6m^2 windowin the west and east façades. The Case 630 includes 1 m overhang extended across the 3m width of each window and side fins different from Case 620. The Case 640 considers set-back termostat at 10°C between 23:00 and 07:00 different than Case 600. The heavyweight cases are geometrically the same as the lightweight cases except than thermal mass. In addition to heavyweight cases, there exists case 960 which considers 2m x 6m south-facing sunspace with 12m^2 window.

Table 5.4. Description of BESTEST qualification cases

Case no.	Description
Case 600/900	8m x 6m x 2.7m ; South facing 12 m^2 window, no shading; internal gains 200W;infiltration rate 0.5 ACH;
Case 610/910	Same as Case 600/900 with 1 m full-width overhang on south facade
Case 620/920	Same as Case 600/900 but with a 6 m^2 east window and a 6 m^2 west window, no shading.
Case 630/930	Same as Case 620/920with 1 m overhang over windows only, plus 1 m fins on both sides of each window.
Case 640/940	Same as 600/900 but heating thermostat set back to 10°C from 23:00 to 07:00
Case 960	Sunspace: 2m x 6m heavyweight south-facing sunspace zone with 12m^2 window; 6m x 8m lightweight back zone separated from sunspace zone by a mass wall. Back zone as for case 600

Figure 5.4 illustrates the results of low mass (qualification) cases for heating while the Figure 5.5 does the results of sensitivity tests. The horizontal black and red lines refer to the maximum and minimum threshold values (acceptance range), respectively. Basically, the results within or close to the acceptance range can be assessed as reasonable.

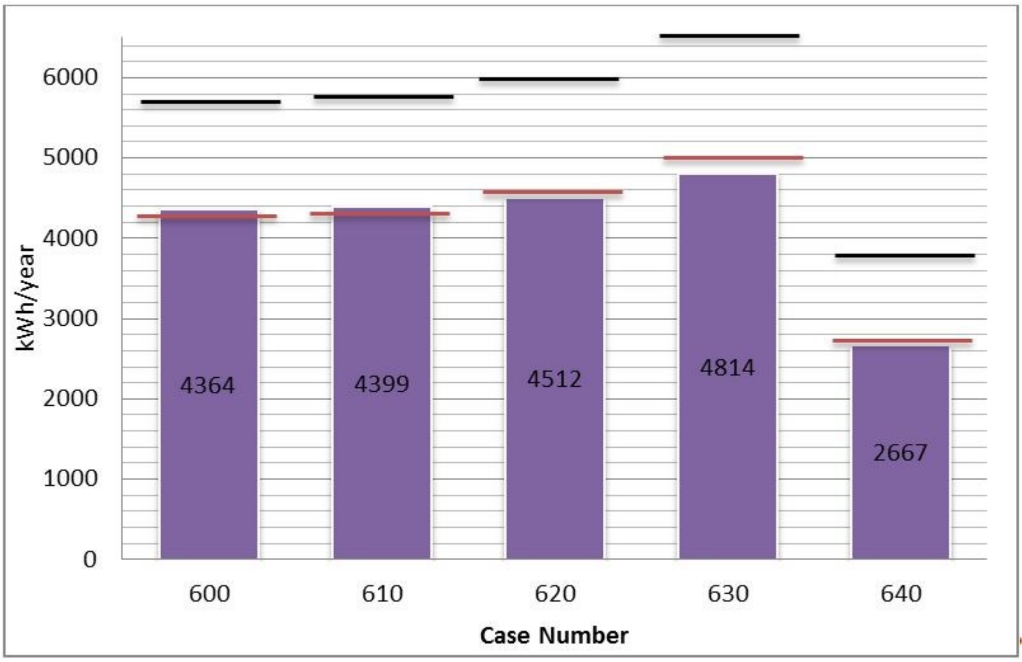


Figure 5.4. Test results of low mass (qualification) cases for heating
(Source: DBV 2011)

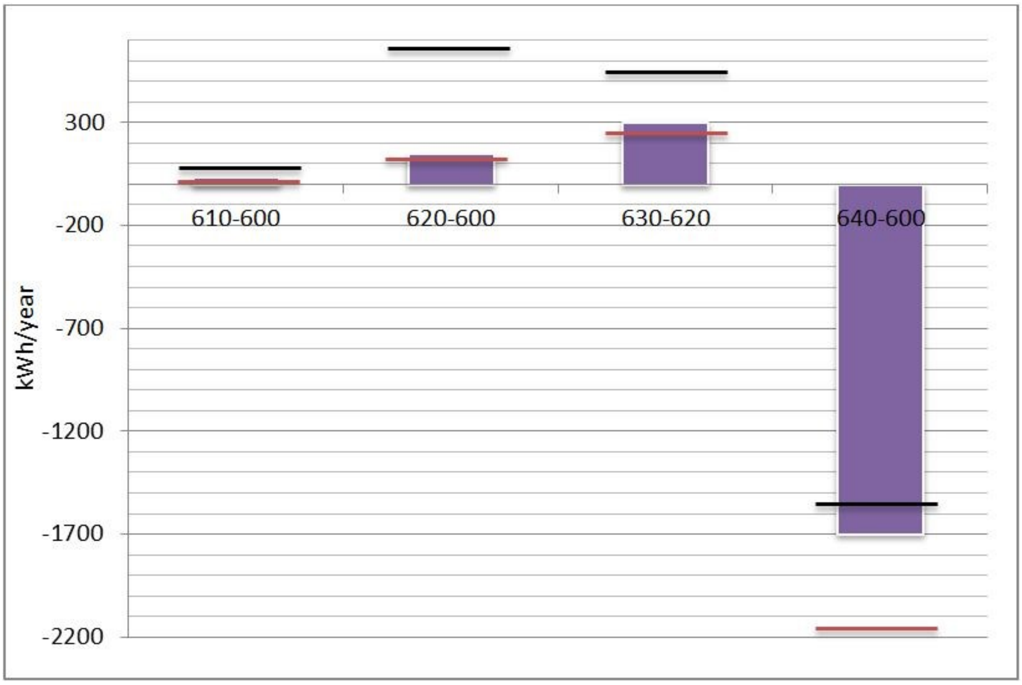


Figure 5.5. The results of sensitivity cases for low mass heating
(Source: DBV 2011)

Similarly, Figure 5.6 shows the results of high mass (qualification) cases for heating while the Figure 5.7 does the results of the corresponding sensitivity tests.

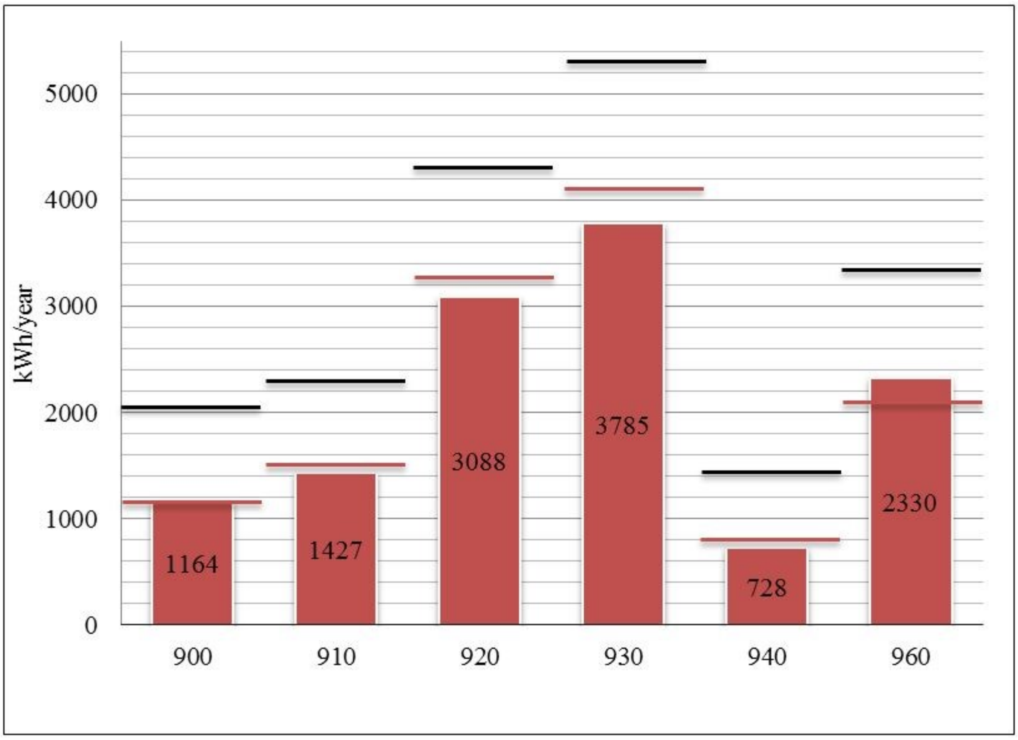


Figure 5.6. Test results of highmass (qualification) cases
(Source:DBV 2011)

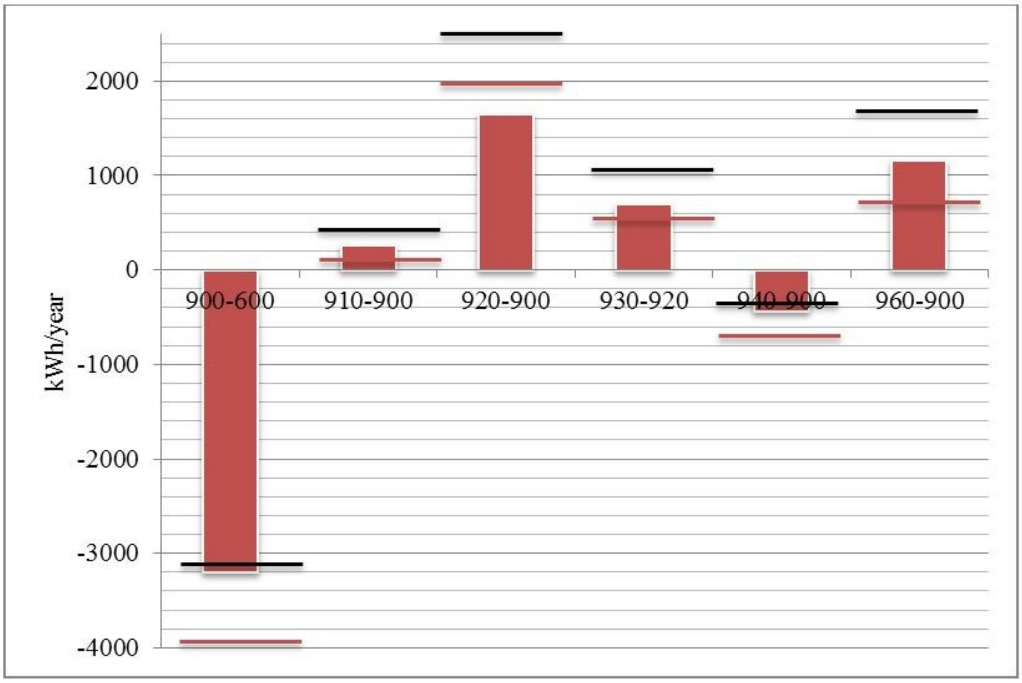


Figure 5.7. The results of sensitivity cases for high mass heating
(Source: DBV 2011)

According to the results, majority of DesignBuilder results are outside the acceptance range (lower than minimum threshold value). Despite the discrepancy on qualification cases, the results are reasonable when considering with the sensitivity cases (DBV 2011).

5.3. Calibration

In this study, building energy simulation calibration will be first made comparing the measured and simulated indoor temperature, then comparing the utility bills to the simulation results. Low cost data loggers (HOBO 2013) were used to measure the indoor and outdoor dry-bulb temperatures. Also, utility bills regarding electricity and fuel consumption were obtained from the building administration.

Calibration of the measurement equipment is also essential to make reliable commitment. The initial calibration information for the low cost data loggers is given in Table 5.5. However, no calibration process has been made since the data loggers were purchased. Therefore, the data loggers need to be calibrated either having it made via the authorised institute or using calibrated equipment.

Table 5.5 Initial calibration information of the low cost data loggers

Parameter	Calibration Data
Temperature	± 0.4°C at 25°C (± 0.7°F at 77°F)
Relative Humidity	± 2.5% from 10% to 90%
External Input	± 2 mV ± 2.5% of absolute reading

In this study, calibration of the low cost data loggers was made using an environmental chamber. Only the dry bulb temperature was considered during the process. Environmental chamber was set to the temperature interval between 0°C and 36°C with 0.4°C temperature increment per minute. Then, the data loggers were started to log the data simultaneously with the environmental chamber. At the end of the 90 minutes, calibration of each data loggers was determined around ± 2.5°C for 0°C - 36°C temperature interval.

Completing the calibration of the low cost data loggers, they were located into the building to measure the dry-bulb temperature of each room and outside for 10 days, which is between May 28th and June 6th, 2013. Location of the each data logger was indicated on the building plan (Figure 3.2 and Figure 3.3) with a small triangle shape. Data loggers inside the building were located approximately 2m high and all data loggers were placed in a position that not exposed to direct sunlight. Measured outdoor temperature data were integrated into the simulation weather data. For the measurement period, simulation was run and the results were compared to the measured temperatures of each room. Figure 5.8 illustrates the comparison of the measured and simulated indoor dry-bulb temperature results for 96 hours period in a sequence within the measured period.

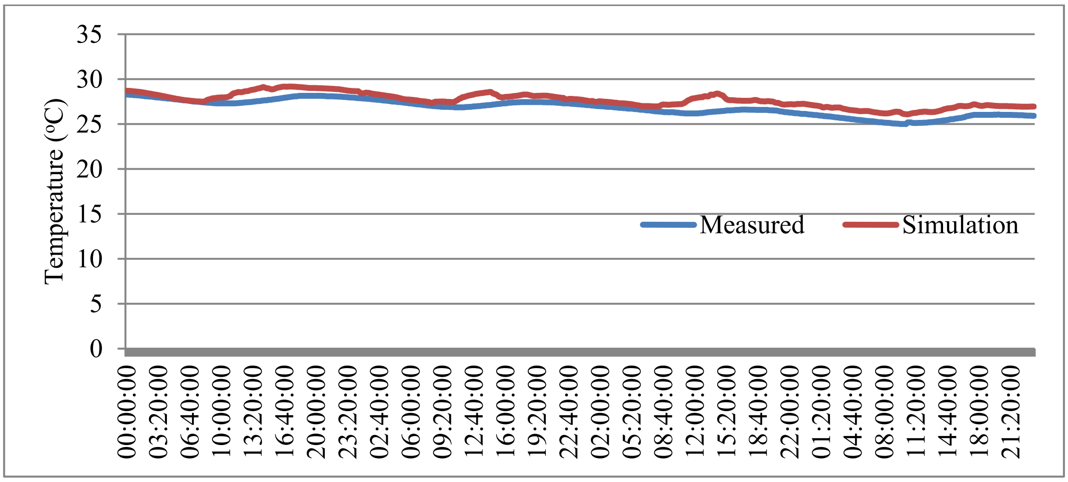


Figure 5.8. Comparison of measured and simulated data (Room 102)

It can be seen from the Figure 5.8 that measured and simulated data show parallel pattern with the negligible temperature differences throughout the period. In ASHRAE Guideline 14 (ASHRAE 2002), acceptable tolerances for calibration of the BES model are required to be compared due mean bias error (MBE) and coefficient of variation of root-mean-squared error (CV(RMSE)). According to the Guideline, models are assumed to be calibrated if MBE and CV(RMSE) are within ±10% and ±30%, respectively when hourly data considered. For each room, errors between the simulated hourly dry-bulb temperatures and the measured ones are given in Table 5.6. The MBE, RMSE and CV(RMSE) were calculated using the equations below (Kandil and Love 2013; Özgören *et al.* 2013).

$$MBE = {(\sum_{i=1}^{n} Residual_i)}/{n} \tag{5.1}$$

$$RMSE = \left[\sum_{i=1}^{n} |\mathrm{t_i} - \mathrm{o_i}|^2 \Big/ \mathrm{n} \right]^{1/2} \tag{5.2}$$

$$CV\left(RMSE_{period}\right) = {RMSE_{period}} \Big/ {A_{period}} \tag{5.3}$$

Table 5.6. Errors for calibration of the BES model for each room

The Spaces	MBE (%)	CV(RMSE) (%)
Administrator Room (Z01)	2.0	5.2
Classroom (Z02)	0.5	2.2
The Scouts Room (Z03)	1.8	3.4
Guest Room (Z04)	1.2	2.6
Corridor (Z05)	0.8	4.3
Administrator Room (101)	4.3	5.0
Ironing Room (102)	4.3	4.9
Sewing Room (103)	2.2	3.2
Marbling Room (104)	1.9	2.8
Corridor (105)	5.8	6.7

Moreover, fuel consumptions regarding electricity and fuel-oil were compared. Figure 5.9 shows the calibration results of the electricity consumption of the building, which is mainly dependent on heating, lighting and office equipment. The comparison denotes that simulation results show similar trend with the recent and previous year's consumption figures on a monthly basis.

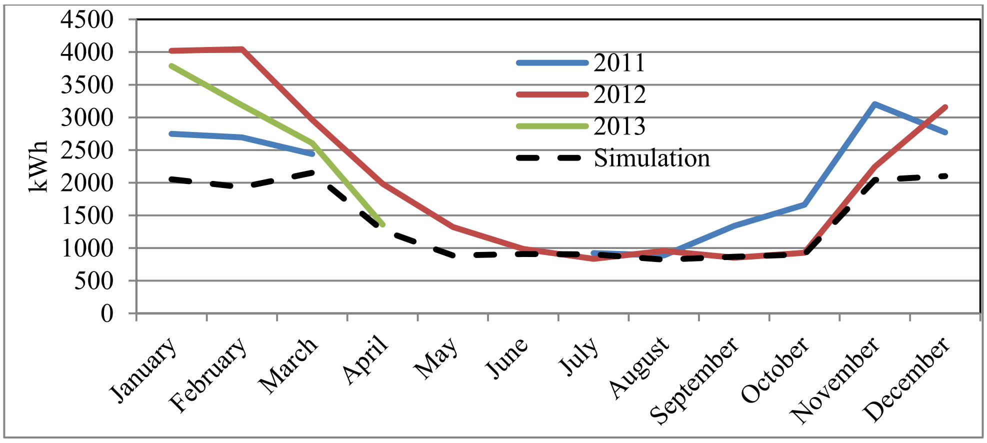


Figure 5.9. Comparison of electricity utility bills and simulation results

Variations in the actual yearly usage figures may be related to the heating degree days (HDD) since the electricity consumption is highly dependent on heating. Figure 5.10 illustrates the HDD of İzmir for the given years. According to the figure, it is possible to say that HDD shows similar pattern with the electricity consumption on both annual and monthly basis.

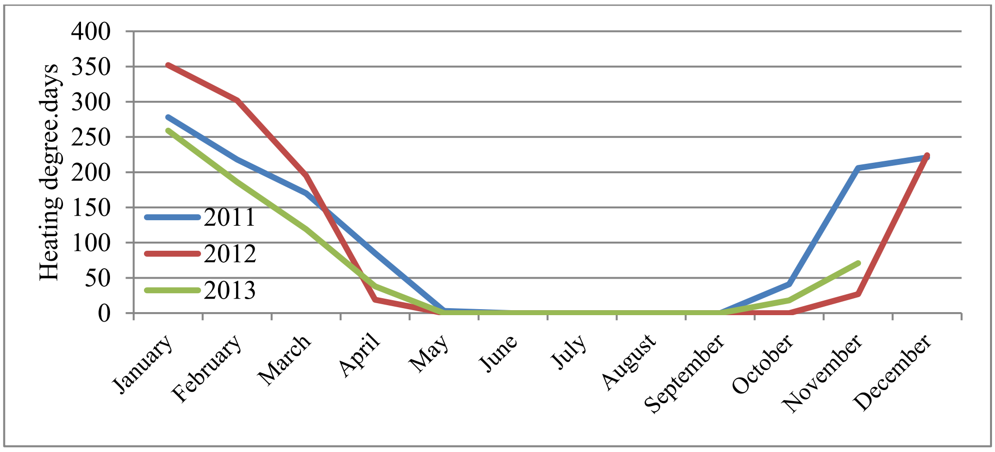


Figure 5.10. Heating degree days of İzmir (Source: DMİ 2013)

Other criterion for the simulation calibration is the fuel-oil consumption figures. Due to the information obtained from the building administration, the fuel-oil consumption for heating was not monitored on the monthly basis. Therefore, the calibration was made due to the annual figures, which can be seen on Figure 5.11.

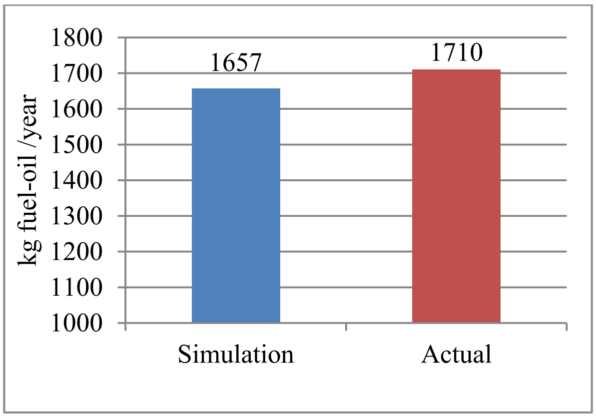


Figure 5.11. Comparison of simulated and actual fuel oil consumption figures

Generally speaking, calibration results show that the BES model of the case building reflects the energy consumptions in an acceptable range.

5.4. Retrofitting

5.4.1. Characterisation of the Case Building

The purpose of the characterisation is to define the heritage value of the case building. Basically, characterisation will be done considering the energy related components especially regarding the building envelope such as walls, doors, windows, roof, floors and shutters. Regarding the historical value of interior decoration elements like mirrors, lighting fixtures and paintings, no special interest will be shown since the content of this thesis is highly associated with energy efficiency.

The rich details of plasterwork and stone claddings with ornamentations on the east façade (Figure 5.12) show that the building was originally built as a typical home for a noble family. The prominent east façade played an important role in the streetscape. On the contrary, west façade consists of relatively plain texture except the stone frames around the windows and doors. The north and south walls, on the other hand, are rather simply built using bricks without plaster.

Figure 5.12. East façade of the building

The internal partitions were built using a timber frame which was then plastered and painted. One detail that makes the internal walls valuable is the plaster cornices.

The wooden windows are tangible elements that enrich the building appearance. Wooden frame and single glazed windows with horizontal and vertical dividers all of which reached today with their original materials and forms make them worth to preserve. Figure 5.13 illustrates a window example from the building.

Figure 5.13. A window with wooden lattices on the *cumba*

The exterior door is made of iron with ornamentations having a considerable impact on the main façade. In addition, doors with wooden frame and crowned with arches placed on the rear façade are other impressive elements perceived from the rich and prestigous garden (Figure 5.14).

Figure 5.14. Wooden frame, arc shaped exterior doors

The floor construction shows different compositions on the ground level whilst it is uniform on the first floor. On ground level, the original marble floor is laid out longitudinally enriching the entrance whilst the rooms have a traditional timber floor pattern.

The *cumba,* which is at the east end of first floor, is a traditional architectural element with a typical wooden framed windows supported by ornamented iron framework. This is a particular component which adds aesthetic value to the building's main façade (Figure 5.12).

To sum up, it can be said that the building's street façade is characterised by its; highly decorated plasterwork and ornamented stone panels, typical for the architectural trends of the late 1800's, and the distinguished hand-made *cumba* supported with cast iron brackets. Any retrofits conflicting with these values would not only harm the building's architectural values, but also, distort the surroundings to some extent. In addition it is also important to acknowledge the traditional single glazed windows with their original forms and materials.

5.4.2. Targets

In this study, the targets and their priorities are defined as below:

a) Reduction in energy consumption:

- The European Union, 20% per year.
- Arbitrary target, 50% per year.

b) Reduction in overall heat transfer coefficients of opaque and transparent components according to the Turkish Standard of TS825 (TS825 2008).

In the TS825, maximum overall heat transfer coefficients for walls, floors, ceilings and windows are described according to climatic regions. Climatic region is defined based on the degree-day phenomenon, which basically categorises the cities (even districts in some cases) due to their coldness magnitude. There are four climatic zones in Turkey from the heating degree day point of view and the U-value limits were described accordingly. Table 5.7 gives the U-value limit according to TS825. Since İzmir is in the first climatic zone, corresponding U-values will be taken into consideration.

Table 5.7. Maximum overall heat transfer coefficients
(Source: TS825 2008)

Climate Zone	Wall (W/m^2K)	Ceiling (W/m^2K)	Floor (W/m^2K)	Windows (W/m^2K)
1st zone	0.70	0.45	0.70	2.40
2nd zone	0.60	0.40	0.60	2.40
3rd zone	0.50	0.30	0.45	2.40
4th zone	0.40	0.25	0.40	2.40

c) Targets on building conservation:

- No visual changes on building appearance are accepted
- Some material changes on construction are accepted

5.4.3. Assessment of the Retrofits

5.4.3.1. Long List of the Retrofits

There is a wide range of possible energy efficient retrofitting interventions. Based on the literature survey and the applicability of the interventions with the BES tool, the following retrofits were chosen for first long list of common interventions.

a) Air tightness improvement of the building envelope (Weather stripping)

Air leakages are more or less responsible for 15% of the heat loss from the buildings (ENH 2008). Generally, heat loss/gain via air leakages occurs from the windows, doors and floors. Therefore, air sealing of these components is thought to be straightforward and relatively cheap interventions for energy saving. Nevertheless, improving the air tightness might affect the ventilation in a negative way since it depends on air leakages in historical buildings. For this reason, it might be seen as a risk for moisture increase and mould growth.

b) Temperature control

Generally, heating in the buildings can be controlled with two ways, which are room thermostats and timers. Employing the new high efficient heating system must be controllable. Most of the heating control applications such as, an electronic timer, a room thermostat, thermostatic radiator valves and a hot water tank thermostat, can be added to the existing systems or included in the new ones (ENH 2008). The temperature, for example, in the unoccupied spaces can be dimmed in order to obtain lower heating system loads and eventually the lower fuel consumption.

c) Changing the windows

Windows are the building components having impact on heat loss around 10% (ENH 2008), which should not be underestimated. Original windows may carry great historical values with their quality and dynamic surface and should thus be treated carefully in similar situations. Therefore changing the windows will be risky and destructive option for the cultural heritage value of the building. On the other hand, it is an option which has high energy saving potential.

d) Insulation of the attic floor

Generally, adding extra insulation layer to the attic floor has no negative impact on the historical heritage value. Heat losses will thereby decrease whilst the attic may be vulnerable to mould damage due to lower temperatures and higher relative humidity (RH) during winter.

e) Insulation of the roof

Roofs are responsible of considerable the heat loss from the buildings. In historical buildings, roof insulation has no adverse effects on roof itself providing that the installation work is carried out carefully (ENH 2008). Benefits of the roof insulation are to keep the attic environment warm and prevent the moisture increase. On the other hand, it might be risky for some cases to add insulation layer due to the change on the building appearance.

f) Exterior insulation of the walls

Typically 35% (ENH 2008) of the heat loss occurs through the walls. External insulation can be assessed as an appropriate application from the energy saving perspective since it has low risk of moisture damage and decreases the thermal bridges. However, many walls in historical buildings contain dressed stone facings, brick façade and some architectural details, which make the external insulation option highly risky for the building appearance and heritage value.

g) Interior insulation of the walls

For some cases, internal wall insulation appears to be favourable retrofit from the building conservation point of view. On one hand, depending on the thickness of the insulation material it increases the thermal resistance of the wall whilst reduces the space. On the other hand, there exists a significant obstacle in front of this intervention which is dampness. If the insulation material added to the older porous wall is non-breathing, this might cause damp within the wall. Therefore the material used for internal insulation should be breathable and special interest should be given to the dampness issue.

h) Additional insulation on the floor

Depending on the structural composition of the building, it can be solid or suspended timber floor. For solid floors such as plaster or lime ash, stone, marble, it might not be possible to insulate the floor without excavating. Therefore this application ought to be avoided, if it is not the only solution to fix a problem (EH 2008).

In timber buildings, floor insulation may be added in two ways, from above and below. Insulating the floor from above requires extra attention not to damage the floorboards. On the other hand installation from below is straightforward providing that there exist enough space to work on. Insulation material can, for example, be pushed between the joists and supported by nylon netting fixed under the joists (ENH 2008). Figure 5.15 shows how insulation (from below) process is made for suspended timber floors.

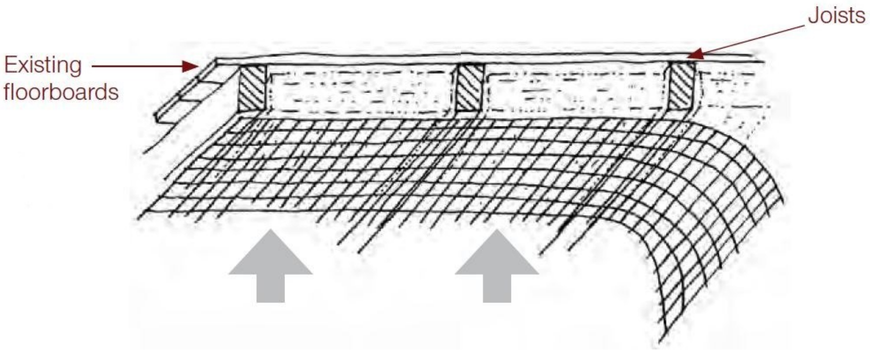


Figure 5.15. Insulation (from below) for suspended timber floors
(Source: ENH 2008)

Nevertheless, after insulation air temperature in crawl space decreases so that it may cause risk of microbial growth due to the high relative humidity (Eriksson et al. 2012). Therefore, both benefits and risk of floor insulation should be weighted at the same time.

i) Changing the heating system

Since the original heating system is well connected with the architectural details it is recommended to keep in mind the original function of the building before making decision on installing new heating system in a historical building (Eriksson et al. 2012). For example, changing (if available) both the boiler and fuel of hot water radiator system is a preferable solution in conservation terms instead of switching to air-to-air heat pump system.

j) Renewable energy sources

Using renewable energy in the buildings does not mean decreasing the energy consumption. Basically, it is to reduce energy related carbon dioxide emissions. The most common renewable energy application in the buildings is to use solar collectors on top of the roofs or façades. However, this will have an impact on the building's appearance. Thus, benefits and risk of renewable energy application need to be well considered before making decision.

5.4.4. Risk & Benefit Analysis of the Retrofits

As stated earlier the risk and benefits of any retrofit can vary depending on the character and heritage values of the building. Therefore, characterisation should be done carefully. Table 5.8 summaries the risk – benefit analysis for the case building, *Basmane Semt Merkezi*. The assessment criteria and what the colours mean were explained in the Section 4.4.3.

Air tightness improvement of the building envelope is generally a straightforward and cheap application. It provides high benefits reducing the heat losses occurring through the draughts. On the other hand, it might cause a low risk for mould growth since the air exchange rate of the case building envelope was reduced.

Changing the windows with the ones having lower U-value is doubtlessly highly risky for the aesthetic view and heritage values of the case building even though it explicitly reduces the heat losses. Also the windows are the retrofits and investments having long term pay-back period from economical perspective.

Table 5.8. Risk and benefits of the retrofits for the case building

Intervention	Assessment					
	Energy Savings	Economic	Heritage Values	Durability	Moisture	Indoor env.
Weather stripping	Reduces heat loss	Cheap	No damage	Should be renewed frequently	Low moisture and mould risk	Improvement
Temperature control	Reduces the excessive heating	Cheap	No damage	Long life time	Beneficial	Improved thermal comfort
Changing the windows	Low U value	Expensive way, long payback period	Negative impact on architectural view, loss of heritage value, high risk	Long life time	Neutral	Improved thermal comfort
Insulation of the attic floor	Decreases heat loss, medium benefit	Expensive	No impact	Long life time	Low moisture and mould risk on the attic	Minor improvement
Additional insulation of the roof	Diminish heat loss medium benefit	Expensive	Minor effect on building appearance	Long life time	Low risk	Minor improvement
Exterior insulation of walls	High energy savings	Expensive	High risk on building appearance and heritage value	Long life time	Almost no moisture risk	Improved thermal comfort
Interior insulation of walls	High benefit	Fairly expensive, long pay-back time	No damage for the case building	Long life time	Should be breathing material	Beneficial
Additional insulation on ground floor	Reduces the heat losses from the basement	Rather expensive	Might require special attention for installation	Long life time	Attention should be paid for basement	Improvement
Changing the heating system and/or fuel	High energy saving	Expensive and long pay-back time	No impact	Long life time	Neutral	Improvement
Renewable energy sources (Solar panel application)	Energy Production	Fairly expensive	High risk on building appearance	Long life time	Neutral	Neutral

Attic floor insulation, in theory, is expected to be an acceptable solution for the case building due to no damage risk on the building appearance. It, however, jeopardises the attic environment increasing the moisture as a result of temperature decrease, in practice. Adding extra insulation layer to the roof appears to be low risk for the building fabric since refitting of the roof tiles is a simple application. Moreover, it increases the thermal resistance of the roof and diminishes the heat losses, which is acceptable when considering pros and cons in total.

Even though adding external insulation is an absolute and highly favourable energy efficient retrofit but is also highly dangerous for damaging the building's symbolic values and architectural identity. Therefore, it is considered as inappropriate intervention for this case. Interior wall insulation is relatively less risky when comparing to exterior insulation for building architectural value as long as it is installed carefully. On one hand, it is a great energy saving proposal to keep the heat inside from the perspective of intermittent heating of the case building. On the other hand, it might be problematic for dampness issue due to rapid heating and cooling. Hence, interior insulation might be assessed as acceptable retrofit.

Ground floor insulation is partly available because of its two different floor patterns, of which is timber on the rooms and marble throughout the longitudinal ground floor corridor. Therefore, timber floor seems to be appropriate for the application both due to the enough space on the basement level and availability of installing it from below the floor construction.

By the time this study was being undertaken, the building had a hot water radiator system with an old and low efficient fuel-oil boiler. Therefore, switching it to the high efficient, condensing natural gas boiler is a good refurbishment for reducing operational inefficiencies, energy related carbon dioxide emissions and expenditures. Changing the fuel type and heating system is, thereby, obviously worthy retrofit although it is expensive.

Solar panels are compatible applications for buildings. Whether it is used for electricity or hot water production, benefits of the retrofit will be less than risks for the building. Because, the larger the solar panel area the more the energy production and also the more risk for the building's roof appearance. Thus, solar application is unacceptable decision for this case.

5.4.5. Short List of Possible Retrofits

For the case building, strengths and threats of the energy efficient retrofits were evaluated using the risk – benefit analysis (Section 5.4.4). Thus the appropriate retrofit applications are:

- Weather stripping
- Indoor air temperature control
- Changing the heating system and/or fuel type
- Insulation of the attic floor
- Additional insulation to the roof
- Interior insulation of the walls
- Additional insulation to the ground floor.
- Interior insulation of the walls.
- Additional insulation to the ground floor.

5.5. Grouping the Retrofits

After determination of the appropriate retrofits, the next step is to put them into packages. According to the risk levels of the retrofits it was preferred to gather the retrofits in three retrofit packages. The retrofits that were assessed as risky and eliminated are also included in a package to better understand ideology of the methodology. Table 5.9 shows the retrofit packages. Evaluation of the retrofit packages will be done in Section 5.6.

Table 5.9. Energy efficient retrofit packages for the case building

Package 1	Package 2	Package 3
-Weather stripping -Changing the heating system and/or fuel type -Temperature control	-Weather stripping -Changing the heating system and/or fuel type -Temperature control -Insulation of the attic floor -Interior insulation of walls -Additional insulation to the ground floor	-Weather stripping -Changing the heating system and/or fuel type -Temperature control -Additional insulation to the roof -Additional insulation to the ground floor -Changing the windows -Exterior insulation of the walls

5.6. The Results and In-Depth Assessment

In this study, energy consumption of the building was simulated using DesignBuilder software. The BES model calibration was done using utility bill and indoor temperature comparison approach so that the simulation model was assumed to reflect the actual energy consumption of the building. After grouping the retrofits into three packages, all scenarios were simulated and the results will be assessed due in relation to the targets.

5.6.1. Assessment of the Package 1

The retrofits included in the Package 1 are air-tightening of the building envelope, changing the heating system and/or fuel type and installing a room air temperature control system. The latter retrofitting packages were grouped adding retrofits to Package 1. The content of the Package 1 is expected to have less impact on building heritage values.

Regarding the air-tightness improvements, the air exchange rate (ACH) is assumed to be improved by 0.1 h^{-1} repairing the cracks and holes on the building envelope. The fuel-oil boiler was changed with the more efficient condensing natural gas one having 83% seasonal efficiency (SAP 2008). Furthermore, the hot water radiator in each room was equipped with thermostat control, which aims to keep the air temperature in the unoccupied and occupied zones during heating period at 20°C and 24°C, respectively.

Since the retrofits that are expected to improve the heating system are implemented, the radiant electrical heaters used as an auxiliary heating were discarded. Also, the actual heating power of the hot water radiators was changed according to Table 3.12. Therefore the radiators at occupied and unoccupied zones are expected to average power about 2.1 kW and 2.3 kW, respectively. The energy reduction in terms of electricity and heating system fuel consumption obtained with the help of the retrofit Package 1 can be seen in Figure 16.

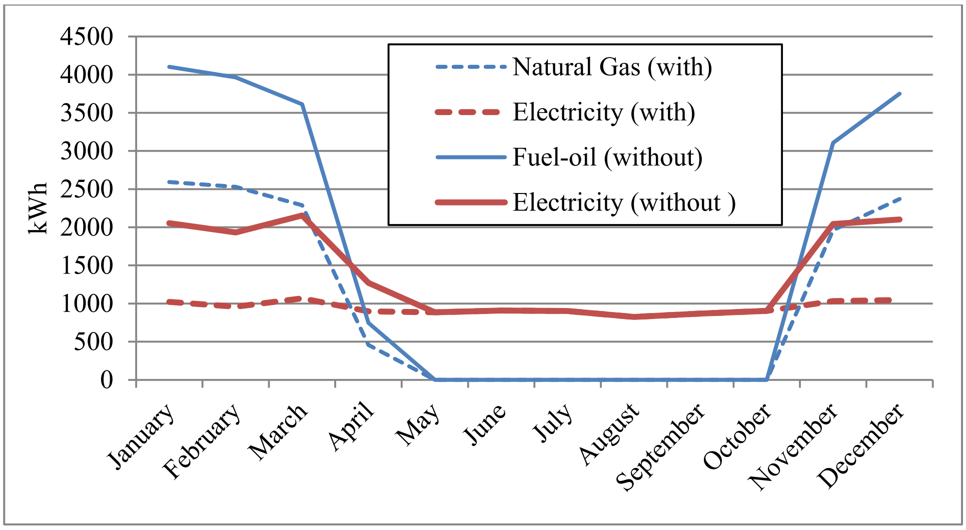


Figure 5.16. Comparison of the fuel breakdowns with and without the retrofits on the monthly basis (Package 1)

Figure 5.17 illustrates the result of the retrofitting scenario, Package 1, on the annual basis. After discarding the auxiliary heating sources, room electricity consumption drops by 68%. Lighting consumption remains intact because of that the retrofits did not include any relevant application. Also, the fuel consumption regarding the hot water radiator system decreased by 37% both due to the temperature control of unoccupied zones and the more efficient boiler. In total, annual energy consumption of the case building decreased by 35%. Hence, the target aiming 20% energy reduction was accomplished whilst the target 50% would not.

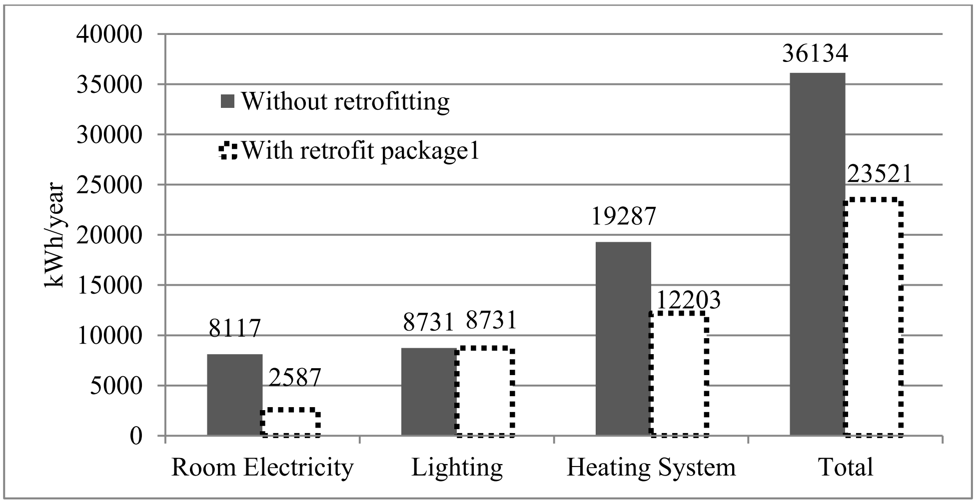


Figure 5.17. Comparison of the fuel breakdowns with and without the retrofits on the annual basis (Package 1)

Since the Package 1 does not include any retrofit regarding the constructional improvement, the target aiming to meet the requirements in the TS825 standard (TS825 2008) would not be reached.

On the other hand, the target that aims to protect the building physics and heritage values was reached because of the absence of any visual and constructional changes in the retrofitting package.

5.6.2. Assessment of the Package 2

The content of the Package 2 is the same with Package 1, with the addition of except attic floor insulation, interior wall insulation and ground floor insulation. The package includes more changing on the building's construction but less on the appearance. Table 5.10 shows the thickness of insulation material and the overall heat transfer coefficients before and after the retrofits.

Table 5.10. Specifications of insulation material and new overall heat transfer coefficients

Retrofits		Old U-value (W/m^{2}K)	Insulation material and thickness (cm)	New U-value (W/m^{2}K)	TS 825 requirements (W/m^{2}K)
Attic floor insulation		1.1	Stone wool (6)	0.414	≤ 0.45
Ground floor insulation (only timber floors)		1.4	Stone wool (5)	0.537	≤ 0.70
Interior insulation of the walls	Wall type A	1.2	Stone wool (5)	0.479	≤ 0.70
	Wall type B	1.1		0.487	
	Wall type C	1.2		0.491	

All insulation applications were implemented to meet the TS825 requirements, except the windows. The breathable insulation material, stone wool, was chosen in order not to face any condensation issue.

Having applied the insulation material and obtained the required U-values indicated in the targets, the simulation was run. Figure 5.18 denotes the fuel breakdowns with and without the retrofits on the monthly basis. Thus, there occurred no changes on the electricity consumptions due to the reason that the Package 2 includes only constructional changes different than the Package 1. Therefore, the reduction occurred only on the heating system fuel consumption (natural gas).

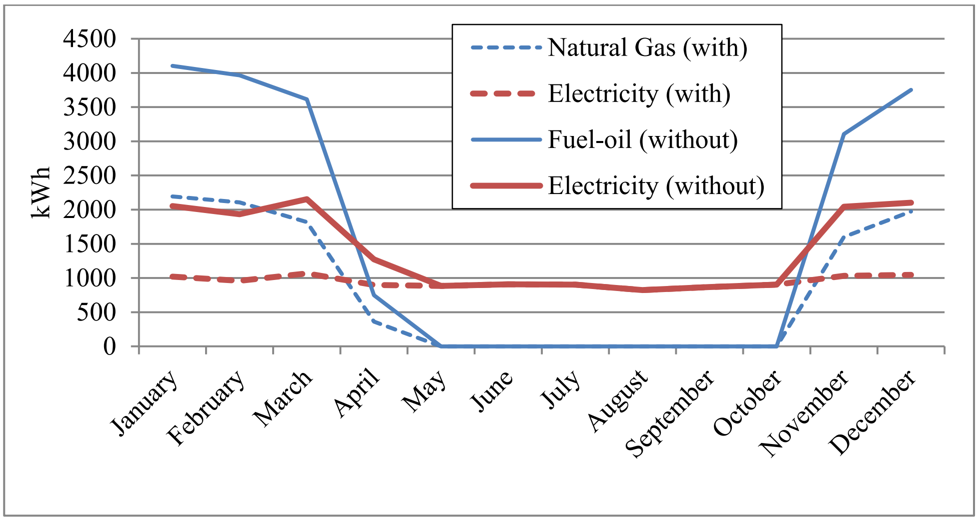


Figure 5.18. Comparison of the fuel breakdowns with and without the retrofits on the monthly basis (Package 2)

The comparison of the fuel breakdown before and after the Package 2 is given in the Figure 5.19 on the annual basis. According to the simulation results, the natural gas consumption diminished by 48%, which accumulates to 41% reduction in total energy consumption. The results showed that the minor energy reduction target 20% was reached while that of aiming 50% would not.

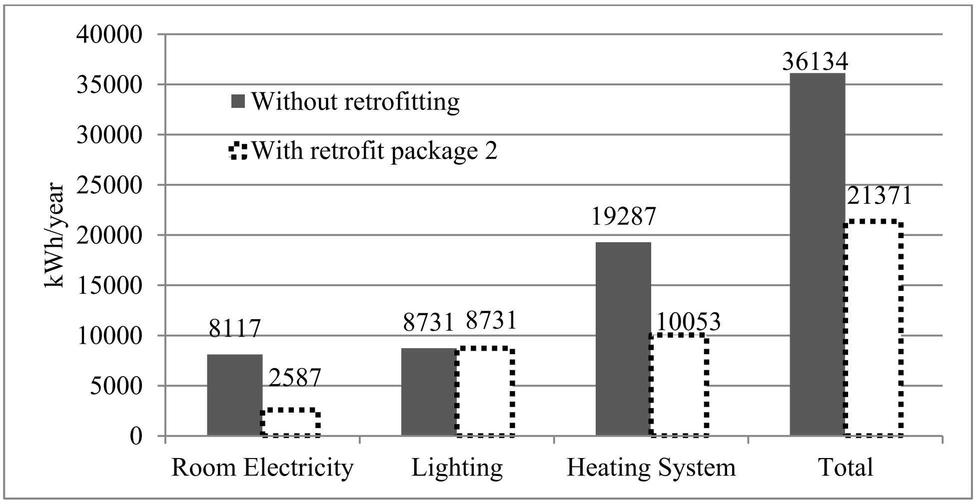


Figure 5.19. Comparison of the fuel breakdowns with and without the retrofits on the annual basis (Package 2)

The targets regarding TS825 requirements were accomplished except the windows since they were assessed as an inappropriate retrofit. Even though the retrofit Package 2 includes some material changes in the construction, it does not affect the building appearance and physics significantly. Therefore, it can be said that the targets regarding the building physics and heritage value were accomplished.

5.6.3. Assessment of the Package 3

The Package 3 was intended to show the techno-economic saving potential when heritage values were not considered. The initial aim of the package is to obtain as much energy savings as possible rather than preserving building heritage values.In addition to the Package 1, exterior wall insulation, changing the windows and roof insulation were included. Also, air-to-air heat pump was used as heating system instead of natural gas boiler. Table 5.11 denotes the U-values with and without the retrofits. Thus, it is clear that overall heat transfer coefficient targets were reached after the retrofits.

Table 5.11. Changes in construction elements and U-values

Retrofits		Old U-value (W/m^{2}K)	Insulation material and thickness (cm)	New U-value (W/m^{2}K)	TS 825 requirements (W/m^{2}K)
Roof insulation		1.5	Stone wool (6)	0.421	≤ 0.45
Ground floor insulation (only timber floors)		1.6	Stone wool (5)	0.537	≤ 0.70
Exterior insulation of the walls	Wall type A	1.2	Stone wool (5)	0.479	≤ 0.70
	Wall type B	1.1		0.487	
	Wall type C	1.2		0.491	
Windows		3.2	Low-e window	1.78	≤ 2.4

Figure 5.20 illustrates the simulation results on the annual basis. The room electricity and heating system consumption was reduced by 68.1% and 88.9%, respectively. In total, it accumulates to 62.7% drop on the annual energy consumption, which meets the major energy saving target aiming 50% reduction.

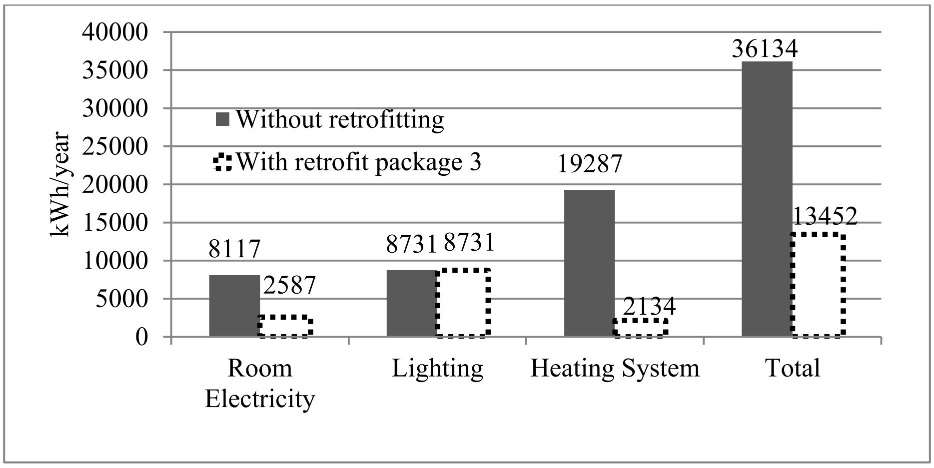


Figure 5.20. Comparison of the fuel breakdowns with and without the retrofits on the annual basis (Package 3)

The target regarding with preserving building physics and heritage value would not be met because of the implication of inappropriate retrofits as well as external insulation and changing the windows. Impact of their implication on the building caused major changes on building appearance and destructed the patina. Furthermore, it is possible to denote that the outer unit of air source heat pump will probably cause a negative visual effect on building appearance.

5.7. General Evaluation of Retrofitting Results

As a result of risk-benefit assessment, inappropriate retrofits were eliminated and appropriate ones were gathered into packages to meet the energy saving targets and to evaluate their combined effects on energy consumption.

At this point, each single retrofit was simulated to evaluate their individual effect on the energy consumption. Even though discarding the auxiliary heating sources was not counted as a retrofit, the impact of it was also included in the evaluation.

Figure 5.21 illustrates the aggregated effect of single retrofits on the package basis. The most effective reduction was obtained by changing the heating system with the air source heat pump, which is by 45.7%. This effect was followed by natural gas boiler (20%), indoor temperature control (11.6%), interior wall insulation (7.7%), exterior wall insulation (6.4%), discarding the auxiliary heating

(3.8%), weather stripping (1.8%), roof insulation (1.5%), attic floor insulation (1.1%), changing the windows (0.9%) and finally ground floor insulation (0.8%). Therefore, summation of the single energy reductions on the package basis corresponds to 37% for Package 1, 47% for Package 2 and 73% for Package 3.

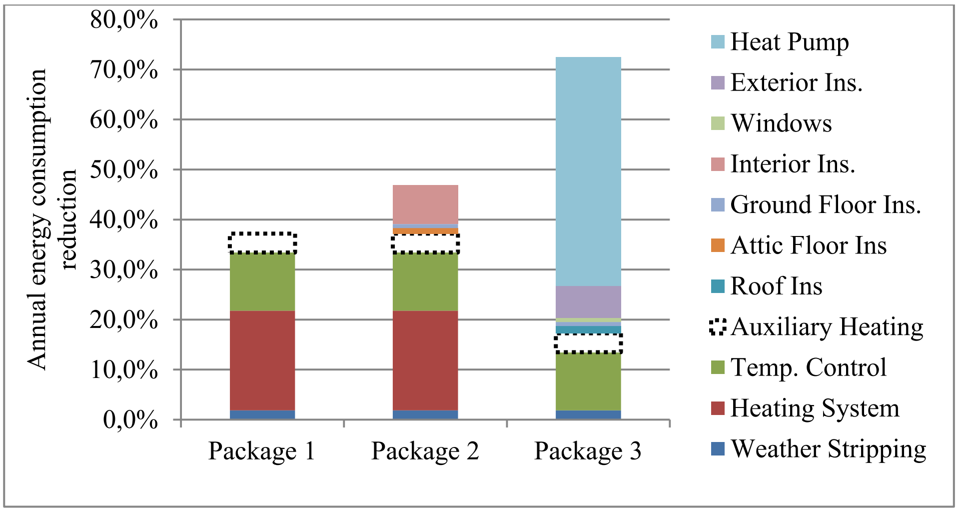


Figure 5.21. Aggregation of single retrofits on the package basis

Nevertheless, combined effect of the single retrofits is not the same as simply adding them up. Insulation of the external walls, for example, will eventually diminish the single effect of changing the boiler (Cluver and Randall 2012). Figure 5.22 shows the comparison of combined and aggregated effect of single retrofits on total annual energy consumption.

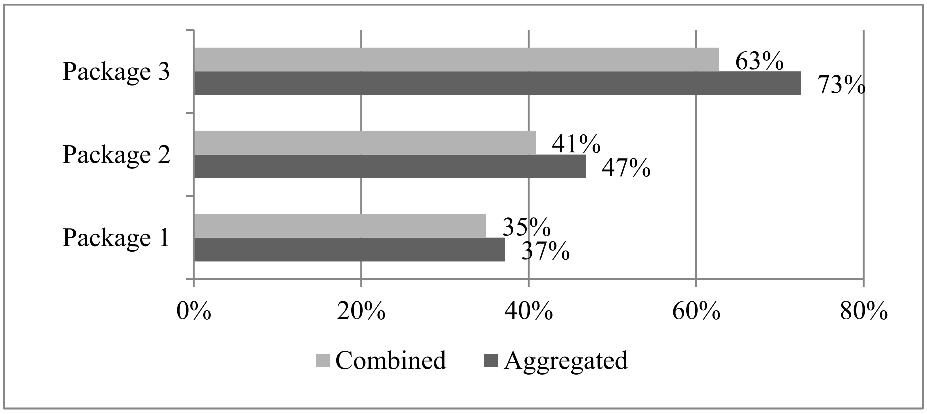


Figure 5.22. Comparison of combined and aggregated effect of single retrofits on total annual energy consumption

Hence, the comparison results indicate that the differences between combined and aggregated impacts are 2% for the Package 1, 6% for the Package 2 and 10% for the Package 3. These differences should not be underestimated when economic calculations are of interest.

Figure 5.23 shows the comparison of the heating system energy demand and total annual energy consumption for in-depth analysis. At this point, it is necessary to give the definition of the heating system energy demand for better understanding. Basically, heating system energy demand is the amount of energy which should be supplied by the heating system to the building in order to keep the indoor environment under the desired conditions.

Results of Package 1 indicate that the annual energy consumption decreased while the heating energy demand increased. This is because the auxiliary heating sources were discarded. Despite the positive effect of the retrofits, weather stripping and temperature control, discarding the auxiliary heating increased the heating load by 1%. However, the total annual energy consumption reduced due to the more efficient heating boiler.

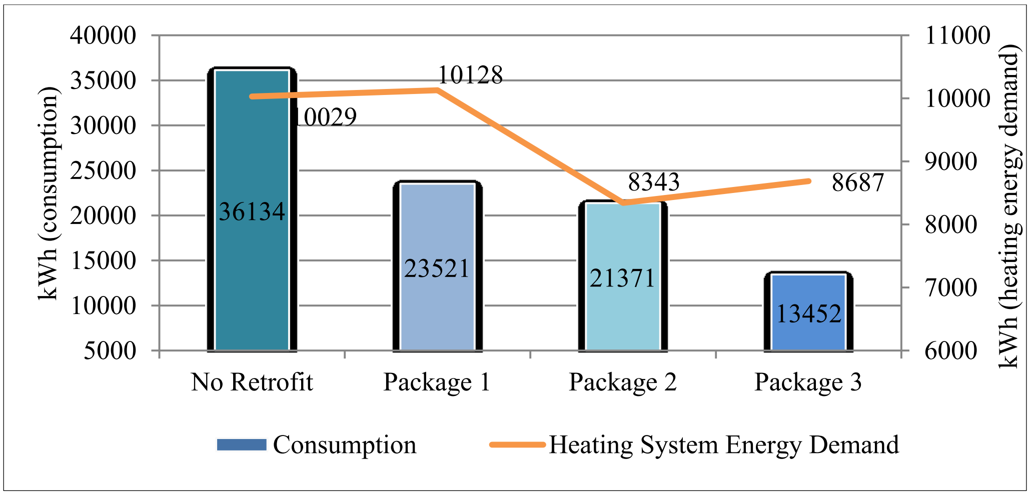


Figure 5.23. Comparison of the results of retrofit packages

Package 2 results show that the heating energy demand and total annual energy consumption were reduced with respect to the Package 1. The main reason of the decrement in Package 2 results is building fabric insulation, which causes 6% reduction.

Package 3 was intended to obtain as much energy saving as possible without considering the heritage values. Even tangible elements having significant role on building's character were changed. One significant change in this retrofit package is an air source heat pump. Each room was individually equipped with a split heat pump unit having 3.4 kW average heating power (min, 0.9 – max, 5.1) and a COP of 4 (MBS 2013). Energy simulation calculations were run accordingly. The results show that heating load increased while the consumption dropped drastically. The reason of the increment in the heating energy demand can be explained due to the average heating power of the heat pump, which is more or less 50% higher than the previous hot water radiators. Yet, total annual energy consumption decreased thanks to high COP of the air source heat pump.

Although there is no clear statement in the Building Energy Performance Directive (BEP 2008) about the historical buildings, their energy class should be obtained to spot the place of them in the energy scale. Therefore, energy class of the buildings is determined calculating annual primary energy consumption per unit occupied floor area. The case building has 419 m^2 floor area of which 296 m^2, 70%, is occupied while 123 m^2, 30%, is unoccupied. Of the building, heated floor area is 217 m^2 which refers to 52% of total. In Turkey, building energy classes are divided into 7 categories (Table 5.12) and calculated due to the intended use and heating region that the building belongs to.

Table 5.12. Energy class scale due to the primary energy consumption (Source: BEP 2008)

Building Energy Class	Energy class scale due to the primary energy consumption (kWh/m^2.year)
A	PEC< 72
B	72 ≤ PEC < 144
C	144 ≤ PEC < 180
D	180 ≤ PEC < 216
E	216 ≤ PEC < 252
F	252 ≤ PEC < 315
G	315 ≤ PEC
PEC: Primary energy consumption (kWh/m^2.year)	

According to the case building's intended use and the geographic position in Turkey, energy class of the building for each retrofit package is given in Table 5.13.

Table 5.13. Energy class of the case building due to the packages

Packages	Total annual energy consumption (kWh)	Annual primary energy consumption (kWh)	Annual primary energy consumption per unit occupied floor area (kWh/m^2)	Energy Class (A – G)
No Retrofit	36135	70126	236,9	E
Package 1	23521	45724	154,5	C
Package 2	21371	43251	146,1	C
Package 3	13452	37665	127,2	B

Thus, the building's energy class before the retrofit packages is found as E, which is not acceptable since the directive, BEP, requires the buildings, at least, to have C energy class. Due to Package 1 results, energy class of the building is determined as C which is followed by Package 2, class C and Package 3, class B. At this point, it should be pointed out that the energy saving based on primary energy consumption does not change with the same proportion as the total energy consumption. This is because of that changing the fuel of the heating system affected to the primary energy consumption and consequently to the energy class of the building which can be seen on Figure 5.24.

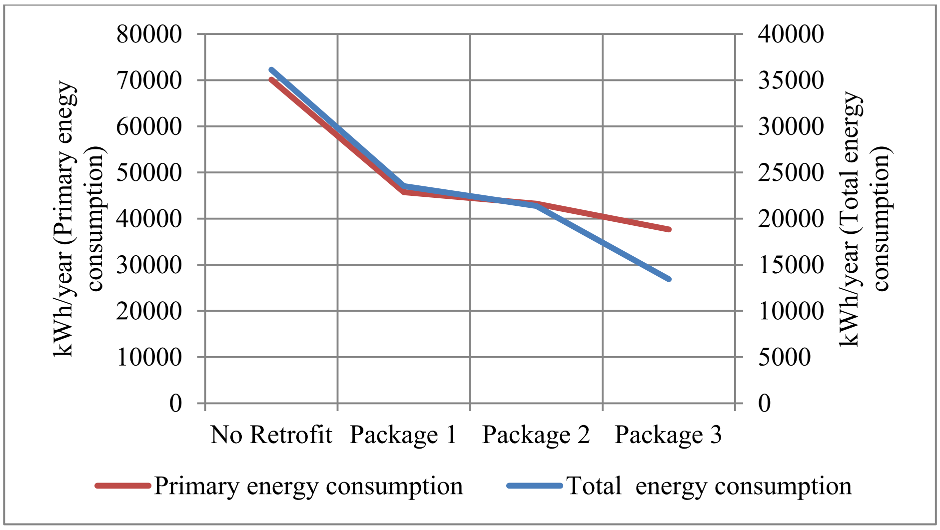


Figure 5.24. Impact of changing the heating fuel on the primary energy consumption

Figure 5.23 illustrates that the primary energy consumption change is not proportional to the total energy consumption on the retrofit packages basis. The reasons behind this are that heating system in no-retrofit case is run by fuel-oil whilst it is changed to natural gas for Packages 1,2 and to electricity (air source heat pump) for Package 3. Although it seems the consumptions alter fairly proportional up until Package 2, primary energy consumption of Package 3 did not reduce as expected since the primary energy factor of the electricity (2.8) is higher than natural gas (1.1) and fuel-oil (1.15) (Table 5.14).

Table 5.14. Primary energy factor of widely-used fuels

Fuel	Primary energy factor
Natural gas	1.15
LPG (Bulk – bottled)	1.10
Heating-oil	1.19
House-coal	1.07
Wood logs	1.10
Electricity	2.8
Geothermal heat source	1.05

In order to assess whether the retrofit packages are economically viable or not, it is necessary to determine the estimated investment expenditures and energy savings on the package basis. Field investigation was conducted to obtain the unit investment prices including workmanship. With the help of the energy savings obtained from the simulation results, simple pay-back period of each retrofit package was calculated and given in Table 5.15.

Table 5.15. Simple pay-back periods of the retrofit packages

The Packages	Estimated Expenditure (TL)	Estimated Saving (TL)	Simple pay-back period (Years)
Package 1	5250	8229	0.64
Package 2	53715	8423	6.38
Package 3	63800	8623	7.40
Unit electricity price: 0.31 TL/kWh (TEDAS 2013) Unit natural gas price: 0.09 TL/kWh (IG 2013) Unit fuel-oil price: 0.389 TL/kWh (SHELL 2013)			

It was assumed that the unit fuel prices were constant throughout the year so that simple pay-back periods are calculated as 0.64 years for Package 1 which is followed by Package 2, 6.38 years and finally Package 3, 7.40 years.

CHAPTER 6

CONCLUSIONS

Historical buildings consume relatively higher energy when compared to the ones built in the recent past. Therefore one can commit that instead of leaving them undisturbed and unattended, the buildings carrying heritage values should be treated intentionally and with great awareness to re-integrate their use into our life.

In this thesis, energy efficient retrofitting of a historical building was investigated with a step by step, interdisciplinary methodology in order to reduce the energy consumption of the building without demolishing the historical heritage values. Validated BES tool, DesignBuilder (DB 2013), was used to model the retrofit scenarios and obtain the simulated energy consumption figures. Moreover, calibration study was performed in order to determine accurate and reliable outputs from the BES tool.

Based on the literature survey, a number of applications which are the most common energy efficient retrofits were selected such as weather stripping, indoor temperature control, changing the windows, attic floor insulation, roof insulation, exterior insulation of the walls, interior insulation of the walls, ground floor insulation, the more efficient heating system and renewable energy technology integration.

Following the elimination of inappropriate applications, retrofits were divided into three packages in order to establish a better understanding about the methodology.

The aim of Package 1 is to meet the energy targets without altering the building appearance and damaging the heritage values. Therefore the retrofits regarding building’s thermal properties were not included within the package. The retrofits that Package 1 includes are weather stripping of the building envelope, changing the boiler with the more efficient one and indoor air temperature control.

In Package 2, more interventions in terms of improving the thermal behaviour of the building were included. In addition to Package 1, interior wall insulation, attic floor insulation and ground floor insulation were considered while the retrofit regarding improvement of the windows was left out of the package.

Package 3 was intentionally grouped in order to determine the maximum possible energy savings. Some inappropriate retrofits were also included in the package. (Table 5.9).

Results of the case study are, in summarily, given in Table 6.1 in which positive (+) sign denotes the target is reached while the negative (-) one is not. Table 6.1 shows that minor energy reduction target, 20%, was reached without disturbing the building construction and view while the target 50% was not. Moreover, the heritage values were conserved while the U-value targets inquiring thermal improvements and alterations on the construction materials could not be met due to the content and aim of Package 1.

Table 6.1. Target results

Targets		Package 1	Package 2	Package 3
Energy Targets	20 %	+	+	+
	50 %	-	-	+
U-value targets due to the standard TS825	Ceiling	-	+	+
	Floor	-	+	+
	Wall	-	+	+
	Windows	-	-	+
Heritage value & Building physics	Construction	+	+	-
	Appearance	+	+	-

According to Package 2 results, the minor energy target, 20%, can easily be accomplished while the TS825 standard partially satisfied. Even the small, reversible constructional changes, the package did not unavoidably affect the building appearance and heritage value so that the associated targets were also reached.

The results of Package 3 indicate that major energy target, 50%, can be accomplished only with the destructive and irreversible changes from the building conservation perspective. Changing the prominent heritage values not only demolish the building appearance but also tangible records and memories that the building has carried for ages. Thus, special attention must be given when the energy efficiency in historical buildings is considered and it is strongly advised that the decisions should be taken through an interdisciplinary approach in collaboration with the administrators and authorities.

Thus, it can easily be concluded that the minor and relatively intermediate energy saving reductions can be reached without disturbing the historical, architectural and cultural values while the major energy target cannot. This is a reasonable proof that the interdisciplinary approach used within the methodology was successful and necessary.

From an engineering perspective, another point which should be concluded and stressed is the combined effect of single retrofits. The results (Figure 5.21) clearly show that the difference that combination of the single retrofits creates increases when energy savings increased. This might cause troubles and economical mistakes when considered the highest pay-back period of the retrofit packages.

Energy class of historical buildings is expected to be at lower levels on the scale. For this reason, effect of the retrofit packages on energy class of the building was also calculated. Packages 1 and 2, which include appropriate energy retrofitting policy in terms of heritage values, both show that energy class of the building can be improved from E to C while Package 3 does class B. Although Package 3 seems to cause relatively higher energy savings and is anticipated to have better energy class, estimated primary energy consumption of the building per unit occupied floor area, 127.2 kWh/m^2.year, is determined higher than expected owing to the changing the fuel of heating system from fuel-oil to electricity. Thus it can be concluded that the retrofit interventions related to heating system and fuel change should be well analysed and scrutinised when energy class of the building considered.

In this thesis, the difference between two approaches, energy saving retrofitting in historical and contemporary buildings, was also enlightened. This outcome, therefore, should be considered and emphasised in the directives and laws. It is known that there is a work on developing a new European Standard (CEN), called “Guidelines for improving energy performance of architecturally, culturally or historically valuable buildings”. However, this work should also be conducted and specified for other countries. Remembering that there is no clear guideline regarding energy efficient improvements of historical buildings in Energy Performance of Buildings Directive (BEP 2008), this issue should be enlightened, clarified and included with the help and liaison of institutional, professional, administrative and practical authorities.

In the light of the results presented and discussed, the further research should be conducted in order to investigate the energy saving issues in the sense of indoor air quality and environmental impact of the retrofitting. This will eventually enlarge the interdependency of the multidisciplinary approach and vitalise the significance of energy saving applications in historical buildings.

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