CHANGING RESIDENTS' STANCE ON BUILDING ENERGY RETROFITS BY USING BUILDING PERFORMANCE SIMULATIONS, COSTS AND PAYBACK PERIOD DATA

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ABSTRACT

CHANGING RESIDENTS' STANCE ON BUILDING ENERGY RETROFITS BY USING BUILDING PERFORMANCE SIMULATIONS, COSTS AND PAYBACK PERIOD DATA

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Starting with Stockholm Conference, countries have realized that excessive energy use can be the main obstacle in solving environmental problems. Studies have shown that buildings play a key role in consumption and production of energy; and one way forward can be to refurbish existing buildings in a way that they can contribute to the solution.

Although there are many reasons to refurbishing existing homes, there are two major barriers that need to be overcome. The first barrier is the initial cost of retrofits and the other is the uncertain attitude of the occupants, regarding the interventions. This study aimed at combining these two issues with building refurbishment strategies and renewable energy usage in existing residential buildings. To this end, two case studies were selected in Ankara, Turkey. The first contains 21 low-rise blocks where 837 people are living; the second is a building complex with three high-rise blocks, having 364 inhabitants.

At first, energy consumption of the existing buildings was determined by simulating their models with DesignBuilder software; and then energy retrofit scenarios were proposed. Afterwards, costs and payback periods of the scenarios were calculated with a computer software. Thereafter, questionnaire surveys were conducted to determine the occupants' attitude towards the proposed retrofits. This thesis presents the results of the simulations with regards to consumption, reduction and production of energy in the buildings before and after retrofitting; and the findings from the questionnaire regarding the change in attitude of occupants due to the financial advantages of the interventions in the long run, rather than information about energy savings only.

Keywords: Occupants' Attitude, Questionnaire Survey, Energy Retrofits, Building Refurbishments, Renewable Energy Integration

ÖZ

BINA PERFORMANS SIMULASYON, MALIYET VE GERI-ÖDEME SÜRE VERILERINI KULLANARAK KULLANICILARIN BINALARINDA ENERJI IYILEŞTIRME MÜDAHALELERINE KARŞI TUTUMLARININ DEĞIŞTIRILMESININ SAĞLANMASI

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Stockholm Konferansı ile başlayarak, dünyanın dört bir yanında ki ülkeler enerjinin çevre sorunlarının çözümünde ana engel olabileceğini fark etmişlerdir. Araştırmaların da desteklediği üzere, binalar enerji tüketiminde ve üretiminde önemli role sahiplerdir. Bu çalışmalar ışığında, enerji sorununa bir çözüm olarak, binaların iyileştirilmesi ve enerji performansı açısından güçlendirilmesi göz önünde bulundurulabilecek bir seçenektir.

Mevcut binaları iyileştirmek ve enerji performansı açısından güçlendirmek için birçok neden olsa da, bu konuda üstesinden gelinmesi gereken iki büyük engel bulunmaktadır: Birincisi, enerji müdahalelerinin başlangıç maliyeti, diğeri ise müdahalelerle ilgili kullanıcıların belirsiz tutumu. Bu çalışma; bu iki konunun, mevcut binalarda bina yenileme stratejileri ve yenilenebilir enerji kullanımı ile birleştirilmesinin incelenmesini amaçlamaktadır. Bu gayeyle, Ankara, Türkiye'de eski bir işçi mahallesinde bulunan iki vaka çalışması seçilmiştir; birincisi, 837 kişinin yaşadığı 21 bloklu asansörsüz binalardan oluşan bir bina adası; ikincisi, 364 kişiyi barındıran yüksek katlı üç yapı bloğuna sahip bir yapı kompleksidir.

Çalışmanın ilk adımı olarak; önce, mevcut binaların enerji tüketimi DesignBuilder yazılımı ile belirlenmiştir; ve elde edilen bulgular ışığında iki vaka için farklı enerji iyileştirme senaryoları önerilmiştir. Daha sonra, senaryoların maliyet ve geri ödeme süreleri hesaplanmıştır. Akabinde, kullanıcıların önerilen iyileştirmelere yönelik tutumlarını belirlemek amacıyla, anket çalışmaları yapılmıştır. Bu makale, enerji tüketimi, tasarrufu ve üretimi için yapılan müdahaleleri ve anketlerden elde edilen bulguları sunmaktadır. Bu bulgularla, kullanıcıların tepkilerini ölçmek için sadece enerji tasarrufu ile ilgili bilgilerden ziyade, müdahalelerle ilgili finansal bilgilerin de sunulması gerektiği sonucuna ulaşılmıştır.

Anahtar Kelimeler: Kullanıcı Tepkisi, Anket Çalışması, Enerji Tadilatları, Bina Yenileştirmesi, Yenilenebilir Enerji

Dedicated to my beloved family, especially to my brother “Fahrettin Aydemir”.

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ABBREVIATIONS

BAS:	Building Automation System
BMS:	Building Management System
EIA:	Energy Information Administration
EPBD:	Energy Performance of Building Directive
HVAC:	Heating Ventilating and Air Conditioning
IEA:	International Energy Agency
IEO:	International Energy Outlook
LCC:	Life Cycle Cost
OECD:	The Organization for Economic Co-operation and Development
PV:	Photovoltaic
PVC:	Polyvinyl chloride
TL:	Turkish Lira
UIA:	Union Internationale des Architectes
UNCHS:	United Nations Conference on Human Settlements
UNFCCC:	United Nations Framework Convention on Climate Change
U.S.A:	United States of America
USD:	United States Dollar
WBSCD:	World Business Council for Sustainable Development

CHAPTER 1

INTRODUCTION

This study focuses on the attitudes of occupants towards energy retrofits in existing residential buildings. In this chapter, the argument, the aim and objectives and procedure of the study are presented together with a disposition of the following chapters

1.1. Argument

Energy is an important resource that makes our life easier. The consumption of energy is growing with the passage of time. However, careful use of non-renewable energy is needed due to the finite source on our planet. In other words, while humanity creates easier life conditions for themselves with the production of energy and improving technologies, nature's limits are needed to be considered carefully. In order to solve the problem of depleting energy resources, buildings can play a key role. This fact has been recognized in the various declarations of international conferences focusing on improving the energy consumption of existing buildings. In addition to the declaration of the United Nations Conference on Human Settlements (UNCHS) in 1976, this topic was addressed as the 11th Goal called "Sustainable cities and human settlements" in the 2012 report entitled "The Future We Want". Moreover, according to report of the International Energy Outlook 2017 (IEO2017) that was prepared by the U.S.A Energy Information Administration (EIA), 21% of worldwide energy consumption belongs to the commercial and residential buildings' sector; while the energy consumption in the residential sector is higher than the commercial sector worldwide. Thus, the existing residential building stock has a greater potential to minimize energy consumption.

In order to decrease unnecessary energy usage, many studies have shown that the target area as the existing residential buildings. However, there are various ways to accomplish this goal, which can be grouped under three headings: thermal insulation as a passive design strategy in buildings; renewable energy generation as an active strategy; and a combination of these two strategies. Kroner (1997) states that the term passive design refers to a set of architectural design strategies applied to provide human comfort with the help of the appropriate use of environmental factors, including climatic and locational conditions. On the other hand, some newer technologies for active systems are also very useful and supportive in mitigating energy consumption; it is easier now to produce clean energy for use in residential buildings. This is because the depletion of non-renewable energy resources and climate change has triggered technological developments in renewable energy generation systems (Suppes & Storvick, 2016). Conversely, most of the energy consumption in buildings is a result of the ineffective usage of active systems for maintaining human comfort in the buildings. Hence, using appropriate active systems and applying suitable passive design strategies are important goals to improve the interior comfort conditions without excessive energy consumption in the buildings (Ubinas, *et al.*, 2014).

The accomplishments of the German Federal Housing board are good examples in this regard. The Urban and Transport Ministry of Germany has announced that until 2020, approximately 30 million housing units are planned to be refurbished and with this action, an 80% reduction in energy consumption is aimed at (Power, 2008). The approach of The Netherlands' government is another example where intervention in large housing estates in the country are mostly related with renovations for upgrading functional and living conditions, and energy efficiency (Gomez *et al*., 2016). Apart from these researches, according to Roberts (2008), due to climate change, the seasons and the temporal changes of the seasons have been differentiating from one year to another. Therefore, whether they like it or not, people will be forced to alter their houses with respect to this change (Roberts, 2008).

Although there are many reasons to renovate existing houses for better living conditions and lesser energy consumption in the buildings, there are two major obstacles to overcome. One of the barriers is defined by Ashrafian *et al*. (2016) as limited amounts of economic resources and a high amount of initial investment cost for energy retrofit actions. In other words, because of financial restrictions of house owners and self-financiers, in order to increase the building energy performance, these owners and financiers should be encouraged with smaller investments and cost-effective solutions (Ballarini *et al*., 2017). The second barrier could be understood as the social acceptance of renovations. As it is mentioned in Power's paper (2008), occupants have the tendency to defend their communities from demolishment and react to these vital and sudden changes. Further, at the end of all calculations, analyses, and implementations, occupants are the real and last decision-makers for any interventions in their living spaces. Furthermore, no matter how much the taxes are increased to prevent energy consumption or how much renovations are done for this purpose in the building, if the occupants are not willing to consume less energy, the energy consumption will remain the same, or even increase. Therefore, understanding the occupants' behaviors towards energy retrofits is another key point to consider in refurbishment initiatives.

The problems discussed in this study are related to the attitudes of the occupants of old residential buildings towards energy retrofits; and their ability to differentiate between passive design strategies, active systems' usage and combination of these two interventions. It was also wondered whether their attitude towards energy retrofit interventions would change if they were made aware of the long-term economic outcomes of the three scenarios.

1.2. Aim and Objectives

The fundamental aim of the study is to determine occupants' attitude towards energy retrofits focused on passive design strategies and active systems' usage in residential buildings. In order to achieve this aim, the followings are the objectives of the study:

- To analyze the energy consumption of the existing building in order to find the deficiencies of the building and the potential for improvements,
- To determine suitable passive design strategies to apply to old residential buildings,
- To determine the suitable active systems for use in old residential buildings,
- To analyze energy retrofit strategies for the selected case study residential buildings, in terms of both cost and energy savings,
- To determine the occupants' attitude towards these design strategies with a questionnaire survey consisting of data derived from the analyses.

1.3. Procedure

In this study, as a first step, the literature was reviewed in detail to get comprehensive knowledge about energy performance, efficiency and retrofit solutions in existing buildings; and occupants' attitudes towards energy retrofits. The questionnaire survey was composed of background information on environmental, economic and social impacts of energy performance of the buildings; passive design strategies and active system usage for energy efficiency; benefits and barriers of energy retrofits in the existing buildings; and occupants' attitude towards passive design strategies and active systems.

In the second step, two sets of case study buildings were selected form a residential area located in Ankara, Turkey; which are referred to as low-rise and high-rise apartments. The case study buildings were simulated to evaluate their existing energy performance according to local weather conditions and regulations. Thereafter, the energy retrofit scenarios which included passive design solutions for both two types of buildings; active system's usage and a hybrid use of these retrofits for the high-rise apartments were simulated with computer software.

In the third step, costs and payback periods of the scenarios were calculated and compared among each other for each case. Finally, all data and information obtained from the building performance simulations and the financial analyses, i.e. energy consumption, savings and production; and economic outcomes of these actions were used in a questionnaire survey to evaluate the change in the occupants' attitudes towards the proposed energy retrofits before and after the became aware of the related benefits.

1.4. Disposition

This thesis contains five chapters.

The first chapter, introduces the subject of study including its argument, aim and objectives with the procedure of study and disposition of the subject matter.

The second chapter is composed of the literature review related to energy performance, energy efficiency, energy retrofit solutions and occupants' attitudes towards energy retrofits of buildings.

The third chapter covers materials and method of the study in detail. It includes features of the case study buildings and the questionnaire.

The fourth chapter focuses on evaluation of the results of simulations, cost calculations and questionnaire data; and also includes discussions of results.

The final chapter presents the conclusions derived from this study.

CHAPTER 2

LITERATURE REVIEW

In this chapter, comprehensive information about the subject area from the literature are presented under five main sections. The first section covers energy performance in buildings while energy efficiency in buildings is explained in the second section. In the third section, energy retrofits in existing buildings are described in detail and in the fourth, the occupants' attitudes towards energy retrofits are discussed in the light of current literature. This section is concluded with a critical analysis of the literature.

2.1. Energy Performance in Buildings

Managing energy performance of existing buildings is one of the most important step to control energy consumption. In order to handle energy consumption in existing buildings, understanding the concept of energy performance and a clear definition of the term is very critical. According to the definition given in Directive 2010/31/EU of the European Parliament, the energy performance of a building is the assessed amount of energy needed to meet the energy demand related to the typical use of the building; which includes energy consumption for heating, cooling, ventilation, hot water and lighting (European Parliament, Council of the European Union, 2010).

As can be seen from the definition, there are several issues to control for managing energy performance of a building. In order to reach that goal, appropriate and useful paths need to be followed. According to Young and Wright (2016), improving the energy performance of buildings can be achieved with integrated approaches and implementations. Creating successful integrated approaches and implementations can be achieved with a holistic point of view considering environmental, economic and social impact of the energy performance actions.

2.1.1. Environmental Impact of Energy Performance in Buildings

From the beginning of time man has relied on nature as his mainstay and has been consuming natural sources thoughtlessly, for producing energy and improving technology for his personal comfort. Vast amount of energy has been used up for building cities, neighborhoods and houses. As a result of that the associated carbon emissions, the world is facing drastic changes in the climate. According to United Nations Framework Convention on Climate Change (1992), climate change is defined as the alteration of natural climate and the composition of the global atmosphere; that can be perceived over comparable time that is caused by direct or indirect human activities. If the consumption and economic growth rate continues to grow at the same speed, within next fifty years the global temperature could rise to 2- 3°C and this will affect human life with increasing droughts and floods, poverty and hunger, and frequent natural disasters(Stern, 2006). Because of the higher urban temperatures, the need for more energy consumption to cool the interiors, deteriorated outdoor and indoor thermal comfort conditions, the concentration of harmful pollutants such as tropospheric ozone, and the ecological footprint of cities which have a serious impact on human health and well-being will increase (Santamouris, 2016). In order to prevent such dangers, humanity needs to take action.

Energy is an important factor in this regard; it has gained great importance for the continuation of the prevailing modern hi-tech lifestyle. However, nonrenewable energy resources being used for modern technologies are not endless for our planet.

In other words, while humanity creates easier life conditions for themselves by producing and consuming more and more energy, nature's limitations should be considered carefully. In order to solve the energy consumption glut, buildings can play a key role because they have great potential for energy saving actions. As can be seen from Figure 2.1, the building sector uses up nearly one-third of global final energy consumption (IEA Secretariat, 2013, p. 25). Moreover, in Turkey, approximately 30% of total energy consumption belongs to the building sector (Ashrafian et al., 2016). In addition to that, most of the existing buildings erected after World War II have inadequate energy performance. In point of fact, these buildings which are still being used have a lack of insulation, low efficiency hot water production and poor performance of the components of heating systems (Magrini, 2016). Therefore, we need to address the problems of consuming and producing energy starting from our homes, in order to reduce environmental impact of our actions. Especially since the existing residential building stock has a great potential to reduce its high energy consumption with the help of appropriate retrofit measures.

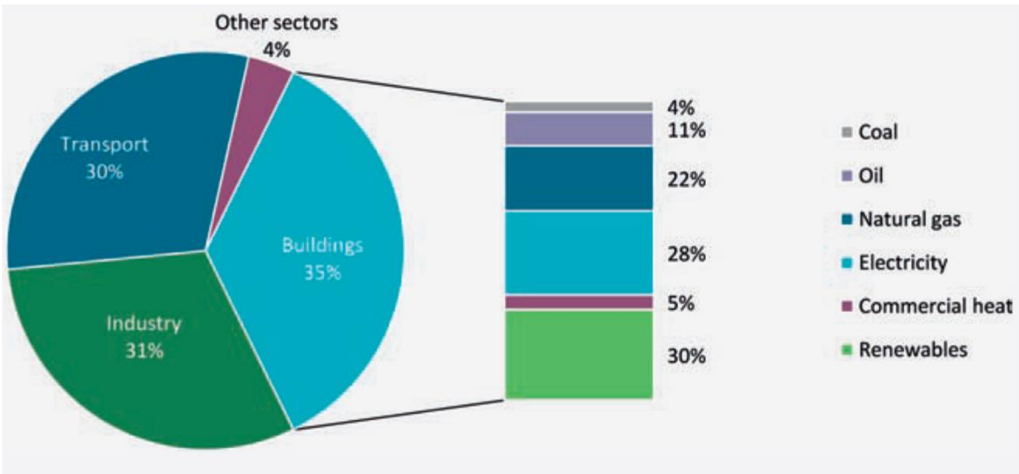

Figure 2.1. Final energy consumption by sector and buildings energy mix, 2010 (IEA Secretariat, 2013, p. 26)

When the renewable energy resources are taken into account, environmental impact of energy performance improvement measures can have more influence on diminishing the carbon foot-print with less dependency on fossil fuels and less greenhouse gas emissions. Moreover, synchronizing with the energy supply grid will scale down the load on these grids (Intelligent Energy Europe Programme of the European Union, 2015).

2.1.2. Economic Impact of Energy Performance in Buildings

Various commercial and financial activities including management, construction, renovation and the extension of assets are related with the building sector. Hence, the building sector has a great amount of share in the global economy (Santamouris, 2019). Moreover, according to IHS Economics (2014), over USD$8.2 trillion were spent on the construction industry in 2013, while for 2025 it was predicted that USD$15 trillion will be the total budget of the building sector (Global Construction Outlook: Executive Outlook 2013). Calculated total budget of the construction industry in 2013 was composed of about USD$3 trillion for the residential building sector, USD$2.7 trillion for infrastructure constructions, and nearly USD$2.5 trillion for commercial buildings (IHS Economics, 2014).

In the light of these calculations and also information which can be seen from Figure 2.2, residential buildings have an important part in the construction economy. As mentioned above, just as the share of the construction industry in the global economy, the building sector has a big share in the global energy consumption also (Figure 2.1).

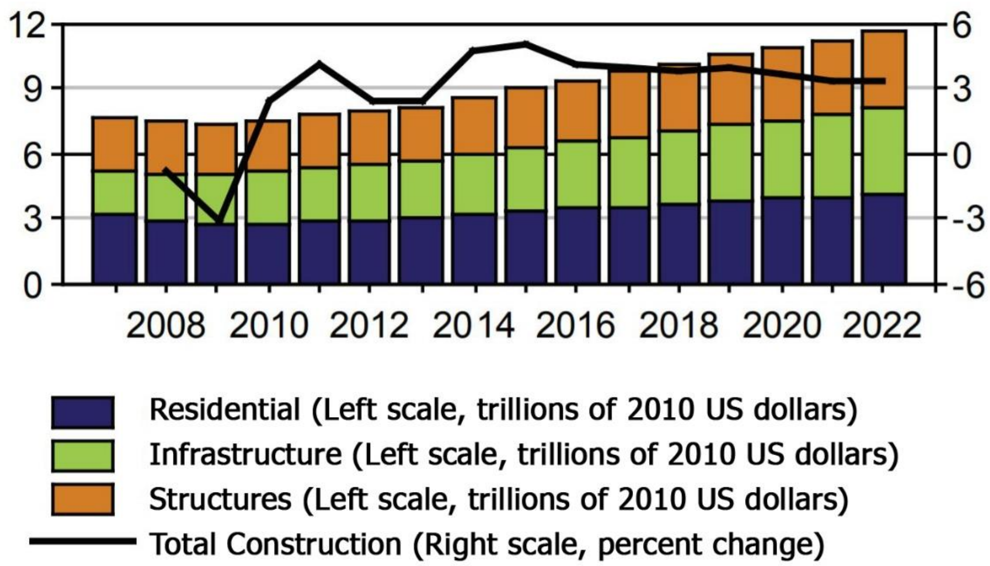

Figure 2.2. Global construction spending, 2013 (IHS Economics, 2014, p. 2)

According to World Business Council for Sustainable Development (WBCSD) (2009), with the help of passive and active measures, energy performances of both new and existing buildings can be enhanced. Using combinations of the passive design and active technical solutions in the buildings can cut energy consumption by about two-thirds, without even considering bettering the performance of small appliances and equipment used in the building (World Business Council For Sustainable Development (WBCSD), 2009). According to this assumption, cutting energy use by approximately 66%, a large amount of money spent on energy can be reduced.

Addition to economic impact of regulating energy consumption for energy performance enhancement purposes, renewable energy usage for the same goal is also effective in economic term. With the energy production, buildings can have less grid depended consumption which will reduce the total net monthly cost of living (Intelligent Energy Europe Programme of the European Union, 2015).

2.1.3. Social Impact of Energy Performance in Buildings

The energy performance of a building is mainly linked with energy consumption for maintaining indoor temperature and air quality at a desired level. It is mostly related with occupants' thermal comfort perception. According to Kalz and Pfafferott (2014), thermal comfort is mainly related with satisfaction of person's expectations of the surrounding conditions. Thermal comfort can be maintained by equalizing the temperature of the human body and its surroundings (Kalz & Pfafferott, 2014). In order to achieve that goal, energy performance of the building is very important because the factors that influence thermal comfort can be listed as clothing; activity level; indoor air temperature and quality; humidity; airflow; the temperatures of surrounding surfaces, such as walls and floors; and the area of windows through which radiant heat transfer occurs (Ching & Shapiro, 2014).

While indoor temperature, air quality, and the temperatures of surrounding surfaces can influence thermal comfort of the occupants and users of the buildings, responses of the thermal indoor environment have an important effect on health, comfort, and performance of the people who are in that environment (Figure 2.3) (Kalz & Pfafferott, 2014). Additionally, poor thermal comfort can cause low productivity, and stresses on the human immune system. These social effects of inadequate thermal comfort standards can be adjusted with the enhancement of energy performance of the building (Ching & Shapiro, 2014).

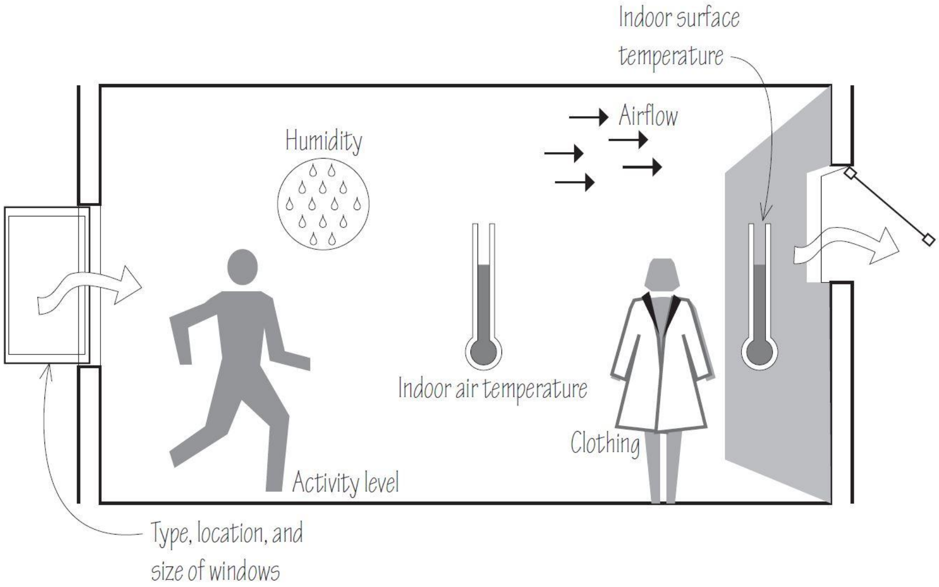

Figure 2.3. Factors effecting thermal comfort (Ching & Shapiro, 2014)

Impacts of insufficient indoor temperature and air quality can also affect materials of the buildings. Inadequate humidity control can cause mold growth and condensation on cold surfaces which can be the reasons of stress and damage to materials. Moreover, mold also affects the health and well-being of the occupants and users of the buildings also (Ching & Shapiro, 2014).

Besides thermal comfort, usage of renewable energy production to improve energy performance of the buildings will create another social impact. With the help of energy production ability, buildings will have the opportunity to reduce their grid dependency. Therefore, the risk of loss from grid block-outs will be diminished and they will have more stable energy (Intelligent Energy Europe Programme of the European Union, 2015).

2.2. Energy Efficiency in Buildings

In order to consume, save and produce energy wisely for the buildings, first of all, energy performance enhancement should be made according to energy efficiency measures. In order to reach that aim, design strategies should be applied appropriately. These design strategies can be divided into two main headings which are passive design strategies and active systems for energy efficiency. In this part of the second chapter, passive design strategies for energy efficiency will be examined under three subheadings that are position with respect to orientation, and location factors, form, and surface including roof and facade surfaces; and active systems for energy efficiency will be mentioned under two subheadings which are energy generation systems including solar, wind and ground heat systems; and building automation systems.

2.2.1. Passive Design Strategies for Energy Efficiency

In order to improve the building's energy performance, researchers, architects who are interested in enhancement of energy efficiency of the buildings from all over the world are examining the suitable building optimization methodologies. From these examinations, the high potential of energy performance improvement has drawn attention to the passive design strategies (Harkouss, Fardoun, & Biwole, 2018). These strategies can be clustered into two groups which are early stage passive design strategies such as position of the building including orientation and location; form of the builiding; and occupational stage passive design strategies such as envelope of the building including wall, facade and roof surface.

i. Position

During early stage applications of passive design strategies about positioning, there are several factors to affect decisions of positioning. Ching and Adams claim that these factors can be arranged as topography; climate; sun path; wind, rain and snow patterns; population including green, building, and road population; in order to orient and locate the building with respect to passive design strategies (2006, pp. 2-3).

In early design stages, in order to provide user comfort and to maximize the benefits about resources and energy usage, positioning the building, and considering nature as a source and not as an obstacle can affect directly the design decisions, if designer wants to create nature sensitive, low-energy buildings. (Ching & Adams, 2006, p. 2). Therefore, with the help of passive design positioning strategies, there are several factors that need to be considered, in order to orient and locate the building (Figure 2.4).

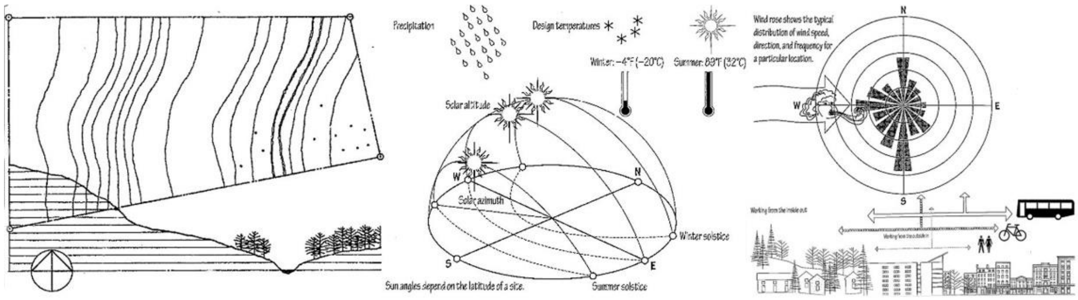

Figure 2.4. Factors affect positioning building; topography; climate; sun path; wind, rain and snow patterns; population including green, building, and road population (Ching & Shapiro, 2014, p. 34, 38, 36)

a. Orientation

Orientation is one of the most important strategy that helps to shape low-energy buildings. Especially solar orientation impacts energy consumption and occupant comfort. With the help of this passive design strategy, the sun can be used for both heating and illumination. Orientation strategy has been used throughout history. For example, in southwestern Colorado, the Native Americans of Mesa Verde shaped their dwellings to take advantage of warm rays of the sun in winter and cool shadows of the hill, where they located their dwellings, during summer (Kruger, & Seville, 2013 p. 67).

With the knowledge of climate and North-South directions, 'which facade should be faced to which direction' can be determined. Furthermore, according to sun and wind pattern, the angle of the building can be arranged or with the help of the snow pattern of this particular site, the shape of the roof of the building can be decided. Additionally, trees and buildings in the vicinity can provide the shadow pattern of the site, so the orientation can be regulated with respect to that knowledge in order to take advantage of the shadow pattern. Moreover, with the help of the roads around the site, entrance orientation can be decided to minimize energy consumed for transportation (Brophy, & Lewis, 2011, pp.51-60).

b. Location

As positioning the building with respect to early stage passive design strategies, orientation is the first step, the second step is location which can be called siting. Siting is affected by the same factors, like orientation, such as sun, wind, and snow pattern or surrounding greenery and structures (Figure 2.5). After deciding on the orientation of the building, the final place where the building will sit is important to maximize passive gains. The solar access for passive solar heating and cooling will be arranged by location because of the facts about closeness or remoteness of the building with nearby trees, hedges or structures creating shade which may be beneficial or harmful (Edminster, 2009, p. 77).

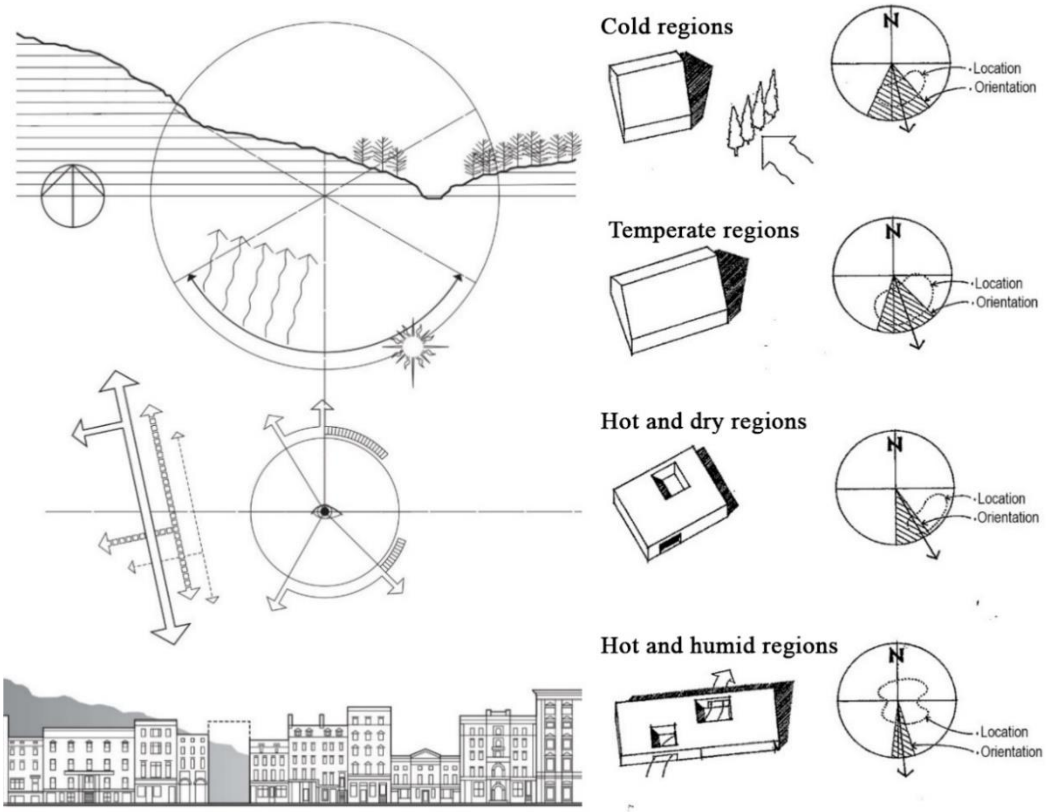

Figure 2.5. (Left) Location for positioning with respect to passive design strategies (Ching & Shapiro, 2014, p. 4), (Right) Relation between location, orientation and form (Ching & Adams, 2006, p. 11)

ii. Form

After orientation and location choices as early stage passive design strategies, some of the criteria which are mentioned above will lead to shape of the building including floor area, number of floors, and openings.

The floor area of the building refers to footprint of the building and it has strong relations with material and energy usage simply because larger buildings need more material usage and more energy for heating, cooling, lighting, and ventilating purposes. Besides floor area, number of the floors also affects the form of the building in the same way, if passive design strategies are considered as a tool to minimize energy consumption. (Ching & Shapiro, 2014, pp. 57-67).

Like floor area and number of the floors of the building, openings of the building are also useful to apply effective passive systems. Openings are mostly related with climatic conditions, as well as location and orientation of the building. As it can be seen from the Figure 2.5, for cold regions, buildings should have a form that has the ability to maximize absorption of solar radiation, to minimize heat loss, and to protect from wind. Hence it does not need large openings. Likewise, for temperate regions building should be shaped as elongated to South-West direction to minimize South-West facade for regulating the heat fluctuations. In this type of climates, buildings need to be ventilated in hot weathers and to be protected from wind in cold weathers. For the hot and dry regions, in order to regulate heat inside, solar heat should be decreased with the help of courtyards and sun protected windows and doors. Hot and humid regions require more or less the same form strategies with adding elongated South-West facades and openings located to support ventilation (Ching & Adams, 2006, p. 11).

iii. Surface

When some of the form characteristics of the building are set based on floor area, number of the floors, and openings, the surface area of the building become the next element of the passive design strategies as occupational stage. Although, the envelope of a building consists of three main elements; foundation, facades and roof, the surface of the building was studied under two main components, which are facade and roof surfaces of the building. These two were chosen because most of the heat losses occur from these exterior surfaces of the buildings (Chambers, 2011, pp. 21-35). Additionally, these two surfaces can be used briefly both to maintain heat inside and also to gain energy from outside. Therefore, building envelope can be defined as thermal envelope that divides conditioned and unconditioned space in a building. In order to keep human comfort at an efficient level, this building envelope must be continuous and complete (Kruger, & Seville, 2014, pp. 50-51).

a. Facade Surface

Facade of the buildings creates a boundary between conditioned spaces of the building and the outdoor. Hence, this element of the building has a crucial part analyzing heating and cooling loads. With the help of convenient selection of form, and material according to climate and applications of passive heating and cooling systems, facades of the buildings can provide great amount of energy efficiency. International Energy Agency (2013) point outs that 30% of the building energy consumption is used for space heating and cooling purposes globally, and this amount increases to 50% for cold climate regions (IEA Secretariat, 2013, p. 118). As a result of these findings, it is needed to manage heating and cooling energy consumption of the building by arranging the facades of these buildings with respect to passive design strategies. Some of the important passive design strategies can be given as improving the building fabric's thermal property, from where the majority of heat losses from buildings could be minimized; eliminating thermal bridges with cleverly designed details; and controlling air leakages by enhancing air tightness of lintels, windows and doors (Altan, & Kim, 2014). On the other hand, these improvements should be done with respect to climatic conditions. To illustrate, insulation levels need to be determined by climatic and local conditions. As it can be seen from Figure 2.6, different climate zones have different solar radiation values. Thus, the insulations must be done accordingly.

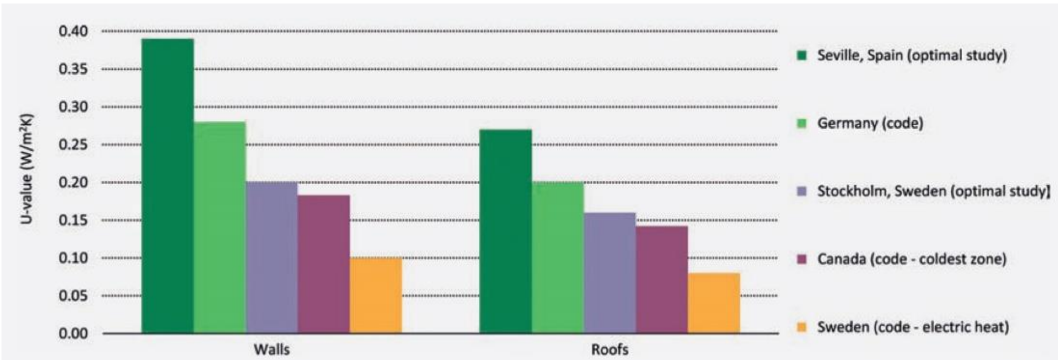

Figure 2.6. Wall and roof U-value comparisons for reference perspectives (IEA Secretariat, 2013, p. 134)

b. Roof Surface

Similar to the facade of the building, the roof surface is another complementary element of the thermal envelope for increasing energy efficiency. Like form of the facade, the type of the roof affects the occupational stage passive energy gaining strategies and these types can be divided according to their materials, shapes and application systems; such as pitched cold roof which is made from timber structure and clay tiles. Besides insulation, these types of roofs provide less condensation and more ventilation, which means that by gaining heat, maintenance efficiency also increases with the right selection of roof types (McMullan, 2012 p. 109) (Figure 2.7).

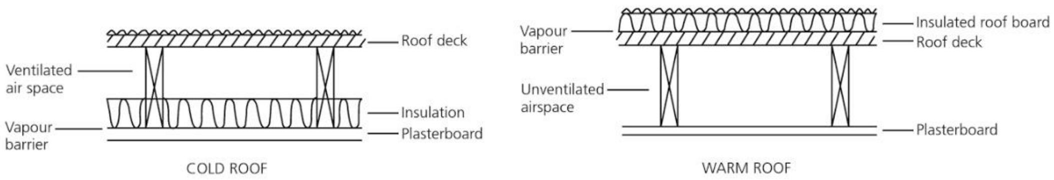

Figure 2.7. Different application types of roofs, cold and warm roof (McMullan, 2012 p. 109)

One of the main design considerations for the roof surface, after selecting the type, would be the roofing material selection. The main aim is saving energy. Due to the fact that, like in other parts of the building, sustainable materials which serve energy saving applications should be used in roofs, too. To illustrate, although asphalt is commonly used as roof insulation material, it is a petroleum-based product. Despite using petroleum-based materials, other sustainable options should be chosen, such as recycled rubber shingles, sustainably harvested wood products or recycled metal products. Another consideration is the material color. For instance, lighter color roofs reflect the solar radiations, so lighter colors provide less heat absorption. As a result, this kind of applications can be used for hot climates (Tucker, 2015, p. 46).

2.2.2. Active Design Strategies for Energy Efficiency

In the light of definitions made by Wigginton & Harris (2002), active design strategies provide effectively functioned building for its occupants, with the help of technology and control systems. Active systems, unlike passive design strategies, require mechanical and electronic devices. Besides these devices, active systems mostly need energy to operate. However, it is desired to consume as less energy as possible. Therefore, for these design strategies, less energy needed devices are preferable. For this purpose, active design strategies which are energy generation systems; and building automation systems are reviewed below.

i. Energy Generation Systems

Energy demand and usage has been changing according to the needs of the time. According to these changes, energy infrastructures and technologies have also evolved. For instance after the first oil crisis, demand for renewable technologies was increased to create an alternative for the high-priced oil. Like these energy generation systems, trying to find a solution to the question of how to consume less energy in buildings is also the product of these problems. Because of the importance of renewable energy generation systems the following sections cover solar, wind, and ground heat energy systems.

a. Solar Systems

The sun is the original resource for nearly all energy resources in the world. It can produce benefits to people, buildings, and spaces around them, but it should be used wisely to take advantage from it properly. In order to reduce energy load of the buildings, solar radiation could be transformed as useful energy source in two ways; passive and active solar strategies. Since, passive solar systems were already discussed above, active approaches to solar heating will be discussed in this section.

For powerful solar energy capturing systems, solar radiation data must be known in a detailed way, with the help of geographical location, time of year, orientation, and daily variations in solar radiation (Bougdah, Sharples, & Smith, 2010). After adequate knowledge about solar radiation is acquired, the solar systems can be implemented onto buildings. There are two main types of solar energy generation systems, which are solar water heating systems and photovoltaic cell systems.

Waterfield (2007) explained that solar water heating systems have two types which are cheap, relatively less efficient flat plate collectors and expensive, more efficient evacuated tube collectors, common feature of these kinds of it is a collector which is used for capturing solar energy to heat water inside of it and this water is fed to a storage tank for usable heated water (Figure 2.8). Collectors of these type of solar systems are usually located on south facing roofs or surfaces to receive as much solar radiation as possible. For the flat roofs, with respect to geographic location, collector angled to appropriate degree and located accordingly (Waterfield, 2007, pp. 120-124).

Bougdah, Sharples, and Smith (2010) define photovoltaic cell (PV) systems as converter of light energy directly into electricity (Figure 2.8). Like solar water heating systems, PV systems have two different kinds which are expensive, more efficient crystalline systems and cheap, less efficient thin film systems. Crystalline systems generate electricity with the help of electronic properties of the crystals. On the other hand, in thin film systems, technology of semi-conductors is used to produce electricity from light energy (Bougdah, Sharples, & Smith, 2010).

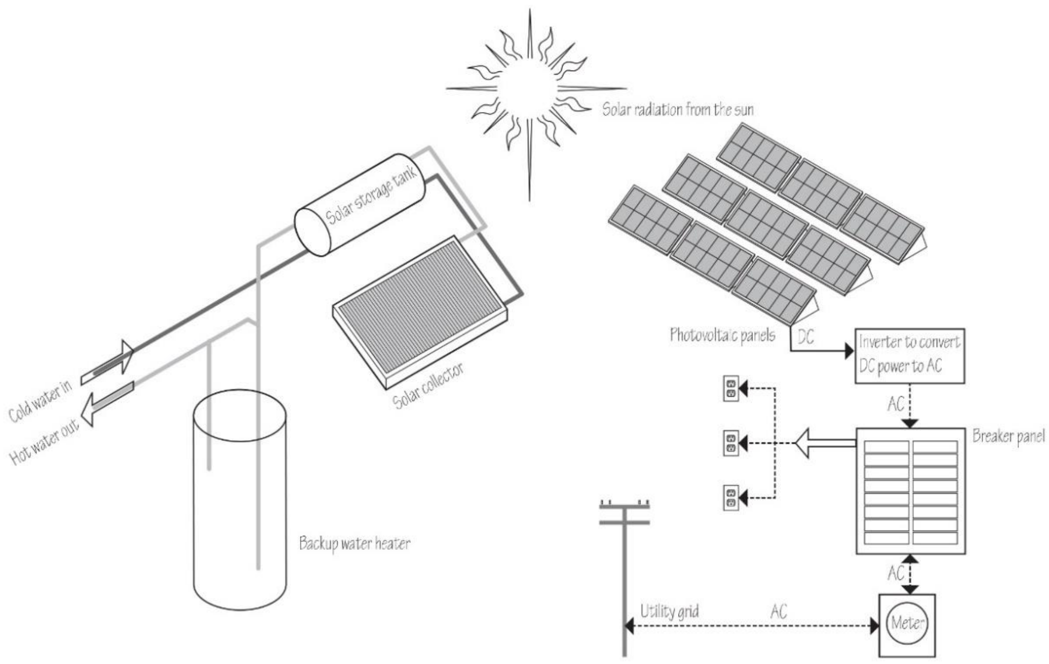

Figure 2.8. Solar energy generation types; solar water heating systems (left) and photovoltaic cell systems (right) (Ching & Shapiro, 2014, p. 207)

b. Wind Systems

In wind energy systems thermodynamic rules were used to produce electricity, like other renewable energy systems except solar ones (Jankovic, 2012). Kinetic energy of wind rotates the turbines attached to an electricity generator, and these rotations produce electricity. There are two main types of wind turbines; horizontal and vertical axis wind turbines. Horizontal axis turbines have large blades and they are suitable for wind farms to generate a great amount of electricity (Figure 2.9). On the contrary, vertical ones are smaller than horizontal ones. They can be applied in urban areas such as on top of a building (Jankovic, 2012, pp. 173-174).

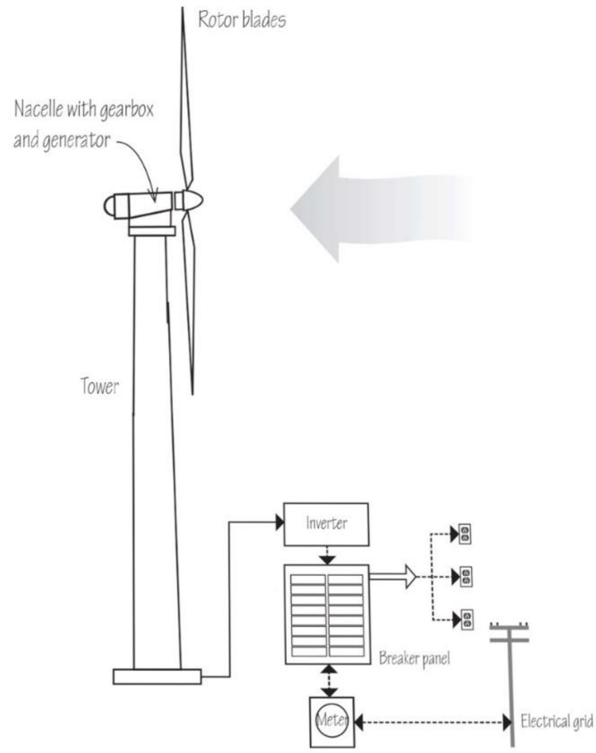

Figure 2.9. Horizontal axis wind turbines (Ching & Shapiro, 2014, p. 209)

c. Ground Heat Systems

Ground heat is used to supply heating and cooling energy of the building in two different ways; geothermal energy systems and ground coupled heating and cooling systems. The main common point of these two systems is using the heat produced under ground. Yet, they are differentiated according to source they are using under the ground. IEA (2011) defines the sources of geothermal energy systems as high-temperature hydrothermal resources, deep aquifer systems with low and medium temperatures, and hot rock resources.

Jankovic (2012) states the working principle of ground coupled heating and cooling systems that these systems use the heat taken from the ground -from sand itself- via pipes filled with water and pumped out it into the underfloor heating in the building (Figure 2.10). Ground coupled heating and cooling systems have two types which are vertical systems which have their ground loop in a bore hole, and horizontal systems which have the ground loop in trenches about 1.5 meters deep (Jankovic, 2012, pp. 171-172). In both ground heat systems, heat produced by these sources is pumped out with water pipes using electricity (Ching & Shapiro, 2014, p. 206). Hence, in the light of information given by Ching and Shapiro (2014), it should be noted that these types of ground heat systems are not as efficient as other kind of systems mentioned above.

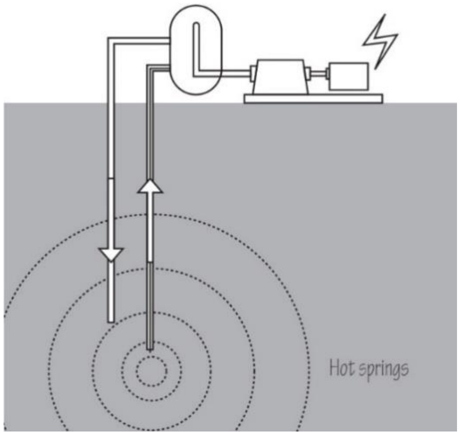

Figure 2.10. Geothermal energy systems (Ching & Shapiro, 2014, p. 206)

ii. Building Automation Systems

Building automation systems (BAS), are also known as building management systems (BMS), are used as an 'umbrella term' which refers to computerized building control systems including special-purpose controllers, independent remote terminals, central computer stations and printers. Additionally, BAS counts as one of the main intelligent building systems and high-tech active design strategy (Wang, 2010, p. 26). Furthermore, BAS can help all of the building systems, as it can be seen from Figure 2.11.

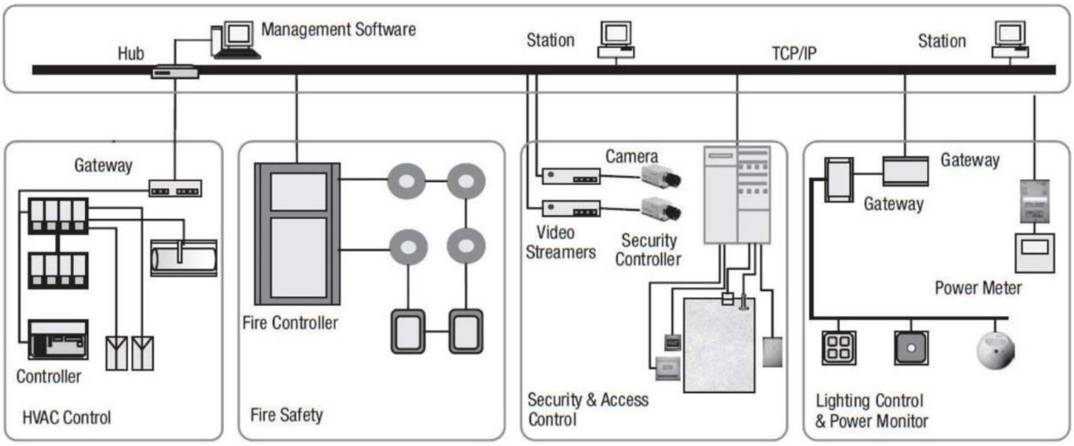

Figure 2.11. Building automation system (Wang, 2010, p. 72)

The functions of BAS are installation management and control functions that provide efficient building services such as on/off controls of lights or heating, cooling services as; energy management functions which allow scheduled and optimized start/stop controls to building services for saving energy; information processing functions that is provide graphs and tables report about performance monitoring, maintenance and diagnosis; risk management functions which is useful for emergencies such as fire; facility management functions that help the system to adapt speedily improving requirements and to provide essential management information (Wang, 2010, pp. 38-42).

2.3. Energy Retrofits in Existing Buildings

In order to use energy efficiently, the design strategies mentioned in the previous sections can be used. However, in order to focus on the energy problem in buildings and to find a solution for the problem, after perceiving the design strategies, the terms used in the field are needed to be clarified, differentiated and understood. In the building sector, there are various terms which may overlap. It is necessary to understand what exactly a retrofit is, and how it differs from other terms that are used in the field. According to Directive 2002/91/EC of The European Parliament and of the Council of 16 December 2002 on the energy performance of buildings (2003), retrofit means changing, modifying or improving something which has been already produced. In the buildings, retrofit addresses the changes that are made in the system of the building after they are operational. Usually this is done with the expectation of altering amenities for the building's occupants and/or improving the performance of the building. With the help of the enhancements of new technologies, building retrofits can allow for significant reductions in energy usage (Mazzarella, 2015).

2.3.1. Energy Retrofits Strategies

Energy retrofit strategies are examined under two subheadings which are refurbishment and usage of renewable technology on existing buildings; because the implementation process of these two strategies are more suitable to the old buildings.

Refurbishment on buildings for energy efficiency include partial interventions, as compared to retrofits. Although retrofitting and refurbishing have some similar features, like both of them are made after occupational phase of the building, refurbishment is a part of the retrofitting strategies (Economidou, et al., 2011). Refurbishment may consist of the installation of current standard of building services, or upgrades to the building's mechanical systems. It is done mostly for esthetical purposes, but when it is made with energy efficiency approach, it is very useful for improving the energy performance of the building (Mazzarella, 2015). Like refurbishment, using renewable energy technologies on buildings for energy harvesting is also a component of the retrofit strategy. In other words, refurbishment of a building for energy efficiency purposes and using renewable energy for the same intentions are strategies of energy retrofitting.

i. Refurbishment

Buildings where we are living are quite durable. If occupants do the maintenance of the buildings on a regular basis, they can sustain their existence for a long time; as long as one or two human life-time or even more (Power, 2008). While they are surviving in time with the help of their regular maintenance, occupants' demands, technology and world are changing. Therefore, their maintenance is starting to transform into energy refurbishment in time, if the occupants want to keep up with changing conditions and to protect the earth and themselves. Because of this reason and the other reasons which will be discussed in later sections, refurbishment is preferable for energy retrofit strategies.

According to Kubba, (2016) refurbishment involves renovation of Heating Ventilating and Air Conditioning (HVAC) elements, envelop and internal system of the building. Likewise, the BRE provides similar approach for the methodology of refurbishment; alteration of thermal elements (walls, roofs and floors), building services (HVAC, lighting systems) and fittings (windows, entrance doors) of the buildings (BRE Global, 2017).

These methods are related with level of refurbishment which is explained by Shah (2012) in five levels. These five levels are defined according to condition and performance of the building, as shown in Figure 2.12. Building conditions and performance were ranked as excellent, good, poor and very poor. The purpose of each level of refurbishment is upgrading the building conditions and/or performance to the excellent. From Level 1 to 5 the scope of the refurbishment is expanded. Level 1 is termed as "light touch/refresh" which includes repairing and upgrading minor elements of the building. In this level, building could have better conditions than the other levels and excellent building performance or vice versa. In the first case, interventions are done for upgrading the building conditions from good to excellent. For the second case called Level 2, in addition to Level 1 refurbishments "medium interventions" are also done; i.e. replacement of building fittings (windows, entrance doors). Shah (2012) divides Level 2 into three types; poor building conditions and excellent building performance; good building condition and performance; and excellent building conditions and poor building performance. For each case, refurbishments are done for enhancing building condition and/or performance to excellent. In Level 3 called “extensive intervention”, works done on Level 2 plus full replacement of building services, while some alteration of thermal elements is done as refurbishment goals. Major refurbishments are done in Level 4 which includes total replacement of thermal elements, building services and fittings of the building. Level 5 covers demolition (Shah, 2012). However, as it mentioned above, the demolition choice is the very final choice for the good of environment, economy and society (Sustainable Development Commission’s Stock Take Report, 2006).

	Building Condition				
Building Performance		Excellent	Good	Poor	Very Poor
	Excellent	Maintain	Level 1	Level 2	Level 3
	Good	Level 1	Level 2	Level 3	Level 3
	Poor	Level 2	Level 3	Level 3	Level 4
	Very Poor	Level 3	Level 3	Level 4	Level 5

Figure 2.12. Level of refurbishment (Shah, 2012)

The effects of these interventions were mainly related with the lifespan of the building and energy consumption. For example, extensive intervention can future-proof the building for a further 15-20 years, while comprehensive refurbishment can make it 20-25 years (Shah, 2012). As it is described by Kruger and Seville (2013), with the help of proper replacement of the building elements and services, the energy consumption of the buildings can approach to zero.

ii. Renewable Energy Usage

According to definition of European Parliament (2003), usage of renewable energy can be examined under 'improving' part of retrofit term while 'changing / modifying' part can be called refurbishment.

After the first and second oil crises related to energy the additional impacts of climate change made matters worse. Hence, because of the threat of climate change associated with greenhouse gasses that are mainly caused by emissions from the buildings' heating, ventilating, cooling and air conditioning (HVAC) systems (Conti et al., pp. 10-11), building professionals started taking actions to solve these issues. The first step was taken with the Chicago Declaration in 1993which emphasizes that:

'Sustainable design integrates consideration of resource and energy efficiency, healthy buildings and materials, ecologically and socially sensitive land use and an aesthetic that inspires, affirms and enables.' (UIA, 1993)

After the establishment of the Union Internationale des Architectes (UIA) via Chicago Declaration, in order to be more effective, Europe and Architecture Tomorrow was established by the Architects' Council of Europe, in 1995 (Brophy, & Lewis, 2011, p. 1). Subsequently, in order to enforce less energy consumption in buildings, Energy Performance of Building Directive (EPBD) was approved by the European Parliament and Council, in 2002 (Jankovic, 2012, pp. 4-5). These declarations and movements supported the use of renewable energy in the buildings. Additionally, they pointed out that renewable energy usage can provide less energy consumption from the grid.

The purpose of using renewable energy technologies for buildings is harvesting energy and achieving the buildings' own energy independence to combat climate change by reducing greenhouse gases. In other words, with the help of this technology, buildings are becoming less grid dependent, which means that buildings start to become net or near zero energy buildings. (Intelligent Energy Europe Programme of the European Union, 2015).

2.3.2. Benefits of Energy Retrofits

There are several advantages of energy retrofit actions for both building owners and occupants. These advantages are given into three headings; environmental, economic, and social benefits of energy retrofits.

Energy retrofitting is done mostly for economic purposes. However, its environmental gains are very powerful. As an example, a refurbished building spent less energy than a regular building, as a result of that, less energy consumption creates an environmental advantage. Moreover, the ability to produce energy from renewable sources ensures independence from fossil fuels, release reduced greenhouse gasses, and have diminished carbon foot print (Intelligent Energy Europe Programme of the European Union, 2015). Also, because of not using the grid as a main supplier of energy, the retrofitted buildings do not put additional load on the energy supply grids. Furthermore, with the help of long-lasting renewable technologies, the consumption of materials is decreasing (Sartori et. al., 2010).

After refurbishments, the building life span is getting longer and due to the lowered life cycle cost (LCC) of the building, maintenance cost, special repairs cost, cleaning cost, energy cost, administration cost of the building has been decreased (Jafari & Valentin, 2018). In addition to refurbishment, the retrofitted buildings have the ability to produce renewable energy, and they are less grid dependent than conventional buildings. Thus, they are energy efficient and they provide reduced total cost of ownership and total net monthly cost of living (Holopainen, Milandru, Ahvenniemi, & Häkkinen, 2016). Additionally, with the help of technological improvements, such energy has become easy to produce, and easy to sell back to the grid. Furthermore, these renewable technologies can be used for a long time. As a result, maintenance cost is very low. In order to make these technologies more efficient, new professions have been born; thus, new job opportunities are increasing day by day with the help of using the renewable energy technology in the buildings (Ferreira, Almeida, & Rodrigues, 2016, pp. 724-737).

As social advantages of energy retrofit, if the passive design strategies, which were mentioned before, can be used effectively, these buildings can provide healthier and more satisfying place to live, and with minimized thermal bridges, they have more uniform interior temperatures (Ching & Shapiro, 2014). Because of reduced grid dependency, residents of the retrofitted buildings have less risk of loss from grid blackouts, so they can have more stable energy supplies, and if they have energy storage, they can have energy all the time (Ferreira, Almeida, & Rodrigues, 2016).

2.3.3. Barriers to Energy Retrofits

Despite various advantages, there are also some barriers which can discourage the investors, building owners or occupants from applying energy retrofit strategies. Like the benefits of the retrofits, their barriers can be grouped into three also; i.e. environmental, financial and social.

Unorganized construction management could be the most influential about the only problematic environmental barrier of the energy retrofits. Sensitive approach is required to pay attention to the construction phase impacts of the actions; such as waste management of residual materials, or transport problems (Sartori et. al., 2010).

Economic barrier to energy retrofitting is one of the most important barriers which is based on its high initial cost. Energy retrofit actions such as renewable energy technology use is still new, and they require an additional effort to understand, apply, and qualify for subsidies, if they exist in that particular site (Ferreira, Almeida, & Rodrigues, 2016, pp. 724-737). Although there are high initial costs, the payback periods of these actions are needed to be considered carefully. Because if the payback periods are taken into consideration, it can be seen that actually the initial cost can be covered in time (Carlson & Pressnail, 2018).

The other important barrier of energy retrofit is social barriers. Due to the fluctuating nature of renewable energy, without energy storage, residents of the retrofitted building can start to depend grid energy. Beside storage problems, another social disadvantage is social acceptance. This disadvantage is the most problematic one, because effort is required to present the real impacts of energy retrofit actions to the public in order to convince them, also if the public is convinced, it also needs to take action (Ferreira, Almeida, & Rodrigues, 2016).

2.3.4. Problems and Deficiencies of Energy Retrofit

Feasible and appropriate energy retrofit applications can provide several benefits which can be very useful in our daily life. On the other hand, there are some major barriers to overcome in order to apply them. These barriers can be defined as problems and deficiencies of energy retrofit. These are cost of renovations and the attitude of occupants.

When energy retrofits are cost-effective and human-based this energy retrofit actions provide less energy consumption, less environmental impact and higher occupant friendly buildings. (Corgnati, Cotana, D'Oca, Pisello, & Rosso, 2017).

In addition, while occupants' attitude is considered, the rebound effect should also be taken into consideration. The rebound effect is one of the most critical issue in energy economics field. The meaning of this effect is that demand for the energy services expands as the price of these services decreases after energy efficiency improves (Lin & Liu, 2015). This is a very challenging problem of the energy retrofit actions. Thus, occupants need to be convinced and made aware of the benefits and importance of these energy retrofit interventions.

2.4. Occupants' Attitudes towards Energy Retrofit

The term attitude is defined as way of thinking or feeling about something (Oxford Dictionaries, 2016). These actions can be reflexive, instinctive, systematic, deliberate, and logical or can be vice versa (Olanrewaju, Tan, Tat, & Mine, 2017). Human beings need triggers to adapt an attitude. In standard economic theory, the foundation of the attitude is based on the individuals' choices, which in turn are shaped by cost and benefit (Darnton, 2008). However, the attitude of people towards the same situation is variable, they do not "receive, perceive, and respond" in the same way, because of different physical and mental characteristics of people, and many other external factors such as economic and governing circumstances (Bluyssen, 2015). In other words, most human behavior depends on the environment and their habits; and is irrational (Olanrewaju, Tan, Tat, & Mine, 2017).

On the other hand, while people may have uncertain attitudes, according to their habits, as building occupants they have a pattern of activities affecting the building energy consumption. For instance, presence of occupants inevitably produces metabolic heat, which causes passive energy differences such as internal heat gains in the building. As an example for active energy actions of occupants, use of lighting, solar shading, hot water, appliances and so on lead to energy consumption (Delzendeh, Wu, Lee, & Zhou, 2017). Therefore, the conscious or unconscious, direct or indirect impact of the occupants have a role in determining their energy consumptions in the buildings. Besides occupants' activities affecting building energy consumption, their attitudes also influence energy consumption and/or production in the building, as well as implementations of energy retrofit strategies. Moreover, with the increased awareness of occupants related to energy retrofits and their benefits, the tendency of the occupants to use energy in an efficient way increases (Zhang, Bai, Mills, & Pezzey, 2018). Because of these reasons, the ignored social dimension of the building retrofits actions such as the occupants' attitudes needed to be taken into consideration (Abreu, Oliveira, & Lopes, 2017).

Like energy efficiency in buildings, occupants' attitudes towards energy retrofits can be examined under two headings. The first, occupants' attitudes towards passive design strategies focusing on refurbishments. The second, reactions of the occupants related to active building systems, mainly renewable energy generation system.

2.4.1. Occupants' Attitudes towards Passive Design Strategies

Due to the large impact of buildings on global energy consumption, international directives and researches have given more attention to the physical conditions of the buildings such as the building envelope, and the HVAC systems (Langevin, Wen, & Gurian, 2015). One way to calculate these impacts is to simulate the performance of buildings; however, significant incompatibility between the simulated, calculated and the real total energy consumption values in buildings have been observed commonly (Rinaldi, Schweiker, & Iannone, 2018). As a matter of fact, according to Hargreaves, Nye, and Burgess, (2010), even identical flats having same installations could show great difference in energy consumption. Hence, other factors needed to be considered to achieve real total energy savings. At this point, analyzing and understanding the occupants' attitude plays a key role in building energy usage optimization, performance assessment, and building energy simulations (Rinaldi, Schweiker, & Iannone, 2018).

In occupants' energy usage pattern, the size of the household, income and age of the occupants play an important role (Steemers & Yun, 2009). The other factors that should be considered in the energy consumption pattern of the occupants is the potential combinations and interactions of occupants which have an essential effect on energy usage. To illustrate, choice of building type and equipment are affected by the occupants income (Steemers & Yun, 2009). In other words, the preferences and attitudes of the occupants who have an important place in the energy expenditures and consumption are largely related to the household size; occupants' age and presence at home; and other individual preferences and characteristics (Santangelo & Tondelli, 2017).

Occupants' attitudes towards refurbihments is mainly affected by similar factors that affect their energy usage pattern, such as size of the flat; income, age and presence of the occupants. Furthermore, there are several other factors that influence occupants' attitudes towards refurbishments. These factors are mailnly related with personal preferences which can be driven by aesthetic or functional concerns (Stieß & Dunkelberg, 2013). These reasons can be beautifying the flat; replacing and/or renewing a defective or broken building component; maintaining and/or increasing the household's value; creating a more comfortable indoor climate and thermal conditions; saving energy; reducing energy consumption as far as possible in the long run; reducing operation costs; making a contribution to climate protection; and becoming less dependent on fossil fuels (Stieß & Dunkelberg, 2013).

2.4.2. Occupants' Attitudes towards Active Design Strategies

Active design strategies were examined mainly focusing on using a renewable energy generation system, because its application is more suitable for existing buildings rather than application of building automation systems (BAS) (Economist Intelligence Unit Rep., 2012). By the way of different explanation, highly serviced modern buildings could need more advanced control systems, while increasing system efficiency could be sufficient for existing old and simpler buildings (Fabi, Spigliantini, & Corgnati, 2017).

Renewable energy generation systems can be very effective for energy efficiency purposes. However, occupants' attitudes towards renewable energy generation system usage depends on several variables. According to empirical data taken from OECD Economics Department Working Papers (2014), the factors which are affecting the investment in renewable energy technologies can be listed as home ownership, occupants' income, social context and occupants' energy use patterns. Indeed, the tendency to invest in clean energy by the occupants having higher income and/or owners of the flat is higher than renters and/or low-income households (OECD Economics Department Working Papers, 2014). In addition to the financial state of the occupants, the social context, energy use and practices of the occupants have a relevant part in renewable technology adoption. For example, if the occupants have a membership in an environmental non-governmental organization, and/or are already environmentally-concerned, they are more likely to invest in clean energy technologies (Caird, Roy, & Herring, 2008).

Like income of the occupants, the initial cost of renewable energy generation system installation is an important factor in determining occupants' attitude. Upfront cost of energy efficiency investment i.e. renewable energy installations could have a great impact on occupants, because it is directly noticeable. On the other hand, the energy savings over the life time of interventions and payback periods of the implementations are more difficult to estimate for the occupants (OECD Economics Department Working Papers, 2015). Additionally, the initial cost will affect the payback period of the intervention. According to Anderson and Newell (2004), 10% increase in payback could cause approximately 0.8% decrease to adopt clean energy technologies (Figure 2.13).

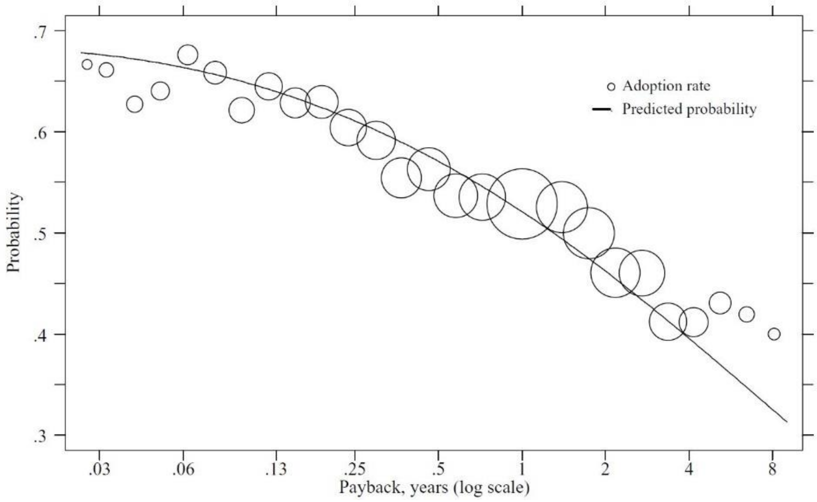

Figure 2.13. Probability of adoption vs. payback (Anderson & Newell, 2004)

2.5. Critical Analysis of Literature Review

The topics of the researches which are in the literature have been mainly concentrated on energy retrofit strategies, energy retrofit efficiency and applications. In the literature, there are also numerous studies related to design strategies for energy efficiency; passive design strategies mainly focused on refurbishment interventions; and active system usage was concentrated around renewable energy generation system usage for existing buildings. On the other hand, the initial cost of retrofits and payback periods of these actions are becoming major problems to overcome. Beside monetary topics, uncertain attitude of occupants for energy retrofit actions is also another major problem. To this end there is not any study on how to persuade building owners/ occupants to adopt these strategies. In addition, in turkey, there are numerous buildings with insufficient energy performance. However, there was not any study focusing on these topics for the Turkish residential buildings. At this point, the aim is to contribute to the literature by determining occupant’s attitude towards refurbishments and using renewable energy in residential buildings for energy retrofit while considering the cost of the interventions, in Turkey.

CHAPTER 3

MATERIALS AND METHOD

The materials used in the research and the method of the study are explained in this chapter under two subheadings separately. In the materials section, features and selection criteria of the case studies, photovoltaic panels and questionnaire surveys with occupants of the two selected case studies are described. The procedure for conducting the simulations, and questionnaires for these two cases are given in the method section.

3.1. Materials

The material of the study were two residential complexes as the case study areas, photovoltaic panels, two questionnaire surveys directed at the building occupants, , a simulation software, a computer program for cost calculations, and the weather data for Ankara. These materials are explained in detail in the following paragraphs.

The DesignBuilder software that employs the EnergyPlus engine for calculations was used for the building performance simulations. The computer program was used to calculate the cost of retrofits and payback periods. While the weather data file for Ankara was downloaded from the EnergyPlus software database (Figure 3.1). Ankara is classified as cold semiarid climate (BSk) in Köppen scale (Lovell, 2010) and is located in the Greenwich Mean Time (GMT) +2 time zone.

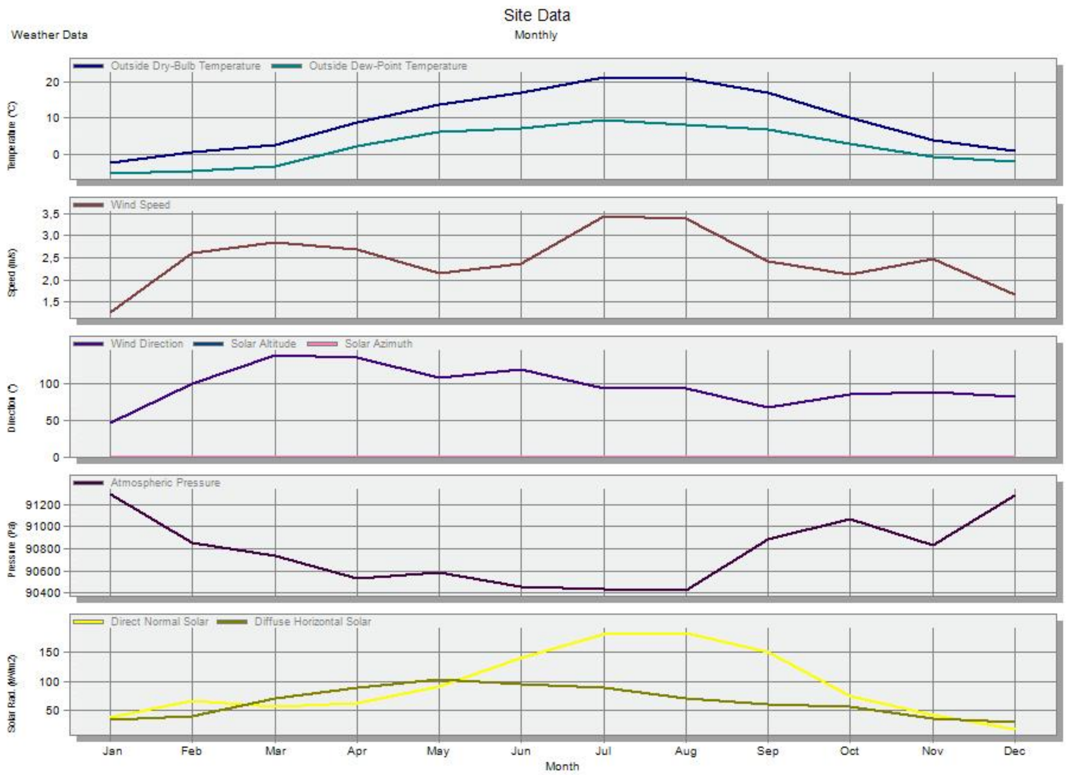

Figure 3.1. Weather data of Ankara taken from EnergyPlus database

3.1.1. Case Studies

The selected case studies were located in the 100. Yıl İşçi Blokları residential neighborhood. In the area there are two types of building blocks which are low-rise and high-rise buildings. These buildings were constructed by S. S. Ankara Workers Unions Confederation Members Cooperative which founded on January 22, 1965 to make their partners home-owner (Kose, 2013). The cooperative first started the construction of a social housing complex consisted of 2566 houses for the families of low-income workers in Aydınlıkevler, Ankara. Thereafter, continued in the 100. Yıl area. In 1973, the same confederation was started to construct second phase of social housing complex consisted of 3500 houses in 100. Yıl İşçi Blokları neighborhood, Ankara. Yet, due to the high demand in this region, the number of houses has been increased from 3500 to 4906. To meet this rising, the number of high-rise blocks has been increased (Basaran, Baskan, & Kalac, 2003).

The construction of these buildings began with German engineers and Intur construction company (Basaran, Baskan, & Kalac, 2003). The neighborhood names were chosen from the names of the cities in Cyprus under the influence of the Cyprus landing in 1974. Firstly, the Kyrenia stage was completed in 1977 (Kose, 2013). Between 1978-1980, the construction was stopped due to the dispute between the management and the firm. Later, agreements were made with different companies and all of the constructions were completed in November 1988 and delivered to their owners. In 1981, with the decision of S. S. Ankara Workers Unions Confederation Members Cooperative, the neighborhood started to be called 100. Yıl İşçi Blokları officially (Basaran, Baskan, & Kalac, 2003).

These dwellings, which are constructed with reinforced concrete skeleton and brick filling material, are examples of social housing where parks, schools, service buildings and bazaar are designed together with social life (Kose, 2013). The high blocks were gathered in the middle and surrounded by low-rise buildings (Basaran, Baskan, & Kalac, 2003). Additionally, the buildings are positioned to form social courtyards. Additionally all of the low-rise houses were placed around a courtyard and the kitchens of the houses were placed to see these courtyards. Buildings were not positioned according to the direction of the sun or other climatic conditions of the site, but according to the areas shaped by social life. One of the most different features of the site was that it had a heating center where heating was provided from the same center and it was one of the first examples of its period with this feature (Kose, 2013). However, with the arrival of natural gas in the region, this heating center was closed, and all buildings were switched from central heating to individual heating via combi.

100. Yıl İşçi Blokları, which are located just east of METU campus, far away from the city center at the time it was built, have provided accommodation to many people, including families of low-income workers and METU students. (Kose, 2013). Because

of the designed social buildings such as bazaar, culture house and green areas consisting of parks and gardens, it can be said that the site has an important place in the social memory due to the modern neighborhood texture and the social life it offers to its inhabitants. However, as a result of the growth of the city to the west, the neighborhood has a very high rent in the city center today. And the modern urban texture of the neighborhood faces the threat of urban transformation unfortunately.

The selected these two different dwelling complexes examined separately, in the thesis. The first building complex encompasses 21 low-rise apartment buildings located in the neighborhood explained above. The second building complex consists of 3 high rise apartment buildings and is also located in the same neighborhood as the first case study.

These existing building blocks were selected because these two complexes have similar occupancy features but some of the building characteristics are different. Additionally, these case studies are located in a neighborhood where strong bonds exist between occupants and the locality. The occupants want to protect their neighborhood, but their buildings are relatively old (constructed in 1970s) and worse for wear, they have excessive energy requirements, and need maintenance. Additionally, these buildings do not have adequate features to provide indoor thermal comfort to the occupants. The space and water heating system of the existing buildings is achieved through an individual combi and radiator system that uses natural gas as fuel for each flat. The radiators were mounted on the walls. Since there are no mechanical cooling systems, occupants of two case study residences use natural ventilation for cooling, by opening the windows. In the following sections, the details about these case studies are given.

i. Case Study 1: Low-rise apartments

The first case study complex consists of 21 identical low-rise apartment buildings and each building has 10 flats (Figure 3.2). All of the buildings have the same plans and facades (Figure 3.3, 3.4 and 3.5), therefore, only one was simulated and evaluated as the reference building.

Figure 3.2. Site plan of the first case study residential area consisting of 21 apartment blocks

Figure 3.3. Architectural plan of a typical floor of first case study apartment building consisting of two flats

Figure 3.4. Photo showing the front and side façades of one of the first case study apartment buildings

Figure 3.5. Photo showing the rear facade of the first case study apartment buildings

Several renovations have been made since the time these buildings were built. However, the architectural elements of the building painted in dark color in the Figure 3.2 did not renovated unlike the other low-rise buildings. This building was very close the state when it was first built. Hence, base assumption related to the architectural elements of the buildings was made based on the architectural elements of the building painted in dark color in the Figure 3.2. For instance, it is assumed that all the case buildings do not have any thermal insulation layers; the exterior doors are uninsulated metal doors and the windows have wooden frames with 6mm single layer of clear glazing. The building structure is composed of a concrete skeleton frame and slabs with uninsulated plastered walls. The interior walls are also made of plastered and painted brick partitions. Uninsulated linoleum flooring has been used over the concrete floor slabs. The pitched clay tile roofs are also not thermally insulated. Heated area of one flat is 78.2 m^2 while the height from floor to ceiling is 2.65 m Therefore, the volume of the occupied heated spaces is 207.2 m^3.

i. Case Study 2: High-rise apartments

The second case study residential complex consists of 3 identical buildings while each building has 15 floors (Figure 3.6). On each floor of each block, there are four identical flats and each block has the same plans and facades (Figure 3.7 and 3.8). There are total of 180 flats in the study area.

Figure 3.6. Site plan of the second case study residential area

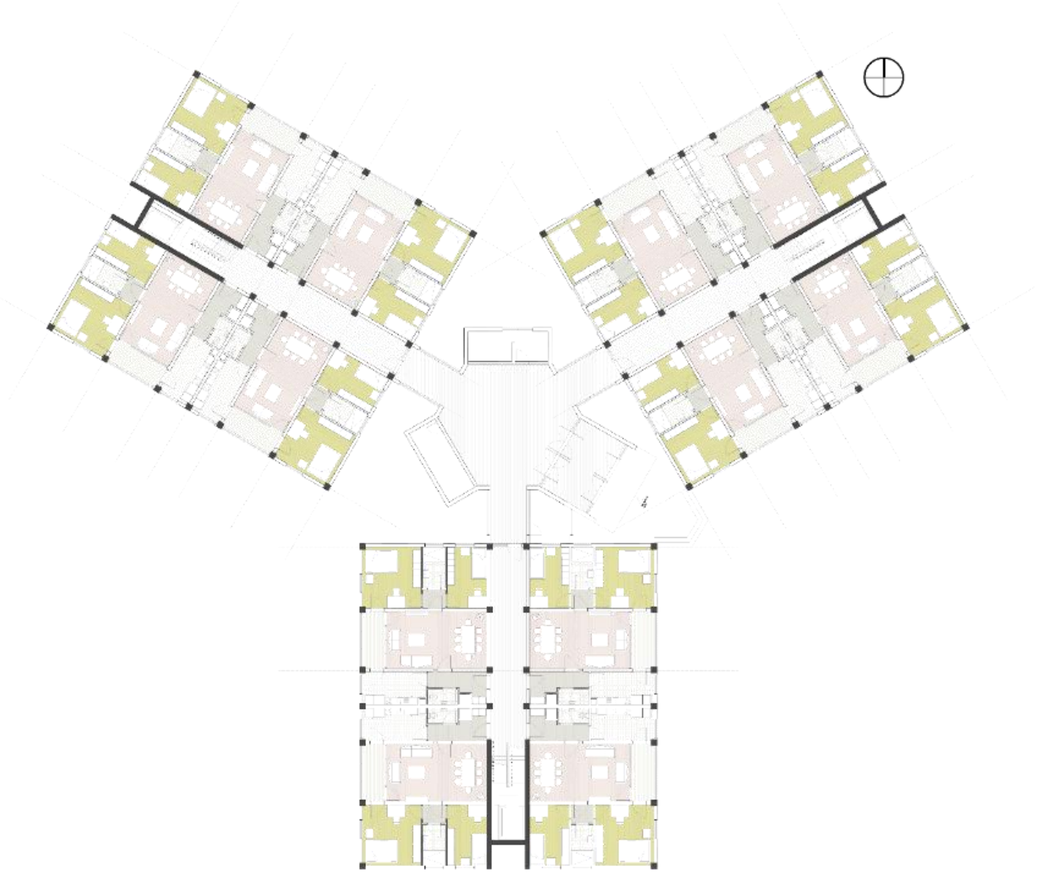

Figure 3.7. Floor plan of the representative building in the second case study residential area

Figure 3.8. Photo showing the facades of the second case study apartment buildings (G Blok Yonetimi, 2012)

The occupants tried to renovate these buildings in order to achieve better thermal conditions in 2013, and thermal insulation was applied to the building facades and the roof of the building. However, the energy consumption of the area was not changed, and the thermal conditions are still not satisfactory because of the insufficient amount of insulation (30mm Rockwool).

Because of the renovations done in 2013, base assumption related to the architectural elements of the buildings was made based on the state when the building was first built. The selected building was painted in dark color in the Figure 3.6. As a result of that, the construction material and building technology is the same as in the low-rise apartments. Yet, the roof of the second case study buildings was assumed as flat roof, because in the drawings taken from municipality, these buildings had flat roofs when they constructed. Whereas, the flats have a floor area of 82.9 m^2 and the height from floor to ceiling is 2.65 m. Thus, the volume of heated space is 219.7 m^3.

3.1.2. Photovoltaic Panels

For the second case study, three retrofit scenarios were considered. For the second one of these three scenarios, photovoltaic (PV) panels were used. These panels consist of 72 polycrystalline high efficiency cells (156 x 156 mm) and are called AC-330P/156-72S (Figure 3.9). The front side of the panels are made of 3.2mm hardened, low-reflection white glass and backside are covered with a proprietary composite film (Axitecsolar, 2014). Electrical data of the PV panels at standard conditions (STC), i.e. when irradiance is 1000 watt/m2, spectrum Air Mass is 1.5 at a cell temperature of 25°C is given in Table 3.1 below.

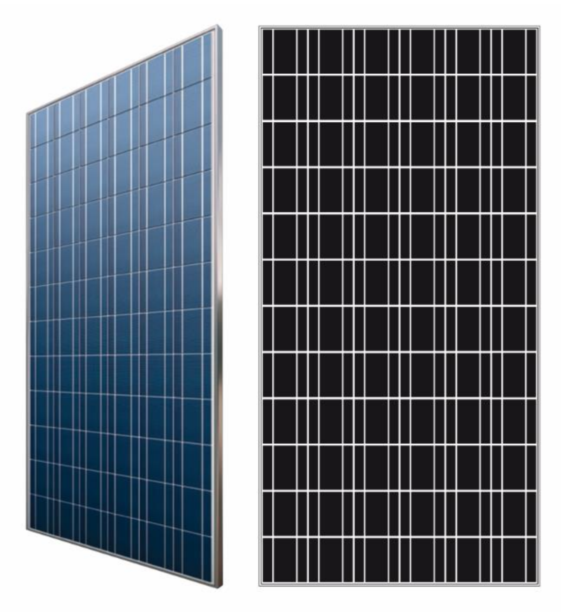

Figure 3.9. PV panels used in the study (Axitecsolar, 2014)

Table 3.1. *Electrical data of the AC-330P/156-72S type PV panels at standard conditions (Axitecsolar, 2014)*

Nominal output (Pmpp)	Nominal voltage (Umpp)	Nominal current (Impp)	Short circuit current (Isc)	Open circuit voltage (Uoc)	Module conversion efficiency
330 Wp	37.70 V	8.76 A	9.27 A	45.83 V	17.01%

The PV panels were chosen from a Swiss company called Anerdgy, because the panels were installed by that company were more efficient and produced more energy with less installation space. Additionally, these panels were installed the edges on top of the roof of the building (Figure 3.10). Therefore, this installation system and the panels could combine functional elements, design options and local energy generation; enable easy roof terracing and greening, generates a high amount of local electricity & hot water with less use of roof surface; and highly cost effective due to its multi-functionality (Axitecsolar, 2014).

For each 2nd and 3rd scenario of the second case buildings, 114 photovoltaic panels were used on top of the roofs of the three buildings. These panels were installed according to angle determined by the environmental conditions such as orientation of the buildings and so on. Moreover, two panels which are pinned from their top edges were installed to the edges of the roofs (Figure 3.11). With the help of these angled two panels, the space between these panels could be used for several purposes (Axitecsolar, 2014).

Figure 3.10. PV panel installation, roof design possibilities (Axitecsolar, 2014)

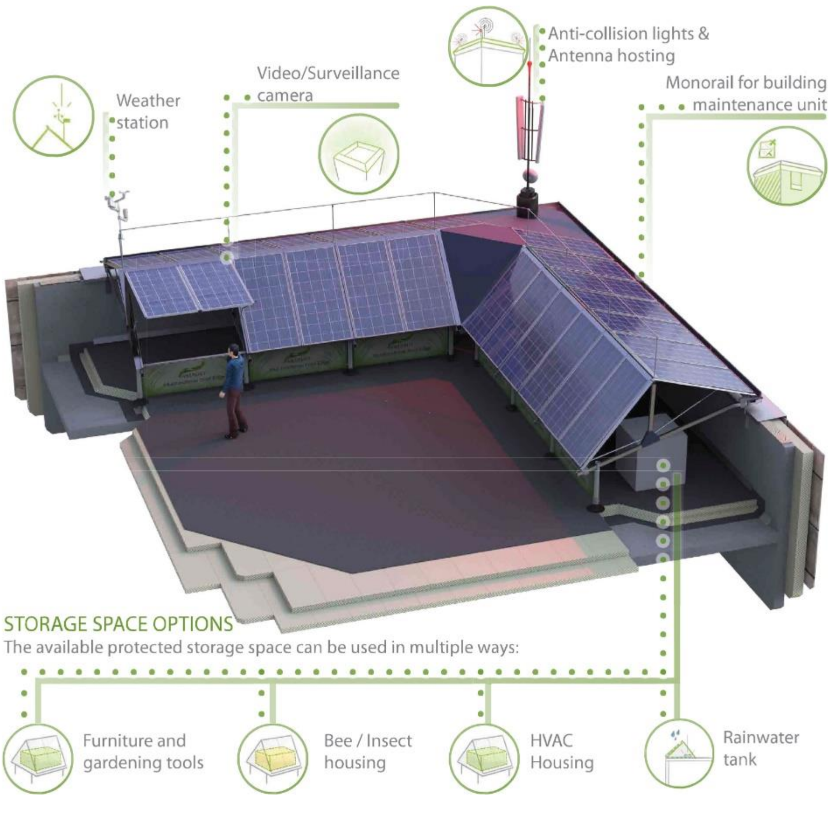

Figure 3.11. PV panel installation, design functions (Axitecsolar, 2014)

3.1.3. Questionnaire Survey

Two separate questionnaires were prepared: the first was composed of 6 parts and was answered by occupants of the 1st case study buildings, while the second one had 3 parts conducted with the 2nd case study buildings' occupants. In these buildings, there are both owner-occupants and tenant-occupants. Because of the fact that, in the beginning of these two questionnaires, participants were asked to answer the questions as if they were the owners of this apartment and they would live in that apartment for the next 30 years.

The first questionnaire survey was conducted personally with the occupants. First part of this survey had one question related with occupancy hours. This question was answered by all 704 occupants; thus it was possible to determine the exact number of people who were in the flats and the time of their occupancy. In the other parts, one participant from each flat responded to the questions, thus, for the rest of the questions 201 answers were analyzed. Second part of the first questionnaire survey consisted of two questions related to the behavior of the occupants regarding electricity and natural gas consumption. Occupants of already refurbished places were asked one question in the third part of the questionnaire. In the fourth part, before giving any information with regard to possible reductions in energy demand due to refurbishment strategies, occupants were asked if they would like to renew their homes. Thereafter, the table with data on the simulation scenarios and cost calculations was shown to the occupants. This the fifth part has only one table with no questions. In the final part, the same question as that in the fourth part was asked again.

An internet-based questionnaire was carried out for the second survey conducted among the occupants of the high rise building in second case study area. The first part of this survey was composed of three questions which are related to the planned retrofits in the flats regarding refurbishments, PV panel installations and implementing these two interventions concurrently. Like the fifth part of the first survey, in the second part of the second questionnaire, a table with information on the advantages of retrofits was shown to the occupants. In the third part, the same three questions of the first part were asked to the occupants again. In total, there were six questions which were answered by 168 participants in the second questionnaire.

3.2. Method

In order to assess the occupants' attitudes towards passive design strategies and active systems installations in their old residential buildings, the energy retrofit scenarios; computer-based energy simulations, economic calculations and questionnaire surveys were used for each case study, separately. The all outputs taken from the simulations and the economic calculations were computed with a monthly base, because occupants receive their salaries monthly. The aim of the study was firstly showing the advantages and expenditures related with energy retrofits with the help of simulations and calculations, and secondly convincing occupants about energy retrofit interventions. The premise of this study was that if occupants are convinced of the superior monetary advantages of energy refurbishments and photovoltaic panel usage compared to their current energy spending, they will change their attitude and stop resisting the renovation works. In this regard, two similar methodologies were shaped for each case studies (Figure 3.12). The methodology used for this research consisted of six steps, which were as follows:

Step 1: Gathering information and drawings related to the selected case study buildings from the municipality of the neighborhood. According to these drawings, site plan and floor plans of the case study buildings were redrawn and color coded, as shown in Figures 3.2, 3.3, 3.6 and 3.7. These plans created a basis for the simulation.

Step 2: Determining the energy performance of existing buildings by conducting an energy analysis with the help of DesignBuilder software.

Step 3: Simulating energy performance of refurbished scenarios for these buildings and analyzing the energy consumption measures again with DesignBuilder.

Step 4: Calculating costs and payback periods of refurbishments with a computer software,

Step 5: Conducting questionnaire surveys in order to gather data on the attitude of the building occupants towards the refurbishments, before and after seeing the energy analyses of existing and refurbished versions of the buildings,

Step 6: Examining and analyzing data obtained from the questionnaire survey to record any changes.

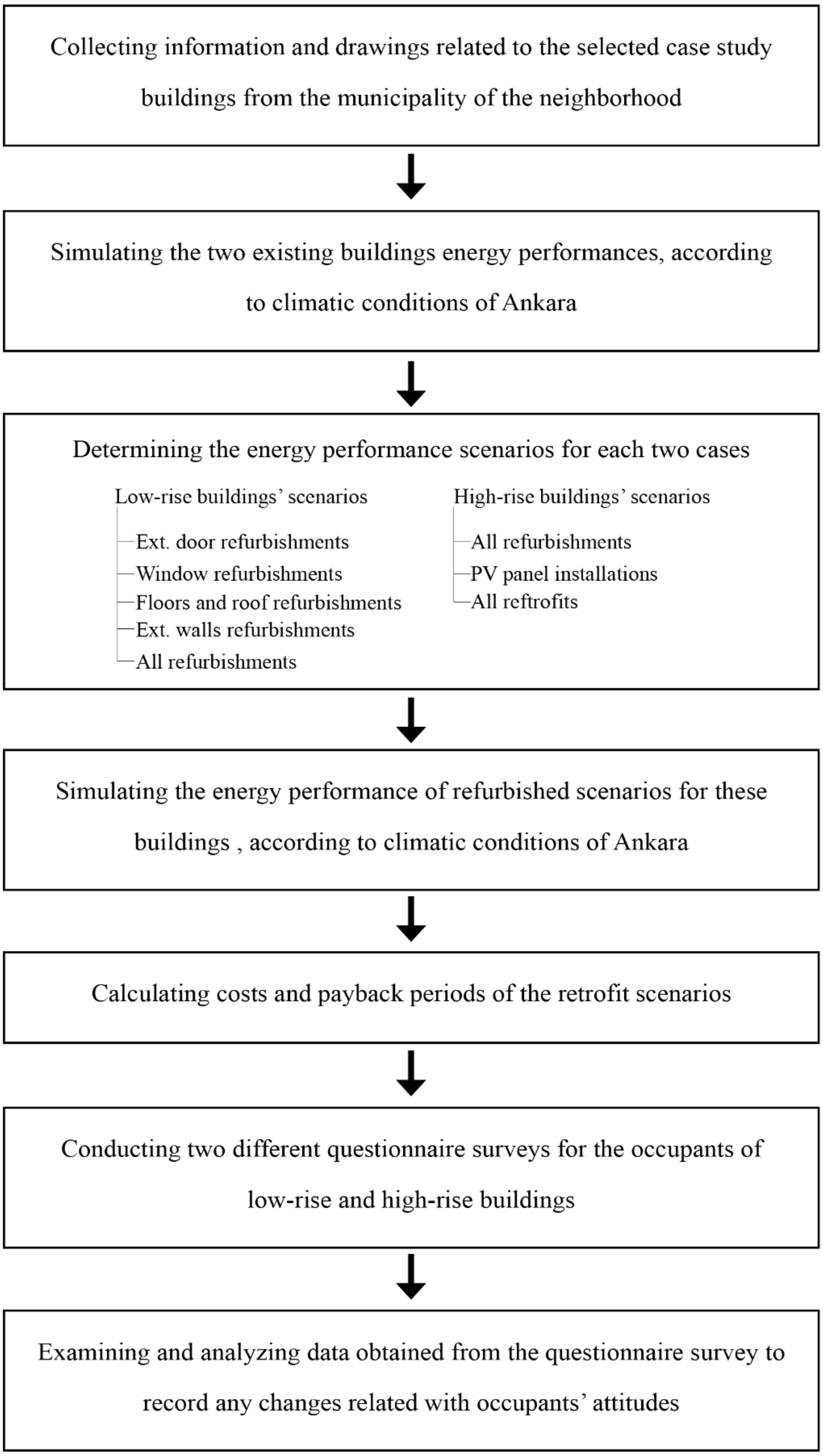

Figure 3.12. The Steps of the Research Methodology

3.2.1. Building Performance Simulations

In order to simulate the energy performance of existing building the thermal models were prepared true to the actual building. The weather data file for Ankara which is classified as continental climate was uploaded from the EnergyPlus software database. Afterwards, the existing heating system and construction materials were defined as it mentioned above. The boundary conditions were assumed as; occupancy schedule is 8:00pm-8:00am. This was based on the assumption the occupants will leave home at around 8:00 am in the morning to go to work or school and will return home around 7:30pm in the evening. Because of the identical features of each case study buildings have the same characteristics in itself, and all neighbor units are same, it was assumed that there was no heat transfer between neighbor units for all simulations; they were simulated as adiabatic zones. For the heating schedule, heating set-points were assigned according to ASHRAE 55-2004 standards for the simulations.

In the low-rise buildings, four different flats facing north, south, east and west were simulated but the values were very close. Therefore, one flat from the building painted in dark color in the Figure 3.2 was simulated and its simulated values were used for the calculations. Same method was applied in the high-rise buildings also. Three different floors of the complex were simulated, yet the outcomes were very similar. As a result, one floor consisting four flats was simulated and the mean value was taken for the one flat of high-rise buildings.

The high energy consumption of the buildings led to the determination of five different energy saving refurbishment scenarios for the first case study and three retrofit scenarios for the second case study. By using DesignBuilder software, the thermal performance and energy consumption and/or production of each intervention were simulated one by one for each scenario.

The costs and payback periods of these refurbishment/retrofit scenarios were calculated with a computer software. For each action, all detailed interventions were considered. To illustrate, workers' hourly payments were also taken into consideration when calculating the costs for the door, window, floor, roof, wall facade refurbishments, and PV panel installations. Moreover, every item used for the interventions was added to the expenditure calculations. These cost figures were taken from the database based on unit price values that are assigned by the Turkish Ministry of Environment and Urban Planning.

i. Case Study 1: Low-rise apartments

For the first case study, the scenarios were analyzed in five steps (Tables 3.2 and 3.3). In the first scenario, only entrance doors to the flats were replaced with insulated metal doors and the model was re-simulated for this refurbishment intervention. For the second scenario, only windows were renovated and the existing single glazed windows (6mm glass) were replaced with double glazed ones (6mm glass + 13 mm air + 6mm glass). In the third scenario, insulation layers were added to the floors and roof of the reference building. Additionally, aluminum roof changed to the clay tile roof. In the fourth scenario, the exterior walls of the building were insulated. In the final scenario, the individual interventions of the previous four scenarios were combined; i.e. all exterior doors, windows, floors, roof, and exterior walls were refurbished.

Table 3.2. *Description of existing and renovated building elements of the first case study buildings*

Building elements	Existing	Renovated
Ext. Doors	Uninsulated metal door	Insulated metal door
Windows	Single glazed wooden frame	Double glazed aluminum frame
Floor	Uninsulated linoleum flooring on concrete slab	Insulated linoleum flooring on concrete slab
Roof	Uninsulated pitched aliminum roof	Insulated pitched clay tile roof
Ext. Walls	Uninsulated ext. walls	Insulated ext. walls

Table 3.3. *U-values (W/m²K) for the reference case and energy reducing refurbishment scenarios of the first case study buildings*

Building elements	Existing building	Ext. Doors Renovations (1stScenario)	Windows Renovations (2ndScenario)	Floor and Roof Ren. (3rdScenario)	Ext. Walls Ren. (4thScenario)	All Renovations (5thScenario)
Ext. Doors	8.2 W/m²K	2.8 W/m²K	8.2 W/m²K	8.2 W/m²K	8.2 W/m²K	2.8 W/m²K
Windows	6.1 W/m²K	6.1 W/m²K	2.7 W/m²K	6.1 W/m²K	6.1 W/m²K	2.7 W/m²K
Floors	2.6 W/m²K	2.6 W/m²K	2.6 W/m²K	0.2 W/m²K	2.6 W/m²K	0.2 W/m²K
Roof	2.9 W/m²K	2.9 W/m²K	2.9 W/m²K	0.2 W/m²K	2.9 W/m²K	0.2 W/m²K
Ext. Walls	2.4 W/m²K	2.4 W/m²K	2.4 W/m²K	2.4 W/m²K	0.1 W/m²K	0.1 W/m²K

The simulation models for the existing building and the refurbished cases that were prepared in DesignBuilder are based on the 3D model given in Figure 3.13. The layers of the existing building and refurbished cases were drawn in the detail drawing in Figure 3.14.

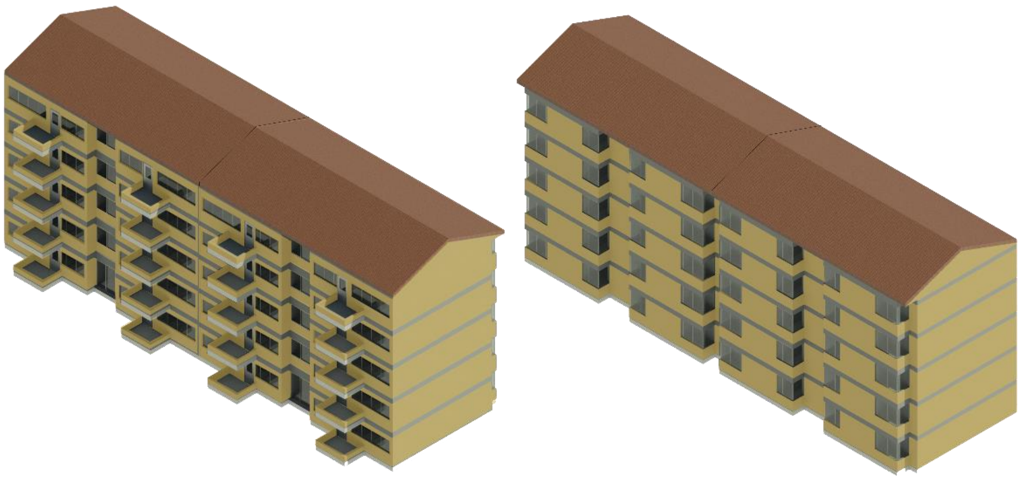

Figure 3.13. 3D views of the first case study (Left; front view, Right; back view)

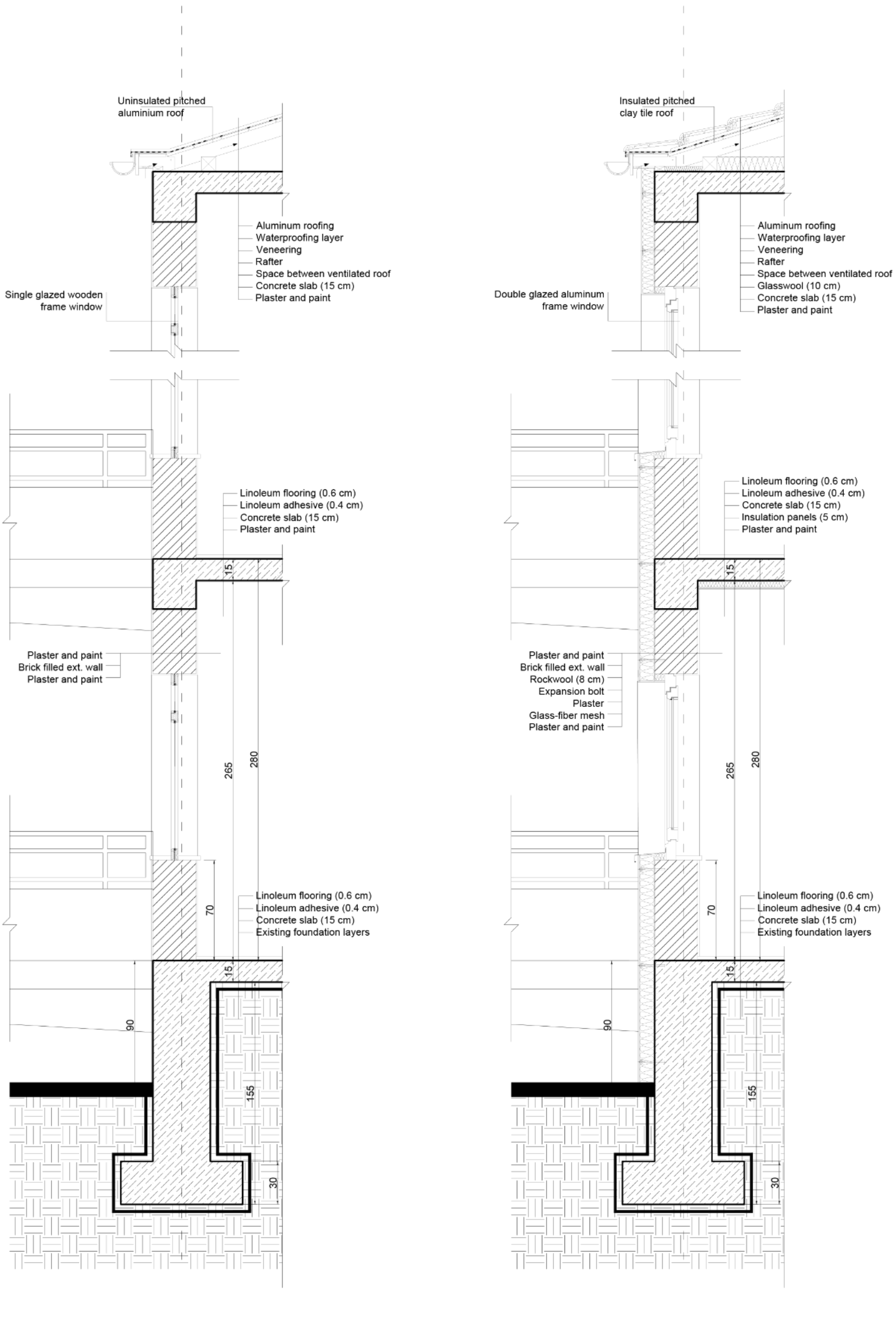

Figure 3.14. System detail drawings of low-rise buildings (Left, existing; Right, refurbished)

ii. Case Study 2: High-rise apartments

The retrofit scenarios of the second case study building were classified into three parts. In the first scenario, existing uninsulated exterior doors, windows, floors, roofs, and exterior walls were replaced with insulated versions. In this scenario, exterior doors were replaced with insulated metal doors, single glazed windows (6mm glass) were replaced with double glazed ones (6mm glass + 13 mm air + 6mm glass), insulation layers were added to the floors, roofs, and walls of the high-rise building complex.

In the second scenario, existing uninsulated architectural elements were used as they are, and photovoltaic panels were added to the roof for energy generating purposes.

In the third scenario, the reference building was insulated and also PV panels were applied on the roof of the second case buildings.

The simulation models for the existing building and the refurbished cases that were prepared in DesignBuilder are based on the 3D model given in Figure 3.15 below. Additionally, the layers of the existing building and retrofitted cases were drawn in the detail drawing in Figure 3.16. Table 3.4 provides the information on the components of buildings that were renovated while Table 3.5 lists the U-values of these materials and components.

Table 3.4. *Description of existing and renovated building elements of the second case study buildings*

	Existing	Renovated
Ext. Doors	Uninsulated metal door	Insulated metal door
Windows	Single glazed wooden frame	Double glazed aluminum frame
Floors	Uninsulated linoleum flooring on concrete slab	Insulated linoleum flooring on concrete slab
Roof	Uninsulated flat roof	Insulated flat roof
Ext. Walls	Uninsulated ext. walls	Insulated ext. walls
PV Panels	Not existed	PV panel installed

Table 3.5. *U-values (W/m²K) and PV panel existence for the reference case and energy retrofit scenarios of the second case study buildings*

	Existing building	All Renovations (1stScenario)	PV panel Installation (2ndScenario)	All Retrofits (3rdScenario)
Ext. Doors	8.2 W/m²K	2.8 W/m²K	8.2 W/m²K	2.8 W/m²K
Windows	6.1 W/m²K	2.7 W/m²K	6.1 W/m²K	2.7 W/m²K
Floors	2.6 W/m²K	0.2 W/m²K	2.6 W/m²K	0.2 W/m²K
Roof	2.9 W/m²K	0.2 W/m²K	2.9 W/m²K	0.2 W/m²K
Ext. Walls	2.4 W/m²K	0.1 W/m²K	2.4 W/m²K	2.4 W/m²K
PV Panels	Not existed	Not existed	PV panel installed	PV panel installed

Figure 3.15. 3D view of the second case study

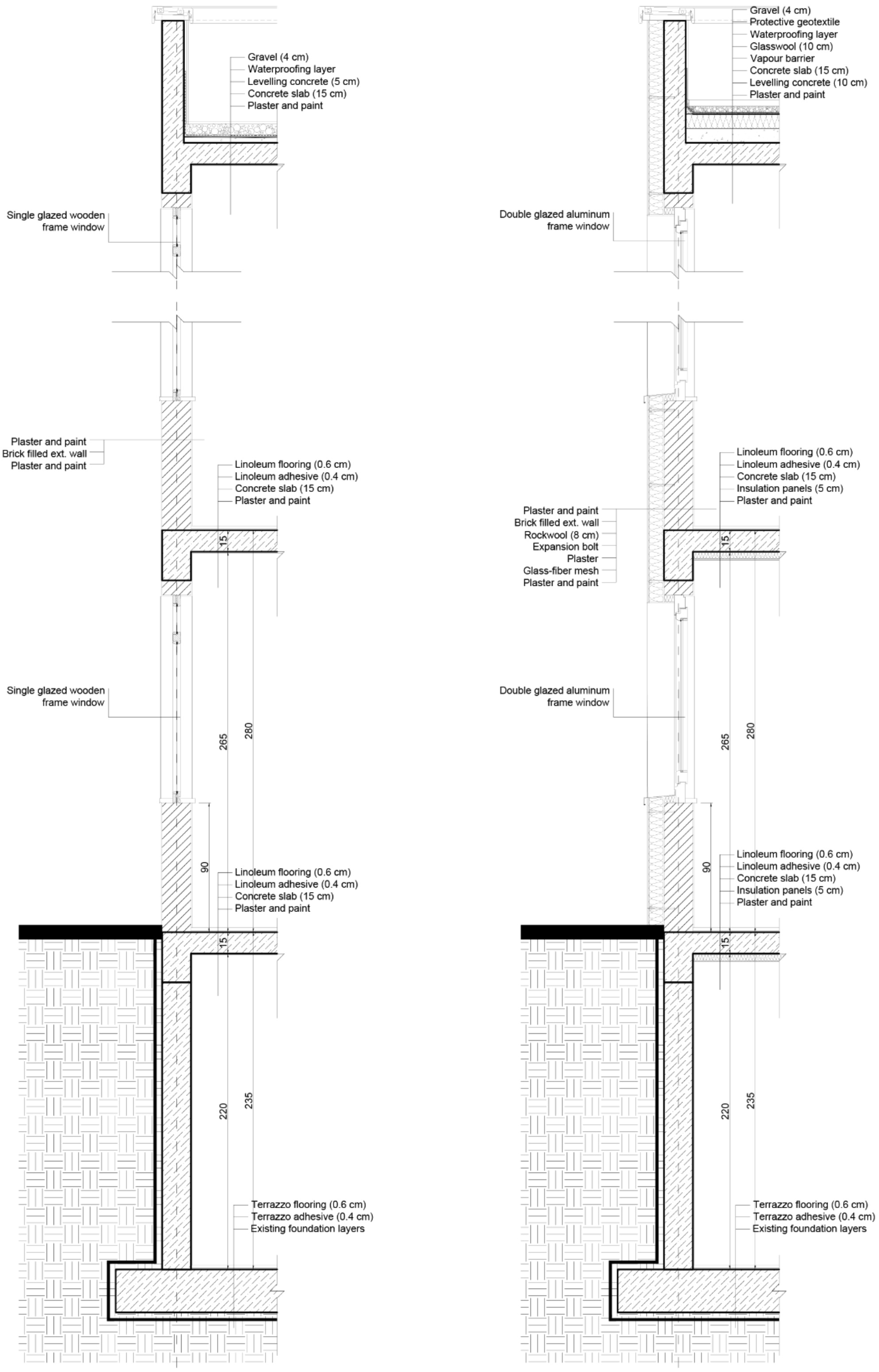

Figure 3.16. System detail drawings of high-rise buildings (Left, existing; Right, refurbished)

3.2.2. Questionnaire Survey

A survey was conducted separately for the two case study areas in order to determine the attitude of the occupants towards refurbishments in their old buildings, before and after the simulation study. All data derived from the thermal simulation of the reference buildings' existing condition as well as the different retrofit scenarios of these two cases, their costs and the payback periods of each intervention were added to questionnaire. The surveys were continued to re-assess the occupants' attitude after they were made aware of the economic advantage of the long-term energy savings that would be possible despite the initial refurbishment costs. Finally, data from the questionnaires were analyzed separately for the two cases.

i. Survey in the Case Study 1: Low-rise apartments

For the first case study area which had 21 apartment buildings consisting of 210 flats, the occupants were requested to participate in the questionnaire survey. However, 9 out of 210 households did not fill the questionnaire. Therefore, the occupancy patterns of 704 inhabitants out of 837 were determined.

The questionnaire consisted of six parts. To gather data on the general user profile, question related to the occupancy hours of the householders in the flat was asked in the first part. For the same purpose, electricity and natural gas consumptions of the flats was asked in the second part. As a third part, already done refurbishments and their purposes were asked in order to reveal current renovations. In the fourth part of the survey, occupants' willingness to renovate their flats for energy saving goal was asked, before showing any data taken from simulations and calculations. In the fifth part, the data extracted from the energy performance simulations, and cost, payback calculations were shown to the occupants of the first case study. In the final part of the questionnaire survey, same questions as in the fourth part were asked again to compare the occupants' attitudes towards these interventions before and after seeing the data.

ii. Survey in the Case Study 2: High-rise apartments

For the second case study area, in order to determine the attitude of the occupants towards refurbishments and PV panel installations in their old buildings another questionnaire was prepared. Each of the 3 apartment buildings having 15 floors each and one questionnaire from each flat were requested to be answered in the survey. If all flats had participated in the survey, there would be 180 answered questionnaires. However, 12 out of 180 households did not fill the questionnaire. Therefore, answers of 168 questionnaires were analyzed.

In order to collect data related with occupants' attitude towards refurbishments and renewable energy generation system usage, the questionnaire survey was divided into three parts. As mentioned earlier, the occupancy profile of the neighborhood is very similar, because of that reason the questions about general user profile were removed from this questionnaire. On the other hand, the last three parts of the questionnaire conducted for the first case study were remained for the second case study also. In the first part of the questionnaire survey, the questions regarding occupants' willingness to retrofit their flats for energy saving and producing purposes were asked, before showing any data obtained from simulations and calculations. In the second part of the survey, the outcome data of the energy simulations, and cost and payback periods of the scenarios were shown to the residents. In the final and third part of the questionnaire survey, the same questions of the first part were asked again to report the changes in the willingness of the occupants about the interventions.

CHAPTER 4

RESULTS AND DISCUSSION

The results of the energy performance simulations of the existing and proposed retrofit scenarios; cost and payback periods of the proposed scenarios of these two case study buildings; and questionnaire survey conducted with the occupants of these two complexes were presented in this chapter under different sections.

4.1. Simulations of Proposed Retrofit Scenarios

The weather data of the site which is located in Ankara, Turkey, is shown in Figure 3.1. As can be seen from the weather data taken from the EnergyPlus software database, Ankara has hot and dry-summers and cold winters. In other words, the weather data has the characteristics of a continental climate. Average Dry-Bulb and Dew-Point temperature of the site is high in the summer and low in the winter. Solar radiation is high in the summers and low in the winters.

Hence, buildings need to be altered or designed according to the weather data for better energy performance (Ching & Shapiro, 2014). On the other hand, for the case study presented in this study, material and insulation were not selected according to the climate of their location. Therefore, these different scenarios for two different cases were conducted to adapt the buildings according to its climatic conditions.

4.1.1. Case Study 1: Low-rise apartments

The results of the energy performance simulations for the five proposed scenarios of the first case study (low-rise buildings) are given here.

The different refurbishment scenarios and the existing case were compared according to the data obtained from their simulation models. These comparisons were grouped under three main headings which are zone sensible heating (kW), heating loads (kWh), and total energy consumptions (kWh). One flat from each building was modeled and then mean values of the data derived from the 210 flats were used for the evaluations. For all calculations, DesignBuilder software database was used. As stated before, these scenario schemes can be ordered as; the first, door renovations; the second, window renovations; the third, floor and roof renovations; the fourth, wall and facade renovations; and the fifth, door, window, floor, roof, wall and facade renovations.

Zone sensible heating values of each scheme varied for level of renovation. For instance, from existing case to total renovation case, zone sensible heating value was reduced gradually. Higher values were computed for existing case and for the first scheme to fifth scheme, the value was decreased respectively (Figure 4.1). Which means that, from door refurbishments to wall and facade refurbishments, maintaining the interior spaces within the defined comfort zone is getting easier according to data derived from software results.

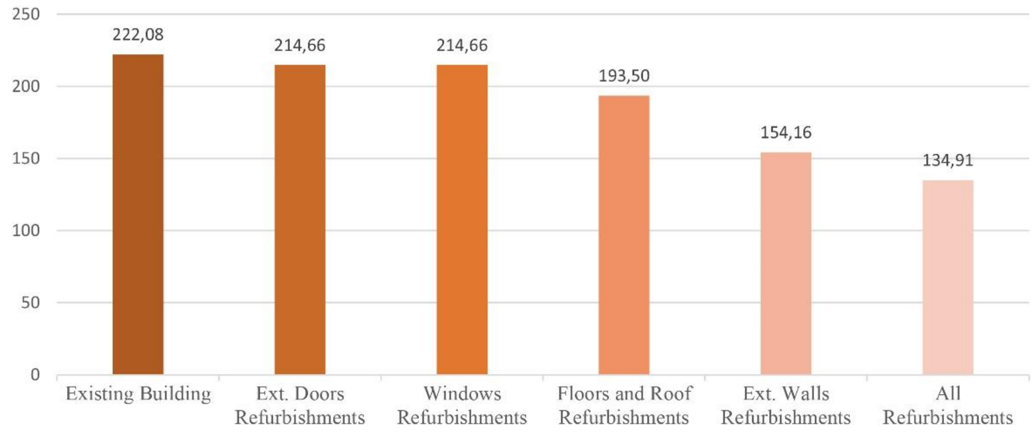

Figure 4.1. Average monthly amount of Zone Sensible Heating (kW) of one flat in the low-rise building from the first case study residential area

Heating loads of the buildings according to renovation types have the similar trend with zone sensible heating with one difference which is that for the facade renovations (4th scenario) where the decline was abrupt when it is compared with other renovations (Figure 4.2).

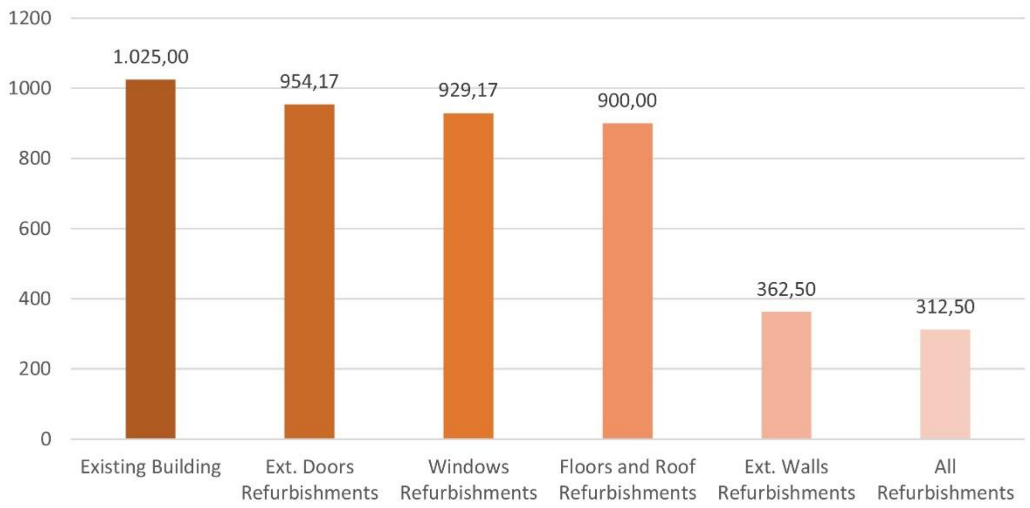

Figure 4.2. Average monthly amount of Heating Load (kW) of one flat in the low-rise building from the first case study residential area

Reduction in total energy consumption had the same trend as in the heating load values. For example, total energy consumption for the facade refurbished scenario was calculated to be nearly half of the total energy consumption of the existing building, while total energy consumption of the other interventions decreased gradually in comparison to each other. (Figure 4.3).

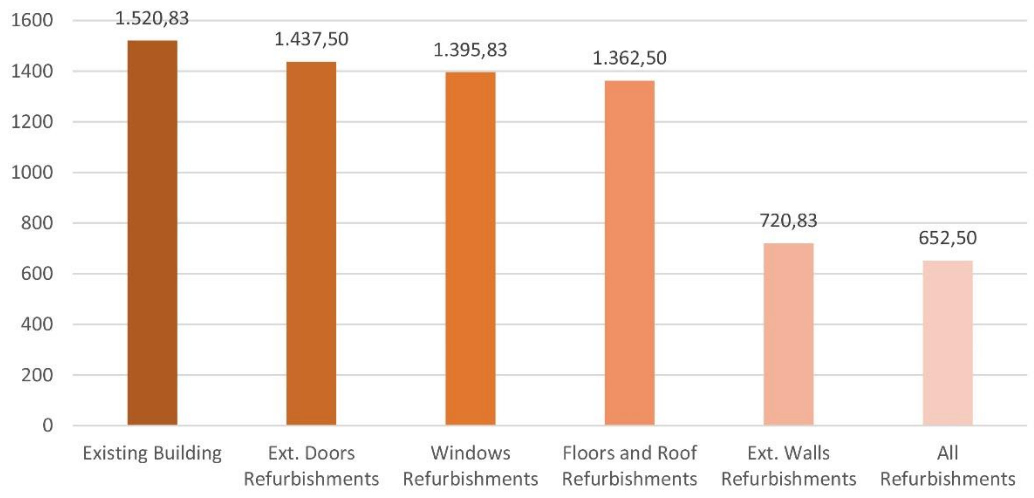

Figure 4.3. Average monthly amount of Total Energy Consumption (kW) of one flat in the low-rise building from the first case study residential area

4.1.2. Case Study 2: High-rise apartments

For the high-rise buildings, three different retrofitting scenarios and the existing case were compared according to the data obtained from their simulation models. These comparisons were grouped under three main headings; i.e. their electricity, gas and total energy consumption values, which were computed in kWh. The entire complex was modeled and then mean values of the data divided into the 180 flats were used for the evaluations. For all calculations, DesignBuilder software database were used. As stated earlier, these scenarios can be ordered as; the first case where exterior doors and windows were improved thermally, and the floors, roofs, and walls were insulated; in the second scenario, PV panels were installed in the existing complex; and in the third scenario the six building elements were renovated as in the first scenario, and PV panels were used.

As it can be seen from Table 4.1, a flat's one month of electricity consumption was calculated as 129.8 kWh in the existing case. But, when the refurbishments were applied to the building, the electricity consumption diminished. For the second scenario, the consumptions remained same with the existing case because existing building is simulated to determine the impact of using PV panels, one flat's one month of electricity production was measured as 179.8 kWh. Which means that, if only electricity expenditure was taken into account, one flat could produce 50 kWh electricity in one month. This value becomes 53.7 kWh when the refurbishments were applied too.

Table 4.1. *Average monthly amount of Electricity Consumption-Production values (kWh) of one flat from the second case study residential area*

Retrofitting scenarios	Electricity consumption (kWh)	Electricity production (kWh)	Net electricity consumption (kWh)
Existing Building	129.80	0	129.80
Refurbished Building	126.10	0	126.10
PV Panel Installation	129.80	+179.80	+50.00
Retrofitted Building	126.10	+179.80	+53.70

Gas consumption values of one flat in one month was calculated as 561 kWh in existing case. With the help of renovations of exterior doors, windows, floors, roofs, and exterior walls, the gas consumption reduced for each flat. In the second scenario, PV panels cannot directly affect gas consumption due to the fact that the installation of PV panels could not affects gas expenditure in a direct way (Table 4.2).

Table 4.2. *Average monthly amount of Gas Consumption values (kWh) of one flat from the second case study residential area*

Retrofitting scenarios	Gas Consumption (kWh)
Existing Building	561.00
Refurbished Building	276.40
PV Panel Installation	561.00
Retrofitted Building	276.40

When the net energy consumption was calculated, 690.8 kWh energy was consumed in the existing case in one month. While, 288.3 kWh energy can be saved with the refurbishments. Additionally, the simulation of PV panels showed that they could produce 179.8 kWh energy hence in the second scenario, net energy consumption was calculated to be 511 kWh. Moreover, if both interventions were applied to the complex, the net energy consumption for one month for one flat was calculated to be 222.7 kWh (Table 4.3).

Table 4.3. *Average monthly amount of Net Energy Consumption-Production values (kWh) of one flat from the second case study residential area*

Retrofitting scenarios	Energy consumption (kWh)	Energy production (kWh)	Net energy consumption (kWh)
Existing Building	690.80	0	690.80
Refurbished Building	402.50	0	402.50
PV Panel Installation	690.80	+179.80	511.00
Retrofitted Building	402.50	+179.80	222.70

4.2. Cost and Payback Periods of the Proposed Retrofit Scenarios

For each proposed scenario for each case study, costs and payback periods were calculated. For each intervention, detailed cost analyses were conducted with the help of the database based on unit price values that are assigned by the Turkish Ministry of Environment and Urban Planning. In the light of data taken from energy performance simulations, payback periods of the refurbishment interventions were also calculated.

In the DesignBuilder software, energy consumption values were computed in kWh unit. In order to calculate payback periods of the retrofit scenarios, the energy consumption values were converted into TL with multiplying coefficients which were announced by the Ministry of Energy and Natural Resources in Turkey (2015) and determined by the Turkish Energy Market Regulatory Authority (2018). For each month, the values were differentiated. Therefore, the mean values of these coefficients which were computed approximately 0.5972 for the electricity and 1.6348 for the gas consumption were used for calculating average monthly amount of the consumption. For the electricity, computed electricity consumption in kWh unit was multiplied the mean value of the coefficient (0.5972) and converted in TL. For the gas consumption, firstly, the data given in kWh unit by the DesignBuilder software was converted to m^3 with dividing the kWh value to 10.64 which was also taken from Ministry of Energy and Natural Resources in Turkey (2015) and Turkish Energy Market Regulatory Authority (2018). Then, the m^3 value was multiplied the mean value of the coefficient (1.6348) and converted in TL.

4.2.1. Case Study 1: Low-rise apartments

Each flat of low-rise apartments has an area of 82.40 m^2 and the costs of the renovations were calculated for one flat because the questionnaire survey was aimed at determining the attitudes of the individual owners/ occupants of each flat separately. For instance, the cost of changing the exterior doors of the one flat was calculated as 643.16 TL which included material and labor costs in Turkey. In the second scenario, when only windows of one flat were renovated, the cost of this refurbishment was calculated accordingly. While the calculation of the third scenario was conducted for the entire roof of the building, the renovation cost was divided equally between the 10 flats in the building (Figure 4.4). Additionally, the values were examined in average monthly base because the occupants of these buildings were paid monthly. The average monthly income of the inhabitants was determined to be approximately 3100 TL.

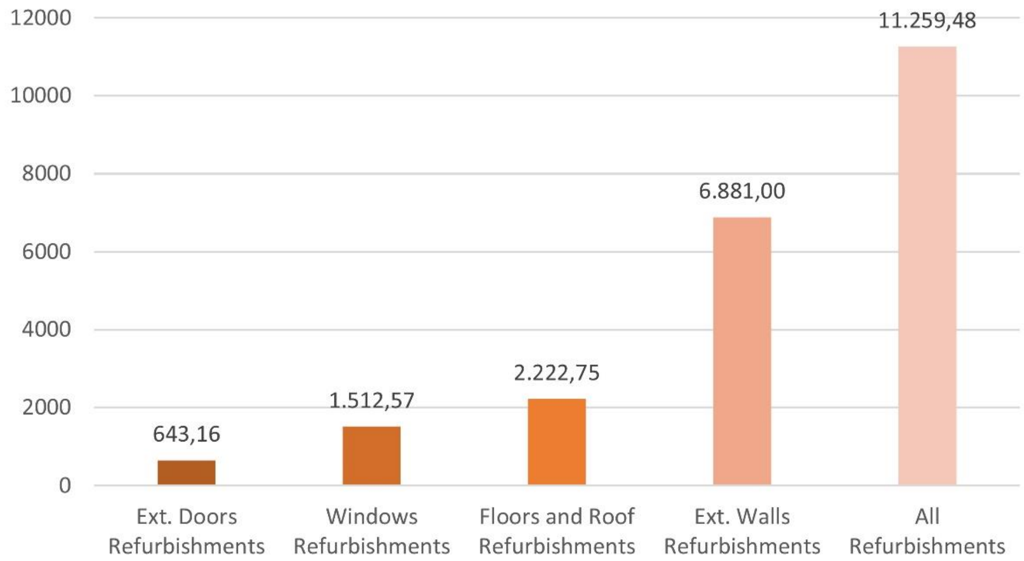

Figure 4.4. Regarding retrofit scenarios, Cost of the retrofit scenarios (TL) of one flat of the low-rise buildings

The calculated average monthly energy consumption values of the one flat from the low-rise buildings were given in the Table 4.4.

Table 4.4. *Average monthly Net Energy Consumption values (TL) of one flat from the first case residential area*

Refurbishment scenarios	Net Energy Consumption (TL)
Existing Building	343.44
Ext. Doors Refurbishment	324.62
Windows Refurbishment	315.21
Floors and Roof Refurbishments	307.68
Ext. Walls Refurbishments	162.78
All Refurbishments	147.35

When these values were taken into consideration, monthly savings from just renovation of exterior doors of the flat was computed as almost 18.82 TL. Which means that, payback period of the door renovation was 34 months (2 years and 10 months). With the same calculation methods, payback period of the other scenarios was calculated (Table 4.5).

As it can be seen from the Table 4.5, facade renovations were calculated to be the most expensive renovation scenario among individual refurbishments. However, the floor and roof renovation had the longest payback period for the first case study residential area.

Table 4.5. *Payback values for one flat from the first case study residential area*

Refurbishment scenarios	Payback periods
Ext. Doors Refurbishment	34 months (2 years and 10 months)
Windows Refurbishment	53 months (4 years and 5 months)
Floors and Roof Refurbishments	62 months (5 years and 2 months)
Ext. Walls Refurbishments	38 months (3 years and 2 months)
All Refurbishments	57 months (4 years and 9 months)

4.2.2. Case Study 2: High-rise apartments

For the three different retrofitting scenarios of high-rise apartments, costs and payback periods were calculated. With the help of data taken from energy performance simulations, payback periods of the scenarios were also calculated individually. Each flat has an area of 82.9 m^2 and the costs of the interventions were calculated according to one flat. Additionally, average monthly income of the inhabitants is almost 2900 TL.

According to data derived from simulations, electricity consumption of one flat in one month was calculated in kWh unit. Like the first case study, the data in kWh were multiplied by the coefficients determined by the Ministry of Energy and Natural Resources in Turkey (2015) and the Turkish Energy Market Regulatory Authority (2018) and converted into TL.

As can be seen from Table 4.6, with the help of the determined coefficient, the mean value of electricity consumption for one month of one flat was calculated to be 77 TL in the existing situation. In the first scenario the value decreased to 75 TL/month. With installation of PV panels on top of the roofs of the buildings, electricity production was calculated as 106 TL per flat per month. In other words, with the help of the installation of PV panels, one flat can meet its own electricity needs and can produce electricity worth 29 TL. Like the second scenario, in the third scenario production of electricity in one month for one flat was computed greater than electricity consumption of that flat.

Table 4.6. *Average monthly Electricity Consumption-Production values (TL) of one flat from the second case study residential area*

Retrofitting scenarios	Electricity consumption (TL)	Electricity production (TL)	Net electricity consumption (TL)
Existing Building	77	0	77
Refurbished Building	75	0	75
PV Panel Installation	77	+106	+29
Retrofitted Building	75	+106	+31

As it explained above, in order to calculate gas consumption values of one flat in one month in TL, first of all, kWh unit was converted into m^3. Then the m^3 value was multiplied by the coefficient. With the light of these values, Table 4.7 was prepared.

Table 4.7. *Average monthly Gas Consumption values (TL) of one flat from the second case study residential area*

Retrofitting scenarios	Gas Consumption (TL)
Existing Building	79
Refurbished Building	38
PV Panel Installation	79
Retrofitted Building	38

Table 4.8 present total energy consumption expenditure of the scenarios for one flat in one month. With the help of refurbishments 43 TL could be saved. By only installing PV panels on top of the buildings' roofs, energy production value was calculated as 106 TL. When these two interventions were applied, the net energy saving was estimated as 149 TL for one month for one flat.

Table 4.8. *Average monthly Net Energy Consumption-Production values (TL) of one flat from the second case study residential area*

Retrofitting scenarios	Energy consumption (TL)	Energy production (TL)	Net energy consumption (TL)
Existing Building	156	0	156
Refurbished Building	113	0	113
PV Panel Installation	156	+106	50
Retrofitted Building	113	+106	7

The expenditures of the interventions including refurbishments, PV panel installations and both retrofitting actions together were calculated in TL with the help of the database on unit price values (Figure 4.5). With the help of these values, and savings calculated by simulations payback periods of all these interventions were computed (Table 4.9).

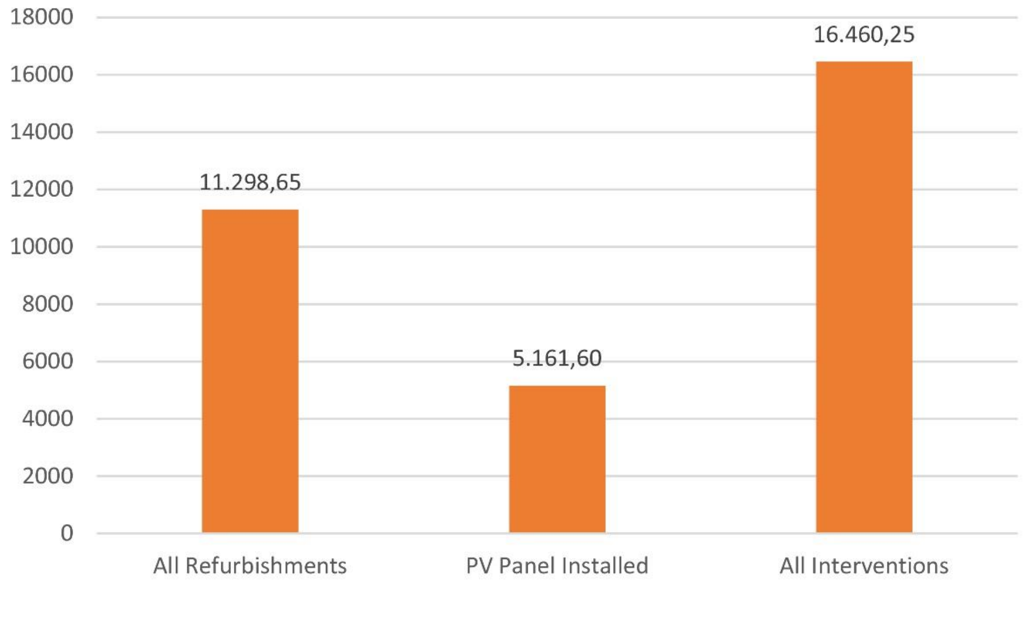

Figure 4.5. Total energy expenditure of the retrofit scenarios for one flat of the high-rise buildings

Table 4.9. *Payback periods of the retrofit scenarios for one flat of the high-rise buildings*

Retrofitting scenarios	Payback periods
Refurbished Building	263 months (21 years and 11 months)
PV Panel Installation	49 months (4 years and 1 month)
Retrofitted Building	111 months (9 years and 3 months)

4.3. Questionnaire Survey

After completing the simulations of the retrofit scenarios and calculating the payback period for each of them, a questionnaire was prepared to gather data on the occupants' attitude towards these retrofits.

4.3.1. Case Study 1: Low-rise apartments

The questionnaire of the low-rise apartments comprised of 6 parts:

In the first part, occupancy hours in the flat were determined in order to crosscheck simulation data. According to data taken from the first part of the questionnaire, in these 201 flats, average occupancy hours were changeable according to weekdays, Saturday and Sunday (Figure 4.6). The answers showed that between work-hours occupancy number in the flat decreased at the weekdays and also on Saturdays more than Sundays.

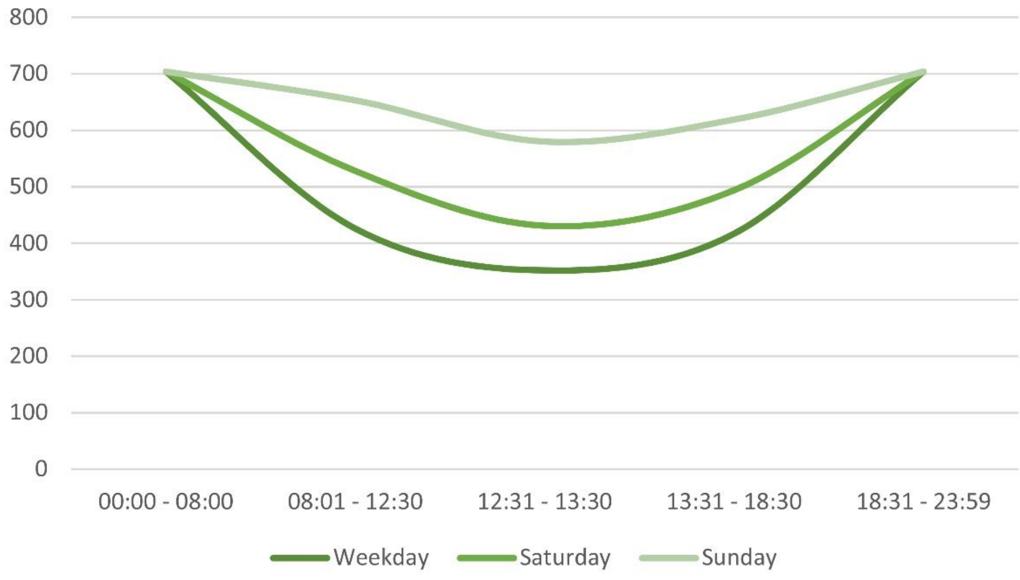

Figure 4.6. Occupancy Hours of the flats of the first case study residential area, according to the data derived from questionnaire

In the second part of the survey, questions related to electricity and natural gas consumption of the flats were asked. As stated before, in each flat, individual combis are used for space and water heating systems. Therefore, the energy consumptions depended on electricity and natural gas, which changed depending on the weather conditions (Figures 4.7 and 4.8).

According to answers of the questionnaire, with the rising outside temperature, energy consumption of the flats decreased. Likewise, in the winter months, natural gas and electricity consumption increased gradually. Moreover, the findings of the simulation data were found accurate and similar with the actual energy consumption values which was prepared according to the mean values of the answers.

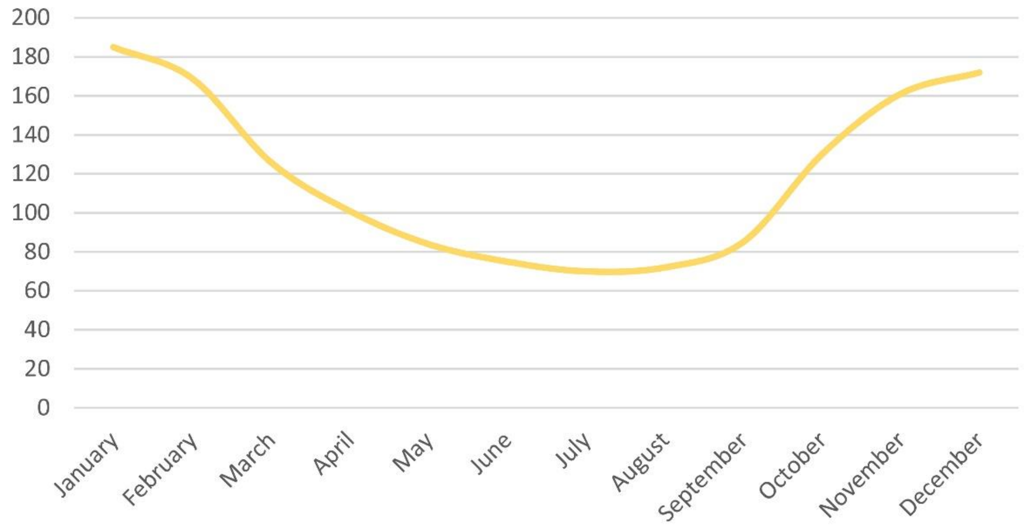

Figure 4.7. Energy Consumption Behavior of the occupants - average electricity consumption (kWh) of the flats of the first case study residential area, according to the data derived from questionnaire

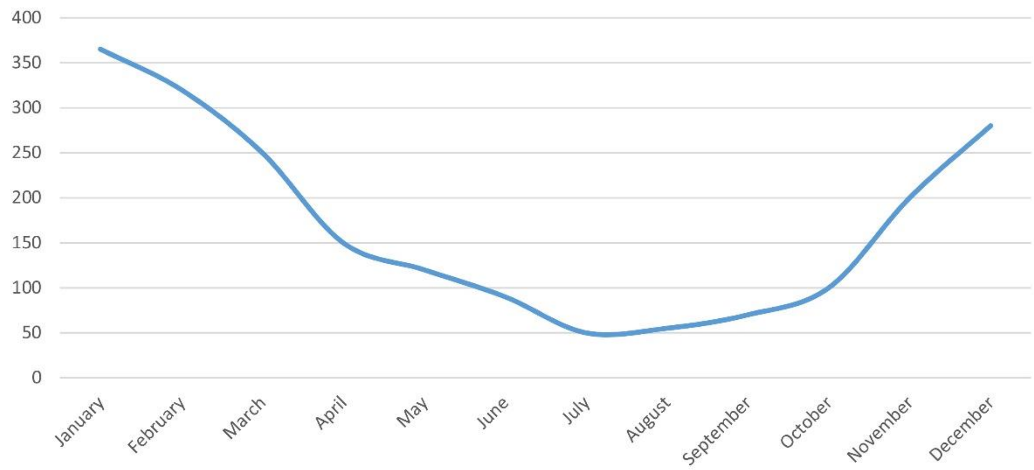

Figure 4.8. Energy Consumption Behavior of the occupants - average gas consumption (m^3) of the flats of the first case study residential area, according to the data derived from questionnaire

In the third part of the questionnaire, current renovations in the flats and their purposes were examined. Answers to these questions helped to determine the occupants' attitude towards renovations; i.e. 143 occupants had already replaced their loose wooden windows with airtight PVC ones to prevent noise and heat-loss. Of the 201 participants 170 had repaired the cracks and repainted the facades because of aesthetical reasons and also energy saving purposes; though they did not give any information on the amount of savings thus achieved. Similarly, roof renovations were done for energy saving reasons and also practical reasons such as changing the thermal and water insulation material as well as replacing the corrugated metal roofing with clay roofing tile that were more durable. On the other hand, doors, floors and walls renovations were done for beautifying the flats. PVC flooring tiles were replaced with laminated parquet flooring. Additionally, walls were repainted for beautifying reasons. As a result, most of the renovations except window, facade and roof renovations were done mainly for aesthetical reasons .

While answers of the participants were evaluated, the fourth and sixth parts were both taken into consideration in order to compare the willingness of the occupants before and after seeing the data regarding energy retrofits that was extracted from the simulations and cost calculations. Although in the fourth part of the questionnaire 94 out of 201 participants had answered “no” to the question regarding their willingness to renovate their flats for energy saving purposes, after seeing the simulation and payback period data 48 of the occupants changed their minds and 142 of them answered as “yes” to refurbishments (Figure 4.9).

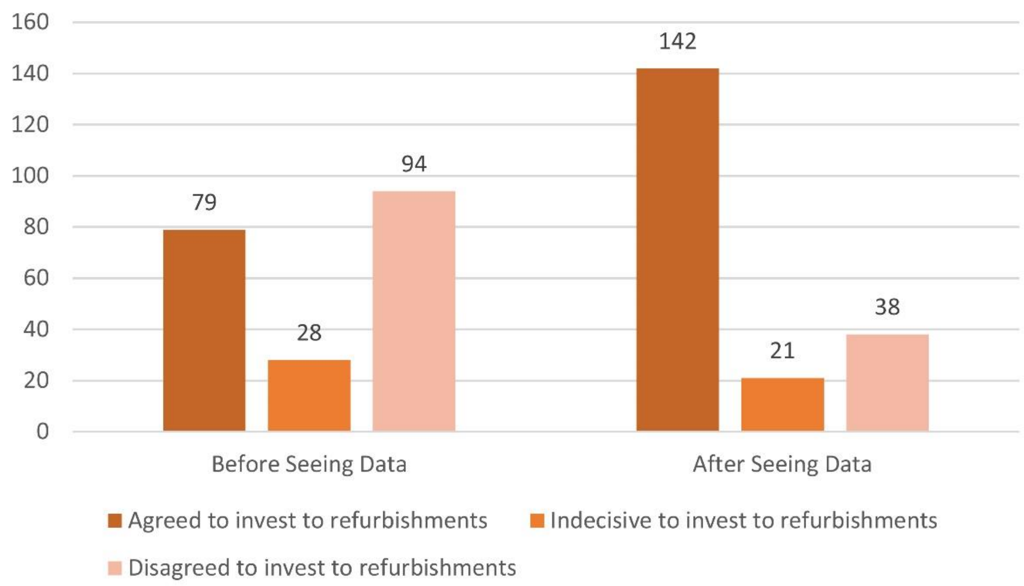

Figure 4.9. The willingness of occupants with regard to refurbishments in their flats, according to the data derived from questionnaire survey in the 1st case study area

4.3.2. Case Study 2: High-rise apartments

The questionnaire survey conducted in the high-rise apartments comprised of three parts: the first part was related with occupants' tendencies to refurbish their flats and use PV panel installations. In order to compare reactions of the occupants, their willingness to refurbish the flats or to install PV panels was first examined with the questions without showing the results of the scenarios. Then in the second part, data on energy savings, and the cost and payback periods of the scenarios were shown to the participants. As a final part, after showing this data, questions about willingness to invest in the refurbishments and PV panels were asked again. Likert scale was used for the questions, like in the questionnaire survey of the first case study.

In the first part of the questionnaire, occupants answered the questions about thermal comfort of their flats. 12 out of 168 participants had declared that the thermal comfort of the flat was adequate. On the other hand, 38 participants were indecisive, and 118 out of 168 occupants found the thermal conditions of their flats insufficient. In other words, 7.1% of occupants of the complex felt comfortable in their flats, while 22.6% of them were indecisive about thermal conditions of their flats and thermal comfort of the flats were not adequate for 70.3% of the occupants. Additionally, 83.3% of the participants stated that they would prefer to keep the temperature of the flat at a comfortable level with less energy consumption.

After asking about the thermal comfort of the occupants, their willingness about refurbishments and PV panel installation were asked without showing the results of the energy simulations and cost-payback data. In this part, 89.8% of the participants showed interest to invest in refurbishments and the rest of them were uncertain about insulating their doors, windows, floors, roofs, and facades of the flats. With regard to PV panels, while 49.4% of the participants supported the PV panel installation, 26.7% were indecisive and 23.9% of the participants did not want to install the PV panels at all. These answers were changed when both interventions were asked together. 80.9% of the occupants agreed to refurbish their flats and to install PV panels. However, 14.3% of the participants were uncertain and 4.8% of them did not agree to invest in these retrofits (Figure 4.10).

When the simulation data was shown to the occupants, the same questions were asked again in the fourth part of the questionnaire. Willingness of the occupants about refurbishments were decreased from 89.8% to 79.7%. The second case study complex were previously renovated with 30mm Rockwool layer of insulation on the exterior walls. However, that amount of insulation layer is not enough for the insulation in Ankara. Therefore, occupants were not satisfied with this intervention. Additionally, when they saw the long payback period of the refurbishments, their willingness decreased. On the other hand, after the data were showed to the occupants about PV panel installation expenditures and their payback periods, all of the participants wanted to support PV panel installations. Moreover, 94.0% of the occupants agreed to apply both interventions (Figure 4.11).

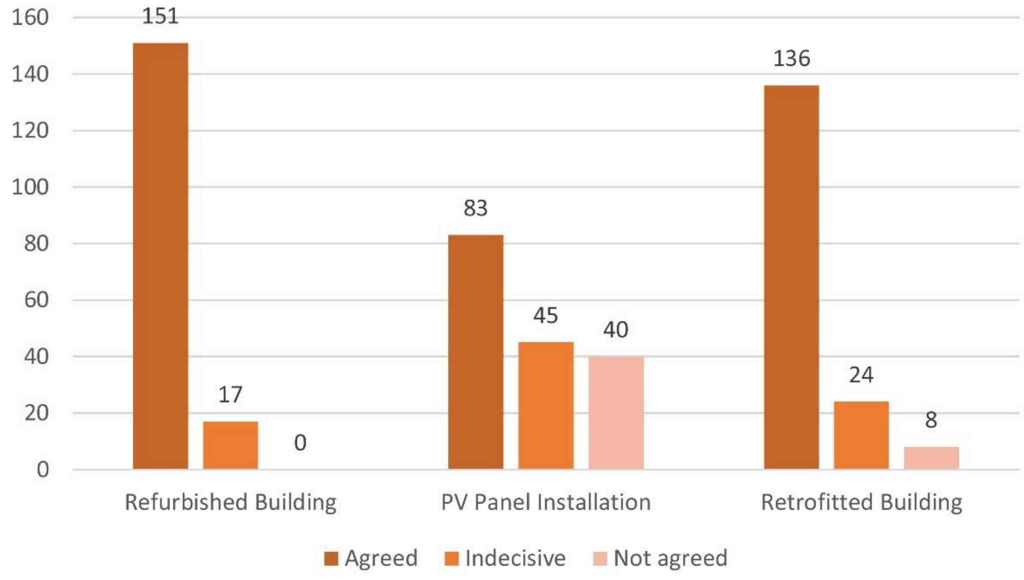

Figure 4.10. Questionnaire results of occupants before seeing the energy simulations and cost-payback periods data for one flat from the second case study

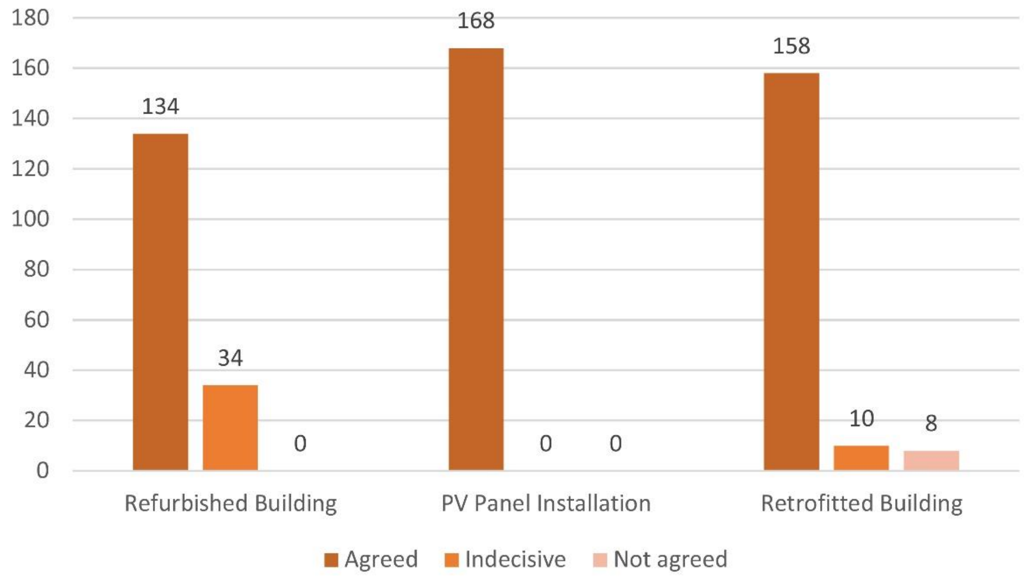

Figure 4.11. Questionnaire results of occupants after seeing the energy simulations and cost-payback periods data for one flat from the second case study

4.4. Discussion

This study looks into consideration the possibility of retrofitting existing residential blocks where a significant amount of energy can be saved. On the other hand, in order to accomplish this goal, energy-oriented refurbishments of old dwellings and use of renewable energy generation system installations in existing dwellings; two obstacles had to be overcome. These obstacles were mainly connected with the occupants' attitude regarding financial concerns and their lack of desire for domestic upheaval due to the renovations. For this reason, it was essential to take into consideration the occupants' attitude to renovations and look into ways of convincing them about the benefits of undertaking them.

In this study, two set of case studies were examined. The first case study buildings called low-rise apartments consisted of 21 old residential building called Işçi Blokları from an old residential neighbor. These buildings were simulated for 5 energy refurbishment scenarios. Energy saving values and costs of these interventions were measured (Table 4.10). In the light of these simulation data, with the database based on unit price values that are assigned by the Turkish Ministry of Environment and Urban Planning, costs and payback periods of renovation scenarios were calculated. These data helped to form questionnaire which asked to the occupants of these 21 apartment blocks. In the questionnaire, after three parts mentioned above, as a fourth part, planned refurbishment place and purpose in the flat were asked. After this part, occupants' willingness about retrofit measures were asked without showing any data extracted from simulations and calculations. In the final part of the questionnaire survey of the first case study, energy saving values, costs and payback periods of renovation scenarios were shown to the occupants and the same questions in the fifth part of the questionnaire were asked again. According to their answers, willingness about energy refurbishments of old residential blocks was measured. Results of the first questionnaire revealed that occupants' attitude towards energy saving refurbishments changed after understanding their monetary benefits. Their willingness to invest in such interventions increased from 44% to 76%.

In the second set of the study, the second case study complex was examined. In the second case complex , an old residential complex with three buildings called Işçi Blokları from same neighbor with low-rise buildings were chosen and simulated for 3 energy retrofit scenarios. Energy savings and costs of these scenarios were calculated (Table 4.10). With the help of simulations, costs and payback periods of retrofit scenarios were measured. The energy performance simulation and cost and payback period data were used in the questionnaire survey which asked to the occupants of this complex. The questionnaire data of the high-rise buildings consisted three parts. In the first part, willingness about refurbishments and PV panel installations were asked before showing simulation and cost and payback period data. In the second part of the survey, the simulated and calculated data related the second case study buildings were shown to the occupants. In the final part of the questionnaire, same questions asked in the first part were asked again. In the light of the questionnaire survey, when the building performance simulations and cost and payback period calculations were shown to the occupants, the willingness of the second case study occupants to invest in both interventions raised from 80.9% to 94.0%.

Table 4.10. *Energy saving for one month and cost per m^2 of each scenario of two case buildings in TL*

TL/ m^2	**Low-Rise Buildings per m^2**					**High-Rise Buildings per m^2**		
	1st Scenario	2nd Scenario	3rd Scenario	4th Scenario	5th Scenario	1st Scenario	2nd Scenario	3rd Scenario
Energy saving for one month	0.2	0.3	0.4	1.7	1.9	0.5	1.3	1.8
Cost	8.25	19.35	28.45	88.0	144.0	136.30	62.25	198.55

These reasons shaped the proposition of this study that if occupants are convinced of the advantages of energy refurbishments and renewable energy usage compared to their current energy spending, they will change their attitude and stop resisting the retrofits.

To sum up, as it can be seen from the results that in the questionnaire conducted with the occupants of the first case study buildings, some of the occupants had already done some refurbishments in their flats for mainly aesthetical reasons, but when energy savings, costs and payback periods of the renovations were shown to them, their willingness to have energy retrofits also in their flats was increased dramatically. For the second case study residents, despite the fact that some of the occupants did not agree to apply the retrofit scenarios, when energy savings, costs and payback periods of the renovations and PV panel installations were shown to them, their willingness to have energy retrofits also in their flats was also increased. However, although the increase could be observed dramatically PV panel installations, a decline could be perceived in the willingness to have refurbishments done, due to previous insufficient refurbishment intervention and calculated long payback period of refurbishments for the second case study occupants.

CHAPTER 5

CONCLUSION

While human beings are trying to make use of natural resources productively, they need to do this wisely, without harming nature. The world now has the knowledge of how to produce, consume and make peace with nature. In order to regulate the consumption of the energy resources and producing wisely from these energy resources of nature, there is a need to adopt energy saving retrofits. Additionally, according to the EU's revised Renewables energy directive (2018/2001), transformation of existing buildings into nearly zero-energy buildings should be oriented clearly until 2020 by each member state. From this point of view, every country needed to take action to retrofit their national stock of buildings. In order to achieve this goal, the occupants' behaviors related to energy retrofits in residential buildings has an important determinate. For this purpose, a long-term renovation strategy needed to be fulfilled.

Several retrofit scenarios were applied to two case studies in this study. According to findings, most effective savings could be accomplished by refurbishing exterior walls with insulation material of the most suitable thickness for the climate for the low-rise buildings. Despite effectiveness of exterior wall refurbishments, PV panel installation was measured as more powerful than refurbishments in energy retrofits for the high-rise buildings because of its short payback period.

According to reactions of the occupants, before and after being informed, answers were seen to be significantly different. Willingness to implementing energy refurbishments increased after seeing benefits, costs and payback periods of these measures. In other words, in the light of data which was gathered with simulations, calculations and questionnaire, in order to evaluate occupants' behavior towards energy retrofits related with costs and payback period of the refurbishment, showing the information about interventions to occupants have an important role because this research showed that after showing information about renovation, willingness of the occupants about refurbishment increased.

When the reactions of the occupants were considered, being informed had a great importance, due to the changes of the answers of the occupants before and after being informed. Willingness to implementing PV panels increased after seeing benefits, costs and payback periods of these measures while willingness related refurbishments were decreased. However, willingness of implementing these two interventions raised after seeing the data. In other words, in the light of data which was gathered with simulations, calculations and questionnaire, in order to evaluate occupants' behavior towards energy retrofits related with costs and payback period of the refurbishments and PV panel installations, informing the occupant about energy retrofit interventions have great importance.

This research pointed out that if the occupants were informed about energy performance values, cost and payback period data, their attitudes towards energy retrofits would change and also their willingness related with the energy retrofit interventions increased. To sum up, the research shows that awareness plays a big role in determining the attitude of the occupants.

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APPENDICES

A. SIMULATION SETTINGS

In this part of the appendices, simulation settings of the first case study: low-rise and the second case study: high-rise residential area are presented. Firstly, existing case and then retrofitted case simulation settings of the first case study are given. Secondly, existing case and retrofitted case simulation settings of the second case study are revealed. In the both retrofitted cases, only changed simulation settings are provided. For the retrofitted low-rise apartments; occupancy and environmental control, lighting, and HVAC systems' settings were not changed and only construction materilas settings, materials and settings related to the openings were changed. Thus, settings related with construction materials and oppenings were shown for the retrofitted first case study residential area. Like low-rise buildings, in the retrofitted second case study residential area; settings of the occupancy and environmental control, lighting, and HVAC systems were not changed and only simulation settings of the construction materilas, and the settings of the openings were changed. In addition to these changes, PV systems' settings of the high-rise buildings were given for the retrofitted simulation settings of the second case study residential area.

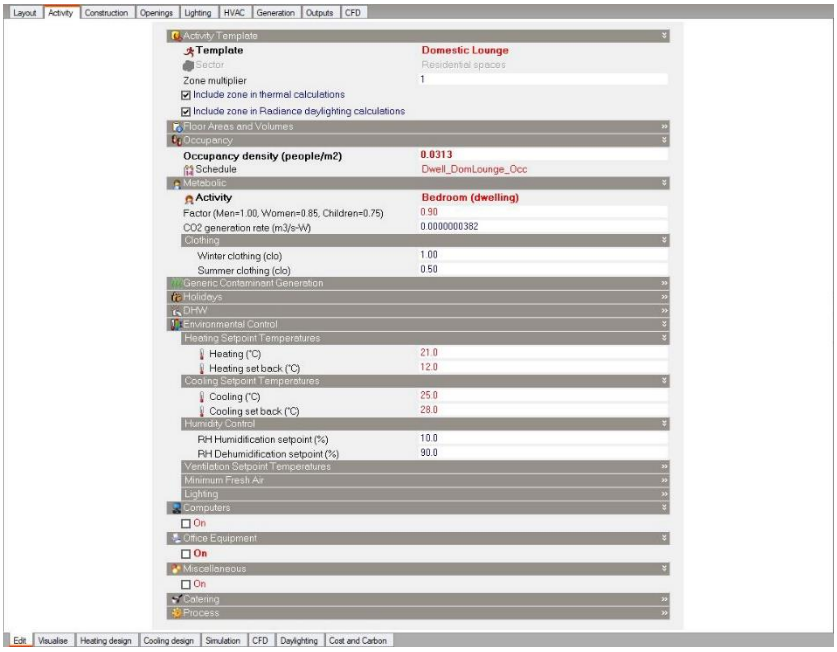

Figure A.1. Existing Case Occupancy and Environmental Control Settings of the Simulations of the Case Study 1: Low-rise apartments

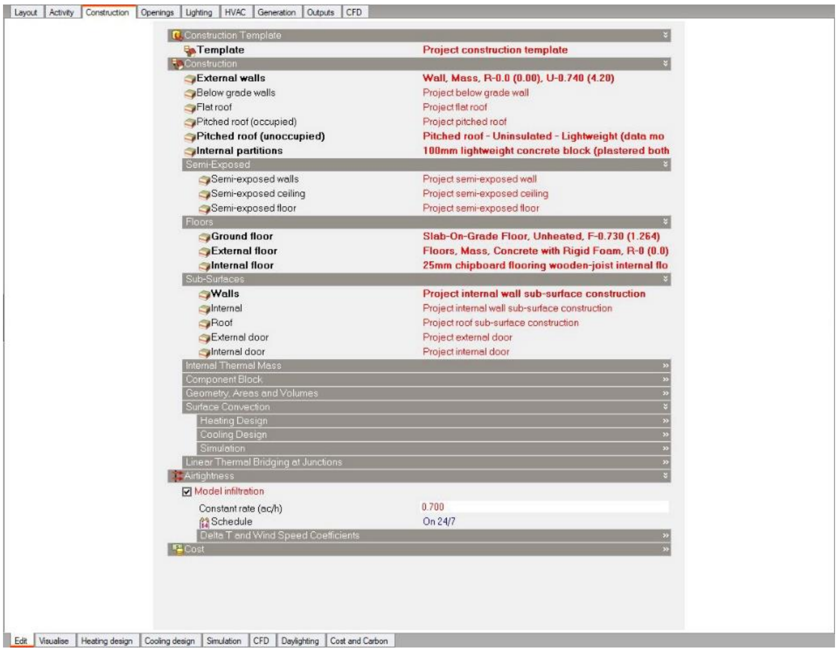

Figure A.2. Existing Case Construction Materials during the Simulations of the Case Study 1: Low-rise apartments

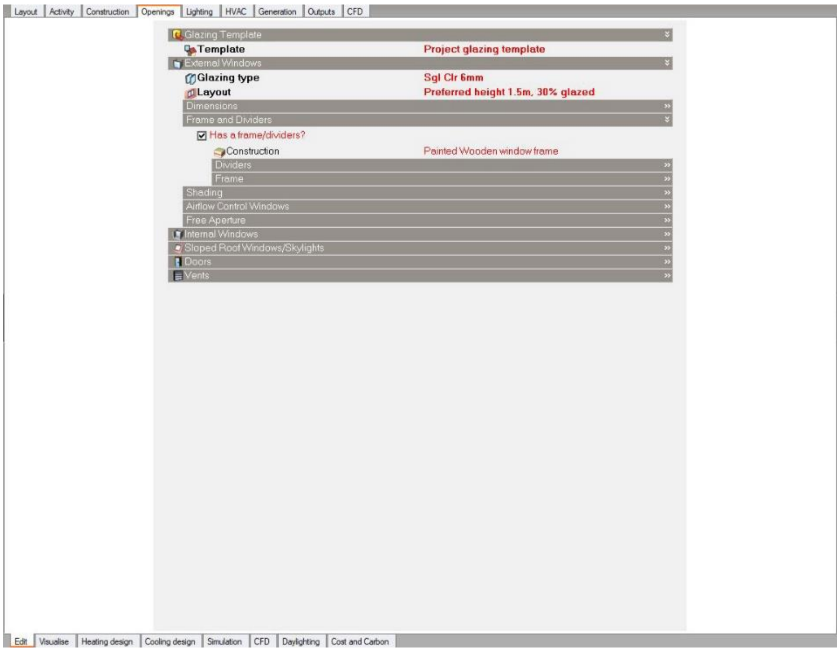

Figure A.3. Existing Case Materials and Settings Related to the Openings during the Simulations of the Case Study 1: Low-rise apartments

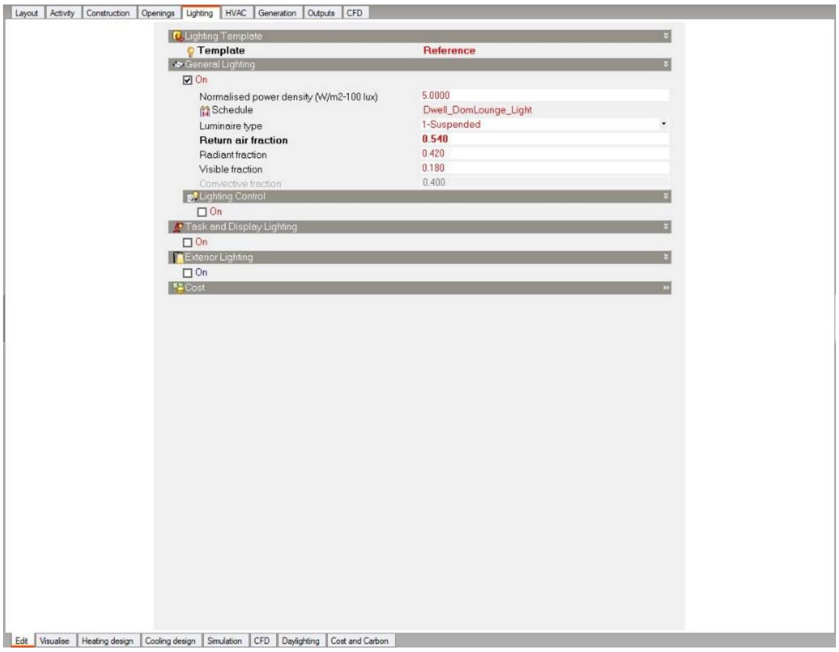

Figure A.4. Existing Case Lighting Settings during the Simulations of the Case Study 1: Low-rise apartments

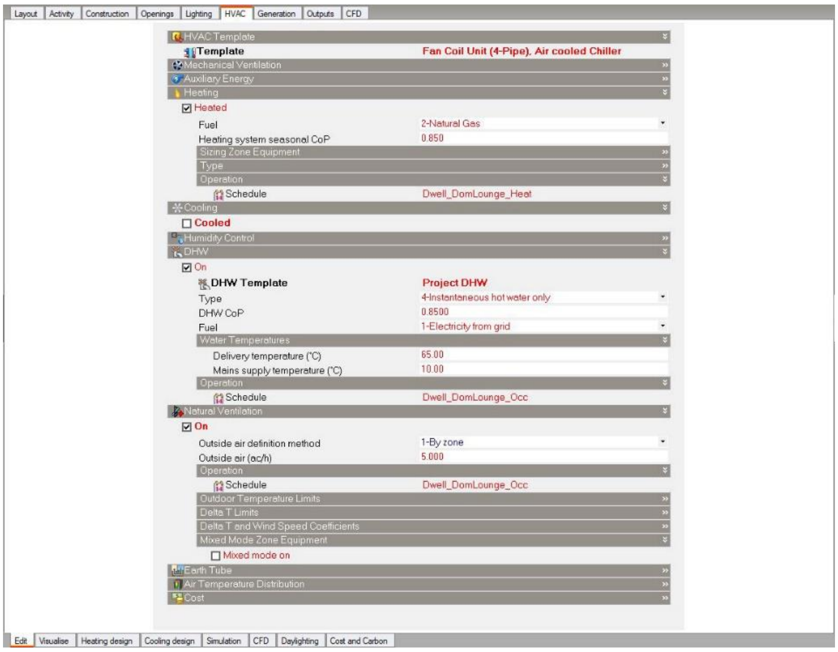

Figure A.5. Existing Case HVAC Systems' Settings during the Simulations of the Case Study 1: Low-rise apartments

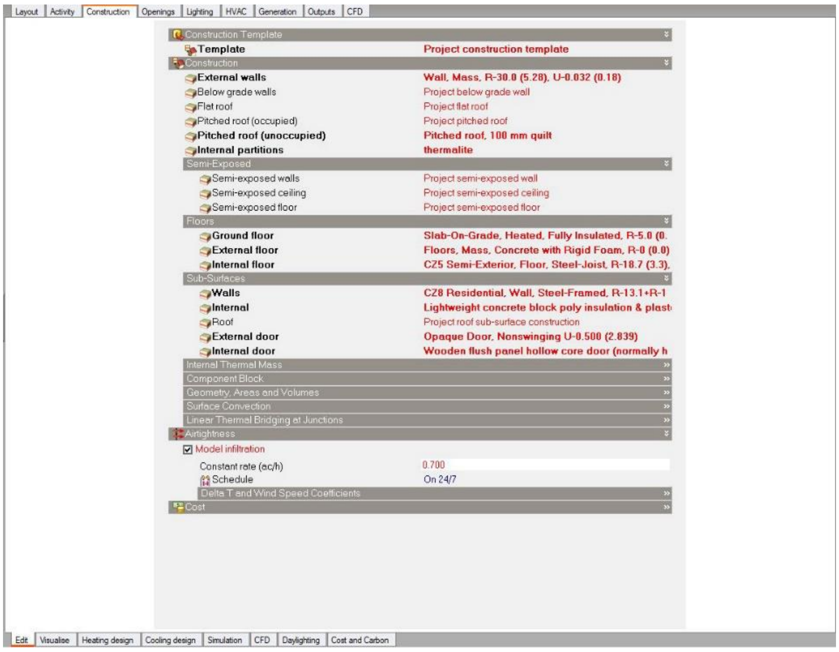

Figure A.6. Retrofitted Case Construction Materials during the Simulations of the Case Study 1: Low-rise apartments

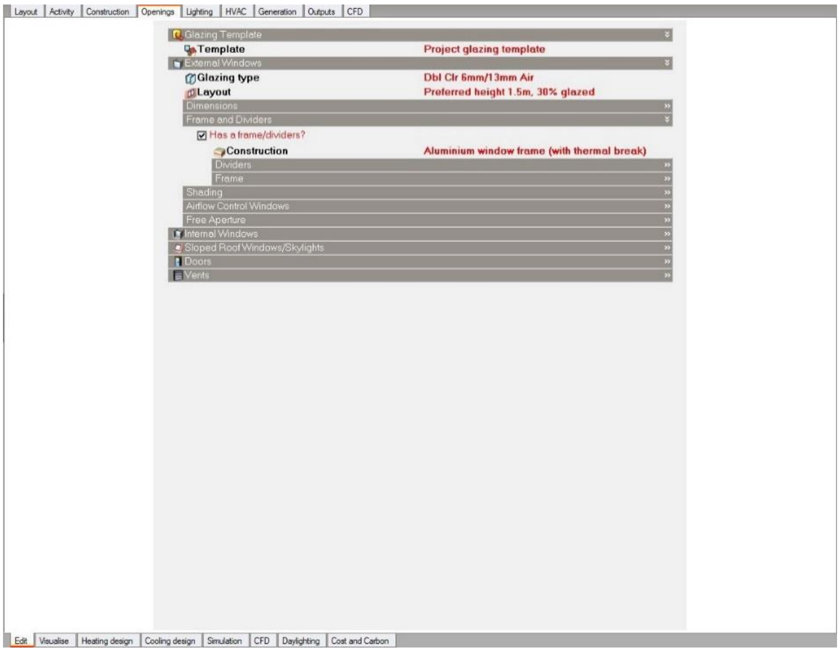

Figure A.7. Retrofitted Case Materials and Settings Related to the Openings during the Simulations of the Case Study 1: Low-rise apartments

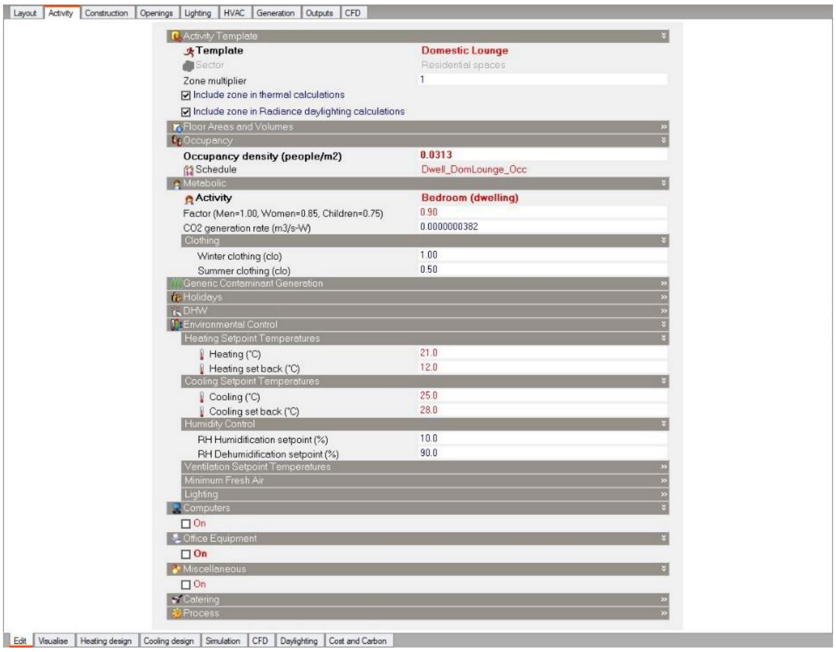

Figure A.8. Existing Case Occupancy and Environmental Control Settings of the Simulations of the Case Study 2: High-rise apartments

Figure A.9. Existing Case Construction Materials during the Simulations of the Case Study 2: High-rise apartments

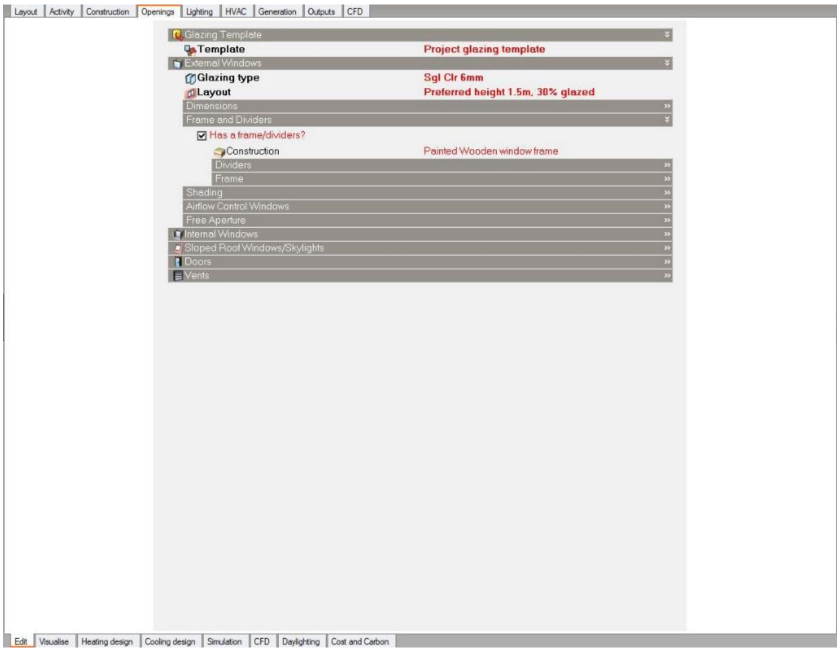

Figure A.10. Existing Case Materials and Settings Related to the Openings during the Simulations of the Case Study 2: High-rise apartments

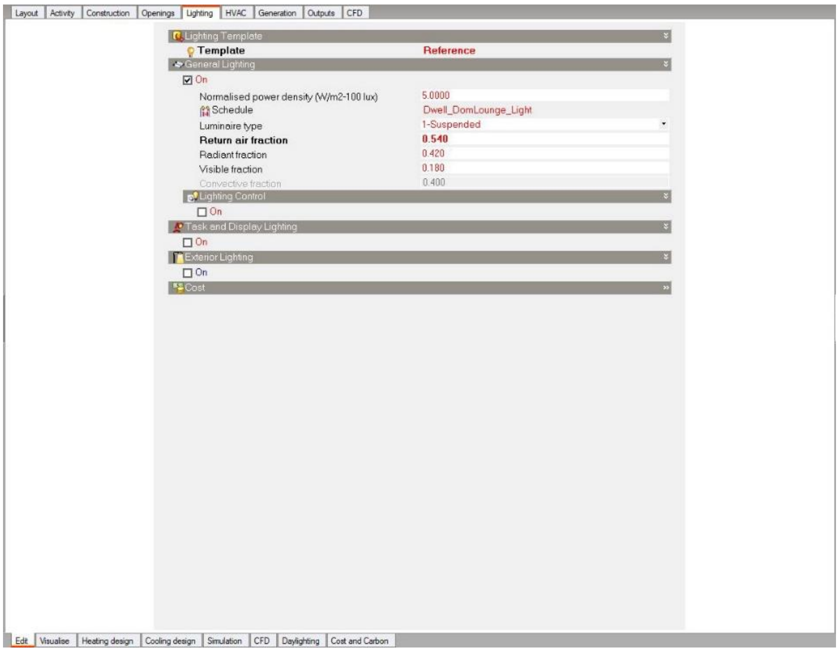

Figure A.11. Existing Case Lighting Settings during the Simulations of the Case Study 2: High-rise apartments

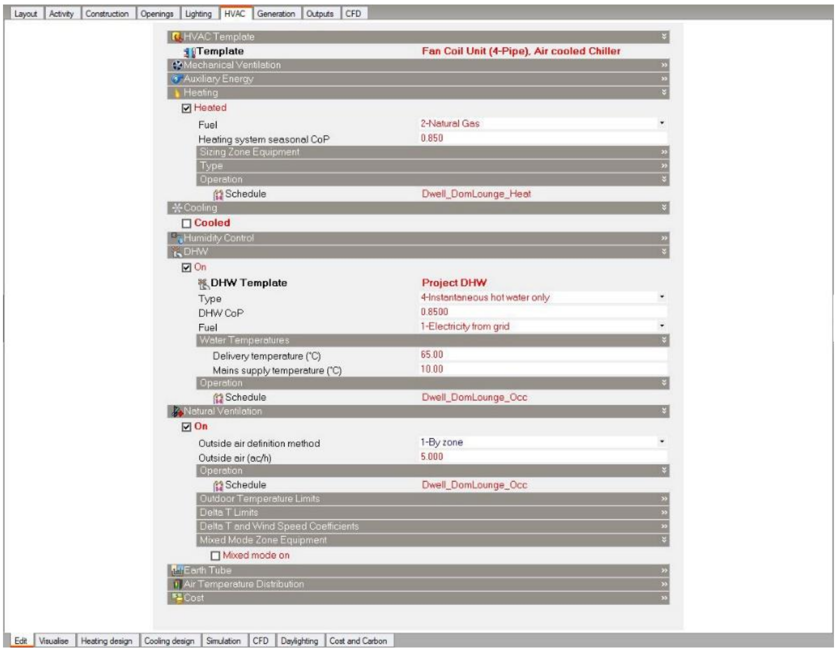

Figure A.12. Existing Case HVAC Systems' Settings during the Simulations of the Case Study 2: High-rise apartments

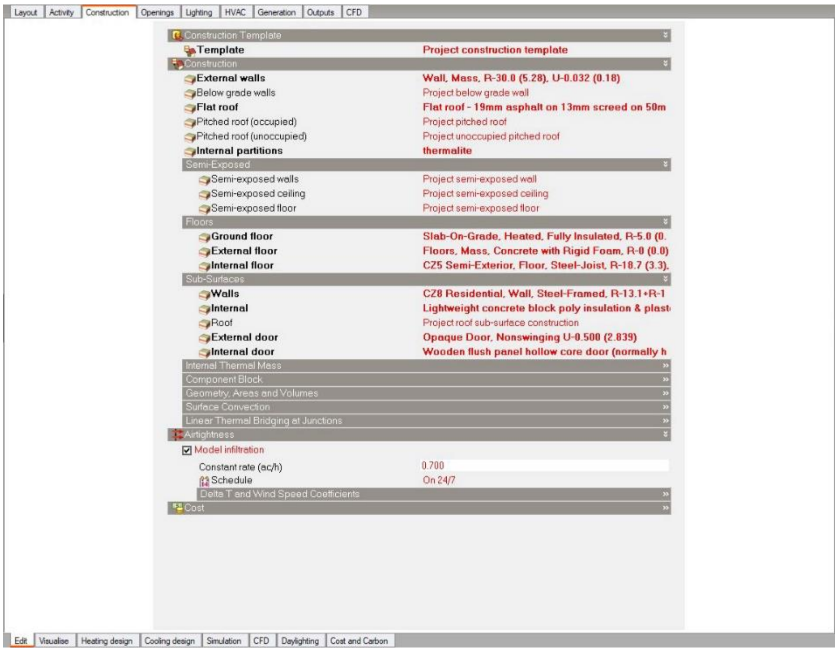

Figure A.13. Retrofitted Case Construction Materials during the Simulations of the Case Study 2: High-rise apartments

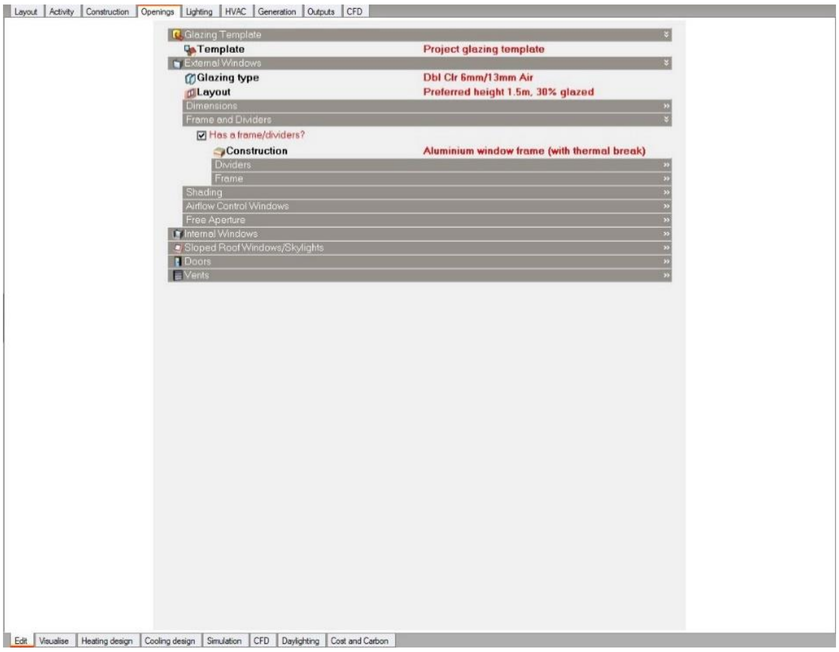

Figure A.14. Retrofitted Case Materials and Settings Related to the Openings during the Simulations of the Case Study 2: High-rise apartments

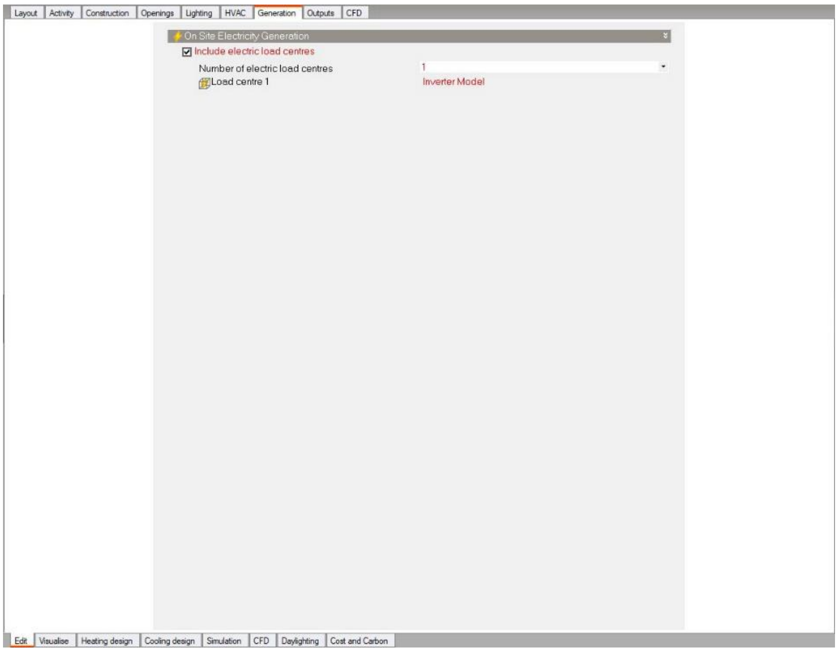

Figure A.15. Retrofitted Case PV Systems' Settings during the Simulations of the Case Study 2: High-rise apartments

B. SAMPLE OF THE QUESTIONNAIRE SURVEY OF THE CASE STUDY 1: LOW-RISE APARTMENTS IN ENGLISH

A- Occupancy Hours (Please fill the table below.)

In the week, between which hours you are usually staying at home and how many people stay in that hours?

	Weekdays	Sunday	Saturday
00:00 – 08:00			
08:01 – 12:30			
12:31 – 13:30			
13:31 – 18:30			
18:31 – 23:59			

B- Energy Consumption Behavior (Please fill the table below.)

1- What is the approximate electricity consumption of your house for each month?

kWh	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
< 50												
51 – 100												
101 – 150												
151 – 200												
> 201												

2- What is the approximate gas consumption of your house for each month?

m^3	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1 – 50												
51 – 100												
101 – 200												
201 – 300												
> 301												

C- **Already Refurbished Places and the Purposes of These Refurbishments in the Flat** (Please fill the table below.)

Which places did you renovate in this flat and why?

	Purpose of the refurbishments
Door	
Window	
Floor	
Roof	
Wall	
Facade	

D- Planned Refurbishments in the Flat (Please mark the box that you think works best for you.)

I think it is necessary to spend money on improvement of the door, window, floor, roof, and facade insulation of the building where I live in to maintain the thermal comfort level with less energy.

I disagree ( )

I am indecisive ( )

I agree ( )

E- The Data of Energy Simulations and Cost and Payback Periods

	Monthly energy consumption	Cost of the refurbishments	Monthly return of the refurbishments	Payback periods of the refurbishments
Existing	343.44 TL	-	-	-
Door ref.	324.62 TL	643.16 TL	18.82 TL	2 years and 10 months
Window ref.	315.21 TL	1515.57 TL	28.23 TL	4 years and 5 months
Floor and Roof refurbishments	307.68 TL	2222.75 TL	35.76 TL	5 years and 2 months
Facade refurbishments	162.78 TL	6881.00 TL	180.66 TL	3 years and 2 months
All ref.	147.35 TL	11262.48 TL	196.09 TL	4 years and 9 months

F- **Planned Refurbishments in the Flat** (Please mark the box that you think works best for you.)

I think it is necessary to spend money on improvement of the door, window, floor, roof, and facade insulation of the building where I live in to maintain the thermal comfort level with less energy.

I disagree ( )

I am indecisive ( )

I agree ( )

C. SAMPLE OF THE QUESTIONNAIRE SURVEY OF THE CASE STUDY 1: LOW-RISE APARTMENTS IN TURKISH

A- Evde

B- geçirilen zaman süresi ve kişi sayısı (Aşağıda bulunan tabloyu doldurunuz, lütfen.)

Haftada, genellikle hangi saatler arasında evde zaman geçiriyorsunuz ve o saatlerde evde kaç kişi bulunmaktadır?

	Hafta içi	Cumartesi	Pazar
00:00 – 08:00			
08:01 – 12:30			
12:31 – 13:30			
13:31 – 18:30			
18:31 – 23:59			

C- Enerji kullanım değerleri (Aşağıda bulunan tabloyu doldurunuz, lütfen.)

1- Evinizin her ay için yaklaşık elektrik tüketimi nedir?

kWh	Oca.	Şub.	Mar.	Nis.	May.	Haz.	Tem.	Ağu.	Eyl.	Eki.	Kas.	Ara.
< 50												
51 – 100												
101 – 150												
151 – 200												
> 201												

2- Evinizin her ay için yaklaşık gaz tüketimi nedir?

m^3	Oca.	Şub.	Mar.	Nis.	May.	Haz.	Tem.	Ağu.	Eyl.	Eki.	Kas.	Ara.
1 – 50												
51 – 100												
101 – 200												
201 – 300												
> 301												

D- Ev içindeki halihazırda yenilenmiş yerler ve bu yenilemelerin sebepleri

(Aşağıda bulunan tabloyu doldurunuz, lütfen.)

Bu dairede hangi yerleri yenilediniz ve neden yenilediniz?

	Yenilemelerin sebepleri
Kapı	
Pencere	
Döşeme	
Çatı	
Duvar	
Cephe	

E- **Dairede planlanan iyileştirmeler** (Size en uygun olduğunu düşündüğünüz kutucuğu işaretleyiniz, lütfen.)

Isıl konfor seviyesini korumak ve daha az enerji harcamak için yaşadığım binanın kapı, pencere, döşeme, çatı ve cephe yalıtımının iyileştirilmesi için para harcanması gerektiğini düşünüyorum.

Katılmıyorum ( )

Kararsızım ( )

Katılıyorum ( )

F- Enerji Simülasyon Verileri, Maliyet ve Geri Ödeme Süreleri;

	Aylık enerji harcamaları	İyileştirmelerin maliyetleri	aylık getirileri	geri ödeme süreleri
Mevcut	343.44 TL	-	-	-
Kapı yalıtımı	324.62 TL	643.16 TL	18.82 TL	2 yıl 10 ay
Pencere yalıtımı	315.21 TL	1515.57 TL	28.23 TL	4 yıl 5 ay
Döşeme ve Çatı yalıtımları	307.68 TL	2222.75 TL	35.76 TL	5 yıl 2 ay
Cephe yalıtımları	162.78 TL	6881.00 TL	180.66 TL	3 yıl 2 ay
Tüm yalıtımlar	147.35 TL	11262.48 TL	196.09 TL	4 yıl 9 ay

G- Dairede planlanan iyileştirmeler (Size en uygun olduğunu düşündüğünüz kutucuğu işaretleyiniz, lütfen.)

Isıl konfor seviyesini korumak ve daha az enerji harcamak için yaşadığım binanın kapı, pencere, döşeme, çatı ve cephe yalıtımının iyileştirilmesi için para harcanması gerektiğini düşünüyorum.

Katılmıyorum ( )

Kararsızım ( )

Katılıyorum ( )

D. RESULTS OF QUESTIONNAIRE SURVEY OF THE CASE STUDY 1: LOW-RISE APARTMENTS

In this section, results of the questionnaire of the first case residential area are depicted.

B- Occupancy Hours (Please fill the table below.)

In the week, between which hours you are usually staying at home and how many people stay in that hours?

Table D.1. *Sum of all participants' answers taken from questionnaire of the first case study area regarding occupancy hours (Number of the participant occupants)*

Occupancy Hours of Building1-Flat1	*Weekday*	*Sunday*	*Saturday*
00:00 – 08:00	704	704	704
08:01 – 12:30	426	528	653
12:31 – 13:30	352	431	580
13:31 – 18:30	417	494	619
18:31 – 23:59	704	704	704

C- **Energy Consumption** Behavior (Please fill the tables below.)

2- What is the approximate electricity consumption of your house for each month?

Table D.2. *Sum of all participants' answers taken from questionnaire of the first case study area regarding electricity consumption (Number of the participant flats)*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Less than 50 kWh	0	0	1	2	3	3	4	3	1	1	0	0
51 – 100 kWh	8	10	12	13	24	32	27	29	23	21	20	12
101 – 150 kWh	63	53	104	128	141	152	159	156	154	113	61	45
151 – 200 kWh	84	96	73	53	33	14	11	13	19	51	94	112
More kWh 201 kWh	46	42	11	5	0	0	0	0	4	15	26	32

3- What is the approximate gas consumption of your house for each month?

Table D.3. *Sum of all participants' answers taken from questionnaire of the first case study area regarding gas consumption (Number of the participant flats)*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1 – 50 m^3	0	0	0	1	2	12	95	96	58	9	2	0
51 – 100 m^3	2	0	9	10	24	98	63	69	76	62	17	7
101 – 200 m^3	29	31	107	117	148	72	36	31	54	102	52	25
201 – 300 m^3	68	74	64	60	25	19	7	5	10	21	106	143
More than 300 m^3	102	96	21	13	2	0	0	0	3	7	24	26

D- Already Refurbished Places and the Purposes of These Refurbishments in the Flat (Please fill the table below.)

Which places did you renovate in this flat and why?

Table D.4. *Sum of all participants' answers taken from questionnaire of the first case study area regarding already done refurbishments (Number of the participant flats)*

	Purposes	Number of the answers	Total numaber
Door renovations	Aesthetic reasons	48	
	Safety	55	103
Window renovations	Aesthetic reasons	62	
	Noise control	39	
	Energy saving	42	143
Floor renovations	Aesthetic reasons	77	77
Roof renovations	Aesthetic reasons	35	
	Practical reasons	72	
	Energy saving	43	150
Wall renovations	Aesthetic reasons	61	61
Façade renovations	Aesthetic reasons	52	
	Energy saving	118	170

E- Planned Refurbishments in the Flat (Please mark the box that you think works best for you.)

I think it is necessary to spend money on improvement of the door, window, floor, roof, and facade insulation of the building where I live in to maintain the thermal comfort level with less energy.

I disagree ( )

I am indecisive ( )

I agree ( )

Table D.5. *Sum of all participants' answers taken from questionnaire of the first case study area regarding planned refurbishments, before seeing the data (Number of the participant flats)*

	Number of the answers
Disagreed to invest to refurbishments	94
Indecisive to invest to refurbishments	28
Agreed to invest to refurbishments	79

F- **Planned Refurbishments in the Flat** (Please mark the box that you think works best for you.)

I think it is necessary to spend money on improvement of the door, window, floor, roof, and facade insulation of the building where I live in to maintain the thermal comfort level with less energy.

I disagree ( )

I am indecisive ( )

I agree ( )

Table D.6. *Sum of all participants' answers taken from questionnaire of the first case study area regarding planned refurbishments, after seeing the data (Number of the participant flats)*

	Number of the answers
Disagreed to invest to refurbishments	38
Indecisive to invest to refurbishments	21
Agreed to invest to refurbishments	142

E. SAMPLE OF THE QUESTIONNAIRE SURVEY OF THE CASE STUDY 2: HIGH-RISE APARTMENTS IN ENGLISH

A- Planned Refurbishments in the Flat (Please mark the box that you think works best for you.)

1- I think it is necessary to spend money on improvement of the door, window, floor, roof, and facade insulation of the building where I live in to maintain the thermal comfort level with less energy.

I disagree ( )

I am indecisive ( )

I agree ( )

2- I think it is necessary to spend money on the PV panel installation on the building where I live in to maintain the thermal comfort level with less energy.

I disagree ( )

I am indecisive ( )

I agree ( )

3- I think it is necessary to spend money on the PV panel installation on the building and improvement of the door, window, floor, roof, and facade insulation of the building where I live in to maintain the thermal comfort level with less energy.

I disagree ( )

I am indecisive ( )

I agree ( )

B- The Data of Energy Simulations and Cost and Payback Periods

	Monthly energy consumption	Cost of the retrofits	Monthly return of the retrofits	Payback periods of the retrofits
Existing	156 TL	-	-	-
All refurbihments	113 TL	11298.65 TL	43 TL	21 years and 11 months
PV panel installation	50 TL	5161.60 TL	106 TL	4 years and 1 month
All retrofits	7 TL	16460.25 TL	149 TL	9 years and 3 months

C- Planned Refurbishments in the Flat (Please mark the box that you think works best for you.)

1- I think it is necessary to spend money on improvement of the door, window, floor, roof, and facade insulation of the building where I live in to maintain the thermal comfort level with less energy.

I disagree ( )

I am indecisive ( )

I agree ( )

2- I think it is necessary to spend money on the PV panel installation on the building where I live in to maintain the thermal comfort level with less energy.

I disagree ( )

I am indecisive ( )

I agree ( )

3- I think it is necessary to spend money on the PV panel installation on the building and improvement of the door, window, floor, roof, and facade insulation of the building where I live in to maintain the thermal comfort level with less energy.

I disagree ( )

I am indecisive ( )

I agree ( )

F. SAMPLE OF THE QUESTIONNAIRE SURVEY OF THE CASE STUDY 2: HIGH-RISE APARTMENTS IN TURKISH

A- Dairede planlanan iyileştirmeler (Size en uygun olduğunu düşündüğünüz kutucuğu işaretleyiniz, lütfen.)

1- Isıl konfor seviyesini korumak ve daha az enerji harcamak için yaşadığım binanın kapı, pencere, döşeme, çatı ve cephe yalıtımının iyileştirilmesi için para harcanması gerektiğini düşünüyorum.

Katılmıyorum ( )

Kararsızım ( )

Katılıyorum ( )

2- Isıl konfor seviyesini korumak ve daha az enerji harcamak için yaşadığım binaya PV panel kurulumu için para harcanması gerektiğini düşünüyorum.

Katılmıyorum ( )

Kararsızım ( )

Katılıyorum ( )

3- Isıl konfor seviyesini korumak ve daha az enerji harcamak için yaşadığım binanın kapı, pencere, döşeme, çatı ve cephe yalıtımının iyileştirilmesi için ve bu binaya PV panel kurulumu için para harcanması gerektiğini düşünüyorum.

Katılmıyorum ( )

Kararsızım ( )

Katılıyorum ( )

B- Enerji Simülasyon Verileri, Maliyet ve Geri Ödeme Süreleri

	Aylık enerji harcamaları	İyileştirmelerin maliyetleri	İyileştirmelerin aylık getirileri	İyileştirmelerin geri ödeme süreleri
Mevcut	156 TL	-	-	-
Tüm Yalıtımlar	113 TL	11298.65 TL	43 TL	21 yıl 11 ay
PV Panel Kurulumu	50 TL	5161.60 TL	106 TL	4 yıl 1 ay
Tüm Yalıtımlar ve PV Panel Kurulumu	7 TL	16460.25 TL	149 TL	9 yıl 3 ay

C- **Dairede planlanan iyileştirmeler** (Size en uygun olduğunu düşündüğünüz kutucuğu işaretleyiniz, lütfen.)

1- Isıl konfor seviyesini korumak ve daha az enerji harcamak için yaşadığım binanın kapı, pencere, döşeme, çatı ve cephe yalıtımının iyileştirilmesi için para harcanması gerektiğini düşünüyorum.

Katılmıyorum ( )

Kararsızım ( )

Katılıyorum ( )

2- Isıl konfor seviyesini korumak ve daha az enerji harcamak için yaşadığım binaya PV panel kurulumu için para harcanması gerektiğini düşünüyorum.

Katılmıyorum ( )

Kararsızım ( )

Katılıyorum ( )

3- Isıl konfor seviyesini korumak ve daha az enerji harcamak için yaşadığım binanın kapı, pencere, döşeme, çatı ve cephe yalıtımının iyileştirilmesi için ve bu binaya PV panel kurulumu için para harcanması gerektiğini düşünüyorum.

Katılmıyorum ( )

Kararsızım ( )

Katılıyorum ( )

G. RESULTS OF QUESTIONNAIRE SURVEY OF THE CASE STUDY 2: HIGH-RISE APARTMENTS

In this section, results of the questionnaire of the second case study residential area are presented.

B- Planned Refurbishments in the Flat (Please mark the box that you think works best for you.)

13- I think it is necessary to spend money on improvement of the door, window, floor, roof, and facade insulation of the building where I live in to maintain the thermal comfort level with less energy.

I disagree ( )

I am indecisive ( )

I agree ( )

Table G.7. *Sum of all participants' answers taken from questionnaire of the second case study area regarding planned refurbishments, before seeing the data (Number of the participant flats)*

	Number of the answers
Disagreed to invest to refurbishments	0
Indecisive to invest to refurbishments	17
Agreed to invest to refurbishments	151

14- I think it is necessary to spend money on the PV panel installation on the building where I live in to maintain the thermal comfort level with less energy.

I disagree ( )

I am indecisive ( )

I agree ( )

Table G.8. *Sum of all participants' answers taken from questionnaire of the second case study area regarding planned PV panel installations, before seeing the data (Number of the participant flats)*

	Number of the answers
Disagreed to invest to PV panel installations	40
Indecisive to invest to PV panel installations	45
Agreed to invest to PV panel installations	83

15- I think it is necessary to spend money on the PV panel installation on the building and improvement of the door, window, floor, roof, and facade insulation of the building where I live in to maintain the thermal comfort level with less energy.

I disagree ( )

I am indecisive ( )

I agree ( )

Table G.9. *Sum of all participants' answers taken from questionnaire of the second case study area regarding planned all interventions, before seeing the data (Number of the participant flats)*

	Number of the answers
Disagreed to invest to all interventions	8
Indecisive to invest to all interventions	24
Agreed to invest to all interventions	136

C- Planned Refurbishments in the Flat (Please mark the box that you think works best for you.)

13- I think it is necessary to spend money on improvement of the door, window, floor, roof, and facade insulation of the building where I live in to maintain the thermal comfort level with less energy.

I disagree ( )

I am indecisive ( )

I agree ( )

Table G.10. *Sum of all participants' answers taken from questionnaire of the second study area regarding planned refurbishments, after seeing the data (Number of the participant flats)*

	Number of the answers
Disagreed to invest to refurbishments	0
Indecisive to invest to refurbishments	34
Agreed to invest to refurbishments	134

14- I think it is necessary to spend money on the PV panel installation on the building where I live in to maintain the thermal comfort level with less energy.

I disagree ( )

I am indecisive ( )

I agree ( )

Table G.11. *Sum of all participants' answers taken from questionnaire of the second case study area regarding planned PV panel installations, after seeing the data (Number of the participant flats)*

	Number of the answers
Disagreed to invest to PV panel installations	0
Indecisive to invest to PV panel installations	0
Agreed to invest to PV panel installations	168

15- I think it is necessary to spend money on the PV panel installation on the building and improvement of the door, window, floor, roof, and facade insulation of the building where I live in to maintain the thermal comfort level with less energy.

I disagree ( )

I am indecisive ( )

I agree ( )

Table G.12. *Sum of all participants' answers taken from questionnaire of the second case study area regarding planned all interventions, after seeing the data (Number of the participant flats)*

	Number of the answers
Disagreed to invest to all interventions	8
Indecisive to invest to all interventions	10
Agreed to invest to all interventions	158