OPTIMIZING GREEN DESIGN OF BUILDINGS USING BUILDING INFORMATION MODELING

by

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ABSTRACT

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Energy performance of the buildings has been a subject topic for years due to many reasons such as financial benefits, environmental and social concerns. All these cause a tendency in the construction sector for analysing the energy performance of the buildings with the aim of increasing the energy efficiency of the building which eventually results in a reduce in the operational costs. Realising the benefits of Building Information Modeling (BIM), energy analysis of the buildings is shifted from being in a paper to a computer with the help the softwares in which the base model and the design alternatives can easily be updated and evaluated in terms of their energy performance. However, only energy performance of a design alternative is not enough to choose that alternative. These design alternatives should also be evaluated in terms of money to assess their feasibility using life cycle costing (LCC). The main aim of this research is to achieve an optimum green design in terms of LCC among the design alternatives for a residential project created in a BIM enabled environment based on both experts opinion and literature review. The results obtained at the end of this research reveal how investments could have dramatic effects on reducing the energy need of the buildings which results in significant reduce in the operational costs. Among the major contributions of this research are the evaluation of energy performance in a 30-year service life using LCC; evidence for significant financial benefits for energy improvements in early design phase of the projects; and proposal of energy performance analysis frameworks for companies based on two options (either through consultancy or in-house).

ÖZET

BİNALARIN YEŞİL TASARIMININ YAPI BİLGİ MODELLEMESİ KULLANARAK OPTİMİZASYONU

Binaların enerji performansı finansal katkılarından, çevresel ve sosyal nedenlerden ötürü yıllardır bir araştırma konusu olmuştur. Bütün bunlar, inşaat sektöründe bina enerji verimliliğinin arttırılması ve operasyonal maaliyetlerin düşürülmesi amacıyla yapılan bina enerji performansının analizinde bir eğilime sebep olmuştur. Yapı Bilgi Modellemesinden (YBM) faydalanarak, binaların enerji analizleri kağıt üstünde yapılmaktan çıkıp, içinde ana modelin ve dizayn alternatiflerinin kolaylıkla güncellenebildiği ve enerji performansı açısından değerlendirilebildiği bilgisayar yazılımlarına taşınmıştır. Yine de bir dizayn alternatifinin sadece enerji performansı onu seçmek için yeterli değildir. Bu dizayn alternatiflerini fizibilitelerini yaşam dönemi maaliyeti yoluyla değerlendirmek için ayrıca parasal açıdan da değelendirmek gerekmektedir. Bu araştırmanın asıl amacı bir konut binası için uzman görüşmeleri ve literatür taraması temel alınarak YBM ortamında oluşturulmuş dizayn alternatifleri arasından yaşam dönemi maaliyeti açısından optimum olan yeşil tasarıma ulaşmaktır. Bu araştırmanın sonunda elde edilecek bulgular, yatırımların, sonunda operasyonel maaliyetlerde büyük ölçüde düşüş meydana getirecek olan enerji ihtiyacını düşürmede büyük ölçüde etkili olabileceğini ortaya koymaktadır. Bu çalışma sonucunda elde edilen önemli katkılardan bazıları şunlardır: 30 yıllık servis periyodu boyunca bina enerji performansının yaşam boyu maliyet yöntemiyle değerlendirilmesi, projenin erken dizayn döneminde yapılan enerji bazlı gelişmelerin sağladığı önemli katkıların ortaya konuşu, ve şirketlerin enerji performans analizi için tercih edebileceği iki seçenekli (danışman aracılığıyla ya da şirket içi) çerçevenin önerilmesi.

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LIST OF ACRONYMS/ABBREVIATIONS

AEC	Architecture, Engineering and Construction
AFUE	Annual Fuel Utiliziation Efficency
AGC	The Associated General Contractos of America
ASHRAE	American Society of Heating, Refrigerating and Air - Conditioning Engineers
ASPE	American Society of Plumbing Engineering
BAS	Building Automation Systems
BIM	Building Information Modeling
BREEAM	Building Research Establishment Environmental Assessment Method
CAD	Computer-Aided Design
CASBEE	Comprehensive Assessment System for Building Environmental Efficiency
CDD	Cooling Degree-Day
CIBSE	The Chartered Institution of Building Services Engineers
CMMS	Computerized Maintenance Management Systems
DHW	Domestic Hot Water
EDMS	Electronic Document Management Systems
EMS	Energy Management Systems
EN	European Standard
EPDK	Energy Market Regulatory Board
FM	Facility Management
HDD	Heating Degree-Day
HVAC	Heating, Ventilation and Air-Conditioning
IEA	International Energy Agency
IES	Integrated Environmental Solutions
IGDAS	Istanbul Gas Distribution Industry and Trade Incorporated Company
IRR	Internal Rate of Return

ISO	International Organization for Standardization
LCC	Life Cycle Costing
LEED	Leadership in Energy and Environmental Design
MGM	Turkish State Meteorological Service
NEER	Nominal Effective Exchange Rate
NIST	The National Institute of Standards and Technology
NPV	Net Present Value
OECD	Organisation for Economic Co-operation and Development
PB	Payback Period
PI	Profitability Index
ROE	Return on Equity
SCOP	Seasonal Coefficient of Performance
SE	Seasonal Efficiency
SEER	Seasonal Effective Exchange Rate
SSEER	Scientific Support for Environmental Emergency Response
TS	Turkish Standard
TSG	Total Solar Gain
TSI	Turkish Standard Institute
TUİK	Turkish Statistical Institute
VAT	Value Added Tax
VE	Virtual Environment
YTSG	Yearly Total Solar Gain

1. INTRODUCTION

1.1. Background of the Study

As stated in the literature, there are many ways of Building Information Modeling (BIM) implementation. Barlish and Sullivan (2012) list top mentioned benefits of BIM after an extensive literature review such as: schedule, visualization, project cost, physical conflicts, and safety and so on. As an addition to those, Azhar *et al.* (2009) state that BIM can facilitate so complex processes of sustainable design. There are several aspects of sustainable design that BIM can help such as determining the best building orientation, reducing the energy needs, optimizing the building envelope (Krygiel and Nies, 2008).

Considering these, in this study, the opportunities provided by BIM for analysing the energy performance of the buildings are tried to be explored. In this respect, a building is going to be analysed in a software as a base which is then going to be followed by creating the design alternatives and analysing their respective energy performances. Finally, the life cycle analysis of these design alternatives is going to made to determine the optimum design among all alternatives.

1.2. Problem Statement

People need shelters to live in as its own nature requires. These shelters are evolved throughout the time and nowadays different types of residential buildings are being used to live in such as detached houses, multi-family apartments. Each of these has their respective capacities in respect to their sizes. As long as the population of the world keeps increasing, the need of constructing more houses is also going to increase. This could eventually result in consuming more energy unless they are constructed as an energy efficient buildings, and cause to catastrophic problems in the entire world. Nowadays, almost 40% of the energy consumption and around 30% of the greenhouse gas emissions are caused by the buildings (Yang *et al.*, 2014; Nejat *et al.*, 2015; European Commission Buildings, 2015 as cited in Gourlis and Kovacic, 2017). These amount of consumptions could cause devastating results as the population keeps rising as mentioned above. Furthermore, considering the fact that the companies wish to be certified for their buildings as they try to attract especially foreign investors since they pay more attention than the local investors to the sustainability, increase their sales and brand value. All the reasons cause a demand for improved buildings in terms of their energy performance.

Another issue is that the most important decisions related to sustainable design of a building are mostly made in the early stages (Azhar *et al.*, 2010). As models being in a computer environment are way easier to be edited and updated, they provide their users to compare design alternatives and easily find the most feasible alternative in terms of energy performance with the help of BIM. This enables the users to be able to make correct decisions and take actions accordingly. Making these analysis is very hard and time-consuming using traditional methods based on 2D.

Life cycle costing is a factor that should be considered with energy performance of the buildings. The reason is that improving the energy performance of a building knows no bound. Even though the amount of investment made could be unreasonable and unfeasible at some point, the energy performance of the building keeps improving. When dealing with it, it is important to know whether the investment is going to pay off not, how much money is going to be saved throughout the each year and the entire project life. Therefore, it is crucial to assess the feasibility of the design alternatives created at the early design stages and making proper decisions accordingly.

The most significant feature of this study is that the findings reveal how relatively basic investments could dramatically help increase the energy efficiency of the buildings and result in reducing the operational costs. Furthermore, this study could promote to make investments on energy efficient buildings by revealing the financial benefits coming through it besides the environmental and social concerns. To do so, the feasibilities of the entire design alternatives should be assessed in terms of life cycle costing. When the entire data is correctly entered and traced, the results become very close to what the investors are going to face with. This obviously helps them see whether they are going to lose money, or their investment is going to pay off, or they are going to make profit. The important thing is that to be able to exploit these opportunities, the early design is crucial. As the stages progress, the cost of making improvement starts being expensive and hard. Similarly, in cases of targeting a certification level in terms of energy performance, the chance of getting it starts reducing because of unapplied possible passive design strategies, being generally easy to apply, and requiring low cost. In this respect, a computer-based model is so beneficial as it is easy to analyse the energy performance of different design alternatives which use also the passive design strategies. Making all these analysis is way more hard to do with traditional, standard-based, and manual approaches. Therefore, at the end, a comparison is also going to made for revealing the potential benefits of using a software and weakness of using a standard-based approach.

1.3. Purpose of Research

The main aim of this research to achieve an optimum green design among the design alternatives created based on both experts' opinion and literature review for a residential project using a software. In this respect, a building information model is going to be created and different design alternatives being created by making some modifications on the base model are going to be evaluated in terms of their energy performance and life cycle costs. In order to reach this main aim, the following objectives are targeted to meet:

- To calculate the energy need of the base and alternative designs,
- To calculate the life cycle costs of each design alternative,
- To assess the design alternatives in terms of life cycle costing,
- To reveal the importance of estimating future unit prices for energy,
- To reveal the importance of making some decisions at early design stages,
- To reveal the potential benefits of using a software when dealing with energy performance,

- To reveal the weak points of calculations manually made based on a standard for energy performance.

1.4. Literature Study

There are several researches in the literature that studied different aspects of building performance using BIM. To begin with, research made by Azhar *et al.* (2010) presents the findings of a research project in order to examine the feasibility of BIM for sustainability analyses using a case study. At the end, the authors find that BIM has some significant contributions for performing complex performance analyses for buildings to guarantee an optimized design. Furthermore, Davaki (2011) studies the analysis of energy use in typical Greek residential buildings and proposes some retrofit strategies accordingly. In addition to, Finch *et al.* (2010) investigate the energy consumption in mid and high rise residential buildings in British Columbia; hence, the authors specify their objective as reporting and discussing the use of gas and electricity in large sample of mid and high rise multi-unit residential buildings. Moreover, Pan *et al.* (2008) study the energy modeling of two office buildings with data center for green building design. To do so, they use energy simulation models developed on a software for these two office buildings to investigate the energy cost savings of design options with the baseline building. During the literature review, the number of studies for analyzing the energy performance of the office buildings seems to be greater than the ones for residential sector. Hachem *et al.* (2014) are another authors studying for energy performance enhancement in multistory residential buildings, and they present some methods to be applied to for energy performance enhancement for multistory residential buildings and investigate some methods that could increase the energy generation potential to match with the consumption. Lastly, Paiho *et al.* (2013) try to investigate energy saving potentials of Moscow apartment buildings in residential districts using different renovation concepts and present three different renovation concepts for energy saving potential. However, the study does not include any life cycle costing issues.

This research, on the other hand, takes a residential building to be constructed in Istanbul, Turkey as a base model and creates four different design alternatives based on both experts' opinion and literature review, and these design alternatives are analysed in terms of energy performance in a software. At the end, the energy consumption throughout a year and cost saving could be investigated, cash flow diagrams throughout its project life could be obtained, and feasibility of each alternative could be assessed.

1.5. Research Methodology

To begin with, an extensive literature review and consulting to experts, four different design alternatives of the base model are created in a software. To advise the experts' opinion, six experts are face-to-face intervieweed with open-ended questions. The questions are related to sustainability with BIM in general, and energy performance calculations based on manual computations. The experience of these experts varies from 5 to 33 years. Furthermore, the company age in which the experts work varies from 9 to 19 years. The design alternatives created use different combinations of insulation thicknesses, efficiency of heating mechanism, and smart home property. At the beginning, the heating need of the base model is evaluated by Turkish Standard (TS) 825. This calculation is made for revealing the differences between manual standard-based and computer-based approaches to reveal weaknesses of manual computations and reveal the potential benefits of using a software. After that, each design alternative is evaluated in a software in terms of its energy performance. The results obtained from the software for natural gas and electricity consumption are taken for life cycle costing calculations. The money spending for implementing some techniques for creating the design alternative is taken as the investment. Moving on, the amount of money that is saved from natural gas and/or electricity through these implemented techniques are taken as earnings. Finally, the time effect is reflected for the money earned in the future and using profit evaluation methods, the feasibility of these design alternatives are assessed.

1.6. Organization of the Thesis

The structure of this thesis is formed in seven main chapters excluding the introduction section that is just covered. Moving on to the second chapter, building information modeling is going to be investigated in terms of its advantages and benefits, disadvantages and challenges, its dimensions, and its application areas. After that, chapter three is going to be about sustainability and green design. In this section, the definition and principles of it is going to be explained first which is then going to be followed by need and rating systems of it, sustainability with building information modeling, energy modeling, energy efficient design of buildings, and lastly softwares. Furthermore, chapter four is going to be consist of life cycle costing in which definition and purposes, elements, and profit evaluation methods of life cycle costing is going to be explained in details. Later, research methodology is going to be mentioned. The calculations made in this section are going to be based on both a Turkish Standard -only for the base model- and a software. Then, these calculations are going to be evaluated in terms of life cycle costing using the profit evaluation methods. Finally, last three chapters are going to be about discussion, conclusion, and references.

2. BUILDING INFORMATION MODELING

2.1. Definition of BIM

There is a misconception in literature about what BIM is and capabilities of it. In terms of definition, there is actually no single-widely-accepted definition made for what BIM is. Thus, the definitions made by different sources can be found below to ensure a good understanding about BIM. To begin with, Eastman *et al.* (2011) define BIM as "one of the most promising developments in AEC industry due to the ability of generating one or more accurate virtual models of a building to support design through its phases, allowing better analysis and control than manual processes, and enhances the collaboration between the actors involved". Secondly, Azhar *et al.* (2009) make the definition of it in a broader sense as "the process of development and use of a computer generated model to simulate the planning, design, construction and operation of a building facility". Furthermore, Wong and Fan (2013) explain it as "a new and innovative technology, which has emerged in recent years and makes possible the efficient achievement of more sustainable designs. Besides, the US National BIM Standard (2007) as cited in Wong and Fan (2013) defines it as three dimensions, namely, a product, a process and a system. In addition to these definitions, a computer model is needed when adopting BIM. The Associated General Contractors of America (AGC) (2005) as cited in Azhar *et al.* (2015) explain this resulting model, namely Building Information Model, as "a data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users' needs can be extracted and analysed to generate information that can be used to make decisions and to improve the process of delivering the facility".

On the other hand, the other important part, as mentioned before, is about the misconception. This issue creates a huge misunderstanding in civil engineering community especially for the ones that are new to BIM. As Fernandes (2013) basically states, in summary:

- "BIM is not a single building model or database, it actually is a series of interconnected models and databases creating relationships with each other and allowing information to be extracted and shared".
- Models only consisting of 3D data only and having no object attributes are not BIM.
- BIM is not Revit, ArchiCAD or Tekla, these are the BIM design tools that can be used for implementation. Although these softwares are the important piece of BIM implementation, they are not "the" BIM.

2.2. Advantages and Benefits of BIM Implementation

There are several advantages and benefits stated in the literature about why BIM keeps its popularity in the community. Wong and Fan (2013) state the advantages of BIM implementation in construction industry in terms of the environmental-economic and social aspects. The first one of those is that BIM can be useful when an assessment of building performance is carried out by choosing the preferable solutions which can considerably reduce the consumption of energy, water and materials. Besides, with the contributions of improved materials and energy efficiency, it also helps to reduce project related cost by reducing the capital and lifetime costs. Second one of those, in social aspect, is that it improves the communication and collaboration between the actors involved in a project and it reduces the risk in the construction projects. Khosrowshahi and Arayici (2012) emphasize the importance of improved communication as it is intended in a project environment to reduce errors and lower costs for all disciplines. Furthermore, Love and Edwards (2004) and Love *et al.* (2009a, 2010a, b) as cited in Love *et al.* (2011) clearly explain that growth in design changes and errors are the fundamental and prominent issues of the construction industry that increase the cost and cause delay. To overcome this issue, Bernstein and Taylor (2009), Sacks *et al.* (2010a, b, c) and Nisbet and Dinesen (2010) as cited in Love *et al.* (2011) emphasize that BIM technology can considerably improve the efficiency and effectives of delivery process. Therefore, considering the significant advantages of BIM implementation, civil engineering industry and its community wish to get most out of it.

2.3. Disadvantages and Challenges of BIM Implementation

Besides its several advantages and benefits, BIM implementation has also its disadvantages and challenges when it is intended to be used. Arayici *et al.* (2010) state some of these disadvantages and challenges as people resisting to change, training people in BIM or finding employees who understand BIM, and understanding of the required high-end hardware resources. Especially, the first one among those, people resisting to change, is also emphasized in different sources such as Egan (1998) and Fairclough (2002) as cited in Ozorhon *et al.* (2015) as that construction industry is one of the industries that has been highly criticized in terms of its weaknesses in embracing new technologies and practices which creates a barrier in front of the BIM implementation. Ziga Turk (2016) implies that BIM is a reason to a change in the organization of building processes, workflow, contractual arrangements and legal relations; therefore, when adopting BIM, the companies have to create some new roles and different processes for their way of work which could be risky. Furthermore, in the study of Khosrowshahi and Arayici (2012), more challenges are listed. Beside similar ones, BIM being not tangible enough to warrant its use is the first remarkable one so it can be said that there is a lack of clear benefits of BIM implementation especially in financial aspect. This inference is also supported by Wix (1997) as cited in Yan and Damian (2008) as it is stated that the AEC industry does not wish to invest in BIM, since there is a lack of case study evidence that reveals the financial benefit of BIM; therefore, an investment in BIM by the architecture, engineering, and construction (AEC) industry will be possible when a good case study is available as an evidence. Moreover, Succar *et al.* (2012) emphasize that little guidance is available for companies being willing to generate new or enhance their existing BIM deliverables which results in for them being left to their own devices. The second remarkable challenge from Khosrowshahi and Arayici (2012) is the lack of capital to invest for hardware and software. This can also be related to the lack of clear benefits of BIM implementation in a financial aspect since as long as there are no case study that reveals the financial benefits, the AEC industry do not wish to invest their both financial and human resources for it. As a result, the AEC industry should be well aware of the disadvantages and challenges of BIM implementation to get most out of it.

2.4. Dimensions of BIM

Kymmell (2007) states that Building Information Modeling is characterized by the availability and connectedness of all information having become a part of the project, such as its dimensionality. The dimensions of BIM consist of 3D, 4D, 5D, 6D,7D and 8D which are all shown in Table 2.1 below with their short explanations.

Table 2.1. BIM Dimensions and its Explanations.

Dimension	**Explanation**
3D	Three-dimensional (Visualization)
4D	Time-related
5D	Cost-related
6D	Sustainability
7D	Facility Management
8D	Safety

Park *et al.* (2011) define 3D computer-aided design (CAD) as a visualization tool to represent the construction projects. According to the authors, project management information consisting of material type, quantity, and price could be embedded in the 3D CAD model by relying on it being object-oriented concept. Furthermore, the virtual 3D parametric model which nowadays is accepted by designers as a natural extension of 2D design (Czmoch and Pekala, 2014). Eastman *et al.* (2011) state that all of the parties involved can visualize the design at any stage of the process knowing that there is not going to be a dimensional problem in any of the views with the help of a 3D model. Moreover, it is also mentioned by the authors that 3D modeling also provides its owners to eliminate the design errors before the field application, as models generated by different disciplines could be brought together and compared, which speeds the process up, reduces the costs, minimizes the chance of legal disputes, and provides a smoother process for the all project team. 4D basically introduces the scheduling into the 3D model by linking a construction plan to the 3D model. It enables activities to be sequenced with the visualization, and provides a simulation for update time and resource schedule (Tulke and Hanff, 2007 as cited in Masood *et al.*, 2014; Wilson and Koehn, 2000 as cited in Masood *et al.*, 2014). Eastman *et al.* (2011) explain the benefits as being able to see how the building is going to be constructed day-by-day, revealing the sources of potential problems, and opportunities for improvement. Furthermore, Park *et al.* (2011) imply that 4D CAD has enabled visualization of sequential construction process which indirectly leads to more effective time management.

5D for BIM stands for BIM including the cost estimation. Forgues *et al.* (2012) states that cost estimating is a highly fragmented, resource intensive, and ineffective process, especially for the large or complex projects. Flyvbjerg *et al.* (2003) and Winch (2010), which both as cited in Forgues *et al.* (2012), mention that variation over 40% with the initial budget could often be observed in these cases. As the firms are in this business the profit, cost estimating is an important part of the project. Kahnzode *et al.* (2007) as cited in Forgues *et al.* (2012) a 3% cost accuracy can be achieved from front-end cost budgeting to building construction cost. 5D BIM includes the cost of labour and delivery for each item and enables fast estimation of cost for the conceptual designs and any other cost estimations (Czmoch and Pekala, 2014).

6D, which is the dimension that is related to this thesis, is the integration of the sustainability to the BIM. Basically, a software compatible with BIM is used for this purpose which are later on going to be investigated in details. Czmoch and Pekala (2014) states that models that are generated in 6D are mostly used as a primary tool to meet the requirements defined by rating systems for sustainable designs. According to Autodesk (2005) as cited in Azhar and Brown (2009), “BIM can reduce the costs associated with sustainability analyses by making the information required for sustainable design, analysis and certification routinely available simply as a byproduct of the standard design process”. BIM for 7D is simply the usage of BIM for facility management purposes. Cotts *el al.* (2009) as cited in Arayici *et al.* (2012) define facility management (FM) as “a multi-disciplinary field encompassing multi-disciplines to ensure the functionality of built environment by integrating people, place, process and technology”. As Becerik-Gerber *et al.* (2011) state, the information collected by a

BIM process and stored by a BIM database could provide great benefits for many FM practices such as commissioning and closeout, quality control and assurance, energy management, maintenance and repair, and space management; as long as the information is integrated with FM information systems such as computerized maintenance management systems (CMMS), electronic document management systems (EDMS), energy management systems (EMS), and building automation systems (BAS).

Lastly, BIM may also be used for applications related to safety. Zhang *et al.* (2013) state that "since safety rules, guidelines, and best practices already exist, they can be used in conjunction with existing three-dimensional (3D) design and schedule information to formulate an automated safety rule checking system". The authors also imply that the intention is to automatically identify the dynamic conditions, as the building is constructed, identify their location in a 3D virtual space, and interactively or automatically provide solutions to mitigate identified hazards. Moreover, they also state that this platform can also be useful to detect dangerous hazard locations on the site.

As a result, BIM can be explained in many dimensions as mentioned above. Each of these dimensions could serve for multiple purposes to provide lots of benefits to its users. These purposes are now going to be explained in details as BIM applications.

2.5. BIM Application Areas

Barlish and Sullivan (2012) identify the top mentioned benefits of BIM based on a literature review and some of them are as follows:

- Physical conflicts/Clash detection
- Schedule
- Visualization
- Project Cost
- Safety

These application areas to achieve the benefits provided by BIM are now going to be explained in details. Sustainability with BIM is going to explained further on in details so it is not going to mentioned here as an application area.

2.6. Physical Conflicts/Clash Detection

Physical conflicts in a project should always be avoided not to waste both money and time. Traditionally, using 2D CAD files, layers having different colours are visually compared in a computer environment (Czmoch and Pekala, 2014). Nevertheless, the authors also mention that 3D CAD now makes the works easier as collision detection in BIM is made based on algorithms developed in gaming industry and computer graphics. According to Hergunsel (2011), collisions, or clashes, have two types: space interference (hard clash) or clearance clash (soft clash). Hard clashes occur when two or more physical elements occupy the same space. An example for hard clash can be seen in Figure 2.1. On the other hand, soft clashes occur when a clearance or tolerance is invaded. Love *et al.* (2011) imply that a dimensional error or spatial conflict being in a engineering could easily go unnoticed until the project is physically constructed on site. This situation then should be solved and could result in unplanned works, producing waste, unanticipated field costs, and wasting time on it. Nevertheless, BIM can eliminate these types of errors from occurring through the in-built clash detection check. Therefore, BIM has the potential to produce a better product as it reduces the amount of mistakes, clash detection, and so on (Coates *et al.*, 2010).

As detecting the clashes before the field application reduces the waste, clash detection indirectly has another potential: lean construction. According to Kymmell (2007), lean construction defines waste as “that which is unnecessary”. Thus, considering this, construction simulation could help the development of more efficient construction procedures, and stimulate ideas to improve the efficiency of the use of materials, time, and energy (Kymmell, 2007).

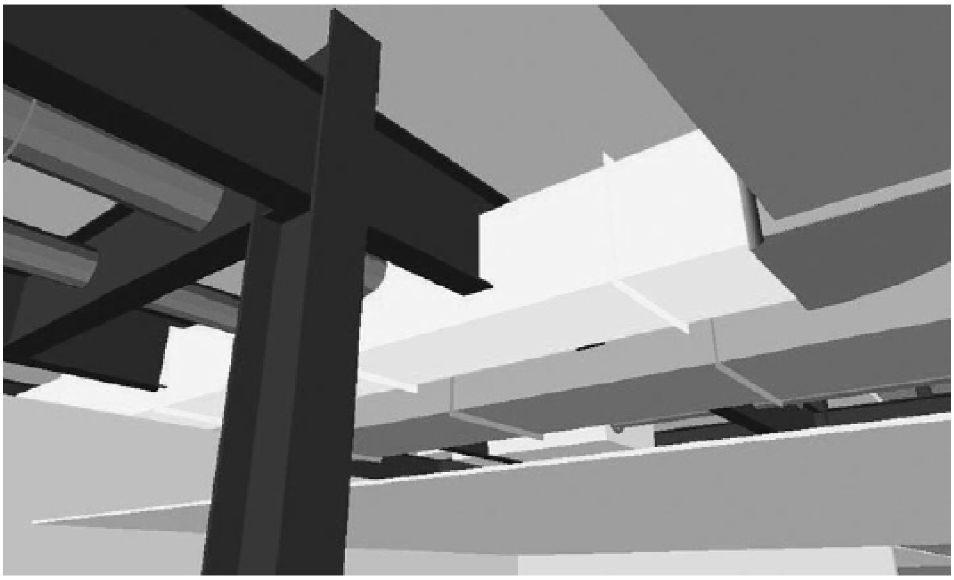

Figure 2.1. An example of clash detection with BIM (Image courtesy of CSU Chico, CM Dept as cited in Kymmell, 2007).

2.6.1. Schedule

Zhang and Li (2011) state that each project is both complex and a dynamic system bringing additional complexity and difficulties to the construction planning, design, site management, and construction management. According to them, these reasons make the works difficult to deal with for the large projects using the traditional processes; therefore, they state that virtual construction technology is a good solution.

BIM-based scheduling, also referred as 4D-modeling or 4D CAD, as stated before, is used for bridging the gap between the 3D-modeling and the planning and scheduling of the construction site (Büchmann-Slorup and Andersson, 2010). According to Around *et al.* (2005) as cited in Zhang and Li (2011), to create a 4D model, time factor is linked with a 3D model that provides displaying the processes of the building dynamically. Nevertheless, Zhang and Li (2011) imply that 4D model is not only a visual media that is only used for simulating the construction process, but also has some capabilities to optimize and control the construction process. Benefits that comes with it which are identified by Koo and Fischer (2000) as cited in Büchmann-Slorup and Andersson

(2010) are that:

- There is more chance of identifying unanticipated problems and inconsistencies before with the help of viewing graphical presentation,
- It facilitates the understanding of the scheduling results,
- It supports the identification of potential time-space conflicts.

Moreover, the advantages that are noticed by Zhang and Li (2011) are as follows:

- Construction process can be simulated dynamically with an added time factor,
- Changes that could be made on the construction plan can be immediately reflected in a 4D model,
- To achieve the purpose of optimization, project information could be added to the 4D model by researchers.

2.6.2. Visualization

One of the basic advantages offered by BIM is visualization as the foundations of BIM lay on the 3D model. It should be noted that models containing only 3D data are not considered as BIM models as the importance of BIM models relies on their parametric details. However, a BIM model can be used for visualization purposes as mentioned here. According to Eastman *et al.* (2011), as the 3D model is directly created rather than being generated using several 2D views, it can be used for visualizing at any stage of the process knowing that there is not going to be an dimensional problem. An example of a 3D-BIM model is shown below in the Figure 2.2. Another advantage is that when a modification is made on the 3D model, the change and its effects could directly be seen in a 3D environment to assess the feasibility and evaluate the change. Lastly, it can also be used as a 4D visualization to see the simulation of the construction site.

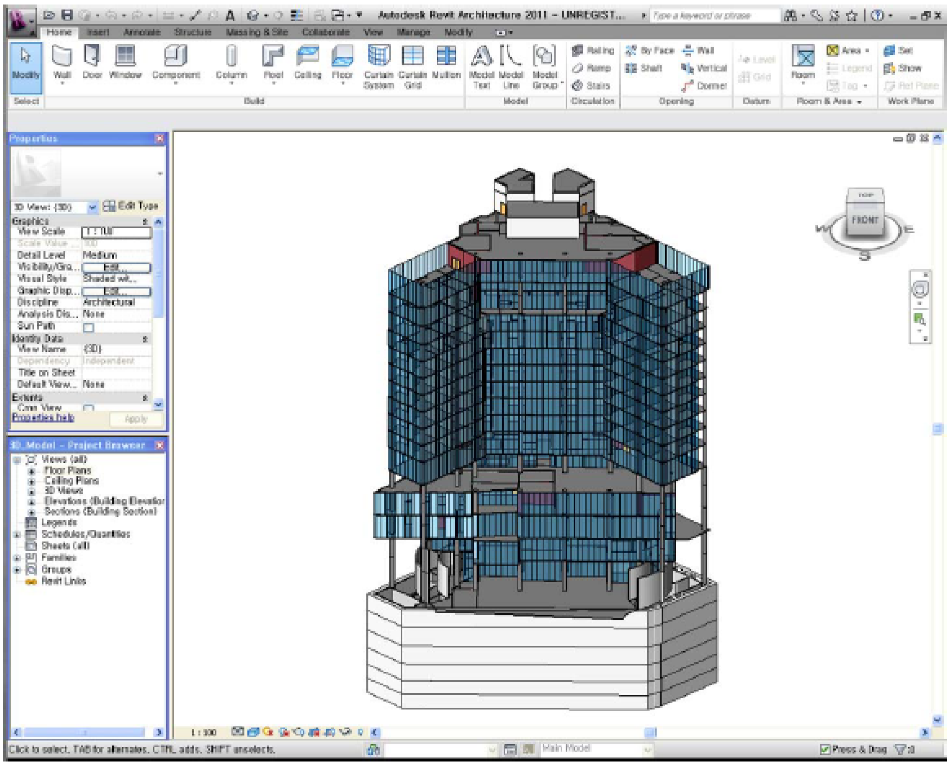

Figure 2.2. 3D CAD model for the Haeundae Hotel project (Park *et al.*, 2011).

2.6.3. Project Cost

Forgues *et al.* (2012) identify that cost estimating for a project is typically made when the conceptual design of the project is advanced or even completed due to fragmentation of the construction industry and the linearity of the design process. According to the authors, this is too late to help the stakeholders make informed decisions so in most of the times, the feedback about the costs emphasizes potential budget concerns and a cost engineering process is performed to be able to decrease the construction costs often at the expense of performance of the building and quality of construction. Wu *et al.* (2014) state that estimating the cost earlier becomes fundamental guideline to assess the feasibility and it also acts as the main parameter with which the design has to conform throughout its development (Odusami and Onukwube, 2008 as cited in Wu *et al.*, 2014; Raisbeck and Aibinu, 2010 as cited in Wu *et al.*, 2014). Wu *et al.* (2014) derive some advantages of the BIM based cost estimation from different sources as follows:

- BIM provides visualiza tion to ease the pro duc tion of concep tual estima tes (Matipa *et al.*, 2008),
- BIM enables the function to automate the generation of quantities and measurements directly from a BIM model (Sabol, 2008),
- BIM allows early design models to be linked to software providing quantity surveyor to be able to extract necessary quantities at the initial stages of a project (Eastman *et al.*, 2011).

As mentioned before, Flyvbjerg *et al.* (2003) and Winch (2010), which both as cited in Forgues *et al.* (2012), state that variation over 40% with the initial budget can often be observed in these cases. However, Kahnzode *et al.* (2007) as cited in Forgues *et al.* (2012) a 3% cost accuracy can be achieved from front-end cost budgeting to building construction cost. Hence, taking advantage of BIM for cost estimation could greatly help the professionals to determine the most appropriate budget necessary for the project with ease.

2.6.4. Safety

Zhang *et al.* (2013) state that "...safety in construction remains a big problem" and "the sad reality of frequent loss of life, injuries, near-misses, and collateral damage is that they pose liabilities that can be prevented". Kamardeen (2010) also shares the same idea that the safety record of the construction industry, remaining one of the most dangerous industries for operatives, has always been poor.

According to Kamardeen (2010) the roles of designer and contractor are traditionally shared as that designer creates a design suitable with the local building codes and safety of construction is left up to the contractor; nevertheless, research reveals that designers could have a considerable influence on the safety of the construction. To make it clear, following curve created by Furst (2009) and Mroszczyk (2008) as both cited in Kamardeen (2010) is shown below in Figure 2.3.

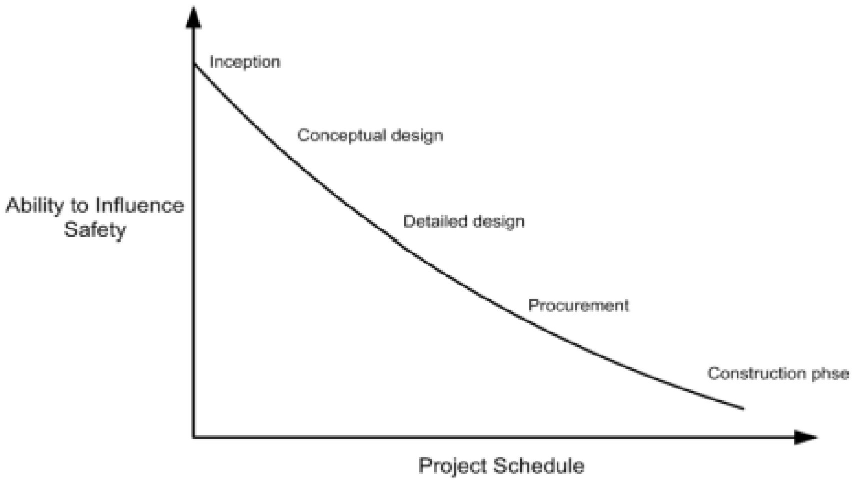

Figure 2.3. The Ability to Influence Safety vs. Project Schedule (Furst, 2009 and Mroszczyk, 2008 as both cited in Kamardeen, 2010).

It is clearly seen from Figure 2.3. that the curve reveals that earlier design stages have much more influence on the safety than the later stages. Therefore, Kamardeen (2010) implies that the ideal time for influencing the safety is inception, concept design and detailed design so basically these are the phases that a designer could have an influence on the safety issues.

According to Kamardeen (2010), prevention through a design with BIM basically involves:

- Hazard profiling of BIM model elements,
- Providing safe design suggestions for revising high hazard profiled elements,
- Proposing on-site risk controls for hazards that are uncontrollable through design revisions.

Moreover, Sulankivi and Kiviniemi (2010) explore the chances for having 4D-BIM for construction site safety related planning activities. The authors state that models that are created in the design phase could be improved so as to serve site and safety planning by adding the planned temporary site and safety arrangements to the model created in the architectural design or structural engineering stages. To develop 4D-BIM for the safety purposes, a structural model combined with a surface of the site area being roughly modelled is used, later on, safety railings are placed to the edges of the intermediate floors and balconies. At the end, 4D-BIM model is created by scheduling the tasks and linking them in the model with the corresponding activities. Overall, a model revealing the construction site with the safety railings is obtained.

In addition to, Zhang *et al.* (2013) introduce an automated safety rule checking to BIM so that algorithms which automatically analyze the model to detect safety hazards and suggest preventive measures are developed for different cases involving fall related hazards. To do so, a rule-based engine utilizing a framework is implemented on top of a commercially available BIM platform to reveal the feasibility of the approach. Accordingly, following figure reveals what the authors achieve at the end. In Figure 2.4, automated rule-based fall protection detection and installation in Tekla is shown. On the left-hand side, modeling without protective system is shown which looks like being prone to hazards due to falling. On the other hand, a modeling with protective system which could help reducing the hazards due to falling at the right-hand side.

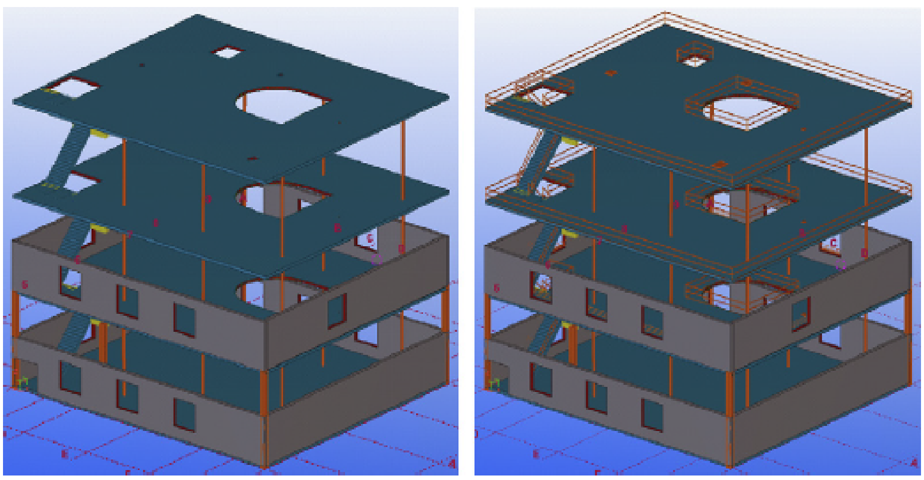

Figure 2.4. Placing a protective system (Zhang *et al.*, 2013).

Overall, BIM could serve as a safety tool as well to reduce the hazards due to several reasons such as falling from height. In literature, it is seen that there are many ways to use BIM as a safety tool which looks like having an increase in future as it spreads.

3. SUSTAINABILITY AND GREEN DESIGN

3.1. Definition and Principles of Sustainable Construction

To begin with the most general term, sustainable development, based on one of the most classical definitions, is defined as "... that meets the needs of the present without compromising the ability of future generations to meet their needs" (Work Commission on Environment and Development, 1987). Based on this definition, it can be well understood that the construction industry is related to sustainability as it continuously depletes the natural sources which are finite, damages environment both by polluting it in short term and global warming by emitting CO_2 in long term, and produces lots of waste. In terms of the construction industry, Plank (2008) defines sustainable construction as "... a subset of sustainable development in which economic growth and social progress for all is coupled with effective protection of the environment and prudent use of resources". Another definition according to The Organisation for Economic Co-operation and Development (OECD) (2002) as cited in John *et al.* (2005) is made for sustainable buildings as "... those buildings that have minimum adverse impacts on the built and natural environment, in terms of the buildings themselves, their immediate surroundings and the broader regional and global settings". Sustainable building design is also known as green design or high performance buildings (Wang and Adeli, 2014).

In addition to, according to Kibert (1994) as cited in Gambatese and Rajendran (2005), there are six principles for sustainable construction:

- Minimization of resource consumption (conserve),
- Maximize resource reuse (reuse),
- Use renewable or recyclable resources (renew/recycle),
- Protect the natural environment (project nature),
- Create a healthy, non-toxic environment (non-toxics),
- Pursue quality in creating the built environment (quality).

Gambatese and Rajendran (2005) emphasize the reason of -minimization of resource consumption taking the first place is that it directly addresses the first problem against sustainability which is over consumption. In much broader sense, construction community should follow all of these principles carefully in their practice to ensure the ability of the future generations to meet their needs.

3.2. The Need of Sustainable Construction

International Energy Agency (IEA) (2013) as cited in Nejat *et al.* (2015) states that the energy demand, made by both residential and commercial buildings, has grown by 1.8% per year since forty years. Nowadays, the buildings are responsible for almost 40% of the energy consumption and around 30% of the greenhouse gas emissions (Yang *et al.*, 2014; Nejat *et al.*, 2015; European Commission Buildings, 2015 as cited in Gourlis and Kovacic, 2017). The main reasons of having this amount of energy consumption are given by Harish and Kumar (2016) as the rising population, expanding economy and a quest for improved quality of life. These reasons cause to a growth in energy consumption over all these years and it is also expected to keep fuelling the energy demand further which will eventually lead to much more greenhouse gas all over the world and have an impact on global environment that may yield a catastrophic result. Furthermore, Sharma *et al.* (2011) imply that the energy is both consumed and considerable amount of waste, emitting harmful gases that contributes to the increase of the amount of greenhouse gases, is produced that is thrown in the environment. Nevertheless, there is a great potential to slow the increase of both the energy demand and the amount of greenhouse gases down since, to illustrate, the residential sector is the third-largest major energy consumer in the world by consuming 27% of the total, after transportation (33%), and industry (29%) shown in Figure 3.1 below (Laustsen, 2008 as cited in Nejat *et al.*, 2015); therefore, the improvements that can be made for residential sector in terms of sustainability can have a great impact on reducing the energy demand and the emission of the greenhouse gases.

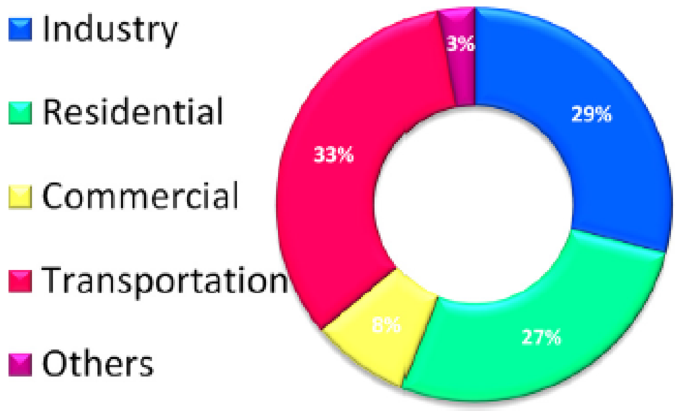

Figure 3.1. Sectorial Shares of Global Energy Consumption (Laustsen, 2008 as cited in Nejat *et al.*, 2015).

3.3. Sustainable Design Rating Systems

In worldwide, some countries have created their rating systems to evaluate the performance of their buildings and these rating systems provide a good opportunity to the users as they define the important terms on which they should focus, guide them, let them save their money, and so on. Accordingly, the buildings meeting the requirements set by the rating systems are certificated in terms of their performance levels. Three of primary rating systems for evaluating the sustainable designs are: Building Research Establishment Environmental Assessment Method (BREEAM), Leadership in Energy and Environmental Design (LEED), and Comprehensive Assessment System for Building Environmental Efficiency (CASBEE). The necessary information about those can be found in the Table 3.1.

Table 3.1. Information about the rating systems (derived from Nguyen and Altan, 2011; Krygiel and Nies, 2008).

	RATING SYSTEMS		
	BREEAM	**LEED**	**CASBEE**
Country	The United Kingdom	The United States	Japan
Year	1990	1998	2001
Available for Public	27 years	19 years	15 years
Update Period	Annually	2 years	Annually
Evaluation Categories	. Management . Health and Well-Being . Energy . Transport . Water . Material and Waste . Land Use and Ecology . Pollution	. Sustainable Sites . Water Efficiency . Energy and Atmosphere . Materials and Resources . Indoor Environmental Quality . Innovation and Design	. Indoor Environment . Quality of Service . Outdoor Environment on Site . Energy . Resources and Materials . Off-Site Environment
Methodology Summary	Score-based system. Building's performance is rated based on overall score	Score-based system. Building's performance is rated based on overall score	Building is rated based on the "BEE Factor"
Presentation Method (from the worst) to the best)	Pass Good Very Good Excellent Outstanding	Certified Silver Gold Platinum	C B- B+ A S

3.4. Sustainability Analysis using BIM

The most important decisions related to sustainable design of a building are generally made in the planning and design stages (Azhar *et al.*, 2010). One of the reasons of this is that models being in a computer environment are way easier to be edited and updated. Hence, the design alternatives can be compared among themselves and the design team can easily find the most feasible alternative in terms of energy efficiency with the help of BIM which is very hard and time-consuming using traditional methods based on 2D.

Stumpf *et al.* (2009) emphasize the advantage of BIM for sustainability as that it supports the making cost-effective decisions and the set of data files gathered in the planning and design is going to remain with the project through the entire stages such as construction and operation. This can later be used for comparing the energy-saving alternatives for retrofit projects.

Wong and Fan (2013) state that waste and inefficiency is the huge problem of construction industry which is a contrast to sustainable development. The reason of it is that in the traditional case, the information and ideas are shared, each party involved makes changes in its part rather than making a revision as a team which most probably is going to result in miscommunication, misunderstandings, waste of time, and waste of effort. This case is illustrated in Figure 3.2. Nevertheless, adopting BIM ensures a good chance of elimination of those stated above with the help of improved communication among the parties involved and eventually is going to reduce the waste and increase the efficiency. An integrated approach to design review is illustrated in Figure 3.3.

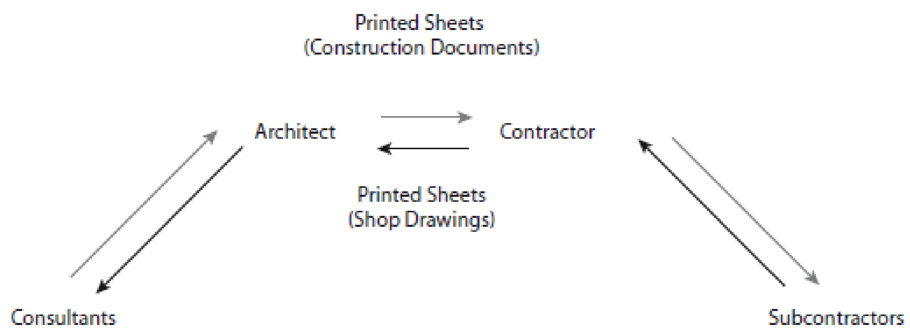

Figure 3.2. The traditional method of design review (Krygiel and Nies, 2008).

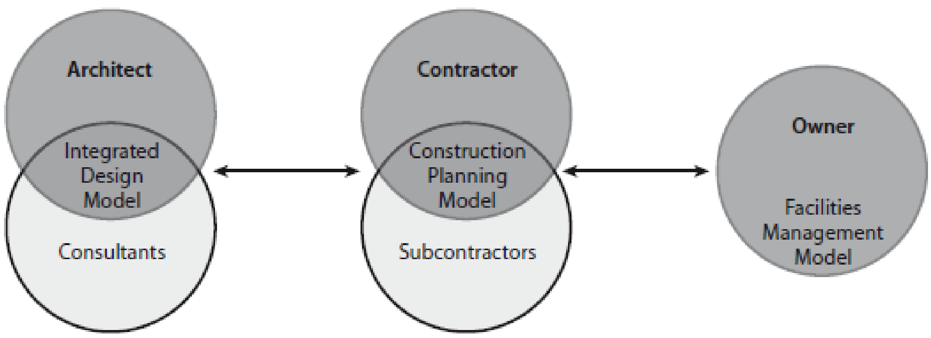

Figure 3.3. An integrated approach to design review (Krygiel and Nies, 2008).

According to Aye *et al.* (2000), the main principle of environmental sustainability is the optimum efficiency in the use of the resources. In terms of sustainable construction, these principles are conservation and reduction of the waste, and these resources are land, energy, materials, and the environment.

The amount of energy that the buildings use is an important factor in terms of sustainability and it is directly related to parameters of the building. Ekici and Aksoy (2011) as cited in Pacheco *et al.* (2012) reveals these parameters determining the energy requirements of the buildings mentioned as shown in Table 3.2 below.

Table 3.2. Physical-Environment and Design Parameters (Ekici and Aksoy, 2011 as cited in Pacheco *et al.*, 2012).

Parameters	
Physical-Environmental	**Design**
. Daily outside temperature (Â°C) . Solar radiation (W/m2) . Wind direction and speed (m/s)	. Shape factor . Transparent surface . Orientation . Thermal-physical properties of buildings materials . Distance between buildings

Feng (2004) states that there is no way to obtain an energy-efficient design of a building using only one approach such as increasing the thermal thickness of thermal insulation. Therefore, one can draw the conclusion that the design parameters stated above should be optimized to obtain a successful design option which can be done with the help of BIM.

Krygiel and Nies (2008) indicate that BIM can greatly help and provide opportunities for the following aspects:

- Building Orientation (determining the best building orientation for minimum energy costs),
- Building Massing (analysing the building form and optimizing the building envelope),
- Daylighting Analysis,
- Energy Modeling (reducing the energy needs),

- Water Harvesting (reducing the water needs),
- Sustainable Materials (reducing the material need and using recycled materials),
- Site and Logistics Management (reducing waste and carbon footprints).

3.5. Energy Modeling

When energy needs of a building are considered, people generally think about turning the lights off when they are going out, unplugging the equipment, and so on. However, energy needs of a building depend on several different issues, are not as easy as people may think, and are way beyond what people may think (Krygiel and Nies, 2008). They basically depend on almost everything that a building can have. Therefore, it is almost impossible to make accurate estimations about the energy needs of a building without having an energy model so that is why it is being used in the industry.

The problems stated as being the reasons for a need of sustainable design can be overcome with the help of an energy model. Energy modeling is defined as the use of computer-based simulations to evaluate the energy consumption, daylighting effects, and so on of a building design (M.E. Group and Hutton Architecture Studio, 2011). An energy model uses the climatic data coupled with building loads; to illustrate, the heating, ventilation, and air-conditioning (HVAC) system, solar heat gain, the number of occupants and their activities, lighting levels are some of the building loads (Krygiel and Nies, 2008).

According to M.E. Group and Hutton Architecture Studio (2011), the benefits of the energy modeling are as follows:

- A robust energy model can evaluate different design options in a way that other tools cannot,
- It is not only for testing feasibility but also making cost-benefit analysis of different design options during any stage of the design process,
- It increases the chance of meeting high performance energy targets,

- Many green building certification systems require energy modeling for compliance,

Moreover, Pan *et al.* (2008) state that energy modeling serves mainly for two purposes:

- Forward modeling: modeling for building and HVAC systems design and associated design optimization,
- Data-driven modeling: modeling energy use of existing buildings for establishing baselines and calculating retrofit savings.

Forward modeling of building energy basically starts from the beginning as choosing the building geometry, location, wall material, thickness, and so on. After the completion of the model, the energy use of the building can be simulated by the forward simulation model to compare different design options and to choose energy-efficient designs in manner of cost effectiveness. There are many energy modeling softwares that are commonly used in the practice which are going to be explained in details in Section 3.7.

An energy model can be obtained in two different ways: by being modeled in a software for sustainable design, if available, or by being modeled in a BIM tool, such as Revit, then being exported from it and finally being imported to the software chosen for the sustainable design. The former option is a straightforward one and the model is directly made in the software if the software provides it and the performance of the building is evaluated in that software; however, the latter option can be applied with the help of a data format. After importing the data format being exported from a BIM tool, the analyses are carried out in the software that is going to be used for the sustainable design. To do so, gbXML, ecoXML, and greenbuildingXML are some of the interoperability standards used for extracting the environmental data (Zanni *et al.*, 2014). According to Moon *et al.* (2011), gbXML basically enables the data exchange among the BIM and software for sustainable design. The use of these public formats mentioned above can enable the exchange of rich and useful information without losing the accuracy (Gupta *et al.*, 2014 as cited in Zanni *et al.*, 2014). Nevertheless, some data may be lost when transferring; therefore, examining the error reports becomes crucial when choosing this way.

3.6. Energy Efficient Design of the Buildings

Recently, considerable amount of efforts have been put on to make improvements on the energy efficiency and to decrease the amount of energy consumption due to the concerns that are mentioned before (Pacheco *et al.*, 2012). To achieve these goals, it is, again, clearly seen that the early design, or conceptual design, is the stage providing both the best time and the best conditions to benefit from the sustainable strategies. Considering this fact, lots of factors can be easily evaluated at this stage, and provide so much benefits in terms of energy performance of the buildings. There are basically two ways available to obtain energy efficient design of the buildings: (i) passive design strategies and (ii) active design strategies.

To begin with the passive design strategies, four key building envelope issues include water, air, vapour and thermal; moreover, the advantages among the passive building systems are: (i) requiring one time cost, (ii) fixed and known costs, and (iii) typically requiring no maintenance (Blumenfeld and Thumm, 2014). Shape of the building is one of the factors that can be listed under the passive design strategies. According to Pacheco *et al.* (2012) state that compactness index, shape factor, and climate are some of the factors related to the shape and determines the amount of both the heating and the cooling requirements of the buildings. Firstly, the compactness index is the ratio of the volume of the building to the total surface area of the building. A building having a high compactness index has a less amount of outer surface and a high volume; therefore, this results in a less amount of heat loss or gain due to having a less amount of surface for heat transfer. Secondly, the shape factor is the ratio of the length of the building to the depth of it. It is not only related to the shape of the building, but also related to the orientation of the building as it determines the surface faÃ§ades that are placed towards to the north, the south, the east, and the west. According to Aksoy and Inalli (2006) as cited in Pacheco *et al.* (2012), when the shape and the orientation is combined, it is possible and likely to reach up to 36% of energy savings. Thirdly, these two factors stated above are decided considering the climate. To illustrate, in very cold climates, the buildings should have lesser amount of outer surfaces as there is a considerable amount of heat losses caused by them. There is also a heat gain from those surfaces; however, the amount of heat losses are much more crucial as Pacheco *et al.* (2012) imply.

Furthermore, the orientation is another crucial factor of passive design strategies that determines the energy consumption of the buildings. In addition to, it is the parameter that has been studied the most (Morrissey et al., 2011 as cited in Pacheco et al., 2012). Some of the advantages that can be taken from the orientation is listed as follows by Pacheco *et al.* (2012).

- It is a low-cost measure that is applicable at the very first stages,
- It reduces the energy demand,
- It reduces the use of more sophisticated passive systems,
- It increases the quantity of daylight.

It is agreed in literature that the southern orientation is the optimal for heat gain in the winter and to control solar radiation in the summer. Mingfang (2002) as stated in Pacheco *et al.* (2012) implies that the longest wall directed to the south as a general rule. Nevertheless, rather than depending on a single factor, orientation with the other parameters should be investigated to get the optimal solution.

Benefitting from the daylighting is another factor of the passive design strategies. As long as available, all of the windows should be able to see the light as it is free and healthy. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Handbook - Fundamentals (SI) (2009) states that daylighting should be considered when the lighting system is designed since with the advantage of daylighting, the need of using bulbs during the whole day except the night can be reduced which results in a decrease in the cost of the electricity, and prevents the use of fossil fuels. To be able to benefit from the daylight, there are some techniques to use such as placing the windows to make them see the sunlight, provide roof apertures and skylights to lighten interiors, choosing suitable glazing transmitting the sufficient light.

Another factor of the passive design strategies is ventilation. The Chartered Institution of Building Services Engineers (CIBSE) Guide A: Environmental Design (2006) defines ventilation as “the process by which fresh air is provided to occupants and by which concentrations of potentially harmful pollutants are diluted and removed from a space”. Ventilation is an important factor for interior environment to satisfy the comfort of the occupants since there are some indoor air quality standard to be guaranteed. There are two types of ventilation techniques that are frequently used: natural ventilation, and mechanical ventilation. CIBSE Guide A: Environmental Design (2006) makes definition of natural ventilation as its being “driven by the climatic forces of wind (wind effect) and temperature (stack effect)”, so its highly variable. However, as a positive fact, it is free and healthy. As an advantage of passive cooling, it can be especially benefited from when the outside temperature is lower than the inside temperature. On the other hand, mechanical ventilation is applied by means of driving fans and a network of ducts, according to CIBSE Guide A: Environmental Design (2006). Moreover, it is fuelled by electricity which obviously results in paying extra for electricity cost. However, contrary to natural ventilation which is highly variable due to its being depend on outside weather conditions, it can be used whenever it is required. Lastly, as a mixed mode ventilation, a combination of natural ventilation and mechanical ventilation can be used.

Building envelope, the surfaces that separate the inside environment from outside environment, is also a crucial factor at this to determine the energy demand of the buildings and consists of the foundation, roof, walls, doors, and windows. The common factor between all of them is that they all contribute to the heat transfer occurring through these. The amount of this heat transfer is directly related to the thermal transmittance (U-value) of the materials placed on the envelope and their respective areas. CIBSE Guide A: Environmental Design (2006) states that the thermal transmittance of the building envelope is the main factor determining the steady-state heat losses/gains; therefore, the capacity of the heating and cooling system should be enough to provide desired inside conditions under design external conditions. Therefore, determining the required thermal transmittance is important to be able to control the heat transfer occurring through the envelope and to satisfy the comfort of the occupants inside. To be able to determine the thermal transmittance, there are some limitations values stated in the guidelines which are advised not to be exceeded. These limitations are going to be mentioned later on.

Besides the passive design strategies, there is another strategy to make the buildings more efficient in terms of energy performance: active design strategies. According to Blumenfeld and Thumm (2014), active building systems are principally mechanical and deal with HVAC. Hence, efficiencies of the equipment of the HVAC system have significant effects of the energy needs. In details, efficiencies of lighting, heating, ventilation, cooling, electricity, water, and the other equipment are crucial. Moreover, they include some sophisticated controls. Advantages of active systems are summarized by Blumenfeld and Thumm (2014) of which some of them are as follows: (i) high performance when properly operated and maintained, (ii) infinitely customizable down, and (iii) maintenance alerts via alarm. On the other hand, the disadvantages are also stated by the authors as follows: (i) high first cost, (ii) high maintenance costs, and (iii) higher failure rates.

Lastly, taking advantage of renewable energy is always beneficial for the buildings. Besides their investment costs, the benefits appear as time goes on. In this perspective, Krygiel and Nies (2008) define seven recognized renewable energy sources as solar, wind, biomass, hydrogen, geothermal, ocean, and hydropower. Nevertheless, the location of the site is the complete determiner in this aspect as the availability of the sources are greatly depends on the location of the site. Therefore, at the early design stage, all of these factors can be evaluated in a computer environment using energy modeling softwares to be able to see all the benefits that could get using it, and if it is advantageous, renewable energy sources could be used and fossil fuel consumption could be reduced. Table 3.3. below reveals the techniques in general.

Table 3.3. Compliation of Techniques

PASSIVE TECHNIQUES	**ACTIVE TECHNIQUES**
Orientation (Natural ventilation, natural light)	Improving the efficiencies of mechanical equipment
Shape (Compactness Index, Shape Factor)	Renewables if possible (Solar, wind, and so on.)
Leakage	
Insulation (Envelope)	

3.7. Software Packages for Sustainable Design

There are several software packages available to make a BIM-based sustainability analysis to test the building performance. Some of the most popular softwares being used in practice are Integrated Environmental Solutions (IES) Virtual Environment (VE), Ecotect, and Green Building Studio. Each of these tools have their relative pros and cons; therefore, the selection of the software is crucial. The pros and cons of all these softwares are stated by Azhar *et al.* (2009) with the courtesy of Holder Construction Company, Atlanta are shown in Table 3.4.

Table 3.4. The pros and cons of the softwares by Azhar *et al.* (2009) with the courtesy of Holder Construction Company, Atlanta, GA.

	PROS	**CONS**
IES VE	. Direct Revit plug-in . User interface mimics Revit . Major analysis in a single click . Relatively short analysis run times . Lifecycle assessment and cost	. Results saved seperately from main project file . Limited model viewing capabilities . Model preperation requires manual gbXML checking with limited error report
Ecotect	. Model viewing capabilities . Analysis results are stored in a single file . Resultant graphics are easily understood	. User interface is difficiult to understand . Analysis stesps, or precedures, are unclear . There is no gbXML error check . Analysis run times are very long
Green Building Studio	. Automated online process with step-by-step procedure . Very little preparation work required . Automated gbXML check	. Trouble with larger files . Unable to specify analysis type(s) . Limited analysis types . Requires internet connection

As a result, the software that is going to be used in this research is determined as IES VE after evaluating all the pros and the cons mentioned in the literature, and also, Azhar *et al.* (2009) emphasize in their study that the IES VE appears to be both the versatile and the powerful in terms of analysis capabilities.

IES VE software is one of the most popular tools used for the energy performance of the buildings. Krygiel and Nies (2008) define IES VE as a robust energy analysis tool offering a high degree of accuracy and interoperability with a BIM model.

Crawley *et al.* (2008) list the modules included in the software as follows:

- ModelIT -geometry creation and editing,
- ApacheCalc -loads analysis,
- ApacheSim -thermal,
- MacroFlo -natural ventilation,
- Apache HVAC -component-based HVAC,
- SunCast -shading visualization and analysis,
- MicroFlo-3D -3D computational fluid dynamics,
- FlucsPro/Radiance -lighting design,
- DEFT -model optimization,
- LifeCycle -life-cycle energy and cost analysis,
- Simulex -building evacuation.

4. LIFE CYCLE COSTING (LCC)

4.1. Definition and Purposes

LCC of an item or an asset is defined in various ways in literature. Following are some of the definitions made in literature.

The life cycle cost of an asset is defined by Addis and Talbot (2001) as cited in Goh and Sun (2016) as "the present value of the total cost of that asset over its operational life".

White and Ostwald (1976) as cited in Korpi and Ala-Risku (2008) define LCC of an item as "... the sum of all funds expended in support of the item from its conception and fabrication through its operation to the end of its useful life".

The National Institute of Standards and Technology (NIST) Handbook 135, (1995) as cited in Cabeza *et al.* (2014), defines LCC as "the total discounted dollar cost of owning, operating, maintaining, and disposing of a building or a building system" over a period of time.

Woodward (1997) as cited in Korpi and Ala-Risku (2008) emphasizes that the LCC of a product can be much more than the initial purchase or investment costs; however, initial investment costs are usually used as the primary and sometimes the only criteria in making decisions for purchase. Nevertheless, remembering this fact, LCC is a factor that should be focused on.

There are various purposes of LCC stated in literature. Briefly, LCC is used for:

- Optimizing the cost of acquiring, owning and operating physical assets over their useful lives (Woodward, 1997),
- Making regarding construction or improvements to a facility (Cabeza *et al.*, 2014),

- Supplier selection and supplier evaluation (Bhutta and Huq, 2002 as cited in Korpi and Ala-Risku, 2008).

4.2. Elements of LCC

Woodward (1997) states that the LCC tries to identify the entire future costs and reduce them to their present value using the discounting techniques through which economic worth of a project can be assessed, and accordingly identifies the following elements of LCC:

- Initial capital costs,
- Life of an asset,
- The discount rate,
- Operating and maintenance costs,
- Disposal cost,
- Information and feedback,
- Uncertainty and sensitivity analysis.

4.2.1. Initial Capital Costs

Initial capital costs consist of purchase cost (land, buildings, fees, furniture and equipment), acquisition/finance costs (cost effect of alternative sources of funds and gearing), and installation / commissioning / training costs (Woodward, 1997).

4.2.2. Life of an Asset

Life expectancy of an asset are depend on five possible determinants according to Ferry and Flanagan (1991) as cited in Woodward (1997), these are: "functional life (the period over which the need for the asset is anticipated), physical life (the period over which the asset may be expected to last physically, to when replacement or major rehabilitation is physically required), technological life (the period until technical obsolescence dictates replacement due to the development of a technologically superior alternative), economic life (the period until economic obsolescence dictates replacement with a lower cost alternative), and lastly, social and legal life (the period until human desire or legal requirement dictates replacement)".

4.2.3. The Discount Rate

Costs of a project which may occur at different points in a life time of a building cannot be compared directly as the time value of money varies over the time; therefore, there is a need to discount these costs back to their present value using the appropriate equations (Stanford University, 2005). To do that, the discount rate is used and the basic discount equation is given in further sections. According to Urien (1975) as cited in Woodward (1997), using the suitable discount rate is crucial when a LCC analysis is carried out. Using a high discount rate favours the options with low capital cost, short life, and high recurring cost; on the other hand, using a low discount rate favours the options with high capital cost, long life, and low recurring cost (Woodward, 1997). The National Institute of Standards and Technology (NIST) Handbook 135, (1995) as cited in Life Cycle Cost Analysis Handbook (1999) prepared by Mearig *et al.* separates the discount rate into two types: real discount rate and nominal discount rate. Accordingly, real discount rate excludes the rate of inflation and the nominal discount rate includes the rate of inflation. However, it does not mean that real discount rates completely neglect the inflation but it means that they just remove the complexity of accounting for inflation within the present value equation. At the end, using a suitable discount rate is important, and it can even significantly vary from organisation to organisation. Korpi and Ala-Risku (2008) imply that choosing the suitable discount and inflation rate could be a challenge, and it may also have a notable effect on the LCC results which are going to be obtained at the end. Hence, it should be determined carefully rather than trusting on an arbitrary selection.

4.2.4. Operating and Maintenance Costs

The operation costs include the annual costs involved in the operation of a facility, excluding the maintenance and repairing costs; and most of these costs are related to utilities of the building and custodial services (Life Cycle Cost Analysis Handbook, 1999). Furthermore, Woodward (1997) states that the operating costs of an asset would include direct labour, direct materials, direct expenses, indirect labour, indirect materials, and establishment costs.

The maintenance costs are another factor that contributes to the LCC. According to Woodward (1997), these costs include direct labour, materials, fuel power, equipment, and purchased services; moreover, they can be classified into three groups as: regular planned maintenance, unplanned maintenance (responding to faults), and intermittent maintenance (for major life refurbishment). As it can be seen, repairing costs are generally included in the maintenance costs even though maintenance costs are scheduled ones to inspect rather than being an unanticipated expenditures as repairing costs are. Similarly, Life Cycle Cost Analysis Handbook (1999) prepared by Mearig et al. implies that maintenance and repairing costs can be combined for simplicity to track them.

4.2.5. Disposal Cost

Woodward (1997) define disposal cost as "the cost incurred at the end of an asset's working life in disposing of the asset". It includes "the cost of demolition, scrapping or selling the asset, adjusted for any tax allowance or charge upon resale" and such costs should be eliminated from the residual value of the asset at the end of the useful life.

4.2.6. Information and Feedback

Collecting information and getting feedback is beneficial and essential to facilitate monitoring of the performance of the asset and enable a source of intelligence on which to base future decisions (Woodward, 1997).

4.2.7. Uncertainty and Sensitivity Analysis

LCC is carried out based on the assumptions made based on historical data, statistical information, and further assistance. Nevertheless, the uncertainty cannot be completely eliminated no matter how good the assumptions are, and what they are made based on. The five major sources of uncertainty stated by Macedo *et al.* (1978) as cited in Woodward (1997) are: differences between the actual and expected performance, changes in operational assumptions, future technological advances that may yield lower cost alternatives, changes in price levels, and errors in estimating relationships.

Considering all of these, sensitivity analysis, which helps understand how sensitive the factors are to changes in the values (Ravalico *et al.*, 2009), have been much more important to be made so as to determine factors that are the most risk sensitive, and with the help of the softwares, it become much more easier. At the end, some actions and precautions could be taken considering the results obtained from the sensitivity analysis to reduce the uncertainty or to remove it by removing or changing the factor that causes a uncertainty.

4.3. Profit Evaluation Methods

Gluch and Baumann (2004) explain that when the timing of the incurring costs and the benefits does not matter, they can be added without any consideration; nevertheless, when the timing of both is important, it should be reflected. When the profits and outcomes of a project is evaluated, the methods that do not reflect the time effect or the methods that reflects the time effect could be used. Most generally used of these methods are tabulated below in Table 4.1.

Table 4.1. Profit Evaluation Methods.

Methods Reflecting	**Methods that do not Reflect**
Time Value	**Time Value**
. Net Present Value (NPV)	. Return on Equity (ROE)
. Profitability Index (PI)	. Payback Period (PB)
. Internal Rate of Return (IRR)	

4.3.1. Net Present Value (NPV)

The most common technique of making income and outcome payments that may occur at different times in future comparable is to discount those future payments to a NPV (Gluch and Baumann, 2004). To be able to do that, a discount rate which is mentioned before is used. When the NPV is greater than 0, the project can be considered to be feasible. The higher the NPV, the more preferable the project is.

When calculating the NPV, firstly, the future all the cash flows should be discounted. The basic discount equation is shown in the formula below.

$$PV = F_Y/(1 + DISC)^Y \tag{4.1}$$

where PV is the present value (in year 0), F_Y is the value in the future (in year Y), $DISC$ is the discount rate used, Y is the number of years in the future

After that the NPV is basically calculated as:

$$NPV = PV_{ICF} - PV_{OCF} - IC \tag{4.2}$$

where PV_{ICF} is the income cash flows at present, PV_{OCF} is the outcome cash flows at present, IC is the investment cost

4.3.2. Profitability Index (PI)

Profitability Index are calculated by dividing the present value of the net cash inflows to the present value of the net cash outflows over the life of the investment at a given discount rate. PI should be greater than 1.

$$PI = \left[\Sigma ICF/(1+DISC)^{Y} + SV/(1+DISC)^{P}\right] / \left[IC + \Sigma OCF/(1+DISC)^{Y}\right] \quad (4.3)$$

where ICF is the inflow cash at year Y, SV is the salvage value at the end of the economic life of P, OCF is the outflow cash at year Y, $DISC$ is the discount rate, IC is the investment cost.

4.3.3. Internal Rate of Return (IRR)

Internal rate of return is basically the discount rate equalizing the present value of the cash outflows to present value of the cash inflows for the economic life of the investment. Hence, IRR is the discount rate equalizing the NPV to 0. The formula used for calculating the IRR is:

$$\Sigma \left[CF_t/(1+IRR)^{t}\right] = 0 \quad (4.4)$$

where CF is the cash flows, IRR is the internal rate of return, t is the time at future.

In the circumstances having an IRR of the project being greater than the minimum attractive rate of return, the project is acceptable.

4.3.4. Return on Equity (ROE)

Return of Equity is calculated by dividing the total profit to the total investment expenditure in the economic life of the project. As mentioned before, it does not take time into account. Higher the ROE, the more preferable the project is. ROE is calculated with the formula below.

$$ROE = \Sigma PRO / \Sigma EXP \tag{4.5}$$

where ROE is the return on equity, PRO is the profit, EXP is the investment expenditure.

4.3.5. Payback Period (PB)

Payback period, another method that does not take time into account, basically answers the question of after how many years the invested money get back. It should be noted that, PB does not deal with profit but net cash flows. In this method, the shortest PB is preferable. When calculating it, all the net cash inflows are added until it is equalized to the investment cost. The time they both equalized is the PB.

4.3.6. LCC and Sustainability

Goh and Sun (2016) imply that the number of the researches devoted to the application of LCC approaches as tools, that can enable obtaining some evidence on the considerable operating benefits derived from green designs, has increased due to a great interest in green buildings since 2000.

As mentioned before, nowadays, the buildings are responsible for almost 40% of the energy consumption and around 30% of the greenhouse gas emissions due to the rising population, expanding economy and a quest for improved quality of life. These reasons cause to a growth in energy consumption over all these years which tends to increase further as expected. According to Sharma *et al.* (2011), almost 85% of the total energy use of the buildings during their life cycles is used when occupants use it. This fact reveals that the maximum energy consumption of the buildings occurs at when the building in use (Adalberth *et al.*, 2001 as cited in Sharma *et al.*, 2011). Furthermore, Bogenstatter (2000) implies that operation costs over the lifecycle of a building could be a multiple of the costs that are caused by the initial construction. In addition to, it is stated that almost 80% of the environmental pollution and building operation costs that can accumulate during the lifetime are determined by programming and building specifications in the early design stage.

Considering all of these facts, it can be well understood that the importance of the early design stage for evaluating energy need of any type of building which is eventually going to determine its LCC cannot be ignored and it provides some advantages at the very early stages.

5. RESEARCH METHODOLOGY

In this research, the optimum design alternative among a set for a residential building is going to be chosen in terms of LCC. Firstly, the need of heating energy of the base model is going to be tested by Turkish Standard (TS) 825. Then, the base model and its alternatives are going to be analysed by the software, namely IES VE, for their energy performance. Finally, the optimum design alternative is going to be selected based on LCC. Before, moving on, firstly, the expert team is going to be introduced.

5.1. Expert Team and Opinion

To obtain the experts' opinion, six professionals are interviewed. These professionals consist of different occupation types such as civil engineer, mechanical engineers, and architects. The range of experience level of the experts is between 5 to 33 years. Moreover, the compny age varies from 9 to 19 years. Table 5.1 given below reveals the important features of the expert team.

Table 5.1. The Features of the Expert Team.

ID	**Job**	**Experience (in years)**	**Company Age (in years)**
A	Civil Engineer	17	9
B	Mechanical Engineer	33	19
C	Mechanical Engineer	5	9
D	Architect	5	9
E	Architect	12	9
F	Architect	7	9

The interviews are conducted face-to-face and based on open-ended questions to reflect their individual ideas about the topic. Interview questions can be found in

Appendix A. The questions aim to assess the reasons of the increase in the number of energy efficient buildings, the benefits of using BIM for sustainable design, the opinions about TS 825.

The interviews reveal that all the experts regardless of their positions agree with that the need of green design and increasing the energy performance of the buildings are mostly based on financial benefits such as increasing the brand value of the company and being known by the public. In addition to, it is seen that getting a certification seems to help to increase the sales which is why it can also be seen as a marketing strategy. Furthermore, it is stated that most of the companies who work or seek to work with a foreign partner are intended to hold a certification got previously. The reason is that the foreign investors are more interested in green and sustainable design as they tend to decrease the consumption. Therefore, the companies think that this is a good way to attract foreign investors as they wish to work with a partner who is certified from its previous works. Moving on, decreasing the operational cost is also seen as a reason to aim high energy efficiency in a building. This applies mostly to shopping centers, multi-use buildings, residential buildings, and hospitals. As the operators are tend to decrease the energy consumption as much as they can so they can reduce the costs related to it. Lastly, environmental factors are seen as one of the reasons; however, its importance for the investors is less than the other factors.

After considering all these reasons, an investor may come with an idea of having its building with a high energy performance. The stages at the very beginning are seen by the professionals as the most effective stages to make some decisions as at this stages, it is much easier to collect some points to be certificated than collecting them at the later stages when the final design is obtained. The reason is obviously that the making some modifications at later stages is hard, restricted and most probably caused to considerable and unanticipated costs. Furthermore, the chance of having a high level of certification is highly reduced. Hence, the early design stages are important to create some design alternatives, and it provides a good chance of having a certification at higher levels. Also, architects emphasize especially the importance of early design to take advantage of passive design techniques in which they could have an impact on the energy performance. Early design stages are therefore important to provide advantages for collecting points through the passive design. If this opportunity is not exploited, the points need to be collected by active design which causes to more cost. Even more money is spent on making those modifications for active design, the desired level of certification could not be achieved because of those lost points.

In respect of type of buildings which are desired to be certified, according to interviews, office buildings are seem to have more attraction than the residential buildings by the professionals. The reasons for that are that:

- Foreign investors are interested in certificated office buildings and they pay attention to the type of modifications made on the office building,
- The number of requests made by the owners are higher than the residential buildings as residential buildings can sell either way, even if they have a certification or not.

Moreover, this does not mean that there is no interest in certificated residential buildings. The reasons for those are:

- Increasing the chance of sale,
- Making some difference in residential sector,
- Reducing the operational costs which could attract the buyers to purchase.

When the manual and computer-based calculations for energy simulation are considered, there are some obvious benefits that need to be paid attention. It is stated by the professionals that by using a computer-based tool for energy simulation, the energy performance of the building can be simulated quickly, cost estimations per area can be made easily, energy consumption per area can much accurately be obtained, and there is a quick and responsive conversation made between the partners based on the results obtained. On the other hand, standards are used for manual calculations. These standards are generally only checked for providing some insight, and satisfying the specified conditions stated in it. As they do not make a dynamic simulation, the results are generally not trustable than the computer-based analysis which can make a dynamic simulation. Moving on, computer-based calculations are made to obtain the energy consumption of the building based on a model created by applying some techniques. These simulations are generally made by the mechanical engineers among the interviewees. According to them, the techniques are based on experience obtained at the previous works so the alternatives could be created easily based on these experience. However, when a specific target is desired by the employer, new techniques are also applied to the energy model.

In respect of sustainability, there are also some methods that can be used at the sites. An architect among the interviewees points out that with a proper guidance, source consumption are greatly reduced at the sites leading to lesser waste. Some amount of this lesser waste can even be recycled. This process also helps to collect some points for being certificated as the amount of waste and the amount of waste being recycled are also a part of the certification. In this respect, it is obviously seen that this is a good way to collect points as the amount of effort spent is less than the other processes, and a very low cost is required. Furthermore, some of the materials can be disassembled from a building which is going to be demolished. This helps to reduce waste, re-use, reduce source consumption, have lesser amount of emission, and reduce cost.

Lastly, when LCC is considered in respect of energy performance, an accurate energy model can provide almost exact results compared to the real results. This can contribute a lot as it provides accurate and quick information about what is going to observed at the real life. An important factor stated by the professionals is the data input. As the trustworthiness of the model relies on the data input, a simple mistake made when inputting the data could deviate the cost greatly. To illustrate, when the wrong thickness of an insulation material is introduced to the tool, it is eventually multiplied with the area of it. When the surface area of the building is considered, it can devastate the cost greatly. A professional states that the situation could even be like either losing money when there is actually going to be a profit in real case or profit when there is actually going to be a loss in real case.

5.2. Energy Analysis based on TS 825

This section briefly explains how TS 825 calculates the need of heating energy of the buildings in Turkey.

5.2.1. General information about TS 825

TS 825 is prepared by Turkish Standard Institute (TSI) (1998) to limit the energy need for heating of the buildings in Turkey which results in energy saving and finding the standard calculation method and values to determine the energy need of them. It can also be used for:

- To determine the best design option providing an optimum energy performance for a new building,
- To determine the net heating energy consumption of the existing buildings,
- To determine the amount of energy saving before retrofitting of an existing building.

Throughout the Section 5.2., the necessary values should be taken from the charts, graphs, and tables that are given in TS 825.

5.2.2. Calculation of Thermal Resistance

The methodology begins with calculation of the thermal resistance value of the building components on the envelope. The thermal resistance is calculated as follows.

For the building components being single-layer:

$$R = d/\lambda_h \tag{5.1}$$

For the building components having multiple layers:

$$R = d_1/\lambda_{h1} + d_2/\lambda_{h2} + \ \ldots \ + d_n/\lambda_{hn} \tag{5.2}$$

where R is the thermal resistance (m^2K/W), d is the thickness of the building component (m), λ_h is the thermal conductivity (W/mK).

5.2.3. Calculation of Heat Transmission Coefficient

The calculation of heat transmission coefficient of the building components being whether single-layer or having multiple components are made as follows:

$$U = 1/\left(R_i + R + R_e\right) \tag{5.3}$$

where U is heat transmission coefficient (W/m^2K), R_i and R_e represents the inside air film thermal resistance and outside air film thermal resistance, respectively (m^2K/W).

5.2.4. Calculation of Annual Heating Energy Need

The calculation of annual heating energy need of the buildings are made as follows:

$$Q_{year} = \Sigma Q_{month} \tag{5.4}$$

$$Q_{month} = \ [H * \ (\theta_i - -\theta_e) \ - -\eta_{month} * \ (\Phi_{i,month} + \Phi_{s,month})] \ * t \tag{5.5}$$

where Q_{year} is the annual heating energy need (Joule), Q_{month} is the monthly heating energy need (Joule), H is the specific heat loss of the building (W/K), θ_i is the monthly average inside temperature (^{o}C), θ_e is the monthly average outside temperature (^{o}C), η_{month} is the monthly average usage factor for gains (no units), $\Phi_{i,month}$ is the monthly average internal gains (W), $\Phi_{s,month}$ is the monthly average solar energy gain (W), t is the time (1 month = 86400*30 seconds) (seconds).

5.2.5. Calculation of Specific Heat Loss

Specific heat loss of the building is calculated as follows:

$$H = H_T + H_V \tag{5.6}$$

where H is the specific heat loss of the building (W/K), H_T is the heat loss due to conduction and convection (W/K), H_V is the heat loss due to ventilation (W/K).

5.2.5.1. Heat Loss due to Conduction and Convection. Heat loss due to conduction and convection is calculated as follows:

$$H_T = \Sigma AU + IU_I \tag{5.7}$$

$$\begin{aligned} \Sigma AU = {} & U_D A_D + U_P A_P + U_k A_k + 0.8 U_T A_T \\ & + 0.5 U_t A_t + U_d A_d + 0.5 U_{ds} A_{ds} \end{aligned} \tag{5.8}$$

where U_D is the heat transmission coefficient of the external wall (W/m^{2}K), U_P is the heat transmission coefficient of the window (W/m^{2}K), U_k is the heat transmission coefficient of the external door (W/m^{2}K), U_T is the heat transmission coefficient of the ceiling (W/m^{2}K), U_t is the heat transmission coefficient of the floor (W/m^{2}K), U_d is the heat transmission coefficient of the floor exposed to outside environment (W/m^{2}K), U_{ds} is the heat transmission coefficient of the building components exposed to inside rooms having lower temperature (W/m^{2}K), A_D is the area of the external wall (m^2), A_P is the area of the window (m^2), A_k is the area of the external door (m^2), A_T is the area of the ceiling (m^2), A_t is the area of the floor (m^2), A_d is the area of the floor exposed to outside environment (m^2), A_{ds} is the area of the building components exposed to inside rooms having lower temperature (m^2).

5.2.5.2. Heat Loss due to Ventilation. Heat loss due to ventilation calculated as follows:

$$H_V = \rho * c * V \tag{5.9}$$

For natural ventilation:

$$H_V = \rho * c * V = \rho * c * n_h * V_h = 0.33 * n_h * V_h \tag{5.10}$$

where ρ is the density of the air (kg/m^3), c is the specific heat of the air (J/kgK), V' is the volumetric discharge of the air exchange (m^3/h), n_h is the ratio of the air change (h^{-1}), V_h is the ventilated volume (V_h = 0.8 * V_{gross}) (m^3). In the Equation 5.10 formulated above, p * c is taken as 0.33 and nh is taken as 0.8 for natural ventilation as suggested by TS 825. For the mechanical ventilation, the necessary formulations can be found in TS 825.

5.2.6. Monthly Average Internal Gains ($\Phi_{i,month}$)

Internal gains consists of:

- Metabolic heat gains due to occupants,
- Heat gains due to how water systems,
- Heat gains due to cooking,
- Heat gains due to lighting,
- Heat gains due to electrical equipment in the buildings.

If the average values are used, average values except lighting can be taken as constant. In TS 825, lighting also is taken as constant and the internal gain values are given as follows:

- 5 W/m^2 for residential buildings, schools, and office buildings being normally equipped,

- 10 W/m^2 for buildings having excessive amount of cooking inside (such as cooking factories), buildings having electrical equipment being used heavily (lighting is provided only by electricity), and buildings having equipment emitting heat to the environment.

For residential buildings, schools, and office buildings being normally equipped:

$$\Phi_{i,month} 5 * A_n \, (W) \tag{5.11}$$

For buildings having high amount of internal gains:

$$\Phi_{i,month} 10 * A_n \, (W) \tag{5.12}$$

where A_n is the area of the building used ($A_n = 0.32$ * V_{gross}) (m^2), V_{gross} is the heated gross volume of the building (m^3).

5.2.7. Monthly Average Solar Energy Gains ($\Phi_{s,month}$)

This factor includes the calculation of the direct sun radiation provided by the windows. The gains that can be gained through passive energy systems is neglected. Monthly average solar energy is calculated as follows:

$$\Phi_{s,month} = \Sigma r_{i,month} * g_{i,month} * I_{i,month} * A_i \tag{5.13}$$

where $r_{i,month}$ is monthly average shading factor of the transparent surfaces on the direction of i, $g_{i,month}$ is the solar energy permeation factor of the transparent components on the direction of i, $I_{i,month}$ is the intensity of the monthly average solar radiation acts on the perpendicular surfaces on the direction of i (W/m^2), A_i is the total window area on the direction of I (m^2).

5.2.8. Usage Factor for Gains (η)

Monthly average usage factor for gains is calculated as follows:

$$\eta_{month} = 1 - -e^{(-1/KKOmonth)} \tag{5.14}$$

where KKO_{month} is the ratio of the gain to loss and calculated as follows:

$$KKO_{month} = \left(\Phi_{i,month} + \Phi_{s,month}\right)/H * \left(\theta_{i,month} - \theta_{e,month}\right) \tag{5.15}$$

where $\Phi_{i,month}$ is the monthly average inside temperature (^{o}C), $\Phi_{s,month}$ is the monthly average outside temperature (^{o}C), $\theta_{i,month}$ is the monthly internal gains (W), $\theta_{e,month}$ is the monthly average solar energy gain (W).

5.3. Energy Analysis of the Base Model based on TS 825

The selected building for the study is a 5-storey building in Istanbul, Turkey. The model of the building is shown in Figure 5.1 given below. The storey plans of it for ground floor, and the rest of the floors which are the same are as shown in Figure 5.2 and Figure 5.3, respectively. The general information required for the calculation of the heating need of the building is given below in Table 5.2.

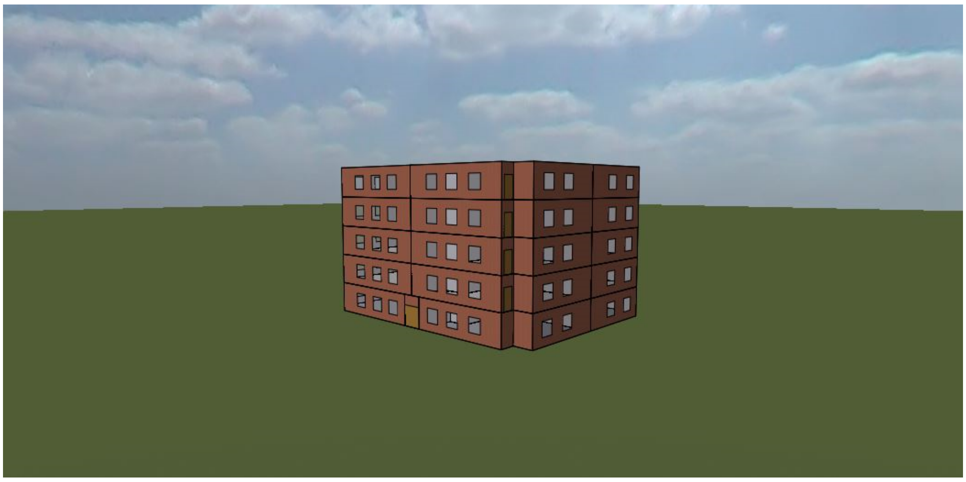

Figure 5.1. The view of the Building.

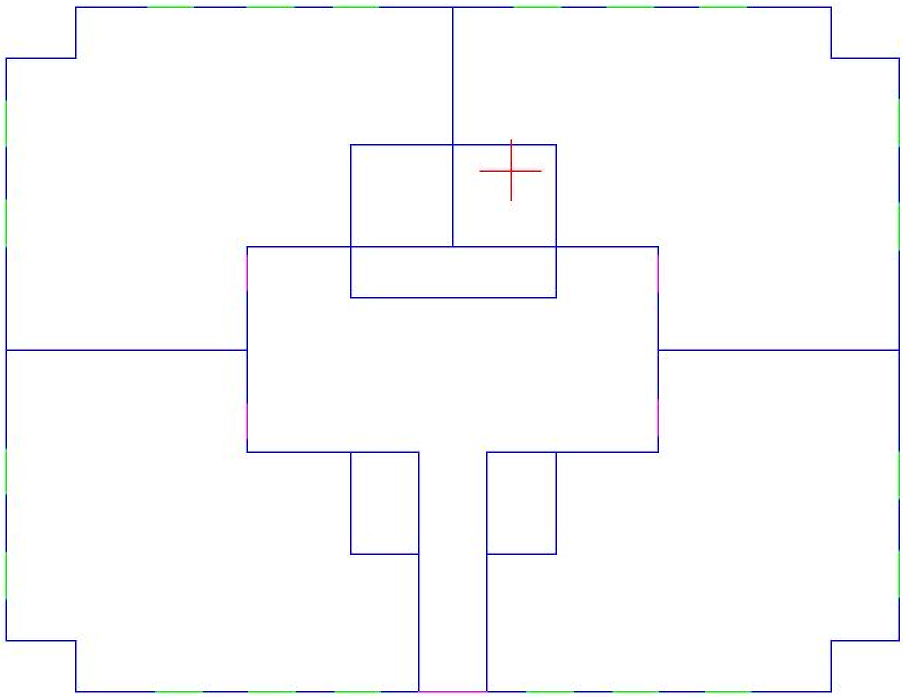

Figure 5.2. Ground Floor Plan of the Building in IES VE.

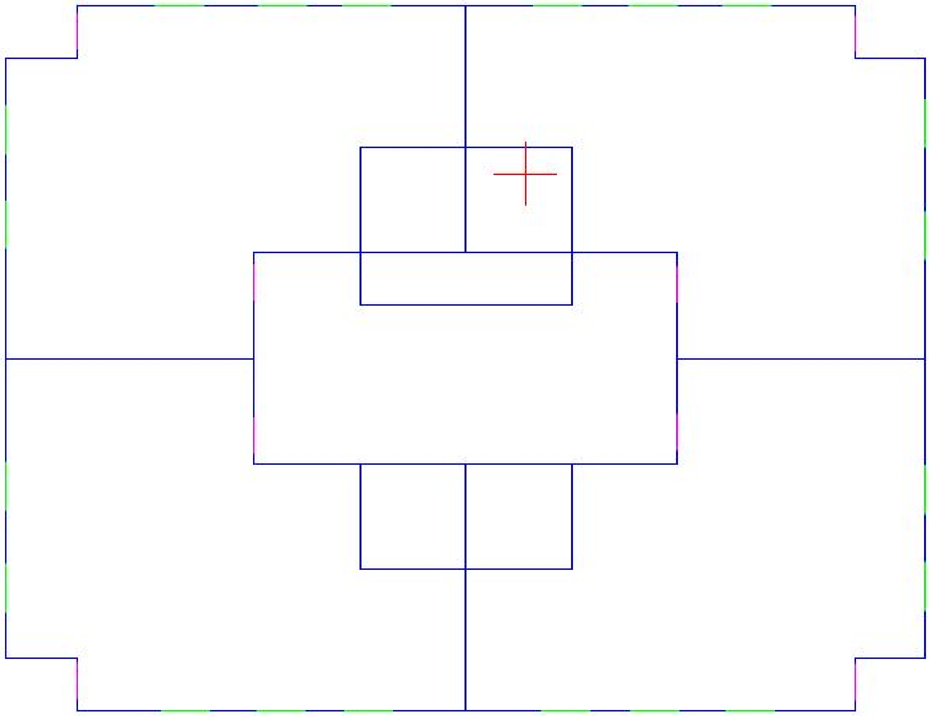

Figure 5.3. The 1^{st}, 2^{nd}, 3^{rd} and 4^{th} Floor Plans of the Building in IES VE.

Table 5.2. The General Information of Building.

Location	Istanbul, Turkey
Number of Storeys	5
Total External Area (m^2)	1380
External Openin Area (m^2)	218.25
Total Floor Area (m^2)	2540
Volume Gross (m^3)	7620

Parameters of the surfaces are given below in Table 5.3, Table 5.4, Table 5.5, Table 5.6, Table 5.7, Table 5.8, and Table 5.9. It should be noted that the base building has no insulation at any of its components except glazing having argon between its panes which helps reducing the U-value of it compared to a single pane glazing.

Table 5.3. Parameters of External Wall.

External Wall				
Surface losing heat	Thickness (m)	Heat Conductance (W/mK)	Resistance (m^2K/w)	U-value (W/m^2K)
Inside Air Film			0.13	1.443
Plaster	0.02	1		
Brick	0.24	0.5		
Plaster	0.008	0.35		
Outside Air Film			0.04	

Table 5.4. Parameters of External Glazing.

Surface losing heat	Thickness (m)	Heat Conductance (W/mK)	Gas filled with	Resistance (m^2K/w)	U-value incl. Frame (W/m^2K)
Inside Air Film				0.13	2.407
Inner Pane	0.006	1.06	-		
Cavity	0.0051	-	Argon		
Outer Pane	0.006	1.06	-		
Outside Air Film				0.04	

Table 5.5. Parameters of Roof.

Roof				
Surface losing heat	Thickness (m)	Heat Conductance (W/mK)	Resistance (m^2K/w)	U-value (W/m^2K)
Inside Air Film			0.1	4.808
Plaster	0.02	1		
Concrete	0.12	2.5		
Outside Air Film			0.04	

Table 5.6. Parameters of Ground Floor.

Ground Floor				
Surface losing heat	Thickness (m)	Heat Conductance (W/mK)	Resistance (m^2K/w)	U-value (W/m^2K)
Inside Air Film			0.17	2.971
Screed	0.05	1.4		
Lighweight Conc.	0.1	1.1		
Outside Air Film			0.04	

Table 5.7. Parameters of Internal Partition.

Internal Partition				
Surface losing heat	Thickness (m)	Heat Conductance (W/mK)	Resistance (m^2K/w)	U-value (W/m^2K)
Inside Air Film			0.13	1.204
Plaster	0.02	1		
Brick	0.19	0.36		
Plaster	0.008	0.35		
Outside Air Film			0.13	

Table 5.8. Parameters of Ceiling.

Ceiling				
Surface losing heat	Thickness (m)	Heat Conductance (W/mK)	Resistance (m^2K/w)	U-value (W/m^2K)
Inside Air Film			0.1	3.170
Plaster	0.02	1		
Concrete	0.15	2.5		
Screed	0.05	1.4		
Outside Air Film			0.1	

Table 5.9. Parameters of External Door.

External Door				
Surface losing heat	Thickness (m)	Heat Conductance (W/mK)	Resistance (m^2K/w)	U-value (W/m^2K)
Inside Air Film			0.13	2.500
Plywood	0.03	0.13		
Outside Air Film			0.04	

Accordingly, the calculation for the total heat losses, including both heat losses due to building envelope, and heat losses due to natural ventilation, and internal gains are made and given in Table 5.10. The heat loss coefficient for roof is generally taken as 0.8; nevertheless, the roof tested here is considered as being in a direct interaction with outside weather. Therefore, TS 825 suggests that in these circumstances, the heat loss coefficient is taken as 1.

Table 5.10. Calculation of the Total Heat Losses and Internal Gain of the Building.

Type	Area (m^2)	U value (W/m^2K)	Heat Loss Coefficient (-)	Heat Loss (W/K)	Ventilation Loss (W/K)	Total Heat Loss (W/K)	Internal Gain (W)
Windows on North	54.675	2.407	1	131.6	1609.34	7063.47	12192
Windows on South	54.675	2.407	1	131.6			
Windows on East	36.45	2.407	1	87.74			
Windows on West	36.45	2.407	1	87.74			
External Wall	1197.75	1.443	1	1728.35			
Floor	508	2.971	0.5	754.63			
Roof	508	4.808	1	2442.46			
Outside Door	36	2.5	1	90			

Temperature values used in the calculation of the heating need for a residential building constructed in a region belonging 2nd degree-day is as follows and given in Table 5.11. as suggested by TS 825.

Table 5.11. Inside and Outside Temperature Values of the Building.

Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Inside Temperature (Â°C)	19	19	19	19	19	19	19	19	19	19	19	19
Outside Temperature (Â°C)	2.9	4.4	7.3	12.8	18	22.5	24.9	24.3	19.9	14.1	8.5	3.8

The calculation of monthly average solar gain is made and given in Table 5.12. At the end, total solar gain (TSG) for each direction and total yearly total solar gain (YTSG) are obtained.

In table above; TSG represents the total solar gain for each direction, and as a total. Moreover, YTSG represents the yearly total solar gain.

Finally, the calculation based on TS 825 for heating energy need in a year is made and given in Table 5.13.

Table 5.12. Calculation of Monthly Average Solar Gain of Building.

	Window Area North (m^2) 54.675	Window Area South (m^2) 54.675	Window Area East (m^2) 36.45	Window Area West (m^2) 36.45					
Months	**I North (W/m^2)**	**I South (W/m^2)**	**I east (W/m^2)**	**I West (W/m^2)**	**North TSG (W)**	**South TSG (W)**	**East TSG (W)**	**West TSG (W)**	**Monthly TSG (W)**
January	26	72	43	43	511.8	1417.2	564.2	564.2	3057.4
February	37	84	57	57	728.3	1653.4	748	748	3877.6
March	52	87	77	77	1023.5	1712.4	1010.4	1010.4	4756.7
April	66	90	90	90	1299.1	1771.5	1181	1181	5432.5
May	79	92	114	114	1555	1810.8	1495.9	1495.9	6357.6
June	83	95	122	122	1633.7	1869.9	1600.9	1600.9	6705.3
July	81	93	118	118	1594.3	1830.5	1548.4	1548.4	6521.6
August	73	93	106	106	1436.9	1830.5	1390.9	1390.9	6049.2
September	57	89	81	81	1121.9	1751.8	1062.9	1062.9	4999.5
October	40	82	59	59	787.3	1614	774.2	774.2	3949.7
November	27	67	41	41	531.4	1318.8	538	538	2926.2
December	22	64	37	37	433	1259.7	485.5	485.5	2663.8
							YTSG (W)		57297.2

Table 5.13. The results based on TS 825.

	Heat Loss			**Heat Gains**					
Months	**Specific Heat Loss H=HT +HV (W/K)**	**Temperature Difference θ_i-θ_e (C)**	**Heat Losses H(θ_i-θ_e) (W)**	**Internal Heat Gain Φ (W)**	**Solar Energy Gain Φ_s Φ+Φ_s (W)**	**Total Φ_T (W)**	**KKO γ (-)**	**Usage** Gain Factor **n-month (-)**	**Need of** Heating Energy **n-month (kJ)**
JAN		16.1	113721.9		3057.4	15249.4	0.134	0.999	255263421
FEB		14.6	103126.7		3877.6	16069.6	0.156	0.998	225720075
MAR		11.7	82642.6		4756.7	16948.7	0.205	0.992	170613622
APR		6.2	43793.5		5432.5	17624.5	0.402	0.917	71637349
MAY		1	7063.5		6357.6	18549.6	2.626	0.317	3082484
JUN		-3.5	0		6705.3	18897.3	0	0	0
JUL		-5.9	0		6521.6	18713.6	0	0	0
AUG		-5.3	0		6049.2	18241.2	0	0	0
SEP	7.063.471	-0.9	0	12192	4999.5	17191.5	0	0	0
OCT		4.9	34611		3949.7	16141.7	0.466	0.883	52774381
NOV		10.5	74166.4		2926.2	15118.2	0.204	0.993	153343163
DEC		15.2	107364.8		2663.8	14855.8	0.138	0.999	239811289
						Qyear = Total Qmonth (kJ)			1.172E+09
						Qyear = Total Qmonth (kWh)			325884.3
						Qyear = Total Qmonth (MWh)			325.9

The results obtained from TS 825 reveal that 325.9 MWh/year is going to be required for demanding the heating need of the base model. In details, it is found that January demands the largest portion of total need of heating energy among the all months with a heating energy of 70.96 MWh. It is followed by December and February with demands of 66.67 MWh and 62.75 MWh, respectively. Based on the analysis, it is seen that June, July, August, and September seem to require no heating energy. However, it should be kept in mind that the analysis based on TS 825 is not a dynamic analysis. Therefore, in each year, the real energy demands change but this analysis always gives the same output.

5.4. Inputs for Energy Analysis of the Base Model based on IES VE

5.4.1. Location

The building that is going to be analysed in this section is located in Istanbul, Turkey which is the biggest city in the country in terms of population. According to Turkish Statistical Institute as cited in the website of Istanbul Metropolitan Municipality, the population of the city based on the report made in 2013 is around 14 million. The city is in the coordinates of 41^{o}00'49"N 28^{o}57'18"E. The map of Turkey and Istanbul which is marked as red in the map is given in Figure 5.4.

Figure 5.4. Map of Turkey and Istanbul.

5.4.2. Climate and Weather Data

Istanbul has a transition climate which is a mix of both the climate of the Black Sea region and the climate of Mediterranean region. This transition climate includes typically hot and humid days in summer, and cold and precipitated days in winter. In winter, snowy days also can be observed. According to Turkish State Meteorological Service (MGM) (2017), Table 5.14. given below indicates the statistical data of Istanbul. The data is collected between the years of 1926-2016. Moreover, average minimum and maximum temperatures taken from MGM (2017) are illustrated in Figure 5.5 for a better understanding.

Table 5.14. Weather Characteristics of Istanbul between 1926-2016.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Average Temperature	6	6.1	7.7	12	16.8	21.4	23.8	23.8	20.1	15.7	11.7	8.2
Average Max. Temperature	8.5	9	10.9	15.5	20	24.6	26.6	26.8	23.7	19.2	14.8	10.7
Average Min. Temperature	3.2	3.1	4.2	7.7	12.1	16.5	19.5	20.1	16.8	13	8.9	5.4
Average Hours of Sunshine	3.6	3.4	4.4	6.3	8.5	10.4	11.3	10.4	8.2	5.4	4	2.5
Average Num. of Prec. Day	17.2	15.1	13.7	10.2	8	6.1	4.2	4.9	7.4	11.2	13	17.2
Monthly Total Prec. Average	104	78.2	71.5	46.1	34.2	35.9	32.5	40.1	60.6	87.8	101	123

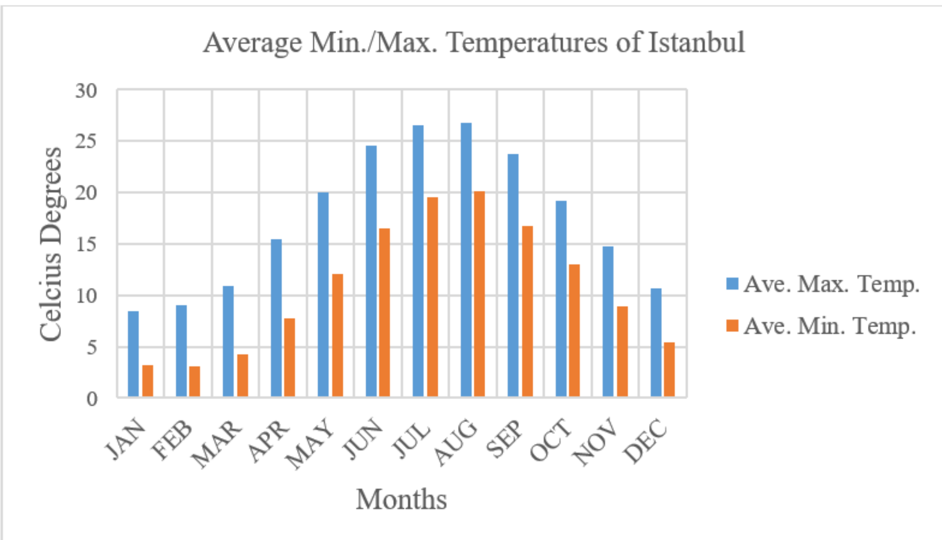

Figure 5.5. Average Minimum and Maximum Temperatures of Istanbul.

The other important parameters are the heating cooling degree-days (HDD) and the cooling degree-days (CDD). These both are measures reflecting the demand of energy need to heat or cool a building. According to MGM (2017), HDD and CDD for Istanbul are given in Table 5.15 and Figure 5.6 illustrates these values.

Table 5.15. HDD and CDD for Istanbul between 2010-2016.

	Year							
Parameter	2010	2011	2012	2013	2014	2015	2016	Average
HDD	1447	2008	1714	1614	1398	1611	1537	1618.4
CDD	308	207	322	236	281	269	327	278.6

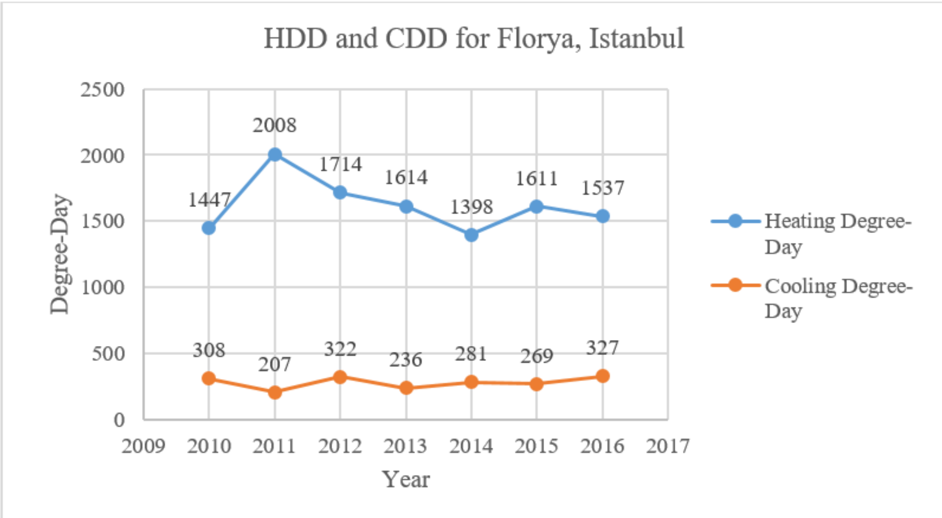

Figure 5.6. HDD and CDD for Istanbul between 2010-2016.

In the software, the source of the design weather is from ASHRAE design weather database v5.0. For the analysis, ASHRAE weather location is selected to be "Istanbul/Ataturk, Turkey". Furthermore, monthly percentile for heating loads design weather is chosen to be as 99.60%, and monthly percentile for cooling loads design weather is chosen to be as 0.40%. Lastly, the simulation weather file in ApacheSim is selected to be as "Istanbul-IWEC.fwt". Dry-bulb and wet-bulb temperatures of "Istanbul-IWEC.fwt" are shown below in Figure 5.7 and Figure 5.8, respectively.

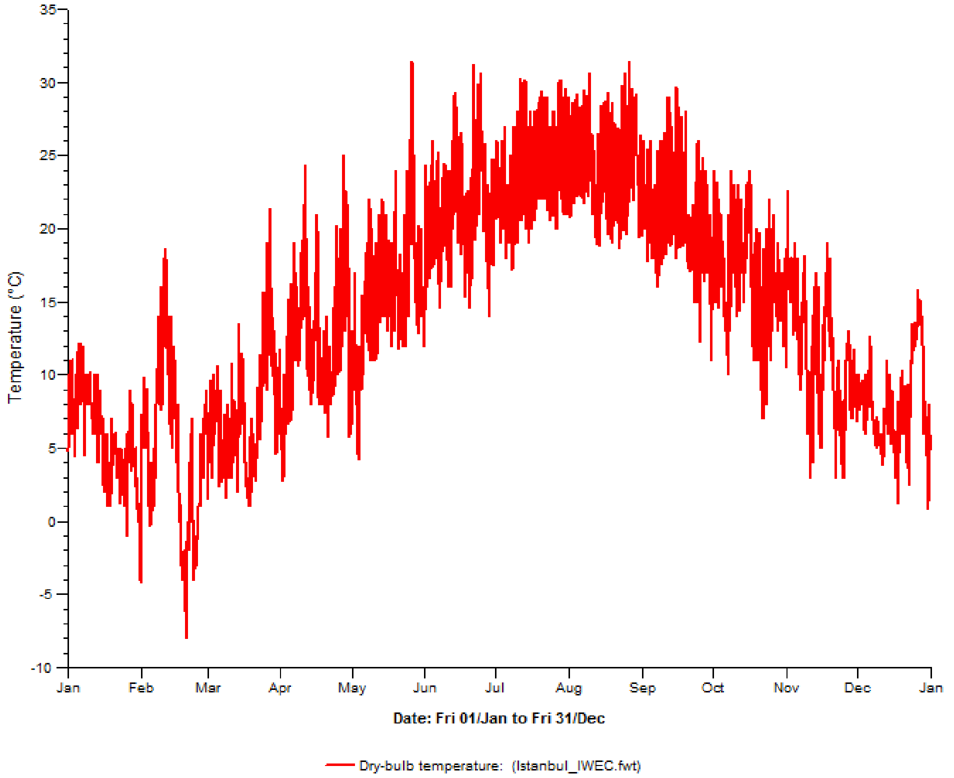

Figure 5.7. Dry-bulb temperature of Istanbul-IWEC.fwt.

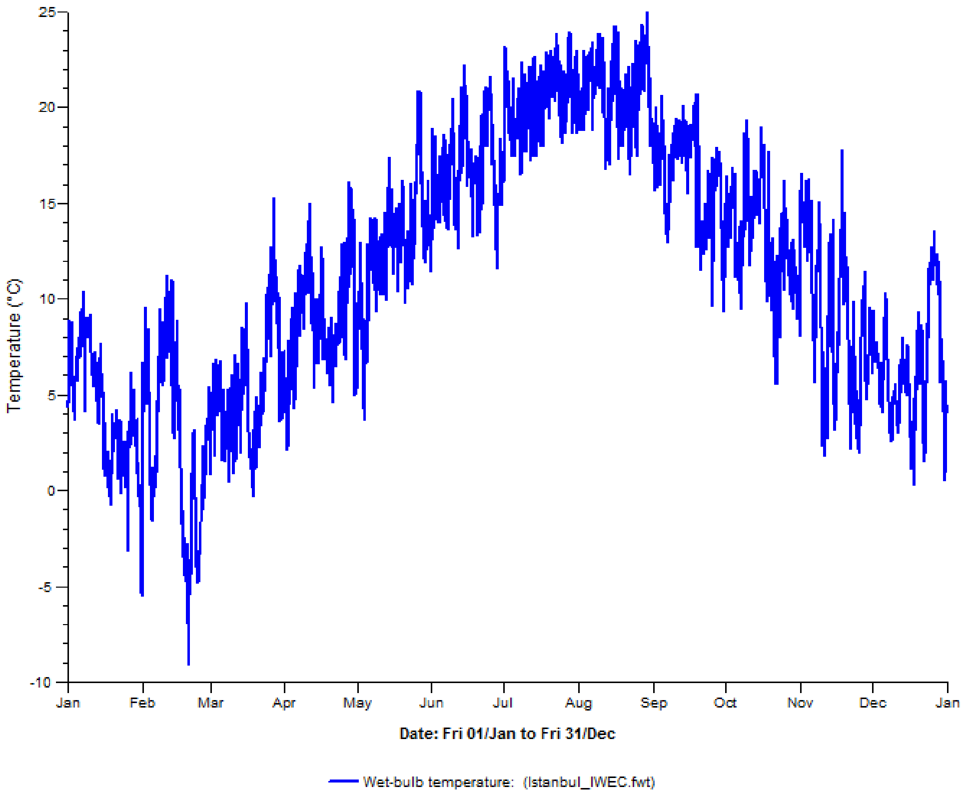

Figure 5.8. Wet-bulb temperature of Istanbul-IWEC.fwt.

5.4.3. Design Parameters

The building is modelled in IES VE. A general view of the building and axonometric view of the building are given below in Figure 5.9 and Figure 5.10.

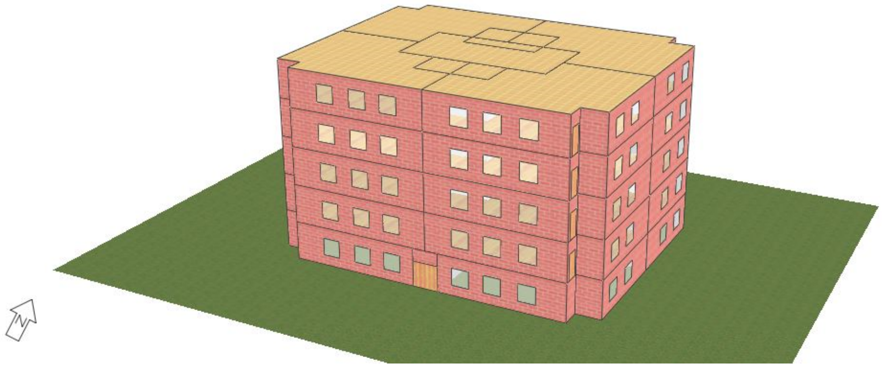

Figure 5.9. View of the building using Model Viewer in IES VE.

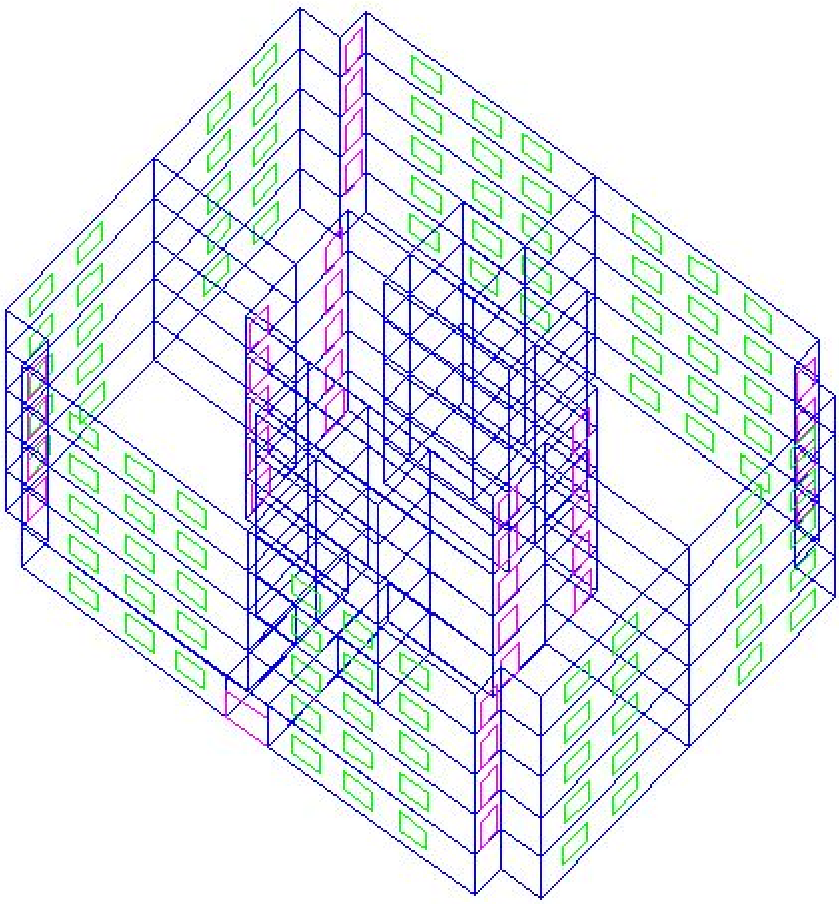

Figure 5.10. Axonometric View of the building in IES VE.

The surfaces losing heat and their parameters required for the analysis of the base model are shown in Table 5.16. below. Performance of the entire parameters are based on European Standard - International Organization for Standardization (EN-ISO) which is chosen in IES VE to calculate the performance of these components. The resistance of the surfaces losing heat is not given for each surface except the inside and outside air films but given as total at the end of a main component. As a base model, it should be noted again that it is decided that there is going to be no insulation at these surfaces, that is why these components are relatively high U-values. The features of the each component are given before. The summary of the U-values of these is given in Table 5.16.

Table 5.16. Summary of U-values of the Components.

Component	**U-values (W/m^2K)**
External Wall	1.443
External Glazing	2.407
Roof	4.808
Ground Floor	2.971
Internal Partition	1.204
Ceiling	3.170
Door	2.500

5.4.4. Heating Characteristics

Heating of the building is set for the residential areas only so there is no heating for the wet areas, such as restrooms, and the spaces occupied by the elevator, stairs, and the corridors. The heating set-point is decided as 21Â°C, provided by natural gas, after consulting to the experts, and heating plant radiant fraction is decided as 0.20 by default. In the base model, heating operation profile is set to be “on continuously”. Besides having no insulation at the outer surface, the base model is going to be inefficient in terms of heating mechanism. To make it clear, this efficiency is stated by annual fuel utilization efficiency (AFUE). AFUE is basically the ratio of annual heat output of the furnace or boiler compared to the total annual fossil fuel energy consumed by a furnace or boiler, and AFUE does not include the heat losses through the pipes, and so on. (U.S. Department of Energy, n.d.). According to Lekov *et al.* (2006), AFUE of nearly all furnaces sold are at 80% or higher. Moreover, the authors also state that the possibilities for higher fuel efficiency has two groups, namely, more efficient condensing furnaces (having 81% AFUE), and condensing furnaces (90-96% AFUE). Therefore, in terms of efficiencies, seasonal efficiency (SE) and seasonal coefficient of performance (SCoP) are both set to 80%. These could be considered to be medium performance efficiency values. Furthermore, ventilation heat recovery return air temperature is decided as 21Â°C by default. Finally, plant (auxiliary energy) operation is also set to be linked to the heating profile.

5.4.5. Cooling Characteristics

Similar to heating, the cooling also works only for the spaces used by the residents to live in except the wet areas. The cooling set-point is determined as 25Â°C based on experts' opinion and it is set to be linked to occupancy profile. Occupancy profile is given below in Figure 5.11 and Figure 5.12 for weekdays and weekend, respectively. All profiles used in the study are based on User's Manual for ANSI/ASHRAE/IESNA Standard 90.1-2007. However, in this manual, the values are given for hotel/motel occupancy. Therefore, some modifications are made on the profiles by consulting to experts. It is stated in the base model that when the room temperature can be reduced by the outside temperature, the advantage of benefiting from natural advantage is going to be taken instead of using the cooling system. The cooling mechanism is decided as air conditioning being fuelled by electricity. In terms of efficiencies, after consulting to the experts, the nominal effective exchange rate (NEER), seasonal effective exchange rate (SEER), and scientific support for environmental emergency response (SSEER) are decided as 4.2 kW/kW, 5.1 kW/kW, and 5.0 kW/kW, respectively. Lastly, heat rejection is set to 10% by default.

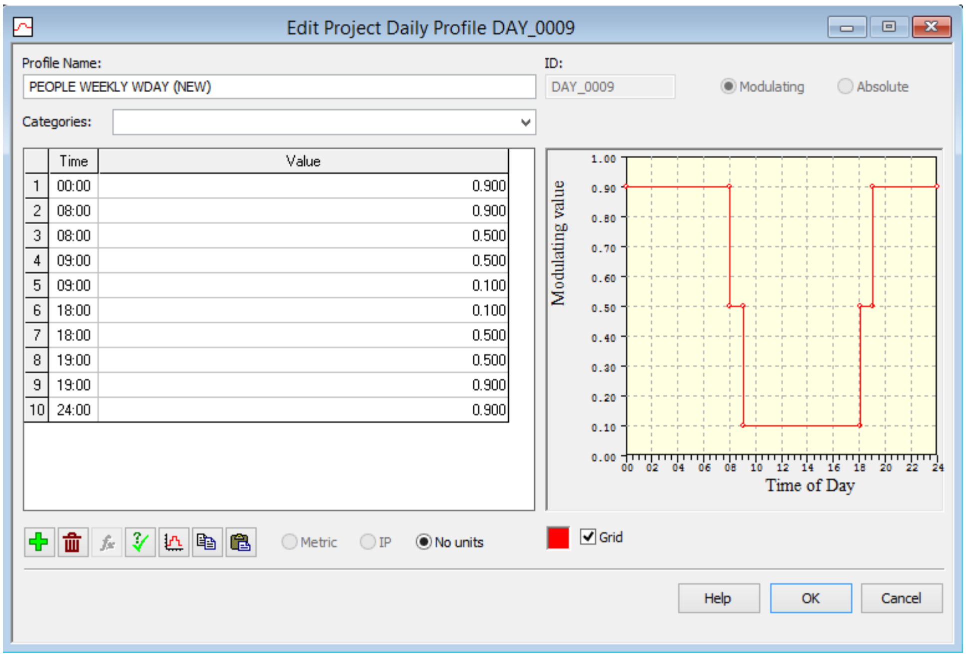

Figure 5.11. Occupancy Weekday Profile.

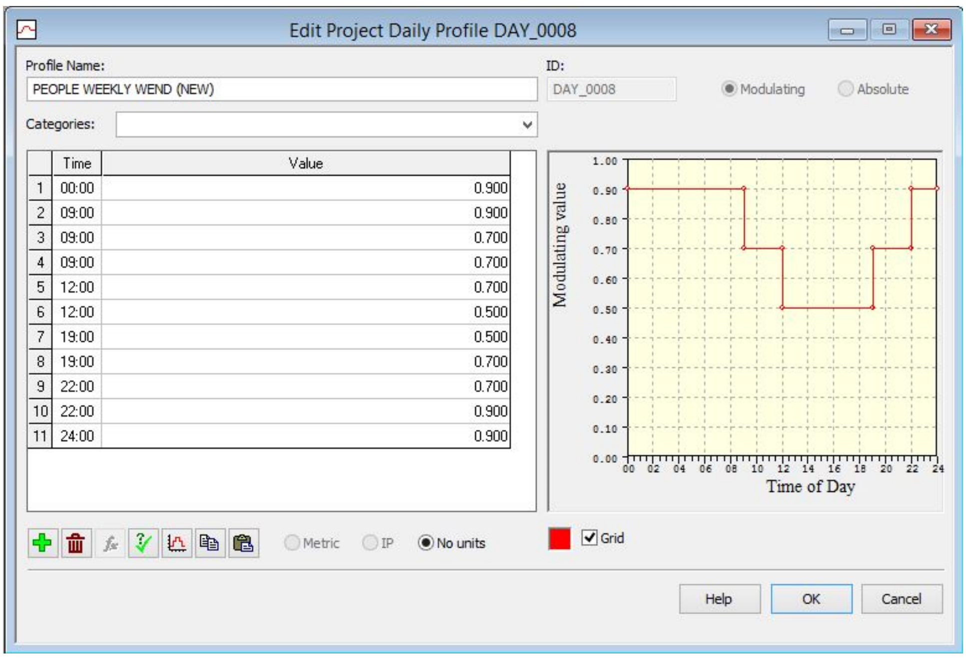

Figure 5.12. Occupancy Weekend Profile.

5.4.6. Domestic Hot Water

Domestic hot water (DHW) is one of the typical needs of the residents which is used for many purposes in a residence. In this model, DHW is also included to study its effects on the boiler needs. DHW is considered to be served by the boiler in the model with having a delivery efficiency of 80%. In terms of set-points, mean cold water inlet temperature is set to 10Â°C, and the hot water supply temperature is set to 60Â°C. According to American Society of Plumbing Engineers (ASPE) (2015), daily average hot water demand and use for multifamily buildings is given as 113.6 litres/person, corresponding to 4.73 litres/hour per person for a medium demand which is valid for families as stated in the source. To be on the safe side, the DHW consumption is chosen to be as 5 litres/hours per person, corresponding to 120 litres/day per person. The use profile of the DHW is linked to the profile of the miscellaneous which has the same profile with lighting. This profile type is going to be illustrated in the next section.

5.4.7. Internal Gains

Internal gains of the model consist of people (occupancy), lighting, and the miscellaneous. These all generate heat gains in the spaces in which they are used, namely, in the spaces used by the residents to live in, and in the spaces occupied by the elevator, stairs, and the corridors. In details, each of these internal gain has some properties. Firstly, these values for people can be found by ASHRAE Handbook - Fundamentals (SI) (2009). Accordingly, degree of activity is chosen as "seated, very light work" at the offices, hotels, and apartments. The corresponding sensible heat and latent heat are 70 W/p and 45 W/p; moreover, the amount of people in the living areas is determined as 4. On the other hand, the amount of people in the other areas is determined as 31.5 m^2/p based on experts' opinion. Again, very light work is assumed to take place in these areas. Secondly, the lighting is chosen to be as fluorescent lighting. According to ASHRAE Handbook - Fundamentals (SI) (2009), lighting power density (LPD) is 12 W/m^2 for hotel/motel guest rooms. This is chosen to be used in this study for the areas in which residents live. For the spaces occupied by stairs, and the corridors, LPD is chosen to be as 6 W/m^2 based on, again, ASHRAE Handbook - Fundamentals (SI) (2009). The radiant fraction for both of these is 0.45 as suggested by the software for fluorescent lighting, and both is fuelled by electricity. Finally, parameters for last internal gain, miscellaneous, are determined based on experts' opinion. This value represents the internal gains caused by the equipment used by people. Accordingly, for the areas in which the residents live, it is decided that maximum sensible gain for it is 8 W/m^2, and maximum latent gain is 2 W/m^2. For the spaces occupied by elevators, stairs, and corridors, miscellaneous value is chosen to be as 5 W/m^2 as only maximm sensible gain. Radiant fraction for miscellaneous gain is suggested by the software as default as 0.22. Table 5.17 and Table 5.18 given below summarize the type of the internal gains and its properties in their respective areas/spaces they are used in.

Table 5.17. Internal Gains for the Spaces in which the Residents Live.

Internal Gains for the Spaces in which the Residents Live						
Type	**Max. Sensible Gain**	**Max. Latent Gain**	**Max. Power Consumption**	**Radiant Fraction**	**Amount**	**Fuel**
People	70 W/p	45 W/p	-	-	4 people	-
Fluorescent L.	12 W/m^2	-	12 W/m^2	0.45	-	Electricity
Miscellaneous	8 W/m^2	2 W/m^2	10 W/m^2	0.22	-	Electricity

Table 5.18. Internal Gains for the Spaces Occupied by the Elevators, Stairs, and Corridors.

Internal Gains for the Spaces Occupied by the elevators, stairs, and corridors						
Type	**Max. Sensible Gain**	**Max. Latent Gain**	**Max. Power Consumption**	**Radiant Fraction**	**Amount**	**Fuel**
People	70 W/p	45 W/p	-	-	31.5 m^2/p	-
Fluorescent L.	6 W/m^2	-	6 W/m^2	0.45	-	Electricity
Miscellaneous	5 W/m^2	-	5 W/m^2	0.22	-	Electricity

Each of these internal gains has an use profile. The use profile of the occupancy have been shown previously. Moreover, the lighting and miscellaneous profiles are the same and shown in Table 5.13 below for the areas in which the residents live.

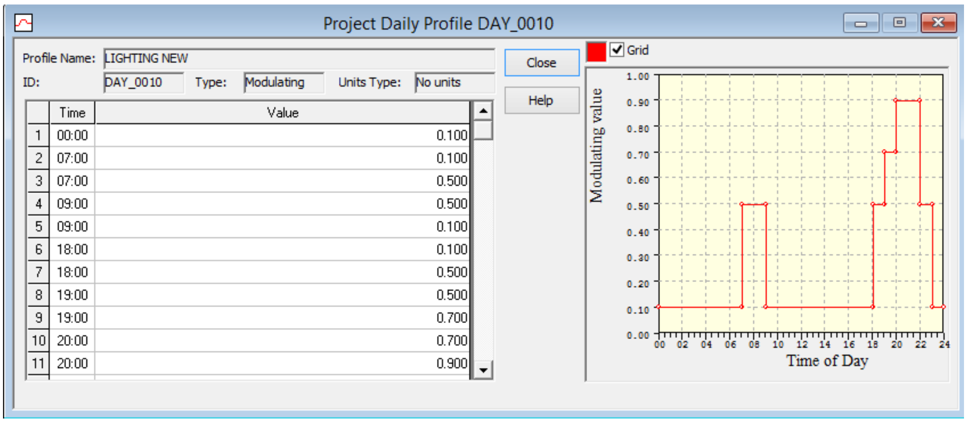

Figure 5.13. Lighting and Miscellaneous Profiles for Occupied Spaces.

In the use profile, it is seen that there is an increased activity in the early morning, and at the end of the day, the maximum use of the lighting and the equipment take place at the prime time between 20:00-22:00. Moreover, the use profile for the spaces occupied by elevators, stairs, and the corridors are shown in Figure 5.14.

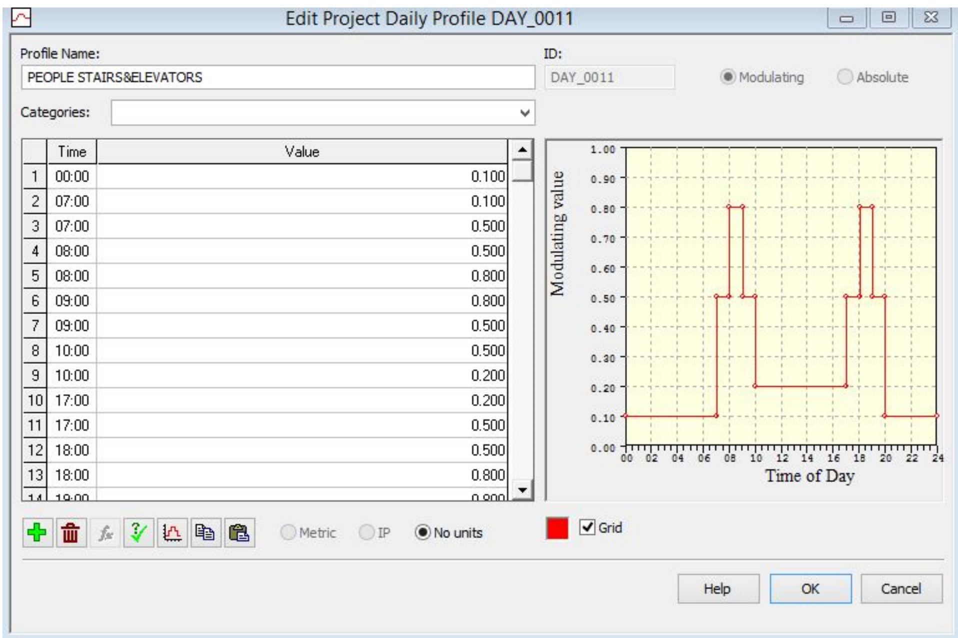

Figure 5.14. Lighting and Miscellaneous for Unoccupied Spaces.

5.4.8. Air Exchanges

The type of the air exchanges of the model includes the natural ventilation and the infiltration. Firstly, the amount of natural ventilation is set to 1.2 air change per hour (ach), corresponding to 25 litres/s/person, based on experts' opinion. European Standard BS EN 13779: Ventilation for buildings. Performance requirements for ventilation and air-conditioning systems (2005) as cited in CIBSE Guide A: Environmental Design (2006) states that the value suggested by the experts corresponds to a high indoor air quality standard. In this source, the ventilation range for high indoor air quality standard should be greater than 15 litres/s/person, and the default value for it is 20 litres/s/person. Therefore, 25 litres/s/person provides high indoor air quality standard throughout the areas in which it is used. The adjacent condition, which is the source of the natural ventilation, is linked to the external air. The use profile of the natural ventilation is formulated in the model to work only for the spaces used by occupants to live in except the wet areas. This formulation basically tells the program that the windows are opened if the outside air temperature is between 21^{o}C - 25^{o}C during any time given; else they are closed. The reason is that it does not make any sense to open them during the cold winter and increase the heating need because of that; and also the vice versa applies to hot summer conditions as it is going to increase the cooling need. The formulation and the graph of it are as shown in Figure 5.15 and Figure 5.16, respectively.

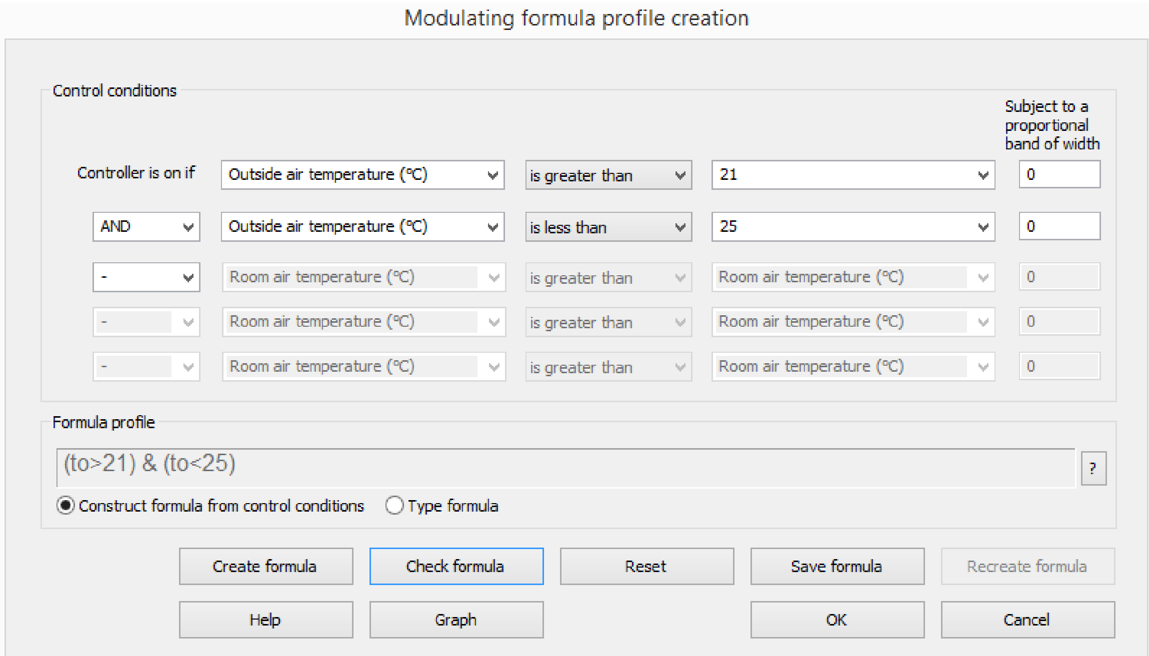

Figure 5.15. Modulating Formula for Windows.

Secondly, the amount of infiltration is set to 0.25 ach whose adjacent condition is also linked to external air. The reason of this value is that, according to CIBSE Guide A: Environmental Design (2006), the infiltration rate for a very tight building that has an air permeability of 3 m^3/m^2h at 50 Pa, classification of which is based on Part L of the Building Regulations (2001) as cited in CIBSE Guide A: Environmental Design (2006), consisting of 1-5 storeys, can be chosen as 0.25 ach. The value is an empirical value for air infiltration rate due to air infiltration for rooms in buildings on normally-exposed sites in winter for partial exposure, and, the air leakage values for residential buildings are based on individual testing of each dwelling. Furthermore, the use profile of the infiltration is set to “on continuously”, and it works for all the areas/spaces in the model since the infiltration is unintended and it occurs through the cracks or small openings in the building envelope.

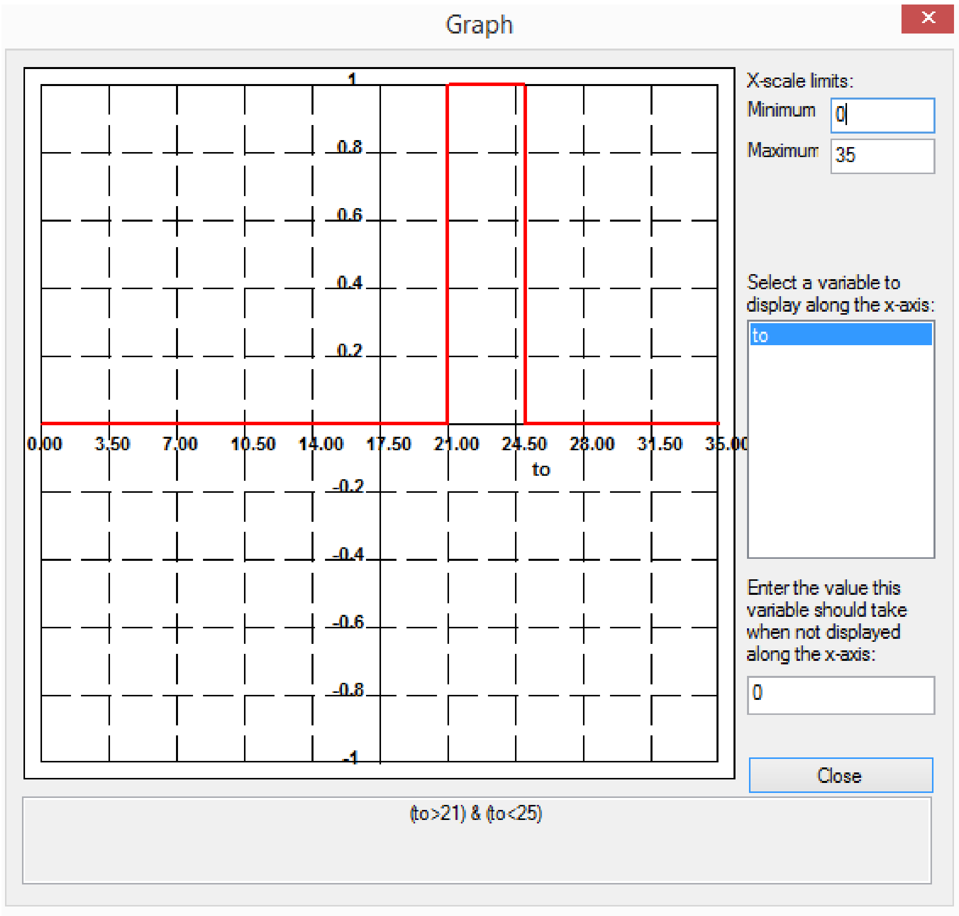

Figure 5.16. Graph of Modulating Window Formula.

Table 5.19. Summary of Inputs for the Base Model.

Model	Base Model			
Parameter		**Value**		**Source**
U-values (in W/m^{2}K)				
	External Wall	1.443		
	External Glazing	2.407		
	Roof	4.808		
	Ground Floor	2.971		
	Internal Partition	1.204		
	Ceiling	3.170		
	Door	2.500		
Heating				
	Set-point	21Â°C		Experts' Advise
	Source	Natural Gas		
	Use Profile	On Continuously		
	SE	80%		Lekov *et al.* (2006)
	ScoP	80%		Lekov *et al.* (2006)
Cooling				
	Set-point	25Â°C		Experts' Advise
	Mechanism	Air conditioning		
	Fuel	Electricity		
	Use Profile	Occupancy		
	NEER	4.2 kW/kW		Experts' Advise
	SEER	5.1 kW/kW		Experts' Advise
	SSEER	5.0 kW/kW		Experts' Advise
Domestic Hot Water				
	Consumption	5 liters/hour.person		ASPE (2015)
	Inlet Temperature	10Â°C		Default in IES VE
	Outlet Temperature	60Â°C		Default in IES VE
	Use Profile	Lighting		
	DHW Delivery Efficiency	80%		Experts' Advise
Air Exchange				
. Natural Ventilation				
	Adjacent Condition	Outside Air		
	Use Profile	Formulated		
	ACH	1.2		Experts' Advise
. Infiltration				
	Adjcent Condition	Outside Air		
	Use Profile	On Continuosly		
	ACH	0.25		CIBSE (2006)
Internal Gains				
. Occupancy				
	Source	People		
	Fuel	-		
	Use Profile	Occupancy		
Â	Max. Sensible Gain	70 W/p		ASHRAE (2009)
	Max. Latent Gain	45 W/p		ASHRAE (2009)
. Lighting				
	Area used in	Homes	Other Spaces	
	Source	Fluorescent Lamp	Fluorescent Lamp	
	Fuel	Electricity	Electricity	
	Use Profile	Lighting	Lighting	
	Max. Sensible Gain	12 W/m^2	6 W/m^2	ASHRAE (2009)
	Max. Latent Gain	-	-	
	Radiant Fraction	0.45	0.45	Default in IES VE
. Miscellaneous				
	Source	Equipment	Equipment	
	Fuel	Electricity	Electricity	
	Use Profile	Lighting	Lighting	
	Max. Sensible Gain	8 W/m^2	5 W/m^2	Experts' Advise
	Max. Latent Gain	2 W/m^2	-	Experts' Advise
	Radiant Fraction	0.22	0.22	Default in IES VE

5.5. Energy Analysis of the Base Model

The energy analysis of the base model is performed and is illustrated below in Table 5.20.

Table 5.20. The results of the Base model using IES-VE.

Model Name: Base Model									
MonthÂ	System Natural gas (MWh)	Chillers Energy (MWh)	Ap Sys aux + DHW/ solar pumps energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total lights energy (MWh)	Total equip energy (MWh)	Total nat. gas (MWh)	Total electricity (MWh)	Total energy (MWh)
Jan 01-31	723.893	0	122.818	0	49.676	41.397	723.893	21.389	937.784
Aug 01-31	69.739	19.833	122.818	12.098	49.676	41.397	69.739	245.822	315.561
Sep 01-30	69.803	0.6081	118.856	0.3709	48.074	40.062	69.803	216.781	286.584
Oct 01-31	158.212	0.0026	122.818	0.0016	49.676	41.397	158.212	213.931	372.144
Nov 01-30	416.743	0	118.856	0	48.074	40.062	416.743	20.699	623.734
Dec 01-31	636.485	0	122.818	0	49.676	41.397	636.485	21.389	850.375
Total	399.305	5.847	1.446.083	35.667	584.899	487.416	3.993.048	2.612.522	660.557
					Energy per total area (kWh/m^2)				260.06
					Energy per conditioned area (kWh/m^2)				331.61

The results obtained from the software for base model reveal that natural gas demand of the building is 399.3 MWh and the electricity demand is 261.3 MWh. When both these results are added, a total of 660.6 MWh total energy is needed for supplying these demands. Considering only some spaces of the building are conditioned, the energy per total area and the energy per conditioned area should also be noted. Accordingly, 260.1 kWh/m^2 is found for energy demand per total area and 331.61 kWh/m^2 is found for energy demand per conditioned area. These values are very high values but expected as the base model is uninsulated and considered as an inefficient design.

The component of "System natural gas" given above in MWh consists of both natural gas for space conditioning and natural gas for domestic hot water needs. The breakdown of natural gas for space conditioning is given in Table 5.21 for comparing the results obtained from TS 825 to results obtained from the software.

Table 5.21. Natural Gas Need for Space Condititioning for Base Model.

Date	Ap Sys boilers space cond'g energy (MWh)
Jan 01-31	654.153
Feb 01-28	635.708
Mar 01-31	536.462
Apr 01-30	239.334
May 01-31	97.835
Jun 01-30	0.1646
Jul 01-31	0
Aug 01-31	0
Sep 01-30	0.2313
Oct 01-31	88.473
Nov 01-30	349.254
Dec 01-31	566.746
Summed total	3.171.924

The results from the software indicate that the building needs 317.2 MWh of heating energy is required for heating the spaces. This values is close to what obtained from TS 825 which is 325.9 MWh. Similar to TS 825, the software reveals that January is the month requiring the largest portion of heating energy. Comparing the heating needs, the analysis made based on TS 825 indicates that 70.96 MWh is going to be needed for heating needs and the analysis made based on software indicates that 65.4 MWh is going to be needed for January. There is a 92% of similarity among these analysis for this month. However, there is a difference between the months following January. Based on the analysis made on the software, February is the month needing the second most heating energy and December is the third. To calculate the price of natural gas for each month, some calculations are made. The formulas used for these calculations are given below.

- Natural Gas Need = System Natural Gas / Total Floor Area
- Natural Gas Need Per Residence = Natural Gas Need * Residence Area
- Required Monthly Volume = Natural Gas Per Residence * 0.093985 (m3/kWh = 0.093985)
- Required Daily Volume = Required Monthly Volume / Number of Days Raw Price = Required Gas Need Per Residence * 0.088 (TL/kWh = 0.088)
- Value Added Tax (VAT) = Raw Price * 0.18
- Total Price = Raw Price + VAT

Using these formulas, the price of natural gas for each month is obtained. These prices are given below in Table 5.22.

Table 5.22. Price for Natural Gas for Base Model.

Natural Gas									
Month	Number of Days	Natural Gas Need (MWh/m^2)	Natural Gas Need Per Residence (MWh)	Natural Gas Need Per Residence (kWh)	Required Monthly Volume (m^3)	Required Daily Volume (m^3)	Raw Price (TL)	VAT (TL)	Total Price (TL)
Jan	31	0.0285	31.065	3106.47	291.96	9.42	275.82	49.65	325.47
Feb	28	0.0275	29.984	2998.35	281.8	10.06	266.22	47.92	314.14
Mar	31	0.0239	26.014	2601.41	244.49	7.89	230.98	41.58	272.55
Apr	30	0.0121	13.167	1316.68	123.75	4.12	116.91	21.04	137.95
May	31	0.0066	0.7191	719.12	67.59	2.18	63.85	11.49	75.34
Jun	30	0.0027	0.2967	296.69	27.88	0.93	26.34	4.74	31.08
Jul	31	0.0027	0.2993	299.27	28.13	0.91	26.57	4.78	31.36
Aug	31	0.0027	0.2993	299.27	28.13	0.91	26.57	4.78	31.36
Sep	30	0.0027	0.2995	299.55	28.15	0.94	26.6	4.79	31.38
Oct	31	0.0062	0.6789	678.94	63.81	2.06	60.28	10.85	71.13
Nov	30	0.0164	17.884	1788.39	168.08	5.6	158.79	28.58	187.37
Dec	31	0.0251	27.314	2731.37	256.71	8.28	242.52	43.65	286.17
Total	365	0.1572	171.355	17135.52	1610.48	4.41	1521.45	273.86	1795.32

5.6. Design Alternatives for the Base Model

Considering the calculations of the base model, base model does not seem to be feasible to use as the cost associated with the energy consumption of the building reaches to considerable amounts. At this stage, the design alternatives are going to be created based on the modifications that are going to be made on the base model. To begin with, as a first alternative, there should be an insulation at the outer surfaces of the building which is expected to reduce the amount of the heat loss between interior and exterior. The amount of insulation, is firstly selected to satisfy the U-values proposed by TS 825 for second region. Moreover, it is obvious that if more efficient heating mechanism is used, these prices are greatly reduced. The reason is that the heating load is a constant value, but because of AFUE, all fuel consumed does not provide the same amount of heat output. This situation increases the heating energy required. Therefore, the more efficient the heating mechanism, the lesser energy is required which results in paying lesser amounts. The efficiency values used in the base model are a bit old, nowadays more efficient heating mechanisms are used in the buildings based on experts' opinion. This results in that these newer heating mechanisms are going to be used except the first alternative. Moving on, the second alternative is going to be tried to be improved for the rest of the alternatives. Finally, advanced systems are now used in the smart buildings; hence, the heating and cooling mechanism does not need to work when there is no use at that zone; therefore, both the heating and the cooling mechanism are set to work based on the assigned profile to them except the first alternative.

Accordingly, four design alternatives are created. These design alternatives are:

- Alternative 1 (Alt. 1) - Applying the proposed limiting U-values for the second region to the outer surfaces.
- Alternative 2 (Alt. 2) - Applying the newer, modern heating mechanisms, and introducing the properties come with smart homes to Alt. 1.
- Alternative 3 (Alt. 3) - Alt. 2 + 15% improvement on the U-values of the external surfaces of the Alt. 2.
- Alternative 4 (Alt. 4) - Alt. 2 + 30% improvement on the U-values of the external surfaces of the Alt. 2.

Corresponding U-values are given in Table 5.23.

Table 5.23. U-values for All Models.

	U-value (W/m^2K)				
Component	**Base**	**Alt. 1**	**Alt. 2**	**Alt. 3**	**Alt. 4**
External Wall	1.44	0.6	0.6	0.51	0.42
External Glazing	2.4	2.4	2.4	2.04	1.68
Roof	4.81	0.4	0.4	0.34	0.28
Ground Floor	2.97	0.6	0.6	0.51	0.42
Internal Partition	1.2	0.51	0.51	0.51	0.51
Ceiling	3.17	3.17	3.17	3.17	3.17
Door	2.5	2.5	2.5	2.5	2.5

To achieve these U-values the alternatives in the analysis, the improvements made on the outer surfaces of the base model are shown in Table 5.24, Table 5.25, Table 5.26 and Table 5.27. It should be noted that the newer and modern heating mechanisms included in Alt. 2, Alt. 3, and Alt. 4. These cannot be reflected in the U-values; nevertheless, they are inside of their corresponding model.

Table 5.24. Improvements for Extern Wall.

	External Wall					
Name	**Surface losing heat on which the improvements are made**	**Improvement**	**Total Thick. (m)**	**Heat Conductance (W/mK)**	**Old U-value (W/m^2K)**	**New U-value (W/m^2K)**
Alt. 1 and Alt. 2	Insulation (XPS)	34 mm is added	0.034	0.035	1.44	0.601
Alt. 3	Insulation (XPS)	10 mm is added	0.044	0.035	0.601	0.513
Alt. 4	Insulation (XPS)	24 mm is added	0.068	0.035	0.601	0.426

Table 5.25. Improvements for New External Glazing.

	New External Glazing						
Name	**Surface losing heat**	**Improvement**	**Total Thick. (m)**	**Heat Conductance (W/mk)**	**Gas filled with**	**U-value incl. frame (W/m^{2}K)**	**New U-value incl. frame (W/m^{2}K)**
Alt. 1 and Alt. 2	Inside Air Film	No Improvement with respect to base model				0.13	2.407
	Inner Pane		0.006	1.06	-		
	Cavity		0.0051	-	Argon		
	Outer Pane		0.006	1.06	-	0.04	
	Outside Air Film						
Alt. 3	Inside Air Film	Thickness of the cavitiy is modified				2.407	2.045
	Inner Pane		0.006	1.06	-		
	Cavity		0.0072	-	Argon		
	Outer Pane		0.006	1.06	-		
	Outside Air Film						
Alt. 4	Inside Air Film	Thickness of the cavitiy is modified				2.407	1.682
	Inner Pane		0.006	1.06	-		
	Cavity		0.0108	-	Argon		
	Outer Pane		0.006	1.06	-		
	Outside Air Film						

Table 5.26. Improvements for Ground Floor.

	Ground Floor					
Name	**Surface losing heat on which the improvements are made**	**Improvement**	**Total Thick. (m)**	**Heat Conductance (W/mK)**	**Old U-value (W/m^{2}K)**	**New U-value (W/m^{2}K)**
Alt. 1 and Alt. 2	Insulation (XPS)	40 mm is added	0.04	0.03	2.97	0.599
Alt. 3	Insulation (XPS)	8 mm is added	0.048	0.03	0.599	0.516
Alt. 4	Insulation (XPS)	20 mm is added	0.068	0.03	0.599	0.428

Table 5.27. Improvements for Roof.

	Roof					
Name	**Surface losing heat on which the improvements are made**	**Improvement**	**Total Thick. (m)**	**Heat Conductance (W/mK)**	**Old U-value (W/m^{2}K)**	**New U-value (W/m^{2}K)**
Alt. 1 and Alt. 2	Insulation (Glasswool)	90 mm is added	0.09	0.04	4.81	0.407
Alt. 3	Insulation (Glasswool)	19 mm is added	0.109	0.04	0.407	0.259
Alt. 4	Insulation (Glasswool)	40 mm is added	0.149	0.04	0.407	0.214

In the next stages, these design alternatives are going to be evaluated in terms of their energy performance in IES VE. Later on, their LCC are going to be calculated, and an optimum design is going to be tried to be achieved among this set of design alternatives.

5.7. Energy Analysis of the Alternative 1

The base model is modified based on all the changes stated above for alternative 1. Accordingly, Table 5.28 is given below for energy performance of alternative 1.

Table 5.28. The results of Alternative 1 using IES-VE.

		Model Name: Alternative 1								
		System natural gas (MWh)	Chillers Energy (MWh) (MWh)	Ap Sys aux + DHW /solar pumps energy (MWh)	Ap Sys heat rej fans/ pumps energy (MWh)	Total Lights Energy (MWh)	Total equip energy (MWh)	Total nat. Gas (MWh)	Total Elec-tricity (MWh)	Total Energy (MWh)
Month	Jan 01-31	230.933	0	122.818	0	49.676	41.397	230.933	21.389	444.823
	Feb 01-28	225.512	0	110.932	0	44.869	37.391	225.512	193.191	418.703
	Mar 01-31	187.181	0	122.818	0	49.676	41.397	187.181	21.389	401.071
	Apr 01-30	87.484	0.0001	118.856	0.0001	48.074	40.062	87.484	206.992	294.477
	May 01-31	71.434	0.2451	122.818	0.1495	49.676	41.397	71.434	217.837	289.271
	Jun 01-30	67.489	10.867	118.856	0.6629	48.074	40.062	67.489	224.487	291.976
	Jul 01-31	69.739	16.123	122.818	0.9835	49.676	41.397	69.739	239.849	309.588
	Aug 01-31	69.739	16.452	122.818	10.036	49.676	41.397	69.739	240.379	310.118
	Sep 01-30	67.489	0.9439	118.856	0.5758	48.074	40.062	67.489	222.187	289.677
	Oct 01-31	69.739	0.1675	122.818	0.1022	49.676	41.397	69.739	216.587	286.327
	Nov 01-30	114.392	0.003	118.856	0.0018	48.074	40.062	114.392	207.039	321.431
	Dec 01-31	197.726	0	122.818	0	49.676	41.397	197.726	21.389	411.617
	Total	1.458.858	57.039	1.446.083	34.794	584.899	487.416	1.458.858	2.610.219	406.908
						Energy per total area (kWh/m^2)				160.2
						Energy per conditioned area (kWh/m^2)				204.27

5.8. Energy Analysis of the Alternative 2

The base model is modified based on all the changes stated above for alternative 2. Accordingly, Table 5.29 is given below for energy performance of alternative 2.

Table 5.29. The results of Alternative 2 using IES-VE.

		Model Name: Alternative 2								
		System natural gas (MWh)	Chillers Energy (MWh) (MWh)	Ap Sys aux + DHW /solar pumps energy (MWh)	Ap Sys heat rej fans/ pumps energy (MWh)	Total Lights Energy (MWh)	Total equip energy (MWh)	Total nat. Gas (MWh)	Total Elec- tricity (MWh)	Total Energy (MWh)
Month	Jan 01-31	180.845	0	73.129	0	49.676	41.397	180.845	164.203	345.048
	Feb 01-28	177.539	0	65.371	0	44.869	37.391	177.539	14.763	32.517
	Mar 01-31	145.639	0	71.809	0	49.676	41.397	145.639	162.882	308.521
	Apr 01-30	65.133	0.0001	69.663	0	48.074	40.062	65.133	157.799	222.932
	May 01-31	52.147	0.2246	73.129	0.137	49.676	41.397	52.147	167.819	219.966
	Jun 01-30	4.942	0.9969	69.663	0.6081	48.074	40.062	4.942	173.848	223.269
	Jul 01-31	51.068	14.791	72.469	0.9022	49.676	41.397	51.068	187.355	238.424
	Aug 01-31	51.068	15.295	72.469	0.933	49.676	41.397	51.068	188.167	239.235
	Sep 01-30	4.942	0.8798	69.663	0.5367	48.074	40.062	4.942	171.963	221.384
	Oct 01-31	51.068	0.166	73.129	0.1012	49.676	41.397	51.068	166.874	217.942
	Nov 01-30	84.128	0.003	69.663	0.0019	48.074	40.062	84.128	157.847	241.976
	Dec 01-31	152.286	0	71.809	0	49.676	41.397	152.286	162.882	315.168
	Total	1.109.762	52.789	851.966	32.201	584.899	487.416	1.109.762	200.927	3.119.032
						Energy per total area (kWh/m^2)				122.8
						Energy per conditioned area (kWh/m2)				156.58

Table 5.30. The results of Alternative 3 using IES-VE.

		Model Name: Alternative 3								
		System natural gas (MWh)	Chillers Energy (MWh)	Ap Sys aux + DHW/ solar pumps energy (MWh)	Ap Sys heat rej fans/ pumps energy (MWh)	Total lights energy (MWh)	Total equip energy (MWh)	Total nat. gas (MWh)	Total Electricity (MWh)	Total energy (MWh)
Month	Jan 01-31	154.948	0	73.129	0	49.676	41.397	154.948	164.203	31.915
	Feb 01-28	152.838	0	65.371	0	44.869	37.391	152.838	14.763	300.468
	Mar 01-31	124.266	0	71.809	0	49.676	41.397	124.266	162.882	287.148
	Apr 01-30	57.146	0.0016	69.663	0.001	48.074	40.062	57.146	157.824	21.497
	May 01-31	51.256	0.3075	73.129	0.1876	49.676	41.397	51.256	169.153	220.409
	Jun 01-30	4.942	10.478	69.663	0.6391	48.074	40.062	4.942	174.667	224.088
	Jul 01-31	51.068	14.892	72.469	0.9084	49.676	41.397	51.068	187.519	238.587
	Aug 01-31	51.068	15.377	72.469	0.938	49.676	41.397	51.068	188.299	239.367
	Sep 01-30	4.942	0.9444	69.663	0.5761	48.074	40.062	4.942	173.004	222.424
	Oct 01-31	51.068	0.2438	73.129	0.1487	49.676	41.397	51.068	168.127	219.195
	Nov 01-30	70.262	0.0127	69.663	0.0078	48.074	40.062	70.262	158.003	228.265
	Dec 01-31	129.586	0	71.809	0	49.676	41.397	129.586	162.882	292.468
	Total	992.345	55.847	851.966	34.066	584.899	487.416	992.345	2.014.192	3.006.538
						Energy per total area (kWh/m2)				118.37
						Energy per conditioned area (kWh/m2)				150.93

5.9. Energy Analysis of the Alternative 4

The base model is modified based on all the changes stated above for alternative 4. Accordingly, Table 5.31 is given below for energy performance of alternative 4.

Table 5.31. The results of Alternative 4 using IES-VE.

		Model Name: Alternative 4								
		System natural gas (MWh)	Chillers Energy (MWh) (MWh)	Ap Sys aux + DHW /solar pumps energy (MWh)	Ap Sys heat rej fans/ pumps energy (MWh)	Total Lights Energy (MWh)	Total equip energy (MWh)	Total nat. Gas (MWh)	Total Elec-tricity (MWh)	Total Energy (MWh)
Month	Jan 01-31	129.136	0	73.129	0	49.676	41.397	129.136	164.203	293.338
	Feb 01-28	128.434	0	65.371	0	44.869	37.391	128.434	14.763	276.065
	Mar 01-31	103.894	0	71.809	0	49.676	41.397	103.894	162.882	266.776
	Apr 01-30	51.936	0.0148	69.663	0.009	48.074	40.062	51.936	158.036	209.972
	May 01-31	51.068	0.4215	73.129	0.2571	49.676	41.397	51.068	170.988	222.056
	Jun 01-30	4.942	11.014	69.663	0.6718	48.074	40.062	4.942	17.553	224.951
	Jul 01-31	51.068	15.017	72.469	0.916	49.676	41.397	51.068	187.719	238.787
	Aug 01-31	51.068	15.473	72.469	0.9438	49.676	41.397	51.068	188.453	239.521
	Sep 01-30	4.942	10.117	69.663	0.6172	48.074	40.062	4.942	174.087	223.508
	Oct 01-31	51.068	0.3476	73.129	0.212	49.676	41.397	51.068	169.799	220.866
	Nov 01-30	58.731	0.035	69.663	0.0214	48.074	40.062	58.731	158.362	217.094
	Dec 01-31	107.055	0	71.809	0	49.676	41.397	107.055	162.882	269.937
	Total	882.298	59.809	851.966	36.483	584.899	487.416	882.298	2.020.572	2.902.871
						Energy per total area (kWh/m^2)				114.29
						Energy per conditioned area (kWh/m^2)				145.73

5.10. Comparison of Energy Needs of All Models

When all five models are considered, Table 5.32 is obtained.

Table 5.32. Reduction in Total Energy per Total Area.

Model Name	Total Energy (MWh)	Total Energy per Total Floor Area (kWh/m^2)	Total Energy Need per Conditioned Area (kWh/m^2)	Reduction in Total Energy per Total Area with respect to Base Model (%)
Base	660.6	260.1	331.6	-
Alt. 1	406.9	160.2	204.3	38.4
Alt. 2	311.9	122.8	156.6	52.78
Alt. 3	300.7	118.4	150.9	54.48
Alt. 4	290.3	114.3	145.7	56.05

It is expected that the total energy need is going to reduce since the purpose of these design alternatives is to make the building use less energy. To begin commenting about these results, as the base model is uninsulated, even insulation amount that should be proposed by standard for limiting the U-values could have a significant effect on reduction in energy needs. It is seen that 38.40% of energy per area could be saved with respect to base model by applying the minimum amount of insulation proposed by standard for this building. Moreover, applying newer and modern heating mechanisms and using features of smart homes to Alt. 1 could save 52.78% of energy per area. Nowadays, these newer and modern heating mechanisms are advised to be used by experts as they have a significant contribution on reducing the energy needs. Moving on, Alt. 3 has 15% improvement for U-values comparing to Alt. 2. The results reveal that this could save 54.48% of energy per area with respect to base model. Finally, Alt. 4 has 30% improvement for its U-values comparing to Alt. 2. The results obtained from the software indicate that this could save 56.05% of energy per area with respect to base model. Nevertheless, energy demands by themselves does not mean anything about feasibility; therefore, each of these design alternatives should be evaluated in terms of LCC in order to assess their feasibility.

5.11. LCC Calculations

These all four different design alternatives have their respective initial investment costs and their respective advantages in the long run. Therefore, the LCC calculations are going to be made as follows:

- Finding the cost of the investment for each design alternative,
- Finding the difference of natural gas and electricity consumption between the base model and the respective model in terms of cost and converting this difference into money,
- Using cash flow formulas to find NPV, IRR, PI, ROE, and the payback period to obtain the optimum design alternative among the set of design. alternatives

5.11.1. Information about the Investment Cost

To calculate the cost of insulation materials, the prices used are taken from the Ministry of Environment and Urbanisation; moreover, these prices are given for the date of 01.01.2016. To reflect the insulation costs associated with the improvements made for each design alternative, the prices corresponding to those improvements are taken as the investment amount.

Furthermore, to reflect the cost associated with using newer and heating mechanisms, the prices for high-efficient boiler devices that is used in the study are taken from a catalogue of a private company. These amounts are also added as an investment amount at the beginning.

5.11.2. Information about the Operational Prices

The two of the operational costs used in LCC calculations are cost of the natural gas, and cost of the electricity.

Firstly, the prices excluding VAT for natural gas are taken from Istanbul Gas Distribution Industry and Trade Incorporated Company (IGDAS) (2017). These prices for the last 7 years are given in Table 5.33. Besides, the values are illustrated in Figure 5.17.

Table 5.33. Changes in the Prices of Natural Gas (IGDAS, 2017).

Date	Natural Gas (TL/kWh)	Change with respect to previous year
1/1/2017	0.08768083	-7.54%
1/1/2016	0.09482726	0.68%
1/1/2015	0.09418233	8.69%
1/1/2014	0.08664944	0.71%
1/1/2013	0.08604135	28.04%
1/1/2012	0.06719709	14.24%
1/1/2011	0.05881983	1.18%
1/1/2010	0.05813214	-

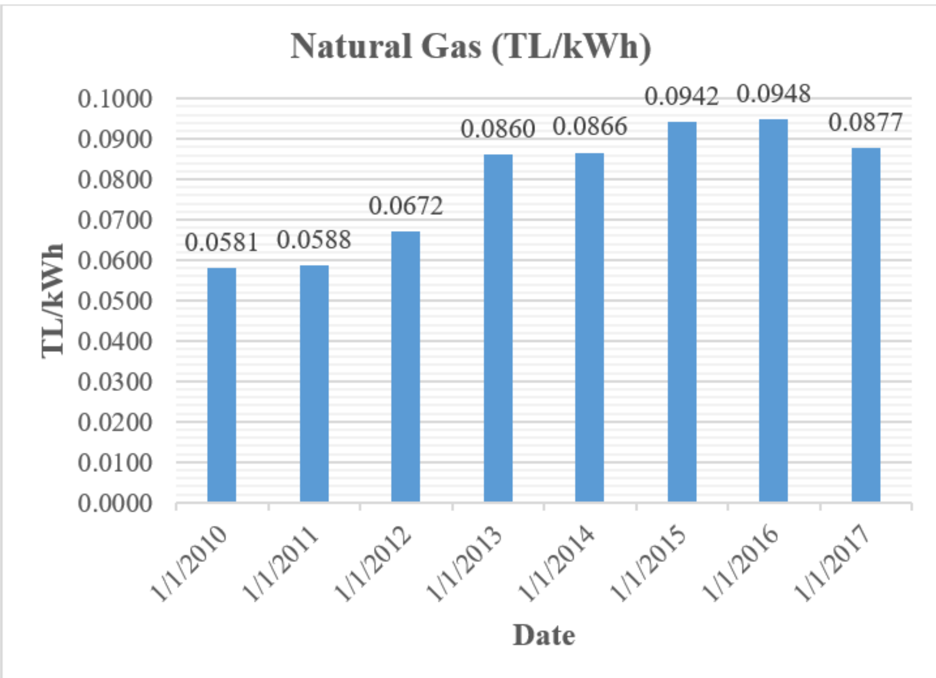

Figure 5.17. Change in the Prices of Natural Gas in Years.

After observing the change in prices for the past couple of years, the future cost of the natural gas should be estimated. To do so, Figure 5.18 is revealed down below. In the figure, y axis is for price for the natural gas (TL/kWh) and x axis for representing year in which a year here is such as 1 for 2010, 2 for 2011, 3 for 2012 and so on.

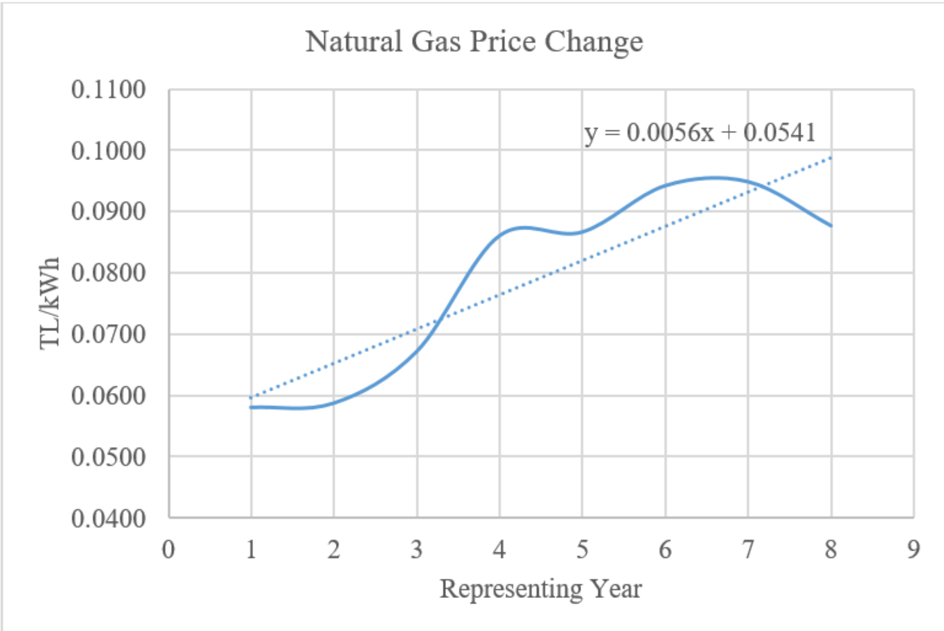

Figure 5.18. Natural Gas Price Change.

Using this equation obtained from the trend line, future prices for natural gas is going to be estimated. Accordingly, the estimated prices for the future are as revealed in Table 5.34.

Secondly, electricity is the other operational cost. The unit prices for the last quarter of 2017 is given by the Energy Market Regulatory Board (EPDK) for the consumers bought their energy from the authorized supplier company in Table 5.35. These prices are given for customers living in residences, using low voltage, and paying based on a fixed unit price throughout a day.

When the prices are calculated, some additional taxes/funds are also considered; however, those are going to be neglected in this study except VAT since it is almost impossible to estimate what value these additional taxes/funds are going to take at the future. Furthermore, in real life, there are rounding in the bills; nevertheless, in this study, there is no rounding up and the costs are going to be used as they are.

Table 5.34. The Estimated Prices for Natural Gas for the Future.

	Date	**The Price (TL/kWh)**
Estimated for	1/1/2018	0.1045
	1/1/2019	0.1101
	1/1/2020	0.1157
	1/1/2021	0.1213
	1/1/2022	0.1269
	1/1/2023	0.1325
	1/1/2024	0.1381
	1/1/2025	0.1437
	1/1/2026	0.1493
	1/1/2027	0.1549
	1/1/2028	0.1605
	1/1/2029	0.1661
	1/1/2030	0.1717
	1/1/2031	0.1773
	1/1/2032	0.1829
	1/1/2033	0.1885
	1/1/2034	0.1941
	1/1/2035	0.1997
	1/1/2036	0.2053
	1/1/2037	0.2109
	1/1/2038	0.2165
	1/1/2039	0.2221
	1/1/2040	0.2277
	1/1/2041	0.2333
	1/1/2042	0.2389
	1/1/2043	0.2445
	1/1/2044	0.2501
	1/1/2045	0.2557
	1/1/2046	0.2613
	1/1/2047	0.2669

Table 5.35. Unit Prices for Electricity for the last quarter of 2017.

	Unit Prices (TL/kWh)
Single Time	0.2161
Distribution	0.115732

To estimate the future price of the electricity, a similar method used for estimating the future prices of the natural gas is going to be used. To estimate the future changes, the changes are observed for the past couple of years, and these changes are given in Table 5.36 and illustrated in Figure 5.19. A price for a year is taken as an average of the prices given by EPDK for each quarter of that year.

Table 5.36. Electricity Prices for Past Couple of Years.

Date	**Representing Year**	**Price (TL/kWh)**
2012	1	271.360
2013	2	283.887
2014	3	291.016
2015	4	310.485
2016	5	331.834
2017	6	331.833

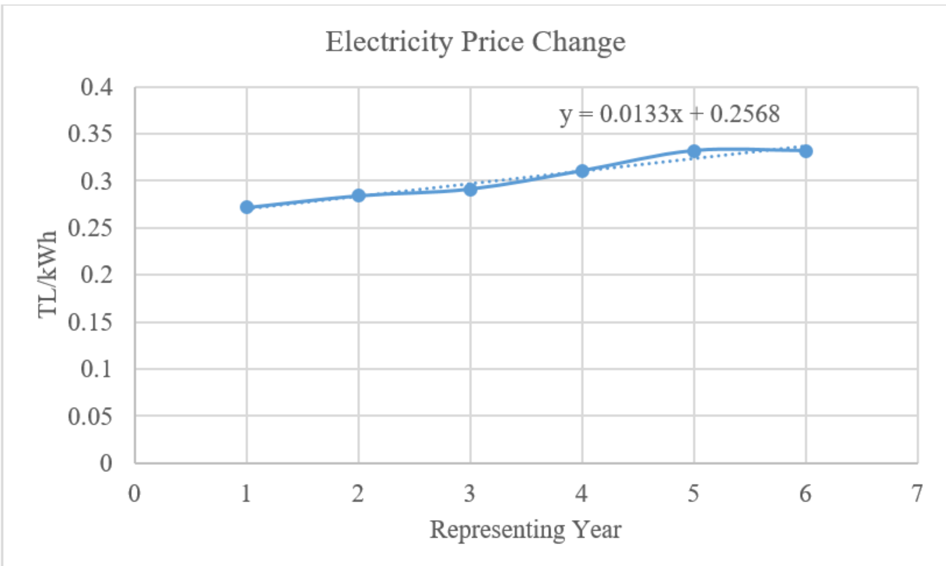

Figure 5.19. Electricity Price Change.

Using the equation given by trend line revealed in Figure 5.19, the future prices can easily be estimated. Accordingly, Table 5.37 reveals the estimated prices for electricity for the future.

Table 5.37. The Estimated Prices for Electricity for the Future.

	Date	The Price (TL/kWh)
Estimated	2018	0.34997
	2019	0.36327
	2020	0.37658
	2021	0.38988
	2022	0.40319
	2023	0.41649
	2024	0.4298
	2025	0.4431
	2026	0.45641
	2027	0.46971
	2028	0.48302
	2029	0.49632
	2030	0.50963
	2031	0.52293
	2032	0.53624
	2033	0.54954
	2034	0.56285
	2035	0.57615
	2036	0.58946
	2037	0.60276
	2038	0.61607
	2039	0.62937
	2040	0.64268
	2041	0.65598
	2042	0.66929
	2043	0.68259
	2044	0.6959
	2045	0.7092
	2046	0.72251
	2047	0.73581

5.11.3. Service Life, Discount Rate, and Escalation Rate

Guidelines for Life Cycle Cost Analysis published by Stanford University, Land and Buildings (October, 2005) tabulates that the study life for different types of construction projects as given in Table 5.38. Hence, considering this study, the service life of the building is selected as 30 years.

Table 5.38. Service Life of Different Types of Projects.

Description	Value Range (years)	Authority
New Construction Projects	30	Project Manager
Retrofit or Renovation Projects	15	Project Manager
Labs or High-Tech Buildings	10	Project Manager

Discount rate used in the calculations is selected as 12% based on the experts' opinion and ErtÃ¼rk (2016).

5.11.4. Notes about Calculations

When the experts' opinion is advised, it is decided that improvements are going to be made on the U-values -of the last two design alternatives- stated by TS 825 by 15% and 30%. Therefore, to be able to achieve U-values stated by TS 825 and make the improvements by 15% and 30%, thickness of the insulation materials has to be fractional. Nevertheless, there is no fractional thickness used for insulation materials in real life. Therefore, when LCC calculations are made, the thicknesses are rounded up to be on the safe side. Moreover, the maintenance costs are not included in the LCC since they are going to be applied on the whole design alternatives.

5.11.5. Evaluation of the Alternatives

At the end of the calculations, Table 5.39 is obtained which shows the NPV, IRR, PI, ROE, and the payback period of each alternative. Moreover, Figure 5.20 demonstrates the NPV and IRR on a graph.

Table 5.39. Evaluations of Profit for Each Alternative.

Design	**NPV**	**IRR**	**PI**	**ROE**	**Payback Period**
Alternative 1	280.587.76 TL	49.26%	4.98	23.68	2-3 years
Alternative 2	535.806.03 TL	55.19%	5.51	25.69	2-3 years
Alternative 3	544.387.13 TL	53.93%	5.37	25.09	2-3 years
Alternative 4	547.670.47 TL	51.33%	5.1	23.81	2-3 years
Alternative 4	547,670.47 TL	51.33%	5.1	23.81	2-3 years

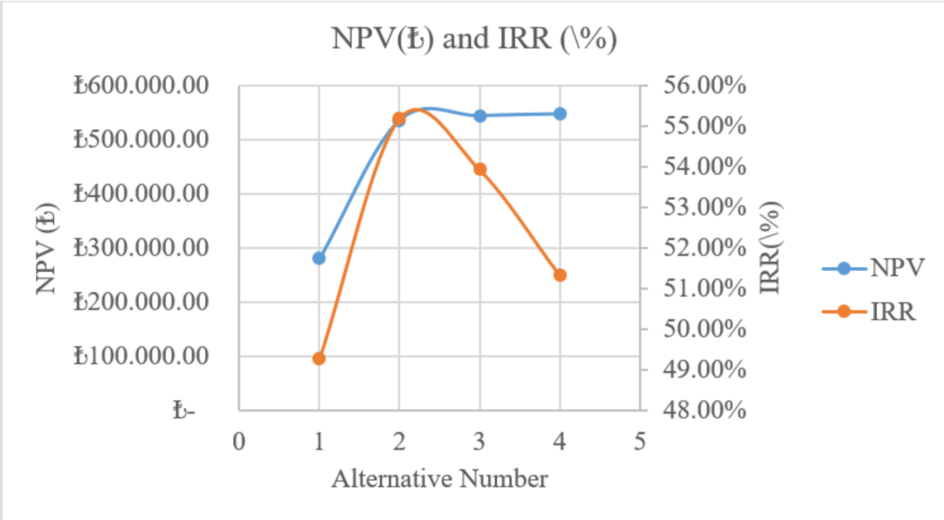

Figure 5.20. NPV and IRR of Design Alternatives.

After LCC analysis, it is seen that the Alt. 4 is the one that provides the highest amount of NPV with a NPV of 547,670.47 TL. It is followed by Alt. 3, Alt. 2, and Alt. 1. In regarding of IRR, the highest IRR is observed at Alt. 2 having an IRR of 55.19% which is followed by Alt. 3, Alt. 4, and Alt. 1. PI, ROE, and payback period are also given for each alternative. However, those methods that ignore the time value of the money are not be considered when determining the optimum alternative as the project has a 30-year of life cycle in which the time value of money is crucial, nevertheless, they are given for giving an insight.

To determine the optimum design alternative, incremental rate of return analysis is going to be performed. To begin with, IRR of the each design alternative is higher than the discount rate which is taken as 12% as mentioned before. Therefore, in this very beginning, there is going to be no discarding. As a second step, the design alternatives are ordered from lowest cost to highest cost, and the evaluation begins by determining the IRR of the cash flow created by the difference of two design alternatives having the lowest cost. To do so, the incremental cash flow is obtained first, and then IRR of this incremental cash flow is tried to be achieved. If the IRR is greater than the minimum attractive rate of return, the design alternative having higher cost becomes the best. If not, the design alternative having lower cost becomes the best. This procedure is followed until reaching the best among all. Table 5.40 given below reveals the results found with this method.

Table 5.40. The Final Results based on Incremental Rate of Return.

Alternatives being compared	**IRR**	**Eliminated**	**Chosen**
Alt. 1 - Alt. 2	63.99%	Alt. 1	Alt. 2
Alt. 2 - Alt. 3	60.14%	Alt. 2	Alt. 3
Alt. 3 - Alt. 4	53.68%	Alt. 3	Alt. 4

Accordingly, the Alt. 4 is decided as the optimum design alternative among all by having NPV of 547,670.47 TL and IRR of 51.33% based on incremental rate of return analysis. Nevertheless, different analysis methods could also have been used for deciding on the optimum alternative. When one goes with NPV, Alt. 4 comes out as the best alternative again. On the other hand, if IRR is chosen to be the determiner, Alt. 2 becomes the optimum design alternative by having an IRR of 55.19%. In addition to, some may do not wish either to choose NPV or IRR; therefore, they may go with the alternative where the NPV and IRR lines intersect to each other: Alt. 2. Sometimes, this method is also used in practice.

6. DISCUSSION

Energy performance of the building has been a subject topic for many researches and is investigated from different aspects. The main aim of this research is to achieve an optimum green design among the design alternatives in terms of LCC created based on experts' opinion for a residential project using a software, namely, IES VE. Davaki (2011) also studied a similar topic and investigate the energy use in typical Greek residential buildings and proposes different types of retrofit strategies. Moreover, the optimum retreofit strategy among three scenario is selected based on payback period. On the other hand, this research deals with the new construction of a residential building. Furthermore, the most significant feature of this study is to reveal how investments could have some dramatic effects on the energy performance of the buildings as reducing the energy need, operational costs, and resulting in making profit with the help of it. Therefore, this research also investigates the economic aspects of energy efficient buildings making LCC analysis. As a difference with Davaki (2011), incremental rate of return analysis is used for a 30-year life span to choose the optimum design alternative in which the time effect on money is also reflected; hence, this research deals with the cash flow diagrams to assess feasibilities of each design alternative using profit evaluation methods.

Paiho *et al.* (2013) focused on estimating the energy saving potentials of Moscow apartment buildings using several renovations concepts. At the end, they conclude that there is an evident for making the buildings in Moscow districts modern and upgrade since the indoor conditions are considered to be poor and the amount of energy losses reaches to considerable amounts. The authors use an indoor default temperature of 18Â°C, and they propose their renovations based on U-value, ventilation type, air tightness factor and so on. However, the findings only include the reduction in percentage on the energy demand per area for three different design alternatives but there is no money related issues for these. This research, on the other hand, use a heating set-point of 21Â°C, and design alternatives are created based on the U-values, efficiencies of the heating mechanisms, using a smart home property. Furthermore, this research not only proposes energy saving potentials by proposing different design alternatives, but also assesses them in terms of LCC. The reason is that there is a threshold determining that the design alternative should be invested on or not. To assess the feasibility of each one, the economic aspects of them should also be assessed since as mentioned before, besides the environmental and social concerns, financial expectations can be considered as the biggest reason of the interest in the energy efficient buildings.

Study by Pan *et al.* (2008) is among the examples focusing on energy modeling of two office buildings with data center for green building design. As there are different types of buildings, they have different characteristics compared to residential buildings such as more need for lighting, more electricity for office equipments and so on. Moreover, the use profiles of each are completely different. Therefore, making a direct comparison of the research of Pan *et al.* (2008) with this research does not seem to be appropriate. In terms of feasibility, the authors assess three models, namely, China Code building, AHRAE budget building, and design proposed building; at the end, they calculate the yearly cost savings for each alternative. On the other hand, as the number of researches covered during the literature review for analysing the energy performance of the office buildings seems to be greater than the number of researches for analysing the energy performance of the residential buildings, this research is about the energy performance of the residential buildings. Furthermore, design alternatives are not only directly compared based on their yearly cost savings, but an analysis of incremental rate of return to make assessment for the feasibilities of each design alternative.

During the extensive literature review, it is seen that BIM is used for several purposes as some of them are mentioned in Section 2.5. Additionaly, as discussed, BIM for analysing the energy performance of the buildings is another one of these purposes. In literature, this subject is addressed in different perspectives which some of those are discussed. However, linking LCC to the energy performance is one of the most important features of this research in terms of body of knowledge. It is seen that most of the studies directly assess the design alternatives based on methods that do not reflect the time value of the money such as payback period or they directly focus on the yearly cost savings. On the other hand, this research makes estimations for the future unit prices using the past data; therefore, tries to simulate the future. In terms of contribution to the practice, it is seen at the end of this research that investments made at the beginning stages could significantly help reducing the energy need of a building through which it also reduces the energy related operational costs. As the experts consulted for this research state, financial benefits in general are seen as the most significant reason for improving the energy performance of a building. The reason is that the employers may want to use the building for themselves so they may want to reduce their operational costs, or they may want to be certified for their buildings to sell it with a greater amount, or they may just to be known in public and increase their brand value. Therefore, this research could promote making investments on energy efficient buildings by revealing some evidences for the financial benefits coming through it besides environmental and social contributions. Nevertheless, it should be kept in mind that energy modeling can be the most important part of analysing the energy performance of a building. The number of data included in the energy models could reach significant amounts. As the analysis for the energy performance is based on the energy model which greatly relies on the data input, even a single mistake made when creating the energy model can result in a significant deviation in the energy need of the building which can also cause to obtain so misleading results for LCC. Therefore, the importance of the energy models should be kept in mind all the time.

This research also provides a basic framework for analysing the energy performance of a building. Mainly, two ways are considered in this research: consultancy for energy performance analysis and in-house analysis. In terms of getting help from a consultant company, firstly, the goals should be set with a meeting of both employer and consultancy team including architects, civil engineers and mechanical engineers. These goals could be a specific level of green building certification, or a specific amount of energy consumption. After that, the base model of the building is analysed to see how much energy is consumed for what. This helps them decide on which of those should be reduced. Accordingly, techniques that are going to be applied are going to be determined. These techniques could be based on a experience or a new one for the specific target. Hence, the goals should be clearly set at the beginning. Based on the specified techniques, the design alternatives are created and analysed in terms of energy performance. The obtained results are firstly checked for if they are appropriate for local standards, and if necessary for international standards. If they are compliant with the standards, the goals are checked if they are achieved, if not, a new alternative should be created. If the goals are achieved, the design alternative is selected, if not, a new alternative is created. Figure 6.1 reveals the consultancy way below.

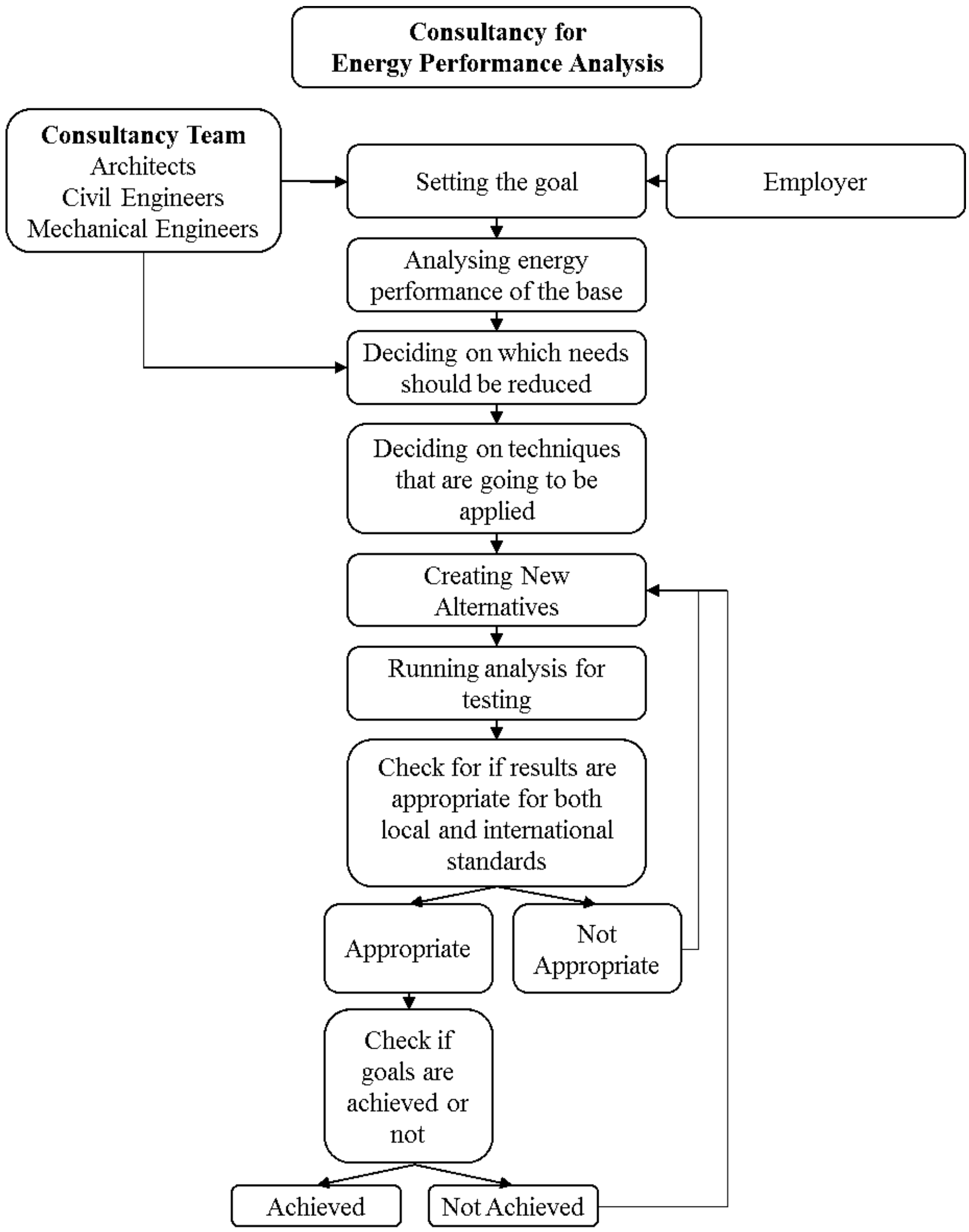

Figure 6.1. The Consultancy Way.

The analysis could also be made as in-house. There are two different ways for that: using a BIM software and using a specific BIM software for building performance analysis. If the first way, BIM software, is chosen, a suitable software should be selected. As the 3D base model is going to be exported when it is completed, and imported in a specific BIM software for building performance analysis. After the selection of BIM software is made, the 3D base model is created, exported, and imported to the BIM software for building performance analysis. After this process is complete, it should be checked if all data from the BIM software is exported and the model is complete or not. To do so, some softwares give an error report in which there is an information about the process. If not, BIM software and the BIM software for building performance analysis should be checked until the model is fully complete and correct. If everything is correct, the energy analysis for the base model is run. The rest is the same as mentioned in the consultancy way. On the other hand, when a building performance analysis software is directly chosen, there is going to be no issue related to information losses between two softwares but model consistency could also be checked in these softwares to make sure that there is no error in the model. When taking this way, a software is chosen at the beginning as a building performance analysis software. In this respect, the software should be carefully chosen so that it could make the intended analysis. To do so, there are many sources in literature that compare the softwares to each other. After the software is selected, the 3D base model is created in the software with all required data and the analysis is made again in this software. After this point, the rest is as mentioned in consultancy way. Figure 6.2 reveals this process.

Improvements that could be made for ensuring a better green design could include reducing the needs of heating, cooling and electricity. This needs differ based on many characteristics such as type of the building. Therefore, the improvements that are going to be made change based on the type of buildings. Lombard *et al.* (2008) state that the energy consumption by end uses in the residential sector mostly caused by HVAC systems; therefore, considering that this research focuses on a residential building, the improvements are made based on HVAC system, especially for the heating component.

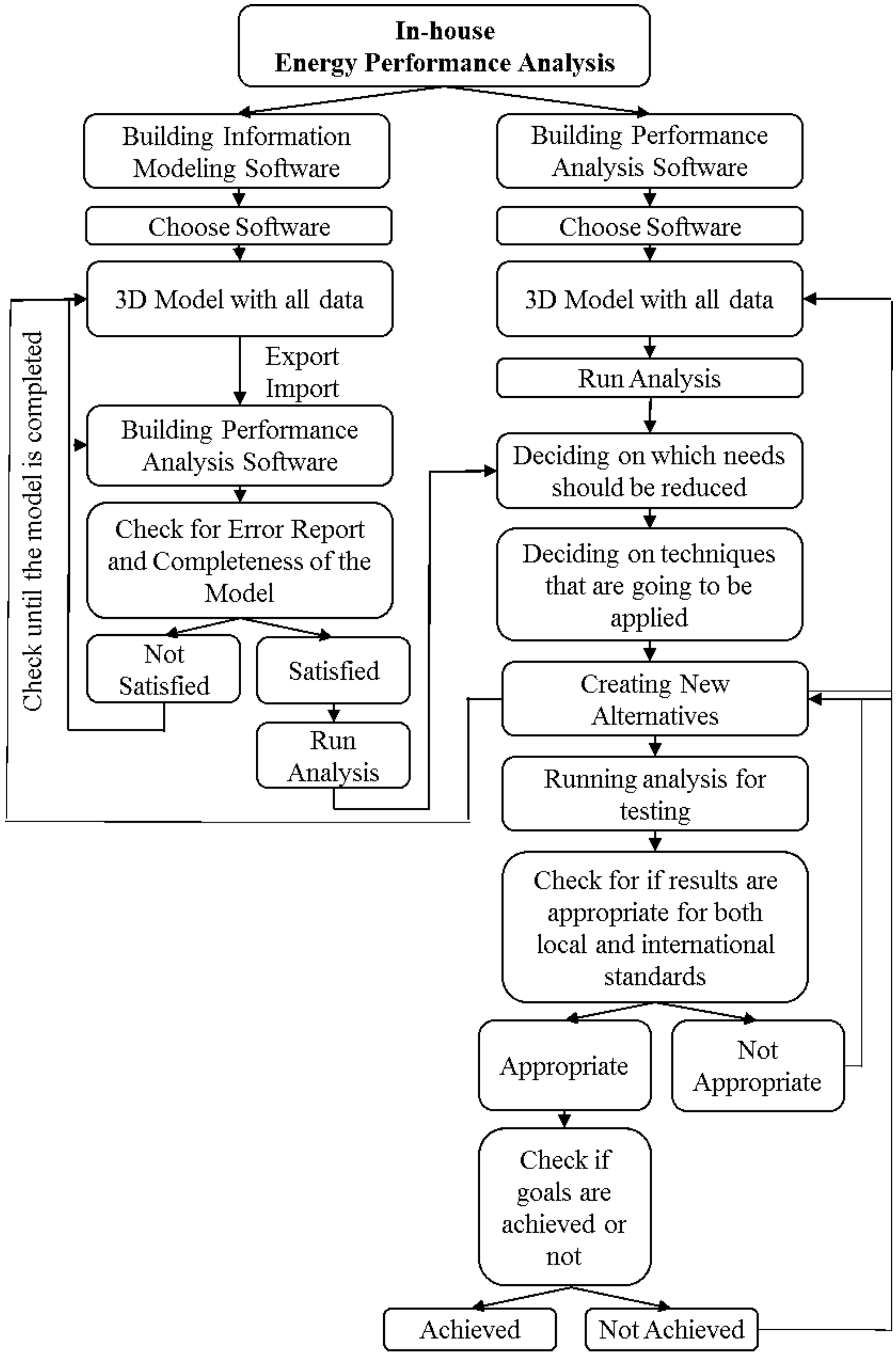

Figure 6.2. The In-House Way.

As indicated in Figure 6.2, the needs which should be reduced are decided after the base model is analysed. In this research, the base model has a significant need for space heating corresponding to 48% of the total energy need so it is selected to be one of the main factors that should be reduced. Through the modifications made for the base model, the need for space heating is greatly reduced. According to Energy Information Administration as cited in Lombard *et al.* (2008), dwellings, schools, offices, and hotels have average energy use intensity of 147 kWh/m^2, 262 kWh/m^2, 293 kWh/m^2, 316 kWh/m^2 in 2003 in the United States of America, respectively. There are many reasons of this difference between dwellings and the others. The first reason could be the LPD. For example, according to ASHRAE Handbook - Fundamentals (SI) (2009), LPD is given for classroom/lecture/training as 15 W/m^2, office having an open plan as 12 W/m^2, and varies for spaces in hotels such as 12 W/m^2 for lobby and 14 W/m^2 dining area. When considering this amounts are equal or greater than what is given for hotel/motel guest rooms that is 12 W/m^2; and given per meter square, the amount of energy need could reach significant amounts in these larger spaces compared to residential buildings. Therefore, using efficient lighting systems could be much beneficial in these types. The second reason could be that natural ventilation may be enough itself for ventilation purposes in the residential buildings; nevertheless, especially the others may need mechanical ventilation to ensure a high indoor air quality which is essential considering the purpose of use of these buildings; therefore, it is going to create an extra for electricity need when compared to residential buildings.

Whether the building is a new construction or not, an existing one, is another significant parameter for deciding on which techniques are going to be applied. If the building is a new construction, passive techniques which could be cheaper and easier to apply such as orientation and shape could be open to change. Doing so, design for daylighting could help reduce the electricity needs for some time periods of a day; moreover, it is free and healthier. In a broader sense, there is a great potential for reducing the energy need by combining the orientation and shape since Aksoy and Inalli (2006) as cited in Pacheco *et al.* (2012) imply that it is possible and likely to reach up to 36% of energy savings as mentioned in Section 3.6. On the other hand, in the existing buildings, the methods start differing as the building orientation and shape were already determined before. Therefore, the techniques wished to be applied could be harder and more expensive than the passive ones. In this circumstances, U-values on the envelope and efficiencies of the mechanical equipments could be investigated for reducing the energy needs. In cold climates, U-values can be tried to be reduced for allowing less heat transfer in cold winter between the indoor and outdoor environment. Moreover, ensuring a better HVAC in terms of efficiency by purchasing newer and modern ones which is most probably going to be expensive can help reduce the energy needs. To illustrate, the amount of energy demand for space heating has a fixed value; however, the amount of energy that is going to be need for providing it is depend on the efficiency of the heating mechanism. As a result, the techniques also differ whether the building is a new construction or not. Therefore, the sooner the better to increase the number of techniques that can be applied and to reduce the cost.

Location characteristics have an effect both on the results and the alternative creation. In this research, limiting U-value for the second region proposed by TS 825 is taken to be used in an alternative. In other countries, their respective local standards and regulations could be used when creating the design alternatives. Furthermore, the effect of location on the energy need and savings cannot be ignored. Even the same building in a different location could yield different results due to the change in weather and climate characteristics. Therefore, when creating the alternatives and making the analysis, location should be investigated properly to obtain more feasible results both for energy need and savings.

When the results obtained for base model using TS 825 is considered, it is found that making manual calculations for determining the energy need of a building is more disadvantageous in terms of the following perspectives. The early design stages are important for making decisions which could result in either making profit or losing money. The decisions made here is cheaper and easier to apply compared to the decisions made in the later stages. Therefore, this stage is mostly about creating and testing different design alternatives. Evaluating these design alternatives manually is error-prone because of the nature of the human; on the other hand, model reports can be taken from the softwares in which the errors going unnoticed may not be problems anymore. Moreover, TS 825, which also provides methods for manual computations, only deals with the heating requirement of a building. It is known that the energy need of a building is more than just being heating requirement. Natural gas usage for DHW, electricity for lights, electricity for equipment, and electricity for cooling are also included in the energy need of a building. TS 825 for these computations seems to be weak as it does not include any of these in details but just makes an estimation to include the effects of some of them. Furthermore, TS 825 is not a dynamic simulation and it determines the heating need of the building based on a fixed temperature values proposed by it. Nevertheless, the weather is a highly dynamic environment and testing a building based on a fixed temperature values does not yield so trustworthy results since TS 825 gives the same amount of heating need even though the real demand is going to change every year. Also, according to experts' opinion, the U-values proposed by TS 825 is greater than what is applied in Europe. Nevertheless, when the heating need of the base model calculated by both TS 825 and IES VE is compared, it is seen that the results are pretty close. TS 825 yields that 325.9 MWh/year is going to be required for the base model for supplying the heating demand; on the other hand, analysis made by IES VE for the base model reveals that 317.19 MWh of heating energy is going to be required for heating. This indicates that there is a 97.33% of accuracy between TS 825 and IES VE for this base model.

In the perspective of using a software for testing the energy performance is much more preferable than using a standard for manual computations. There are many advantages of using softwares for testing the energy performance of the buildings. To begin with, making analysis is easier and less time-consuming. This provides the users creating and evaluating the energy performance of several types of design alternatives as making modifications are easier. Moving on, the softwares provide dynamic analysis. This dynamic analysis tries to mimic the outside conditions. Therefore, it yields more trustworthy results. Thirdly, profiles for occupancy, lighting, equipment and so on are entered to the model. These profiles change based on the frequency of usage and types of the buildings. Moreover, they have a significant effect on the energy performance. Therefore, using software enables professionals to attach them into the software and obtain more realistic results. As the fourth advantage, the zoning is important for the energy performance of the building as the all zones are not heated or cooled at the same rate. Some of them may even not be heated or cooled. The zoning also have significant effects on the demands. Reflecting this onto a manual computations is a real test. Nevertheless, it is easy to do in a software. As the fifth advantage, using a software increases the chance of meeting high performance energy targets since several alternatives could be created and evaluating until achieving the specific targets. Also, several certification systems on green buildings require energy modeling for compliance. Considering all these, the softwares for testing the energy performance are more powerful and more trustworthy than the manually made computations.

When obtaining this results, the discount rate is assumed to be as 12% for this research. Nevertheless, it should be kept in mind that this value may change in the future, and this change is going to have some effects on the NPV. Moreover, these values obtained like all others are based on the assumptions made in the unit prices of natural gas and electricity for the future. These assumptions are made based on a trendline created by the unit prices of the previous years. These assumptions are used in this research rather than just assuming an escalation rate since escalation rate could have a great impact on the results, and not estimating it correctly could significantly change the results obtained in LCC. Furthermore, as it is going to be also mentioned in Section 7.2., the unit prices of the natural gas and electricity for the future are two determinants of NPV and IRR. Therefore, the rate of changes of these two has a significant importance on the results. To conclude, LCC analysis on energy performance could mislead in a highly changing environment in which it may be hard to estimate the future prices of those; nevertheless, could yield trustworthy results in a steady environment in which it may be easier to estimate the future prices of those. As a result, the unit prices of natural gas and electricity may be the parameters determining whether the investment is going to fail, or pay off, or be successful and result in making profit, so a good estimation should be made for these.

7. CONCLUSION

7.1. Summary

Energy performance of the buildings is becoming much more important as time goes on due to financial expectations from it as well as environmental and social concerns. In this perspective, the main aim of this research is to achieve an optimum green design in terms of LCC among the design alternatives created based on experts' opinion for a residential project. In this respect, a BIM model is created and different design alternatives being created by making some modifications on the base model are evaluated in terms of their energy performance and life cycle costs.

To achieve these, firstly, the model is analysed using TS 825 to reveal the weak points of calculations manually made based on a standard for energy performance. After this analysis; total heat loses and internal gain, monthly average solar gain, and the need of heating energy of the building are obtained. The need of heating energy found at the end reveals the amount of heating energy required for each month.

Secondly, the building is analysed in a software, namely, IES VE. In this analysis, a base model is created in the software at the beginning. The model includes data for the location, the climate and weather, design parameters, heating characteristics, cooling characteristics, domestic hot water, internal gains, and air exchange. Based on these input data, the base model is analysed to determine how much natural gas and electricity are required for supplying the demands.

Thirdly, using the base model, the design alternatives are created consulting to experts' opinion. The first design alternative created at this stage includes the proposed limiting U-values for the second region to its outer surfaces. The second design alternative consists of newer and modern heating mechanisms, and the properties come with smart homes as an addition to the first alternative. The third design alternative is the same with the second design alternative; nevertheless, it has 15% improvements on the U-values of the external surfaces of the second design alternative. Lastly, the fourth design alternative is again the same with the second design alternative; nevertheless, it has 30% improvements on the U-values of the external surfaces of the second design alternative. At the end of this stage, four design alternatives are analysed to obtain their energy performance.

Fourthly, there are some investment cost associated with the modifications made on the base model for creating these design alternatives. Besides, it is obvious that there are some savings provided by these modifications. To have a better understanding of if making investments are feasible or not, LCC analysis performed. Accordingly, cash flow diagrams for each design alternative are created. Using them, NPV, IRR, PI, ROE, and payback period are obtained to assess feasibilities of these alternatives. In regard of the profit evaluation methods who also consider the time effect of money, the results reveal that the highest NPV is observed at Alt. 4 having a NPV of 547,670.47 TL Alt. 4 is then followed by Alt. 3 by having a NPV of 544,387.13 TL, Alt. 2 having a NPV of 535,806.03 TL, and Alt. 1 having a NPV of 280,587.76 TL. Furthermore, in respect of IRR, the design alternatives are in order as Alt. 2, Alt. 3, Alt. 4, and Alt. 1, having IRRs of 55.19%, 53.93%, 51.33%, and 49.26%, respectively.

Lastly, the incremental rate of return analysis is performed to choose between design alternatives. The results obtained from this analysis yield that Alt. 4 is the optimum and the most feasible design alternative among all.

7.2. Further Suggestions

This research provides a way for achieving the optimum design in terms of LCC in a set of design alternatives created and analysed in a software. When creating the design alternatives, some modifications are made. As the number of factors having an effect on energy performance of a building is very high, there may be millions of different combinations of these factors. Assessing all these combinations seems to be an impossible task. Nevertheless, it is better to assess feasibilities of huge set of alternatives. Therefore, in this perspective, the number of design alternatives should be high as much as possible. By increasing the number of design alternatives, the chance of ignoring a better design alternative could be reduced. The higher the number of design alternatives, the lower the chance of ignoring a better design.

When analysing the energy performance of the building, the profiles, or schedules, used for occupancy, lighting, and so on. These profiles have a significant importance as the energy need is affected by these profiles. Even though some guidelines suggest profiles for different types of buildings, it should be kept in mind that those profiles are general ones. To achieve much more realistic results for energy performance of a building, the actual profiles should be used if possible. Using the actual profiles provides much more realistic amounts of energy need and the results become closer what they are going to be in real life. Besides, much trustworthy cash flow diagrams are obtained since the energy needs are calculated based on these actual profiles.

LCC analysis for this study is manually made; however, some softwares are also capable of making this analysis. As the trustworthiness of these analysis in a computer environment is based on the quality and quantity data input, the software usage can provide so realistic and close results what is going to be observed in real life if all data belong to these analysis is carefully entered.

The future cash flows have a significant importance for LCC analysis. As in this case, the savings provided by different design alternatives are calculated by the multiplication of the amount of energy saving and the unit price. The unit prices used here should be significantly paid attention. As mentioned in Section 6, the reason is that, the future unit price may not be as what it is estimated in a highly changing environment. In this type of environment, it is challenging to estimate what the future prices of this utilities are going to be. Deviations that may occur could cause unanticipated loss which may eventually result in losing money. Therefore, LCC analysis based on energy performance of a building could be much more trustworthy in a steady environment in which the future prices of these utilities change based on a limited amount of range. Therefore, LCC on energy performance is better to be made in a steady environment.

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APPENDIX A: INTERVIEW FORM

Table A.1. Open-Ended Interview Form.

OPEN-ENDED INTERVIEW FORM		
Â INFORMATION	**Date**	
Position **Experience (in years)**		
Company Age (in years)		

#	**QUESTIONS**
1	Why do employers want to make their buildings energy efficient so they consult to you?
2	What are the benefits of using BIM for sustainable design?
3	How does the process work for analysing the energy performance?
4	Which methods are applied first to improve the energy performance? Using the experiences or trying new techniques?
5	What do you want to say about the advantages of softwares for the early design stage?
6	Do you think that TS 825 works in practice in a good way?
7	What are the disadvantageous parts of TS 825?
8	What do you think about the relationship between the energy performance and LCC?
9	Which contributions do you make for benefiting at the early design in terms of passive design if possible?
10	What are the reasons for demands for energy efficient offices being higher than demands for energy efficient residents?
11	What can you say about the importance of the site to make contributions for sustainability?

APPENDIX B: CASH FLOW OF ALTERNATIVES

Table B.1. Cash Flow of Alt. 1.

NPV		IRR	ROE	PI	Payback Period	
280.587.76 TL		49.26%	23.68	4.98	2-3 years	
CASH FLOW						
Year	**Natural Gas Unit Price (TL/kWh)**	**Electricity Unit Price (TL/kWh)**	**Investment (TL)**	**Natural Gas Saving (TL)**	**Electricity Saving (TL)**	**Net (TL)**
0	0.0888	0.33183	-70.544.36 TL	- TL	- TL	- 70.544.36 TL
1	0.1045	0.34997	-	31.249.12 TL	95.10 TL	31.344.23 TL
2	0.1101	0.36327	- TL	32.923.72 TL	98.72 TL	33.022.44 TL
3	0.1157	0.37658	- TL	34.598.31 TL	102.34 TL	34.700.65 TL
4	0.1213	0.38988	- TL	36.272.90 TL	105.95 TL	36.378.86 TL
5	0.1269	0.40319	- TL	37.947.50 TL	109.57 TL	38.057.06 TL
6	0.1325	0.41649	- TL	39.622.09 TL	113.18 TL	39.735.27 TL
7	0.1381	0.4298	- TL	41.296.69 TL	116.80 TL	41.413.48 TL
8	0.1437	0.4431	- TL	42.971.28 TL	120.41 TL	43.091.69 TL
9	0.1493	0.45641	- TL	44.645.87 TL	124.03 TL	44.769.90 TL
10	0.1549	0.46971	- TL	46.320.47 TL	127.65 TL	46.448.11 TL
11	0.1605	0.48302	- TL	47.995.06 TL	131.26 TL	48.126.32 TL
12	0.1661	0.49632	- TL	49.669.66 TL	134.88 TL	49.804.53 TL
13	0.1717	0.50963	- TL	51.344.25 TL	138.49 TL	51.482.74 TL
14	0.1773	0.52293	- TL	53.018.84 TL	142.11 TL	53.160.95 TL
15	0.1829	0.53624	- TL	54.693.44 TL	145.72 TL	54.839.16 TL
16	0.1885	0.54954	- TL	56.368.03 TL	149.34 TL	56.517.37 TL
17	0.1941	0.56285	- TL	58.042.63 TL	152.96 TL	58.195.58 TL
18	0.1997	0.57615	- TL	59.717.22 TL	156.57 TL	59.873.79 TL
19	0.2053	0.58946	- TL	61.391.81 TL	160.19 TL	61.552.00 TL
20	0.2109	0.60276	- TL	63.066.41 TL	163.80 TL	63.230.21 TL
21	0.2165	0.61607	- TL	64.741.00 TL	167.42 TL	64.908.42 TL
22	0.2221	0.62937	- TL	66.415.60 TL	171.03 TL	66.586.63 TL
23	0.2277	0.64268	- TL	68.090.19 TL	174.65 TL	68.264.84 TL
24	0.2333	0.65598	- TL	69.764.79 TL	178.27 TL	69.943.05 TL
25	0.2389	0.66929	- TL	71.439.38 TL	181.88 TL	71.621.26 TL
26	0.2445	0.68259	- TL	73.113.97 TL	185.50 TL	73.299.47 TL
27	0.2501	0.6959	- TL	74.788.57 TL	189.11 TL	74.977.68 TL
28	0.2557	0.7092	- TL	76.463.16 TL	192.73 TL	76.655.89 TL
29	0.2613	0.72251	- TL	78.137.76 TL	196.34 TL	78.334.10 TL
30	0.2669	0.73581	- TL	79.812.35 TL	199.96 TL	80.012.31 TL

Table B.2. Cash Flow of Alt. 2.

NPV		**IRR**	**ROE**	**PI**	**Payback Period**	
535.806.03 TL		55.19%	25.69	5.51	2-3 years	
Year	**Natural Gas Unit Price (TL/kWh)**	**Electricity Unit Price (TL/kWh)**	**Investment (TL)**	**Natural Gas Saving (TL)**	**Electricity Saving (TL)**	**Net (TL)**
0	0.0888	0.33183	- 118.924.36 TL	- TL	- TL	- 118.924.36 TL
1	0.1045	0.34997	- TL	35.553.82 TL	24.911.82 TL	60.465.64 TL
2	0.1101	0.36327	- TL	37.459.10 TL	25.858.92 TL	63.318.02 TL
3	0.1157	0.37658	- TL	39.364.38 TL	26.806.02 TL	66.170.39 TL
4	0.1213	0.38988	- TL	41.269.65 TL	27.753.11 TL	69.022.77 TL
5	0.1269	0.40319	- TL	43.174.93 TL	28.700.21 TL	71.875.15 TL
6	0.1325	0.41649	- TL	45.080.21 TL	29.647.31 TL	74.727.52 TL
7	0.1381	0.4298	- TL	46.985.48 TL	30.594.41 TL	77.579.90 TL
8	0.1437	0.4431	- TL	48.890.76 TL	31.541.51 TL	80.432.27 TL
9	0.1493	0.45641	- TL	50.796.04 TL	32.488.61 TL	83.284.65 TL
10	0.1549	0.46971	- TL	52.701.31 TL	33.435.71 TL	86.137.03 TL
11	0.1605	0.48302	- TL	54.606.59 TL	34.382.81 TL	88.989.40 TL
12	0.1661	0.49632	- TL	56.511.87 TL	35.329.91 TL	91.841.78 TL
13	0.1717	0.50963	- TL	58.417.14 TL	36.277.01 TL	94.694.16 TL
14	0.1773	0.52293	- TL	60.322.42 TL	37.224.11 TL	97.546.53 TL
15	0.1829	0.53624	- TL	62.227.70 TL	38.171.21 TL	100.398.91 TL
16	0.1885	0.54954	- TL	64.132.97 TL	39.118.31 TL	103.251.29 TL
17	0.1941	0.56285	- TL	66.038.25 TL	40.065.41 TL	106.103.66 TL
18	0.1997	0.57615	- TL	67.943.53 TL	41.012.51 TL	108.956.04 TL
19	0.2053	0.58946	- TL	69.848.81 TL	41.959.61 TL	111.808.41 TL
20	0.2109	0.60276	- TL	71.754.08 TL	42.906.71 TL	114.660.79 TL
21	0.2165	0.61607	- TL	73.659.36 TL	43.853.81 TL	117.513.17 TL
22	0.2221	0.62937	- TL	75.564.64 TL	44.800.91 TL	120.365.54 TL
23	0.2277	0.64268	- TL	77.469.91 TL	45.748.01 TL	123.217.92 TL
24	0.2333	0.65598	- TL	79.375.19 TL	46.695.11 TL	126.070.30 TL
25	0.2389	0.66929	- TL	81.280.47 TL	47.642.21 TL	128.922.67 TL
26	0.2445	0.68259	- TL	83.185.74 TL	48.589.31 TL	131.775.05 TL
27	0.2501	0.6959	- TL	85.091.02 TL	49.536.41 TL	134.627.42 TL
28	0.2557	0.7092	- TL	86.996.30 TL	50.483.51 TL	137.479.80 TL
29	0.2613	0.72251	- TL	88.901.57 TL	51.430.61 TL	140.332.18 TL
30	0.2669	0.73581	- TL	90.806.85 TL	52.377.70 TL	143.184.55 TL

Table B.3. Cash Flow of Alt. 3.

NPV		IRR	ROE	PI	Payback Period	
544.387.13 TL		53.93%	25.09	5.37	2-3 years	
CASH FLOW						
Year	**Natural Gas Unit Price (TL/kWh)**	**Electricity Unit Price (TL/kWh)**	**Investment (TL)**	**Natural Gas Saving (TL)**	**Electricity Saving (TL)**	**Net (TL)**
0	0.0888	0.33183	- 124.475.44 TL	- TL	- TL	- 124.475.44 TL
1	0.1045	0.34997	- TL	37.001.69 TL	24.708.56 TL	61.710.25 TL
2	0.1101	0.36327	- TL	38.984.56 TL	25.647.93 TL	64.632.49 TL
3	0.1157	0.37658	- TL	40.967.43 TL	26.587.30 TL	67.554.73 TL
4	0.1213	0.38988	- TL	42.950.29 TL	27.526.67 TL	70.476.97 TL
5	0.1269	0.40319	- TL	44.933.16 TL	28.466.05 TL	73.399.20 TL
6	0.1325	0.41649	- TL	46.916.02 TL	29.405.42 TL	76.321.44 TL
7	0.1381	0.4298	- TL	48.898.89 TL	30.344.79 TL	79.243.68 TL
8	0.1437	0.4431	- TL	50.881.75 TL	31.284.16 TL	82.165.92 TL
9	0.1493	0.45641	- TL	52.864.62 TL	32.223.53 TL	85.088.16 TL
10	0.1549	0.46971	- TL	54.847.49 TL	33.162.91 TL	88.010.39 TL
11	0.1605	0.48302	- TL	56.830.35 TL	34.102.28 TL	90.932.63 TL
12	0.1661	0.49632	- TL	58.813.22 TL	35.041.65 TL	93.854.87 TL
13	0.1717	0.50963	- TL	60.796.08 TL	35.981.02 TL	96.777.11 TL
14	0.1773	0.52293	- TL	62.778.95 TL	36.920.40 TL	99.699.35 TL
15	0.1829	0.53624	- TL	64.761.82 TL	37.859.77 TL	102.621.58 TL
16	0.1885	0.54954	- TL	66.744.68 TL	38.799.14 TL	105.543.82 TL
17	0.1941	0.56285	- TL	68.727.55 TL	39.738.51 TL	108.466.06 TL
18	0.1997	0.57615	- TL	70.710.41 TL	40.677.88 TL	111.388.30 TL
19	0.2053	0.58946	- TL	72.693.28 TL	41.617.26 TL	114.310.53 TL
20	0.2109	0.60276	- TL	74.676.14 TL	42.556.63 TL	117.232.77 TL
21	0.2165	0.61607	- TL	76.659.01 TL	43.496.00 TL	120.155.01 TL
22	0.2221	0.62937	- TL	78.641.88 TL	44.435.37 TL	123.077.25 TL
23	0.2277	0.64268	- TL	80.624.74 TL	45.374.74 TL	125.999.49 TL
24	0.2333	0.65598	- TL	82.607.61 TL	46.314.12 TL	128.921.72 TL
25	0.2389	0.66929	- TL	84.590.47 TL	47.253.49 TL	131.843.96 TL
26	0.2445	0.68259	- TL	86.573.34 TL	48.192.86 TL	134.766.20 TL
27	0.2501	0.6959	- TL	88.556.21 TL	49.132.23 TL	137.688.44 TL
28	0.2557	0.7092	- TL	90.539.07 TL	50.071.61 TL	140.610.68 TL
29	0.2613	0.72251	- TL	92.521.94 TL	51.010.98 TL	143.532.91 TL
30	0.2669	0.73581	- TL	94.504.80 TL	51.950.35 TL	146.455.15 TL

Table B.4. Cash Flow of Alt. 4.

NPV		IRR	ROE	PI	Payback Period	
547.670.47 TL		51.33%	23.81	5.1	2-3 years	
CASH FLOW						
Year	**Natural Gas Unit Price (TL/kWh)**	**Electricity Unit Price (TL/kWh)**	**Investment (TL)**	**Natural Gas Saving (TL)**	**Electricity Saving (TL)**	**Net (TL)**
0	0.0888	0.33183	- 133.686.40 TL	- TL	- TL	- 133.686.40 TL
1	0.1045	0.34997	- TL	38.358.68 TL	24.445.09 TL	62.803.77 TL
2	0.1101	0.36327	- TL	40.414.27 TL	25.374.45 TL	65.788.71 TL
3	0.1157	0.37658	- TL	42.469.85 TL	26.303.80 TL	68.773.65 TL
4	0.1213	0.38988	- TL	44.525.44 TL	27.233.16 TL	71.758.59 TL
5	0.1269	0.40319	- TL	46.581.02 TL	28.162.51 TL	74.743.54 TL
6	0.1325	0.41649	- TL	48.636.61 TL	29.091.87 TL	77.728.48 TL
7	0.1381	0.4298	- TL	50.692.19 TL	30.021.22 TL	80.713.42 TL
8	0.1437	0.4431	- TL	52.747.78 TL	30.950.58 TL	83.698.36 TL
9	0.1493	0.45641	- TL	54.803.36 TL	31.879.93 TL	86.683.30 TL
10	0.1549	0.46971	- TL	56.858.95 TL	32.809.29 TL	89.668.24 TL
11	0.1605	0.48302	- TL	58.914.53 TL	33.738.65 TL	92.653.18 TL
12	0.1661	0.49632	- TL	60.970.12 TL	34.668.00 TL	95.638.12 TL
13	0.1717	0.50963	- TL	63.025.70 TL	35.597.36 TL	98.623.06 TL
14	0.1773	0.52293	- TL	65.081.29 TL	36.526.71 TL	101.608.00 TL
15	0.1829	0.53624	- TL	67.136.87 TL	37.456.07 TL	104.592.94 TL
16	0.1885	0.54954	- TL	69.192.46 TL	38.385.42 TL	107.577.88 TL
17	0.1941	0.56285	- TL	71.248.04 TL	39.314.78 TL	110.562.82 TL
18	0.1997	0.57615	- TL	73.303.63 TL	40.244.14 TL	113.547.76 TL
19	0.2053	0.58946	- TL	75.359.21 TL	41.173.49 TL	116.532.70 TL
20	0.2109	0.60276	- TL	77.414.80 TL	42.102.85 TL	119.517.64 TL
21	0.2165	0.61607	- TL	79.470.38 TL	43.032.20 TL	122.502.58 TL
22	0.2221	0.62937	- TL	81.525.97 TL	43.961.56 TL	125.487.52 TL
23	0.2277	0.64268	- TL	83.581.55 TL	44.890.91 TL	128.472.46 TL
24	0.2333	0.65598	- TL	85.637.14 TL	45.820.27 TL	131.457.40 TL
25	0.2389	0.66929	- TL	87.692.72 TL	46.749.62 TL	134.442.35 TL
26	0.2445	0.68259	- TL	89.748.31 TL	47.678.98 TL	137.427.29 TL
27	0.2501	0.6959	- TL	91.803.89 TL	48.608.34 TL	140.412.23 TL
28	0.2557	0.7092	- TL	93.859.48 TL	49.537.69 TL	143.397.17 TL
29	0.2613	0.72251	- TL	95.915.06 TL	50.467.05 TL	146.382.11 TL
30	0.2669	0.73581	- TL	97.970.65 TL	51.396.40 TL	149.367.05 TL