İSTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

ECONOMIC ASSESSMENT OF TRANSPARENT ELEMENTS IN THE INTEGRATED USE OF ATRIUM AND COURTYARD IN DIFFERENT REGIONS OF TURKEY

Ph.D THESIS

Tofigh TABESH

Department of Architecture

Building Science Program

JUNE 2016

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

TÜRKİYE'DE BÖLGELERE GÖRE ATRİUM VE AVLULU BİNALARIN ENTEGRE KULANIMININ SAYDAM BİLEŞEN AÇISINDAN EKONOMİK OLARAK DEĞERLENDİRİLMESİ

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Tofigh-TABESH, a Ph.D. student of İTU Graduate School of Science Engineering and Technology student 502102010, successfully defended the thesis/dissertation entitled "ECONOMIC ASSESSMENT OF TRANSPARENT ELEMENTS IN THE INTEGRATED USE OF ATRIUM AND COURTYARD IN DIFFERENT REGIONS OF TURKEY", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To my parents,

FOREWORD

I am blessed and I thank God for the ability to accomplish such an amazing achievement. I would like to thank my supervisor Assoc. Dr. Begüm Sertyeşilışık for excellent guidance and giving me valuable advice and support always when needed. Evaluating new topics with her was always interesting for me to investigate and provided me with alternative ways to improve my dissertation. She taught me how to be a researcher and encouraged me to determine appropriate solution methodologies to organize research findings. Besides completing a PhD dissertation, she stimulated and directed me in publishing conference papers, journal papers and a book. Without her support, I could not have done what I was able to do. She was very generous in sharing her experiences on architectural engineering, academic life and beyond. These experiences will be my primary guide during my life and academic career.

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I wish to acknowledge my friends; my colleagues and everybody who supported me.

June 2016 Tofigh TABESH
(Architect)

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ABBREVIATIONS

HVAC	**:** Heating, Ventilation and Air Conditioning
ASHRAE	**:** American Society of Heating, Refrigerating and Air-Conditioning Engineers
IEA	**:** International Energy Agency
EU	**:** European Union
GUI	**:** Graphical Usage Interface
CAD	**:** Computer-Aided Drafting
WWR	**:** Window-to-Wall Ratio
SHGR	**:** Solar Heat Gain Coefficient Ratio
COP	**:** Coefficient of Performance
IEA	**:** International Energy Agency
TS	**:** Turkish Standard
LCA	**:** Life Cycle Assessment
LCE	**:** Life Cycle Energy
WLCC	**:** Whole Life Cycle Cost
LCC	**:** Life Cycle Cost
LCCA	**:** Life Cycle Cost Analysis
kWh/m^2	**:** Kilowatt Hour per Square Meter
CPI	**:** Consumer Price Index

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ECONOMIC ASSESSMENT OF TRANSPARENT ELEMENTS IN THE INTEGRATED USE OF ATRIUM AND COURTYARD IN DIFFERENT REGIONS OF TURKEY

SUMMARY

During the last two decades, energy consumption and CO_2 emissions has grown all over the world. Certainly, reducing emissions of greenhouse gases decreasing energy consumption and providing security of energy supply are main global targets against environmental problems. As a candidate member of the European Union, Turkey is an energy-importing country because of its limited energy sources. Furthermore, Turkey's energy demand has increased annually due to population increase and economic growth. As a result, Turkey is going to face specific problems on providing energy and declining pollutant on environment. All over the industrialized world, the building sector accounts for more than one third of the global energy consumption. It is expected that, awareness and demand for better quality of the indoor environment would lead to rising building energy consumption in the coming years. Considering type of buildings, offices and retail spaces are among the most energy-intensive typologies in the non-domestic building sector. The commercial buildings sector consumes a huge amount of energy and its energy consumption pattern will likely increase sharply in the near future. As a result, there has been a general movement towards finding effective design strategies to reduce the energy demands of buildings and encourage further awareness of energy-conscious design. The energy efficiency of built environment can play an important role in reducing the challenges of climate change, resource diminution, and wider environmental issues. Lately, due to crisis in energy consumption, energy efficiency is becoming more of a priority in recent years and there is a need to consider passive design options (e.g., building form, orientation, and envelope) more carefully and to enhance energy efficient indoor air quality by energy-efficient means.

Over the past few decades there have been changes in the environmental and energy policy. New strategies, regulations and economic measures related to sustainability and energy conservation have been introduced. Life Cycle Assessment (LCA) is intensively employed for the evaluation of the environmental impacts in relation to the production, use, disposal and recycling of the products, containing the materials made from. life cycle energy analysis, operating energy has a major share of total energy

usage during building lifespan. Since operating energy of the buildings has the largest share in the life cycle energy distribution, reducing its share appears to be an important criterion in the design of buildings. Design of low energy building can achieve by reducing its operating energy through active and passive technologies. In order to reduce operational energy demand of the buildings, usage of integrated passive and active technics come into play. For instance, using capability of atria and courtyards can be effective. Both building types have ability to provide daylight and additional heating or cooling to adjacent spaces and reduce transmission losses. The thermal performance of courtyard/atrium buildings depends greatly on the factors (such as geometry, location, latitude, height, external climate, microclimate, etc.) which involve working with the climate rather than against it, so that the need for artificial space conditioning is reduced.

There have been various researches on the courtyard and atrium design. None of these researches, however, considered energy-efficient and integrated usage of atrium and courtyard. There is a gap in the literature with respect to research into improving the energy performance of the buildings through the integrated usage of atria and courtyards. The current research is significant as it fulfills these gaps in the literature.

This research aims to investigate seasonal usage of courtyard and atrium for enhancing energy efficiency and energy cost effectiveness of the integrated usage of atrium and courtyard buildings in five cities of Turkey which namely are Istanbul, Ankara, Antalya, Erzurum and Diyarbakir as representatives of mild-humid, temperate, hot-humid, cold, and hot-dry climate respectively. This research aims to identify the effect of seasonal time on the integrated usage of courtyard and atrium to find a cost optimal energy usage in commercial office buildings. The research objectives have been listed as follows:

- Optimization of the passive energy performance of courtyard and atrium spaces in buildings.
- Studying the effect of using pivot windows on energy consumption of atria and courtyards as well as of their integrated usage.
- Investigation of energy performance of the courtyard and atrium buildings to find an optimum integrated solution.

- Establishment of an integrated atrium-courtyard building to enhance sustainability of the buildings and to minimize their energy consumption in the operation phase of the buildings carrying out lifecycle cost analysis.

This research answers to the following main research questions:

- How can we optimize the passive performance of courtyard and atrium space in the buildings?
- How can we integrate atrium and courtyard usage to increase energy efficiency of the buildings?
- How can we integrate atrium and courtyard usage to minimize the operational cost?

Thermal behavior of two buildings, modeled within the scope of this research, were analyzed. One of the models had a central atrium enclosed with skylight and the other had a central courtyard. This research examined thermal performance of both atrium and courtyard spaces as well as their integrated usage. DesignBuilder as an interface and Energy Plus (based on ASHRAE) as an analytical software were used to find thermal behavior of atrium and courtyard with regard to climatic variables in Turkey. This research is original and contributes to the literature, as it investigates the integrated usage of atrium and courtyard with respect to the energy efficiency.

The findings revealed that the integrated usage of a courtyard and atrium can save energy in all five climates if a courtyard mode/strategy is adopted during the summer and an atrium architectural mode is used in the cold months. The results of this research also showed that using the passive characteristics of courtyards, atria, and, most importantly, their integrated usage influences energy consumption.

Transforming atrium into the courtyard by investing on pivot windows on the skylight of atrium area has acceptable payback time in Antalya, Diyarbakir and Istanbul, however in Erzurum and Ankara has senseless compensation.

Regarding to investigated certain characteristic of atrium and courtyard on adjacent building, natural ventilation was turned off during simulation process.

Since a number of alternatives appear to impact on building energy consumption, further studies are recommended to be carried out on the energy performance impacts of the integration of other passive energy strategies (e.g., the stack effect) on buildings.

TÜRKİYE'DE BÖLGELERE GÖRE ATRİUM VE AVLULU BİNALARIN ENTEGRE KULANIMININ SAYDAM BİLEŞEN AÇISINDAN EKONOMİK OLARAK DEĞERLENDİRİLMESİ

ÖZET

Son yirmi yılda enerji tüketimi ve CO_2 emisyonu tüm dünyada artmıştır. Sera gazları ve diğer toksinlerin emisyonlarının azaltılması, enerji tüketiminin azaltılması ve enerji arz güvenliğinin sağlanması çevre sorunlarına karşı ana küresel hedeflerdir. Avrupa Birliği'yle müzakere halindeki Türkiye, sınırlı enerji kaynakları nedeniyle enerji ithal eden bir ülkedir. Türkiye'nin enerji talebi nüfus artışı ve ekonomik büyüme sebebiyle her yıl artmaktadır. Bu nedenle, Türkiye enerji sağlamak ve çevre üzerindeki kirletici etkisini azaltmak gibi özel sorunlarla karşı karşıya kalmaktadır. Bütün sanayileşmiş dünyada, küresel enerji tüketiminin üçte birden fazlası inşaat sektörü için kullanılmaktadır. İç ortamın hava kalitesinin arttırılması isteği, binaların önümüzdeki yıllarda yükselen enerji tüketimiyle daha da artacaktır. Binaların tipi göz önüne alındığında ofis ve perakende alanları ticari alan tipolojileri arasında en enerji-yoğun tipolojiler arasında bulunmaktadır. Ticari bina sektörü büyük miktarda enerji tüketmektedir ve ayrıca enerji tüketimleri yakın gelecekte muhtemelen hızla artacaktır. Sonuç olarak; binaların enerji taleplerini azaltmaya ve enerji bilinçli tasarımın daha fazla farkındalığını teşvik eden, etkili tasarım stratejileri bulmaya yönelik genel bir hareket olmuştur. Yapısal çevrenin enerji verimliliği, iklim değişikliği ve çevre sorunlarının azaltılmasında önemli rol oynamaktadır. Enerji tüketimi krizi nedeniyle enerji verimliliği, son yıllarda bir öncelik haline gelmektedir. Bu sebeple enerji etkinliğini ve iç ortamın hava kalitesini arttırmak için pasif tasarım seçeneklerini (bina yapısı, yönlendirme ve bina kabuğu gibi) dikkate almaya ihtiyaç vardır.

Son birkaç yıldır; yeni stratejiler, yönetmelik ve sürdürülebilirlik ve enerji tasarrufuyla ilgili ekonomik önlemlerle, çevre ve enerji politikasında değişiklikler olmuştur. Yaşam Döngüsü Analizi; üretim, kullanım, ortadan kaldırma ve geri dönüşümle ilgili çevresel etkilerin değerlendirilmesinde bir yöntem olarak kullanılmaktadır. Yaşam Döngüsü Analizinin başka bir yöntemi ise inşaat sanayi için uygun bulunan geçen sene enerji verimliliği için kullanılan enerjiyi analiz etmektir. Çalışmalar yaşam döngüsü enerji analizinde işletme enerjisinin bina ömrü boyunca toplam enerji kullanımında önemli bir paya sahip olduğunu göstermektedir. Binaları işletmenin enerjisi yaşam döngüsü enerji dağılımında en büyük paya sahip olduğundan, bina yaşamı boyunca kullanılan

enerjinin azaltımı binaların tasarımında en önemli yön olarak görünmektedir. Düşük enerjili bina tasarımı aktif ve pasif teknolojiler aracılığıyla işletme enerjisini azaltarak elde edilmektedir. Binaların operasyonel enerji talebini azaltmak için, entegre pasif ve aktif tekniklerin kullanımı devreye girer. Örneğin, atrium ve avluların özelliklerini kullanmak bu konuda son derece etkili olabilir. Her iki yapı tipinin entegre kullanımı ile iletim kayıplarını azaltarak; gün ışığı sağlama, ek ısıtma veya soğutma yapabilme yeteneklerinden yararlanılabilir. Avlulu / atriumlu binaların termal performansı büyük ölçüde geometri, konum, enlem, yükseklik, dış iklim, mikroklima gibi faktörlere bağlıdır. Bu faktörler, iklimle uyumlu çalıştıklarından yapay alanların havalandırma ihtiyacı azalır.

Avlu ve atrium tasarımı üzerinde çeşitli araştırma ve çalışmalar yapılmıştır. Bunların hiçbiri, atrium ve avlunun entegre kullanımıyla enerji verimliliği konusunu içermez. Literatürde atrium ve avlular entegre kullanımı ile enerji performansının geliştirilmesi konusunda bir boşluk vardır. Mevcut araştırma literatürdeki bu boşlukların doldurulması açısından önemlidir. Türkiye'nin hafif-nemli, sıcak-menli, soğuk, ılıman ve sıcak kuru iklim temsileri olan beş ilinde: İstanbul, Ankara, Antalya, Erzurum ve Dıyarbakır'da avlu ve atriumun entegre kullanımı enerji performansı açısından incelenmiştir. Bu araştırmada avlu ve atriumun mevsimsel kullanımıyla enerji verimliliğinin artırılması ve enerji maliyet etkisinin araştırılması amaçlanmıştır.

Bu araştırma, avlu ve atriumun entegre kullanımıyla mevsimsel zaman etkisini belirleyerek, ticari ofis binalarının optimal enerji kullanımını maliyetini araştırmaktadır. Araştırma hedefleri aşağdaki şekilde özetlenebilir:

- Binalarda avlu ve atrium alanlarının pasif enerji performansının optimizasyonu.
- Pivot pencerelerin, atrium ve avluların entegre kullanımında enerji tüketimine etkisinin incelenmesi.
- Avlulu ve atriumlu binalarda en uygun entegre çözümü bulmak için enerji performansının incelenmesi.
- Binaların sürdürülebilirliğini artırmak için entegre atrium ve avlulu binaların yaşam döngüsü maliyet analizi yapılarak binaların işletme aşamasındaki enerji tüketimini en aza indirmek.

Bu araştırmanın odaklandığı araştırma soruları aşağıda sunulmuştur:

- Binalarda avlu ve atrium alanlarının pasif performansı nasıl optimize edilebilir?
- Binaların enerji verimliliğini artırmak için avlu ve atrium kullanımı nasıl entegre edilebilir?
- Operasyonel maliyeti en aza indirmek için avlu ve atrium kullanımın nasıl entegre edilebilir?

Bu araştırma kapsamında iki binanın termal davranışı modellenerek analiz edilmiştir. Bunlardan biri ışıklık ile kapalı bir merkezi atriumu olan bina, diğeri ise merkezi bir avlusu olan bina olarak planlanmıştır. Bu araştırmada, avlu ve atrium alanlarının entegre kullanımınının ısıl performansı incelenmiştir. DesignBuilder arayüzü ve Energy Plus (ASHRAE'ye dayalı) analitik yazılımı, Türkiye'de iklim değişkenleri açısından avlu ve atriumun termal davranışını bulmak için kullanılmıştır. Bu araştırma, enerji verimliliği konusunda avlu ve atriumun entegre kullanımını araştıran orijinal ve literatüre katkı sağlayacak bir çalışmadır.

Bulgular, bir avluyla ve atriumun entegre (avlu modu yaz aylarında, atrium modun soğuk aylarda) kullanımının beş iklimde enerji tasarrufu sağladığını göstermiştir. Bu araştırmanın sonuçları, avlu, atrium ve özellikle ikisinin entegre halinin pasif özelliklerinin enerji tüketimini etkilediğini göstermiştir. Atrium alanını ışıklık pivot pencerelerle atriuma dönüştürmek, Antalya, Diyarbakır ve Istanbul'da kabul edilebilir yatırım geri ödemesi sağlarken, bu durum Erzurum ve Ankara'da anlamsızdır.

Avlu ve atriumun bitişik binalarda belirli karakteristiklerini araştırmak için doğal havalandırma işlemi simülasyon sırasında kapalıydı.

Bina enerji tüketimi üzerinde, ileride yapılacak çalışmalarda binaların diğer pasif enerji stratejilerinin entegrasyonunun enerji performansına etkilerinin araştırılması tavsiye edilmektedir.

1. INTRODUCTION

The concerns over global warming and need for reduction of high emission of greenhouse gases, ever-growing energy consumption and higher global oil prices suggest the need for long-term demand for the utilization of strategies for indoor climate modification in promoting comfortable indoor environment[1]. Feng et al (2009) expressed that the building industry is considered to be an important contributor to the total national energy consumption. It is expected that the proportion of building energy consumption in national energy consumption will keep rising in the coming years[2]. Cai et al, (2009) stated that due to the improvement of the living requirements and the rapid urbanization, there will be a dramatic increase in the amount of energy consuming appliances (such as air-conditioners) and built environment, which will result in more energy consumption[3]. For instance, Steemers, (2003) highlighted that in the UK, buildings account for about half of all energy consumption, compared to 41% in Europe and 36% in the USA. Energy efficiency of built environment in urban areas is an important factor in reducing the challenges of climate change, resource diminution and wider environmental issues [4]. The modern day practice does not give due respect to passive and natural environment control measures in buildings. With modern materials and technology, the buildings of present architectural style results in high energy consumption, in an attempt to provide indoor thermal comfort indoors.

Designing without taking into consideration proper design of building form, orientation, and envelope can lead to considerable increase in heat gains and energy usage. Givoni (1994) analyzed several specific issues related to adjacent outdoor spaces such as courtyards and internal patios. With some details, courtyards can provide a pleasant outdoor environment and also improve the indoor thermal conditions[1]. The courtyard can modify the climatic conditions of the ambient environment and thus improve the indoor climate by shading the walls, increasing the insulation value of the adjacent walls by dense and high shrubs and vines, and lowering the air temperature by evaporative cooling systems such as wetted pavement, wet walls, or a small pond with a fine spray[1].

Currently, efforts are made to determine the influence of windows on the energy consumption and economy of high-rise buildings. The area and orientation of glazing have a great impact on building energy usage [5].

Modeling energy usage in buildings is an important step towards designing and implementing policy measures related to energy savings in buildings. Simulation of buildings' thermal-performances is necessary to predict comfort of the occupants in buildings and to identify alternate mechanical control-systems for achieving better indoor thermal environments.

1.1 Problem Definition

The annual energy consumption in European office building varies from 100 to 1000 kWh/m^2 of conditioned floor space, depending on location, construction, HVAC and lighting installations, use and type of office equipment, operating schedules, etc.[6].

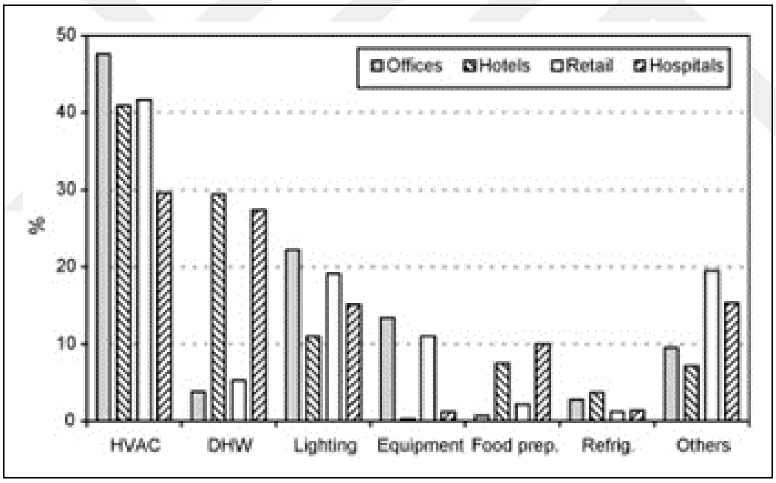


Figure 1.1 : Consumption by end use for different building type[6].

Table 1.1: Energy use in the commercial sector by building type[7].

Table 5
Energy use in the commercial sector by building type

Building type	USA (%)	Spain (%)	UK (%)
Retail	32	22	22
Offices	18	33	17
Hotels and restaurants	14	30	16
Schools	13	4	10
Hospitals	9	11	6
Leisure	6	–	6
Others	9	–	23

Year 2003. Sources: EIA, IDAE and BRE.

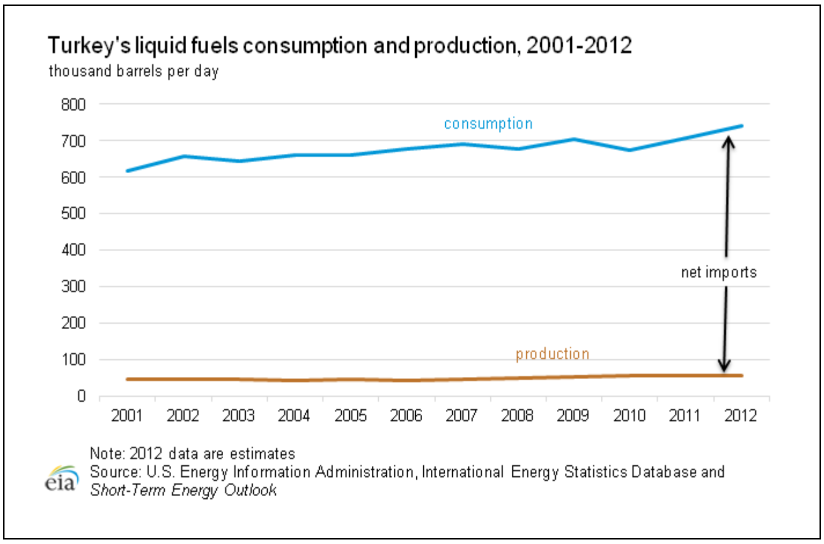


Figure 1.2 : Turkey's liquid fuels consumption and production, 2001-2012 [8].

Offices and retail spaces are among the most energy intensive typologies in the nondomestic building sector as they account for over 50% of total energy consumption for non-domestic buildings[7].

Recent work on the end-use of load characteristics of high-rise air-conditioned office buildings has revealed that air-conditioning and electric lighting account for respectively, 30–60% and 20–35% of total building electricity consumption [9].

1.2 Research Method

Thermal behavior of two buildings, which will be modeled within the scope of this research, will be analyzed. One of them is planned to have a central atrium enclosed with skylight and the other is planned to have a central courtyard. This research will examine thermal performance of both atrium and courtyard spaces as well as their integrated usage. DesignBuilder as an interface and Energy Plus (based on ASHRAE) as an analytical software will be used to find thermal behavior of atrium and courtyard with regard to climatic variables in Turkey, different glazing type, and glazing area ratios as well as different numbers of floors. This research is original and will contribute to the literature, as it investigates the integrated usage of atrium and courtyard with respect to the energy efficiency.

The analyses which will be carried out within the scope of this research will be based on two main building energy performance simulation tools, namely EnergyPlus and DesignBuilder.

The EnergyPlus will be used for calculating heating, cooling, lighting, ventilating and other energy flows. As EnergyPlus has been validated under the comparative Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs BESTEST/ASHARE STD 140, it is reliable [10].

DesignBuilder, as GUI (Graphical Usage Interface) for EnergyPlus the DesignBuilder is the most comprehensive interface for EnergyPlus available today. Its current version includes a simplified CAD interface, templates, wizards, and most compact air system configurations of EnergyPlus. The typical usage of DesignBuilder will be used in this research to evaluate façade options, and to analyze thermal simulation, daylighting, total energy consumption, CO_2 reduction, natural ventilation, and sizing of HVAC equipment and systems [11].

1.3 Research Aims and Objectives

A substantial part of energy consumption happens in buildings especially in commercial office buildings. The considerable part of this consumption is related to design of buildings which has significant role in energy efficiency. In the literature, there are researches on the energy performance optimization in buildings. This research aims to identify the effect of seasonal time on the integrated usage of courtyard and atrium to find a cost optimal energy usage in commercial office buildings. The research objectives can be listed as follows:

- Optimization of the passive energy performance of courtyard and atrium spaces in buildings
- Studying the effect of glazing type on energy consumption of atria and courtyards as well as of their integrated usage.
- Investigation of energy performance of the courtyard and atrium buildings to find an optimum integrated solution.
- Establishment of an integrated atrium-courtyard building to enhance sustainability of the buildings and to minimize their energy consumption in the operation phase of the buildings carrying out lifecycle cost analysis.

1.4 Significance of the Research

The research gives valuable feedback to professionals and academicians especially with respect to the effect of the courtyard adjacent spaces material on the energy performance. The findings are expected to help increase in energy efficiency and thermal comfort as well as decrease in CO_2 emission.

The advanced technology of highly glazed atriums is currently being incorporated in the design of large modern buildings in order to take advantage of day lighting, solar heating and natural ventilation. This paper aims to have an approach to the natural ventilation on central, open to sky spaces by examining samples of modern building. This study is expected to encourage building designers to reconsider natural ventilation as an important strategy for green building in terms of energy efficiency demands and environmental concerns.

As literature survey revealed, there is gap in the literature with respect to the research on the integrated usage of atrium and courtyard in a within a building so that energy performance of the building can be improved. The current research is significant as it contributes to filling this gap in the literature. The benefits of the research have been summarized in the (Table 1.2).

Table 1.2 : Benefits of the current research.

Categories	Importance for the project
Health effects (increased health, reduced illness, reduced sick building syndrome…)	High
Ecological effects (reduced CO_2 emission, reduced air pollution, reduced fossil fuel consumption…)	High
Economic effects (improved productivity of building users, reduced energy consumption….)	High
Social effects	High

2. A BRIEF REVIEW OF ATRIA AND COURTYARDS

2.1 Historic Development of Buildings with Courtyards

Since centuries ago, one of the most distinctive forms of residential architecture has been the house with a courtyard in hot-dry, and warm-humid climates [12]. It was chiefly due to the requirements of the climate that the courtyard came into being. The function of courtyard for the residents was to accumulate cool air during the night and a source of shade in the daytime [13](See Figure 2.1).

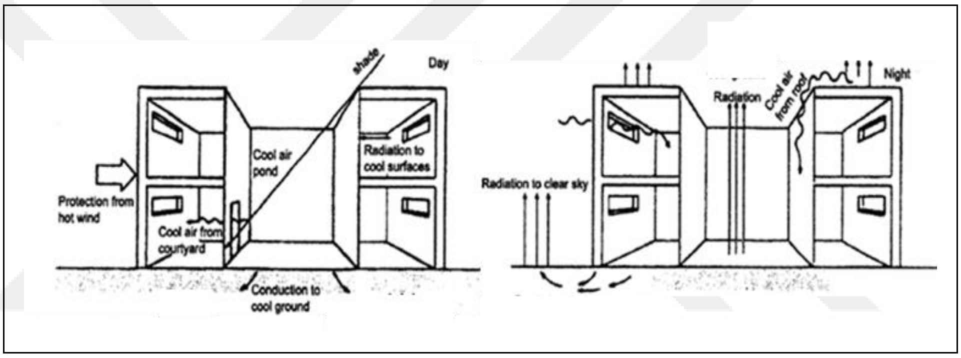


Figure 2.1 : Thermal behavior of courtyard during day and night.

Courtyard housing can be considered as one of the forms of residential domicile which has been developed as the oldest one. The location of the earliest case of a house with a courtyard at Ur on the Euphrates River in Mesopotamia was learned through archaeological discoveries (See Figure 2.2).

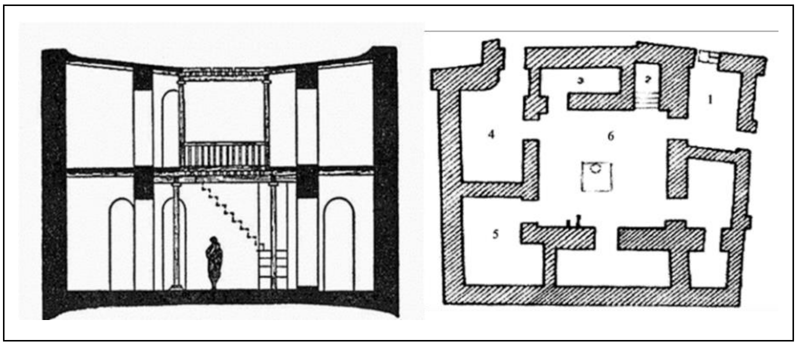


Figure 2.2 : Section (left) and plan (right) of House at Ur, Mesopotamia.

Its floor plan was constructed around a square courtyard. Round the courtyard, the rooms were arranged and the second floor of the house was open to the courtyard.

Fired brick was its main building material. The date of the house went back to around 2000 B.C. [14]. There was a diversity of living purposes causing courtyards to be used. For instance, they were utilized as a living room, a recreational room, a kitchen, or a family room in the Mediterranean houses.

2.1.1 China

The Chinese courtyard was a place of privacy and meditation. The courtyard often consisted of a garden and water feature. In a Chinese house with a courtyard, some self-standing houses were organized in a way to surround a courtyard. Different members of a family lived in each of the houses (See Figure 2.3). As the climate in southern China was a warm tropical one, courtyard was used as a cooling technique [14].

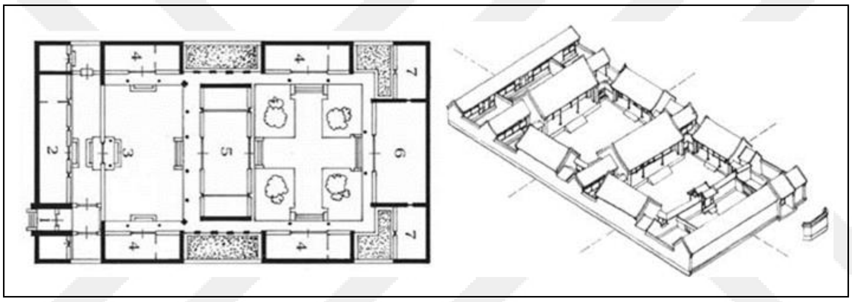


Figure 2.3 : Plan and 3D view of Chinese traditional courtyard at Beijing.

2.1.2 Italy (Before Christ)

The Etruscans had commenced to construct a certain kind of house with a courtyard called as the atrium house in Italy by around 700 B.C. There were several rooms round a little courtyard in the atrium house, with a cistern in the center of the courtyard catching the rainwater from the roof for drinking. The courtyard was open to the sky, and served as a private outdoor space (See Figure 2.4).

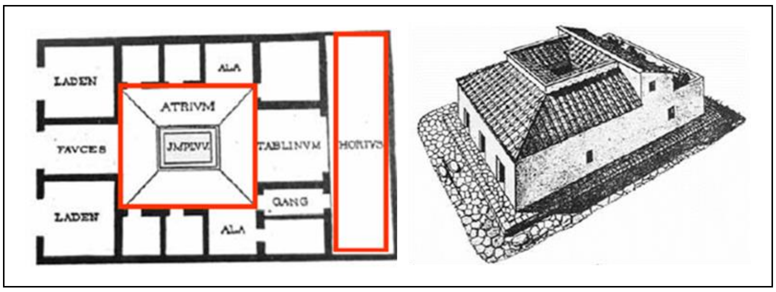


Figure 2.4 : Plan (left) and 3D view (right) of traditional Roman house.

2.1.3 Italy

After Romans' subjugating southern Italy from the Greeks about 275 B.C. their architecture style got a mixture of the elements inherited from the Greeks and the Etruscans. The atrium house met up with the Greek peristyle house (court enclosed by columns) (See Figure 2.5). People began to build larger houses that combined the two styles, the atrium- peristyle house. The location of an atrium would be in the front, which was near the street, while a peristyle would be in the back part of the house [14].

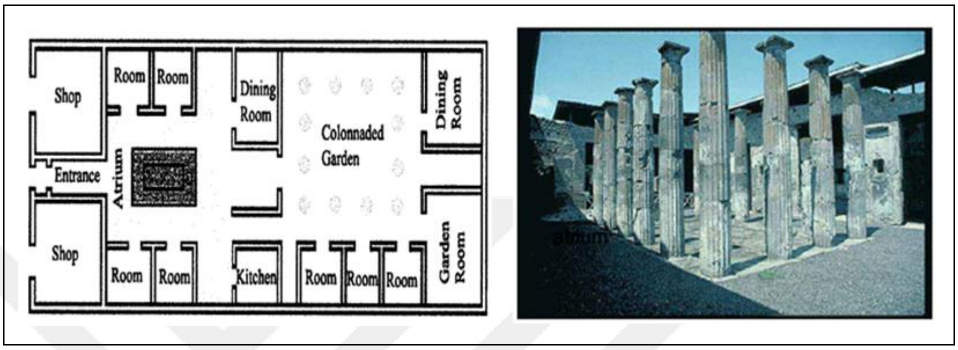


Figure 2.5 : Plan (left) and picture (right) of traditional atrium- peristyle house, A.C.

During the era of early Christian architecture, which extended to the eleventh century, the atrium was common in early Christian churches as the main entrance. The atrium was a large arcaded or colonnaded open court, serving as a general meeting place, in front of the church itself. There was also a fountain or well placed in the middle of the atrium for the worshipers to wash their hands before they went into the church [14].

2.1.4 Middle East

In the Middle East, courtyards were employed for achieving the best inside thermal comfort, during the day or at night, within the local limits of material (See Figure 2.6).

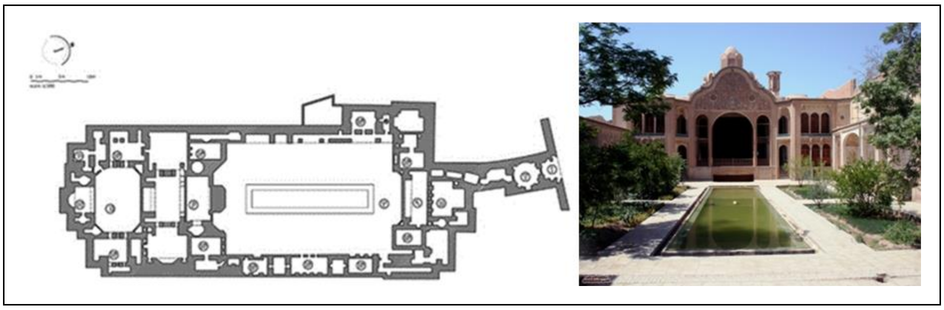


Figure 2.6 : Plan (left) and picture (right) of courtyard house, Kashan, Iran.

Most activities were moved during the year as proper to conform the temperature alterations and the sun location. In some Islamic cultures, private courtyards supply the best outdoor space for women, according to their cultures, for relaxation without being observed in a sheltered place having a pool, outdoor furniture and trees surrounding courtyard.

Moreover, there were other advantages provided by courtyards in the hot-arid climates. With their tall walls, the rooms (constructed round the courtyard) provided wind shading effects for one another, could decrease the penetration of hot and often dusty winds into the rooms. The existence of different plants and a pool in courtyards managed to make a micro-environment, the temperature fell a few degrees lower and the relative humidity rose slightly higher. The courtyard tall trees played a good role in shading the walls and the ground from the severe direct radiation of the summer sun. These could cause the building to receive lower heat [13].

2.2 Purposes for the Inclusion of Courtyards in Buildings

There are many advantages out of the inclusion of courtyards in houses and buildings:

- Psycho-Social advantages: The courtyard provides a feeling of privacy and independence for the people residing the house.
- Cultural advantages: The courtyard is used as a cultural element dividing the house spaces into private and public spaces. The inner court is especially limited for the family and is an outdoor space enclosed in complete privacy for the enjoyment of the female members of the family in the house which separates the public and private spaces within the house [14].
- Energy advantages: Courtyards are mostly considered as a "microclimate modifier" of the house which is because of their capability in diminishing severe temperatures, channeling breezes and adjusting the degree of humidity [15].
- Architectural advantages: Courtyards are mostly located in the middle of buildings and houses connecting the different areas and functions.
- Symbolical-Religious advantages**:** Courtyards are not only symbolically but also religiously notable. Courtyard area is located in the middle of the building and gets the highest interest in the house while having no roof and surrounded within the walls of a house [14].

- Economical advantages: Courtyards' form and construction can provide some financial benefits. Their designs have a kind of land use efficiency; for the case of which there is no need for a conventional yard as an outdoor space. Especially when adjoining courtyard houses share walls, the cost of both construction and maintenance is significantly reduced.

2.3 Historic Development of Atrium Buildings

Progress in producing glass and iron in the nineteenth century provided the possibility of prefabricating cast-iron constructions and glass elements and of sheltering the roofless central court with glass for making an indoor atrium. The novel method of using iron and glass was introduced by John Root in 1885 to cover the court roof of the eleven-floor Rookery office building in Chicago at the third floor [15]. Designers and builders wanted to display their skills and ability in creating new, exciting iron and glass structures. This tendency in cities can be considered as the reason for the progress of the atrium. Overcrowded cities, the lack of space, pollution, and high density were the driving force which provided the grounds for the appearance of the enclosed atrium. Atrium provided a proper solution by supplying daylight and fresh air, while being with a visual connection to the external environment [16].

2.3.1 Europe

The spread of atrium buildings has been successful and increased to a lot of extent after the industrial revolution [15]. Atria first became popular in Europe (The Galleria, Milan, Italy, 1867) and took different forms depending on the type of the buildings and the societal needs. Atria, soon, started to be used in public buildings, offices, shops and hotels as reception areas, circulation centers or even large areas where people were accommodated in large numbers to get different services (See Figure 2.7).

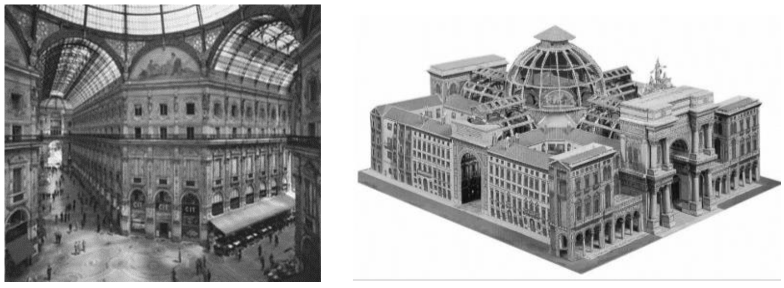


Figure 2.7 : The Galleria's inside view (left) and outside view (right), Milan, Italy, 1867.

2.3.2 United States

The earlier experience that the Europeans had on the atrium technology was taken by the Americans in the early 20th century. The designers used all heavy masonry construction on the exterior, with iron, steel, and glass being used only in the atrium space itself. This design strategy was a response to the new technology and to the fire problems encountered in Europe.

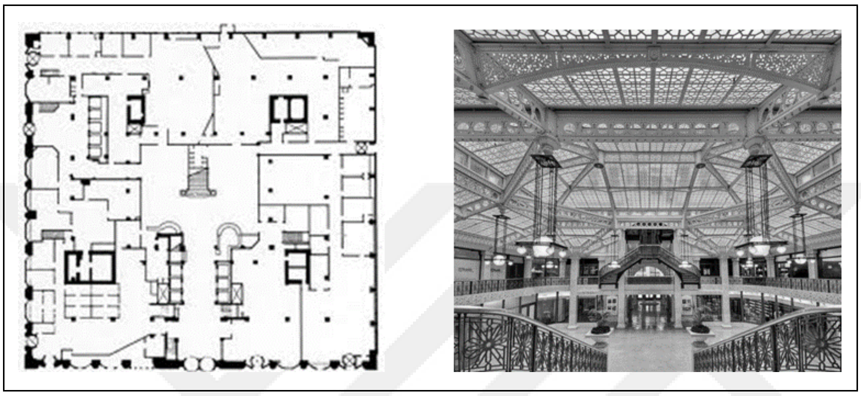


Figure 2.8 : Figure 2.8 Plan (left) and a view (right) from lobby of Rookery Building in Chicago, Illinois, 1905.

In 1905, Frank Lloyd Wright remodeled the lobby of Rookery Building in Chicago, Illinois (See Figure 2.8). Afterwards, in 1936, he completed Johnson Wax headquarters in Racine, Wisconsin (See Figure 2.9 left) and, in 1959, Guggenheim Museum in New York (See Figure 2.9 right). Both buildings were top-lit and have central focal spaces that later became a direct inspiration to Portman works. In this period, the shape of the atria was mostly square or rectangular [17].

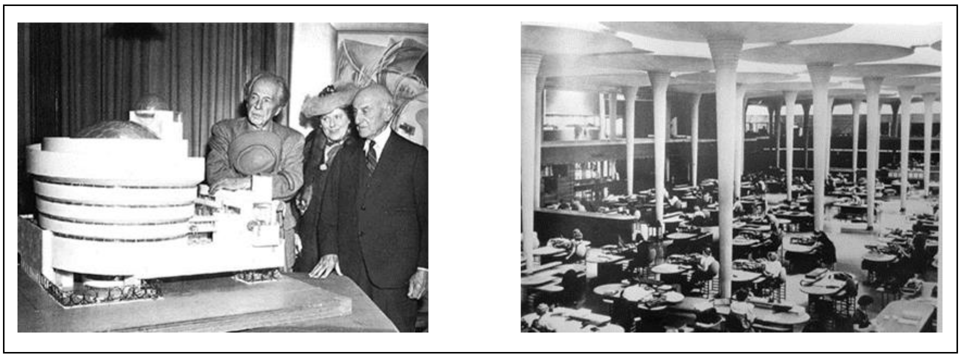


Figure 2.9 : Guggenheim Museum, Manhattan, New York, Completed 1959 (right) - Johnson Wax Headquarters, Racine, Wisconsin, 1936-39(left).

The atrium started getting further attention in the second half of the twentieth century. It was considered as the focal space of the building by the designers. Occupants and users of these buildings also find them attractive and enjoy the additional advantages the atrium offers. John Portman’s works such as the Hyatt Regency Hotel in Atlanta, Georgia in 1967 (See Figure 2.10) reflected atria on a large scale that changed the future concept of atrium building design [15]. This was John Portman's first atrium-centered building. The twenty-two story sky-lit atrium being away from noise and pollution is utilized as a public space. There are elevators taking people up and down the atrium height which are exposed and glassed.

Figure 2.10 : Internal view (left) outside view (right) of the Hyatt Regency Hotel’s Atrium, Atlanta, Georgia, 1967.

Kevin Roche and John Dinkeloo designed the Ford Foundation in New York City as one of the most significant designs in the present period (See Figure 2.11). The completion of the building was in 1968. Its spaces were mostly organized in L-shape.

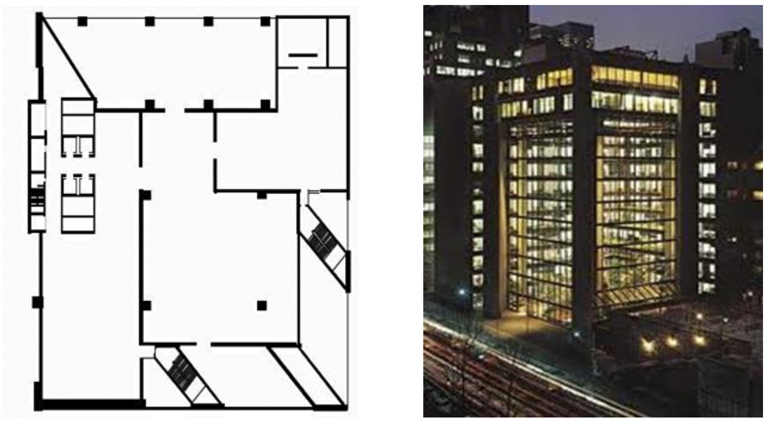


Figure 2.11 : Plan (left) and outside view (right) of the Ford Foundation in New York City, 1968.

The structure is of glass, steel, and granite providing inward-looking offices around a twelve story atrium (about 160 feet high). The spacious atrium filled with enormous garden was the inspiration for all the dramatic full height atriums of the period [15].

2.4 Reasons for Including Atriums in Buildings

The atrium is now found in different kinds of buildings comprising hotels, hospitals, offices and even shopping malls around the globe. The advantages an atrium has include: an environmentally controlled space, with natural lighting where wind, snow and rain are kept out. These provide some urban design social and functional convenience. Here are many reasons for the inclusion of atriums in buildings:

- Architectural Function: Useful space can be provided by the atrium itself. For the efficient utilization of the land, architects, designers and planners make use of the atrium in buildings for complex and uncommon sites[15].
- Connection to Outdoor Environment: Modern glazed atriums supply exciting views. Even landscaped atriums without glazed facade provide a sense of connection to the outside world [16].
- Economic Function: Market studies show that atrium buildings are more attractive and have higher occupancy rate. The reason is that atria provide the space required for the public to get together, special events, shows and exhibitions to take place, which caused the rate of habitation and profits to increase [15].
- Energy Conservation: Potentiality of atrium buildings for the efficient usage of energy is high. The utilization of daylight inside the atrium provides a reduction in the cost of electrical lighting. A more comfortable environment can be provided by the atrium when passive energy is used to the most extent, causing less reliance on mechanical systems [16].

2.5 Atrium Classification

The designs and structures of buildings comprising atriums could be limitless. The basic structures of atrium space are of some simple and some complex ones. Atriums are categorized into various generic forms by Saxon (1994). According to Saxon these atrium forms are summed up in Figure 2.12 (left) [15].

Atriums are categorized into five basic kinds by Hastings (1995), (See Figure 2.12 (right)][18].

- Attached: It is a glazed space joined to an outdoor wall of a building. Their tendency is towards having at least two of the vertical surfaces to be exposed to the outside.
- Envelope: In an Envelope Atrium, the building is enclosed inside, similar to a building inside another building. Some of the time, some parts of the building facade may be encompassed by the outside envelope; however, the atrium is usually more like glazed double wall to the building.
- Core: It is the classical atrium form located in the middle of the building which provides a sheltered glazed courtyard. The roof is the only surface of these atria which is exposed to the outside. Adjacent spaces encircle them on all sides.
- Integrated: In a building, it is situated in a way that just one vertical surface is exposed to the outside. Usually they cover a courtyard form created by an 'U' shaped building.
- Linear: It is for covering the gap between two blocks of buildings. A semi-public open-to -sky space and sheltered movements between the two building blocks are provided by them most of the time.

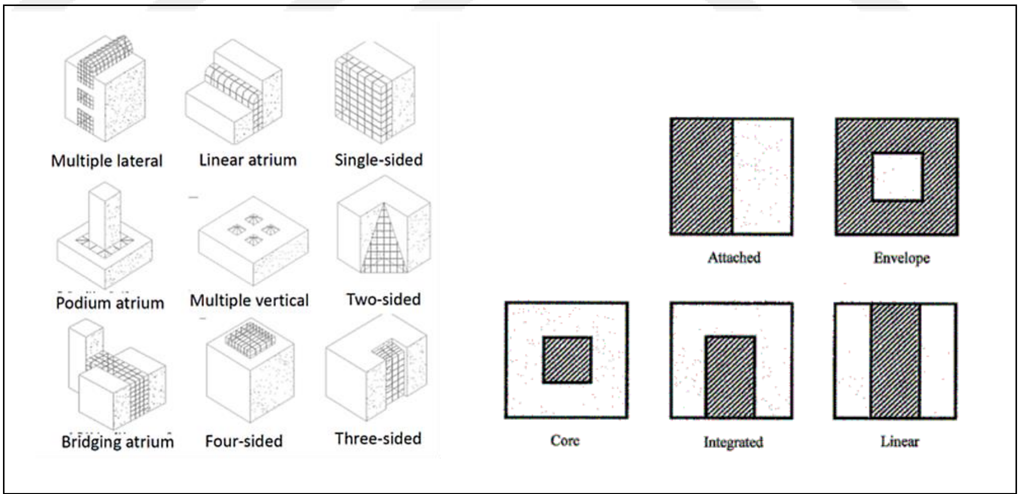


Figure 2.12 : (Left)Atrium Classification, Saxon 1994 [15] and (Right) Atrium Classification, Hasting, 1995[18].

3. ENERGY PERFORMANCE OF COURTYARDS AND ATRIA

Atria have the potential to contribute significantly to lower energy consumption by allowing the penetration of daylighting into a building interior directly through the skylight [19]. The incorporation of an atrium into commercial buildings can save energy by providing good daylight, natural ventilation and a buffer zone between indoor and outdoor environment. However, large glazing surfaces of atrium absorb excessive solar heat in the summer and loss heat in the winter. Atria and courtyards can be extremely effective in providing daylight and additional heat to adjacent spaces and in reducing transmission losses. The thermal performance of courtyard / atrium buildings depends greatly on the factors (such as geometry, location, latitude, height, external climate, microclimate etc.) that involve working with the climate rather than against it so that the need for artificial space conditioning is reduced [20]. This research aims to identify the effect of seasonal time on the integrated usage of courtyard and atrium to find a cost optimal energy usage in buildings

3.1 Energy Performance of courtyards

Energy efficiency is becoming more of a priority in recent years as energy consumption has become a serious concern and is becoming a crisis [12]. The commercial buildings sector consumes a huge amount of energy and their energy consumption pattern will likely increase sharply in the near future [21]. As a result, there has been a general movement towards finding effective design strategies to lower the energy demands of buildings and to encourage further awareness of energy-conscious design [22].

For buildings in general and for commercial buildings specifically, using artificial lighting is considered as a key problem that can lead to excessive energy usage as it affects cooling and heating loads requirements of the buildings [21]. Krarti (2000) estimated that artificial lighting accounts for 25%-40% of total energy consumption [23]. Many papers and researches reveal substantial opportunities for improving energy efficiency in the building by incorporating courtyards into buildings as daylight-enhancing techniques to bring light into the interior and consequently to minimize space conditioning (cooling and heating) and lighting loads. For this reason, all aspects of the courtyards in buildings (i.e. their proportion, orientation, shape and size, height, shading control, glazing type and ratio, and the thermal mass of walls) need to be carefully considered in the design phase. Poor or inappropriate design may create challenges for controlling temperature, glare, and energy consumption [24]. Gratia et al (2003) have stressed that passive solar energy can reduce the auxiliary heating costs in office buildings, without compromising occupant comfort[25].

Cantón et al (2014) analyzed summer thermal behavior of two courtyards and adjacent classrooms in a refurbished pre-elementary school building in Mendoza, Argentina. Methodology used in this research was comparing installed data loggers and dynamic simulation results. The simulation was performed by user friendly interface of OpenStudio and calculation engine of EnergyPlus. Two investigated courtyards had different ratio in depth of the form R1(courtyard's floor perimeters to the form's height) and the elongation of the form R 2(rectangular courtyard width to its length). Their study indicated that in the case of North-South oriented courtyards, and for equal materiality of the courtyard, low geometric ratios of R1 and R2 limit solar access to a greater extent in the morning and in the afternoon. Furthermore, High R1 and R2 ratios performed higher convective and radiative cooling capacity of open spaces.

This research also highlighted that in the hot time of the day, the shade condition of the exterior is one of the variables with the biggest impact on the behavior of the interior of classrooms. They concluded combination blockage of the solar resource in summer with guarantee of full access in winter can lead to get better energy performance of courtyard in hot climate[26].

Kocagil and Oral (2015) investigated the effect of courtyard building form and settlement texture on heating and cooling loads by analyzing design parameters of traditional Diyarbakır houses as the representative city of the hot-dry climate zone in Turkey via simulations performed by Design Builder. Four commonly seen reference standardized plan types which were called L-type plan, U-type plan, inner courtyard plan and central courtyard plan were determined to be used in this study. Authors used "A/V ratio" (form factor) to indicate the interaction between the total surface area that losses heat (A) and the total volume that is sheltered within the building(V). During the simulation process courtyard models were considered in four different settlement texture (ST1 as well as ST2 with respectively 6m and 3m street width, and ST3 also ST4 consisted of blocks respectively with four buildings and six buildings). The transparency ratio of the courtyard façade and street façade were defined as 40% and 0% respectively. According to the results of this study, the combination of inner courtyard plan type with A/V ratio of 0.50 consumed 63% less heating energy as reference building and 79% less cooling energy within ST4 than the combination of L-type plan with A/V ratio of 1.00. The winter part of inner courtyard plan type with A/V ratio of 0.50 needed 25% less heating energy than total heating energy of the building and the summer part 76% less cooling energy than the total cooling energy of the building. They concluded cooling loads were always lower than the heating loads because these houses were designed compatible with the hot-dry climate[27].

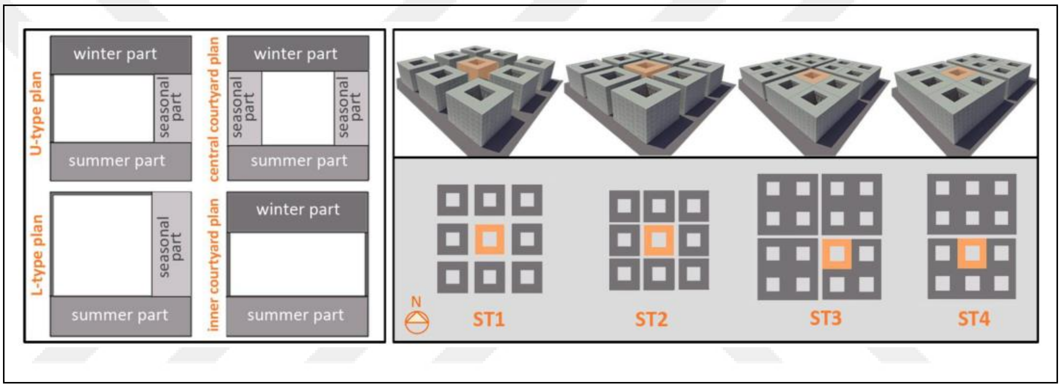


Figure 3.1 : plan type and settlement texture alternatives[27].

There are various studies on the energy performance of the courtyards. The researches mainly focused on the shape, ventilation and performance of the courtyards in terms of daylight factor.

3.1.1 Shape of the courtyards

Several studies tried to find optimum size of circular, polygon, rectangular and square form of courtyard in different climates and location latitude. Muhaisen and Gadi (2005) showed that changing the form's proportions in circular model significantly influences shading or exposure potential of the internal courtyard envelope and that shallow courtyards perform better than the deeper ones[12].

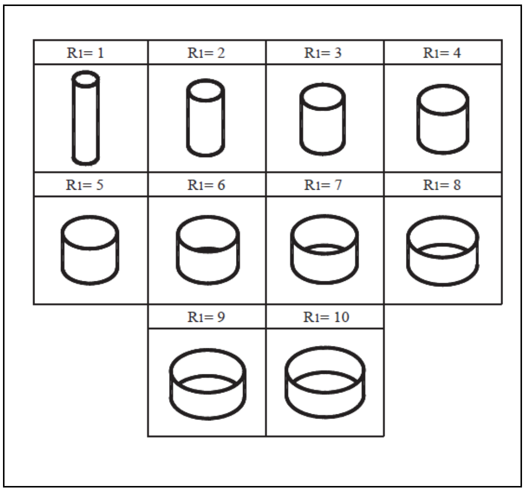


Figure 3.2 : Circular Courtyard Form [12].

R1= floor perimeters P/ form's height H & R2= elongation of the form L/ it's diameter W

Muhaisen and Gadi (2006a) used computer tool (IES) to carry out the effect of solar heat gain on the energy demand of courtyard building form with different proportions. They found that courtyards having deep forms require low energy for cooling in summer[28]. Muhaisen and Gadi (2006b) stressed that in polygon models deep courtyard forms with any geometry are recommended to achieve maximum internal shaded areas in summer. However in winter, shallow forms were desired for obtaining sunlit areas[29].

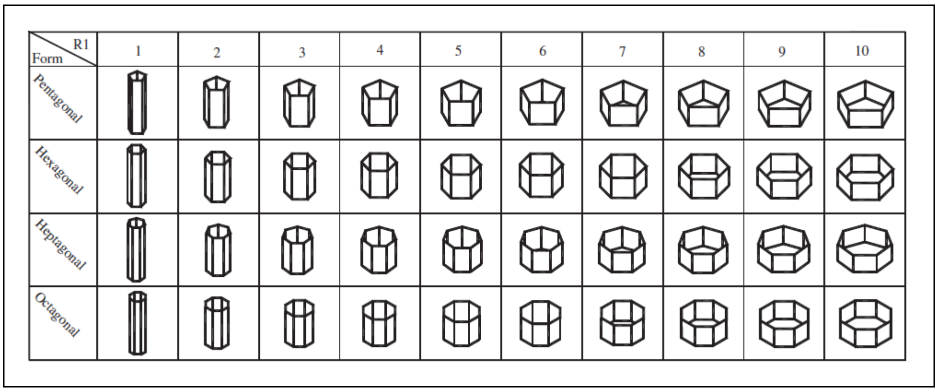


Figure 3.3 : Polygon Courtyard Form [29].

R1= floor perimeters P/ form's height H & R2= elongation of the form L/ it's diameter W

Muhaisen (2006) carried out a modeling study into the effect of rectangular courtyard proportions on the shading and exposure conditions on the internal envelope of the form in four different locations. The outcomes showed optimum courtyard height to obtain a reasonable performance in summer and winter are three stories in hot humid climates, two-story in hot dry and temperate climates, and one-story in a cold climate[30].

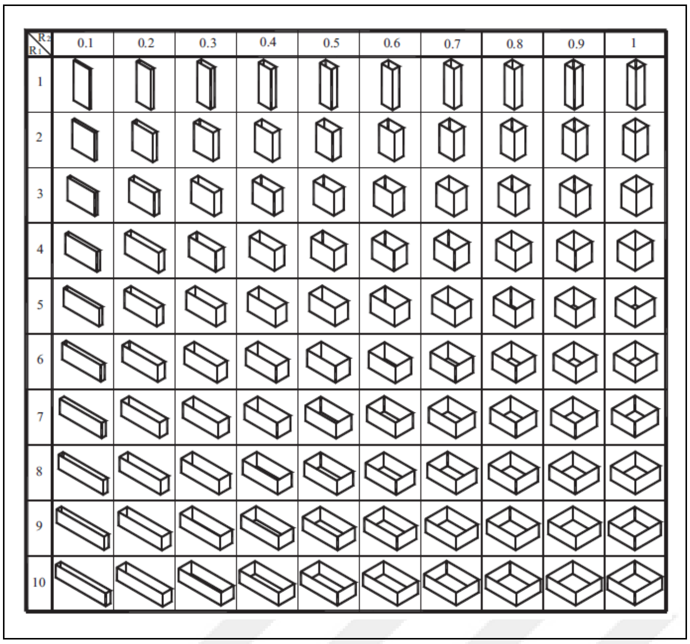


Figure 3.4 : Rectangular Courtyard Proportions [30].

(R1= floor perimeters P/ form's height H & R2= elongation of the form L/ it's length W)

Yasa and Ok (2014) used Computational Fluid Dynamic (CFD) program to investigate thermal comfort statuses and energy performances of courtyard shapes in Diyarbakır, Antalya and Erzurum as representative of hot-dry, hot humid and cold regions in Turkey respectively. They developed courtyard model dimension ratios for use in all regions within the optimization model by increasing 1.5, 2, 2.5, 3 and 5 fold at east–west direction in proportion with the building or facade height the (H = 6 m). The results highlighted in Antalya and Diyarbakır the maximum solar radiation value is seen in the 5H option; whereas it is emerged 3H option in Erzurum. They concluded during warm period, "H" option appeared as the optimum choice for all three regions in terms of inter-courtyard thermal gain according to the criteria of comfort and energy gain required cooling and heating loads[31].

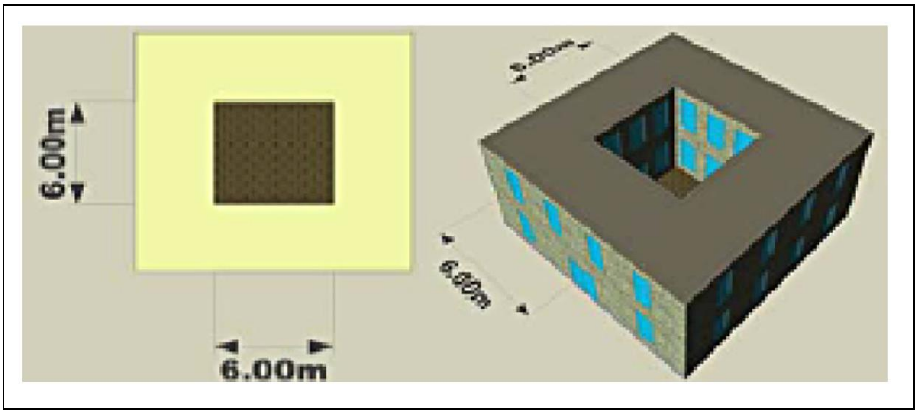


Figure 3.5 : The plan and perspective for the reference courtyard-building[31].

Manioglu and Oral (2015) studied courtyard shape, varying the ratio of courtyard width (W) to courtyard length (L) to reduce heating and cooling loads. In the study Design Builder as interface and Energy Plus as calculation software were used in simulation process. Diyarbakır was selected as representative city of hot and dry region in Turkey. The courtyard shape factors (W/L) were changed between 0,2 and 2 with 0,2 intervals to compare the alternatives with different courtyard shapes. The floor area of the building was changed between 100m^2 and 200 m^2 with 20 m^2 intervals to compare the building types with different areas. From the results, it appeared that increasing the floor area, the heating loads and consequently the total loads gradually increase at all courtyard shape factor. However, the rate of increase becomes distinctly greater as the floor area becomes greater than 140 m^2 for heating, cooling and total loads. From their study it come in to view that, W/L ratios which provide low energy requirement for cooling be able to ensure high heat loads and thus the need for heating. Finally, they concluded, effect on energy loads in winter is more critical than in summer[32].

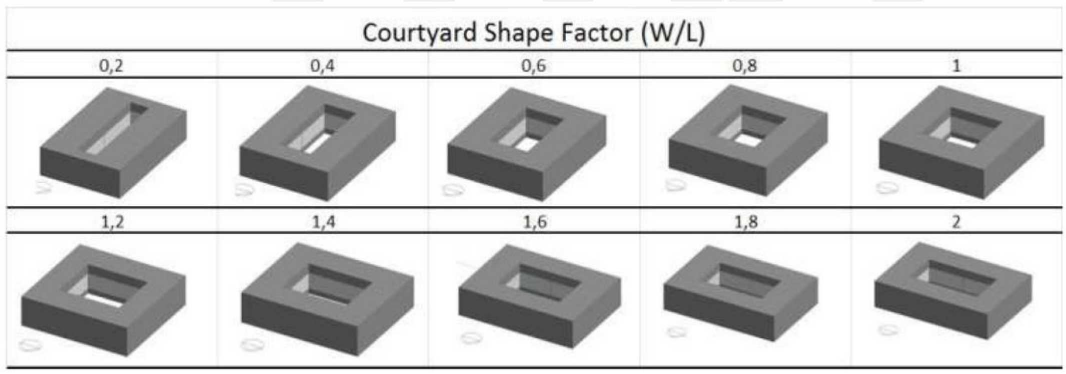


Figure 3.6 : Courtyard building form derived from different W/L value.

3.1.2 Ventilation of the courtyards

Horan and Finn (2008) examined the influence of variations in external wind speed and direction on the air change rate for the atrium space of a two-story naturally ventilated building by CFD study. They found external wind speed have an almost linear relationship with air change rate(ACH) for all wind directions irrespective of the number of side vents included in the model. The results stressed increase in ACH rate with external wind direction was caused by increased airflow entering into the building through the rooftop windows. This study disclose no clear relationship could be identified between the proportion of vents opened and the atrium ACH rate although the relationship was found to be independent of wind speed but dependent on wind direction[33].

Yasa and Ok (2008) tested effects of ventilation of the openings on the building with a courtyard in a wind tunnel. It is observed on buildings disposing openings at different configurations, (compared courtyard building lacking openings) that openings on vertical surfaces are increasing the speed of air flows inside courtyards. They also indicated that openings located on perpendicular surfaces increase the velocities of airflows within courtyards in proportion to their dimensions and positions[34].

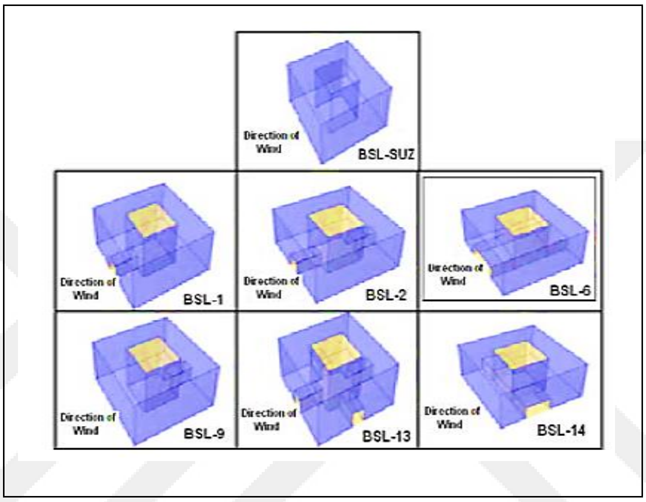


Figure 3.7 : Illustration of the courtyard configurations [34].

Haw et al. (2012) highlighted that beside wind towers, there are other architectural features, such as atriums, courtyards, wing walls, and dome roofs which have been integrated into building designs that have significant influence on improving the indoor air quality[35]. Haw et al. (2012) also stated that courtyards are transitional zones that improve comfort conditions by modifying the microclimate around the building and by enhancing the airflow in the building[35]. Haw et al. (2012) concluded that courtyard can provide a relatively enclosed space to channel and direct the airflow which is promoted by large openings (gates, doors, arches, etc.) and results in convective natural ventilation in and around a building[35].

Minke et al, (1994) stated that having a courtyard is preferred in warm and humid climates especially when courtyard can induce ventilation due to stack effect where the wind direction should be taken into account. In summer conditions, buildings are typically a net source of heat, and the use of the natural ventilation to eliminate some of this heat from the building is very energy efficient. Most modern building designs in hot and humid regions are not equipped with passive architectural features for improving natural ventilation except through window and door openings[36].

Nguyen et al (2011) showed that the distribution and configuration of the openings should be adjusted to improve natural ventilation and lighting. They found that courtyard house played a significant role on ventilation flow rate of the rooms facing the courtyard. Their investigation highlighted that courtyard facing windows sometimes played a more important role than street-facing windows. The research indicated that wind velocity in the courtyard house was independent from wind conditions at point in front of the house. They suggested that it is suitable and effective to employ natural ventilation, building orientation, building shape and solar shading strategies in Vietnamese climatic conditions while earth cooling, thermal insulation and high thermal mass are inappropriate[37].

Priya et al (2012) studied on vernacular settlement pattern of Nagapattinam in India that breathes through the smaller indoor open spaces like courtyards because of its location in urban fabric. The buildings were designed to achieve cross ventilation through courtyards, wind catchers, etc. The study showed that during the night times the courtyard becomes a heat sink and by natural convective cooling this courtyard allows the hot air to be moved up and thereby acts as an excellent thermal regulator and creates a comfortable living environment. The horizontal surface insulates the inside from outside and creates temperature zone helping the courtyard to become a heat sink. They also presented that during summer time, due to the principle of buoyancy, low pressure develops in the courtyard and that there was an air movement from inside which is pushed towards the surrounding spaces to move out through the openings (doors, windows and ventilators) in the leeward[38].

Al-Sallal et al, (2013) achieved considerable improvement over the square-form house (typical Emirati house) and the basic courtyard house (envelope not yet improved) with 59% and 55% reduction in the greenhouse gas emissions and the utility bill, respectively. They suggested that their methodology could be valuable to other building professionals in the UAE who might search for a clear application model. The results of their study showed a potential in reducing the energy use of the house (compared to the improved envelope or the baseline case) by 19% for cooling and 13% for lighting and equipment; and helped to reduce the greenhouse gas emissions and the utility bill by 12%. The research also indicated the lower part of the courtyard is the coolest part inside the building as the cooler air settles at the bottom and the hot air travels up due to stalk ventilation. Since the courtyard buildings were located in the coastal region the outdoor relative humidity reaches to 95% while the indoor relative humidity is maintained around 80%. This is achieved because of the presence of the wind catchers, courtyards, etc.[5].

3.1.3 Performance in terms of daylight factor in courtyard

Al-Masri and Abu-Hijleh (2012) compared conventional and courtyard buildings by using computer simulation (Virtual Environment by Integrated Environmental Solutions) to determine the overall energy consumption, energy savings potential and available daylight levels. The simulation calculated effects of number of floors, type of glazing, wall thickness, and insulation type as well as insulation thickness on the performance of a courtyard type.

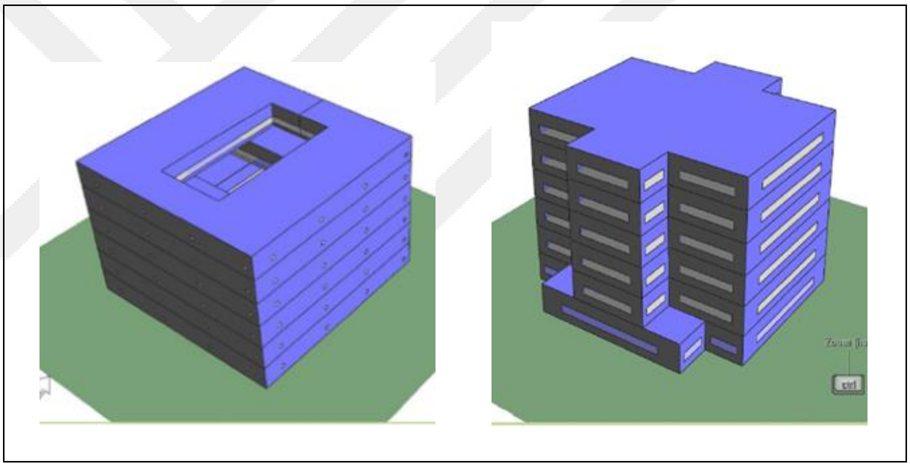


Figure 3.8 : Examined courtyard forms conventional (left) and Examined six-floors of conventional (right) [39].

The result showed 11.16% reduction in the overall year-round energy consumption in optimized courtyard model compared to the reference conventional form building. Assessment between the daylight performances of the two forms highlighted that the courtyard form provides more usable daylight without excessive glare[39].

Luis and Perez-Garci (2004) studied seasonal control of the solar gains on the roof apertures. Refurbishment of an open courtyard by installing an innovative roof which, a part of other solar features as the integration of PV modules and a device to promote natural air movements, it has been designed to maximize solar gains during the winter months and minimize them in summer to reduce the corresponding space thermal loads[40].

Heras et al (2005) analyzed the energetic performance of a courtyard covered by saw tooth roof in the building of University of Almeria in Spain. The measurement carried out by equipment, thermal and meteorological sensors for a year. Thermal evolution in typical summer and winter days and thermal comfort analyses showed a good thermal behavior in winter; stratification did not appear during all year and this fact produced overheating in summertime. They stated around the noon an increase in the air velocity happens, consequently the chimney effect is greater during these hours. The results also highlighted that, the needed annual thermal loads required to obtain comfort conditions are lower into courtyard than in a conventional saw tooth roof. The loads values are different depending on monthly requirements[41].

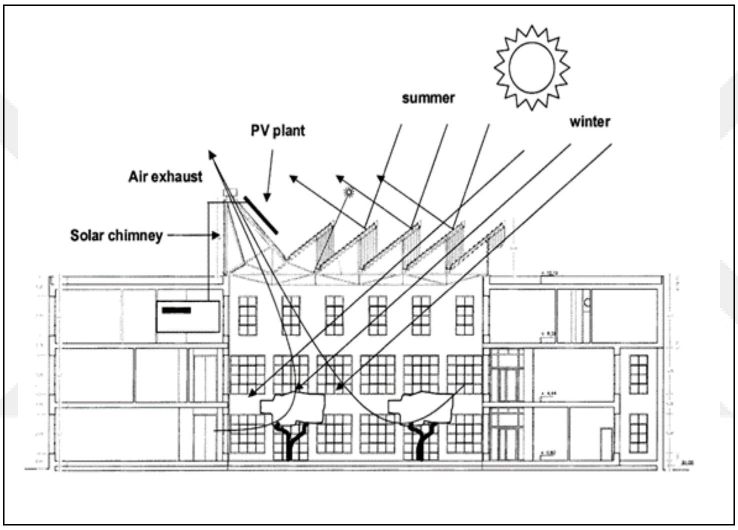


Figure 3.9 : Section of courtyard covered by Saw Tooth Roof, University of Almeria in Spain[41].

3.2 Energy Performance of Atria

There are some studies about atrium buildings energy performance. The atria architecture deals with day lighting, energy, climate, air movements, acoustics and investment costs with instances of contemporary glazed spaces.

Bednar (1986) introduces the new atrium as an enclosed space with a glass roof and uses the term atrium building to name the whole building. His comprehensive book shows many examples of atrium buildings[17].

Wall (1996) conducted a complete study on glazed spaces and atrium buildings in some Scandinavian countries. She explained the relationship between building design and climate, thermal comfort and energy requirements in different types of glazed spaces and developed a simple calculation method for the assessment of temperature and energy requirements in glazed spaces. Moreover, this study evaluated the effect of atrium buildings on energy requirements of adjacent buildings[42].

Most atrium buildings depend on mechanical systems for cooling or heating all year round and do not take advantage of being an enhancing tool to minimize energy consumption. Causes of dependence on mechanical systems to maintain the proper comfort level within the structure include: incorporation of atria and courtyards wherein they are vastly less efficient than the nominal case [16]; and miscalculation of the importance of controlling the factors determining the atrium's energy efficiency (i.e. orientation, size or ratio of atrium to adjacent spaces, envelope constructions, and type and function of atrium [16]. Similarly, Atif (1994) mentioned a lack of designing tools for optimizing the energy consumption in an atrium and emphasized a need to an integrated design considering all aspects of atrium (i.e. acoustics, smoke control management, etc.)[43]. Mills (1991) states the problem in designing atrium buildings as the lack of available definitive guidance while most architects tend to look towards exemplar projects for inspiration or learn through trial and error[44]. Mills (1991) also notes that by correct design of atria, the building can be capable of capturing solar energy to reduce the building's energy consumption in addition to creating a comfortable and visually pleasant environment[44].

There are various studies on the energy performance of the atria. These researches can be classified as: shape; stack effect; ventilation; performance in terms of daylight factor; and climate conditions related studies.

3.2.1 Studies on atrium's shape:

Laouadi, et al. (2002) conducted computer simulation research to investigate the thermal and energy performance of atria in cold climates. Atrium shapes as simulated with Pyramidal Skylights Design alternatives focused on glazing types, fenestration surface area, skylight shape, atrium type, and interaction of the atrium with its adjacent spaces. The ESP-r* (Environmental Systems Performance- research) was used for thermal and energy simulation, and ADELINE (integrated lighting design computer software) was used for lighting. As a conclusion of the research, pyramidal/pitched skylights increased the solar heat gain ratio by up to 25% in the heating season for the enclosed and linear atriums, and by up to 10% for the three-sided atrium, as compared to the flat skylight; however, the skylight shape did not significantly affect the solar heat gain ratio in the cooling season. The annual cooling energy ratio decreased with decreasing the Solar Heat Gain Coefficient Ratio (SHGCR) and with increasing the U-value ratio (UR). Reducing the fenestration surface area by 50% resulted in more than 48% reduction in the cooling peak load ratio and annual cooling and total energy ratios[19].

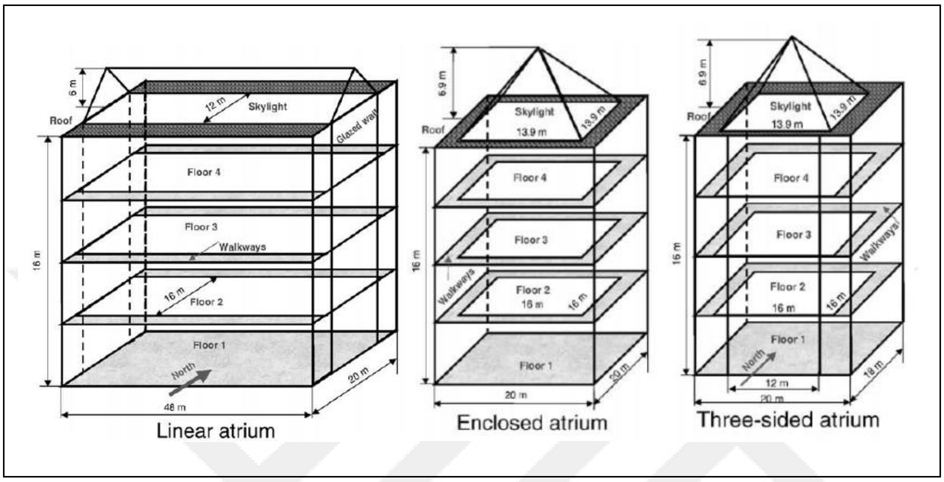


Figure 3.10 : Various Pyramid Skylights for Atrium Space [19].

Galasiu and Atif (2002) carried out a comparison between simulation and field measurements of thermal parameters of an atrium building in Ottawa, Canada. The case study was based on a three-story atrium. The selected atrium has an octagonal shape with a pyramidal skylight and is surrounded by walkways that lead to the adjacent spaces. The simulation results were obtained using the ESP-r computer program. The comparisons included those of predicted and measured solar radiation entering the atrium space at the rooftop, and predicted and measured indoor temperatures of the atrium floors. Results for the solar radiation showed good agreement between the measured and predicted values. When the mechanical system was turned off, the predicted temperatures were within ± 2°C of the measured temperatures in winter. In summer, however, the predicted temperatures were 2-3°C higher than the measured temperatures. The solar heat gains resulted in significant temperature stratification of about 5°C between the top and bottom floors[45].

Figure 3.11 : Exterior (right) and interior (left) views of the atrium skylight [45].

Aldawoud (2013) by using DOE-2.1 as a simulation tool indicated that thermal performance of square and rectangular shape of atria differ according to different climate, glazing type and ratio of its length to width. The results of this study highlighted that the total energy consumption of the narrow, elongated atrium or the rectangular atrium with high ratio of length to width is significantly greater than the square shaped atrium[24].

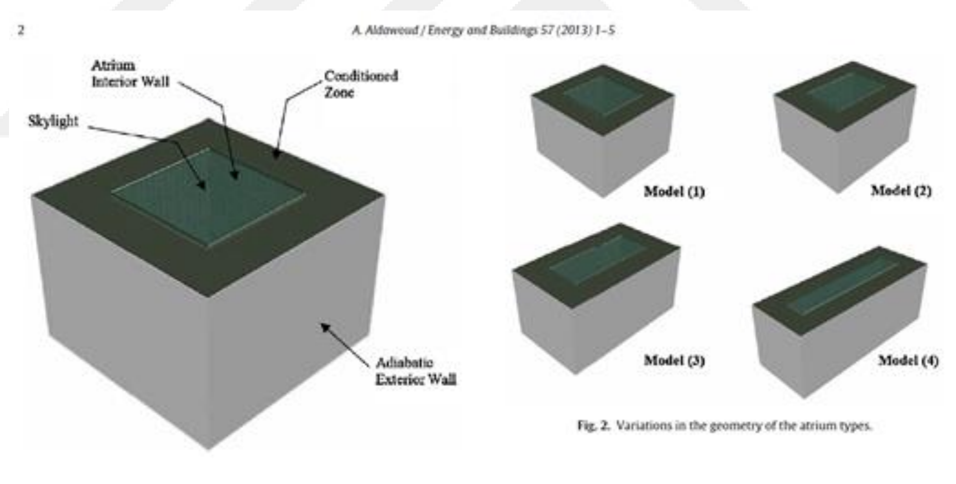


Figure 3.12 : Variations in the geometry of the atrium types [24].

Assadi et al (2011) studied a mathematical simulation model to discover the relation between the passive heating and ventilating effect and the dimension of a rectangular atrium as well as the parent building. They stated beside all factors which considered in modeling, glass height and atrium diameter had significant impact on total absorption area of incident solar radiation. On the other word, dimension has a great dependency on solar radiation absorption on glass, by increasing the height of glass with 50%, the diameter decreased by 75%. As cited in their investigation when the diameter of the atrium changes from 20 to 14m, the glass height out of the building increases from 0 to 2 m. The result also showed that the energy for warming the building mitigates by the average of 19.5% at the day hours in the first two weeks of January[46].

Haw et al (2012) undertook full-scale experimental building with a Venturi shaped wind-induced ventilation tower under hot and humid climate in Malaysia. Based on empirical data analysis, they highlighted that the Venturi shaped roof tower is able to generate extraction air flow rate 8 times greater than normal cross ventilation in the hot and humid climate. Their study also revealed the aerodynamic performance of the Venturi shaped roof of the wind-induced natural ventilation tower can produce sufficient low pressure required to induce fresh air from outdoor into indoor spaces of building[35].

3.2.2 Studies on the stack effect in atria:

Lin and Chuah (2011) considered calculation model of stack effect for natural ventilation and cooling in three cities of Taiwan as subtropical weather types. They presented a method to design of openings for large spaces, and also the air conditioning control strategies for different seasons of the year. It was found that for a large space of above 6 m, opening ratio of greater than 0.9% can satisfy the requirement of fresh air rate. This research showed Taipei, Taichung have about 151 days of strong or medium cooling potential. However, the respective number of days was found only 90 for Kaohsiung. The number of days of weak cooling potential emerged to be 92 for Taipei, 30 for Taichung, and 61 for Kaohsiung[47].

Liu et al (2009) used computational fluid dynamics (CFD) and scale model tests to predict the performance of buoyancy driven ventilation in atrium buildings during the design stage. The result showed temperature change caused by the internal thermal load is not as significant as that caused by outdoor climate conditions. They highlighted the size of the stack openings, located in atrium roof, affect the temperature distribution in the atrium space and stack openings position can create direct ventilation paths, which will be helpful in improving the internal thermal environment. The research also revealed that due to the small temperature difference in hot and humid climates, a buoyancy-only ventilation strategy is not very effective in such a situation[48].

3.2.3 Studies on ventilation of atrium:

Karava et al (2012) presented an extensive experimental study considering large institutional building integrated with an atrium located in Montreal, Canada. In this research they evaluated night cooling strategies for heat removal from concrete (thermal mass) floor slabs. The investigation showed that the inflowing air stream at lower temperatures has increased cooling capacity resulting in higher amounts of cooling stored in the thermal mass. The heat removal from concrete floor slabs was 2-5 times higher with the inlet air stream at an average temperature of 12° C, compared to that with an air stream at 15° C or 18° C respectively. Also they found that Indoor temperature in the atrium is strongly dependent on solar radiation, with the maximum thermal stratification on a clear day[49].

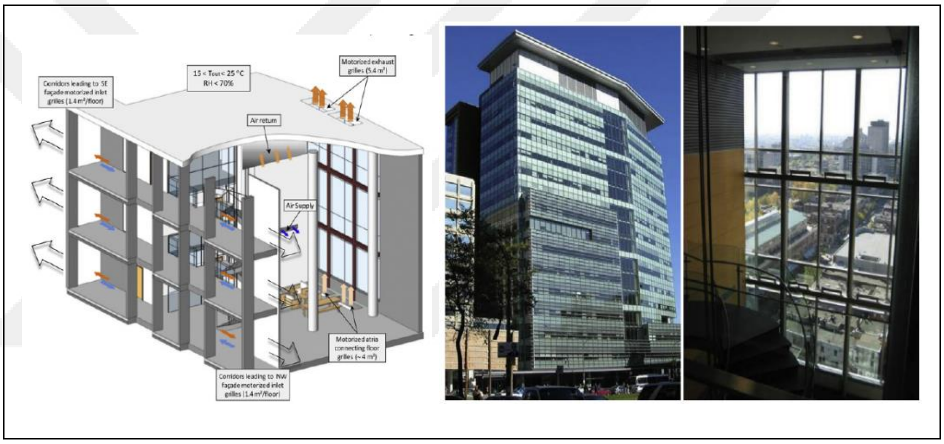


Figure 3.13 : Hybrid ventilation concept Outside and Inside view of the Atrium[49].

Haw et al (2012) undertook full-scale experimental building with a Venturi shaped wind-induced ventilation tower under hot and humid climate in Malaysia. Based on empirical data analysis, they highlighted that the Venturi shaped roof tower is able to generate extraction air flow rate 8 times greater than normal cross ventilation in the hot and humid climate. Their study also revealed the aerodynamic performance of the Venturi shaped roof of the wind-induced natural ventilation tower can produce sufficient low pressure required to induce fresh air from outdoor into indoor spaces of building[35].

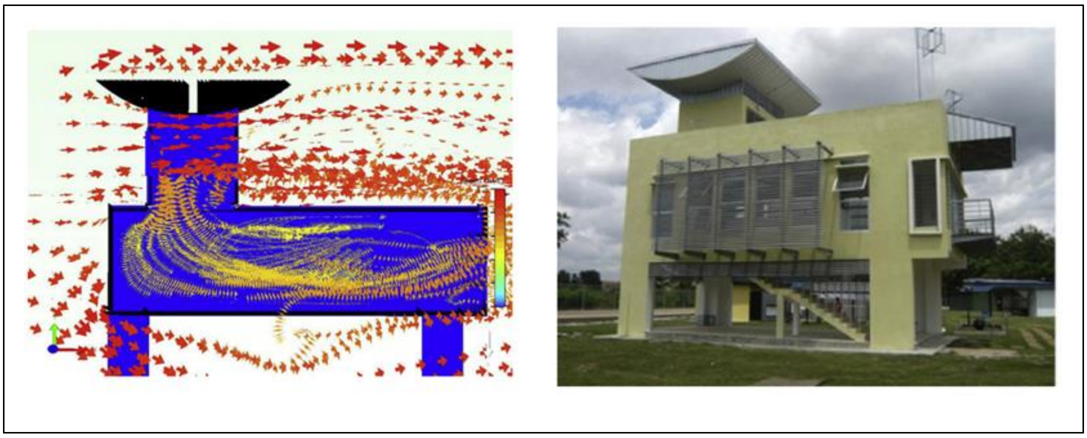


Figure 3.14 : Hybrid ventilation concept. Karava et al [35].

Woods et al (2009) illustrated a strategy for the natural mixing ventilation in order that the rooms surrounding the atrium receive both pre-heated but also sufficiently fresh air, while the central atrium zone remains warm. They tested the principles with some laboratory experiments in which a model air chamber is ventilated using both mixing and displacement ventilation, and compare the energy loads in each case. The study revealed that in order to mitigate temperature contrasts of several degrees, the ventilation rates between the different floors and the atrium should have independent controls, so that the rates may be varied in response to the measurements of the local temperatures within the building. They concluded that the summer strategy involves air entering through the windows of the building, and then venting through the offices into the central atrium space[50].

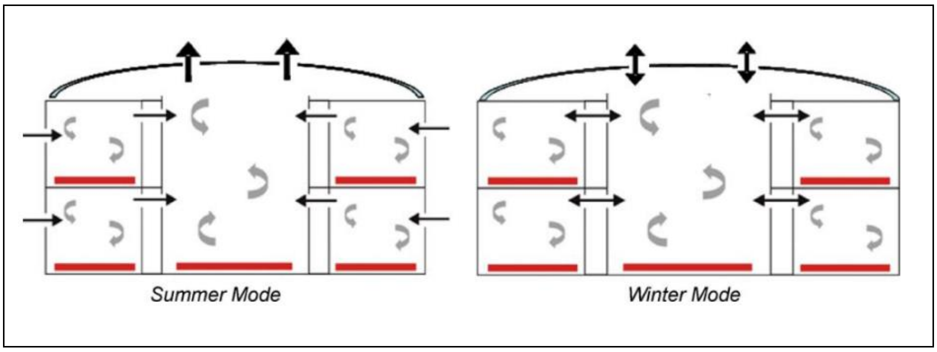


Figure 3.15 : Comparison of the summer and winter strategies for ventilation[50].

Gocer (2006) studied on thermal performance simulation of an atrium building by specifying a prototype model of an office building in Istanbul. With the help of building simulation tools -EnergyPlus (Version 1.2.3), FLUENT (Version6.2.16) - total energy consumption and air stratification of the atrium building is calculated. He concluded that atrium must be designed as a part of energy strategy of the building[51].

3.2.4 Studies on performance of daylight factor of atrium:

Kim and Tai Kim (2010) examined the atrium performance in terms of daylight factor, well index, and balcony depth. They highlighted Well index and balcony depth are the most significant factors in daylighting performance in atrium spaces with interior balconies. For the position not covered by balcony, adequate illumination can be achieved for circulation regardless of building Well index and balcony depth although it may be that involved well indices are relatively low. On the other hand, light attenuation on the position under balcony floor is up to 70–90%, in particular, when the Well index becomes higher than 1 m and balcony floor becomes deeper than 3 m[52].

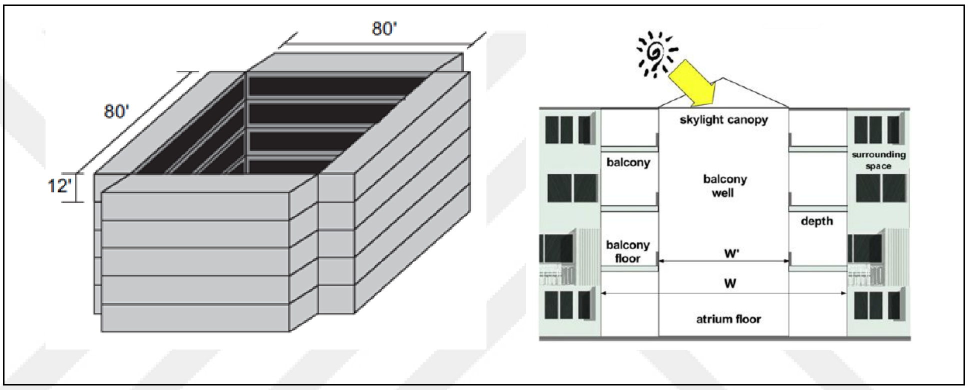


Figure 3.16 : Axonometric view of scale model of the atrium and Well index in atriums [52].

Du and Sharples (2011) used radiance as simulation tools for predicting average daylight factors of adjoining room in atrium. The average daylight levels in rooms displayed a linear relationship with the vertical daylight levels on the well wall. In terms of the well geometry and well façades (decided by the ratio of window area to solid wall area) and well surface reflectance, the variations of daylight level in the adjoining rooms have been analyzed and some conclusions and design strategies for supporting preliminary design decisions are presented. The average daylight factor levels in the adjoining rooms have a linear relationship with the vertical daylight level at the center of the facade for each floor[53].

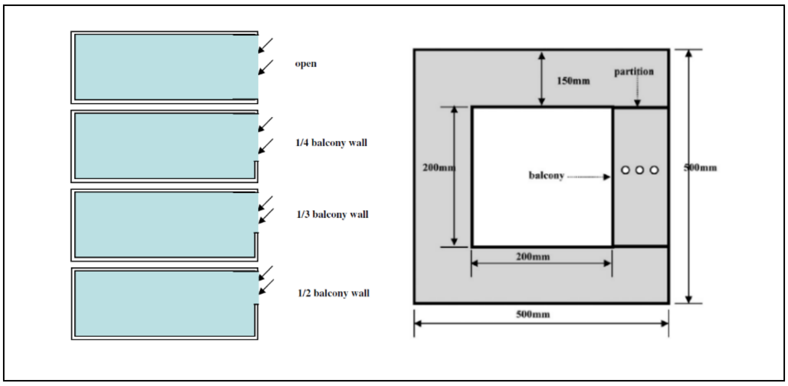


Figure 3.17 : Window Systems at Façade in Atria, Atrium Plan and Measurement Points [53].

Calcagni and Paroncini (2004) presented simplified formulas based on radiance computer simulation tool. They published a method to evaluate daylight conditions in the adjoining space and on the atrium floor. The result highlighted that increase in the reflectance of the atrium surface does not produce a significant improvement in the Daylight Factor levels on the ground floor due to the large extension of the windows with high transmittance. Furthermore, surfaces that could reflect light are very limited while the presence of the atrium roof cuts the Daylight Factor by about 45% in the area adjacent to the atrium[54].

3.2.5 Studies on the effects of climate on the atrium's energy performance:

Abdullah et al (2009) investigated the application of two low-cost measures, namely high level internal solar blinds and water spray, on the three levels inside the atrium of a guesthouse in Southern China, where summer is hot and humid. They indicated that in hot-humid tropical climates, partially air-conditioned three levels top-glazed atrium would suffer high-temperature stratification on the top floor causing great discomfort to the occupants. There was also an indication that the two solar gain control measures contributed to the improvement of the thermal condition inside the atrium[55].

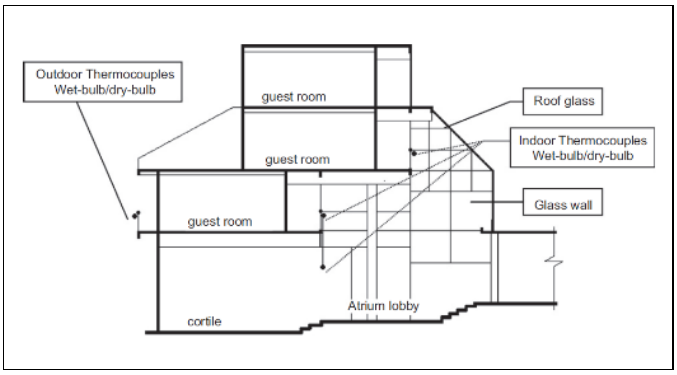


Figure 3.18 : Cross-Section Showing Vertical Measuring Points, [55].

Atif and Laouadi (1998) worked on skylight and developing skylight design tools for thermal and energy performance of atria in cold climate. These studies compared computed and measured thermal parameters in an atrium building[56].

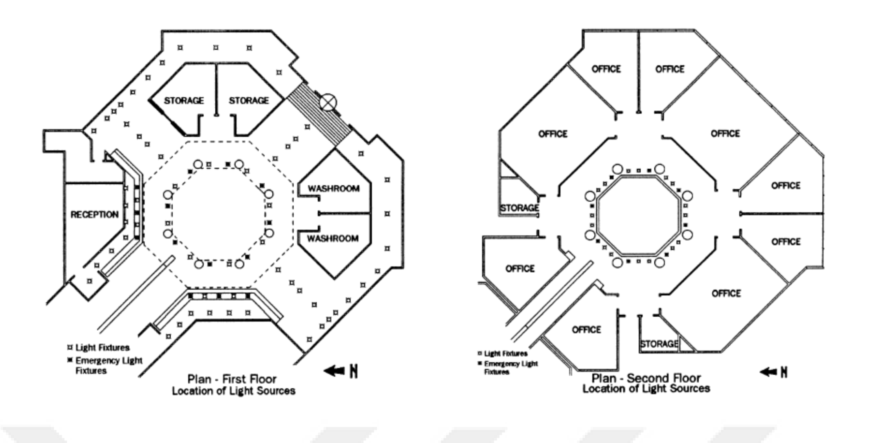


Figure 3.19 : Plan of Atrium with Location of Light Source [56].

Aldawoud and Clark (2008) by using DOE-2.1 analyzed energy performance of atria and courtyards. The general conclusion was in favor of open courtyards for smaller height buildings as being more energy efficient. Their study revealed that increasing building height, the 'enclosed atrium' became more energy efficient[20].

The literature review revealed that the researches have been focused on the energy performance of either atria or courtyards (see Table 3.1). There is gap in the literature with respect to the researches on the integrated usage of atrium and courtyard within a building so that energy performance of the building can be improved according to the seasons. This research aims to fulfill this gap in the literature.

Table 3.1 : List of the literature on the energy performance of atria / courtyards.

Authors and publication years	Research topic	Topic covered in the research (Atrium or courtyard)
Laouadi et al. (2002) [19]	Towards developing skylight design tools for thermal and energy performance of atriums in cold climates	Atrium
Laouadi, and Atif (1998) [56]	Comparison between computed and field measured thermal parameters in an atrium building	Atrium
Galasiu [45] and Atif (2002)	Applicability of daylighting computer modeling in real case studies: Comparison between measured and simulated daylight availability and lighting consumption	Atrium
Luis and Perez-Garci (2004)[40]	Parametric study of solar gains in saw-tooth roofs	Courtyard
Muhaisen [12] and Gadi (2005)	Mathematical model for calculating the shaded and sunlit areas in a circular courtyard geometry	Courtyard
Muhaisen and Gadi (2006a)	Using computer tool (IES) to investigate the effect of solar heat gain on the energy demand of a courtyard	Courtyard

Table 3.1 (Continued): List of the literature on the energy performance of atria / courtyards

Muhaisen and Gadi (2006b) [29]	Shading performance of a polygonal courtyard	Courtyard
Muhaisen (2006) [30]	Shading simulation of the courtyard form in different climatic regions	Courtyard
Aldawoud and Clark (2008) [20]	Computer simulation analyzed energy performance of atria and courtyards	Atrium
Horan and Finn (2008) [33]	Sensitivity of air change rates in a naturally ventilated atrium	Atrium
Liu et al. (2009) [48]	Evaluation of buoyancy-driven ventilation in atrium	Atrium
Woods et al. (2009) [50]	Comparison of winter pre-heating requirements for natural displacement and natural mixing ventilation	Atrium
Abdullah et al. (2009)[55]	Field study on indoor thermal environment in an atrium	Atrium
Kim and Tai Kim (2010)[52]	Luminous impact of balcony floor at atrium spaces	Atrium
Ok et al. [34]	Effects of surface openings on air flow caused by wind in courtyard buildings	Courtyard
Du and Sharples (2011)[53]	Assessing and predicting average daylight factors of adjoining spaces in atrium	Atrium
Assadi et al. (2011) [46]	Analytical model of atrium for heating and ventilating an institutional building	Atrium
Lin and Chuah (2011) [47]	Study on the potential of natural ventilation and cooling for large spaces in subtropical climatic regions	Atrium
Karava et al. (2012) [49]	Experimental study of the thermal performance of a large institutional building with mixed-mode cooling and hybrid ventilation.	Atrium
Haw et al. (2012) [35]	Empirical study of wind-induced natural ventilation	Atrium
Al-Masri and Abu-Hijleh (2012) [39]	An environmental assessment of the courtyard	Courtyard
Aldawoud (2013) [24]	The influence of the atrium geometry on the building energy performance	Atrium
Cantón et al. (2014) [26]	Courtyards as a passive strategy in semi-dry areas. Assessment of summer energy and thermal conditions in a refurbished school building.	Courtyard
Yaşa and Ok (2014) [31]	Evaluation of the effects of courtyard building shapes on solar heat gains and energy efficiency according to different climatic regions.	Courtyard
Kocagil and Oral (2015) [27]	The effect of building form and settlement texture on energy efficiency for hot, dry climate zone in Turkey	Courtyard
Manioğlu and Oral (2015) [32]	Effect of courtyard shape factor on heating and cooling energy loads in hot, dry climatic zone	Courtyard

There are series of details which have significant impact on thermal performance of courtyard building types such as climate conditions, building shape or height, orientation and internal loads, height of the building, window to wall ration, glazing type, the insulation levels, wind directions well as wind speed, impact of adjusting building characteristics on the buoyancy ventilation performance, the ventilation requirements and etc. It is evident that additional research is necessary to optimize the existing courtyard and atrium building systems and develop new ones.

3.3 Samples of Converting Courtyard to Atrium

3.3.1 Smithsonian American Art Museum

Smithsonian officials, in 2003, started off by discussing a main shift to the renovation design which was adding a glass roof to the open courtyard in the middle of the Old Patent Office Building in Washington. In March 2004, the Smithsonian claimed that Norman Foster, would design the glass canopy to the American Art Museum courtyard. To shield the old building new roof on eight aluminum-clad columns with 864 panes placed within the courtyard. Just a thin rubber seal a few feet deep joins the glass canopy to the original rooftops. The courtyard was taken into an atrium space involved new uses and presents how an architect can respect the past without affecting the standards (see Figure 3.20). When the weather is sunny, the grid will spread a fishnet pattern of shadows over the old front of building; at nights it becomes more forceful and strange. This atrium-courtyard is a friendly and pleasant space downtown in the capital city as well as a public place for the museums' performances, lectures and special events this open to sky area has become one of the biggest public event places in Washington sunny days the grid will cast a fishnet pattern of shadows over the old facades; at night its forms become more muscular and mysterious. This atrium-courtyard is a welcoming space downtown in the nation's capital as well as a public venue for the museums' performances, lectures and special events this open to sky area has become one of the largest public event spaces in Washington[57].

Figure 3.20 : Smithsonian American Art Museum (Left: internal view of courtyard), (Right: view of courtyard roof).

3.3.2 Queen Elizabeth II Great Court

Formally the place is called the Queen Elizabeth II Great Court, which was designed by Foster and Partners in September 1999.They moved the Museum's inner courtyard into the biggest public square in Europe which covers the 6000-m^2 space between the Reading Room in the middle of the atrium and the outer buildings. It is a two-acre space surrounded by a fantastic glass roof. The canopy of the roof was made out of 3,312 panes of glass, none of them are the same. The height of roof is 26 m at the south portico and 28.5 m on the northern side of the room. The space also hides twenty new columns made to support the glass roof, as well as smoke extract risers, rain water pipes and vents. The goal of the heating and air conditioning system is to supply ease apart from of the season, but this is not easy in such a big glass-covered area with its problems of solar radiation [58].

The major issue was the ventilation for such a large area. Extract air outlets are concealed behind the floodlights, which make clear the Great Court from the height of the Reading Room's circular dome. Solar irradiation in most of the Great Court is decreased by the use of specially treated glass. Each of the 3312 triangular panels is to some extent covered with small ceramic dots, so-called "frits", to distract the sunlight. One of the sudden effects of building the glass roof is that heat loss from the existing museum buildings has been reduced by 55–65%. At the same time, the shading coefficient of the fritted glass shields too much light from entering sensitive exhibits, which were protected by the outbuildings before [59].

Figure 3.21 : Queen Elizabeth II Great Court (Left: view of courtyard roof) and (Right: internal view of courtyard).

3.3.3 Bertolt-Brecht-School

The Bertolt-Brecht-School represents one of the so-called "typical schools" built with a prefabricated modular concept (Plattenbauweise) in the former German Democratic Republic in the 60's and 70's. The Bertolt-Brecht-School is located in the urban environment of the city of Dresden, the capital of the state of Saxony, in the Eastern part of Germany at Lat. The monthly average outdoor temperatures are close to 0°C in winter and near 17°C in summer. The building is almost unobstructed. After retrofitting, as a result of transforming the courtyards into two atria, the building can be described as a main hall school. Additional usable floor areas of about 400 m^2 have been gained which are now used as schoolyard, auditorium and reading spaces [60].

The heating energy consumption of the school was very high before the retrofit because of no insulation, bad window qualities and poor airtightness. The energy-efficient retrofit concept included the reduction of the thermal transmittance of the building envelope and the transformation of the courtyards into two atria. Therefore, they can be used as normal rooms such as canteen and auditorium. The object was to show the energy saving potentials and the possible improvements of the school's social facilities [61].

Figure 3.22 : Bertolt-Brecht-School (Left: before covering the courtyard roof) and (Right: converting courtyard to atrium).

The building involved of two rectangular east-west aligned three-story blocks joined by three staircases. The rooms were heated by radiators with thermostats. Ventilation was supplied by windows and air leakage. The lighting was mainly by daylight. The day lighting conditions were good because of the windows on two sides and the large window area. Next to standard measures like improving the thermal insulation of the facades, the retrofitting process strongly focused on transforming the courtyards into atria, and hence including these spaces into the thermal as well as social-cultural concept. The atria are the heart of the ventilation concept, permitting for night ventilation during summertime, drawing the colder air from the outside classroom facades through the classrooms into the atrium and in wintertime using the opposite direction by ventilating preconditioned air of the atria into the classrooms helped by fans [60].

The transformation of the open courtyards into atria decreased the daylight supply to the classrooms because of structural elements and the additional glazing layer. The need of electrical energy for artificial lighting was reduced a great deal in some classrooms by a daylight dependent artificial lighting control system. The heating energy demand was reduced by 75%, the artificial lighting energy in certain classrooms up to 77%. The comparison between rooms with and without a daylight dependent artificial lighting control system presented, that the saving of energy was about 77%, but on the other hand the system used was not cheap. Unlike the change of usage of the atria the expected energy savings could be mostly recognized [61].

3.3.4 City Creek Center

The City Creek Center is a big open-air retail, residential and office complex in Downtown Salt Lake City, Utah. Developers wanted an urban, open-air setting, but also needed the guarantee that retail businesses would be protected during stormy weather. After studying many skylight possibilities, the project's structural engineer made a retractable roof concept that fully met the developer's demand [62].

Barrel-vaulted roof is configured in two parts, each spanning one city block. The precision-sculpted steel and glass transparently shields patrons when shut, and vanishes from sight when open; joining nature with the areas below. When closed, all six panels close together and make an air and water tight barrier [63].

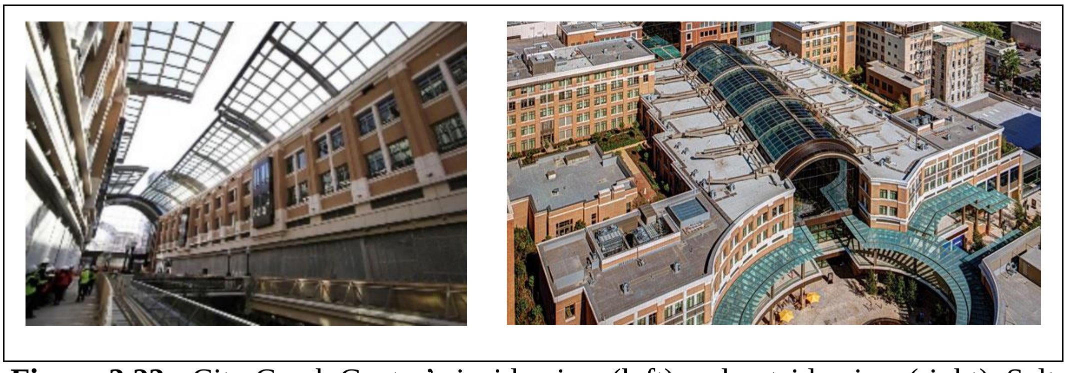


Figure 3.23 : City Creek Center's inside view (left) and outside view (right), Salt Lake City, Utah,USA.

4. LIFE CYCLE

4.1 Life Cycle Assessment

The notion of life cycle studies took years of time to come into existence during the 70 and 80 decades. In addition to that, the studies did their best to concentrate on the measurement of energy and materials used and wastes left behind in the environment [64]. It is emphasized that Life Cycle Assessment (LCA) is a way employed more and more for the evaluation of the environmental impacts in relation with the production, use, disposal and recycling of the products. This method tries to measure the amount used from the resource and the amount scattered in the environment in relation with the evaluated products. [65]. LCA was mainly developed for designing low environmental impact products. To put it into different words, Life Cycle Assessment evaluates the effects of a product or service on the environment, as an environmental management methodology. The process begins with the extraction of raw materials, continues with manufacturing, production, and use and ends up with the final disposal [66]. Society of Environmental Toxicology and Chemistry (SETAC) has a more comprehensive definition[67]:

"Life-cycle assessment is an objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment, to assess the impacts of those energy and material uses and releases on the environment, and to evaluate and implement opportunities to affect environmental improvements. The assessment includes the entire life cycle of the product, process, or activity, encompassing extraction and processing of raw materials, manufacturing and distribution, use/reuse/maintenance, recycling, and final disposal"

As part of 14,000 standards series, with the 14040 series concentrating on methodologies to be established for LCA (ISO 14040: 2006 and ISO 14044: 2006), the ISO, the International Organization for Standardization, adopted an environmental management standard[68]. A crucial aspect of the ISO standards is a four-stage framework for administering LCA analyses. Here are the four stages:

1. goal and scope definition
2. inventory analysis
3. life-cycle impact assessment (LCIA)
4. interpretation

There was an attempt to summarize and organize through the review of literature on life assessment by Luisa et al (2014). Their classifications were emerged differently as follow [69]:

1. Life cycle assessment in the building industry:
   - LCA applications for construction products selection
   - LCA applications for construction systems/process evaluation
   - LCA tools and databases related to the construction industry
   - LCA methodological developments related to the construction industry
2. Life cycle assessment of buildings and the building sector:
   - LCA of residential buildings
   - LCA of non-residential buildings
   - LCA of civil engineering constructions

The foremost target groups, for applying LCA in the early design of a building phases, were proposed by Bribian et al (2009)[70]. The Table 4.1below indicates that the most potential users of the LCA results are: architects, urban planners and property.

Table 4.1 : Application of life cycle assessment to the building sector [70].

Type of user	Stage of the process	Purpose of LCA use
Consultants advising municipalities, urban designers	-Preliminary phases	-Setting targets at municipal level -Defining zones where residential/office building is encouraged or prohibited -Setting targets for development areas
Property developers and clients	-Preliminary phases	-Choosing a building site -Sizing a project
Architects	-Early design and detailed design in collaboration with engineers -Design of a renovation project	-Setting environmental targets in a program -Comparing design options (geometry/orientation, technical choices)
Engineers/consultants	-Early design in collaboration with architects, and detailed design -Design of a renovation project	-Comparing design options (geometry, technical choices)

The system boundaries - established by Asdrubali et al (2013) - need defining process units and determining the life-cycle phases as well, in order to be comprised in the assessment. The model is concerned with three different phases of evaluation [71]:

1. Construction phase:

- materials production phase
- building construction phase

2. Use phase
3. End-of-life

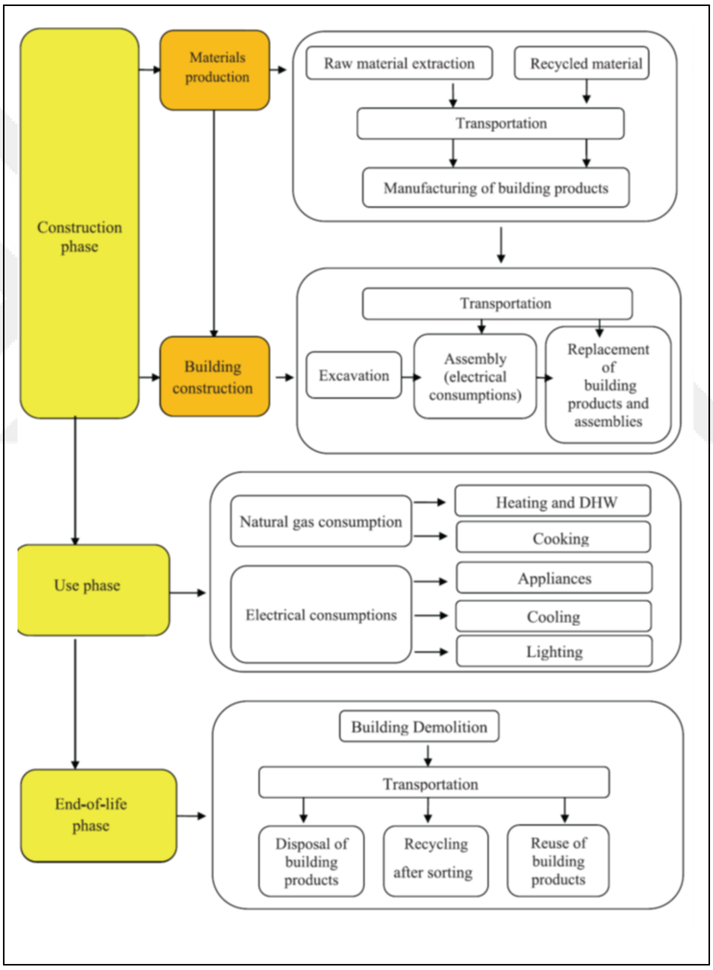


Figure 4.1 : System boundaries for determining the life-cycle phases [71].

4.2 Life Cycle Energy Analysis

Another form of life cycle assessment is life cycle energy analyses which is pertinent to the building industry owing to energy efficiency attempts during the previous decades. LCA is being considered as part of the ISO 14,000 series of standards on environment management. It is shown by Sartori and Hestnes (2007) that low energy buildings have a particular design. These buildings demand less operating and life-cycle energy providing that they are built on the basis of conventional criteria the same as all other circumstances [72]. That life cycle energy accounts for all of the energy inputs to a building in its life was emphasized by Ramesh et al (2010). Three main phases comprise the above mentioned energy as follows [73]:

1. Embodied energy: refers to the energy content of all of the materials employed in the building and technical installations and the energy received while there were novel construction and renovation of the building.
2. Operating energy: refers to the energy needed for maintaining everyday maintenance of the buildings. Energy for HVAC (heating, ventilation, air conditioning), domestic hot water, lighting and for running appliances.
3. Demolition energy: refers to the energy needed for demolishing the building at the end of its service life and transporting the material to landfill sites and/or recycling plants.

Here are data sources for life cycle energy analysis proposed by Luisa et al (2012[69]:

1. Manufacturing phase:

- Production of building materials
- Construction of the building comprising renovation
- Transportation

2. Use phase: Provision of lighting, clean water and heating by using electricity and fuels
3. Demolition phase:

- Demolition of the building
- Transportation
- Recycling

4. Life cycle energy: Total consumption of the energy of the building during its life cycle
5. Life cycle assessment: Estimation of life cycle materials and energy flow

4.3 Life Cycle Cost Key Concepts and Definitions

Life cycle costing which is considered as an economic investigation method takes action about diverse costs encountered during all the years of a measure or services that make a thorough assessment of the total profits gained in a design decision. This type of investigation greatly approves of the credentials of the options of cost effective building design. Also, an obvious suggestion of the parameter economic practicability is a low life cycle cost (LCC) [74].

Life cycle cost analysis is considered as a method by which the total cost of facility ownership is computed. This gives proper consideration to all of the cost of obtaining, having and destroying a building or a building system[75]. The use of LCC is particularly at the time when the project alternatives fulfilling the same performance needs, but are different concerning initial and operating costs, have to be compared so as to choose the one which enhances net savings to the highest. For instance, by the help of LCC, it will be determined whether or not the incorporation of a high-performance HVAC or glazing system, which has the possibility of increasing the initial cost but also may end in dramatic reduction of operating and maintenance costs, is cost-effective. The role that the early planning phases play is of high importance for a building performance in the future along the life cycle at a cost which is very low. According to Bogenstatter, 80 percent of the operational costs of a building, and also of the environmental impacts are determined by the early design stages[75]. The possibility of changes decreases very fast exactly at the time when costs increase, in the latter planning phases (Fig. 4.2).

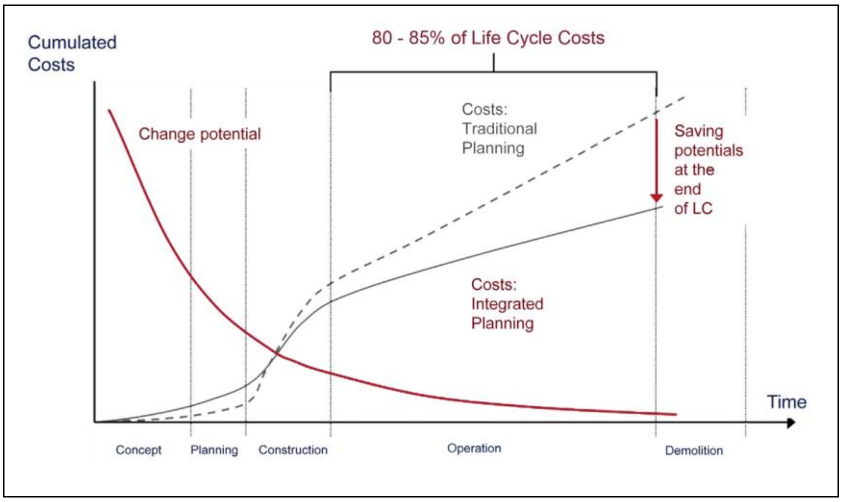


Figure 4.2 : A comparison between change potential and cost development over the life cycle of a building[75].

There is a claim made by not only academic research but also industry that integrated planning process, comprising life cycle costing and optimization, can reduce the subsequent costs greatly[76]. Early evaluation of the operational saving potentials or compilation and assessment of variant-study are allowed by the LCC analysis application [76] (Fig. 2).

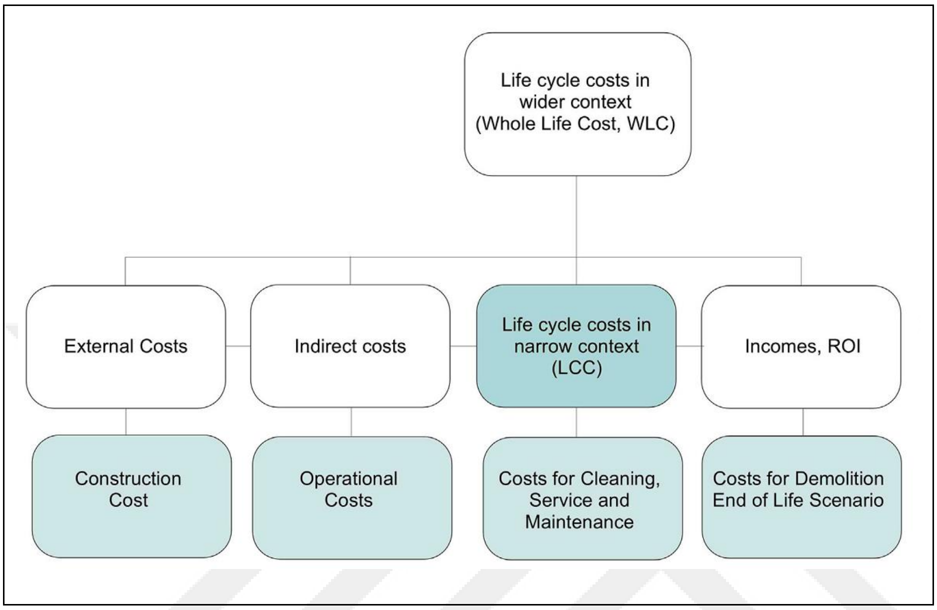


Figure 4.3 : Whole life cycle costs, after ISO 15686[77].

There is a problem that the phases of the early planning are marked by the lack of data, information and also instruments. Thus, planning tools are more and more needed by the investors and planners, as deciding assistance instruments, enabling the simulation and improvement of life cycle costs previously in the phases of the early planning (pre-design) [75]. The ISO 15686 gives a definition for LCC and also the whole life costs principle - known also as whole life cycle costing - in order to manage long term cost assessment of capital plans [77].

Life cycle cost analysis is different than life cycle assessment. Life cycle assessment mostly has something to do with environmental aspects and potential impacts pertaining to a commodity or service. LCA also comprises the consumed energy and material and potential environmental impacts pertaining to releases and inputs recognized for assisting the designer in identifying extra bearable design solutions [78]. An amount of the data used by LCA is utilized by LCC without the consideration of environmental impacts. LCC analysis is carried out so as to demonstrate if the commodity is economically well balanced and market achievable. It explains the worth of money in time through computing the time of payback and the actual saving at the end of the time long. LCC analysis should be considered as a method of engineering economic analysis of choices which takes into account all of the pertinent costs pertaining to each choice activity and plan during the allotted time[75,78].

The common employment of LCC is to specify the cost minimizing option. The LCC of a plan alone does not provide adequate information according to which economic decisions can be made. In order to determine the option having the lowest LCC there is the need for LCC data on investment options before the possibility of making a comparison. When there happen to be a must in choosing one of the options, in that case the option with the lowest LCC will be the most efficacious[75,78].

The hardest part of any computation lies in the difficult being of value evaluations between plans which are not made in equal units of measurement. Comparing of the values might not be done, for which at least two reasons are[79]:

4.3.1 Discounting

Each design option is streamed for by life cycle cost. For converting the costs into the currency and summing for each option, an economic method called as discounting is used. It is after this that the analyst can specify which option is the highest cost-efficient[79].

Costs or profits made at various points in time, in the past, present or future, if not permitted for the opportunity value of time cannot be comparable. The opportunity value of time relating to the present or future funds can be found out with regard to the return that could be made economically on funds in their following options employed the best - for example, interest could be earned out of the funds - or paying as a compensation in order to lead people to postpone the extra amount of the consumption of the present year to a year later. The act of adjusting for opportunity value of time is called as discounting[79,80].

4.3.2 Inflation

Normally, spending happens at different points of time whether in the past or future, and for this reason are measured in various value units. A tendency which is general and toward higher prices through time, as mentioned above, is known as inflation. And, on the contrary, a tendency which is again general and toward low prices is known as deflation. Currency comprising the results of inflation and deflation through time are called as nominal, current or data year currency. Currency not comprising an inflation or deflation component - that is to say, their power in purchasing foods and services remains the same - are known as constant or base year currency [79,80]. When the costs and profits of a plan in the future are supplied in nominal currency, converting the nominal currency to constant ones can be conducted by utilizing the following applicable indices:

Inflation indexes can be accessible for each possible commodity and service. Choosing a choice from among indices from broad - for example, Gross Domestic Product chain deflator - to average - for instance, a consumption index like the Consumer Price Index - or to narrow section or article - as an example, broad way construction or resurfacing expenses) relies on how the outcomes will be interpreted.

The range of real discount rates utilized in life cycle cost analysis is variable which is a representation of the current rate of interest on the funds borrowed, lower inflation. Since there always exists an opportunity value of time, the rates of real discount will constantly be over zero.

4.4 Life Cycle Cost Methodology

LCC has the aim of estimating the general costs of plan options and also of choosing the design ensuring the means will supply the least general cost of ownership with its quality and function being unchanging. The time when the LCC should be conducted is early in the plan process as there exists an opportunity to improve the plan so as to ensure a decrease in LCC. The most demanding LCC task, or any economic assessment technique, is the determination of economic effects of option plans of constructions and building systems, quantification of the effects and also their expression in dollar amounts[81].

Lowest LCC can be considered as the least demanding and complicated measure of economic assessment. Here are some other typically utilized measures: Net Savings (or Net Profits), Savings-to-Investment Ratio (or Savings Profit-to-Cost Ratio), Internal Rate of Return, and Payback Period. The Lowest LCC measure of assessment will be unchanging if the same parameters and duration of study time are employed. Construction economists verified that many experts of the field including architects, operation researchers, cost engineers, quantity surveyors, value specialists and some others could utilize any or several of these methods to assess a plan. The method in cost effective selections for plans relating to construction may be quite alike whether it is known as cost estimating, economic analysis or value engineering[80,81].

LCC has two chief methods, viz. deterministic and sensitive methods which are explained as follows:

4.4.1 Deterministic methods

The life cycle cost evaluation can be regarded as a part of the study of economic feasibility, which demonstrates economic achievement of a real estate, and the resources - efficiency at the same time. There are static or dynamical methods for considering life cycle costs and cost- efficiency. The static methods focus on a certain point in time or time-duration and they do not value the time impact. In other words, the static method pays no attention to the time's impact on value of money. For this reason, as construction investments need to be carried out throughout the buildings' life cycle, the static methods are not suitable as they only focus on a certain point in time [81]. Owing to the occurrence of future investments at a future point in time, there is need for the values to be discounted with today's values. The dynamical methods fill this gap as they pay attention to the time feature of the money. The net present value considers the future investment value at the present point of time (the amount of the money required to be invested at the present time, at a considered rate of return, to provide the flow of money in the future). This, as a value of an investment, needs to be put at a regarded discount rate for having future returns [82].

After the identification of the whole costs annually and discounting them to the current value, they are added to the total life cycle costs for each of the options as detailed below [82]:

LCC = I + Repl - Res + E + W + OM&R + O

LCC = Total LCC in present-value (PV) currency of a given alternative

I = PV investment costs (if received at base date, they don't require to be discounted)

Repl = PV capital replacement costs

Res = PV residual value (resale value, salvage value) less disposal costs

E = PV of energy costs

W = PV of water costs

OM&R = PV of non-fuel operating, maintenance and repair costs

O = PV of other costs

4.4.2 Sensitivity analysis

The life-cycle cost need to be considered with the help of sensitivity analysis which covers scenarios (e.g. potential benefits and conditions). The fruitfulness of sensitivity analysis goes to[81,82]:.

- the identification of the most important impact of one of the several equivocal input values on a certain measure of economic assessment,
- the determination of the effect of variability in the input value on the range of an economic assessment measure, and
- the testing of various scenarios in replying 'what if' queries.

"In order to identify parameters which are critical, upper and lower bounds need to be estimated, or 'what if' queries should be answered, for doing so the value of each input needs to be modified to up or down, while all other are kept unchanging, and the economic measure has to be calculated again for being tested"[74].

4.5 Studies on LCA, LCE and LCC

4.5.1 Studies on LCA

Pajchrowski et al, (2014) analyzed comparative environmental life cycle assessment of four prototype single-family residential building in Poland for a family with 4 members in a usable area of 98.04 square meters. There were differences between the buildings in structure materials, building technology and the standard energy. The buildings which were subject to analysis were as below [83]:

- Traditional masonry building (A1)
- Passive masonry building (A2)
- Traditional wooden building (B1)
- Passive wooden building (B2)

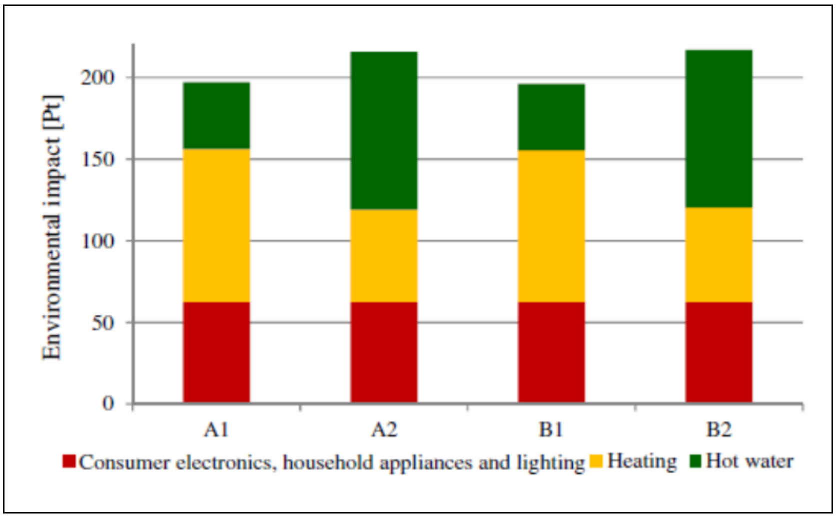


Figure 4.4 : Eco indicator results for three main contributions in energy consumption during the use stage [83].

The factor which appoints the outcome of passive building environmental indicators is made up by the high environmental impact of the production of the electric energy in Poland (90% of which was based on coal). It was emphasized that the total energy requirement of passive buildings is almost 3.6 times lower, in comparison[83].

Asdrubali et al (2013) studied life cycle assessment of three conventional Italian buildings - a detached residential house, a multi-family building and a multi-story office building [71]. In this analysis, all of the life phases were included from the production of the construction materials to the operating phases including transportation, lighting, assembling, cooling, heating and appliances, and to the finishing life of all the material and components. The environmental impacts of the phases have been assessed as follows[71]:

1. Construction phase: It ranged from 13.7% for the office building to 20.9% for the detached house
2. Operational stage: It ranged from 77.2% for independent house to 85% for the office building
3. End-of-life phase: It ranged from 1.3% to 2% of the total impact.

The values obtained made it clear that the impacts of operation - energy fell between 80% to 90% and of embodied-energy between 10% to 20% in the range.

Peuportier et al (2013) appled life cycle assessment to a case study of two attached passive houses which had been built in France. Their attention was thrown onto the environmental benefit obtained through higher quality constructions, and the quality of the strong impact of the occupant's behavior on the environmental performance of the buildings as well. In spite of the strong impact, the ranking between passive and standard designs was not changed by various occupants' behaviors in order that the outcome of LCA can be regarded as vigorous in this respect.[84].

Proietti et al (2013) investigatied passive house environmental impact comprising a combination of developed technological solutions in the building envelope, recycled materials, reuse of rainwater, decreased energy consumption, renewable energy utilization, and intelligent employment of insulation, Applying energy saving measures including: solar PV, recycled products in the preproduction phase, highly insulated building envelope and passive-house standard, and waste recycling could cause a great reduction in the influence of modern dwellings, being aware of this fact that novel building methods will not generally supply a positive environmental outcome [85].

Rakhshan et al (2013) investigated consumption of energy, emission of CO_2 and end-of-service implications of Expanded Polystyrene (EPS) wall insulation of a typical two-story semi-detached villa in Dubai. There used to be EnergyPlus 6.0 through Design Builder interface for assessing the impact of the suggested variations of insulation on the emissions of CO_2 and annual energy consumption of the villa. Its construction comprises a significant non-insulated reinforced concrete (RC) structure - covering approximately 50% the full perimeter of the building - and mid-plane insulated concrete blocks. In order that the environmental behavior of the villa could be improved, different wall insulation scenarios were taken into consideration as follows [86]:

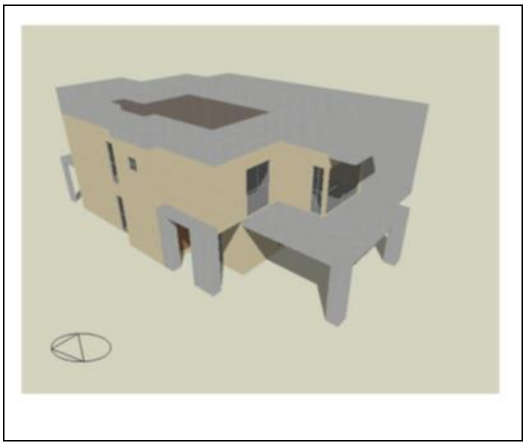


Figure 4.5 : DesignBuilder model for case study villa [86].

1. Baseline: overall U-value of the walls is = 0.523 W/m^2 K.
2. Baseline + 50 mm Expanded Polystyrene on thermal bridges only.
3. Baseline + 50 mm Expanded Polystyrene full wall perimeter.
4. Baseline + 160 mm Expanded Polystyrene full wall perimeter.

As the results show, a noticeable decrease in the emission of CO_2 in comparison with the baseline source can be seen. The amount of decrease in the emission of CO^2 for scenarios 2,3 and 4 were 16, 18, and 23%, respectively. Besides, out of the results it got clear that in 9 months of operation at most, as the outcome of extra wall insulation thickness of 160mm over rules the total embodied CO_2 of EPS insulation, the CO_2 saved[86].

Stazi et al (2012) studied on an integrated method for optimizing the energy and environmental performances of complex building envelopes. It provides a combination of life cycle assessment optimization analysis and energy simulation with that of factorial plan technique. In this examination, the attitude of the function of Trombe wall was regarded to employ solar energy so that the energy requirements for heating and cooling of the building could be reduced [87]. They considered a Trombe wall as a case study, which was located in a solar residential building prototype in Ancona (a city in Italy). In the production and operational phases, there was a calculation of the environmental performance regarding the energy needs and CO_2 emissions. The outcome of this study made it clear that solar walls could cause a high environmental impact on not only the production phase but on the operational phase, also. The optimization analysis outcome clarified the possibility of the reduction of CO_2 emissions and cumulative energy needs of solar wall for both of the production and use phases to as much as 55% if compared with a traditional plan. It was learned out of the outcome for the solar wall in this study that there was a high environmental impact from the side of the system on the pre-use and use phases both. In the production process, the reason for high environmental burdens was because of aluminum and concrete, whereas, in the operational stage, high CO_2 emissions and energy needs were because of the summer cooling energy consumption. In analyzing the impact of different variations of each one of the plan features, preliminary parametric analysis was fruitful. [87].

Radhi (2010) evaluated assessing the impact of five covering systems including: vinyl siding, aluminum siding, stucco, masonry veneer and the finish systems and exterior insulation, and materials on the UAE building CO_2 emissions, employing DesignBuilder as simulation software. The diversities of the economic and environmental performances among the five studied cladding systems were indicated to be totally significant, and regarding the operational energy the ranking of the cladding materials is diverse concerning the existing wall systems. Here is the summary of the study result[88]:

1. As there is a wall absorption increase, the cooling load and sol-air temperature both go up. Therefore, the cooling load and CO_2 emissions can be decreased by the utilization of light color wall covering materials.
2. Novel building technologies, like the exterior insulation and the finish systems (EIFS) can be introduced as influential techniques in decreasing the energy consumption and CO_2 emissions and finally leading to the reduction of global warming and climate change.
3. The vinyl system, aluminum siding system and last masonry veneer system owing to the decrease in cooling load.
4. The decrease in CO_2 emission from the operational energy relies on operation schedule, building system, power plants and types of fuels which are employed in generating electricity and the carbon emission factor.

Ortiz et al (2010) evaluated life cycle assessment of two buildings within the residential building sector, one of which was located in a developed country - Spain - and another situated in a developing one – Colombia. In order to calculate the energy demand, the building energy simulation software DesignBuilder was utilized. There was a comparison between the two real scenarios in this study [66]:

Situation 1: All of the energy required for the dwelling is provided just with electricity.

Situation 2: Operating of dwellings can be with electricity and natural gas.

The results of this research suggested that a significant part is played by the energy source origin utilized in each country for minimizing environmental impacts, the way as it is indicated by the environmental impacts of its utilization in Colombia in which most of the electricity (78%) was taken from hydroelectric plants, while it was taken from different sources in Spain including: fossil fuels 55%, nuclear power 18% and wind 9%. The results of the environmental impacts which used gas and electricity indicated the air conditioning environmental impacts in Spain got the highest impact within the range of 27 and 42% approximately, owing to the electricity consumption for powering it. At the meantime, the results obtained in Colombia indicated appliances consuming electricity got the highest environmental impacts - about 60% - and cooking got the most decrease in emissions owing to natural gas consumption, with a range of 10 to less than 2% [66].

4.5.2 Studies on LCE

Taleb (2012) investigated amount of energy and water consumed in an apartment complex in Saudi Arabia, using DesignBuilder simulation software. The conservation measures of energy examined in this study were as follows [89]:

- Thermal insulation of the external walls and roofs
- Efficient glazing
- External shading devices
- Energy-efficient fluorescent lighting

Taleb (2012) showed that when the above mentioned measures were applied in the apartment complex (being examined), there could be a collective achievement of reduction in energy consumption of about 32.4% - plus a decrease of 32 tons of CO_2 each year[89].

Ballarini and Corrado (2012) put forward a methodology concerned with the analysis of various contributions to the internal air convective heat balance and their interrelations with various boundary circumstances. EnergyPlus was utilized to compute the thermal analysis of the building and DesignBuilder software was used to make the three-dimensional building models. On two case studies - an office building and a residential building - the impact of the opaque envelope and thermal insulation was studied. By referring to the examined external climate and uses, the outcomes indicated a weak impact of all the envelope on the office building energy performance, which was because of the common impact of the internal heat sources. In the residential building, the transferring of energy through all of the envelope demonstrates a basic contribution to the need for the cooling energy, however the effect of the opaque envelope on the cooling energy demand and the maximum cooling load both was restricted. By referring to the size and solar and thermal parameters of the surface which was glazed for the residential building, the significant contribution of the transparent envelope was underlined by the sensitivity analysis outcomes[90].

Nassen et al (2012) studied a comparison between the buildings which had concrete and wooden frames concerning their total energy, material and carbon dioxide costs and also the emissions of carbon dioxide during the lifetime. This study also made it clear that the net present costs for the various buildings were influenced by the energy supply system in future, in spite of the fact that, particularly in comparison with the total construction cost, the influence was not much. At last they made a conclusion that there was an ambiguity in deciding whether buildings with wooden frames would be a cost-effective carbon mitigation option and that costs should be analyzed even more before the enforcement of prescriptive materials policies in the building sector [91].

Ihm and Krarti (2012) made an effort to discover the building energy performance in detail by employing simulation environment utilizing DOE-2 as the energy simulation engine of the whole building. There were 4 sites in Tunisia which were considered for analysis including: one in Tunis, one in Mednine, another in Gafsa, and the last one in Nefta [92]. Lifespan was considered to be as much as 30 years, and 5% to be the annual discount rate.

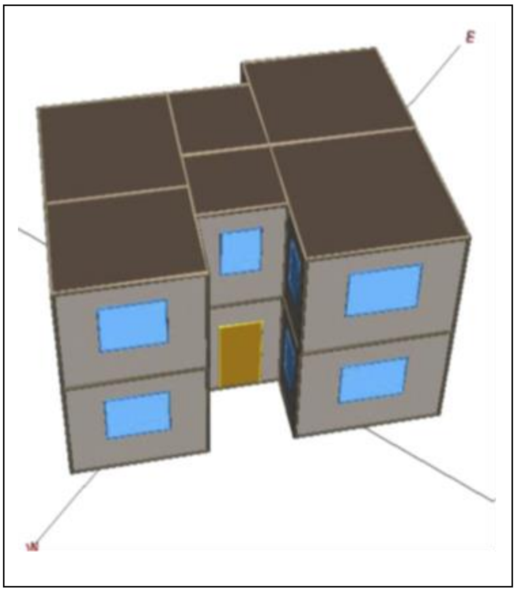


Figure 4.6 : DOE-2 model for case study [92].

And that the analysis cases included various combinations of design options listed as below [92]:

1. Package: window to wall ratio, glazing type, lighting level, infiltration rate.
2. Package: exterior wall insulation, roof insulation, window to wall ratio, glazing type, lighting level, Infiltration rate.
3. Package: indoor and exterior wall insulation, roof insulation, WWR, glazing type, lighting level, infiltration rate, cooling set point.

According to the study results, villa optimal designs situated in Tunis and Mednine experience less initial costs compared to the ones situated in Gafsa and Nefta. Nevertheless, villa energy costs in Mednine were more than the ones for other places. As a result, there is a similarity of life cycle costs for all climate zones. In comparison with the baseline design option, as villa is situated in Tunis, Mednine, Gafsa and Nefta, the result is set by optimal design in the source energy savings of 30, 33, 48, and 48%, respectively. In annual source energy saving, the best energy efficient was of 57% for Tunis, Gafsa and Nefta and 56% for Mednine[92].

There was an attempt by Ramesh et al (2010) in designing low energy building. For doing so, active and passive technologies were used to decrease its operating energy. Nevertheless, owing to the consumption of energy intensive materials in the energy saving measures, a decrease in operation energy is mostly followed by little increase in the building embodied energy. In life cycle context, if low energy buildings are designed in a careful way, their performance will be better than self-sufficient houses. Ramesh et al (2010) claim that a large number of technical installations are not eligible in making a building self-sufficient.[73].

Sartori and Hestnes (2007) evaluated life cycle energy consumption of six versions of the building - consisting of one conventional, one self-sufficient and four low energy - were analyzed in the German context conventional [72]. Looking at the results of the study, it has been observed that life cycle energy of the self-sufficient buildings in comparison with some of its low energy versions is higher. The reason, in case of low energy buildings, is that owing to energy saving measures, there is little increase in embodied energy in comparison with the decrease in its operating energy. That's why there appears to be a significant decrease in their life cycle energy. On the contrary, in case of a self-sufficient house, its embodied energy becomes high to the extent that it surpasses life cycle energy of some of the low energy cases although the operating energy of the self-sufficient house is zero. There was an emphasis that it is not the self-sufficient house which consumes life cycle energy less than all the other versions of a building and that installing complex and energy intensive technical installations can cause a decrease in the operating energy, which is a limit for life cycle energy savings.[72].

4.5.3 Studies on LCC

According to Pajchrowski et al (2014), when the cost of purchasing materials increase, particularly the insulation, the expected costs of use decrease, which is in connection with lower energy losses [83]. As Pajchrowski et al (2014) emphasized it to be rather normal between the increased building costs and the higher costs of use, it is usual for the investors to make decision on the basis of the economic criteria. In any case, along with the process of resolving such a problem, there go the economical costs pertaining to the decision making models of an individual, which have got a more common extra criterion, in the period of sustainable buildings and an inclination of bringing environmental elements in the decision making processes [83]. It was suggested that the newly made economic assessments employed the life cost analysis together with the total net present value in a defined building life cycle (Corgnati et al 2013). The global cost calculation derived from En 15459 (the European Standard) is considered to be the chief reference of the economic calculation methodology[93].

Han et al (2014) had an investigation on the optimization framework of office building life cycle. The outcomes demonstrated that the major parts of life cycle cost comprise the capital cost and the consumption of the operating energy both. The longer the lifespan of a building, the more important its annual energy consumption. In the current case study, when the lifespan of the building is above 30 years, most of the part of the life cost is for operating energy (cost). The materials having the best thermal properties are emphasized by the optimum combination for annual energy cost, whereas materials of poor quality and of smaller HVAC system size are highlighted by the optimization of capital cost. Consequently, out of the results of this study it can be learned that a comprehensive life cycle analysis model arranges a higher understanding of purposes for the optimization of building systems. Again, it proposes that it is the lifespan of the building that determines combinations of the optimized building components. In this investigation, two scenarios of energy pricing are taken into consideration. As the outcomes determine, optimization results and life cycle cost will be affected by any increase in prices. There was a case study of an office building which indicates that as the lifespan of the building goes up to more than 30 years, the increasing annual energy consumption cost is calculated to reach an extent more than the initial construction cost. At last, it should be notified that the optimal component combinations determine the lifespan of a building to be longer or shorter. We have considered wooden window frames as an example, which have got the optimal component for a lower energy and maintenance cost when the lifespan of the building differs and rises from 14 to 60 years.[94].

Pikas et al (2014) dealing with the optimality of cost and also the efficiency of energy, took possible design solutions of office building fenestration into account. There was a simulation of an open-plan generic single office floor which was separated into five different parts for which IDA-ICE 4.5 and an experimental reference year for Estonia were employed. The chief purpose of this study was to find out the optimal external wall insulation thickness and evaluation of solutions which were cost optimal and most energy efficient for the facade. The outcome indicated that for the cold climate in Estonia, triple glazed argon filled windows with a little window to wall ratio together with 200mm-thick-insulation walls can be cost optimal and energy efficient within 20 years of duration.[95].

Bras et al (2014) assessed the advantages of employing ETICS (which stands for External Thermal Insulation Composite System) and made a comparison between this one and a double brick wall. The latter is a traditional (but strongly implemented) construction technique of Portugal. Whatever the aim of the research was it should be mentioned that it made an attempt to compare the behavior of the buildings, which had been constructed in three various climates: one in the South of Portugal (Leule), another in the South-center (Lisbon), and the third one in the North of the country (Bragana). There were two dwellings (I and II) regarded as case studies so as to implement a thermal study and an energy cost analysis, which was electricity-based, for various scenarios, the chief scenarios of which are indicated in the following[96]:

1. The impact of the shading device systems in the thermal gains and losses
2. Changes in the quality of glass

3. The impact of PVC taking the place of the openings by the extruded aluminum system

Figure 4.7 : Dwelling 1 (left), Dwelling11(right) [96].

First, according to the energy analysis, ETICS solution uses up 65% of the total energy for constructing a traditional air cavity wall. Studying the electricity cost for heating and cooling purposes in the two buildings was the second step to take. The results clarified that dwelling I (in Leule and Lisbon) construction leads to a cost which 400 D/year lower than Dwelling II. However, a 20% reduction can be observed (by referring to the initial cost) that is led by scenario I, shading systems. Moreover, by considering scenario 2, glazing type, a 3% cost reduction (in Lisbon) was the outcome, while it was not like in Braganca or Loule. Indeed, a 10% increase with this scenario in Braganca is the difference existing between the electricity cost for heating in the two dwellings (I and II). In addition, openings frames, scenario 3 caused a reduction of cost which was more indicative in Braganca rather than in Loule or Lisbon. In this study, there was also an emphasis on colder climates (the same as the one in Braganca town) that the air-renewal is of a lot of importance in being considered from the negative viewpoint. It's because any increase in it causes the heating needs to go up and therefore the electricity consumption cost for heating[96].

Sertsungnern and Sertsungnern (2011) investigated developing an appropriate plan to rate the energy performance of air conditioning systems in Thailand, using DesignBuilder simulation software. The performance in this plan was arranged into the levels of good, very good and excellent. The excellent performance was consistent with the minimum system life cycle cost. But the good performance level was consistent with the minimum performance needs of air-conditioning systems which had been proclaimed in Thailand's building energy code (BEC) [97]. The chief manufacturers and distributors of Thailand gave the information about the capital cost of air-conditioning equipment to them. By using the DesignBuilder, they got the operating cost through the yearly electrical energy consumption of the simulated system. According to the results of the analysis, in most of the cases, the minimum life cycle cost was offered by the best performance of the chillers found in the market. The life cycle cost of the equipment was determined as the function of its Coefficient of Performance (COP). In most of the cases, the best performance of the chillers was found to offer the minimum life cycle cost without considering the size of the equipment and the type of the buildings. According to the results of the life cycle cost analysis, in order to rate the energy performance of A/C equipment the appropriate plans can be introduced as follows [97].

Table 4.2 : Performance rating scheme air conditioning equipment, in Thailand [97].

Performance rating scheme	Chiller's Performance COP (kW/TR]	
	Water-cooled chiller	Water-cooled chiller
Good	2.61< COP ≤ 2.68 (1.35> kW/TR ≥1.31]	4.63 < COP ≤ 5.25 (0.76 > kW/TR≥0.67]
Very Good	2.68< COP < 2.81 (1.31> kW/TR >1.25]	5.25 < COP < 6.39 (0.67 > kW/TR>0.55]
Excellent	2.81≤ COP ≤ 3.02 (1.25≥ kW/TR ≥ 1.17]	6.39 ≤ COP ≤ 7.65 (0.55 ≥ kW/TR≥ 0.46]

Chel and Tiwaric (2009) studied thermal model of a vault roof building with an earth to air heat exchanger (EAHE) thought out. The construction being assessed was made of adobe and brick vault structures. The technique that they utilized for the equation of energy balance was the 4th order Runge-Kutta numerical. Based on the results obtained in this experiment, the air temperature of the room got higher between 5 to 15 degrees centigrade during winter (in comparison with the ambient air temperature), whereas during summer it was vice versa. Besides, they emphasized that earlier and later than the integration of EAHE, the energy saving potential of the building in a year was 4946 kWh/year and 10321 kWh/year, respectively. It was found out that the SEER (seasonal energy efficiency ratio) for EAHE was as 2-3. This significant raise in the energy saving potential of building through a year caused by EAHE results in the reduction of CO_2 emissions nearly 16 tons/year and the related annual carbon credit of building which is roughly calculated to be as much as 340 (euro)/year [98]. As the life cycle cost analysis indicates, the period for recompensing is lower than 2 years of time for investing on EAHE system.

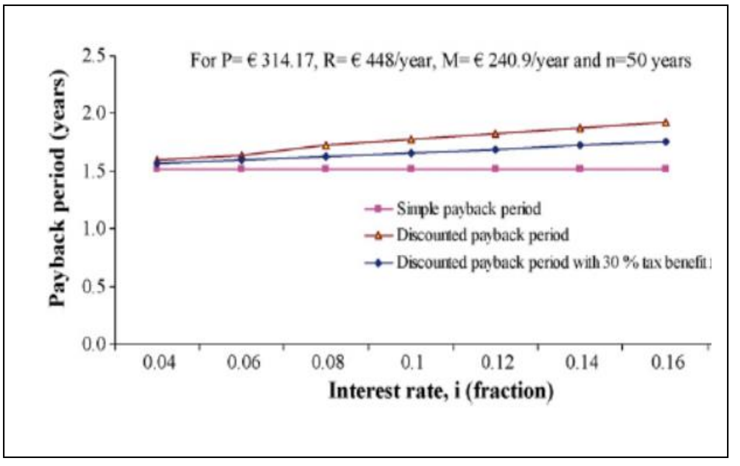


Figure 4.8 : Payback period for the existing earth to air heat exchanger setup for different interest rates [98].

Chel et al (2009) studied size and cost of Photovoltaic power system components employing a real case study in India (New Delhi). On the basis of life cycle cost analysis, it was capital and unit costs of electricity which determined Photovoltaic systems (e.g. stand-alone Photovoltaic system and building integrated Photovoltaic). The impact that carbon credit had on Photovoltaic system economics indicated a decrease in unit cost of electricity by 17-19% for stand-alone Photovoltaic system and 21-25% for integrated Photovoltaic system. In addition, they emphasized that the size of the existing 2.32 kWp Photovoltaic system was appropriate for the operation of the load given for the previous 5 years while Photovoltaic system did not confront any failure[99].

Table 4.3 : List of the literature on LCA, LCE and LCC.

Authors and publication years	Research topic	Topic covered in the research
Pajchrowski et al (2014) [83]	Wood as a building material in the light of environmental assessment of full life cycle of four buildings	LCA
Asdrubali et al (2013) [71]	Life cycle analysis in the construction sector: Guiding the optimization of conventional Italian buildings	LCA
Rakhshan et al (2013)	Evaluating the sustainability impact of improved building insulation: A case study in the Dubai residential built environment	LCA
Peuportier et al (2013) [84]	Eco-design of buildings using thermal simulation and life cycle assessment	LCA
Proietti et al (2013) [85]	Life cycle assessment of a passive house in a seismic temperate zone	LCA

Table 4.3 (Continued): List of the literature on LCA, LCE and LCC.

Stazi et al (2012) [87]	Life cycle assessment approach for the optimization of sustainable building envelopes: An application on solar wall system	LCA
Radhi (2010) [88]	On the optimal selection of wall cladding system to reduce direct and indirect CO_2 emissions	LCA
Ortiz et al (2010) [66]	Life cycle assessment of two dwellings: one in Spain, a developed country, and one in Colombia, a country under development	LCA
Ballarini and Corrado (2012) [90]	Analysis of the building energy balance to investigate the effect of thermal insulation in summer conditions	LCE
Nassen et al(2012)	Concrete vs. wood in buildings–An energy system approach	LCE
Ihm and Krarti (2012) [92]	Design optimization of energy efficient residential buildings in Tunisia	LCE
Taleb (2012) [89]	Developing sustainable residential buildings in Saudi Arabia: A case study	LCA and LCE
Ramesh et al (2010) [73]	Life cycle energy analysis of buildings: An overview	LCE
Sartori and Hestnes (2007) [72]	Energy use in the life cycle of conventional and low-energy buildings: A review article	LCE
Bras et al (2014)	Economic evaluation of the energy consumption and thermal passive performance of Portuguese dwellings	LCC
Han et al (2014) [94]	Variability of optimal solutions for building components based on comprehensive life cycle cost analysis	LCC
Pikas et al (2014) [95]	Cost optimal and nearly zero energy building solutions for office buildings	LCC
Corgnati et al (2013) [93]	Reference buildings for cost optimal analysis: Method of definition and application	LCC
Sertsungnern and Chaiwiwatworakul (2011) [97]	Development of a Performance Rating Scheme of Air-Conditioning Systems for Buildings: A Case of Thailand	LCC
Chel and Tiwaric (2009) [98]	Performance evaluation and life cycle cost analysis of earth to air heat exchanger integrated with adobe building for New Delhi composite climate	LCC
Chel et al (2009) [99]	Simplified method of sizing and life cycle cost assessment of building integrated photovoltaic system	LCC

From the literature it is possible to absence that, energy requirement of buildings is directly related to the technology of their construction and the type and amount of used building materials. Life cycle mostly focuses on the quantification of energy and materials used and wastes released in to the environment. One of the life cycle forms is life cycle energy analyses that particularly relevant to the building industry due to energy efficiency efforts. Life cycle energy accounts for all embodied, operation and demolition energy inputs to a building in its life. The impacts of operation-energy have been recognized in the range of 80–90% from whole energy usage during building lifespan. Nowadays, low energy buildings are known as the buildings which have specific design that demand less operating and lifecycle energy. The amount of energy needed by buildings has a direct relationship with their construction technology and the amount of building materials employed.

5. RESEARCH METHODS

5.1 Introduction

The purpose of this study is to investigate the energy performance of typical courtyard and atrium office buildings at various climate zones. This study calculates both courtyard and atrium building performance in terms of cooling, heating, lighting requirements and both buildings total energy cost to present a simplified prediction method for an integrated building. This study presents an overview of each building energy performance requirement and energy cost effectiveness regarding to find a solution of integrated courtyard and atrium.

This chapter includes three parts. For the first step, the main design parameters of a typical courtyard and atrium office building are considered. These comprise building geometry and height of the buildings. The area and other properties of windows are also considered because the performance of any building depends on how the fenestration factors are configured. Second, for the assessment of geographical and climatic influences, five climate zones of Turkey for energy performance analysis are selected. Third, the performance requirements for buildings are described and energy cost of modeled buildings are presented.

5.2 Hypothesis and Assumption

The study focuses on the following specific research area. These objectives are discussed in the light of both the results and the development of the method.

1. Passive energy performance of courtyard and atrium lead to optimum design of building.

- Different glazing types impact energy demand of courtyard and atrium.
- Different climate conditions, influence glazing types in courtyard and atrium building.

2. Seasonal period usage of courtyard and atrium leads to reach an energy efficient building.

- Integration of atrium and courtyard can increase energy efficiency of the building.

3. Arrangement of atrium and courtyard usage leads to sustainable building.

- Time usage of atrium and courtyard reduce operation costs.
- Investments on integrated atrium -courtyard are feasible.

5.3 Simulation Program

The growing complexity of buildings in function and design has made whole building energy performance simulation an integral part of the planning process for building services engineers. It has three key phases: modeling, simulation, and results analysis. In the modeling phase, a baseline-building model is generated first. The effort spent in this phase varies according to the required accuracy of simulation; more effort is required to develop highly specific, complex building models that produce more accurate simulation results. In the simulation phase, the simulators take the building models as input and perform simulations over a specified time and climate. In this phase, the performance of the building systems is evaluated. In addition, the energy consumption profile of the building systems is computed. In the final phase, results analysis, the results of the simulation are presented to the user. Building energy simulation provides a quick and easy estimate of the energy consumption in a given building, based on the corresponding climate and building characteristics. Among several building energy simulators, EnergyPlus and DOE-2 are popular ones [100]. EnergyPlus is a whole-building energy simulation software, which allows users to model complex mechanical heating and cooling, lighting, and ventilation systems in detail. The software allows for user specified time increments permitting sub-hourly analysis of building and energy systems as well as a wealth of output data reporting options. Today the most restricting limitation of EnergyPlus is the missing graphical user interface that provides all EnergyPlus capabilities [101].

Besides eQUEST and several other graphical user interfaces DesignBuilder is one of the most advanced user interface, which provides several usability enhancements to the EnergyPlus simulation engine. It includes a simplified CAD interface, templates, wizards, and most compact air system configurations of EnergyPlus[100].

DesignBuilder provides a variety of country or region specific templates for selection of parameters (such as materials and constructions). Lists of other definable parameters include internal loads (with occupancy patterns/activities), construction types, openings (windows and doors), lighting, and HVAC systems. The typical usage of DesignBuilder includes evaluation of façade options, daylighting analysis, visualization of site layouts and solar shading, thermal simulation of natural ventilation, and sizing of HVAC equipment and systems [11].

The accuracy of the DesignBuilder software has been validated using the BESTest (Building Energy Simulation TEST) procedure, originally developed by the International Energy Agency. The BESTest is a comparative set of tests that has been regarded by the American Department of Energy and the international community as being a reputable basis for evaluating the capabilities of building energy simulation programs[88].

The analyses have been carried out applying two main building energy performance simulation tools, namely EnergyPlus (Version 8.1) and DesignBuilder (Version 4.2.0.054):

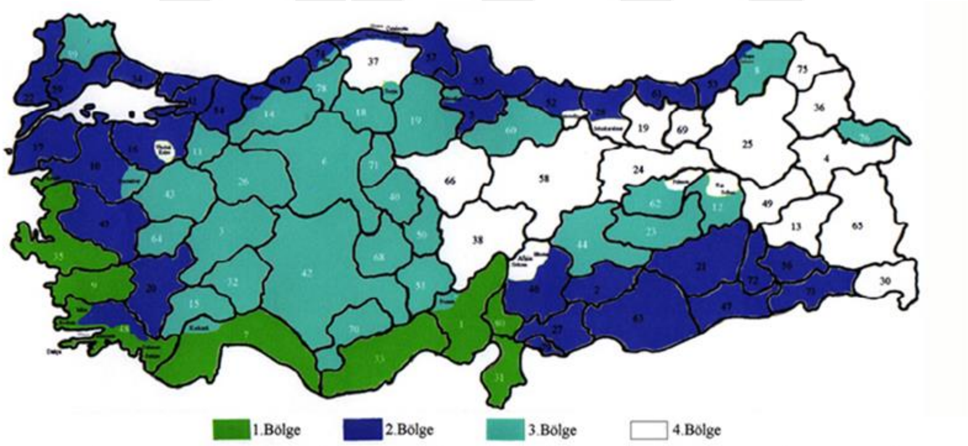
- EnergyPlus has been used for calculating heating, cooling, lighting, ventilating, and other energy flows. EnergyPlus is reliable as it has been validated under the comparative Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs BESTEST/ASHRAE STD 140[10].
- DesignBuilder, as the GUI (Graphical Usage Interface) for EnergyPlus, is the most comprehensive interface for EnergyPlus available today. DesignBuilder has been used to evaluate façade options, and to analyze thermal simulation, daylighting, total energy consumption, CO_2 reduction, and sizing of HVAC equipment and systems[11].

5.4 Energy Simulation Parameters

The thermal behavior of two office buildings (one with a central, enclosed atrium with a skylight and the other with a central courtyard) has been modeled and analyzed. The thermal performance of both atrium and courtyard spaces as well as their integrated usage have been analyzed. Alternatives for each model in this research varied according to the identified variables. The variables investigated in this study were:

5.4.1 Weather and climate zone

The climate has a great impact upon both the energy and environmental performance of the building as well as on the occupants themselves. Climate affects buildings, and subsequently the comfort of the occupants, in different ways. Each climate presents its own unique challenges for building design and low energy performance. Based on climate zone classification system, there are Five unique climates in Turkey. Turkey has a mid-latitude location between three sees. As a result, it experiences a wide variety of climates. The impact of the five climatic regions of cold, mild, mild-humid, hot-humid and hot-dry on the energy performance of models and their alternatives are investigated. A city is selected to represent each climate in the simulation process.



01- ADANA	10- BALIKESİR	19- ÇORUM	28- GİRESUN	37- KASTAMONU	46- K.MARAŞ	55- SAMSUN	64- UŞAK	73- ŞIRNAK
02- ADIYAMAN	11- BİLECİK	20- DENİZLİ	29- GÜMÜŞHANE	38- KAYSERİ	47- MARDİN	56- SİİRT	65- VAN	74- BARTIN
03- AFYON	12- BİNGÖL	21- DİYARBAKIR	30- HAKKARİ	39- KIRKLARELİ	48- MUĞLA	57- SİNOP	66- YOZGAT	75- ARDAHAN
04- AĞRI	13- BİTLİS	22- EDİRNE	31- HATAY	40- KIRŞEHİR	49- MUŞ	58- SİVAS	67- ZONGULDAK	76- IĞDIR
05- AMASYA	14- BOLU	23- ELAZIĞ	32- ISPARTA	41- KOCAELİ	50- NEVSEHİR	59- TEKİRDAĞ	68- AKSARAY	77- YALOVA
06- ANKARA	15- BURDUR	24- ERZİNCAN	33- İÇEL	42- KONYA	51- NİĞDE	60- TOKAT	69- BAYBURT	78- KARABÜK
07- ANTALYA	16- BURSA	25- ERZURUM	34- İSTANBUL	43- KÜTAHYA	52- ORDU	61- TRABZON	70- KARAMAN	79- KİLİS
08- ARTVİN	17- ÇANAKKALE	26- ESKİŞEHİR	35- İZMİR	44- MALATYA	53- RİZE	62- TUNCELİ	71- KIRIKKALE	80- OSMANİYE
09- AYDIN	18- ÇANKIRI	27- GAZİANTEP	36- KARS	45- MANİSA	54- SAKARYA	63- ŞANLIURFA	72- BATMAN	81- DÜZCE

Figure 5.1 : Climatic region in Turkey.

- Hot-Dry Climate: Low and unpredictable precipitation is the primary characteristic of a hot-dry climate. Hot-dry weather in summer, cold in winter, very little rainfall, very low humidity, and a high temperature difference between night and day are the characteristics of this climate [102]. In this research Diyarbakir is considered as the representative of the hot-dry climate in Turkey during the simulation stages. The average monthly relative humidity and temperature in Diyarbakir are shown in Table 5.1.

Table 5.1: Monthly average relative humidity and average temperature in Diyarbakir[103].

Diyarbakir	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Humidity	74%	68%	66%	64%	55%	34%	24%	25%	34%	50%	60%	79%
Min (°C)	−2	−1	2	7	11	16	22	21	16	10	4	0
Max (°C)	7	9	14	20	27	33	38	38	33	25	16	9

- Mild-Humid Climate: According to Köppen–Geiger classifications, a mild, humid climate is typified by large seasonal temperature differences, a subtropical climate with no dry season, and consistent moisture. Summers are hot and humid with thunderstorms. Winters are mild with precipitation. Seasonality is moderate. Precipitation is usually well distributed through the year[102]. Istanbul was considered as the representative of a mild-humid climate in this research. The average monthly relative humidity and temperature in Istanbul are shown in Table 5.2.

Table 5.2 : Monthly average relative humidity and average temperature in Istanbul [103].

Istanbul	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Humidity	79%	76%	75%	74%	74%	70%	71%	74%	75%	80%	79%	80%
Min (°C)	3	2	3	7	12	16	18	19	16	13	9	5
Max (°C)	8	9	11	16	21	25	28	28	24	20	15	11

- Cold Climate: Erzurum is the characteristic city for cold climate. According to Köppen–Geiger classifications, Erzurum has a humid continental climate with severe winters, no dry season, warm summers, and strong seasonality [102]. The average monthly relative humidity and temperature in Erzurum are displayed in Table 5.3.

Table 5.3 : Monthly average relative humidity and average temperature in Erzurum [103].

Erzurum	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Humidity	78%	77%	75%	67%	63%	59%	54%	51%	54%	66%	75%	79%
Min (°C)	−13	−12	−7	0	5	8	11	11	7	2	−3	−10
Max (°C)	−4	−3	2	11	17	21	26	27	22	15	7	−1

- Mild-Dry Climate: A temperate climate has very unpredictable weather. One day it may be raining, the next it may be sunny. This ever-changing weather occurs in summer as well as in winter. Also this climate exhibits extremes in weather conditions[102]. Ankara as a representative of mild climate in turkey is considered to study. The average monthly relative humidity and temperature in Ankara are shown in Table 5.4.

Table 5.4 : Monthly average relative humidity and average temperature in Ankara[103].

Ankara	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Humidity	79%	76%	66%	58%	57%	51%	43%	41%	46%	56%	71%	79%
Min (°C)	-3	-2	1	5	9	13	15	16	12	7	2	-1
Max (°C)	4	6	11	17	22	26	30	30	26	19	12	6

- Hot-Humid Climate: These climates have moderate temperatures and changeable, rainy weather. Summers are hot and dry, due to the domination of the subtropical high pressure systems and high humidity are the characteristics of this region[102]. Antalya is chosen in this climatic region. The average monthly relative humidity and temperature in Antalya are presented in Table 5.5.

Table 5.5 : Monthly average relative humidity and average temperature in Antalya[103].

Antalya	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Humidity	69%	68%	65%	68%	68%	63%	58%	60%	58%	62%	67%	70%
Min (°C)	6	6	8	11	15	19	22	22	19	15	10	7
Max (°C)	15	15	18	21	25	30	34	34	31	26	21	16

5.4.2 Shape of the courtyard and atrium

The courtyard and atrium models are designed based on the criteria obtained from the literature survey. Courtyard thermal performance is mainly affected by the solar radiation penetration of the internal envelope, which is dependent on the courtyard geometrical parameters and the sun's position [12,28,29]. Shading and exposure conditions on the internal envelope of the courtyard are affected by rectangular courtyard proportions[30]. By considering the elongation of the courtyard form (a rectangular courtyard width /its length), it appeared that a square courtyard is optimum in terms of energy demand [30]. Yasa and Ok (2014) highlighted that during summer a square courtyard shows better energy performance in the three climate regions of Turkey. Aldawoud (2013), studied on various shape of atrium regarding to achieve optimum form. The outcome of the research showed that square shape atrium is optimum shape from energy requirements point of view [24]. As a result, to achieve energy-efficient building in this study atrium and courtyard are modeled as a square[31].

5.4.3 Building Height

From the literature survey it appeared that shallow courtyards perform better than deeper ones during winter; however, courtyards having deep forms require low energy for cooling in summer [12,28,29]. With regard to the achievement of an optimum height for courtyard building, Muhaisen (2006) suggested three stories in hot, humid climates, two stories in hot, dry, and temperate climates, and one story in a cold climate [30]. Considering alternatives such as R1 (floor perimeters P/form's height H) and R2 (elongation of the form L/its length W) that affect a rectangular courtyard's shape and height when the height of each story is set at 3.30 m (floor to floor), the side of the square courtyard for two and three stories are calculated at around 8 m and 25 m, respectively. (DesignBuilder measures the height of the last story at more than 3.3 m due to having characteristics of a roof layer.) In this research a courtyard building is considered to have three stories because of providing architectural aspect, outside view, and more natural light for adjacent buildings.

5.4.4 Depth of the surrounding building

The depth is the distance from a fixed interior element, such as the building core, to an exterior window wall. It depends upon the functional requirements and size of the floor plate and is a very important consideration for interior planning, as well as for the entire courtyard building configuration. considering the daylight in courtyard building performance, there is a need to concentrate on the depths of the surrounding building in tall building design because the quantity and quality of daylight can be determined by the depth of the surrounding building. Shpuza (2006) considered four types of building characterized by the depth of the space: very deep (over 20 m deep), deep (11–19 m deep), medium (6–10 m deep), and shallow (4–5 m deep) [104]. According to the Ko et al. (2008), the depth of the building should usually be between 10 and 14 m for office functions[105]. Cho, (2007) also highlighted that 80% of high-rise buildings use a space depth of 10 to 15m [106]. The maximum allowable depth of space in Germany is typically about 5.5m, whereas in the United States as much as 15m is no rarity [105].

Therefore, based on the collected depth of space range data mentioned above, office types with space depth 10m is considered and simulated in this research.

5.4.5 Description of the construction layers

Since the building envelope was a critical component in the simulation process, this study investigated glazing for the courtyard walls and the atrium skylight for both base models and their alternatives. Figure 5.2 show the description of the construction layers and the area. The U-values have been selected in accordance with Turkish standard "Thermal insulation requirements for buildings" (TS 825) as the reference cities were chosen from Turkey [107]. The selected U-values are provided in Table 5.6 and Table 5.7.

Table 5.6 : U-values of construction for the reference cities in the research (Turkish Standard, 2014) [107].

U-Value(W/m²K)	Istanbul	Diyarbakir	Erzurum	Ankara	Antalya
External wall	0.60	0.60	0.40	0.50	0.70
Roof	0.40	0.40	0.25	0.30	0.45
Floor	0.60	0.60	0.40	0.45	0.70
Windows	2.4	2.4	2.4	2.4	2.4

Table 5.7 : Construction layers' thickness and conductivity adopted from DesignBuilder.

Element	Layers of the construction	λ (W/mK)	Istanbul	Diyarbakir	Erzurum	Ankara	Antalya
External wall	Brickwork, Outer leaf	0.84	10 cm	10 cm	10 cm	10 cm	10 cm
	XPS Extruded Polystyrene -CO_2 Blowing	0.034	3.91 cm	3.91 cm	6.74 cm	5.04 cm	3.1 cm
	Concrete Block (Medium)	0.51	10 cm	10 cm	10 cm	10 cm	10 cm
	Gypum Plastering	0.4	1.3 cm	1.3 cm	1.3 cm	1.3 cm	1.3 cm
Roof	Asphalt	0.7	1 cm	1 cm	1 cm	1 cm	1 cm
	Glass Wool	0.04	8.45 cm	8.45 cm	14.45 cm	11.79 cm	7.34 cm
	Air gap	R=0.18 (m^2K/W)	20 cm	20 cm	20 cm	20 cm	20 cm
	Plasterboard	0.25	1.3 cm	1.3 cm	1.3 cm	1.3 cm	1.3 cm
Floor	Timber Flooring	0.14	3 cm	3 cm	3 cm	3 cm	3 cm
	Floor Screed	0.41	7 cm	7 cm	7 cm	7 cm	7 cm
	Cast Concrete	1.13	1 cm	1 cm	1 cm	1 cm	1 cm
	Urea Foam	0.04	3.93 cm	3.93 cm	7.27 cm	6.15 cm	2.98

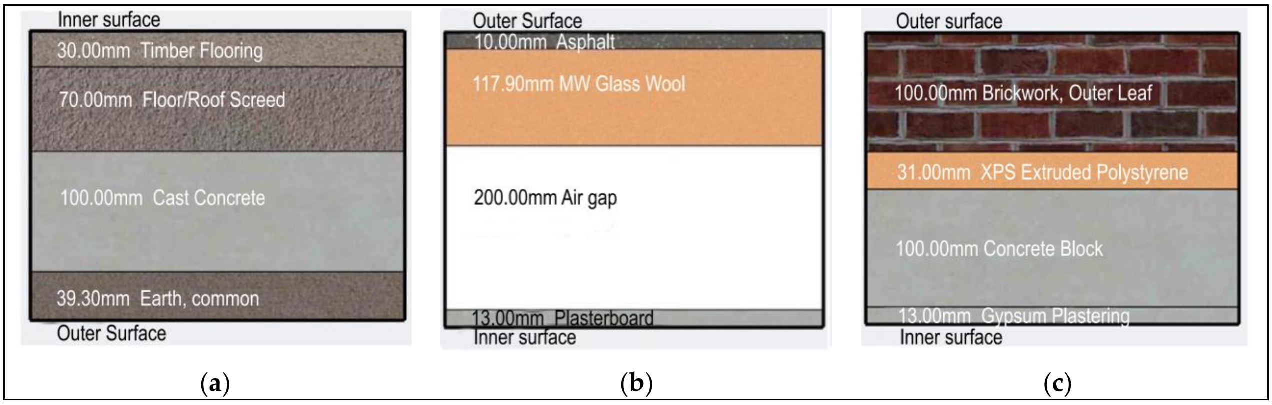


Figure 5.2 : Construction details and layers of (a) ground floor; (b) external roof; and (c) external wall.

5.4.6 Glazing System

Selected glazing types for the courtyard and atrium walls as well as atrium skylight summarized as fallow:

1. Single glazing: It is a single pane of glass with low thermal properties compared with other glazing types.
2. Double-glazing: Ordinary double-glazing which consists of two layers of glass filled with air.
3. Triple glazing: triple panes of glass filled with air.

Table 5.8 : Characteristics of glazing types (adapted from the data taken from DesignBuilder).

Characteristics of Glazing Types	Single Clear, 6 mm	Double Clear, Each Pan: 6 mm with Air 6 mm	Triple Clear, Each Pan: 3 mm with Air 6 mm
Total solar transmission (SHGC)	0.819	0.7	0.682
Direct solar transmission	0.775	0.604	0.595
Light transmission	0.881	0.781	0.738
U-Value (W/m^{2}K)	5.778	3.094	2.178

5.4.7 Window area and properties

Courtyard and atrium buildings, which simulated in this research, are considered to have 30% window to wall (WWR) ratio on the external facade of the building and 60% (WWR) on the wall in open to sky area of buildings regarding to study energy performance of the adjacent area of courtyard and atrium.

5.4.8 General model descriptions

This study examined the integrated strategy of both courtyard and atrium building in different climates, namely hot-dry, hot-humid, mild-humid, mild and cold climates. In order to reach the aforementioned goal, an open central courtyard surrounded by adjacent spaces and open to sky atrium were modeled in DesignBuilder. In terms of investigation, three-story square courtyard and atrium were modeled. The central area for both building type was 625 m^2 (25 m length and 25 m width). In the adjacent spaces floor height was 3.50 m and the depth of the office area was designed to be 10 m (Figure 5.3). The internal environment of the four office spaces was modeled as fully air-conditioned. The area of the office building was considered to be 1400 m^2 for each floor and the total area in the three stories was measured at 4200 m^2. Table 5.9 provides possible parameters from the literature review regarding the design of courtyard and atrium forms. Figure 5.5 shows the process of simulation in this research, which is divided in two stages. The first stage tries to illustrate the feasibility of a variety of window-to-wall ratios and different glazing types as applied to courtyard walls. The second stage attempts to model an energy-efficient building by covering a courtyard and shifting it to the atrium type to conserve energy.

Table 5.9 : Parameters for courtyard and atrium design.

Criteria Obtained from Literature Review	Alternatives	Author (year)	Best Possible Parameter
Shape for courtyard	Rectangular R1 = floor perimeters P/form's height H R2 = elongation of the form L/its length W	Muhaisen and Gadi[12] (2006a) (courtyard)	Energy demand of R1 = 5, 6, 7, 8, 9, 10 are very close to each other R1 = 1, 2, 3, 4 have no architectural aspect R1 = 5 is optimum R2 = 1, 2, 3, 4 have no architectural aspect Energy demand of R1 = 5, 6, 7, 8, 9, 10 are very close to each other R2 = 7 is optimum (tend to be a square)
Shape for atrium	Square	Aldawoud (2013) [24] (atrium)	(Square shape) length × width = 1.0 × 1.0 is optimum
Shape of courtyard	Square	Yasa and Ok (2014)[31] (courtyard)	Square shape is the optimum
Window-to-wall ratio	Various window-to-wall ratios	Aldawoud and Clark (2006) [20] (courtyard and atrium)	40%, 60%, and 80%
Climate	Different climate and longitude	Muhaisen (2006) [30] (courtyard)	Hot-dry (Diyarbakir), cold (Erzurum), temperate (Istanbul)
Number of floors	Different heights	Muhaisen (2006) [30] (courtyard)	three stories
Type of glazing	Various types	Al-Masri and Abu-Hijleh (2012) [39]	single, double, triple
Type of HVAC	Various types	DesignBuilder types	compact type

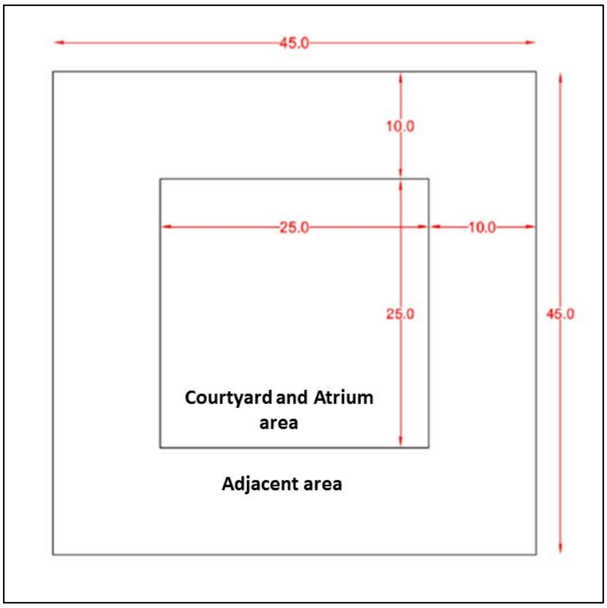


Figure 5.3 : Dimensions of courtyard and atrium plan.

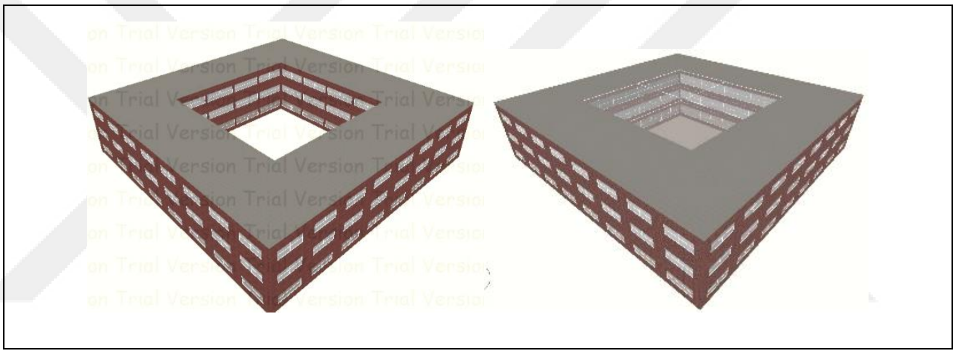


Figure 5.4 : Modeled courtyard (right) and atrium (left) in DesignBuilder.

5.5 Simulation Process

The disadvantage of atriums and skylights is heat gain with the direct beam radiation and the creation of thermal differentials in large volumes of air especially in summer. Sunlight penetration into atria is different from normal buildings due to the vertical view through the glazing. As the suns elevation rises in hot seasons, the radiation penetrates further into the atrium but less into the adjoining spaces. The large amount of glazing in atria results in an overheating greenhouse effect. This is the process that is used practically in glassed covered gardens in cold climates to provide a warmer temperature to grow plants.

The large amount of glazing which results in excess heat gain via direct radiation input also overrides the natural convection process. This produces a thermal stratification stack effect within the atrium well. The result is a much higher temperature towards the top of the atrium. The hot air also flows into the upper level adjoining spaces, making them hot as well. If the thermal stratification can be reduced, then the comfort in the adjoining spaces is improved. It is an important concept in terms of the energy running costs of the building and increasing the human comfort level. If there is no access to the upper areas of the atrium well then a thermally stratified atrium will in fact keep the hot air away from the occupants at the bottom of the well.

This research proposes conversion of atrium space into the courtyard using flexible windows on top of the skylight so that energy efficiency and cost effectiveness of the building can be improved.

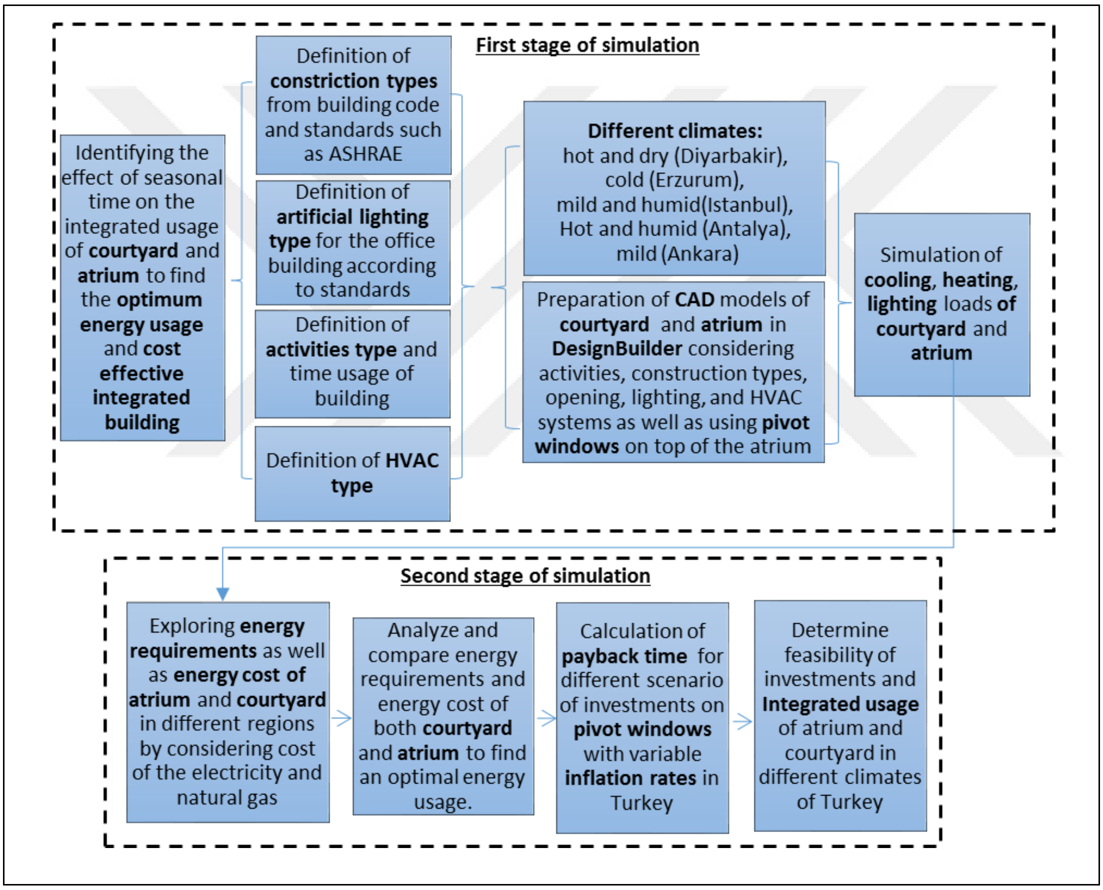


Figure 5.5 : Stages of the simulation process.

5.6 Pivot Windows

Pivot windows seems ideal for open to sky building with large windows due to providing natural light and ventilation. Pivoting roof windows and open able skylight windows can save a huge amount of energy normally used by air conditioner. By creating a passage for hot air to rise up and out of building, the whole building becomes noticeably cooler and more energy efficient.

Depending on their size, they provide larger amounts of daylight and passive solar gains than facade windows, thus reducing the need for electrical light and heating. Because of their strategic location in the roof, pivot roof windows would have highly energy efficient monument of a building and have a significant impact on energy saving. Pivot windows have a long life span up to twenty years. Most of the timber used in making them comes from sustainable windows improve the indoor climate by supplying generous amounts of daylight. As they are located at the top of the building, they also provide efficient ventilation and fresh air to the occupiers. They help regulate the temperature and ensure efficient cooling of the building at night. The electrically operated models maximize all the advantages of the manual models.

Figure 5.6 : Type of pivot window.

- Cost of 625 square meter flexible pivot window altenative (2): 243750 TL
- Cost of 625 square meter fixed window with same size and materials altenative (2): 134375 TL
- Cost difference of 625 square metre of pivot windows and fix ones in alternative (2): 110000 TL
- U value of window frame: 1,4 W/m^{2}K
- U value of glass: 3,095 W/m^{2}K
- U value of whole window (fram + glass): 2.45 W/m^{2}K
- Window panes: (pane- air- pane) 4mm – 6mm – 4mm

Table 5.10 : Cost of the flexible and fixed pivot window from different companies.

1 m^2	Remote + Shading	Remote	Manual flexible	Fixed	flexible and fixed cost differences for 625 m^2
Alternative 1	1.266 TL	980 TL	534 TL	420 TL	133750
Alternative 2	-	-	390 TL	215 TL	109375
Altenative 3	460 €	280 €	452 TL	350 TL	88750

Cost of one square meter open able pivot windows varies from 500 TL to 1400 TL depend on its type of material used in window as well as glass type also having remote control. Beside that fixed roof window as like as pivot widow size differ from 410 to 900.

The first stage of simulation process applied to three stories atrium building that was covered by pivot roof windows in Istanbul, Erzurum and Diyarbakir, which are representative of mild humid, cold and hot climate in Turkey respectively. In this practice the atrium, which had double-glazing on top, is considered as base model regarding energy consumption comparison with courtyard during the year. The area of skylight is 625 square meter, which covers by 625 windows. Each pivot window has one square meter area and a clear double glass. The main reason for choosing the pivot windows for skylight on top of the atrium is to have option regarding to transforming atrium to the courtyard for energy conservation.

Courtyard model also cover by same size frame as pivot windows regarding to calculating shading effect of frames during the usage of courtyard. This study tries to evaluate effect of atrium and courtyard space on energy behavior of their adjacent office area. In order to find a cost optimal energy usage building, identifying the effect of seasonal time on the integrated usage of courtyard and atrium is a necessary stage. By definition of construction, artificial lighting, activity and HVAC type as well as time usage of building form standards such as ASHRAE and Turkish Standards, CAD file of courtyard models in DesignBuilder are prepared. Courtyard and atrium buildings, which simulated in this research, are considered to have 30% window to wall ratio on the external facade of the building, however, the ratio of glazing to the wall in open to sky area of buildings are 60% regarding to study energy performance of courtyard and atrium space on the adjacent area.

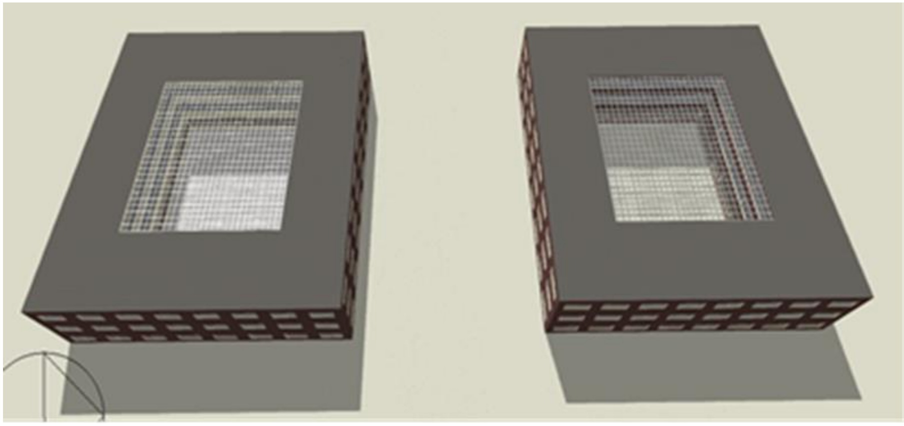


Figure 5.7: Flexible pivot windows can convert atrium to courtyard.

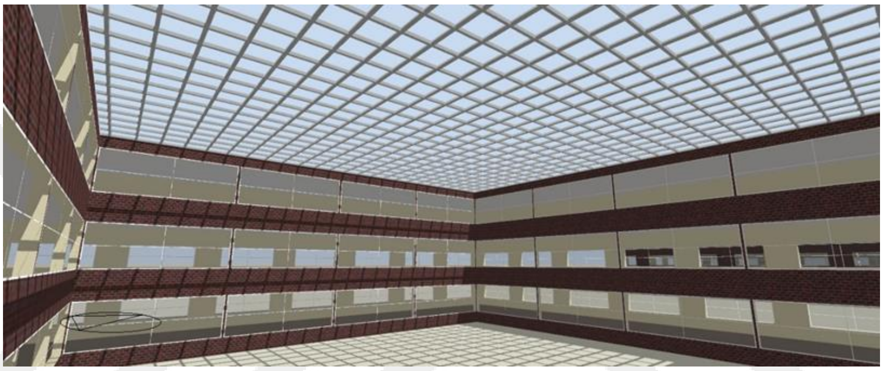


Figure 5.8 : Inside of the covered courtyard by pivot windows.

Utility rates for electricity and natural gas are obtained from Authority of Energy Market Regulation in Turkey, which is called EPDK[108]. The statewide average retail price per 1kWh of electricity and natural gas for 2014 have given in Table 12.

Table 5.11 : Electricity and natural gas prices in different cities of Turkey in 2016[108].

	Gas (1kw = 0.113m3)	Electric
Istanbul	1m3=8.81kWh=1.07 1kW=0.12TL	1kw=0.42
Diyarbakir	1 m3=8.81kWh=0.96 TL 1kW=0.096 L	1kw=0.408 TL
Erzurum	1 m3=8.81kWh=0.0985 TL 1kW=0.096 L	1kw=0.401TL
Ankara	1 m3=8.81kWh=1.02 TL 1kW=0.118 L	1kw=0.416 TL
Antalya	1 m3=8.81kWh=0.096 TL 1kW=0.094L	1kw=0.408 TL

5.7 Economic Assessment

Since the energy crisis in the 1970s the energy-efficiency approach has become gradually significant in building design. Cost is one of the important factors to be considered for developing energy-efficient strategies. The initial costs, annual expenses and profits, maintenance, and the other alternatives are making the cost of a building. Now a day, decision makers for the economic assessment of building design use a way which is called the life-cycle cost (LCC). LCC is used in the analysis and selection of building size, structure, and building enclosure including exterior walls, exterior windows, and roof. Also, the selection of mechanical and electrical systems depends on the LCC in the later stages of design development. In spite of these advantages, the LCC approach is unable to compute parameters such as social aspects, privacy, prestige, and aesthetics. The analysis of an energy-efficient approach along with life-cycle cost is essential for building design [109]. Life cycle energy analyses energy is divided to three main phase embodied, operation and demolition energy through whole building life. As operation energy range 80-90% of whole energy need for office building, this study focused on total energy cost of courtyard and atrium to clarifying feasibility of investment on an atrium-courtyard integrated building under many conditions such as different climates and variation of electricity and natural gas cost in Turkey. Accordingly, life cycle cost technique has been considered via net present value using minimum discount rate 7 percent and continue to 15 percent as maximum rate.

$$\text{Net present value} = -\text{Capital investment} + \text{Annual revenues} * ((1+i)^{n} - 1) / (i * (1+i)^{n})$$

n = Period = 20 (due to optimum life time of glass)

i = discount Rate

5.7.1 Techniques of economic analysis

Economic analysis can be used in a number of ways to increase the economic efficiency of investments in energy conservation. It can be used to obtain the largest possible reductions in energy costs for a given energy budget and to achieve a targeted reduction in energy costs for the lowest possible conservation investment. It also can be used to determine how much it pays to spend on energy conservation in order to lower total life building costs, including investment, energy, and non-fuel operating and maintenance costs. Economic analysis aims at minimizing the total building costs or, in other words, at maximizing the net benefits from energy conservation [109].

5.7.1.1 Concepts of economic efficiency

Achieving economic efficiency in energy conservation has the following two dimensions:

- Determining the most profitable level of energy conservation.
- Determining the most profitable combination of energy conservation techniques for a given investment budget.

These two dimensions are actually inseparable, in that the overall level of conservation which is most economically efficient depends on the cost and saving of available energy conservation techniques [109].

5.7.2 Inflation, natural gas and electricity in turkey

Inflation is a rise in the general price level reflecting a decline in the purchasing power of monetary unit. Although all prices cannot be expected to rise or fall together and in the same amount, average price increase in specific and general categories of goods and services can be measured. In making economic evaluations of energy conservation investment, it is important that price inflation as indicated by average price increase in economy be adjusted for, such that a consistent unit of value is used to assess estimates of benefits and costs [109]. Analysis of the inflation rate in Turkey during 2003 and 2016 (Figure 5.9) reveals that minimum inflation rate emerged in 2010 by 6.4 percent whereas maximum amount of inflation except 2003 has been observed in 2011 by 10.5 percent.

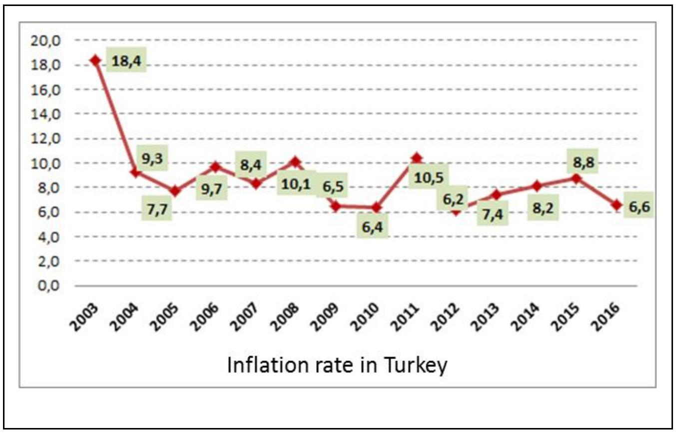


Figure 5.9 : Annually inflation rates in Turkey [110].

Figure 5.10 shows comparison between inflation rate and interest rate within the 2002-2015 period in Turkey [110]. This information illustrates that from 2002 until 2009 the rate of inflation was lower than interest rate, and both rates were over 60 percent in 2002 whereas both of them have been decreased under 10 percent until 2010. From 2010 till 2015 the rate of inflation and interest differ close to each other between 10 and 6 percent (Figure 5.10).

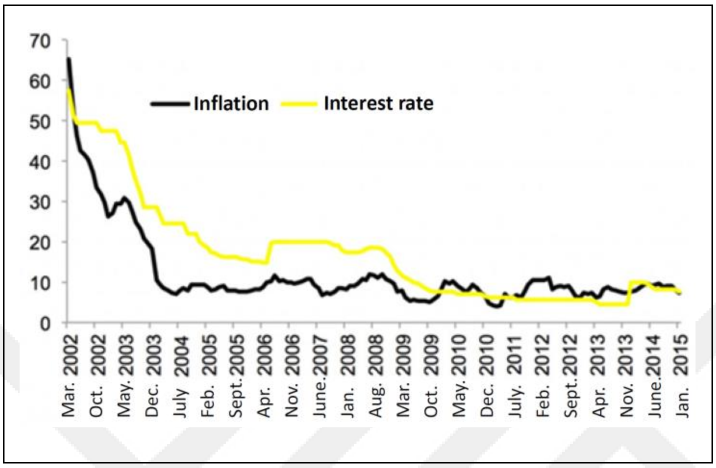


Figure 5.10 Comparison between inflation rate and interest rate, [111].

Fuel prices have increased rapidly in recent years (as shown in Table 5.12) that they must be given special attention in evaluating energy conservation investment. Since benefits from conservation vary directly with fuel prices, assumption regarding the change in fuel prices over time have a large impact on the prediction of benefits of a conservation project.

Increase rate in energy price is not the same as the inflation rate in Turkey. As it is shown in Table 5.12 cumulative inflation rate for 7 years during 2003 till 2010 was 85.8 percent whereas average increase rate in price has been appeared to be 57.7 and 85 percent for electricity and natural gas during aforementioned period[110].

Table 5.12: Increasing price of electricity natural gas and inflation rate in Turkey between 2003 till 2010 [110].

	Natural gas and electricity price increase in Turkey between 2003/2010. %		
	Electric	Natural gas	Inflation rate
2004-1	0	-19.2	10.6
2005-1	0	30.9	9.2
2006-1	0	19.5	7.9
2007-1	0	24.5	9.9
2008-1	17.3	7.9	8.2
2009-1	30.4	62.7	9.5
2010-1	9.2	-33.5	8.2
2003/2010	56.9	92.8	96.9

According to the Turkish Statistical Institute (Table 5.13), electric and natural gas prices have been varied from 2011 till 2016. During this period price of electricity has been increased around 34 percent whereas natural gas price has been increased 71 percent at the same time.

Table 5.13 : Average electricity and natural gas price increase between 2011-2016 in Turkey [110].

	Electricity and natural gas average price (kur)		
	Electricity (kWh)	Natural gas (m^3)	Inflation rates (%)
2011	29.8	60.8	10.5 (%)
2016	40	104	6.6 (%)
20011/2016 (%)	34%	71 %	37.2%
Annually increase	6.8%	14%	7.45%

During 2011 until 2016 based on all above data gathered, annually average of increasing electricity, natural gas and inflation rate in Turkey seemed to be 6.8, 14 and 7.45 percent respectively as shown in Table 5.13. This means that increase in price of natural gas and electricity does not follows directly inflation rate in Turkey.

Turkish central bank (2013) has an estimation for inflation from 2014 till 2019 as show in Figure 5.11. Maximum rate for inflation is expected to be 8 percent for mid of 2017 and minimum is predicted to be around 6 percent for 2019. Average inflation rate has been calculated as 7.04 percent annually for the next five years[111].

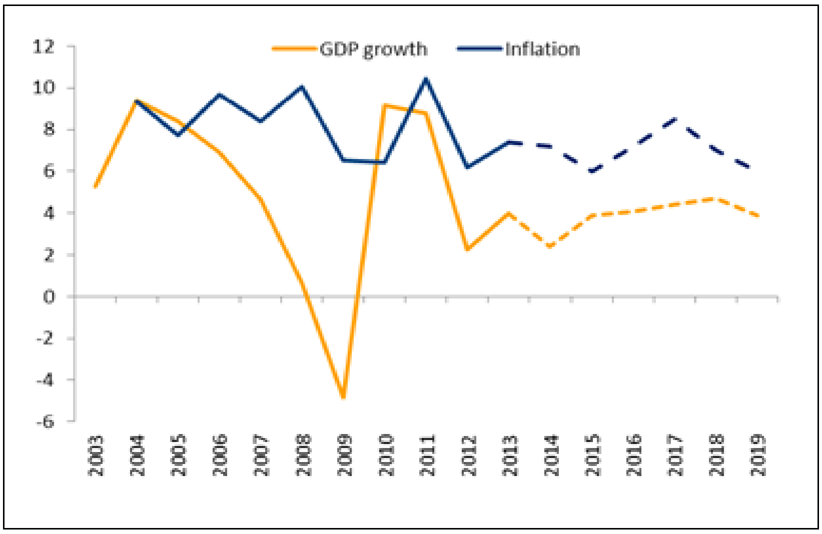


Figure 5.11 : Estimation for inflation from 2014 till 2019[111].

In order to calculate LCC of transforming atrium into courtyard with respect to energy consumption reduction, average discount rate has been assumed in five values (7%, 9%, 11%, 13%, and 15%) during 20 years with respect to sensitive analysis.

Furthermore, investment on pivot windows on top of the atrium considered in four scenarios based on scenario analysis covering optimistic, pessimistic, and probabilistic situations as follows:

- Scenario 1: Investment on replacing of all (100%) fix windows with openable pivot windows on top of the atrium. It means initial investment regarding changing fix windows with pivot ones is 110000 TL.
- Scenario 2: Investment on replacing only 80% of fix windows with openable pivot windows on top of the atrium assuming to have same energy load as courtyard. It means initial investment is 88000 TL.
- Scenario 3: Investment on replacing of 60% of fix windows with openable pivot windows on top of the atrium assuming to have same energy load as courtyard. It means initial investment is 66000 TL.
- Scenario 4: Investment on replacing of 40% of fix windows with openable pivot windows on top of the atrium assuming to have same energy load as courtyard. It means initial investment is 44000 TL.

6. RESULTS

6.1 Exploring Feasibility of Integrated Building

Regarding to investigating feasibility of integrated atrium-courtyard building first attempt was to explore courtyard and atrium energy load differences regarding to examine the potential of creating integrated atrium-courtyard building. A courtyard model having double glazing on its walls and a window-to-wall ratio of 60% on inside walls and 30% on outside walls is compared with three types of atrium using the same glazing type and window-to-wall ratio. Different glazing types (clear single, double, and triple) have been examined for an atrium skylight in order to choose the proper type for the parent building from an energy consumption point of view (Figure 6.1). In first effort three climate region namely Istanbul(mild-humid), Diyarbakir (hot-dry) and Erzurum (cold) of Turkey have been taken to account.

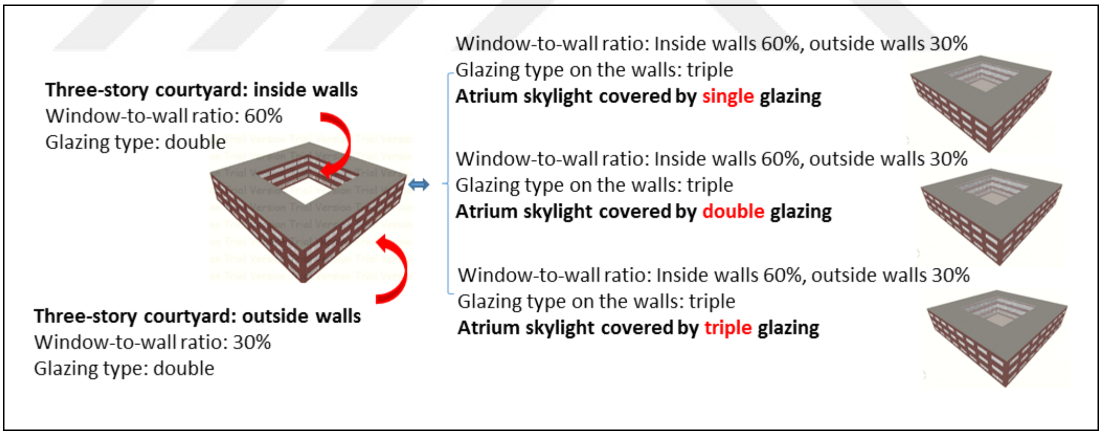


Figure 6.1 : Comparison of the energy performance of a courtyard with three different types of atrium (taking the glazing type and window-to-wall ratio as constant) covered with different glazing types (clear single, double, or triple).

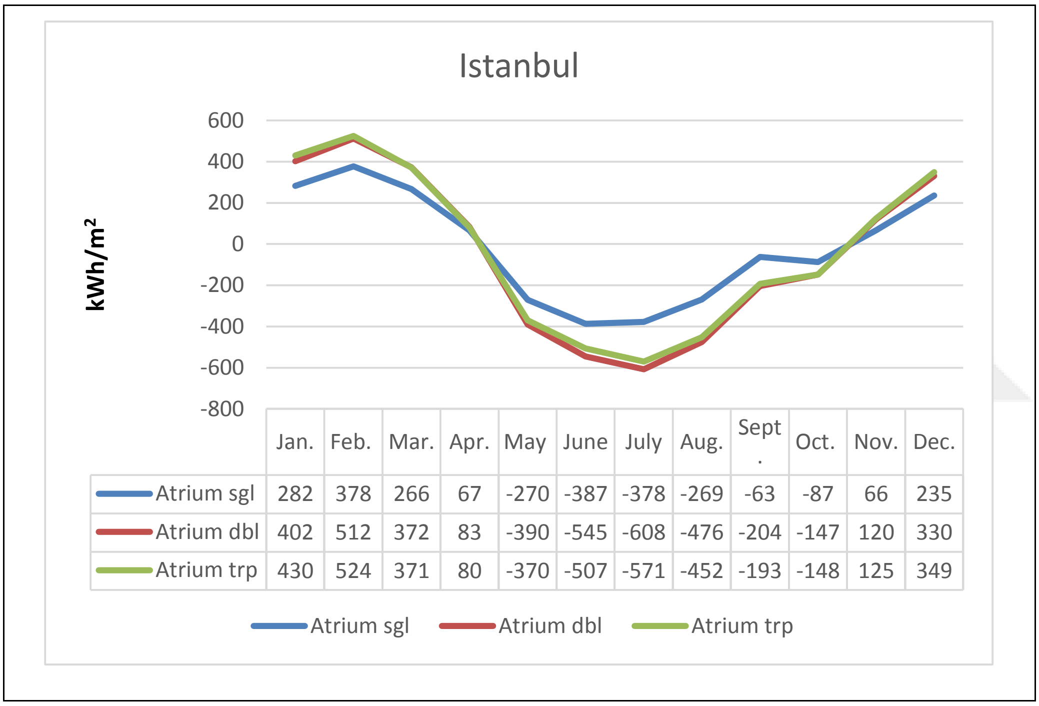
6.1.1 Istanbul

In Figure 6.2, the zero line is considered to be the courtyard energy performance of a reference building for comparing three atrium buildings covered with single, double, and triple glazing.

Simulation outcomes reveal that in Istanbul an atrium building can conserve energy, starting from November for all single, double, and triple glazing and lasting until April.

The amount of energy saved varied, however, by glazing type. It also appeared that a skylight with either triple or double glazing can perform better than single glazing. The most energy savings in atriums (377.7 kWh/m^2) is observed in February, by using single glazing on top of the atrium and 511.9 and 524.5 kWh/m^2 for double and triple glazing, respectively. During the warm period from May until October atrium types use more energy compared to a courtyard.

Comparing atriums roofed with triple, double and single glazing maximum energy consumption, 571, 608 and 387 kWh/m^2 respectively with courtyard in July, means that the courtyard shows better performance than an atrium during warm periods. This is due to the greenhouse effect of an atrium covered by various types of glazing.



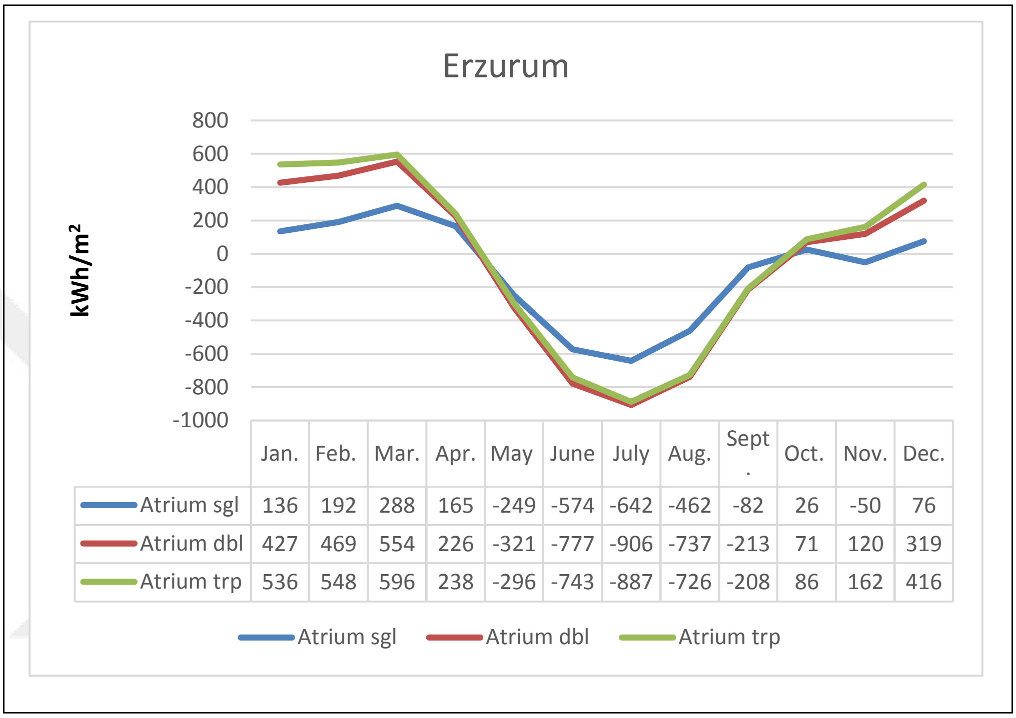
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Atrium sgl	282	378	266	67	-270	-387	-378	-269	-63	-87	66	235
Atrium dbl	402	512	372	83	-390	-545	-608	-476	-204	-147	120	330
Atrium trp	430	524	371	80	-370	-507	-571	-452	-193	-148	125	349

Figure 6.2 : Monthly energy conservation of an atrium model with different type of glazing (clear single, double, and triple) on top of the atrium building in comparison to the courtyard (taken as the zero line) in Istanbul (kWh/m^2).

6.1.2 Erzurum

In Figure 8, the zero line is considered to be the courtyard energy performance of a reference building to be compared with three atrium buildings covered with single, double, and triple glazing.

Outcomes reveal that, similar to Istanbul, both triple and double glazing can perform better than single glazing in Erzurum (Figure 6.3). Unlike Istanbul, the most energy savings in atria occurred in March. Using single, double, and triple glazing on top of the atrium can conserve total energy by 288, 554 and 596 kWh/m^2, respectively, compared to a courtyard. During the warm period from May until September, atria use more energy compared with a courtyard. Atria roofed with single, double, and triple glazing used 642, 906, and 887 kWh/m^2 more energy, respectively, in July compared to a courtyard. This means that in Erzurum, like in Istanbul, a courtyard shows better performance than an atrium during warm periods.



	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Atrium sgl	136	192	288	165	-249	-574	-642	-462	-82	26	-50	76
Atrium dbl	427	469	554	226	-321	-777	-906	-737	-213	71	120	319
Atrium trp	536	548	596	238	-296	-743	-887	-726	-208	86	162	416

Figure 6.3 : Monthly energy conservation of an atrium model with different type of glazing (clear single, double, and triple) on top of the atrium building in comparison to the courtyard (taken as the zero line) in Erzurum (kWh/m^2).

6.1.3 Diyarbakir

Simulations revealed that, in Diyarbakir, the duration for using covered atriums to save energy is shorter than the duration needed in both Istanbul and Erzurum (Figure 6.4). In Diyarbakir a courtyard shows better performance than an atrium from April until August. Atria use more energy compared to a courtyard model from mid-April until July. The maximum energy waste was observed for atria with double and triple glazing in June (445 and 497 kWh/m^2, respectively, compared to 334 kWh/m^2 for a single-glazed atrium in May). Like in Istanbul and Erzurum, in Diyarbakir during the winter all atria show better performance compared to a courtyard. Maximum energy savings was observed in January for single, double, and triple-glazed atria compared to a courtyard by 141, 244 and 261 kWh/m^2, respectively.

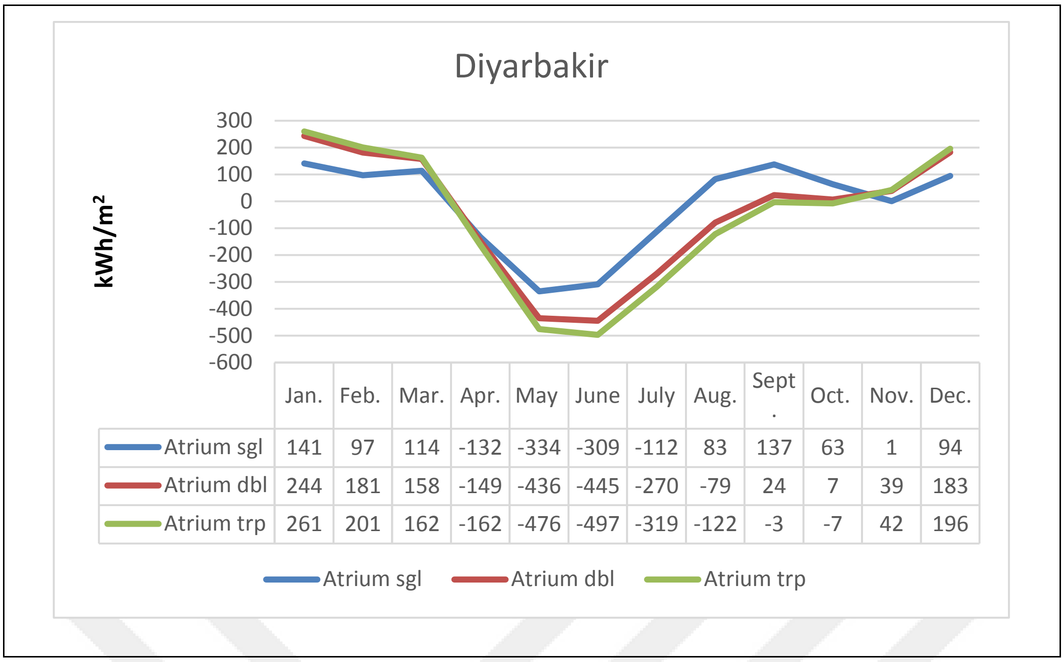


Figure 6.4 : Monthly energy conservation of atrium model with different types of glazing (clear single, double, and triple) on top of the atrium building in comparison to a courtyard (taken as the zero line) in Diyarbakir (kWh/m^2).

In the literature, there is a lack of a comprehensive strategy in terms of courtyards' and atriums' integrated usage with respect to their thermal performance under different conditions. Various studies indicated that the characteristics of both building types affect the indoor environment conditions which were described on literature review in this thesis. The thermal behavior of courtyard and atrium buildings, as well as their integrated usage with respect to climatic variables (e.g., cold, hot and dry, or mild and humid), different glazing types, and glazing area ratios have been analyzed within the first attempt of this research. The results revealed that glazing types should be selected to minimize energy consumption so that occupant comfort is enhanced and daylight effectiveness is maximized while meeting architectural objectives. Simulation results revealed that considering the glazing type when covering a courtyard (single, double, or triple) can conserve energy in certain time of the year (Table 6.1).

Table 6.1 : Using integrated, energy-conscious courtyard or atrium buildings according to time.

	Courtyard Is More Energy Efficient Compared to the Atrium		
City	Istanbul (mild and humid)	Erzurum (cold)	Diyarbakir (hot and dry)
Usage period	May until mid-Oct.	May until mid-Sept.	Apr. until Aug.
	Atrium Is More Energy Efficient Compared to the Courtyard		
City	Istanbul (mild and humid)	Erzurum (cold)	Diyarbakir (hot and dry)

Table 6.1(Continued): Using integrated, energy-conscious courtyard or atrium buildings according to time.

Single glazing on skylight	Nov. until Apr.	Oct. until Apr.	Apr. until July
Double glazing on skylight	Nov. until Apr.	Oct. until Apr.	Sept. until 15th Mar.
Triple glazing on skylight	Nov. until Apr.	Oct. until Apr.	Oct. until 15th Mar.

6.2 Transforming Atrium to the Courtyard by Using Pivot Windows

Exploring potential of integrated atrium-courtyard building on first attempt highlighted that both atrium and courtyard have ability to save energy in different period of a year. Atrium showed better performance during cold period and courtyard was suitable for warm period. Second attempt tried to present a strategy regarding transforming atrium building to the courtyard in order to design integrated artrium-courtyrad building. Sky light of atrium building mostly designs by fix windows and leads to overheating during summer time due to greenhouse effect of glassing on top of the atrium. More over during the summer, angle of sun radiation is in a high range on flat roofs and causes excessive hot environment inside of the atrium results in increasing adjacent building cooling load. Using pivot windows on atrium roof has capability to opening during warm period and transforming atrium to courtyard regarding to decreasing cooling energy need for parental building. Furthermore, closed mode of openable windows on top of the skylight leads building to use capability of atrium in cold period regarding to decrease heating load of adjacent building compared with courtyard.

Courtyard and atrium which have been modeled in this part had same characteristic of fist attempt. All five different climates of turkey namely mild-humid(Istanbul), (hot-dry) Diyarbakir, hot-humid (Antalya), mild (Ankara) and cold (Erzurum) have been taken to account in this part of simulation. Regarding to investigate feasibility of investing on pivot windows with clear double glassing rather than fix windows, economic calculation performed via net present value method for twenty years. Cost differences of fix and pivot windows considered as initial investment in four scenarios. In first scenario (S1) assumed all fix windows on top of the atrium replaced with pivot windows which initial investment calculated 110000 TL as described in methodology chapter in this thesis. Assuming having same energy load of courtyard second, third and fourth scenarios considered on only 80(88000TL), 60(66000TL) and 40(44000) percent of fixed windows replaced by pivot ones. During calculation of payback time discount rates in Turkey considered in five values of 7,9,11,13 and15 percent regarding to find feasibility of integrated atrium-courtyard building in all critical investments. The results of this session have been presented as follow.

6.2.1 Istanbul

Figure 6.5 shows monthly energy demand and energy cost of both atrium and courtyard throughout the year in Istanbul. Between January and March as well as among November and December there is no cooling energy demand for both buildings whereas from April till October atrium and courtyard buildings consume energy for cooling and through in this period atrium needs more cooling energy than courtyard. Maximum cooling load appear around 50300 and 43920 kWh for atrium and courtyard in August. From the outcomes, heating energy demand for both courtyard and atrium appeared during cold months whereas courtyard needed more energy for heating compared with atrium. Maximum heating energy require observed in January 54030 and 47905 kWh for courtyard and atrium respectively.Figure 6.6 shows differences in heating, cooling, lighting energy loads as well as total energy cost of atrium compared with courtyard in Istanbul. Comparing energy loads of atrium with courtyard, it is appeared that atrium conserve heating energy around 29953.5 kWh during winter time. Throughout warm period however, atrium loses energy via cooling load around 27663.8 kWh compared with courtyard. Lighting energy load is in a minor range compared with both heating and cooling energy loads. All over the year lighting energy load of the atrium is higher than of the courtyard (in total 6262.7 kWh) because the skylight roof of the atrium blocks natural light (Figure 6.6).

With respect to the annual total energy cost for atrium and courtyard, as shown in the Figure 6.5, from January to April and from November to December atrium building performs a little bit better than the courtyard building due to the greenhouse effect. During warm periods (from April to October), courtyard has less energy cost compared to the atrium building. The highest total energy cost observed in August because of the high demand for cooling energy and appeared 21614 and 18883 TL related to atrium and courtyard respectively. Minimum total energy cost emerged in April 3868 TL for atrium and 3580 TL for courtyard. The main difference between total energy cost of courtyard and atrium happen from April till October when the cooling energy demand is in a high range for both building. With comparison total energy cost of courtyard and atrium during aforementioned months there will be 11925 TL conservation in energy cost as a result of using courtyard form of building instead of atrium in Istanbul (Figure 6.5).

Calculation outcomes highlighted that, increasing average discount rate results in increasing payback time (Figure 6.7). However, in Istanbul payback times regarding to first (S1) and second (S2) scenarios appear to have critical points. As, S1and S2 seem feasible only under 7% and 11% of average discount rate respectively. S1 shows payback period of 15.3 years for average discount rate of 7% and S2 is not feasible when average discount rate reaches more than 11% because payback period ranges more than twenty years. Payback times of S3 and S4 in all considered discount rates appeared lower than twenty years. Among S3 and S4 maximum payback period appears 12.7 years related to S3 with average discount rate of 15% and minimum payback time has become 4.3 years for S4 with 7% average discount rate. All in all, in Istanbul, replacing fix windows with pivot windows on top of the atrium skylight (regrading transforming atrium to the courtyard during summer time) are feasible for third and fourth scenarios (S1 and S4) in all average discount rates but for first and second scenarios (S1 and S2), there are some hazards with a recognized risk. (Figure 6.7). Figure 6.8 demonstrates benefits attained by different investment scenarios using pivot windows on top of the atrium under variable discount rate during 20 years in Istanbul. It has been seen that the lower payback time means the higher benefits during considered period and vice versa. For instance, highest benefit related to first scenario with average discount rate of 7% which has been emerged 82338 TL. Minimum benefit achieved in Istanbul by second scenario under discount rate of 11% around 6963 TL. First scenario has been determined as critical one which had only one feasibility option under 7% discount rate around with 16334 TL benefit.

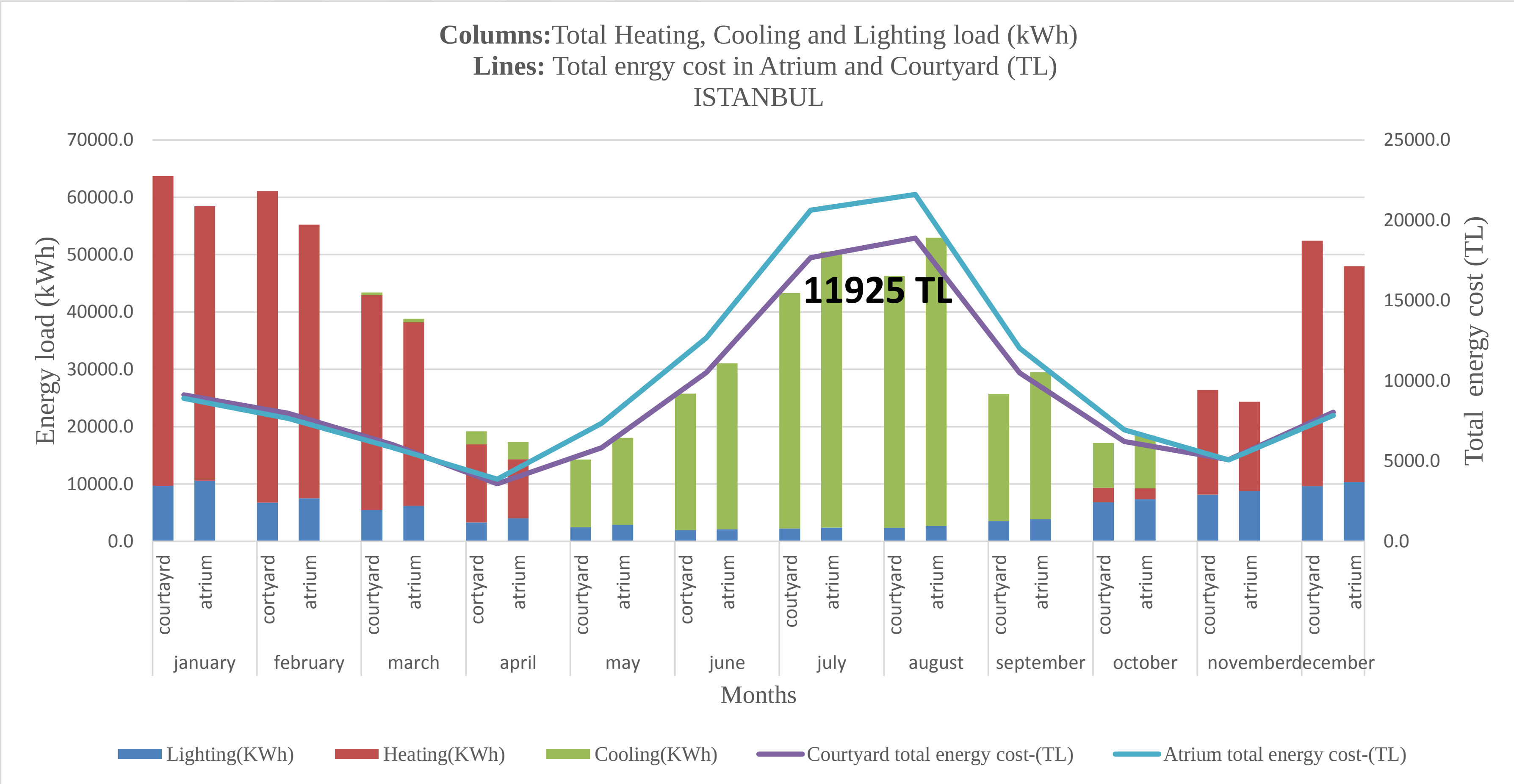
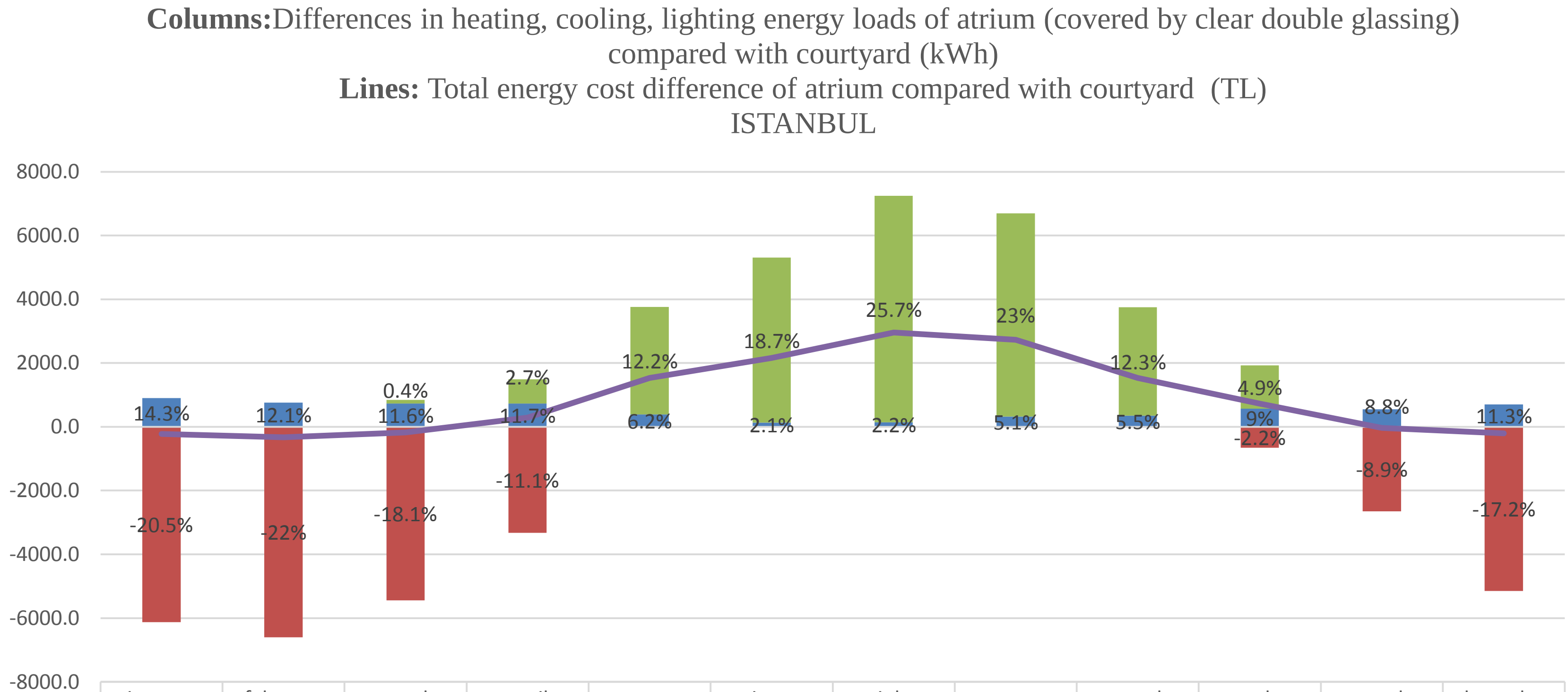


Figure 6.5: Total, heating, cooling and lighting loads as well as total energy cost of atrium (covered by double clear glassing) and courtyard – Istanbul.



	january	february	march	april	may	june	july	august	september	october	november	december
Cooling(kWh)	0.0	0.0	119.1	752.6	3371.6	5177.4	7104.0	6376.0	3403.9	1359.2	0.0	0.0
Heating(kWh)	-6129.3	-6602.2	-5439.7	-3321.6	0.0	0.0	0.0	0.0	0.0	-660.3	-2651.0	-5149.5
Lighting(kWh)	898.6	759.2	727.9	733.4	389.3	128.6	140.1	317.7	346.7	565.4	551.2	704.6
Total cost(TL)	-221.8	-324.1	-176.6	287.4	1534.4	2164.9	2955.6	2731.0	1530.3	721.9	-29.6	-206.9

Lighting(kWh) Heating(kWh) Cooling(kWh) Total cost(TL)

Figure 6.6 : Differences in heating, cooling, lighting energy loads as well as total energy cost of atrium compared with courtyard (zero line considered as courtyard) in Istanbul.

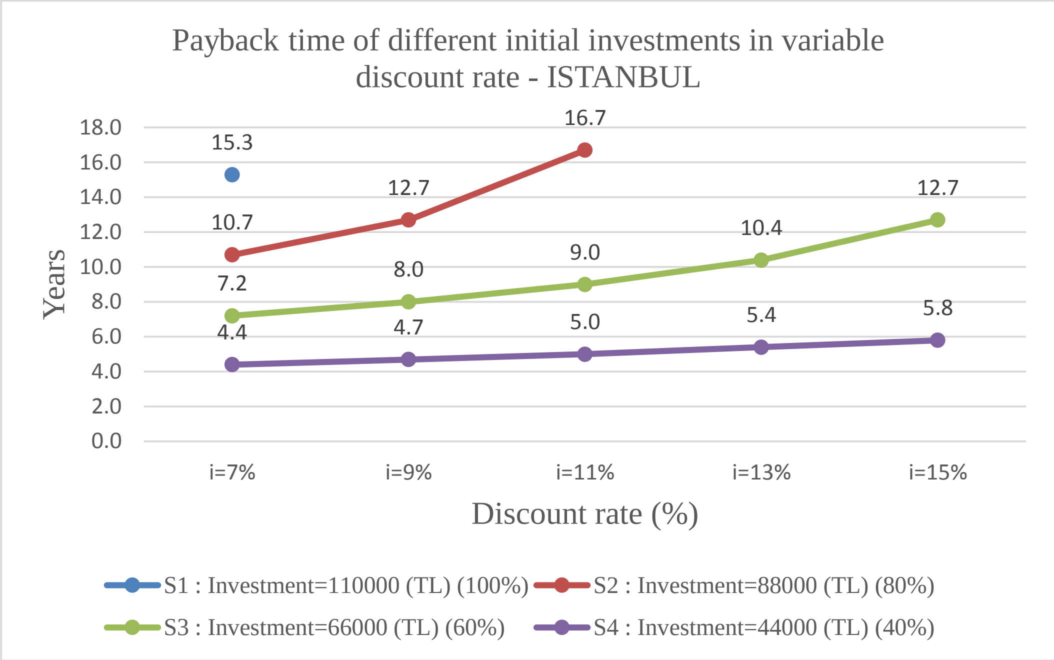


Figure 6.7 : Payback time by using pivot windows on top of the atrium with different initial investment in Istanbul considering variable discount rate.

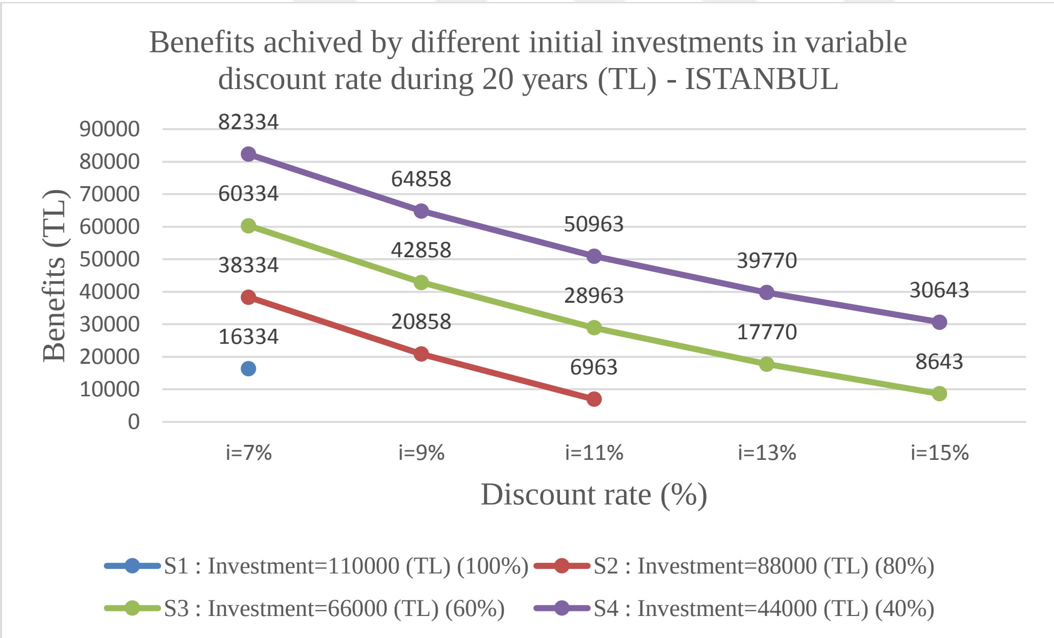


Figure 6.8 : Benefits achieved by different initial investments using pivot windows on top of the atrium in Istanbul considering variable discount rate (TL).

6.2.2 Diyarbakir

In Diyarbakir, heating and cooling energy demand for both building types is in a high range in cold and hot months respectively. From the results, it is appeared that courtyard consumes more energy for heating compared with atrium in January, February, March, November and December. Maximum heating energy demand happen in January 57490 and 52050 kWh for courtyard and atrium respectively. Atrium cooling energy need is emerged higher than courtyard throughout warm months between April and October in Diyarbakir. For atrium 57880 kWh and courtyard 50363 kWh seemed maximum cooling energy demand in Aguste. Throughout the year, both courtyard and atrium need more energy for lighting compared with summer time. Lighting energy demand of atrium is higher than same courtyard as a result of prevented natural light by glassing roof of the atrium (Figure 6.9). From Figure 6.9 it is appeared that minimum total energy cost of atrium and courtyard, has been observed in April, 5127 and 4310 TL. Highest total energy cost has been happened in August 24885 and 21740 TL regarding atrium and courtyard respectively. 16550 TL reduction in energy cost can be obtained as a result of using courtyard form (opening pivot windows during warm period) of building instead of atrium from April to October in Diyarbakır (Figure 6.9).

Since Diyarbakir has cold winter and hot summer, heating and cooling energy loads are in high level for both type of buildings. Figure 6.10 shows, in winter, atrium save energy through heating load compared with courtyard at most 5442.6 kWh in January and in total 20081.5 kWh. But during summer time courtyard perform better than atrium, as 8543.8 kWh saving happen in July through cooling load and overall 38629.1 kWh. All over the year atrium losses 5968kWh energy via lighting compared with courtyard. Maximum total energy cost saving is seemed during warm period of the year (Figure 6.10).

Figure 6.11, displays payback times of all initial investments (S1, S2, S3 and S4) with considered average discount rates. There is no senesce of reasonable investment when average discount rate reaches more than 13% for S1, however, all remain scenario of investments, are feasible. S2 with 13 % average discount rate has 11.4 years as a highest and S4 with 7% average discount rate has 3 years as a lowest payback period. In conclusion replacing fix windows with pivot windows on top of the atrium skylight are feasible for S2, S3 and S4 however, there are certain situation of risk related to S1 in Diyarbakir (Figure 6.11). Maximum benefits achieved by first scenario under 7% average discount rate around 131331 TL and minimum amount of benefit related to first scenario with 13% discount rate nearly 6260 TL during 20 years in Diyarbakir (Figure 6.12).

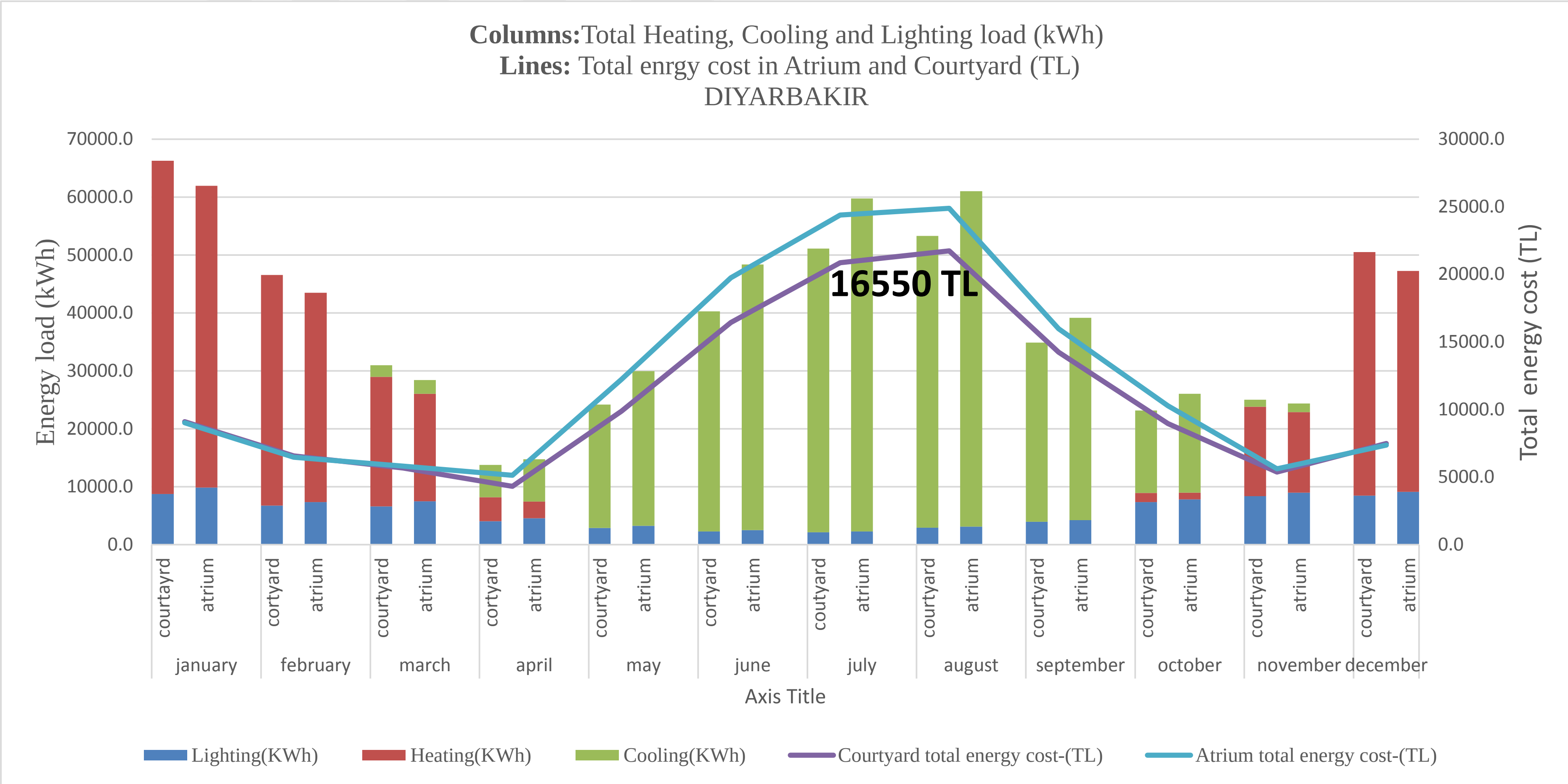
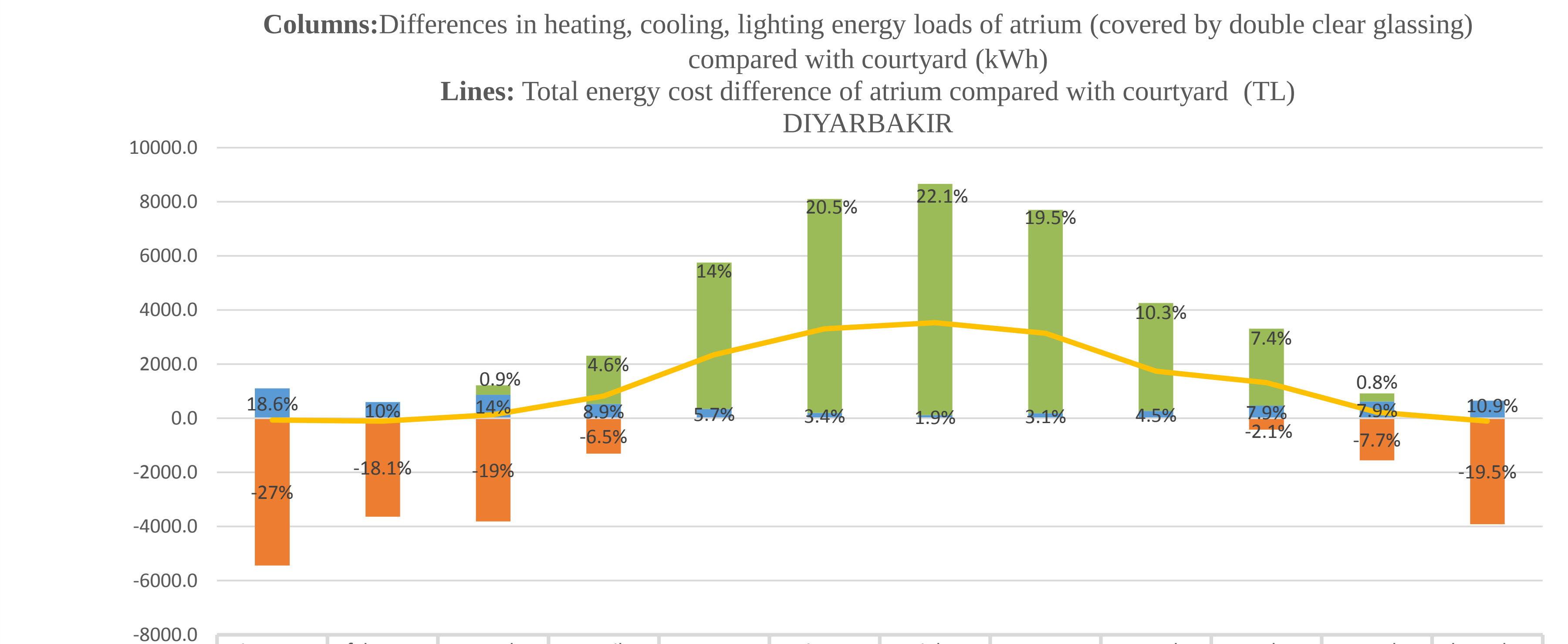


Figure 6.9 : Total, heating, cooling and lighting as well as total energy cost of atrium (covered by double clear glassing) and courtyard – Diyarbakir.



	january	february	march	april	may	june	july	august	september	october	november	december
Cooling(kWh)	0.0	0.0	349.9	1779.8	5411.9	7900.5	8543.8	7518.8	3985.4	2842.2	296.7	0.0
Heating(kWh)	-5442.6	-3632.6	-3808.3	-1309.7	0.0	0.0	0.0	0.0	0.0	-419.9	-1552.3	-3916.0
Lighting(kWh)	1109.3	597.5	871.5	531.4	341.7	202.7	114.2	186.0	271.1	470.9	621.5	650.4
Total cost(TL)	-69.9	-105.0	132.7	817.2	2347.5	3306.1	3532.4	3143.6	1736.7	1311.4	225.6	-110.6

Lighting(kWh) Heating(kWh) Cooling(kWh) Total cost(TL)

Figure 6.10: Differences in heating, cooling, lighting energy loads and total energy cost of atrium compared with courtyard (zero line considered as courtyard) in Diyarbakir.

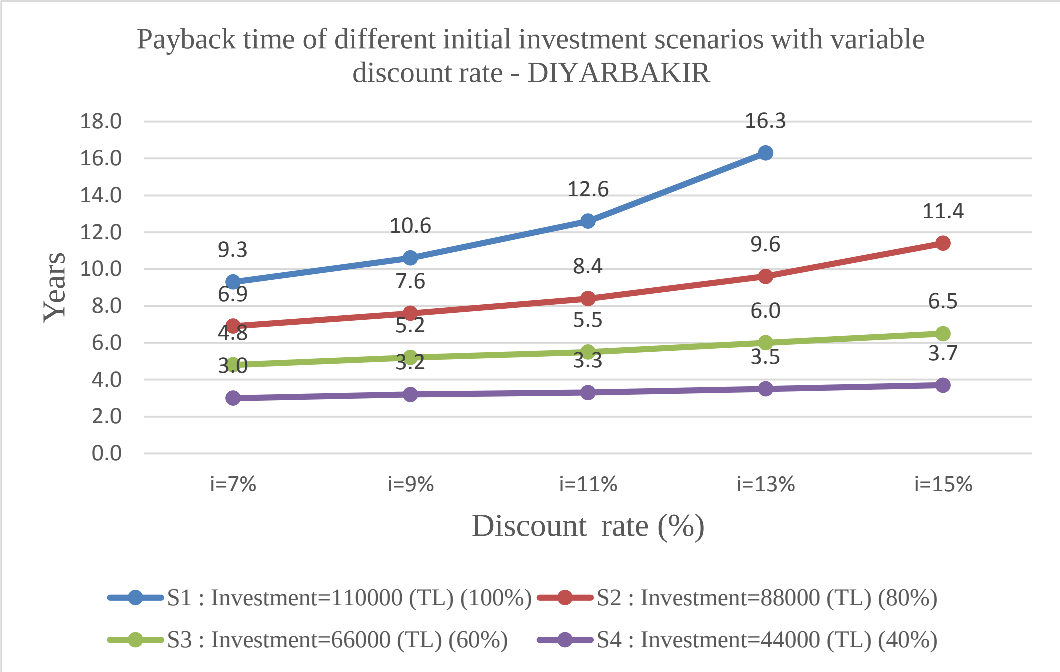


Figure 6.11 : Payback time by using pivot windows on top of the atrium with different initial investments in Diyarbakir considering variable discount rate.

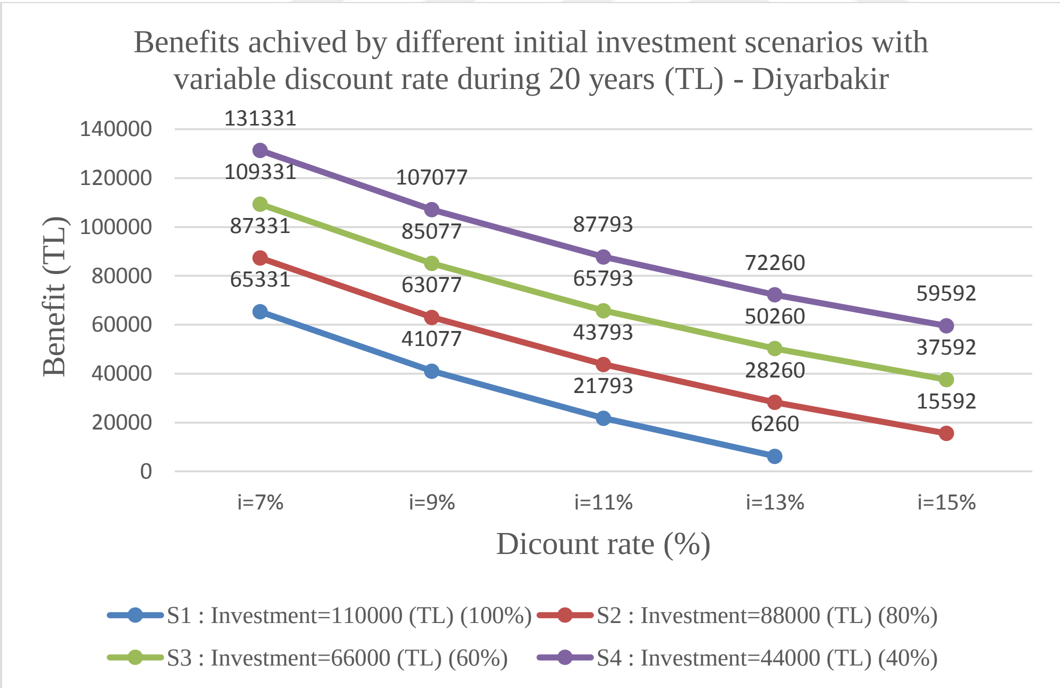


Figure 6.12: Benefits achieved by using pivot windows on top of the atrium with different initial investments in Diyarbakir considering variable discount rate (TL).

6.2.3 Antalya

In Antalya, as a representative of hot humid climate, courtyard and atrium buildings have high cooling energy load from March till November (Figure 6.13). Maximum cooling energy demand observed in August 69640 kWh for atrium and 61240 for courtyard. Only in five months of a year, the modeled buildings show energy need for heating in a low level. Highest heating energy need for both building seemed in January 19180 and 16860 kWh for atrium and courtyard respectively (Figure 6.13).

In total, cooling energy conservation regarding using courtyard mode (opening pivot windows on top of the atrium) instead of atrium type, seemed 47024.4 kWh (Figure 6.14). From Figure 6.14, it is come in to view that, total heating energy saving of atrium is 8267.1 kWh compared with courtyard throughout the year. All over the year, lighting energy conservation of courtyard is higher than atrium and it is appeared 3634.6 kWh in total amount (Figure 6.14).

Approaching to the total energy cost, similar to Diyarbakir, courtyard building shows better energy performance than atrium form in summer time (Figure 6.13). In Aguste 29410 and 25920 TL as a maximum level of total energy cost observed for atrium and courtyard respectively. Moreover, minimum total energy cost revealed 4496TL related to atrium and 4166 TL discovered for courtyard in February. Difference between total energy cost of courtyard and atrium calculated 19875 TL during warm period, from the first of March until the end of October in Antalya (Figure 6.13).

Figure 6.15 shows, transforming atrium into the courtyard by investing on pivot windows on the skylight of atrium area has prompt payback time due to saved cooling energy in the warm period of the year (Figure 6.15). Minimum payback time appeared 2.5 years with average discount rate of 7 % for S4 (40% of fix windows on top of the atrium replace with pivot windows). Furthermore, maximum payback time seemed 12.7 years in average discount rate of 15% for S1 (100% of fix windows on top of the atrium replace with pivot windows). As a result, four scenarios of investment (S1, S2, S3 and S4) are feasible with all considered average discount rate (Figure 6.15).

From Figure 6.16 it is appeared that maximum benefit is dedicated to Antalya compared with other regions. Fourth scenario of investment under 7% average discount rate emerged to have highest benefit around 166503 TL during 20 years. Minimum amount of benefit is related to first scenario with average discount rate of 15% and appeared around 14373 TL.

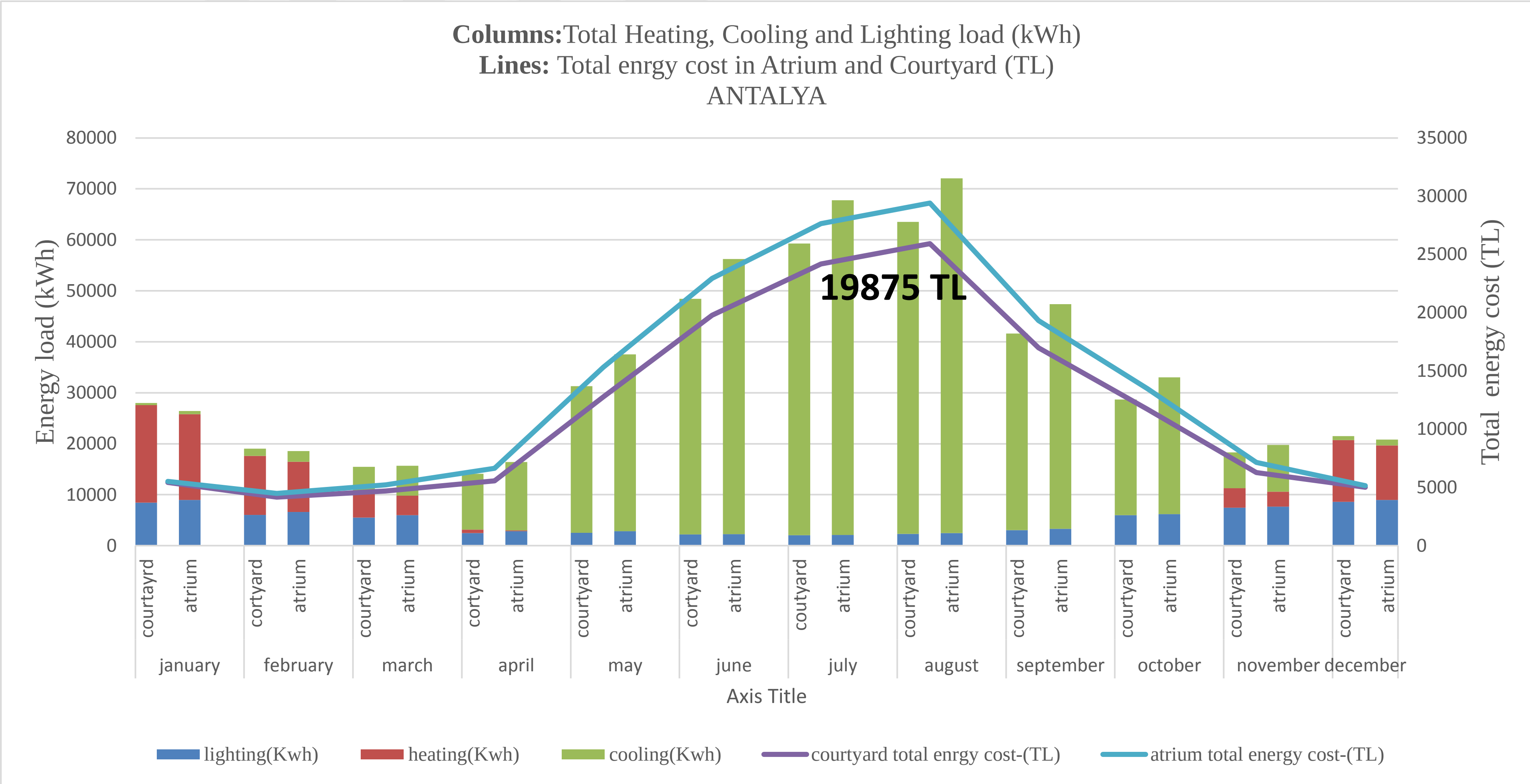
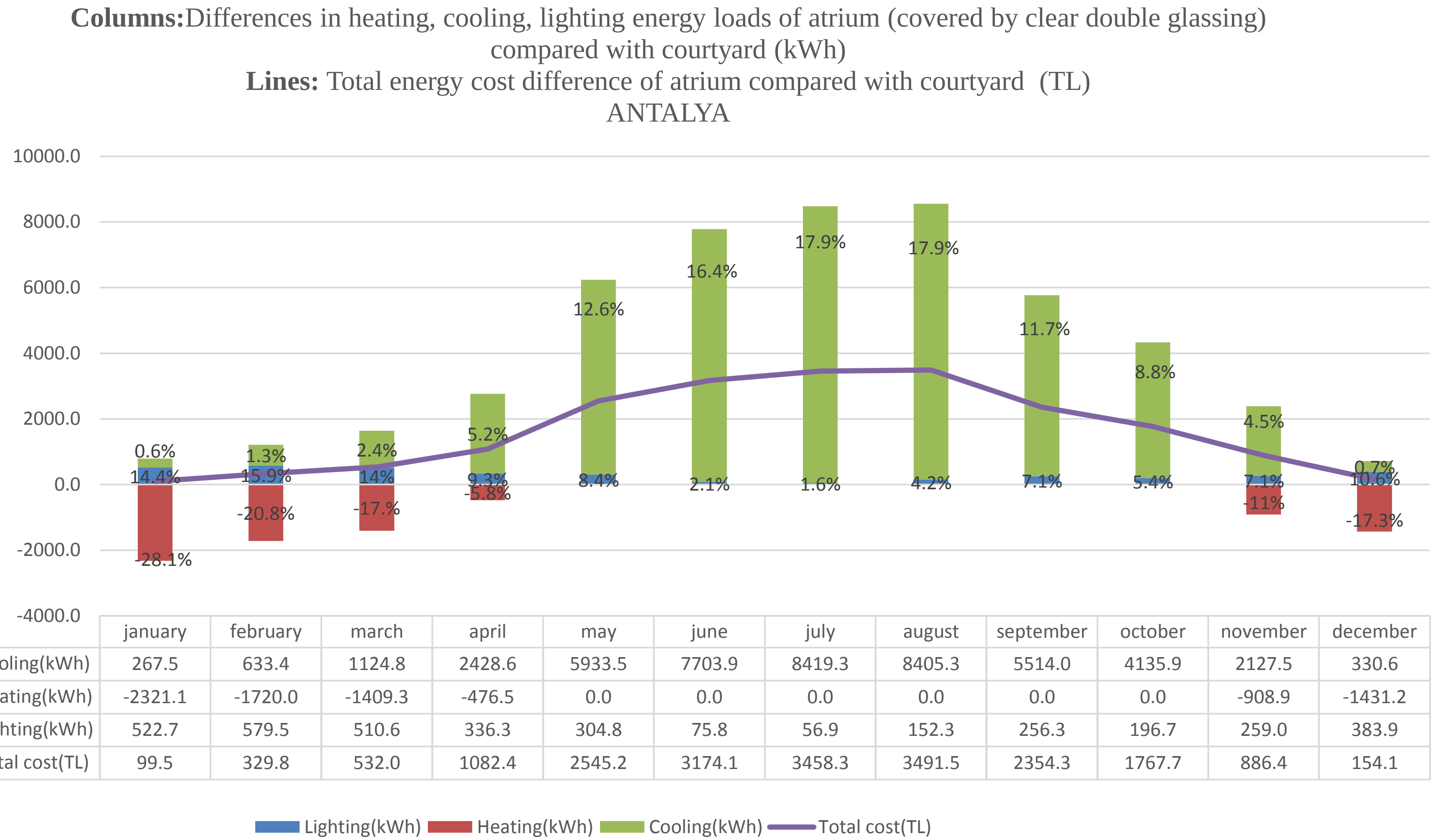


Figure 6.13 : Total, heating, cooling and lighting as well as total energy cost of atrium (covered by double clear glassing) and courtyard – Antalya.



	january	february	march	april	may	june	july	august	september	october	november	december
Cooling(kWh)	267.5	633.4	1124.8	2428.6	5933.5	7703.9	8419.3	8405.3	5514.0	4135.9	2127.5	330.6
Heating(kWh)	-2321.1	-1720.0	-1409.3	-476.5	0.0	0.0	0.0	0.0	0.0	0.0	-908.9	-1431.2
Lighting(kWh)	522.7	579.5	510.6	336.3	304.8	75.8	56.9	152.3	256.3	196.7	259.0	383.9
Total cost(TL)	99.5	329.8	532.0	1082.4	2545.2	3174.1	3458.3	3491.5	2354.3	1767.7	886.4	154.1

Figure 6.14 : Differences in heating, cooling, lighting energy loads as well as total energy cost of atrium compared with courtyard (zero line considered as courtyard) in Antalya.

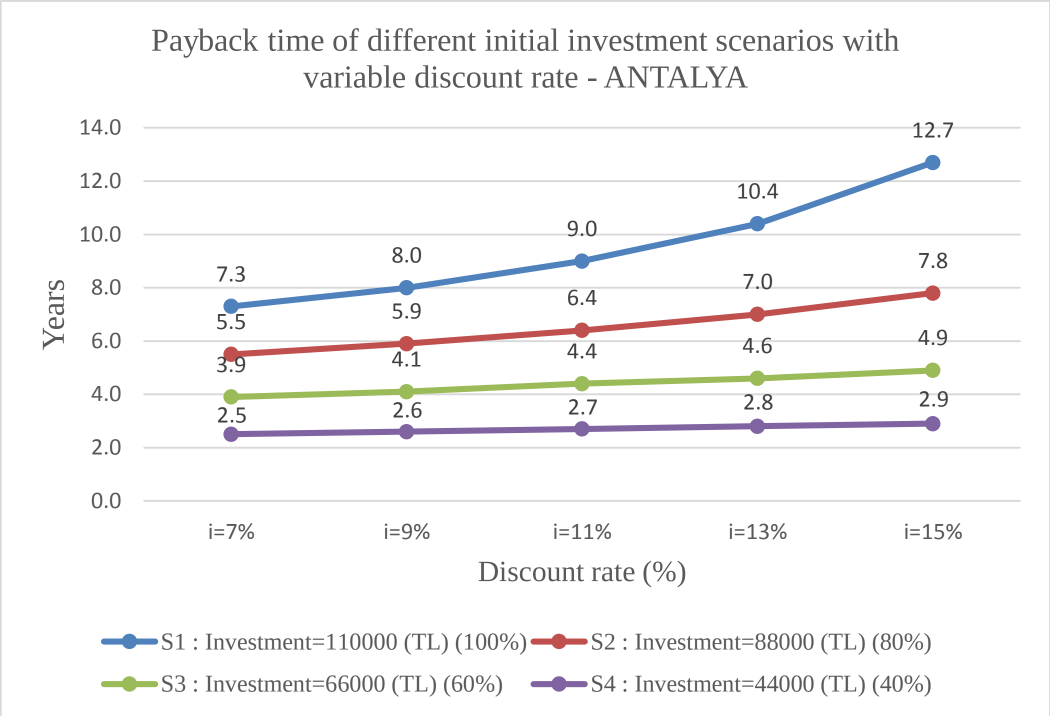


Figure 6.15 : Payback time of different initial investment scenarios using pivot windows on top of the atrium in Antalya considering variable discount rate.

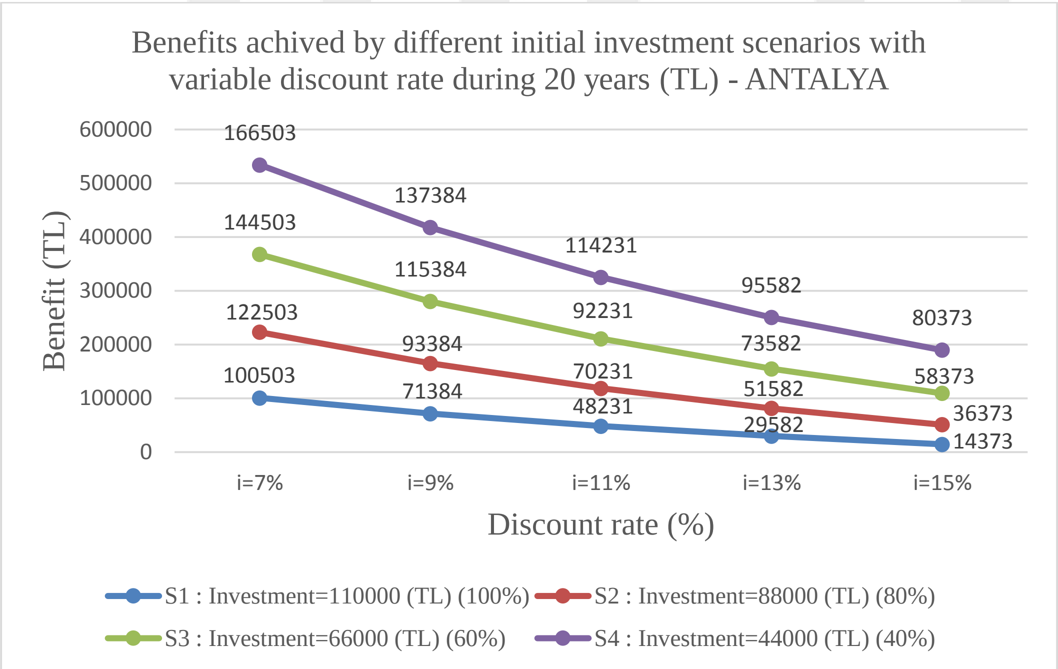


Figure 6.16 : Benefits achieved by using pivot windows on top of the atrium with different initial investments in Antalya considering variable discount rate (TL).

6.2.4 Erzurum

Since Erzurum is located in a cold climate, heating energy has priority (Figure 6.17).

Atrium type demands less energy compared to the courtyard during the cold period. Maximum heating energy need observed in January (124824 kWh for courtyard and 116730 kWh for atrium). Most cooling energy need happens in Aguste for both building (28570 kWh for atrium and 24965 kWh for courtyard). During the warm period of the year, courtyard shows better energy performance.

In Erzurum, total energy cost calculations indicated that the period of using courtyard to save energy happens in four months of the year, whereas in remaining months, atrium shows slightly better performance than courtyard. Figure 6.17 shows, the highest total energy cost occurs in January (15567 TL for atrium and 15864 TL for courtyard. Minimum energy expense is observed in May for courtyard around 3890 TL and in April for atrium 4510 TL. There will be 7700 TL reduction in the energy cost by using courtyard form (opening pivot windows on top of the atrium skylight) instead of atrium from first of May until end of September (Figure 6.17). Comparing atrium with courtyard, maximum heating energy saving happen in January around 8094.9 kWh and in total 47412.7kWh for atrium. All over the year courtyard conserves 7891.8 kWh via cooling energy compared with atrium. Courtyard compared with atrium saves energy via lighting load 7891.8 kWh all over the year.

Figure 6.19 shows S1 and S2 have not reasonable payback time, moreover, only in average discount rate of 7% there was sign of 15.6 years' payback period for S3. In all average discount rate S4 shows feasibility, as 19.5 and 8.4 years are the payback time of 7 and 15% discount rate respectively.

Figure 6.16 shows benefit achieved by third scenario limited to one optioned around 9059 TL under average discount rate of 7% in Erzurum. Maximum amount of benefit for fourth scenario has been emerged nearly 31059 TL with average discount rate of 7% and 347 TL as minimum benefit under 15% average discount rate.

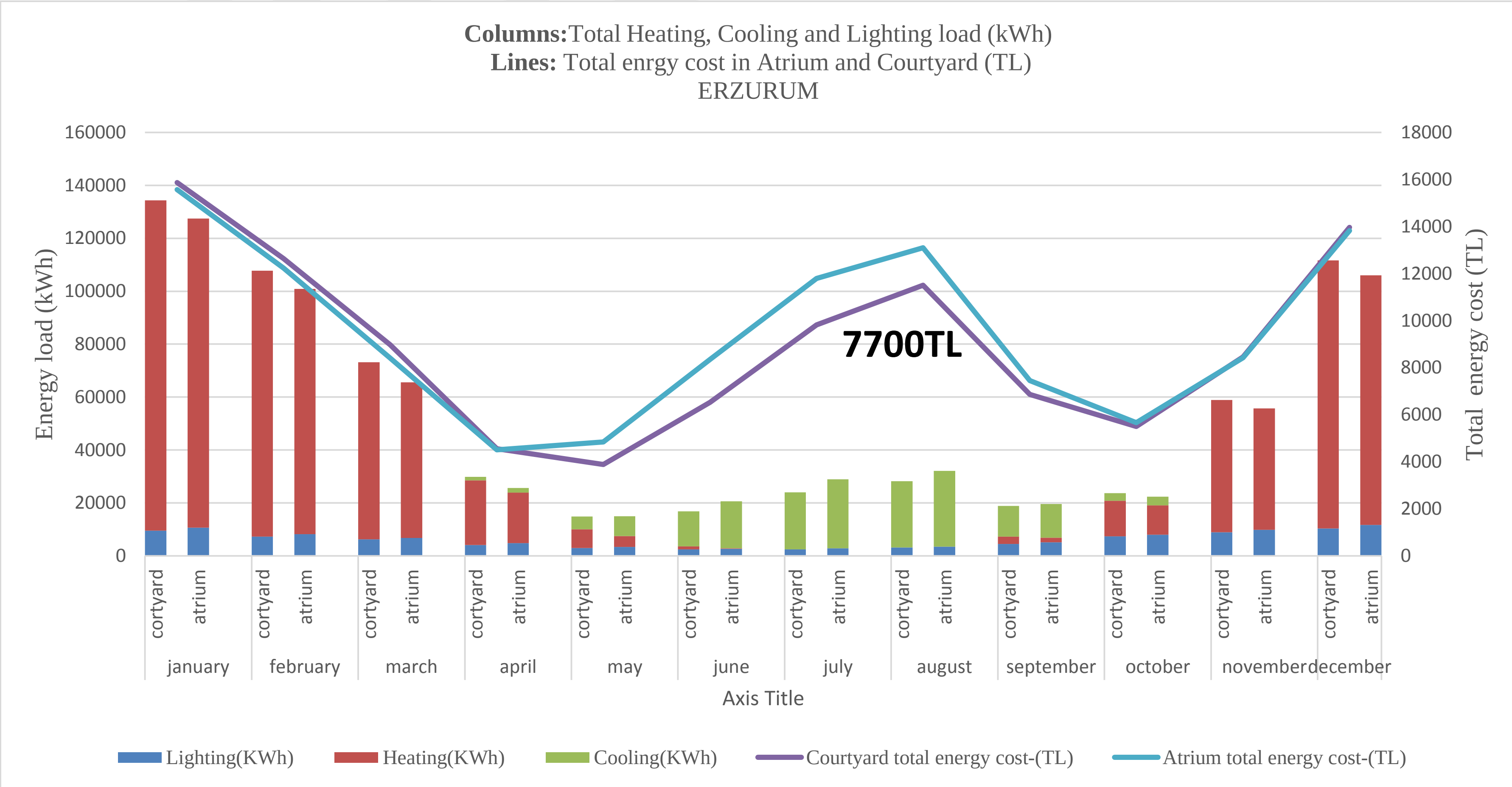
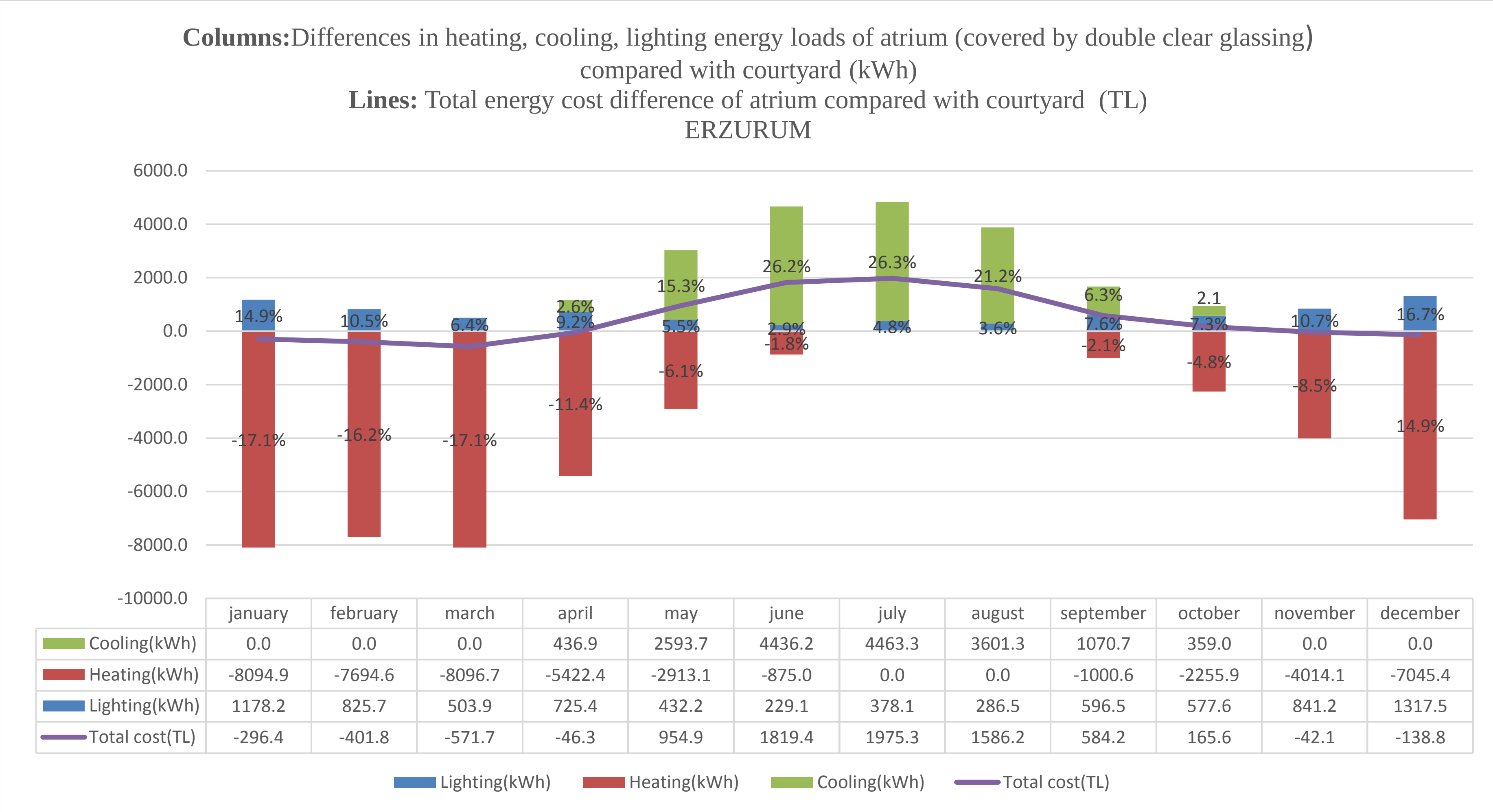


Figure 6.17 : Total, heating, cooling and lighting as well as total energy cost of atrium (covered by double clear glassing) and courtyard – Erzurum.



	january	february	march	april	may	june	july	august	september	october	november	december
Cooling(kWh)	0.0	0.0	0.0	436.9	2593.7	4436.2	4463.3	3601.3	1070.7	359.0	0.0	0.0
Heating(kWh)	-8094.9	-7694.6	-8096.7	-5422.4	-2913.1	-875.0	0.0	0.0	-1000.6	-2255.9	-4014.1	-7045.4
Lighting(kWh)	1178.2	825.7	503.9	725.4	432.2	229.1	378.1	286.5	596.5	577.6	841.2	1317.5
Total cost(TL)	-296.4	-401.8	-571.7	-46.3	954.9	1819.4	1975.3	1586.2	584.2	165.6	-42.1	-138.8

Figure 6.18 : Differences in heating, cooling, lighting energy loads as well as total energy cost of atrium compared with courtyard (zero line considered as courtyard) in Erzurum.

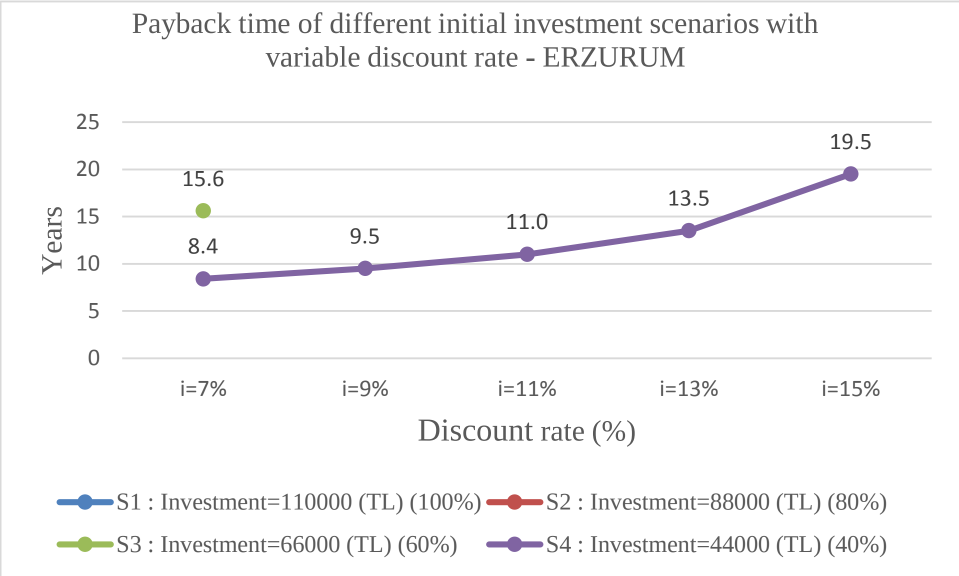


Figure 6.19 : Payback time of different initial investment scenarios using pivot windows on top of the atrium in Erzurum considering variable discount rate.

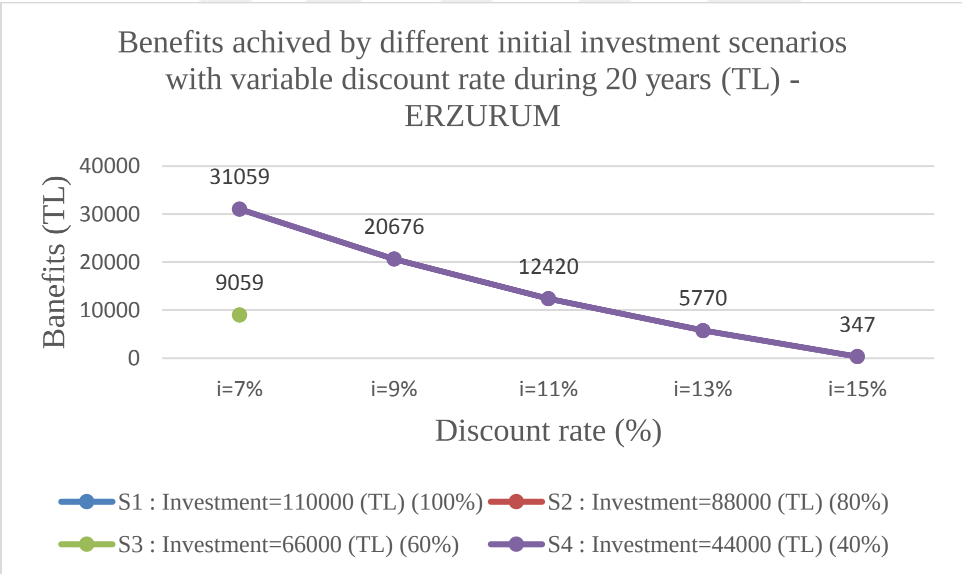


Figure 6.20 : Benefits achieved by using pivot windows on top of the atrium with different initial investments in Erzurum considering variable discount rate (TL).

6.2.5 Ankara

In Ankara, during the summer time both modeled building types need cooling energy. however, similar Erzurum energy demand for cooling is in a low level compared to heating energy demand. In January maximum heating energy needs for both building types, as it is appeared 90630 kWh for courtyard and for atrium 82810 kWh. During the summer July is the time for most demanding cooling energy for both buildings.

Maximum cooling energy need observed 33367 kWh for atrium and 28500 kWh for courtyard in July.

Approaching to differences of energy load (Figure 6.22) it is emerged 42875.6 kWh is total heating energy conservation of atrium compared to courtyard all over the year. Vice versa, courtyard has ability to conserve energy through cooling load 16390 kWh in total, compared with atrium. Total amount of saving energy via lighting load is 5907.7 kWh for courtyard compared with atrium whole year (Figure 6.22).

Considering of total energy cost for atrium and courtyard (Figure 6.21), it is appeared that maximum energy cost observed in January (12595 and 12160 TL for courtyard and atrium respectively) and in July (12555 and 14600 TL for courtyard and atrium respectively. Whereas minimum total energy cost emerged in April (3743 TL for courtyard and 3765 TL for atrium) (Figure 6.21). Throughout the summer time in Ankara, courtyard model shows better performance than the atrium form. Difference of total energy cost as a result of using courtyard type (opening pivot windows on top of the atrium) instead of atrium mode during aforementioned period is 6715 TL.

Investment on openable widows on the top of atrium skylight and transforming atrium into a courtyard during the warm period are not feasible for S1 and S2. Looking S3, only average discount rate under 7% seemed feasible with payback time of 17.2 years. S4 has feasibility to investment on all discount rate as 15.6 and 9.1 years observed for highest and lowest discount rate respectively (Figure 6.23).

Fourth scenario of investment shows 27139 TL as a maximum amount of benefit in fourth scenario of investment during 20 years in Ankara (Figure 6.20). there is sign of feasibility for fourth scenario as a minimum amount of benefit under average discount rate of 13%. Third scenario showed only one option for getting benefit by using pivot windows which under 7% average discount rate and was around 5139 TL (Figure 6.20).

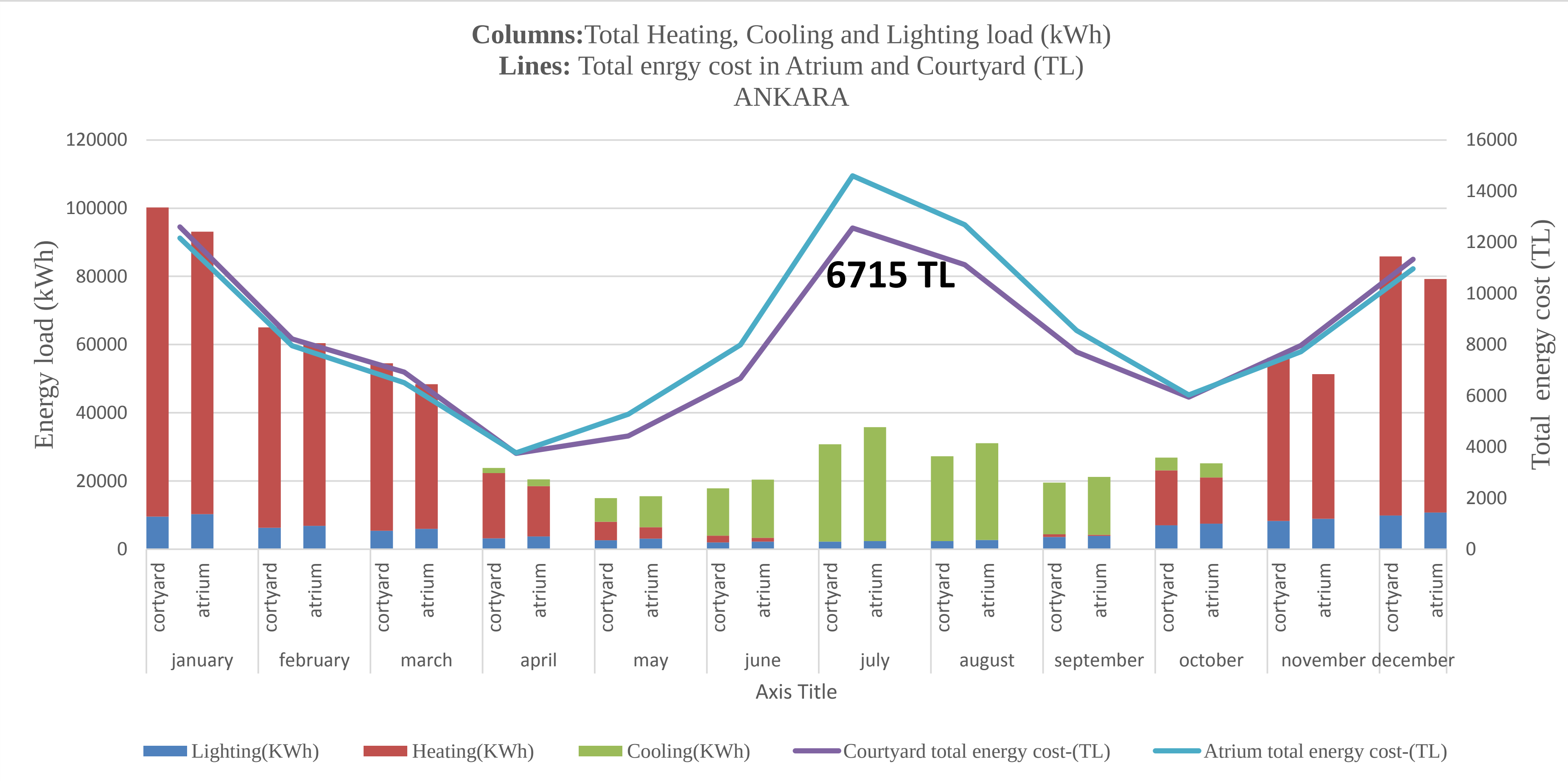
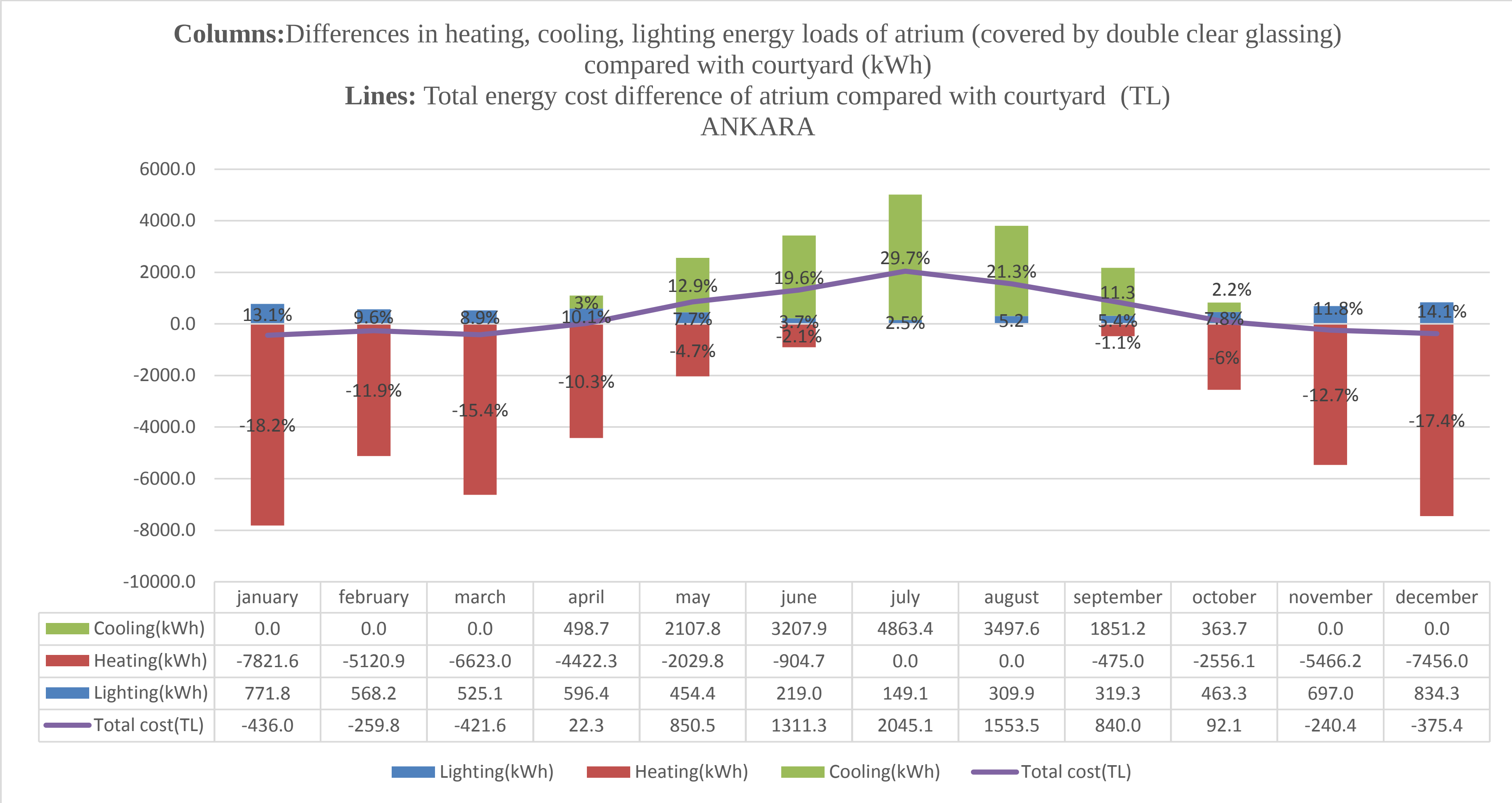


Figure 6.21 : Total, heating, cooling and lighting as well as total energy cost of atrium (covered by double clear glassing) and courtyard – Ankara.



	january	february	march	april	may	june	july	august	september	october	november	december
Cooling(kWh)	0.0	0.0	0.0	498.7	2107.8	3207.9	4863.4	3497.6	1851.2	363.7	0.0	0.0
Heating(kWh)	-7821.6	-5120.9	-6623.0	-4422.3	-2029.8	-904.7	0.0	0.0	-475.0	-2556.1	-5466.2	-7456.0
Lighting(kWh)	771.8	568.2	525.1	596.4	454.4	219.0	149.1	309.9	319.3	463.3	697.0	834.3
Total cost(TL)	-436.0	-259.8	-421.6	22.3	850.5	1311.3	2045.1	1553.5	840.0	92.1	-240.4	-375.4

Figure 6.22 : Differences in heating, cooling, lighting energy loads as well as total energy cost of atrium compared with courtyard (zero line considered as courtyard) in Ankara.

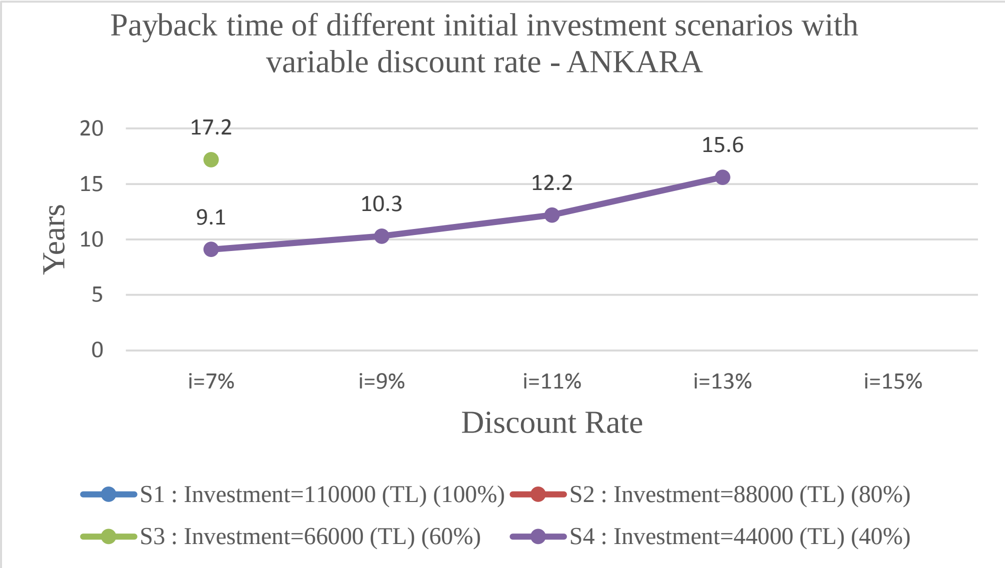


Figure 6.23 : Payback time of different initial investment scenarios using pivot windows on top of the atrium with in Ankara considering variable discount rate.

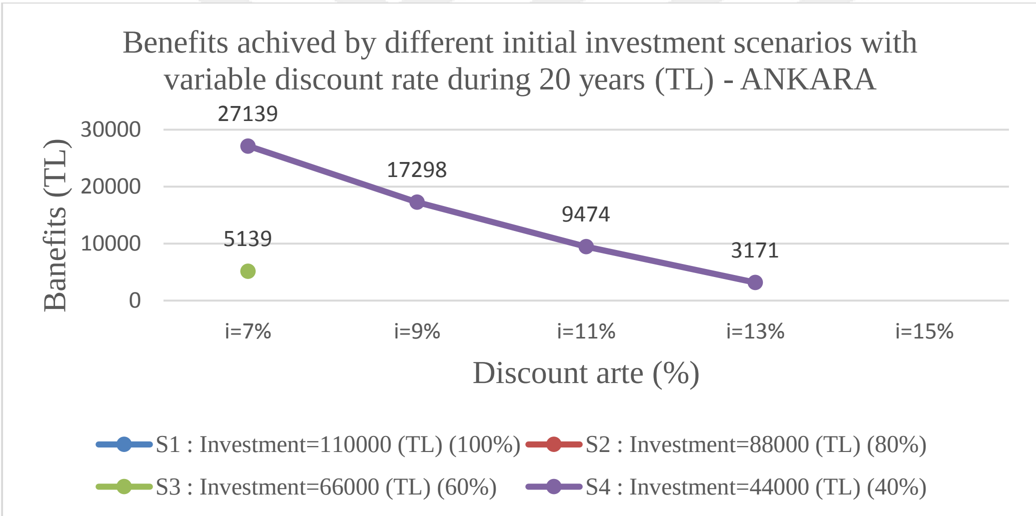


Figure 6.24 : Benefits achieved by using pivot windows on top of the atrium with different initial investment in Ankara considering variable discount rate (TL).

7. DISCUSSION

The first attempt of simulations has been carried out taking into account three different climates, namely cold (Erzurum), mild and humid (Istanbul), and hot (Diyarbakir). The simulation model has been prepared in the DesignBuilder using the following criteria: construction, artificial lighting, activity, and HVAC type as well as time usage of building from standards such as ASHRAE and Turkish Standards, CAD file of courtyard models.

First effort has been carried out to identify the effect of seasonal time on the energy efficiency of the integrated usage of a courtyard and atrium. The simulation has been based on a courtyard model that later, assumed covered by a skylight with single, double, or triple glazing regarding to compare energy load of courtyard and atrium. The aforementioned different glazing types have been examined for an atrium skylight to determine the proper glazing type with respect to energy consumption for the parent building. Simulation results revealed covering a courtyard considering the different glazing type (single, double, or triple) can conserve energy in cold months in all climate regions. However, the amount of energy savings differs with respect to climate conditions and glazing types. The highest total energy conservation happened in the simulation model where an atrium skylight was covered by triple glazing for all regions in cold months. On the other hand, covering a courtyard with single glazing provided lower performance compared to the two other glazing types. Simulations for an atrium covered by triple glazing in Erzurum (as a representative of cold climates) provided the maximum total energy savings in March, 596 kWh/m^2. The simulations have revealed that the most energy savings were observed in February (524 kWh/m^2) for Istanbul and in January (261 kWh/m^2) for Diyarbakir by atrium with triple glazing on top of sky light. During the summer, however, using an atrium instead of a courtyard increased the total energy consumption in Erzurum, Istanbul, and Diyarbakir (887, 571, and 497 kWh/m^2, respectively). It should be mentioned that clear double and clear triple glazing on top of the atrium showed similar performance in all months of considered regions.

After exploring feasibility of integrated atrium-courtyard building via energy saving capability of both courtyard and atrium in three climate of Turkey, economical calculation come in to play as main part. In this part five climates of Turkey (hot-humid (Antalya), hot-dry (Diyarbakir), mild (Ankara), mild-humid (Istanbul) and cold (Erzurum)) have been considered for evaluation in simulation. The strategy for transforming atrium to the courtyard was second attempt considered using pivot widows with clear double glassing on top of the atrium instead of fix windows. The cost difference between two types of windows (fix and pivot windows with clear double glazing) was taken as an initial cost. Investment on top of the atrium by replacing fix windows with pivot ones was the main strategy regarding to achieve integrated atrium and courtyard building. During calculation initial investments on pivot windows considered in four scenarios. First scenario (S1) considered all fix windows replaced with pivot windows and initial investment emerged 110000 TL. Assuming to have same energy load of courtyard, second, third and fourth scenario of investment considered to replacing 80%,60% and 40% of all fixed windows on top of the atrium. Throughout the simulation process, natural gas has been considered for heating whereas electricity energy has been taken for cooling and lighting adjacent space of courtyard and atrium.

Considering energy loads in investigated cities (Figure 7.1), annual maximum and minimum heating, cooling and lighting energy demand have been observed in Erzurum and Antalya. In Erzurum, courtyard needs 492274, 80630 and 69655 kWh for heating, cooling and lighting energy respectively. In Antalya, courtyard energy demands have been emerged 52500, 280157 and 56600kWh for heating, cooling and lighting. Heating energy demand of 444860 kWh, cooling energy need of 97592kWh and lighting energy call of 77547 kWh have been observed for atrium in Erzurum. In Antalya 44234, 326032, 60236 kWh have been seen for heating, cooling and lighting energy load for atrium building respectively. Figure 7.1 demonstrates total annual heating, cooling and lighting loads as well as total annual energy cost of atrium and integrated atrium-courtyard building in considered cities. Considering energy loads it has appeared that Antalya and Erzurum have highest cooling and heating energy loads respectively. Lighting energy demand for investigated buildings are close to each other in all regions (Figure 7.1). Total energy cost differences of atrium compared with integrated atrium-courtyard is high in hot climate due to cooling energy price during warm period. Among investigated regions, maximum amount of total annual energy cost has been observed in Antalya for atrium and integrated atrium-courtyard building around 146862 and 130309 TL respectively. This means a reduction of 12.7% in total energy cost by using integrated atrium-courtyard building. Among the studied cities Ankara has minimum expanse of total energy cost, which is 10420 TL for atrium and 97505 TL for integrated atrium-courtyard building (Figure 7.1). This means by investing on pivot windows and using integrated atrium-courtyard building there will be 6.88% decrease in total energy cost in Ankara. Reductions on total energy cost by using integrated atrium-courtyard building are 12.7, 10.99 and 6.61 percent in Diyarbakir, Istanbul and Erzurum respectively.

Figure 7.2 shows payback time of all investment scenarios (S1, S2, S3, and S4) with considered average discount rates in investigated climates. The results of payback period of investment on pivot windows on top of the atrium skylight through replacing fix windows by pivot windows are as fallow:

- Antalya: Investment scenarios had acceptable payback period for all investments with all consideration average discount rates. As maximum period for payback was 12.70 years for S1 with average discount rate of 15% and minimum was 2.5 years for S4 with 7% average discount rate.
- Diyarbakir: Only in S1 Diyarbakir had not adequate time with average discount rate of 15%, but in the remain scenarios and average in discount rates seemed to come up feasible. 16.30 years for S1 as maximum and 3 years for S4 as minimum were acceptable payback time in Diyarbakir.
- Istanbul: Istanbul had acceptable payback period for all investment scenarios when average discount rate was equal and under 9%. There is not reasonable point for S1 and S2 when average discount rate reaches more that 11and 13 % respectively. 16.7 years for S2 with average discount rate of 11% as a highest, and 4.4 years for S2 with average discount rate of 7% as a lowest are sufficient period for repay in Istanbul.
- Erzurum: Approaching to the Erzurum, S4 has adequate payback period in all considered average discount rates. First and second scenarios of investment (S1 and S2) have not any feasibility and except 15%, S3 shows acceptable time to payback in remained average discount rates.19.5 years with average

discount rate of 15% is maximum and 8.4 years with average discount rate 7% is minimum acceptable periods to repay forth scenario of investment in Erzurum.

- Ankara: In Ankara S1and S2 are not feasible at all but, S3 and S4 have adequate payback time with equal and under average discount rate of 7% and 13%, respectively. S4 has maximum and minimum period for repay, as 15 years with average discount rate of 13% and 9.1 years with average discount rate of 7% appeared for payback time.

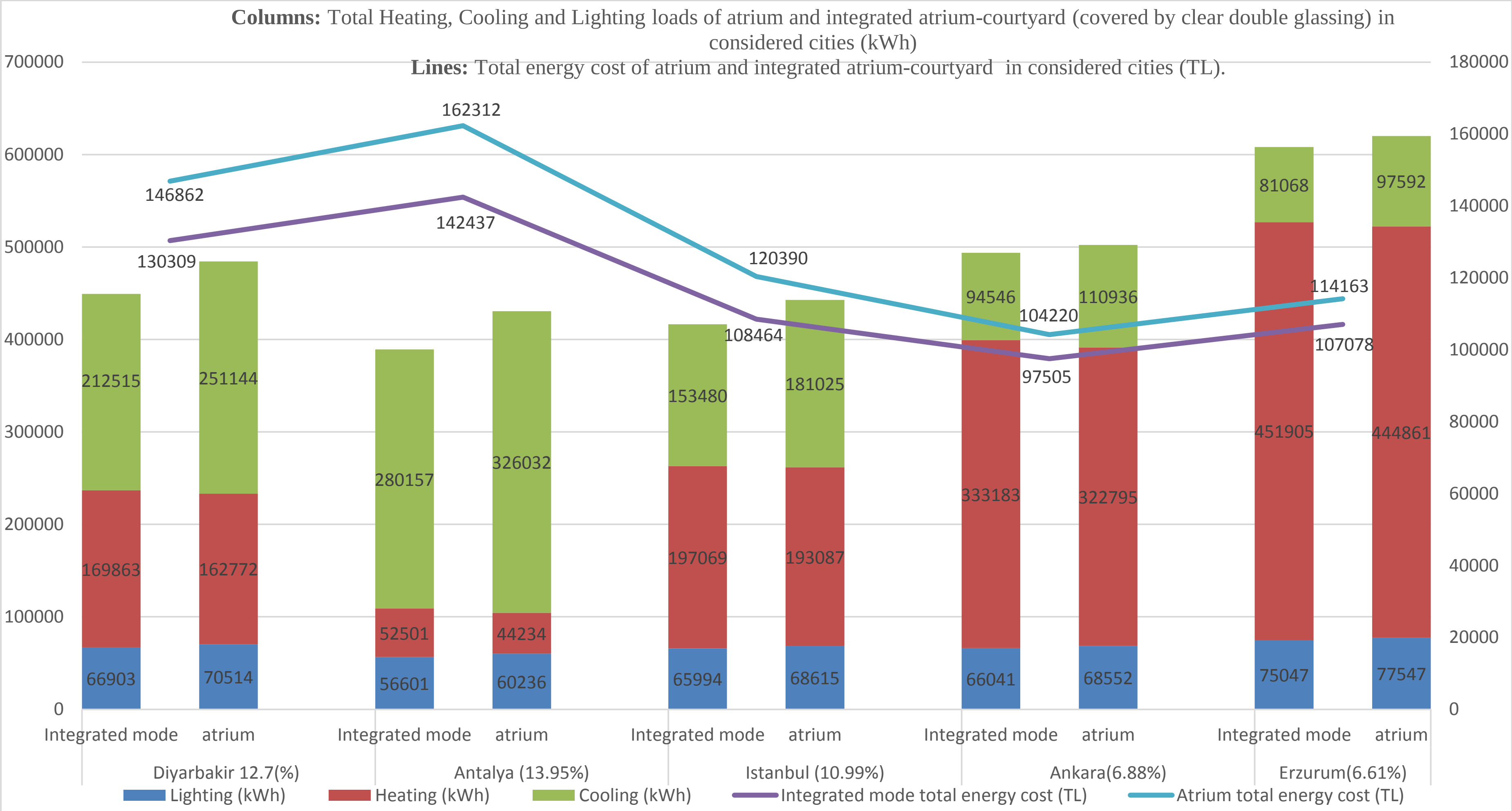


Figure 7.1 : Total heating, cooling and lighting loads as well as total energy cost of atrium and integrated atrium-courtyard (covered by clear double glassing) building in considered cities.

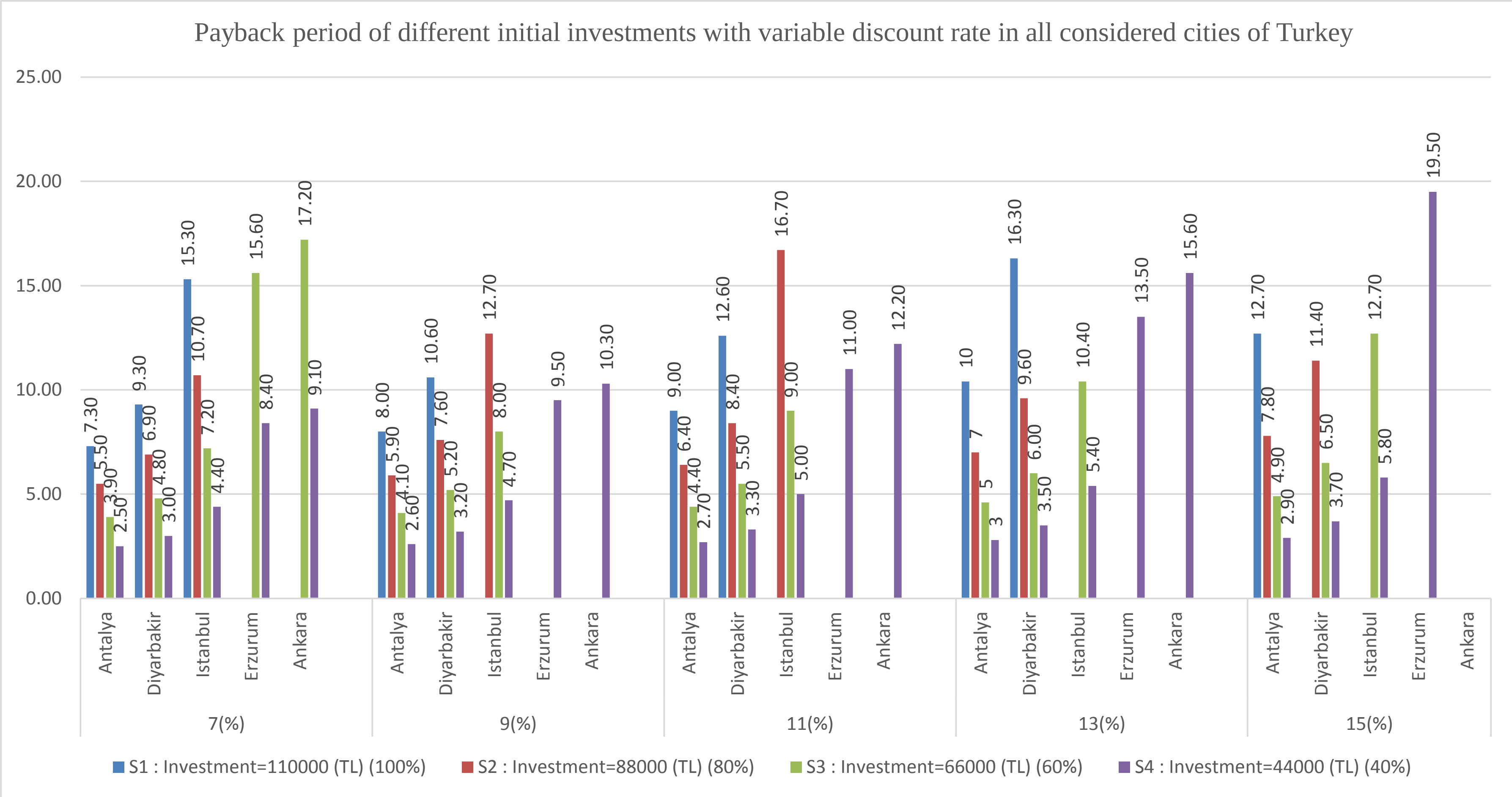


Figure 7.2 : Payback period of different initial investments with variable discount rate in all considered cities of Turkey.

8. CONCLUSION

In building sector, from total amount of energy consumption point of view, office buildings take second place following commercial ones. Heating, cooling and lighting energy loads have significant impact on office buildings' energy consumption. In recent years using effective design strategies has become a general movement to reduce energy demand of building. Using passive design strategies in buildings are among the effective methods with respect to energy-conscious building design. Passive design strategies such as using atrium and courtyard space provides potential for building to save energy. Incorporation of an atrium or a courtyard into office buildings can save energy by providing good daylight, natural ventilation and making available of a buffer zone between indoor and outdoor environment.

This research aimed to identify the energy-efficient, integrated usage of an atrium and courtyard so that energy performance for office buildings can be improved with respect to seasonal and climate factors. With this aim, simulations have been performed in two steps. The first step simulations were carried out by exploring energy-efficient courtyard and atrium in different climates of Turkey (hot-humid (Antalya), hot-dry (Diyarbakir), mild (Ankara), mild-humid (Istanbul) and cold (Erzurum)) by using pivot windows on top of the atrium. The second step simulations have been carried out to identify the effect of seasonal time on the energy efficiency and cost effectiveness of the integrated usage of a courtyard and atrium. Throughout the simulation process, natural gas has been considered for heating whereas electricity energy has been taken for cooling adjacent space of courtyard and atrium. The study revealed the following findings:

- Having atrium and courtyard area in one building at the same time, means using different capabilities and energy saving potentials of both spaces for building.
- As artificial lighting demand of office building is high, using courtyard and atrium space in building can reduce day light energy demand due to natural daylight provided from outside and inside walls.

- During summer time sun radiation angle is in a high altitude and causes excessive heat on building roof especially on areas covered by glass. For this reason, transforming atrium into the courtyard can help elimination of greenhouse effect from glass covered area leading to reduced cooling energy load in summer time.
- Even though during winter, sun radiation angle is in a low altitude, atrium form of the building can lead to the reduction of heating energy demand.
- Natural gas and electricity prices have a great influence on operational cost of buildings. In Turkey, electricity price is around one fourth of natural gas price in the unit of kWh. Consequently, reducing cooling energy demand plays a vital role with respect to the design of cost effective and energy efficient building.
- Lighting energy consumption of the atrium has been observed to be higher than of the courtyard in all considered regions throughout the year as the skylight roof of the atrium blocks natural light.
- During the summer, amount of cooling energy conservation of courtyard has been observed to be more in hot climates than in cold climates. In winter, however, amount of heating energy saving of atrium has been observed to be more in cold climates than in hot climates.
- Regarding the cost of electricity in Turkey, maximum energy cost appears in the mid-summer due to cooling loads whereas minimum energy cost occurs at the beginning or end of the warm period in all considered climates.
- Using integrated atrium and courtyard can save total annual energy cost in Antalya, Diyarbakir, Istanbul, Ankara, and Erzurum. The total annual energy cost saving percentages are 13.95, 12.7, 10.99, 6.88 and 6.61% respectively.
- Investment on openable windows on the top of atrium skylight and on transforming atrium into a courtyard during the warm period have been observed to be more feasible in hot-humid, mild-humid and hot climates. In cold climate, on the other hand, using pivot window on atrium roof has been observed not to be feasible.

- Table 8.1 summarizes suggested seasonal usage of courtyard or atrium mode of an integrated atrium-courtyard building with respect to energy consumption cost in different regions of Turkey. In Erzurum, courtyard mode has been observed to be feasible from May till October, whereas, atrium mode demonstrates better performance for remaining months. In Ankara and in Istanbul courtyard type displays cost effectiveness from April till October whereas using atrium type is more feasible for other months. In Diyarbakir, using atrium form is cost effective on January, February and December, whereas courtyard form performs better form March till November. In Antalya. courtyard mode is recommended to be used in all months of a year.

Table 8.1: Seasonal usage of courtyard or atrium mode of an integrated atrium-courtyard building with respect to energy consumption cost in different regions of Turkey.

	Erzurum	Ankara	Istanbul	Antalya	Diyarbakir
January	atrium	atrium	atrium	courtyard	atrium
February	atrium	atrium	atrium	courtyard	atrium
March	atrium	atrium	atrium	courtyard	courtyard
April	atrium	courtyard	courtyard	courtyard	courtyard
May	courtyard	courtyard	courtyard	courtyard	courtyard
June	courtyard	courtyard	courtyard	courtyard	courtyard
July	courtyard	courtyard	courtyard	courtyard	courtyard
August	courtyard	courtyard	courtyard	courtyard	courtyard
September	courtyard	courtyard	courtyard	courtyard	courtyard
October	courtyard	courtyard	courtyard	courtyard	courtyard
November	atrium	atrium	atrium	courtyard	courtyard
December	atrium	atrium	atrium	courtyard	atrium

Understanding impact of variable elements upon energy demand and operational energy cost of atrium and courtyard as well as their integrated mode, leads to make a proper decision in process of early design and investment. Comparative graphs and information of this study support the idea of capability of energy conservation in building by presenting energy efficient and cost effective building. The strategy of using integrated atrium and courtyard in building boosts energy performance of building and assists architectures and contractors to achieve a solution (among the variety of choices) to design and built energy efficient and cost effective buildings.

Limitation:

Although the dissertation studied the effect of both courtyard and atrium as well as their integrated mode, there are four limitations in this research:

The first limitation is related to the nature of energy simulation program that provides comparative assessment scale instead of real one because it has been built on assumptions.

The second limitation is connected to designed model which represented a special case of courtyard and atrium which has been described in methodology chapter of this thesis. Therefore, values and results have potential to change when the accepted measures (e.g. form, condition of climate and natural ventilation) are altered.

The third limitation is linked to economical evaluation of the research. Economic estimation for the future, regarding to cost effectiveness of the study, has been mainly based on the values of 2016 and earlier years. Future variation on material costs, energy prices, discount rate can affect the result of the study.

The fourth limitation is that the study has focused on life-cycle analyses of transparent elements of the building.

The findings need to be considered for the specific building type and simulation conditions specified in this study and they cannot be generalizable. It should be mentioned that besides aforementioned limitations, the method has the ability to achieve and predict energy performance and cost effectiveness of designed buildings.

Suggestion for further research:

Since a number of alternatives appear to impact building energy consumption, further studies are recommended to be carried out on the energy performance impacts of the integration of other passive energy strategies (e.g. the Computational fluid dynamics) on buildings.

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APPENDICES

Appendices A: Payback time calculations of four scenarios of initial investment under different discount rate in Turkey.

Table A.1 : Payback time calculations of S1and S2 with all average discount rates in Diyarbakir.

Diyarbakir	savings	i=7%		
years	Cash flow	PV	Balance	PB period
0.0			-110000.0	
1.0	16550.0	15467.3	-94532.7	
2.0	16550.0	14455.4	-80077.3	
3.0	16550.0	13509.7	-66567.6	
4.0	16550.0	12625.9	-53941.7	
5.0	16550.0	11799.9	-42141.7	
6.0	16550.0	11028.0	-31113.8	
7.0	16550.0	10306.5	-20807.3	
8.0	16550.0	9632.3	-11175.0	
9.0	16550.0	9002.1	-2172.9	9.3
10.0	16550.0	8413.2	6240.3	
11.0	16550.0	7862.8	14103.1	
12.0	16550.0	7348.4	21451.5	
13.0	16550.0	6867.7	28319.1	
14.0	16550.0	6418.4	34737.5	
15.0	16550.0	5998.5	40736.0	
16.0	16550.0	5606.1	46342.0	
17.0	16550.0	5239.3	51581.3	
18.0	16550.0	4896.5	56477.9	
19.0	16550.0	4576.2	61054.1	
20.0	16550.0	4276.8	65330.9	

Diyarbakir		i=9%		
years	Cash flow	PV	Balance	PB period
0.0			-110000.0	
1.0	16550.0	15183.5	-94816.5	
2.0	16550.0	13929.8	-80886.7	
3.0	16550.0	12779.6	-68107.1	
4.0	16550.0	11724.4	-56382.6	
5.0	16550.0	10756.4	-45626.3	
6.0	16550.0	9868.2	-35758.0	
7.0	16550.0	9053.4	-26704.6	
8.0	16550.0	8305.9	-18398.7	
9.0	16550.0	7620.1	-10778.7	
10.0	16550.0	6990.9	-3787.8	10.6
11.0	16550.0	6413.7	2625.9	
12.0	16550.0	5884.1	8510.0	
13.0	16550.0	5398.3	13908.3	
14.0	16550.0	4952.5	18860.8	
15.0	16550.0	4543.6	23404.4	
16.0	16550.0	4168.4	27572.8	
17.0	16550.0	3824.3	31397.1	
18.0	16550.0	3508.5	34905.6	
19.0	16550.0	3218.8	38124.4	
20.0	16550.0	2953.0	41077.4	

Diyarbakir		i=11%		
years	Cash flow	PV	Balance	PB period
0.0			-110000.0	
1.0	16550.0	14909.9	-95090.1	
2.0	16550.0	13432.4	-81657.7	
3.0	16550.0	12101.2	-69556.5	
4.0	16550.0	10902.0	-58654.5	
5.0	16550.0	9821.6	-48832.9	
6.0	16550.0	8848.3	-39984.6	
7.0	16550.0	7971.4	-32013.2	
8.0	16550.0	7181.5	-24831.7	
9.0	16550.0	6469.8	-18361.9	
10.0	16550.0	5828.7	-12533.2	
11.0	16550.0	5251.0	-7282.2	
12.0	16550.0	4730.7	-2551.5	12.6
13.0	16550.0	4261.9	1710.4	
14.0	16550.0	3839.5	5549.9	
15.0	16550.0	3459.0	9008.9	
16.0	16550.0	3116.2	12125.1	
17.0	16550.0	2807.4	14932.5	
18.0	16550.0	2529.2	17461.8	
19.0	16550.0	2278.6	19740.3	
20.0	16550.0	2052.8	21793.1	

Diyarbakir		i=13%		
years	Cash flow	PV	Balance	PB period
0.0			-110000.0	
1.0	16550.0	14646.0	-95354.0	
2.0	16550.0	12961.1	-82392.9	
3.0	16550.0	11470.0	-70922.9	
4.0	16550.0	10150.4	-60772.5	
5.0	16550.0	8982.7	-51789.8	
6.0	16550.0	7949.3	-43840.6	
7.0	16550.0	7034.8	-36805.8	
8.0	16550.0	6225.4	-30580.4	
9.0	16550.0	5509.2	-25071.1	
10.0	16550.0	4875.4	-20195.7	
11.0	16550.0	4314.5	-15881.1	
12.0	16550.0	3818.2	-12062.9	
13.0	16550.0	3378.9	-8684.0	
14.0	16550.0	2990.2	-5693.8	
15.0	16550.0	2646.2	-3047.6	
16.0	16550.0	2341.8	-705.9	16.3
17.0	16550.0	2072.4	1366.5	
18.0	16550.0	1833.9	3200.4	
19.0	16550.0	1623.0	4823.4	
20.0	16550.0	1436.2	6259.6	

Diyarbakir		i=15%		
years	Cash flow	PV	Balance	PB period
0.0			-110000.0	
1.0	16550.0	14391.3	-95608.7	
2.0	16550.0	12514.2	-83094.5	
3.0	16550.0	10881.9	-72212.6	
4.0	16550.0	9462.5	-62750.1	
5.0	16550.0	8228.3	-54521.8	
6.0	16550.0	7155.0	-47366.8	
7.0	16550.0	6221.8	-41145.1	
8.0	16550.0	5410.2	-35734.8	
9.0	16550.0	4704.5	-31030.3	
10.0	16550.0	4090.9	-26939.4	
11.0	16550.0	3557.3	-23382.1	
12.0	16550.0	3093.3	-20288.8	
13.0	16550.0	2689.8	-17598.9	
14.0	16550.0	2339.0	-15259.9	
15.0	16550.0	2033.9	-13226.0	
16.0	16550.0	1768.6	-11457.4	
17.0	16550.0	1537.9	-9919.5	
18.0	16550.0	1337.3	-8582.2	
19.0	16550.0	1162.9	-7419.3	
20.0	16550.0	1011.2	-6408.1	

Diyarbakir	savings	i=7%		
years	Cash flow	PV	Balance	PB period
0.0			-88000.0	
1.0	16550.0	15467.3	-72532.7	
2.0	16550.0	14455.4	-58077.3	
3.0	16550.0	13509.7	-44567.6	
4.0	16550.0	12625.9	-31941.7	
5.0	16550.0	11799.9	-20141.7	
6.0	16550.0	11028.0	-9113.8	6.9
7.0	16550.0	10306.5	1192.7	
8.0	16550.0	9632.3	10825.0	
9.0	16550.0	9002.1	19827.1	
10.0	16550.0	8413.2	28240.3	
11.0	16550.0	7862.8	36103.1	
12.0	16550.0	7348.4	43451.5	
13.0	16550.0	6867.7	50319.1	
14.0	16550.0	6418.4	56737.5	
15.0	16550.0	5998.5	62736.0	
16.0	16550.0	5606.1	68342.0	
17.0	16550.0	5239.3	73581.3	
18.0	16550.0	4896.5	78477.9	
19.0	16550.0	4576.2	83054.1	
20.0	16550.0	4276.8	87330.9	

Diyarbakir		i=9%		
years	Cash flow	PV	Balance	PB period
0.0			-88000.0	
1.0	16550.0	15183.5	-72816.5	
2.0	16550.0	13929.8	-58886.7	
3.0	16550.0	12779.6	-46107.1	
4.0	16550.0	11724.4	-34382.6	
5.0	16550.0	10756.4	-23626.3	
6.0	16550.0	9868.2	-13758.0	
7.0	16550.0	9053.4	-4704.6	7.6
8.0	16550.0	8305.9	3601.3	
9.0	16550.0	7620.1	11221.3	
10.0	16550.0	6990.9	18212.2	
11.0	16550.0	6413.7	24625.9	
12.0	16550.0	5884.1	30510.0	
13.0	16550.0	5398.3	35908.3	
14.0	16550.0	4952.5	40860.8	
15.0	16550.0	4543.6	45404.4	
16.0	16550.0	4168.4	49572.8	
17.0	16550.0	3824.3	53397.1	
18.0	16550.0	3508.5	56905.6	
19.0	16550.0	3218.8	60124.4	
20.0	16550.0	2953.0	63077.4	

Diyarbakir		i=11%		
years	Cash flow	PV	Balance	PB period
0.0			-88000.0	
1.0	16550.0	14909.9	-73090.1	
2.0	16550.0	13432.4	-59657.7	
3.0	16550.0	12101.2	-47556.5	
4.0	16550.0	10902.0	-36654.5	
5.0	16550.0	9821.6	-26832.9	
6.0	16550.0	8848.3	-17984.6	
7.0	16550.0	7971.4	-10013.2	
8.0	16550.0	7181.5	-2831.7	8.4
9.0	16550.0	6469.8	3638.1	
10.0	16550.0	5828.7	9466.8	
11.0	16550.0	5251.0	14717.8	
12.0	16550.0	4730.7	19448.5	
13.0	16550.0	4261.9	23710.4	
14.0	16550.0	3839.5	27549.9	
15.0	16550.0	3459.0	31008.9	
16.0	16550.0	3116.2	34125.1	
17.0	16550.0	2807.4	36932.5	
18.0	16550.0	2529.2	39461.8	
19.0	16550.0	2278.6	41740.3	
20.0	16550.0	2052.8	43793.1	

Diyarbakir		i=13%		
years	Cash flow	PV	Balance	y back period
0.0			-88000.0	
1.0	16550.0	14646.0	-73354.0	
2.0	16550.0	12961.1	-60392.9	
3.0	16550.0	11470.0	-48922.9	
4.0	16550.0	10150.4	-38772.5	
5.0	16550.0	8982.7	-29789.8	
6.0	16550.0	7949.3	-21840.6	
7.0	16550.0	7034.8	-14805.8	
8.0	16550.0	6225.4	-8580.4	
9.0	16550.0	5509.2	-3071.1	9.6
10.0	16550.0	4875.4	1804.3	
11.0	16550.0	4314.5	6118.9	
12.0	16550.0	3818.2	9937.1	
13.0	16550.0	3378.9	13316.0	
14.0	16550.0	2990.2	16306.2	
15.0	16550.0	2646.2	18952.4	
16.0	16550.0	2341.8	21294.1	
17.0	16550.0	2072.4	23366.5	
18.0	16550.0	1833.9	25200.4	
19.0	16550.0	1623.0	26823.4	
20.0	16550.0	1436.2	28259.6	

Diyarbakir		i=15%		
years	Cash flow	PV	Balance	PB period
0.0			-88000.0	
1.0	16550.0	14391.3	-73608.7	
2.0	16550.0	12514.2	-61094.5	
3.0	16550.0	10881.9	-50212.6	
4.0	16550.0	9462.5	-40750.1	
5.0	16550.0	8228.3	-32521.8	
6.0	16550.0	7155.0	-25366.8	
7.0	16550.0	6221.8	-19145.1	
8.0	16550.0	5410.2	-13734.8	
9.0	16550.0	4704.5	-9030.3	
10.0	16550.0	4090.9	-4939.4	
11.0	16550.0	3557.3	-1382.1	11.4
12.0	16550.0	3093.3	1711.2	
13.0	16550.0	2689.8	4401.1	
14.0	16550.0	2339.0	6740.1	
15.0	16550.0	2033.9	8774.0	
16.0	16550.0	1768.6	10542.6	
17.0	16550.0	1537.9	12080.5	
18.0	16550.0	1337.3	13417.8	
19.0	16550.0	1162.9	14580.7	
20.0	16550.0	1011.2	15591.9	

Table A.2 : Payback time calculations of S3 and S4 with all average discount rates in Diyarbakir.

Diyarbakir	savings	i=7%		
years	Cash flow	PV	Balance	PB period
0.0			-66000.0	
1.0	16550.0	15467.3	-50532.7	
2.0	16550.0	14455.4	-36077.3	
3.0	16550.0	13509.7	-22567.6	
4.0	16550.0	12625.9	-9941.7	4.8
5.0	16550.0	11799.9	1858.3	
6.0	16550.0	11028.0	12886.2	
7.0	16550.0	10306.5	23192.7	
8.0	16550.0	9632.3	32825.0	
9.0	16550.0	9002.1	41827.1	
10.0	16550.0	8413.2	50240.3	
11.0	16550.0	7862.8	58103.1	
12.0	16550.0	7348.4	65451.5	
13.0	16550.0	6867.7	72319.1	
14.0	16550.0	6418.4	78737.5	
15.0	16550.0	5998.5	84736.0	
16.0	16550.0	5606.1	90342.0	
17.0	16550.0	5239.3	95581.3	
18.0	16550.0	4896.5	100477.9	
19.0	16550.0	4576.2	105054.1	
20.0	16550.0	4276.8	109330.9	

Diyarbakir		i=9%		
years	Cash flow	PV	Balance	PB period
0.0			-66000.0	
1.0	16550.0	15183.5	-50816.5	
2.0	16550.0	13929.8	-36886.7	
3.0	16550.0	12779.6	-24107.1	
4.0	16550.0	11724.4	-12382.6	
5.0	16550.0	10756.4	-1626.3	5.2
6.0	16550.0	9868.2	8242.0	
7.0	16550.0	9053.4	17295.4	
8.0	16550.0	8305.9	25601.3	
9.0	16550.0	7620.1	33221.3	
10.0	16550.0	6990.9	40212.2	
11.0	16550.0	6413.7	46625.9	
12.0	16550.0	5884.1	52510.0	
13.0	16550.0	5398.3	57908.3	
14.0	16550.0	4952.5	62860.8	
15.0	16550.0	4543.6	67404.4	
16.0	16550.0	4168.4	71572.8	
17.0	16550.0	3824.3	75397.1	
18.0	16550.0	3508.5	78905.6	
19.0	16550.0	3218.8	82124.4	
20.0	16550.0	2953.0	85077.4	

Diyarbakir		i=11%		
years	Cash flow	PV	Balance	PB period
0.0			-66000.0	
1.0	16550.0	14909.9	-51090.1	
2.0	16550.0	13432.4	-37657.7	
3.0	16550.0	12101.2	-25556.5	
4.0	16550.0	10902.0	-14654.5	
5.0	16550.0	9821.6	-4832.9	5.5
6.0	16550.0	8848.3	4015.4	
7.0	16550.0	7971.4	11986.8	
8.0	16550.0	7181.5	19168.3	
9.0	16550.0	6469.8	25638.1	
10.0	16550.0	5828.7	31466.8	
11.0	16550.0	5251.0	36717.8	
12.0	16550.0	4730.7	41448.5	
13.0	16550.0	4261.9	45710.4	
14.0	16550.0	3839.5	49549.9	
15.0	16550.0	3459.0	53008.9	
16.0	16550.0	3116.2	56125.1	
17.0	16550.0	2807.4	58932.5	
18.0	16550.0	2529.2	61461.8	
19.0	16550.0	2278.6	63740.3	
20.0	16550.0	2052.8	65793.1	

Diyarbakir		i=13%		
years	Cash flow	PV	Balance	PB period
0.0			-66000.0	
1.0	16550.0	14646.0	-51354.0	
2.0	16550.0	12961.1	-38392.9	
3.0	16550.0	11470.0	-26922.9	
4.0	16550.0	10150.4	-16772.5	
5.0	16550.0	8982.7	-7789.8	6.0
6.0	16550.0	7949.3	159.4	
7.0	16550.0	7034.8	7194.2	
8.0	16550.0	6225.4	13419.6	
9.0	16550.0	5509.2	18928.9	
10.0	16550.0	4875.4	23804.3	
11.0	16550.0	4314.5	28118.9	
12.0	16550.0	3818.2	31937.1	
13.0	16550.0	3378.9	35316.0	
14.0	16550.0	2990.2	38306.2	
15.0	16550.0	2646.2	40952.4	
16.0	16550.0	2341.8	43294.1	
17.0	16550.0	2072.4	45366.5	
18.0	16550.0	1833.9	47200.4	
19.0	16550.0	1623.0	48823.4	
20.0	16550.0	1436.2	50259.6	

Diyarbakir		i=15%		
years	Cash flow	PV	Balance	PB period
0.0			-66000.0	
1.0	16550.0	14391.3	-51608.7	
2.0	16550.0	12514.2	-39094.5	
3.0	16550.0	10881.9	-28212.6	
4.0	16550.0	9462.5	-18750.1	
5.0	16550.0	8228.3	-10521.8	
6.0	16550.0	7155.0	-3366.8	6.5
7.0	16550.0	6221.8	2854.9	
8.0	16550.0	5410.2	8265.2	
9.0	16550.0	4704.5	12969.7	
10.0	16550.0	4090.9	17060.6	
11.0	16550.0	3557.3	20617.9	
12.0	16550.0	3093.3	23711.2	
13.0	16550.0	2689.8	26401.1	
14.0	16550.0	2339.0	28740.1	
15.0	16550.0	2033.9	30774.0	
16.0	16550.0	1768.6	32542.6	
17.0	16550.0	1537.9	34080.5	
18.0	16550.0	1337.3	35417.8	
19.0	16550.0	1162.9	36580.7	
20.0	16550.0	1011.2	37591.9	

Diyarbakir	savings	i=7%		
years	Cash flow	PV	Balance	PB period
0.0			-44000.0	
1.0	16550.0	15467.3	-28532.7	
2.0	16550.0	14455.4	-14077.3	
3.0	16550.0	13509.7	-567.6	3.0
4.0	16550.0	12625.9	12058.3	
5.0	16550.0	11799.9	23858.3	
6.0	16550.0	11028.0	34886.2	
7.0	16550.0	10306.5	45192.7	
8.0	16550.0	9632.3	54825.0	
9.0	16550.0	9002.1	63827.1	
10.0	16550.0	8413.2	72240.3	
11.0	16550.0	7862.8	80103.1	
12.0	16550.0	7348.4	87451.5	
13.0	16550.0	6867.7	94319.1	
14.0	16550.0	6418.4	100737.5	
15.0	16550.0	5998.5	106736.0	
16.0	16550.0	5606.1	112342.0	
17.0	16550.0	5239.3	117581.3	
18.0	16550.0	4896.5	122477.9	
19.0	16550.0	4576.2	127054.1	
20.0	16550.0	4276.8	131330.9	

Diyarbakir		i=9%		
years	Cash flow	PV	Balance	PB period
0.0			-44000.0	
1.0	16550.0	15183.5	-28816.5	
2.0	16550.0	13929.8	-14886.7	
3.0	16550.0	12779.6	-2107.1	3.2
4.0	16550.0	11724.4	9617.4	
5.0	16550.0	10756.4	20373.7	
6.0	16550.0	9868.2	30242.0	
7.0	16550.0	9053.4	39295.4	
8.0	16550.0	8305.9	47601.3	
9.0	16550.0	7620.1	55221.3	
10.0	16550.0	6990.9	62212.2	
11.0	16550.0	6413.7	68625.9	
12.0	16550.0	5884.1	74510.0	
13.0	16550.0	5398.3	79908.3	
14.0	16550.0	4952.5	84860.8	
15.0	16550.0	4543.6	89404.4	
16.0	16550.0	4168.4	93572.8	
17.0	16550.0	3824.3	97397.1	
18.0	16550.0	3508.5	100905.6	
19.0	16550.0	3218.8	104124.4	
20.0	16550.0	2953.0	107077.4	

Diyarbakir		i=11%		
years	Cash flow	PV	Balance	PB period
0.0			-44000.0	
1.0	16550.0	14909.9	-29090.1	
2.0	16550.0	13432.4	-15657.7	
3.0	16550.0	12101.2	-3556.5	3.3
4.0	16550.0	10902.0	7345.5	
5.0	16550.0	9821.6	17167.1	
6.0	16550.0	8848.3	26015.4	
7.0	16550.0	7971.4	33986.8	
8.0	16550.0	7181.5	41168.3	
9.0	16550.0	6469.8	47638.1	
10.0	16550.0	5828.7	53466.8	
11.0	16550.0	5251.0	58717.8	
12.0	16550.0	4730.7	63448.5	
13.0	16550.0	4261.9	67710.4	
14.0	16550.0	3839.5	71549.9	
15.0	16550.0	3459.0	75008.9	
16.0	16550.0	3116.2	78125.1	
17.0	16550.0	2807.4	80932.5	
18.0	16550.0	2529.2	83461.8	
19.0	16550.0	2278.6	85740.3	
20.0	16550.0	2052.8	87793.1	

Diyarbakir		i=13%		
years	Cash flow	PV	Balance	PB period
0.0			-44000.0	
1.0	16550.0	14646.0	-29354.0	
2.0	16550.0	12961.1	-16392.9	
3.0	16550.0	11470.0	-4922.9	3.5
4.0	16550.0	10150.4	5227.5	
5.0	16550.0	8982.7	14210.2	
6.0	16550.0	7949.3	22159.4	
7.0	16550.0	7034.8	29194.2	
8.0	16550.0	6225.4	35419.6	
9.0	16550.0	5509.2	40928.9	
10.0	16550.0	4875.4	45804.3	
11.0	16550.0	4314.5	50118.9	
12.0	16550.0	3818.2	53937.1	
13.0	16550.0	3378.9	57316.0	
14.0	16550.0	2990.2	60306.2	
15.0	16550.0	2646.2	62952.4	
16.0	16550.0	2341.8	65294.1	
17.0	16550.0	2072.4	67366.5	
18.0	16550.0	1833.9	69200.4	
19.0	16550.0	1623.0	70823.4	
20.0	16550.0	1436.2	72259.6	

Diyarbakir		i=15%		
years	Cash flow	PV	Balance	PB period
0.0			-44000.0	
1.0	16550.0	14391.3	-29608.7	
2.0	16550.0	12514.2	-17094.5	
3.0	16550.0	10881.9	-6212.6	3.7
4.0	16550.0	9462.5	3249.9	
5.0	16550.0	8228.3	11478.2	
6.0	16550.0	7155.0	18633.2	
7.0	16550.0	6221.8	24854.9	
8.0	16550.0	5410.2	30265.2	
9.0	16550.0	4704.5	34969.7	
10.0	16550.0	4090.9	39060.6	
11.0	16550.0	3557.3	42617.9	
12.0	16550.0	3093.3	45711.2	
13.0	16550.0	2689.8	48401.1	
14.0	16550.0	2339.0	50740.1	
15.0	16550.0	2033.9	52774.0	
16.0	16550.0	1768.6	54542.6	
17.0	16550.0	1537.9	56080.5	
18.0	16550.0	1337.3	57417.8	
19.0	16550.0	1162.9	58580.7	
20.0	16550.0	1011.2	59591.9	

Table A.3 : Payback time calculations of S1 and S2 with all average discount rates in Antalya.

Antalya	savings	i=7%		
years	Cash flow	PV	Balance	PB period
0.0			-110000.0	
1.0	19870.0	18570.1	-91429.9	
2.0	19870.0	17355.2	-74074.7	
3.0	19870.0	16219.8	-57854.8	
4.0	19870.0	15158.7	-42696.1	
5.0	19870.0	14167.0	-28529.1	
6.0	19870.0	13240.2	-15288.9	
7.0	19870.0	12374.0	-2914.8	7.3
8.0	19870.0	11564.5	8649.7	
9.0	19870.0	10808.0	19457.7	
10.0	19870.0	10100.9	29558.6	
11.0	19870.0	9440.1	38998.7	
12.0	19870.0	8822.5	47821.2	
13.0	19870.0	8245.3	56066.5	
14.0	19870.0	7705.9	63772.4	
15.0	19870.0	7201.8	70974.3	
16.0	19870.0	6730.7	77704.9	
17.0	19870.0	6290.3	83995.2	
18.0	19870.0	5878.8	89874.1	
19.0	19870.0	5494.2	95368.3	
20.0	19870.0	5134.8	100503.1	

Antalya		i=9%		
years	Cash flow	PV	Balance	PB period
0.0			-110000.0	
1.0	19870.0	18229.4	-91770.6	
2.0	19870.0	16724.2	-75046.5	
3.0	19870.0	15343.3	-59703.2	
4.0	19870.0	14076.4	-45626.8	
5.0	19870.0	12914.1	-32712.6	
6.0	19870.0	11847.8	-20864.8	
7.0	19870.0	10869.6	-9995.2	
8.0	19870.0	9972.1	-23.1	8.0
9.0	19870.0	9148.7	9125.6	
10.0	19870.0	8393.3	17518.9	
11.0	19870.0	7700.3	25219.1	
12.0	19870.0	7064.5	32283.6	
13.0	19870.0	6481.2	38764.8	
14.0	19870.0	5946.0	44710.8	
15.0	19870.0	5455.1	50165.9	
16.0	19870.0	5004.7	55170.5	
17.0	19870.0	4591.4	59762.0	
18.0	19870.0	4212.3	63974.3	
19.0	19870.0	3864.5	67838.8	
20.0	19870.0	3545.4	71384.2	

Antalya		i=11%		
years	Cash flow	PV	Balance	PB period
0.0			-110000.0	
1.0	19870.0	17900.9	-92099.1	
2.0	19870.0	16126.9	-75972.2	
3.0	19870.0	14528.8	-61443.4	
4.0	19870.0	13089.0	-48354.4	
5.0	19870.0	11791.9	-36562.5	
6.0	19870.0	10623.3	-25939.2	
7.0	19870.0	9570.6	-16368.7	
8.0	19870.0	8622.1	-7746.5	9.0
9.0	19870.0	7767.7	21.1	
10.0	19870.0	6997.9	7019.0	
11.0	19870.0	6304.4	13323.5	
12.0	19870.0	5679.7	19003.1	
13.0	19870.0	5116.8	24119.9	
14.0	19870.0	4609.7	28729.7	
15.0	19870.0	4152.9	32882.6	
16.0	19870.0	3741.4	36623.9	
17.0	19870.0	3370.6	39994.5	
18.0	19870.0	3036.6	43031.1	
19.0	19870.0	2735.7	45766.8	
20.0	19870.0	2464.6	48231.3	

Antalya		i=13%		
years	Cash flow	PV	Balance	PB period
0.0			-110000.0	
1.0	19870.0	17584.1	-92415.9	
2.0	19870.0	15561.1	-76854.8	
3.0	19870.0	13770.9	-63083.9	
4.0	19870.0	12186.6	-50897.3	
5.0	19870.0	10784.6	-40112.6	
6.0	19870.0	9543.9	-30568.7	
7.0	19870.0	8446.0	-22122.7	
8.0	19870.0	7474.3	-14648.4	
9.0	19870.0	6614.4	-8034.0	
10.0	19870.0	5853.5	-2180.5	10.4
11.0	19870.0	5180.1	2999.5	
12.0	19870.0	4584.1	7583.6	
13.0	19870.0	4056.7	11640.4	
14.0	19870.0	3590.0	15230.4	
15.0	19870.0	3177.0	18407.5	
16.0	19870.0	2811.5	21219.0	
17.0	19870.0	2488.1	23707.1	
18.0	19870.0	2201.8	25908.9	
19.0	19870.0	1948.5	27857.4	
20.0	19870.0	1724.4	29581.8	

Antalya		i=15%		
years	Cash flow	PV	Balance	PB period
0.0			-110000.0	
1.0	19870.0	17278.3	-92721.7	
2.0	19870.0	15024.6	-77697.2	
3.0	19870.0	13064.8	-64632.3	
4.0	19870.0	11360.7	-53271.6	
5.0	19870.0	9878.9	-43392.7	
6.0	19870.0	8590.3	-34802.3	
7.0	19870.0	7469.9	-27332.5	
8.0	19870.0	6495.5	-20836.9	
9.0	19870.0	5648.3	-15188.6	
10.0	19870.0	4911.6	-10277.1	
11.0	19870.0	4270.9	-6006.1	
12.0	19870.0	3713.8	-2292.3	12.7
13.0	19870.0	3229.4	937.1	
14.0	19870.0	2808.2	3745.3	
15.0	19870.0	2441.9	6187.2	
16.0	19870.0	2123.4	8310.6	
17.0	19870.0	1846.4	10157.1	
18.0	19870.0	1605.6	11762.7	
19.0	19870.0	1396.2	13158.9	
20.0	19870.0	1214.1	14372.9	

Antalya	savings	i=7%		
years	Cash flow	PV	Balance	PB period
0.0			-88000.0	
1.0	19870.0	18570.1	-69429.9	
2.0	19870.0	17355.2	-52074.7	
3.0	19870.0	16219.8	-35854.8	
4.0	19870.0	15158.7	-20696.1	
5.0	19870.0	14167.0	-6529.1	5.5
6.0	19870.0	13240.2	6711.1	
7.0	19870.0	12374.0	19085.2	
8.0	19870.0	11564.5	30649.7	
9.0	19870.0	10808.0	41457.7	
10.0	19870.0	10100.9	51558.6	
11.0	19870.0	9440.1	60998.7	
12.0	19870.0	8822.5	69821.2	
13.0	19870.0	8245.3	78066.5	
14.0	19870.0	7705.9	85772.4	
15.0	19870.0	7201.8	92974.3	
16.0	19870.0	6730.7	99704.9	
17.0	19870.0	6290.3	105995.2	
18.0	19870.0	5878.8	111874.1	
19.0	19870.0	5494.2	117368.3	
20.0	19870.0	5134.8	122503.1	

Antalya		i=9%		
years	Cash flow	PV	Balance	PB period
0.0			-88000.0	
1.0	19870.0	18229.4	-69770.6	
2.0	19870.0	16724.2	-53046.5	
3.0	19870.0	15343.3	-37703.2	
4.0	19870.0	14076.4	-23626.8	
5.0	19870.0	12914.1	-10712.6	5.9
6.0	19870.0	11847.8	1135.2	
7.0	19870.0	10869.6	12004.8	
8.0	19870.0	9972.1	21976.9	
9.0	19870.0	9148.7	31125.6	
10.0	19870.0	8393.3	39518.9	
11.0	19870.0	7700.3	47219.1	
12.0	19870.0	7064.5	54283.6	
13.0	19870.0	6481.2	60764.8	
14.0	19870.0	5946.0	66710.8	
15.0	19870.0	5455.1	72165.9	
16.0	19870.0	5004.7	77170.5	
17.0	19870.0	4591.4	81762.0	
18.0	19870.0	4212.3	85974.3	
19.0	19870.0	3864.5	89838.8	
20.0	19870.0	3545.4	93384.2	

Antalya		i=11%		
years	Cash flow	PV	Balance	PB period
0.0			-88000.0	
1.0	19870.0	17900.9	-70099.1	
2.0	19870.0	16126.9	-53972.2	
3.0	19870.0	14528.8	-39443.4	
4.0	19870.0	13089.0	-26354.4	
5.0	19870.0	11791.9	-14562.5	
6.0	19870.0	10623.3	-3939.2	6.4
7.0	19870.0	9570.6	5631.3	
8.0	19870.0	8622.1	14253.5	
9.0	19870.0	7767.7	22021.1	
10.0	19870.0	6997.9	29019.0	
11.0	19870.0	6304.4	35323.5	
12.0	19870.0	5679.7	41003.1	
13.0	19870.0	5116.8	46119.9	
14.0	19870.0	4609.7	50729.7	
15.0	19870.0	4152.9	54882.6	
16.0	19870.0	3741.4	58623.9	
17.0	19870.0	3370.6	61994.5	
18.0	19870.0	3036.6	65031.1	
19.0	19870.0	2735.7	67766.8	
20.0	19870.0	2464.6	70231.3	

Antalya		i=13%		
years	Cash flow	PV	Balance	PB period
0.0			-88000.0	
1.0	19870.0	17584.1	-70415.9	
2.0	19870.0	15561.1	-54854.8	
3.0	19870.0	13770.9	-41083.9	
4.0	19870.0	12186.6	-28897.3	
5.0	19870.0	10784.6	-18112.6	
6.0	19870.0	9543.9	-8568.7	
7.0	19870.0	8446.0	-122.7	7.0
8.0	19870.0	7474.3	7351.6	
9.0	19870.0	6614.4	13966.0	
10.0	19870.0	5853.5	19819.5	
11.0	19870.0	5180.1	24999.5	
12.0	19870.0	4584.1	29583.6	
13.0	19870.0	4056.7	33640.4	
14.0	19870.0	3590.0	37230.4	
15.0	19870.0	3177.0	40407.5	
16.0	19870.0	2811.5	43219.0	
17.0	19870.0	2488.1	45707.1	
18.0	19870.0	2201.8	47908.9	
19.0	19870.0	1948.5	49857.4	
20.0	19870.0	1724.4	51581.8	

Antalya		i=15%		
years	Cash flow	PV	Balance	PB period
0.0			-88000.0	
1.0	19870.0	17278.3	-70721.7	
2.0	19870.0	15024.6	-55697.2	
3.0	19870.0	13064.8	-42632.3	
4.0	19870.0	11360.7	-31271.6	
5.0	19870.0	9878.9	-21392.7	
6.0	19870.0	8590.3	-12802.3	
7.0	19870.0	7469.9	-5332.5	7.8
8.0	19870.0	6495.5	1163.1	
9.0	19870.0	5648.3	6811.4	
10.0	19870.0	4911.6	11722.9	
11.0	19870.0	4270.9	15993.9	
12.0	19870.0	3713.8	19707.7	
13.0	19870.0	3229.4	22937.1	
14.0	19870.0	2808.2	25745.3	
15.0	19870.0	2441.9	28187.2	
16.0	19870.0	2123.4	30310.6	
17.0	19870.0	1846.4	32157.1	
18.0	19870.0	1605.6	33762.7	
19.0	19870.0	1396.2	35158.9	
20.0	19870.0	1214.1	36372.9	

Table A.4 : Payback time calculations of S3 and S4 with all average discount rates in Antalya.

Antalya	savings	i=7%		
years	Cash flow	PV	Balance	PB period
0.0			-66000.0	
1.0	19870.0	18570.1	-47429.9	
2.0	19870.0	17355.2	-30074.7	
3.0	19870.0	16219.8	-13854.8	3.9
4.0	19870.0	15158.7	1303.9	
5.0	19870.0	14167.0	15470.9	
6.0	19870.0	13240.2	28711.1	
7.0	19870.0	12374.0	41085.2	
8.0	19870.0	11564.5	52649.7	
9.0	19870.0	10808.0	63457.7	
10.0	19870.0	10100.9	73558.6	
11.0	19870.0	9440.1	82998.7	
12.0	19870.0	8822.5	91821.2	
13.0	19870.0	8245.3	100066.5	
14.0	19870.0	7705.9	107772.4	
15.0	19870.0	7201.8	114974.3	
16.0	19870.0	6730.7	121704.9	
17.0	19870.0	6290.3	127995.2	
18.0	19870.0	5878.8	133874.1	
19.0	19870.0	5494.2	139368.3	
20.0	19870.0	5134.8	144503.1	

Antalya		i=9%		
years	Cash flow	PV	Balance	PB period
0.0			-66000.0	
1.0	19870.0	18229.4	-47770.6	
2.0	19870.0	16724.2	-31046.5	
3.0	19870.0	15343.3	-15703.2	
4.0	19870.0	14076.4	-1626.8	4.1
5.0	19870.0	12914.1	11287.4	
6.0	19870.0	11847.8	23135.2	
7.0	19870.0	10869.6	34004.8	
8.0	19870.0	9972.1	43976.9	
9.0	19870.0	9148.7	53125.6	
10.0	19870.0	8393.3	61518.9	
11.0	19870.0	7700.3	69219.1	
12.0	19870.0	7064.5	76283.6	
13.0	19870.0	6481.2	82764.8	
14.0	19870.0	5946.0	88710.8	
15.0	19870.0	5455.1	94165.9	
16.0	19870.0	5004.7	99170.5	
17.0	19870.0	4591.4	103762.0	
18.0	19870.0	4212.3	107974.3	
19.0	19870.0	3864.5	111838.8	
20.0	19870.0	3545.4	115384.2	

Antalya		i=11%		
years	Cash flow	PV	Balance	PB period
0.0			-66000.0	
1.0	19870.0	17900.9	-48099.1	
2.0	19870.0	16126.9	-31972.2	
3.0	19870.0	14528.8	-17443.4	
4.0	19870.0	13089.0	-4354.4	4.4
5.0	19870.0	11791.9	7437.5	
6.0	19870.0	10623.3	18060.8	
7.0	19870.0	9570.6	27631.3	
8.0	19870.0	8622.1	36253.5	
9.0	19870.0	7767.7	44021.1	
10.0	19870.0	6997.9	51019.0	
11.0	19870.0	6304.4	57323.5	
12.0	19870.0	5679.7	63003.1	
13.0	19870.0	5116.8	68119.9	
14.0	19870.0	4609.7	72729.7	
15.0	19870.0	4152.9	76882.6	
16.0	19870.0	3741.4	80623.9	
17.0	19870.0	3370.6	83994.5	
18.0	19870.0	3036.6	87031.1	
19.0	19870.0	2735.7	89766.8	
20.0	19870.0	2464.6	92231.3	

Antalya		i=13%		
years	Cash flow	PV	Balance	PB period
0.0			-66000.0	
1.0	19870.0	17584.1	-48415.9	
2.0	19870.0	15561.1	-32854.8	
3.0	19870.0	13770.9	-19083.9	
4.0	19870.0	12186.6	-6897.3	4.6
5.0	19870.0	10784.6	3887.4	
6.0	19870.0	9543.9	13431.3	
7.0	19870.0	8446.0	21877.3	
8.0	19870.0	7474.3	29351.6	
9.0	19870.0	6614.4	35966.0	
10.0	19870.0	5853.5	41819.5	
11.0	19870.0	5180.1	46999.5	
12.0	19870.0	4584.1	51583.6	
13.0	19870.0	4056.7	55640.4	
14.0	19870.0	3590.0	59230.4	
15.0	19870.0	3177.0	62407.5	
16.0	19870.0	2811.5	65219.0	
17.0	19870.0	2488.1	67707.1	
18.0	19870.0	2201.8	69908.9	
19.0	19870.0	1948.5	71857.4	
20.0	19870.0	1724.4	73581.8	

Antalya		i=15%		
years	Cash flow	PV	Balance	PB period
0.0			-66000.0	
1.0	19870.0	17278.3	-48721.7	
2.0	19870.0	15024.6	-33697.2	
3.0	19870.0	13064.8	-20632.3	
4.0	19870.0	11360.7	-9271.6	4.9
5.0	19870.0	9878.9	607.3	
6.0	19870.0	8590.3	9197.7	
7.0	19870.0	7469.9	16667.5	
8.0	19870.0	6495.5	23163.1	
9.0	19870.0	5648.3	28811.4	
10.0	19870.0	4911.6	33722.9	
11.0	19870.0	4270.9	37993.9	
12.0	19870.0	3713.8	41707.7	
13.0	19870.0	3229.4	44937.1	
14.0	19870.0	2808.2	47745.3	
15.0	19870.0	2441.9	50187.2	
16.0	19870.0	2123.4	52310.6	
17.0	19870.0	1846.4	54157.1	
18.0	19870.0	1605.6	55762.7	
19.0	19870.0	1396.2	57158.9	
20.0	19870.0	1214.1	58372.9	

Antalya	savings	i=7%		
years	Cash flow	PV	Balance	PB period
0.0			-44000.0	
1.0	19870.0	18570.1	-25429.9	
2.0	19870.0	17355.2	-8074.7	2.5
3.0	19870.0	16219.8	8145.2	
4.0	19870.0	15158.7	23303.9	
5.0	19870.0	14167.0	37470.9	
6.0	19870.0	13240.2	50711.1	
7.0	19870.0	12374.0	63085.2	
8.0	19870.0	11564.5	74649.7	
9.0	19870.0	10808.0	85457.7	
10.0	19870.0	10100.9	95558.6	
11.0	19870.0	9440.1	104998.7	
12.0	19870.0	8822.5	113821.2	
13.0	19870.0	8245.3	122066.5	
14.0	19870.0	7705.9	129772.4	
15.0	19870.0	7201.8	136974.3	
16.0	19870.0	6730.7	143704.9	
17.0	19870.0	6290.3	149995.2	
18.0	19870.0	5878.8	155874.1	
19.0	19870.0	5494.2	161368.3	
20.0	19870.0	5134.8	166503.1	

Antalya		i=9%		
years	Cash flow	PV	Balance	PB period
0.0			-44000.0	
1.0	19870.0	18229.4	-25770.6	
2.0	19870.0	16724.2	-9046.5	2.6
3.0	19870.0	15343.3	6296.8	
4.0	19870.0	14076.4	20373.2	
5.0	19870.0	12914.1	33287.4	
6.0	19870.0	11847.8	45135.2	
7.0	19870.0	10869.6	56004.8	
8.0	19870.0	9972.1	65976.9	
9.0	19870.0	9148.7	75125.6	
10.0	19870.0	8393.3	83518.9	
11.0	19870.0	7700.3	91219.1	
12.0	19870.0	7064.5	98283.6	
13.0	19870.0	6481.2	104764.8	
14.0	19870.0	5946.0	110710.8	
15.0	19870.0	5455.1	116165.9	
16.0	19870.0	5004.7	121170.5	
17.0	19870.0	4591.4	125762.0	
18.0	19870.0	4212.3	129974.3	
19.0	19870.0	3864.5	133838.8	
20.0	19870.0	3545.4	137384.2	

Antalya		i=11%		
years	Cash flow	PV	Balance	PB period
0.0			-44000.0	
1.0	19870.0	17900.9	-26099.1	
2.0	19870.0	16126.9	-9972.2	2.7
3.0	19870.0	14528.8	4556.6	
4.0	19870.0	13089.0	17645.6	
5.0	19870.0	11791.9	29437.5	
6.0	19870.0	10623.3	40060.8	
7.0	19870.0	9570.6	49631.3	
8.0	19870.0	8622.1	58253.5	
9.0	19870.0	7767.7	66021.1	
10.0	19870.0	6997.9	73019.0	
11.0	19870.0	6304.4	79323.5	
12.0	19870.0	5679.7	85003.1	
13.0	19870.0	5116.8	90119.9	
14.0	19870.0	4609.7	94729.7	
15.0	19870.0	4152.9	98882.6	
16.0	19870.0	3741.4	102623.9	
17.0	19870.0	3370.6	105994.5	
18.0	19870.0	3036.6	109031.1	
19.0	19870.0	2735.7	111766.8	
20.0	19870.0	2464.6	114231.3	

Antalya		i=13%		
years	Cash flow	PV	Balance	PB period
0.0			-44000.0	
1.0	19870.0	17584.1	-26415.9	
2.0	19870.0	15561.1	-10854.8	2.8
3.0	19870.0	13770.9	2916.1	
4.0	19870.0	12186.6	15102.7	
5.0	19870.0	10784.6	25887.4	
6.0	19870.0	9543.9	35431.3	
7.0	19870.0	8446.0	43877.3	
8.0	19870.0	7474.3	51351.6	
9.0	19870.0	6614.4	57966.0	
10.0	19870.0	5853.5	63819.5	
11.0	19870.0	5180.1	68999.5	
12.0	19870.0	4584.1	73583.6	
13.0	19870.0	4056.7	77640.4	
14.0	19870.0	3590.0	81230.4	
15.0	19870.0	3177.0	84407.5	
16.0	19870.0	2811.5	87219.0	
17.0	19870.0	2488.1	89707.1	
18.0	19870.0	2201.8	91908.9	
19.0	19870.0	1948.5	93857.4	
20.0	19870.0	1724.4	95581.8	

Antalya		i=15%		
years	Cash flow	PV	Balance	PB period
0.0			-44000.0	
1.0	19870.0	17278.3	-26721.7	
2.0	19870.0	15024.6	-11697.2	2.9
3.0	19870.0	13064.8	1367.7	
4.0	19870.0	11360.7	12728.4	
5.0	19870.0	9878.9	22607.3	
6.0	19870.0	8590.3	31197.7	
7.0	19870.0	7469.9	38667.5	
8.0	19870.0	6495.5	45163.1	
9.0	19870.0	5648.3	50811.4	
10.0	19870.0	4911.6	55722.9	
11.0	19870.0	4270.9	59993.9	
12.0	19870.0	3713.8	63707.7	
13.0	19870.0	3229.4	66937.1	
14.0	19870.0	2808.2	69745.3	
15.0	19870.0	2441.9	72187.2	
16.0	19870.0	2123.4	74310.6	
17.0	19870.0	1846.4	76157.1	
18.0	19870.0	1605.6	77762.7	
19.0	19870.0	1396.2	79158.9	
20.0	19870.0	1214.1	80372.9	

TableA.5 : Payback time calculations of S1 and S2 with all average discount rates in Istanbul.

Istanbul	savings	i=7%		
years	Cash flow	PV	Balance	PB period
0.0			-110000.0	
1.0	11925.0	11144.9	-98855.1	
2.0	11925.0	10415.8	-88439.4	
3.0	11925.0	9734.4	-78705.0	
4.0	11925.0	9097.5	-69607.5	
5.0	11925.0	8502.4	-61105.1	
6.0	11925.0	7946.1	-53159.0	
7.0	11925.0	7426.3	-45732.7	
8.0	11925.0	6940.5	-38792.3	
9.0	11925.0	6486.4	-32305.9	
10.0	11925.0	6062.1	-26243.8	
11.0	11925.0	5665.5	-20578.3	
12.0	11925.0	5294.8	-15283.5	
13.0	11925.0	4948.5	-10335.0	
14.0	11925.0	4624.7	-5710.3	
15.0	11925.0	4322.2	-1388.1	15.3
16.0	11925.0	4039.4	2651.3	
17.0	11925.0	3775.1	6426.4	
18.0	11925.0	3528.2	9954.6	
19.0	11925.0	3297.4	13252.0	
20.0	11925.0	3081.6	16333.6	

Istanbul		i=9%		
years	Cash flow	PV	Balance	PB period
0.0			-110000.0	
1.0	11925.0	10940.4	-99059.6	
2.0	11925.0	10037.0	-89022.6	
3.0	11925.0	9208.3	-79814.3	
4.0	11925.0	8448.0	-71366.3	
5.0	11925.0	7750.4	-63615.9	
6.0	11925.0	7110.5	-56505.4	
7.0	11925.0	6523.4	-49982.0	
8.0	11925.0	5984.8	-43997.3	
9.0	11925.0	5490.6	-38506.7	
10.0	11925.0	5037.2	-33469.4	
11.0	11925.0	4621.3	-28848.1	
12.0	11925.0	4239.8	-24608.4	
13.0	11925.0	3889.7	-20718.7	
14.0	11925.0	3568.5	-17150.2	
15.0	11925.0	3273.9	-13876.3	
16.0	11925.0	3003.5	-10872.7	
17.0	11925.0	2755.5	-8117.2	
18.0	11925.0	2528.0	-5589.2	
19.0	11925.0	2319.3	-3269.9	
20.0	11925.0	2127.8	-1142.1	

Istanbul		i=11%		
years	Cash flow	PV	Balance	PB period
0.0			-110000.0	
1.0	11925.0	10743.2	-99256.8	
2.0	11925.0	9678.6	-89578.2	
3.0	11925.0	8719.5	-80858.7	
4.0	11925.0	7855.4	-73003.3	
5.0	11925.0	7076.9	-65926.4	
6.0	11925.0	6375.6	-59550.8	
7.0	11925.0	5743.8	-53807.1	
8.0	11925.0	5174.6	-48632.5	
9.0	11925.0	4661.8	-43970.7	
10.0	11925.0	4199.8	-39770.9	
11.0	11925.0	3783.6	-35987.3	
12.0	11925.0	3408.7	-32578.7	
13.0	11925.0	3070.9	-29507.8	
14.0	11925.0	2766.5	-26741.3	
15.0	11925.0	2492.4	-24248.9	
16.0	11925.0	2245.4	-22003.5	
17.0	11925.0	2022.9	-19980.6	
18.0	11925.0	1822.4	-18158.2	
19.0	11925.0	1641.8	-16516.4	
20.0	11925.0	1479.1	-15037.3	

Istanbul		i=13%		
years	Cash flow	PV	Balance	PB period
0.0			-110000.0	
1.0	11925.0	10553.1	-99446.9	
2.0	11925.0	9339.0	-90107.9	
3.0	11925.0	8264.6	-81843.3	
4.0	11925.0	7313.8	-74529.4	
5.0	11925.0	6472.4	-68057.0	
6.0	11925.0	5727.8	-62329.2	
7.0	11925.0	5068.8	-57260.4	
8.0	11925.0	4485.7	-52774.7	
9.0	11925.0	3969.7	-48805.0	
10.0	11925.0	3513.0	-45292.0	
11.0	11925.0	3108.8	-42183.2	
12.0	11925.0	2751.2	-39432.1	
13.0	11925.0	2434.7	-36997.4	
14.0	11925.0	2154.6	-34842.8	
15.0	11925.0	1906.7	-32936.1	
16.0	11925.0	1687.3	-31248.8	
17.0	11925.0	1493.2	-29755.6	
18.0	11925.0	1321.4	-28434.1	
19.0	11925.0	1169.4	-27264.7	
20.0	11925.0	1034.9	-26229.8	

Istanbul		i=15%		
years	Cash flow	PV	Balance	PB period
0.0			-110000.0	
1.0	11925.0	10369.6	-99630.4	
2.0	11925.0	9017.0	-90613.4	
3.0	11925.0	7840.9	-82772.5	
4.0	11925.0	6818.2	-75954.4	
5.0	11925.0	5928.8	-70025.6	
6.0	11925.0	5155.5	-64870.0	
7.0	11925.0	4483.0	-60387.0	
8.0	11925.0	3898.3	-56488.7	
9.0	11925.0	3389.8	-53098.9	
10.0	11925.0	2947.7	-50151.2	
11.0	11925.0	2563.2	-47588.0	
12.0	11925.0	2228.9	-45359.1	
13.0	11925.0	1938.1	-43421.0	
14.0	11925.0	1685.3	-41735.6	
15.0	11925.0	1465.5	-40270.1	
16.0	11925.0	1274.4	-38995.7	
17.0	11925.0	1108.1	-37887.6	
18.0	11925.0	963.6	-36924.0	
19.0	11925.0	837.9	-36086.1	
20.0	11925.0	728.6	-35357.5	

Istanbul	savings	i=7%		
years	Cash flow	PV	Balance	PB period
0.0			-88000.0	
1.0	11925.0	11144.9	-76855.1	
2.0	11925.0	10415.8	-66439.4	
3.0	11925.0	9734.4	-56705.0	
4.0	11925.0	9097.5	-47607.5	
5.0	11925.0	8502.4	-39105.1	
6.0	11925.0	7946.1	-31159.0	
7.0	11925.0	7426.3	-23732.7	
8.0	11925.0	6940.5	-16792.3	
9.0	11925.0	6486.4	-10305.9	
10.0	11925.0	6062.1	-4243.8	10.7
11.0	11925.0	5665.5	1421.7	
12.0	11925.0	5294.8	6716.5	
13.0	11925.0	4948.5	11665.0	
14.0	11925.0	4624.7	16289.7	
15.0	11925.0	4322.2	20611.9	
16.0	11925.0	4039.4	24651.3	
17.0	11925.0	3775.1	28426.4	
18.0	11925.0	3528.2	31954.6	
19.0	11925.0	3297.4	35252.0	
20.0	11925.0	3081.6	38333.6	

Istanbul		i=9%		
years	Cash flow	PV	Balance	PB period
0.0			-88000.0	
1.0	11925.0	10940.4	-77059.6	
2.0	11925.0	10037.0	-67022.6	
3.0	11925.0	9208.3	-57814.3	
4.0	11925.0	8448.0	-49366.3	
5.0	11925.0	7750.4	-41615.9	
6.0	11925.0	7110.5	-34505.4	
7.0	11925.0	6523.4	-27982.0	
8.0	11925.0	5984.8	-21997.3	
9.0	11925.0	5490.6	-16506.7	
10.0	11925.0	5037.2	-11469.4	
11.0	11925.0	4621.3	-6848.1	
12.0	11925.0	4239.8	-2608.4	12.7
13.0	11925.0	3889.7	1281.3	
14.0	11925.0	3568.5	4849.8	
15.0	11925.0	3273.9	8123.7	
16.0	11925.0	3003.5	11127.3	
17.0	11925.0	2755.5	13882.8	
18.0	11925.0	2528.0	16410.8	
19.0	11925.0	2319.3	18730.1	
20.0	11925.0	2127.8	20857.9	

Istanbul		i=11%		
years	Cash flow	PV	Balance	PB period
0.0			-88000.0	
1.0	11925.0	10743.2	-77256.8	
2.0	11925.0	9678.6	-67578.2	
3.0	11925.0	8719.5	-58858.7	
4.0	11925.0	7855.4	-51003.3	
5.0	11925.0	7076.9	-43926.4	
6.0	11925.0	6375.6	-37550.8	
7.0	11925.0	5743.8	-31807.1	
8.0	11925.0	5174.6	-26632.5	
9.0	11925.0	4661.8	-21970.7	
10.0	11925.0	4199.8	-17770.9	
11.0	11925.0	3783.6	-13987.3	
12.0	11925.0	3408.7	-10578.7	
13.0	11925.0	3070.9	-7507.8	
14.0	11925.0	2766.5	-4741.3	
15.0	11925.0	2492.4	-2248.9	
16.0	11925.0	2245.4	-3.5	16.0
17.0	11925.0	2022.9	2019.4	
18.0	11925.0	1822.4	3841.8	
19.0	11925.0	1641.8	5483.6	
20.0	11925.0	1479.1	6962.7	

Istanbul		i=13%		
years	Cash flow	PV	Balance	PB period
0.0			-88000.0	
1.0	11925.0	10553.1	-77446.9	
2.0	11925.0	9339.0	-68107.9	
3.0	11925.0	8264.6	-59843.3	
4.0	11925.0	7313.8	-52529.4	
5.0	11925.0	6472.4	-46057.0	
6.0	11925.0	5727.8	-40329.2	
7.0	11925.0	5068.8	-35260.4	
8.0	11925.0	4485.7	-30774.7	
9.0	11925.0	3969.7	-26805.0	
10.0	11925.0	3513.0	-23292.0	
11.0	11925.0	3108.8	-20183.2	
12.0	11925.0	2751.2	-17432.1	
13.0	11925.0	2434.7	-14997.4	
14.0	11925.0	2154.6	-12842.8	
15.0	11925.0	1906.7	-10936.1	
16.0	11925.0	1687.3	-9248.8	
17.0	11925.0	1493.2	-7755.6	
18.0	11925.0	1321.4	-6434.1	
19.0	11925.0	1169.4	-5264.7	
20.0	11925.0	1034.9	-4229.8	

Istanbul		i=15%		
years	Cash flow	PV	Balance	PB period
0.0			-88000.0	
1.0	11925.0	10369.6	-77630.4	
2.0	11925.0	9017.0	-68613.4	
3.0	11925.0	7840.9	-60772.5	
4.0	11925.0	6818.2	-53954.4	
5.0	11925.0	5928.8	-48025.6	
6.0	11925.0	5155.5	-42870.0	
7.0	11925.0	4483.0	-38387.0	
8.0	11925.0	3898.3	-34488.7	
9.0	11925.0	3389.8	-31098.9	
10.0	11925.0	2947.7	-28151.2	
11.0	11925.0	2563.2	-25588.0	
12.0	11925.0	2228.9	-23359.1	
13.0	11925.0	1938.1	-21421.0	
14.0	11925.0	1685.3	-19735.6	
15.0	11925.0	1465.5	-18270.1	
16.0	11925.0	1274.4	-16995.7	
17.0	11925.0	1108.1	-15887.6	
18.0	11925.0	963.6	-14924.0	
19.0	11925.0	837.9	-14086.1	
20.0	11925.0	728.6	-13357.5	

Table A.6 : Payback time calculations of S3 and S4 with all average discount rates in Istanbul.

Istanbul	savings	i=7%		
years	Cash flow	PV	Balance	PB period
0.0			-66000.0	
1.0	11925.0	11144.9	-54855.1	
2.0	11925.0	10415.8	-44439.4	
3.0	11925.0	9734.4	-34705.0	
4.0	11925.0	9097.5	-25607.5	
5.0	11925.0	8502.4	-17105.1	
6.0	11925.0	7946.1	-9159.0	
7.0	11925.0	7426.3	-1732.7	7.2
8.0	11925.0	6940.5	5207.7	
9.0	11925.0	6486.4	11694.1	
10.0	11925.0	6062.1	17756.2	
11.0	11925.0	5665.5	23421.7	
12.0	11925.0	5294.8	28716.5	
13.0	11925.0	4948.5	33665.0	
14.0	11925.0	4624.7	38289.7	
15.0	11925.0	4322.2	42611.9	
16.0	11925.0	4039.4	46651.3	
17.0	11925.0	3775.1	50426.4	
18.0	11925.0	3528.2	53954.6	
19.0	11925.0	3297.4	57252.0	
20.0	11925.0	3081.6	60333.6	

Istanbul		i=9%		
years	Cash flow	PV	Balance	PB period
0.0			-66000.0	
1.0	11925.0	10940.4	-55059.6	
2.0	11925.0	10037.0	-45022.6	
3.0	11925.0	9208.3	-35814.3	
4.0	11925.0	8448.0	-27366.3	
5.0	11925.0	7750.4	-19615.9	
6.0	11925.0	7110.5	-12505.4	
7.0	11925.0	6523.4	-5982.0	8.0
8.0	11925.0	5984.8	2.7	
9.0	11925.0	5490.6	5493.3	
10.0	11925.0	5037.2	10530.6	
11.0	11925.0	4621.3	15151.9	
12.0	11925.0	4239.8	19391.6	
13.0	11925.0	3889.7	23281.3	
14.0	11925.0	3568.5	26849.8	
15.0	11925.0	3273.9	30123.7	
16.0	11925.0	3003.5	33127.3	
17.0	11925.0	2755.5	35882.8	
18.0	11925.0	2528.0	38410.8	
19.0	11925.0	2319.3	40730.1	
20.0	11925.0	2127.8	42857.9	

Istanbul		i=11%		
years	Cash flow	PV	Balance	PB period
0.0			-66000.0	
1.0	11925.0	10743.2	-55256.8	
2.0	11925.0	9678.6	-45578.2	
3.0	11925.0	8719.5	-36858.7	
4.0	11925.0	7855.4	-29003.3	
5.0	11925.0	7076.9	-21926.4	
6.0	11925.0	6375.6	-15550.8	
7.0	11925.0	5743.8	-9807.1	
8.0	11925.0	5174.6	-4632.5	9.0
9.0	11925.0	4661.8	29.3	
10.0	11925.0	4199.8	4229.1	
11.0	11925.0	3783.6	8012.7	
12.0	11925.0	3408.7	11421.3	
13.0	11925.0	3070.9	14492.2	
14.0	11925.0	2766.5	17258.7	
15.0	11925.0	2492.4	19751.1	
16.0	11925.0	2245.4	21996.5	
17.0	11925.0	2022.9	24019.4	
18.0	11925.0	1822.4	25841.8	
19.0	11925.0	1641.8	27483.6	
20.0	11925.0	1479.1	28962.7	

Istanbul		i=13%		
years	Cash flow	PV	Balance	PB period
0.0			-66000.0	
1.0	11925.0	10553.1	-55446.9	
2.0	11925.0	9339.0	-46107.9	
3.0	11925.0	8264.6	-37843.3	
4.0	11925.0	7313.8	-30529.4	
5.0	11925.0	6472.4	-24057.0	
6.0	11925.0	5727.8	-18329.2	
7.0	11925.0	5068.8	-13260.4	
8.0	11925.0	4485.7	-8774.7	
9.0	11925.0	3969.7	-4805.0	
10.0	11925.0	3513.0	-1292.0	10.4
11.0	11925.0	3108.8	1816.8	
12.0	11925.0	2751.2	4567.9	
13.0	11925.0	2434.7	7002.6	
14.0	11925.0	2154.6	9157.2	
15.0	11925.0	1906.7	11063.9	
16.0	11925.0	1687.3	12751.2	
17.0	11925.0	1493.2	14244.4	
18.0	11925.0	1321.4	15565.9	
19.0	11925.0	1169.4	16735.3	
20.0	11925.0	1034.9	17770.2	

Istanbul		i=15%		
years	Cash flow	PV	Balance	PB period
0.0			-66000.0	
1.0	11925.0	10369.6	-55630.4	
2.0	11925.0	9017.0	-46613.4	
3.0	11925.0	7840.9	-38772.5	
4.0	11925.0	6818.2	-31954.4	
5.0	11925.0	5928.8	-26025.6	
6.0	11925.0	5155.5	-20870.0	
7.0	11925.0	4483.0	-16387.0	
8.0	11925.0	3898.3	-12488.7	
9.0	11925.0	3389.8	-9098.9	
10.0	11925.0	2947.7	-6151.2	
11.0	11925.0	2563.2	-3588.0	
12.0	11925.0	2228.9	-1359.1	12.7
13.0	11925.0	1938.1	579.0	
14.0	11925.0	1685.3	2264.4	
15.0	11925.0	1465.5	3729.9	
16.0	11925.0	1274.4	5004.3	
17.0	11925.0	1108.1	6112.4	
18.0	11925.0	963.6	7076.0	
19.0	11925.0	837.9	7913.9	
20.0	11925.0	728.6	8642.5	

Istanbul	savings	i=7%		
years	Cash flow	PV	Balance	PB period
0.0			-44000.0	
1.0	11925.0	11144.9	-32855.1	
2.0	11925.0	10415.8	-22439.4	
3.0	11925.0	9734.4	-12705.0	
4.0	11925.0	9097.5	-3607.5	4.4
5.0	11925.0	8502.4	4894.9	
6.0	11925.0	7946.1	12841.0	
7.0	11925.0	7426.3	20267.3	
8.0	11925.0	6940.5	27207.7	
9.0	11925.0	6486.4	33694.1	
10.0	11925.0	6062.1	39756.2	
11.0	11925.0	5665.5	45421.7	
12.0	11925.0	5294.8	50716.5	
13.0	11925.0	4948.5	55665.0	
14.0	11925.0	4624.7	60289.7	
15.0	11925.0	4322.2	64611.9	
16.0	11925.0	4039.4	68651.3	
17.0	11925.0	3775.1	72426.4	
18.0	11925.0	3528.2	75954.6	
19.0	11925.0	3297.4	79252.0	
20.0	11925.0	3081.6	82333.6	

Istanbul		i=9%		
years	Cash flow	PV	Balance	PB period
0.0			-44000.0	
1.0	11925.0	10940.4	-33059.6	
2.0	11925.0	10037.0	-23022.6	
3.0	11925.0	9208.3	-13814.3	
4.0	11925.0	8448.0	-5366.3	4.7
5.0	11925.0	7750.4	2384.1	
6.0	11925.0	7110.5	9494.6	
7.0	11925.0	6523.4	16018.0	
8.0	11925.0	5984.8	22002.7	
9.0	11925.0	5490.6	27493.3	
10.0	11925.0	5037.2	32530.6	
11.0	11925.0	4621.3	37151.9	
12.0	11925.0	4239.8	41391.6	
13.0	11925.0	3889.7	45281.3	
14.0	11925.0	3568.5	48849.8	
15.0	11925.0	3273.9	52123.7	
16.0	11925.0	3003.5	55127.3	
17.0	11925.0	2755.5	57882.8	
18.0	11925.0	2528.0	60410.8	
19.0	11925.0	2319.3	62730.1	
20.0	11925.0	2127.8	64857.9	

Istanbul		i=11%		
years	Cash flow	PV	Balance	PB period
0.0			-44000.0	
1.0	11925.0	10743.2	-33256.8	
2.0	11925.0	9678.6	-23578.2	
3.0	11925.0	8719.5	-14858.7	
4.0	11925.0	7855.4	-7003.3	5.0
5.0	11925.0	7076.9	73.6	
6.0	11925.0	6375.6	6449.2	
7.0	11925.0	5743.8	12192.9	
8.0	11925.0	5174.6	17367.5	
9.0	11925.0	4661.8	22029.3	
10.0	11925.0	4199.8	26229.1	
11.0	11925.0	3783.6	30012.7	
12.0	11925.0	3408.7	33421.3	
13.0	11925.0	3070.9	36492.2	
14.0	11925.0	2766.5	39258.7	
15.0	11925.0	2492.4	41751.1	
16.0	11925.0	2245.4	43996.5	
17.0	11925.0	2022.9	46019.4	
18.0	11925.0	1822.4	47841.8	
19.0	11925.0	1641.8	49483.6	
20.0	[illegible]	[illegible]	[illegible]	

Istanbul		i=13%		
years	Cash flow	PV	Balance	PB period
0.0			-44000.0	
1.0	11925.0	10553.1	-33446.9	
2.0	11925.0	9339.0	-24107.9	
3.0	11925.0	8264.6	-15843.3	
4.0	11925.0	7313.8	-8529.4	
5.0	11925.0	6472.4	-2057.0	5.4
6.0	11925.0	5727.8	3670.8	
7.0	11925.0	5068.8	8739.6	
8.0	11925.0	4485.7	13225.3	
9.0	11925.0	3969.7	17195.0	
10.0	11925.0	3513.0	20708.0	
11.0	11925.0	3108.8	23816.8	
12.0	11925.0	2751.2	26567.9	
13.0	11925.0	2434.7	29002.6	
14.0	11925.0	2154.6	31157.2	
15.0	11925.0	1906.7	33063.9	
16.0	11925.0	1687.3	34751.2	
17.0	11925.0	1493.2	36244.4	
18.0	11925.0	1321.4	37565.9	
19.0	11925.0	1169.4	38735.3	
[illegible]	[illegible]	[illegible]	[illegible]	

Payback time with different initial investment in variable different

Istanbul		i=15%		
years	Cash flow	PV	Balance	
0.0			-44000.0	PB period
1.0	11925.0	10369.6	-33630.4	
2.0	11925.0	9017.0	-24613.4	
3.0	11925.0	7840.9	-16772.5	
4.0	11925.0	6818.2	-9954.4	
5.0	11925.0	5928.8	-4025.6	5.8
6.0	11925.0	5155.5	1130.0	
7.0	11925.0	4483.0	5613.0	
8.0	11925.0	3898.3	9511.3	
9.0	11925.0	3389.8	12901.1	
10.0	11925.0	2947.7	15848.8	
11.0	11925.0	2563.2	18412.0	
12.0	11925.0	2228.9	20640.9	
13.0	11925.0	1938.1	22579.0	
14.0	11925.0	1685.3	24264.4	
15.0	11925.0	1465.5	25729.9	
16.0	11925.0	1274.4	27004.3	
17.0	11925.0	1108.1	28112.4	
18.0	11925.0	963.6	29076.0	
19.0	11925.0	837.9	29913.9	
20.0	11925.0	728.6	30642.5	

Table A.7 : Payback time calculations of S1 and S2 with all average discount rates in Ankara.

Ankara	savings	i=7%		
years	Cash flow	PV	Balance	PB period
0.0			-110000.0	
1.0	6715.0	6275.7	-103724.3	
2.0	6715.0	5865.1	-97859.2	
3.0	6715.0	5481.4	-92377.7	
4.0	6715.0	5122.8	-87254.9	
5.0	6715.0	4787.7	-82467.2	
6.0	6715.0	4474.5	-77992.7	
7.0	6715.0	4181.8	-73810.9	
8.0	6715.0	3908.2	-69902.7	
9.0	6715.0	3652.5	-66250.2	
10.0	6715.0	3413.6	-62836.6	
11.0	6715.0	3190.2	-59646.4	
12.0	6715.0	2981.5	-56664.9	
13.0	6715.0	2786.5	-53878.4	
14.0	6715.0	2604.2	-51274.2	
15.0	6715.0	2433.8	-48840.4	
16.0	6715.0	2274.6	-46565.8	
17.0	6715.0	2125.8	-44440.0	
18.0	6715.0	1986.7	-42453.2	
19.0	6715.0	1856.8	-40596.5	
20.0	6715.0	1735.3	-38861.2	

Ankara		i=9%		
years	Cash flow	PV	Balance	PB period
0.0			-110000.0	
1.0	6715.0	6160.6	-103839.4	
2.0	6715.0	5651.9	-98187.6	
3.0	6715.0	5185.2	-93002.4	
4.0	6715.0	4757.1	-88245.3	
5.0	6715.0	4364.3	-83881.0	
6.0	6715.0	4003.9	-79877.1	
7.0	6715.0	3673.3	-76203.7	
8.0	6715.0	3370.0	-72833.7	
9.0	6715.0	3091.8	-69741.9	
10.0	6715.0	2836.5	-66905.4	
11.0	6715.0	2602.3	-64303.1	
12.0	6715.0	2387.4	-61915.7	
13.0	6715.0	2190.3	-59725.4	
14.0	6715.0	2009.4	-57716.0	
15.0	6715.0	1843.5	-55872.5	
16.0	6715.0	1691.3	-54181.2	
17.0	6715.0	1551.7	-52629.5	
18.0	6715.0	1423.5	-51206.0	
19.0	6715.0	1306.0	-49900.0	
20.0	6715.0	1198.2	-48701.8	

Ankara		i=11%		
years	Cash flow	PV	Balance	PB period
0.0			-110000.0	
1.0	6715.0	6049.5	-103950.5	
2.0	6715.0	5450.0	-98500.4	
3.0	6715.0	4910.0	-93590.5	
4.0	6715.0	4423.4	-89167.1	
5.0	6715.0	3985.0	-85182.1	
6.0	6715.0	3590.1	-81591.9	
7.0	6715.0	3234.3	-78357.6	
8.0	6715.0	2913.8	-75443.8	
9.0	6715.0	2625.1	-72818.7	
10.0	6715.0	2364.9	-70453.8	
11.0	6715.0	2130.6	-68323.2	
12.0	6715.0	1919.4	-66403.8	
13.0	6715.0	1729.2	-64674.6	
14.0	6715.0	1557.8	-63116.8	
15.0	6715.0	1403.5	-61713.3	
16.0	6715.0	1264.4	-60448.9	
17.0	6715.0	1139.1	-59309.8	
18.0	6715.0	1026.2	-58283.6	
19.0	6715.0	924.5	-57359.1	
20.0	6715.0	832.9	-56526.3	

Ankara		i=13%		
years	Cash flow	PV	Balance	PB period
0.0			-110000.0	
1.0	6715.0	5942.5	-104057.5	
2.0	6715.0	5258.8	-98798.7	
3.0	6715.0	4653.8	-94144.9	
4.0	6715.0	4118.4	-90026.4	
5.0	6715.0	3644.6	-86381.8	
6.0	6715.0	3225.3	-83156.5	
7.0	6715.0	2854.3	-80302.2	
8.0	6715.0	2525.9	-77776.3	
9.0	6715.0	2235.3	-75540.9	
10.0	6715.0	1978.2	-73562.8	
11.0	6715.0	1750.6	-71812.2	
12.0	6715.0	1549.2	-70263.0	
13.0	6715.0	1371.0	-68892.0	
14.0	6715.0	1213.2	-67678.8	
15.0	6715.0	1073.7	-66605.1	
16.0	6715.0	950.1	-65655.0	
17.0	6715.0	840.8	-64814.1	
18.0	6715.0	744.1	-64070.0	
19.0	6715.0	658.5	-63411.5	
20.0	6715.0	582.7	-62828.8	

Ankara		i=15%		
years	Cash flow	PV	Balance	PB period
0.0			-110000.0	
1.0	6715.0	5839.1	-104160.9	
2.0	6715.0	5077.5	-99083.4	
3.0	6715.0	4415.2	-94668.1	
4.0	6715.0	3839.3	-90828.8	
5.0	6715.0	3338.5	-87490.3	
6.0	6715.0	2903.1	-84587.2	
7.0	6715.0	2524.4	-82062.8	
8.0	6715.0	2195.1	-79867.6	
9.0	6715.0	1908.8	-77958.8	
10.0	6715.0	1659.8	-76299.0	
11.0	6715.0	1443.3	-74855.6	
12.0	6715.0	1255.1	-73600.5	
13.0	6715.0	1091.4	-72509.2	
14.0	6715.0	949.0	-71560.1	
15.0	6715.0	825.2	-70734.9	
16.0	6715.0	717.6	-70017.3	
17.0	6715.0	624.0	-69393.3	
18.0	6715.0	542.6	-68850.7	
19.0	6715.0	471.8	-68378.9	
20.0	6715.0	410.3	-67968.6	

Ankara	savings	i=7%		
years	Cash flow	PV	Balance	PB period
0.0			-88000.0	
1.0	6715.0	6275.7	-81724.3	
2.0	6715.0	5865.1	-75859.2	
3.0	6715.0	5481.4	-70377.7	
4.0	6715.0	5122.8	-65254.9	
5.0	6715.0	4787.7	-60467.2	
6.0	6715.0	4474.5	-55992.7	
7.0	6715.0	4181.8	-51810.9	
8.0	6715.0	3908.2	-47902.7	
9.0	6715.0	3652.5	-44250.2	
10.0	6715.0	3413.6	-40836.6	
11.0	6715.0	3190.2	-37646.4	
12.0	6715.0	2981.5	-34664.9	
13.0	6715.0	2786.5	-31878.4	
14.0	6715.0	2604.2	-29274.2	
15.0	6715.0	2433.8	-26840.4	
16.0	6715.0	2274.6	-24565.8	
17.0	6715.0	2125.8	-22440.0	
18.0	6715.0	1986.7	-20453.2	
19.0	6715.0	1856.8	-18596.5	
20.0	6715.0	1735.3	-16861.2	

Ankara		i=9%		
years	Cash flow	PV	Balance	PB period
0.0			-88000.0	
1.0	6715.0	6160.6	-81839.4	
2.0	6715.0	5651.9	-76187.6	
3.0	6715.0	5185.2	-71002.4	
4.0	6715.0	4757.1	-66245.3	
5.0	6715.0	4364.3	-61881.0	
6.0	6715.0	4003.9	-57877.1	
7.0	6715.0	3673.3	-54203.7	
8.0	6715.0	3370.0	-50833.7	
9.0	6715.0	3091.8	-47741.9	
10.0	6715.0	2836.5	-44905.4	
11.0	6715.0	2602.3	-42303.1	
12.0	6715.0	2387.4	-39915.7	
13.0	6715.0	2190.3	-37725.4	
14.0	6715.0	2009.4	-35716.0	
15.0	6715.0	1843.5	-33872.5	
16.0	6715.0	1691.3	-32181.2	
17.0	6715.0	1551.7	-30629.5	
18.0	6715.0	1423.5	-29206.0	
19.0	6715.0	1306.0	-27900.0	
20.0	6715.0	1198.2	-26701.8	

Ankara		i=11%		
years	Cash flow	PV	Balance	PB period
0.0			-88000.0	
1.0	6715.0	6049.5	-81950.5	
2.0	6715.0	5450.0	-76500.4	
3.0	6715.0	4910.0	-71590.5	
4.0	6715.0	4423.4	-67167.1	
5.0	6715.0	3985.0	-63182.1	
6.0	6715.0	3590.1	-59591.9	
7.0	6715.0	3234.3	-56357.6	
8.0	6715.0	2913.8	-53443.8	
9.0	6715.0	2625.1	-50818.7	
10.0	6715.0	2364.9	-48453.8	
11.0	6715.0	2130.6	-46323.2	
12.0	6715.0	1919.4	-44403.8	
13.0	6715.0	1729.2	-42674.6	
14.0	6715.0	1557.8	-41116.8	
15.0	6715.0	1403.5	-39713.3	
16.0	6715.0	1264.4	-38448.9	
17.0	6715.0	1139.1	-37309.8	
18.0	6715.0	1026.2	-36283.6	
19.0	6715.0	924.5	-35359.1	
20.0	6715.0	832.9	-34526.3	

Ankara		i=13%		
years	Cash flow	PV	Balance	PB period
0.0			-88000.0	
1.0	6715.0	5942.5	-82057.5	
2.0	6715.0	5258.8	-76798.7	
3.0	6715.0	4653.8	-72144.9	
4.0	6715.0	4118.4	-68026.4	
5.0	6715.0	3644.6	-64381.8	
6.0	6715.0	3225.3	-61156.5	
7.0	6715.0	2854.3	-58302.2	
8.0	6715.0	2525.9	-55776.3	
9.0	6715.0	2235.3	-53540.9	
10.0	6715.0	1978.2	-51562.8	
11.0	6715.0	1750.6	-49812.2	
12.0	6715.0	1549.2	-48263.0	
13.0	6715.0	1371.0	-46892.0	
14.0	6715.0	1213.2	-45678.8	
15.0	6715.0	1073.7	-44605.1	
16.0	6715.0	950.1	-43655.0	
17.0	6715.0	840.8	-42814.1	
18.0	6715.0	744.1	-42070.0	
19.0	6715.0	658.5	-41411.5	
20.0	6715.0	582.7	-40828.8	

Ankara		i=15%		
years	Cash flow	PV	Balance	PB period
0.0			-88000.0	
1.0	6715.0	5839.1	-82160.9	
2.0	6715.0	5077.5	-77083.4	
3.0	6715.0	4415.2	-72668.1	
4.0	6715.0	3839.3	-68828.8	
5.0	6715.0	3338.5	-65490.3	
6.0	6715.0	2903.1	-62587.2	
7.0	6715.0	2524.4	-60062.8	
8.0	6715.0	2195.1	-57867.6	
9.0	6715.0	1908.8	-55958.8	
10.0	6715.0	1659.8	-54299.0	
11.0	6715.0	1443.3	-52855.6	
12.0	6715.0	1255.1	-51600.5	
13.0	6715.0	1091.4	-50509.2	
14.0	6715.0	949.0	-49560.1	
15.0	6715.0	825.2	-48734.9	
16.0	6715.0	717.6	-48017.3	
17.0	6715.0	624.0	-47393.3	
18.0	6715.0	542.6	-46850.7	
19.0	6715.0	471.8	-46378.9	
20.0	6715.0	410.3	-45968.6	

Table A.8 : Payback time calculations of S3 and S4 with all average discount rates in Ankara.

Ankara	savings	i=7%		
years	Cash flow	PV	Balance	PB period
0.0			-66000.0	
1.0	6715.0	6275.7	-59724.3	
2.0	6715.0	5865.1	-53859.2	
3.0	6715.0	5481.4	-48377.7	
4.0	6715.0	5122.8	-43254.9	
5.0	6715.0	4787.7	-38467.2	
6.0	6715.0	4474.5	-33992.7	
7.0	6715.0	4181.8	-29810.9	
8.0	6715.0	3908.2	-25902.7	
9.0	6715.0	3652.5	-22250.2	
10.0	6715.0	3413.6	-18836.6	
11.0	6715.0	3190.2	-15646.4	
12.0	6715.0	2981.5	-12664.9	
13.0	6715.0	2786.5	-9878.4	
14.0	6715.0	2604.2	-7274.2	
15.0	6715.0	2433.8	-4840.4	
16.0	6715.0	2274.6	-2565.8	
17.0	6715.0	2125.8	-440.0	17.2
18.0	6715.0	1986.7	1546.8	
19.0	6715.0	1856.8	3403.5	
20.0	6715.0	1735.3	5138.8	

Ankara		i=9%		
years	Cash flow	PV	Balance	PB period
0.0			-66000.0	
1.0	6715.0	6160.6	-59839.4	
2.0	6715.0	5651.9	-54187.6	
3.0	6715.0	5185.2	-49002.4	
4.0	6715.0	4757.1	-44245.3	
5.0	6715.0	4364.3	-39881.0	
6.0	6715.0	4003.9	-35877.1	
7.0	6715.0	3673.3	-32203.7	
8.0	6715.0	3370.0	-28833.7	
9.0	6715.0	3091.8	-25741.9	
10.0	6715.0	2836.5	-22905.4	
11.0	6715.0	2602.3	-20303.1	
12.0	6715.0	2387.4	-17915.7	
13.0	6715.0	2190.3	-15725.4	
14.0	6715.0	2009.4	-13716.0	
15.0	6715.0	1843.5	-11872.5	
16.0	6715.0	1691.3	-10181.2	
17.0	6715.0	1551.7	-8629.5	
18.0	6715.0	1423.5	-7206.0	
19.0	6715.0	1306.0	-5900.0	
20.0	6715.0	1198.2	-4701.8	

Ankara		i=11%		
years	Cash flow	PV	Balance	PB period
0.0			-66000.0	
1.0	6715.0	6049.5	-59950.5	
2.0	6715.0	5450.0	-54500.4	
3.0	6715.0	4910.0	-49590.5	
4.0	6715.0	4423.4	-45167.1	
5.0	6715.0	3985.0	-41182.1	
6.0	6715.0	3590.1	-37591.9	
7.0	6715.0	3234.3	-34357.6	
8.0	6715.0	2913.8	-31443.8	
9.0	6715.0	2625.1	-28818.7	
10.0	6715.0	2364.9	-26453.8	
11.0	6715.0	2130.6	-24323.2	
12.0	6715.0	1919.4	-22403.8	
13.0	6715.0	1729.2	-20674.6	
14.0	6715.0	1557.8	-19116.8	
15.0	6715.0	1403.5	-17713.3	
16.0	6715.0	1264.4	-16448.9	
17.0	6715.0	1139.1	-15309.8	
18.0	6715.0	1026.2	-14283.6	
19.0	6715.0	924.5	-13359.1	
20.0	6715.0	832.9	-12526.3	

Ankara		i=13%		
years	Cash flow	PV	Balance	PB period
0.0			-66000.0	
1.0	6715.0	5942.5	-60057.5	
2.0	6715.0	5258.8	-54798.7	
3.0	6715.0	4653.8	-50144.9	
4.0	6715.0	4118.4	-46026.4	
5.0	6715.0	3644.6	-42381.8	
6.0	6715.0	3225.3	-39156.5	
7.0	6715.0	2854.3	-36302.2	
8.0	6715.0	2525.9	-33776.3	
9.0	6715.0	2235.3	-31540.9	
10.0	6715.0	1978.2	-29562.8	
11.0	6715.0	1750.6	-27812.2	
12.0	6715.0	1549.2	-26263.0	
13.0	6715.0	1371.0	-24892.0	
14.0	6715.0	1213.2	-23678.8	
15.0	6715.0	1073.7	-22605.1	
16.0	6715.0	950.1	-21655.0	
17.0	6715.0	840.8	-20814.1	
18.0	6715.0	744.1	-20070.0	
19.0	6715.0	658.5	-19411.5	
20.0	6715.0	582.7	-18828.8	

Ankara		i=15%		
years	Cash flow	PV	Balance	PB period
0.0			-66000.0	
1.0	6715.0	5839.1	-60160.9	
2.0	6715.0	5077.5	-55083.4	
3.0	6715.0	4415.2	-50668.1	
4.0	6715.0	3839.3	-46828.8	
5.0	6715.0	3338.5	-43490.3	
6.0	6715.0	2903.1	-40587.2	
7.0	6715.0	2524.4	-38062.8	
8.0	6715.0	2195.1	-35867.6	
9.0	6715.0	1908.8	-33958.8	
10.0	6715.0	1659.8	-32299.0	
11.0	6715.0	1443.3	-30855.6	
12.0	6715.0	1255.1	-29600.5	
13.0	6715.0	1091.4	-28509.2	
14.0	6715.0	949.0	-27560.1	
15.0	6715.0	825.2	-26734.9	
16.0	6715.0	717.6	-26017.3	
17.0	6715.0	624.0	-25393.3	
18.0	6715.0	542.6	-24850.7	
19.0	6715.0	471.8	-24378.9	
20.0	6715.0	410.3	-23968.6	

Ankara	savings	i=7%		
years	Cash flow	PV	Balance	PB period
0.0			-44000.0	
1.0	6715.0	6275.7	-37724.3	
2.0	6715.0	5865.1	-31859.2	
3.0	6715.0	5481.4	-26377.7	
4.0	6715.0	5122.8	-21254.9	
5.0	6715.0	4787.7	-16467.2	
6.0	6715.0	4474.5	-11992.7	
7.0	6715.0	4181.8	-7810.9	
8.0	6715.0	3908.2	-3902.7	
9.0	6715.0	3652.5	-250.2	9.1
10.0	6715.0	3413.6	3163.4	
11.0	6715.0	3190.2	6353.6	
12.0	6715.0	2981.5	9335.1	
13.0	6715.0	2786.5	12121.6	
14.0	6715.0	2604.2	14725.8	
15.0	6715.0	2433.8	17159.6	
16.0	6715.0	2274.6	19434.2	
17.0	6715.0	2125.8	21560.0	
18.0	6715.0	1986.7	23546.8	
19.0	6715.0	1856.8	25403.5	
20.0	6715.0	1735.3	27138.8	

Ankara		i=9%		
years	Cash flow	PV	Balance	PB period
0.0			-44000.0	
1.0	6715.0	6160.6	-37839.4	
2.0	6715.0	5651.9	-32187.6	
3.0	6715.0	5185.2	-27002.4	
4.0	6715.0	4757.1	-22245.3	
5.0	6715.0	4364.3	-17881.0	
6.0	6715.0	4003.9	-13877.1	
7.0	6715.0	3673.3	-10203.7	
8.0	6715.0	3370.0	-6833.7	
9.0	6715.0	3091.8	-3741.9	
10.0	6715.0	2836.5	-905.4	10.3
11.0	6715.0	2602.3	1696.9	
12.0	6715.0	2387.4	4084.3	
13.0	6715.0	2190.3	6274.6	
14.0	6715.0	2009.4	8284.0	
15.0	6715.0	1843.5	10127.5	
16.0	6715.0	1691.3	11818.8	
17.0	6715.0	1551.7	13370.5	
18.0	6715.0	1423.5	14794.0	
19.0	6715.0	1306.0	16100.0	
20.0	6715.0	1198.2	17298.2	

Ankara		i=11%		
years	Cash flow	PV	Balance	PB period
0.0			-44000.0	
1.0	6715.0	6049.5	-37950.5	
2.0	6715.0	5450.0	-32500.4	
3.0	6715.0	4910.0	-27590.5	
4.0	6715.0	4423.4	-23167.1	
5.0	6715.0	3985.0	-19182.1	
6.0	6715.0	3590.1	-15591.9	
7.0	6715.0	3234.3	-12357.6	
8.0	6715.0	2913.8	-9443.8	
9.0	6715.0	2625.1	-6818.7	
10.0	6715.0	2364.9	-4453.8	
11.0	6715.0	2130.6	-2323.2	
12.0	6715.0	1919.4	-403.8	12.2
13.0	6715.0	1729.2	1325.4	
14.0	6715.0	1557.8	2883.2	
15.0	6715.0	1403.5	4286.7	
16.0	6715.0	1264.4	5551.1	
17.0	6715.0	1139.1	6690.2	
18.0	6715.0	1026.2	7716.4	
19.0	6715.0	924.5	8640.9	
20.0	6715.0	832.9	9473.7	

Ankara		i=13%		
years	Cash flow	PV	Balance	PB period
0.0			-44000.0	
1.0	6715.0	5942.5	-38057.5	
2.0	6715.0	5258.8	-32798.7	
3.0	6715.0	4653.8	-28144.9	
4.0	6715.0	4118.4	-24026.4	
5.0	6715.0	3644.6	-20381.8	
6.0	6715.0	3225.3	-17156.5	
7.0	6715.0	2854.3	-14302.2	
8.0	6715.0	2525.9	-11776.3	
9.0	6715.0	2235.3	-9540.9	
10.0	6715.0	1978.2	-7562.8	
11.0	6715.0	1750.6	-5812.2	
12.0	6715.0	1549.2	-4263.0	
13.0	6715.0	1371.0	-2892.0	
14.0	6715.0	1213.2	-1678.8	
15.0	6715.0	1073.7	-605.1	15.6
16.0	6715.0	950.1	345.0	
17.0	6715.0	840.8	1185.9	
18.0	6715.0	744.1	1930.0	
19.0	6715.0	658.5	2588.5	
20.0	6715.0	582.7	3171.2	

Ankara		i=15%		
years	Cash flow	PV	Balance	PB period
0.0			-44000.0	
1.0	6715.0	5839.1	-38160.9	
2.0	6715.0	5077.5	-33083.4	
3.0	6715.0	4415.2	-28668.1	
4.0	6715.0	3839.3	-24828.8	
5.0	6715.0	3338.5	-21490.3	
6.0	6715.0	2903.1	-18587.2	
7.0	6715.0	2524.4	-16062.8	
8.0	6715.0	2195.1	-13867.6	
9.0	6715.0	1908.8	-11958.8	
10.0	6715.0	1659.8	-10299.0	
11.0	6715.0	1443.3	-8855.6	
12.0	6715.0	1255.1	-7600.5	
13.0	6715.0	1091.4	-6509.2	
14.0	6715.0	949.0	-5560.1	
15.0	6715.0	825.2	-4734.9	
16.0	6715.0	717.6	-4017.3	
17.0	6715.0	624.0	-3393.3	
18.0	6715.0	542.6	-2850.7	
19.0	6715.0	471.8	-2378.9	
20.0	6715.0	410.3	-1968.6	

Table A.9 : Payback time calculations of S1 and S2 with all average discount rates in Erzurum.

Erzurum	savings	i=7%		
years	Cash flow	PV	Balance	PB period
0.0			-110000.0	
1.0	7085.0	6621.5	-103378.5	
2.0	7085.0	6188.3	-97190.2	
3.0	7085.0	5783.5	-91406.7	
4.0	7085.0	5405.1	-86001.6	
5.0	7085.0	5051.5	-80950.1	
6.0	7085.0	4721.0	-76229.1	
7.0	7085.0	4412.2	-71816.9	
8.0	7085.0	4123.5	-67693.4	
9.0	7085.0	3853.8	-63839.6	
10.0	7085.0	3601.7	-60237.9	
11.0	7085.0	3366.0	-56871.9	
12.0	7085.0	3145.8	-53726.1	
13.0	7085.0	2940.0	-50786.0	
14.0	7085.0	2747.7	-48038.4	
15.0	7085.0	2567.9	-45470.4	
16.0	7085.0	2399.9	-43070.5	
17.0	7085.0	2242.9	-40827.6	
18.0	7085.0	2096.2	-38731.4	
19.0	7085.0	1959.1	-36772.3	
20.0	7085.0	1830.9	-34941.4	

Erzurum		i=9%		
years	Cash flow	PV	Balance	PB period
0.0			-110000.0	
1.0	7085.0	6500.0	-103500.0	
2.0	7085.0	5963.3	-97536.7	
3.0	7085.0	5470.9	-92065.8	
4.0	7085.0	5019.2	-87046.6	
5.0	7085.0	4604.8	-82441.8	
6.0	7085.0	4224.6	-78217.3	
7.0	7085.0	3875.7	-74341.5	
8.0	7085.0	3555.7	-70785.8	
9.0	7085.0	3262.1	-67523.7	
10.0	7085.0	2992.8	-64530.9	
11.0	7085.0	2745.7	-61785.2	
12.0	7085.0	2519.0	-59266.3	
13.0	7085.0	2311.0	-56955.3	
14.0	7085.0	2120.2	-54835.1	
15.0	7085.0	1945.1	-52890.0	
16.0	7085.0	1784.5	-51105.5	
17.0	7085.0	1637.2	-49468.4	
18.0	7085.0	1502.0	-47966.4	
19.0	7085.0	1378.0	-46588.4	
20.0	7085.0	1264.2	-45324.3	

Erzurum		i=11%		
years	Cash flow	PV	Balance	PB period
0.0			-110000.0	
1.0	7085.0	6382.9	-103617.1	
2.0	7085.0	5750.3	-97866.8	
3.0	7085.0	5180.5	-92686.3	
4.0	7085.0	4667.1	-88019.2	
5.0	7085.0	4204.6	-83814.6	
6.0	7085.0	3787.9	-80026.6	
7.0	7085.0	3412.5	-76614.1	
8.0	7085.0	3074.4	-73539.7	
9.0	7085.0	2769.7	-70770.0	
10.0	7085.0	2495.2	-68274.8	
11.0	7085.0	2248.0	-66026.8	
12.0	7085.0	2025.2	-64001.7	
13.0	7085.0	1824.5	-62177.2	
14.0	7085.0	1643.7	-60533.5	
15.0	7085.0	1480.8	-59052.7	
16.0	7085.0	1334.1	-57718.6	
17.0	7085.0	1201.8	-56516.8	
18.0	7085.0	1082.7	-55434.0	
19.0	7085.0	975.4	-54458.6	
20.0	7085.0	878.8	-53579.8	

Erzurum		i=13%		
years	Cash flow	PV	Balance	PB period
0.0			-110000.0	
1.0	7085.0	6269.9	-103730.1	
2.0	7085.0	5548.6	-98181.5	
3.0	7085.0	4910.3	-93271.2	
4.0	7085.0	4345.4	-88925.9	
5.0	7085.0	3845.5	-85080.4	
6.0	7085.0	3403.1	-81677.4	
7.0	7085.0	3011.6	-78665.8	
8.0	7085.0	2665.1	-76000.7	
9.0	7085.0	2358.5	-73642.2	
10.0	7085.0	2087.2	-71555.1	
11.0	7085.0	1847.0	-69708.0	
12.0	7085.0	1634.6	-68073.5	
13.0	7085.0	1446.5	-66627.0	
14.0	7085.0	1280.1	-65346.9	
15.0	7085.0	1132.8	-64214.0	
16.0	7085.0	1002.5	-63211.5	
17.0	7085.0	887.2	-62324.4	
18.0	7085.0	785.1	-61539.3	
19.0	7085.0	694.8	-60844.5	
20.0	7085.0	614.9	-60229.6	

Erzurum		i=15%		
years	Cash flow	PV	Balance	PB period
0.0			-110000.0	
1.0	7085.0	6160.9	-103839.1	
2.0	7085.0	5357.3	-98481.9	
3.0	7085.0	4658.5	-93823.4	
4.0	7085.0	4050.9	-89772.5	
5.0	7085.0	3522.5	-86250.0	
6.0	7085.0	3063.0	-83186.9	
7.0	7085.0	2663.5	-80523.4	
8.0	7085.0	2316.1	-78207.3	
9.0	7085.0	2014.0	-76193.3	
10.0	7085.0	1751.3	-74442.0	
11.0	7085.0	1522.9	-72919.2	
12.0	7085.0	1324.2	-71594.9	
13.0	7085.0	1151.5	-70443.4	
14.0	7085.0	1001.3	-69442.1	
15.0	7085.0	870.7	-68571.4	
16.0	7085.0	757.1	-67814.2	
17.0	7085.0	658.4	-67155.9	
18.0	7085.0	572.5	-66583.4	
19.0	7085.0	497.8	-66085.5	
20.0	7085.0	432.9	-65652.6	

Erzurum	savings	i=7%		
years	Cash flow	PV	Balance	yback period
0.0			-88000.0	
1.0	7085.0	6621.5	-81378.5	
2.0	7085.0	6188.3	-75190.2	
3.0	7085.0	5783.5	-69406.7	
4.0	7085.0	5405.1	-64001.6	
5.0	7085.0	5051.5	-58950.1	
6.0	7085.0	4721.0	-54229.1	
7.0	7085.0	4412.2	-49816.9	
8.0	7085.0	4123.5	-45693.4	
9.0	7085.0	3853.8	-41839.6	
10.0	7085.0	3601.7	-38237.9	
11.0	7085.0	3366.0	-34871.9	
12.0	7085.0	3145.8	-31726.1	
13.0	7085.0	2940.0	-28786.0	
14.0	7085.0	2747.7	-26038.4	
15.0	7085.0	2567.9	-23470.4	
16.0	7085.0	2399.9	-21070.5	
17.0	7085.0	2242.9	-18827.6	
18.0	7085.0	2096.2	-16731.4	
19.0	7085.0	1959.1	-14772.3	
20.0	7085.0	1830.9	-12941.4	

Erzurum		i=9%		
years	Cash flow	PV	Balance	yback period
0.0			-88000.0	
1.0	7085.0	6500.0	-81500.0	
2.0	7085.0	5963.3	-75536.7	
3.0	7085.0	5470.9	-70065.8	
4.0	7085.0	5019.2	-65046.6	
5.0	7085.0	4604.8	-60441.8	
6.0	7085.0	4224.6	-56217.3	
7.0	7085.0	3875.7	-52341.5	
8.0	7085.0	3555.7	-48785.8	
9.0	7085.0	3262.1	-45523.7	
10.0	7085.0	2992.8	-42530.9	
11.0	7085.0	2745.7	-39785.2	
12.0	7085.0	2519.0	-37266.3	
13.0	7085.0	2311.0	-34955.3	
14.0	7085.0	2120.2	-32835.1	
15.0	7085.0	1945.1	-30890.0	
16.0	7085.0	1784.5	-29105.5	
17.0	7085.0	1637.2	-27468.4	
18.0	7085.0	1502.0	-25966.4	
19.0	7085.0	1378.0	-24588.4	
20.0	7085.0	1264.2	-23324.3	

Erzurum		i=11%		
years	Cash flow	PV	Balance	yback period
0.0			-88000.0	
1.0	7085.0	6382.9	-81617.1	
2.0	7085.0	5750.3	-75866.8	
3.0	7085.0	5180.5	-70686.3	
4.0	7085.0	4667.1	-66019.2	
5.0	7085.0	4204.6	-61814.6	
6.0	7085.0	3787.9	-58026.6	
7.0	7085.0	3412.5	-54614.1	
8.0	7085.0	3074.4	-51539.7	
9.0	7085.0	2769.7	-48770.0	
10.0	7085.0	2495.2	-46274.8	
11.0	7085.0	2248.0	-44026.8	
12.0	7085.0	2025.2	-42001.7	
13.0	7085.0	1824.5	-40177.2	
14.0	7085.0	1643.7	-38533.5	
15.0	7085.0	1480.8	-37052.7	
16.0	7085.0	1334.1	-35718.6	
17.0	7085.0	1201.8	-34516.8	
18.0	7085.0	1082.7	-33434.0	
19.0	7085.0	975.4	-32458.6	
20.0	7085.0	878.8	-31579.8	

Erzurum		i=13%		
years	Cash flow	PV	Balance	yback period
0.0			-88000.0	
1.0	7085.0	6269.9	-81730.1	
2.0	7085.0	5548.6	-76181.5	
3.0	7085.0	4910.3	-71271.2	
4.0	7085.0	4345.4	-66925.9	
5.0	7085.0	3845.5	-63080.4	
6.0	7085.0	3403.1	-59677.4	
7.0	7085.0	3011.6	-56665.8	
8.0	7085.0	2665.1	-54000.7	
9.0	7085.0	2358.5	-51642.2	
10.0	7085.0	2087.2	-49555.1	
11.0	7085.0	1847.0	-47708.0	
12.0	7085.0	1634.6	-46073.5	
13.0	7085.0	1446.5	-44627.0	
14.0	7085.0	1280.1	-43346.9	
15.0	7085.0	1132.8	-42214.0	
16.0	7085.0	1002.5	-41211.5	
17.0	7085.0	887.2	-40324.4	
18.0	7085.0	785.1	-39539.3	
19.0	7085.0	694.8	-38844.5	
20.0	7085.0	614.9	-38229.6	

Erzurum		i=15%		
years	Cash flow	PV	Balance	y back peri
0.0			-88000.0	
1.0	7085.0	6160.9	-81839.1	
2.0	7085.0	5357.3	-76481.9	
3.0	7085.0	4658.5	-71823.4	
4.0	7085.0	4050.9	-67772.5	
5.0	7085.0	3522.5	-64250.0	
6.0	7085.0	3063.0	-61186.9	
7.0	7085.0	2663.5	-58523.4	
8.0	7085.0	2316.1	-56207.3	
9.0	7085.0	2014.0	-54193.3	
10.0	7085.0	1751.3	-52442.0	
11.0	7085.0	1522.9	-50919.2	
12.0	7085.0	1324.2	-49594.9	
13.0	7085.0	1151.5	-48443.4	
14.0	7085.0	1001.3	-47442.1	
15.0	7085.0	870.7	-46571.4	
16.0	7085.0	757.1	-45814.2	
17.0	7085.0	658.4	-45155.9	
18.0	7085.0	572.5	-44583.4	
19.0	7085.0	497.8	-44085.5	
20.0	7085.0	432.9	-43652.6	

Table A.10 : Payback time calculations of S1 and S2 with all average discount rates in Erzurum.

Erzurum	savings	i=7%		
years	Cash flow	PV	Balance	y back period
0.0			-66000.0	
1.0	7085.0	6621.5	-59378.5	
2.0	7085.0	6188.3	-53190.2	
3.0	7085.0	5783.5	-47406.7	
4.0	7085.0	5405.1	-42001.6	
5.0	7085.0	5051.5	-36950.1	
6.0	7085.0	4721.0	-32229.1	
7.0	7085.0	4412.2	-27816.9	
8.0	7085.0	4123.5	-23693.4	
9.0	7085.0	3853.8	-19839.6	
10.0	7085.0	3601.7	-16237.9	
11.0	7085.0	3366.0	-12871.9	
12.0	7085.0	3145.8	-9726.1	
13.0	7085.0	2940.0	-6786.0	
14.0	7085.0	2747.7	-4038.4	
15.0	7085.0	2567.9	-1470.4	15.6
16.0	7085.0	2399.9	929.5	
17.0	7085.0	2242.9	3172.4	
18.0	7085.0	2096.2	5268.6	
19.0	7085.0	1959.1	7227.7	
20.0	7085.0	1830.9	9058.6	

Erzurum		i=9%		
years	Cash flow	PV	Balance	y back period
0.0			-66000.0	
1.0	7085.0	6500.0	-59500.0	
2.0	7085.0	5963.3	-53536.7	
3.0	7085.0	5470.9	-48065.8	
4.0	7085.0	5019.2	-43046.6	
5.0	7085.0	4604.8	-38441.8	
6.0	7085.0	4224.6	-34217.3	
7.0	7085.0	3875.7	-30341.5	
8.0	7085.0	3555.7	-26785.8	
9.0	7085.0	3262.1	-23523.7	
10.0	7085.0	2992.8	-20530.9	
11.0	7085.0	2745.7	-17785.2	
12.0	7085.0	2519.0	-15266.3	
13.0	7085.0	2311.0	-12955.3	
14.0	7085.0	2120.2	-10835.1	
15.0	7085.0	1945.1	-8890.0	
16.0	7085.0	1784.5	-7105.5	
17.0	7085.0	1637.2	-5468.4	
18.0	7085.0	1502.0	-3966.4	
19.0	7085.0	1378.0	-2588.4	
20.0	7085.0	1264.2	-1324.3	

Erzurum		i=11%		
years	Cash flow	PV	Balance	y back period
0.0			-66000.0	
1.0	7085.0	6382.9	-59617.1	
2.0	7085.0	5750.3	-53866.8	
3.0	7085.0	5180.5	-48686.3	
4.0	7085.0	4667.1	-44019.2	
5.0	7085.0	4204.6	-39814.6	
6.0	7085.0	3787.9	-36026.6	
7.0	7085.0	3412.5	-32614.1	
8.0	7085.0	3074.4	-29539.7	
9.0	7085.0	2769.7	-26770.0	
10.0	7085.0	2495.2	-24274.8	
11.0	7085.0	2248.0	-22026.8	
12.0	7085.0	2025.2	-20001.7	
13.0	7085.0	1824.5	-18177.2	
14.0	7085.0	1643.7	-16533.5	
15.0	7085.0	1480.8	-15052.7	
16.0	7085.0	1334.1	-13718.6	
17.0	7085.0	1201.8	-12516.8	
18.0	7085.0	1082.7	-11434.0	
19.0	7085.0	975.4	-10458.6	
20.0	7085.0	878.8	-9579.8	

Erzurum		i=13%		
years	Cash flow	PV	Balance	y back period
0.0			-66000.0	
1.0	7085.0	6269.9	-59730.1	
2.0	7085.0	5548.6	-54181.5	
3.0	7085.0	4910.3	-49271.2	
4.0	7085.0	4345.4	-44925.9	
5.0	7085.0	3845.5	-41080.4	
6.0	7085.0	3403.1	-37677.4	
7.0	7085.0	3011.6	-34665.8	
8.0	7085.0	2665.1	-32000.7	
9.0	7085.0	2358.5	-29642.2	
10.0	7085.0	2087.2	-27555.1	
11.0	7085.0	1847.0	-25708.0	
12.0	7085.0	1634.6	-24073.5	
13.0	7085.0	1446.5	-22627.0	
14.0	7085.0	1280.1	-21346.9	
15.0	7085.0	1132.8	-20214.0	
16.0	7085.0	1002.5	-19211.5	
17.0	7085.0	887.2	-18324.4	
18.0	7085.0	785.1	-17539.3	
19.0	7085.0	694.8	-16844.5	
20.0	7085.0	614.9	-16229.6	

Erzurum		i=15%		
years	Cash flow	PV	Balance	y back peri
0.0			-66000.0	
1.0	7085.0	6160.9	-59839.1	
2.0	7085.0	5357.3	-54481.9	
3.0	7085.0	4658.5	-49823.4	
4.0	7085.0	4050.9	-45772.5	
5.0	7085.0	3522.5	-42250.0	
6.0	7085.0	3063.0	-39186.9	
7.0	7085.0	2663.5	-36523.4	
8.0	7085.0	2316.1	-34207.3	
9.0	7085.0	2014.0	-32193.3	
10.0	7085.0	1751.3	-30442.0	
11.0	7085.0	1522.9	-28919.2	
12.0	7085.0	1324.2	-27594.9	
13.0	7085.0	1151.5	-26443.4	
14.0	7085.0	1001.3	-25442.1	
15.0	7085.0	870.7	-24571.4	
16.0	7085.0	757.1	-23814.2	
17.0	7085.0	658.4	-23155.9	
18.0	7085.0	572.5	-22583.4	
19.0	7085.0	497.8	-22085.5	
20.0	7085.0	432.9	-21652.6	

Erzurum	savings	i=7%		
years	Cash flow	PV	Balance	y back period
0.0			-44000.0	
1.0	7085.0	6621.5	-37378.5	
2.0	7085.0	6188.3	-31190.2	
3.0	7085.0	5783.5	-25406.7	
4.0	7085.0	5405.1	-20001.6	
5.0	7085.0	5051.5	-14950.1	
6.0	7085.0	4721.0	-10229.1	
7.0	7085.0	4412.2	-5816.9	
8.0	7085.0	4123.5	-1693.4	8.4
9.0	7085.0	3853.8	2160.4	
10.0	7085.0	3601.7	5762.1	
11.0	7085.0	3366.0	9128.1	
12.0	7085.0	3145.8	12273.9	
13.0	7085.0	2940.0	15214.0	
14.0	7085.0	2747.7	17961.6	
15.0	7085.0	2567.9	20529.6	
16.0	7085.0	2399.9	22929.5	
17.0	7085.0	2242.9	25172.4	
18.0	7085.0	2096.2	27268.6	
19.0	7085.0	1959.1	29227.7	
20.0	7085.0	1830.9	31058.6	

Erzurum		i=9%		
years	Cash flow	PV	Balance	y back period
0.0			-44000.0	
1.0	7085.0	6500.0	-37500.0	
2.0	7085.0	5963.3	-31536.7	
3.0	7085.0	5470.9	-26065.8	
4.0	7085.0	5019.2	-21046.6	
5.0	7085.0	4604.8	-16441.8	
6.0	7085.0	4224.6	-12217.3	
7.0	7085.0	3875.7	-8341.5	
8.0	7085.0	3555.7	-4785.8	
9.0	7085.0	3262.1	-1523.7	9.5
10.0	7085.0	2992.8	1469.1	
11.0	7085.0	2745.7	4214.8	
12.0	7085.0	2519.0	6733.7	
13.0	7085.0	2311.0	9044.7	
14.0	7085.0	2120.2	11164.9	
15.0	7085.0	1945.1	13110.0	
16.0	7085.0	1784.5	14894.5	
17.0	7085.0	1637.2	16531.6	
18.0	7085.0	1502.0	18033.6	
19.0	7085.0	1378.0	19411.6	
20.0	7085.0	1264.2	20675.7	

Erzurum		i=11%		
years	Cash flow	PV	Balance	y back period
0.0			-44000.0	
1.0	7085.0	6382.9	-37617.1	
2.0	7085.0	5750.3	-31866.8	
3.0	7085.0	5180.5	-26686.3	
4.0	7085.0	4667.1	-22019.2	
5.0	7085.0	4204.6	-17814.6	
6.0	7085.0	3787.9	-14026.6	
7.0	7085.0	3412.5	-10614.1	
8.0	7085.0	3074.4	-7539.7	
9.0	7085.0	2769.7	-4770.0	
10.0	7085.0	2495.2	-2274.8	
11.0	7085.0	2248.0	-26.8	11.0
12.0	7085.0	2025.2	1998.3	
13.0	7085.0	1824.5	3822.8	
14.0	7085.0	1643.7	5466.5	
15.0	7085.0	1480.8	6947.3	
16.0	7085.0	1334.1	8281.4	
17.0	7085.0	1201.8	9483.2	
18.0	7085.0	1082.7	10566.0	
19.0	7085.0	975.4	11541.4	
20.0	7085.0	878.8	12420.2	

Erzurum		i=13%		
years	Cash flow	PV	Balance	y back period
0.0			-44000.0	
1.0	7085.0	6269.9	-37730.1	
2.0	7085.0	5548.6	-32181.5	
3.0	7085.0	4910.3	-27271.2	
4.0	7085.0	4345.4	-22925.9	
5.0	7085.0	3845.5	-19080.4	
6.0	7085.0	3403.1	-15677.4	
7.0	7085.0	3011.6	-12665.8	
8.0	7085.0	2665.1	-10000.7	
9.0	7085.0	2358.5	-7642.2	
10.0	7085.0	2087.2	-5555.1	
11.0	7085.0	1847.0	-3708.0	
12.0	7085.0	1634.6	-2073.5	
13.0	7085.0	1446.5	-627.0	13.5
14.0	7085.0	1280.1	653.1	
15.0	7085.0	1132.8	1786.0	
16.0	7085.0	1002.5	2788.5	
17.0	7085.0	887.2	3675.6	
18.0	7085.0	785.1	4460.7	
19.0	7085.0	694.8	5155.5	
20.0	7085.0	614.9	5770.4	

Erzurum		i=15%		
years	Cash flow	PV	Balance	y back peri
0.0			-44000.0	
1.0	7085.0	6160.9	-37839.1	
2.0	7085.0	5357.3	-32481.9	
3.0	7085.0	4658.5	-27823.4	
4.0	7085.0	4050.9	-23772.5	
5.0	7085.0	3522.5	-20250.0	
6.0	7085.0	3063.0	-17186.9	
7.0	7085.0	2663.5	-14523.4	
8.0	7085.0	2316.1	-12207.3	
9.0	7085.0	2014.0	-10193.3	
10.0	7085.0	1751.3	-8442.0	
11.0	7085.0	1522.9	-6919.2	
12.0	7085.0	1324.2	-5594.9	
13.0	7085.0	1151.5	-4443.4	
14.0	7085.0	1001.3	-3442.1	
15.0	7085.0	870.7	-2571.4	
16.0	7085.0	757.1	-1814.2	
17.0	7085.0	658.4	-1155.9	
18.0	7085.0	572.5	-583.4	
19.0	7085.0	497.8	-85.5	19.2
20.0	7085.0	432.9	347.4	

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