BIOCLIMATIC INTERVENTIONS FOR REDUCING COOLING ENERGY DEMAND IN HOT AND HUMID CLIMATES

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

BURAK DÖNMEZ

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
BUILDING SCIENCE IN ARCHITECTURE

SEPTEMBER 2019

Approval of the thesis:

BIOCLIMATIC INTERVENTIONS FOR REDUCING COOLING ENERGY DEMAND IN HOT AND HUMID CLIMATES

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ABSTRACT

BIOCLIMATIC INTERVENTIONS FOR REDUCING COOLING ENERGY DEMAND IN HOT AND HUMID CLIMATES

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September 2019, 142 pages

While development of industry and science has been tremendous, population has also increased dramatically in the last centuries. As a consequence, unchecked consumption of energy mainly based on fossil fuels is the main culprit for triggering climate change worldwide. Meanwhile, an impressive amount of energy is being used for just cooling or heating the existing building stock. The need for energy can be reduced by adopting traditional bioclimatic measures that can be tested for their appropriateness through building performance simulations. To this end, collection and evaluation of empirical data through parametric design simulations can enable predictions about the adaptability and appropriateness of different bioclimatic interventions/features in different buildings in different climates. For instance, predictions about the impact of all or a combination of some interventions on energy performance of buildings may be helpful for optimizing the retrofit design. This approach was adopted to provide a design process where the parametric variations in the building design are made according to the building performance simulation outputs. The aim of this research was to determine, test, select and implement the most effective passive cooling strategies in retrofitting a local government building located in the hot and humid climate of Alanya, in Turkey. To realize this purpose, the municipality building was visited and observations were made regarding the current physical and thermal conditions and the cooling equipment used. The architectural drawings and relevant information were obtained in order to model the building and simulate it for its energy use, with the DesignBuilder software. Appropriate bioclimatic interventions were then integrated one by one and simulated for their impacts; and finally, the most efficient ones were integrated together to test their combined effect in reducing the cooling energy used. It was determined that by using bioclimatic measure to reduce the cooling energy demand, it was possible to achieve 70.23% savings in energy required to cool the building.

Keywords: Bioclimatic Interventions, Passive Cooling in Hot and Humid Climate, Energy Simulation, Sustainable Design, Alanya

ÖZ

SICAK VE NEMLİ İKLİMLERDE SOĞUTMA ENERJİSİ GEREKSİNİMLERİNİ AZALTMAK İÇİN YAPILAN BİYOİKLİMSEL MÜDAHALELER

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Yüksek Lisans, Yapı Bilimleri
Tez Danışmanı: Prof. Dr. Soofia Tahira Elias-Ozkan

Eylül 2019, 142 sayfa

Sanayi ve bilimdeki gelişmelerle birlikte , son yüzyılda nüfus da çarpıcı bir şekilde artmıştır. Bunun sonucu olarak, fosil yakıtlara dayanan kontrolsüz enerji tüketimi, dünyadaki iklim değişikliğinin temelini oluşturmaktadır. Aynı zamanda, mevcut yapıların ısıtılması ve soğutulması için harcanan enerji de ciddi miktarlara ulaşmıştır. Yapılarda ihtiyaç duyulan enerji miktarı, biyoiklimsel önlemler alınarak ve bina performans simülasyonları ile uygunlukları test edilerek azaltılabilir. Bu yöntemler kullanılarak, ampirik verilerin parametrik tasarım simülasyonları ile toplanması ve değerlendirilmesi sonucunda farklı iklimlerde farklı binalardaki farklı biyoiklimsel müdahalelerin/ özelliklerin uygulanabilirliği hakkında öngörüler elde edilebilir. Örnek olarak, binaların enerji performansına etki edecek müdahalelerin farklı kombinasyonlarıyla elde edilen tahminler, binaların iyileştirme çalışmalarını optimize etmede yardımcı olabilir. Bu yaklaşım, bina tasarımındaki parametrik değişikliklerin bina performans simülasyon çıktılarına göre yapıldığı bir tasarım süreci sağlamak için hayata geçirilmiştir. Bu çalışmanın amacı, sıcak ve nemli iklimde bulunan Alanya belediye binasının, enerji performansının iyileştirmesinde kullanılacak en etkili pasif soğutma stratejilerini belirlemek, test etmek, kararlaştırmak ve uygulamaktır. Bu amacı gerçekleştirmek adına, belediye binasına gidilip, yapının mevcut fiziki ve ısıl durumuyla ve yapıda kullanılan soğutma ekipmanlarıyla ilgili gözlemler yapılmıştır. DesignBuilder yazılımı ile binayı modellemek ve enerji performansını simüle etmek amacıyla, yapıyla ilgili bilgiler ve mimari çizimler toplanmıştır. Öncelikle, uygun biyoiklimsel müdahaleler ayrı ayrı yapıya entegre edilip, etkilerini gözlemlemek için simüle edilmiştir; ve son olarak da, en verimli sonucu veren müdahaleler, yapıda kullanılan soğutma enerjisini azaltmadaki etiklerini test etmek için bir araya getirilmişlerdir. Soğutma enerjisi talebini azaltmak için kullanılan biyoiklimsel müdahalelerin, binanın soğutulması için gereken enerjide %70,23 tasarruf sağladıkları tespit edilmiştir.

Anahtar Kelimeler: Biyoiklimsel Müdahaleler, Sıcak ve Nemli İklimlerdeki Pasif Soğutma Stratejileri, Enerji Simülasyonu, Sürdürülebilir Tasarım, Alanya

To My Family - Gülşen, Kamil, Burcu, Ali Engin, and Gözde

ACKNOWLEDGEMENTS

This thesis was funded by TUBITAK grant no 116M030 and it presents a part of the research conducted for the ERA-NET Co-Fund Project called “Smart bioclimatic low-carbon urban areas as innovative energy isles in the sustainable city”.

I would like to owe my deepest gratitude to my supervisor, Prof. Dr. Soofia Tahira Elias- Ozkan, not only for giving the opportunity to study with her, but also for her comments, criticism, trust and valuable support. Without her contribution, this study could not be accomplished. Because of that, my appreciation to her can never be enough.

I would like to thank to all academicians of Faculty of Architecture at METU for endless support since the first day I started the department.

Additionally, I would like to thank to Prof. Dr. Tayyibe Nur Çağlar, and Asst. Prof. Murat Sönmez, who are the academicians at TOBB University, for their guidance and contributions to shape my understanding and point of view related to my academic career.

I would like to thank to all members of my family, for their endless love, support, and encouragement.

I am grateful to my friends, Mustafa Eren Bük, Melih Akca, Ezgi Atçakan Akca, Jülide Arzu Uluçay, Burak Akpınar, Berk Yaşyerli, Seren Oğuz, and Mehmet Taşkıran who have always supported me not only in the process of this study but also in the period of my education and life.

Lastly, I would like to express my special thanks to my dear wife Gözde Bulut Dönmez for her endless support, encouragement, and guidance by her intelligence, patience, understanding, joy, friendship and love. Without her, I could not have completed this study.

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LIST OF ABBREVIATIONS

BPS	Building Performance Simulation
COP	Coefficient of Performance
EBD	Evidence Based Design
HVAC	Heating, Ventilating, and Air Conditioning
ISO	International Organization for Standardization
KWH	Kilowatt hour
MCA	Michael Collins Associates
PV	Photovoltaic Panels
SCOP	Seasonal Coefficient of Performance
TUBITAK	The Scientific and Technological Research Council of Turkey

CHAPTER 1

INTRODUCTION

This study examines the decrease in cooling energy demands of buildings in hot and humid climates by applying bioclimatic interventions. In this chapter, the argument for and the objectives of the study, and its procedure are explained. The chapter is concluded with the disposition of contents in this thesis.

1.1. Argument

Mankind had a sustainable lifestyle by using local resources and agriculture until the industrial revolution. After the industrial revolution, fossil fuels have been used for almost every industrial production (Bovill, 2015). With the rapid growth of industry and technology, population has also increased dramatically in the last centuries. For instance, population bounced from 1 billion to 7 billion between the years 1800 and 2010. Since production per person has been increasing, resources in the ecosystem of the earth will not be sufficient. The use of fossil fuels as energy for production has, in turn, increased the carbon dioxide levels in the atmosphere greatly, which has resulted in a situation that has a high potential to speed up climate change.

Sustainable projects, carried out considering bioclimatic interventions have become important in recent years. According to Greenspace (2011), which is a non-profit organization, designing and constructing sustainable building gives the tools to create high-performing, healthy homes and communities. Sustainable design considerations should be involved in every stage of the design and construction process and create opportunities for each member of the development team to come up with a better building. Working through a collaborative process with the whole team is essential to making the most appropriate decisions. For new construction, the building orientation to take advantage of sun and wind, efficient space planning, appropriate systems selection and sizing, and tight building envelopes are the best practices of sustainable design. By applying these design principles, initial and long-term operating costs can be lowered, even in existing buildings. For instance, it is possible to optimize whole building performance by coordinating window replacement with an upgrade to a high-efficiency, correctly-sized mechanical system, energy efficient appliances and HVAC systems, water saving devices and landscaping, and use of nontoxic materials to improve the quality of life for the occupants. Moreover, by eliminating waste through recycling, purchasing materials from local sources, and minimizing storm water runoff, the buildings become sustainable and adapt to surrounding environment and the planet (Greenspace, 2011). This approach is the basis of bioclimatic architecture.

According to Erkinay and Erten (2010), with the increase in population and industrialization in Turkey, energy use and environmental pollution has been increased and has reached dangerous dimensions. The energy use for heating per unit in Turkey is 50% more than Germany, 60% more than USA, and 73% more than Sweden. These figures demonstrate the necessity to construct buildings more consciously. While the rate of increase in the energy consumption per capita is considered to be a positive indicator for development, the increase of energy use shows that energy consumed should be reduced not only for economy but also for a healthy life. Reducing the energy usage intensity in the short and medium term can only be achieved by adopting energy efficient bioclimatic design principles.

On the other hand, there are some obstacles and reasons why bioclimatic buildings are not widespread and are not usually built instead of current conventional buildings. In order to promote bioclimatic architecture, informing and persuading both clients and contractors in the pre-design stage can help overcome some of these problems. In order to make them realize the need for bioclimatic design, empirical data and predictions about different features of buildings are very important. For instance, predictions about performance of buildings such as indoor thermal comfort, energy usage for cooling and heating, etc. may be helpful for optimizing design. Moreover, being aware of buildings costs while planning for the building use period, and also comparing the running costs for conventional buildings versus bioclimatic buildings may help to understand and select the one which is more economical and also more comfortable for the occupants.

On the other hand, Brophy and Lewis (2011) point out that although occupants prefer designs which are environmentally friendly and cost efficient for building maintenance, contractors or investors prefer to lower the cost for investments as much as possible. Hence, it is very difficult to convince the client to agree to the integration of sustainable and bioclimatic architecture principles. For instance, project owners who are also occupants gain better awareness of eco-friendly designs and their outputs and benefits in the long term. Besides that, some contractors want to get their investment back immediately. This situation directly affects the initial budget of the project. Therefore, architects have to face and overcome not only the design and construction issues but also relations between the consultants and clients who may be builders and/or owners.

Ken Yeang (2010) states that one of the most important issues of today's architecture is designing sustainable future. Ecological strategies, production systems, materials and processes facilitate and organize the spread and implementation of sustainability. These strategies should be implemented not only for the rating systems such as LEED and BREAM, but also for application of sustainable thinking and for spreading to the wider public.

The main issues while designing sustainable buildings are informing and persuading both clients and contractors in the pre-design stage. In order to realize that, numerical data and predictions about different features of buildings are very important. For instance, being aware of building costs during building utilization period and comparing the costs between conventional building and bioclimatic building may help to understand and choose which one is better and more comfortable.

The architect has a key role in putting sustainable design into practice. That is, the architect can function as a bridge between the design and its application. Besides that, showing that the cost will be reduced in time and informing and convincing clients and design team about environmental aspects which are the important and necessary for a sustainable design may also aid the architect for applying the environmentally-conscious design. In the pre-design stage, climate and location features are the key factors for the relation between the design and context; while, building size and usage are other factors for design. Climate is one the basic parameters that shape the building and structure. In the historical process, social, economic and political influences have always been variable and have affected the aesthetic perception of the buildings. However, as can be seen from human experiences and production in this historical process, climatic adaptation has been the basic architectural principle. Therefore, bioclimatic influences should be a guideline when creating the form of the structure, not the dogmas that shape the design. In other words, these all affect the energy performance and requirement of buildings (Yeang. 1994). That is, energy usage for cooling and heating is directly related to orientation, daylight penetration, ventilation, material selection and insulation of building. Thus, although the design process is related to different aspects, architect should manage and take into account all of these in the early design stage and also inform the client or investor about outputs of the sustainable design (Brophy & Lewis, 2011).

1.2. Aim and Objectives

The aim of the research is renovating existing buildings in hot-humid climate to reduce energy consumption for cooling by employing bioclimatic design principles, such as controlling the sunlight by using shading devices, choosing appropriate material for finishing and insulation, using natural ventilation and passive cooling systems, and finally, checking these interventions with an energy simulation software. The objective is to adopt a design process where the variations in the building design are made according to the building performance simulation outputs; such that, these decisions and simulation results can guide architects, clients and contractors in realizing buildings designed regarding to bioclimatic principles.

To investigate these objectives, the research questions needing answers are listed below:

- Which bioclimatic interventions can be used for reducing energy demand by improving thermal comfort in existing buildings?
- How can an existing building be renovated by considering these bioclimatic interventions?
- What are the traditional passive design methods for hot and humid climate?
- How can natural ventilation and passive cooling be provided in hot and humid climate?
- How can natural ventilation and passive cooling strategies be integrated easily and effectively in existing buildings?
- Which bioclimatic interventions can be used for reducing energy demand by improving thermal comfort in existing buildings?

1.3. Procedure

In this thesis, passive cooling principles used for bioclimatic architecture in hot and humid climate are examined. To demonstrate how these principles can be effective in improving thermal comfort and thus reducing cooling energy loads, the municipality building in Alanya was selected as a case study. Accordingly, bioclimatic interventions in renovating the building were applied, evaluated and tested virtually by using an energy simulation software.

Firstly, the microclimate of the existing municipality building was studied. After that, the deficiencies of the building in terms of climatic behavior were determined. The architectural drawings of the building were obtained, and the building was modelled by using Design Builder software. The building was renovated by applying bioclimatic interventions to the virtual model, i.e., improving the building envelope and promoting natural ventilation.

Finally, after the simulation of existing and renovated situations, the effects of the different interventions on the energy consumption were tested and compared.

1.4. Disposition

This study consists of five chapters.

Firstly, the study is introduced by argument, and then, aim and objectives, procedure, and disposition of the study are given in introduction chapter.

In the second chapter, literature review of sustainable architectural design, bioclimatic interventions, and assessing the renovation of existing building by using energy simulation software are presented. In addition to that, at the end of this chapter, the critical analysis of literature is given.

Materials and methods of the study are described in the third chapter. The building selected as case study, the software which are used for the study, and the bioclimatic interventions which are applied for reducing the energy demand of the building are explained in this chapter.

The results of the simulations and evaluation of the results are examined in fourth chapter.

Lastly, the fifth chapter presents the conclusion of the study.

CHAPTER 2

LITERATURE REVIEW

In this chapter, a survey of literature regarding the subject of the study is presented. Literature review is composed of three sections, and it contains relevant information about sustainable architectural design, bioclimatic interventions, and virtual renovation of existing building by using energy simulation software. In the first section, principles of sustainable architecture, the relation between design stages and integration of sustainability are investigated in detail. Moreover, description of bioclimatic architecture, passive cooling in hot and humid climate, and natural ventilation are researched in the second section. In the third section, integration of bioclimatic interventions and energy simulation software, and comparisons of existing and renovated building in terms of energy usage are studied. Moreover, a critical review of literature is given at the end of this chapter.

2.1. Sustainable Design

Sustainability has been defined as the need to protect current natural resources in order to continue earth's resources for future generations. (Costanza & Patten, 1995). This concept has gained much importance after the impact of climate change has started to be felt worldwide. Consequently, there is need to further decrease energy consumption or change the type of energy sources due to the risks of global warming and depletion of fossil fuels (Xu H. , 2016).

Energy consumption has increased extremely because of economic growth and developments in urbanization. One of the biggest factors for this situation is building sector (Ran & Tang, 2018). Building sector which is one of the largest economic sectors worldwide has significant impact for greenhouse gas emission (Mohammadi, Saghafi, Tahbaz, & Nasrollahi, 2018). It is determined that building sector accounts for 35% of total energy demand. Ran & Tang (2018) point that this situation causes energy problems and also unusual weather conditions because of climate change (Frank, 2005). In addition to that, while economic and social conscious are increasing, people's demand for thermal comfort has also been increased.

Because of rapid population growth, urbanization and most importantly energy consuming buildings are highly increased in the developed and developing cities (Mohammadi *et al*, 2018). For these reasons, sustainable approaches and compatible decisions with regard to environmental factors have become critical issues especially for design of building. Mohammadi *et al* point that there is necessity that a new sustainable path which is based on using renewable energy and considering energy efficiency should be followed to decrease the risks of climate change and dependency to fossil fuels.

To ensure sustainability through architectural design, it is necessary to work with basic principles of ecology and essentials of cultural (Rego, Uson , & Furnado, 2015). Architecture is a practice that combines technology and art, but sustainable architecture has additional disciplines like ecology, sociology and philosophy that must be considered at the design stage (Rego *et al*, 2015).

The sustainability issue in design is extensive and sensitive topic, with new innovations generating new unanswered questions and experiments. The principles of sustainable design were not employed in conventional practices until progress was made in knowledge and technology. Thus, there are some steps and criteria for making any building sustainable (Shelton, 2007). With the balance between human beings, architecture and climate, low carbon architecture can be designed. Recently, low carbon architecture has become one of the key factors of sustainable architecture (Li W. , 2011). Because of that, Li (2011) emphasizes that sustainable architecture can be associated with human ecology which is related to economy, society and environment, respectively. In other words, sustainable design is created as a whole by integrating these three major aspects.

Li (2011) points that sustainability includes four parts which are low carbon economy, society, natural environment and architecture (Figure 2.1). The components of these parts are detailed below:

- Natural Environment: Orientation, climate, light, natural ventilation, energy, water.
- Low Carbon Economy: Added value, flexibility, commercial reality, longevity.
- Society: Culture, social benefits, people, health and well-being.
- Architecture: Form and function, identity, structure, materials, innovation.

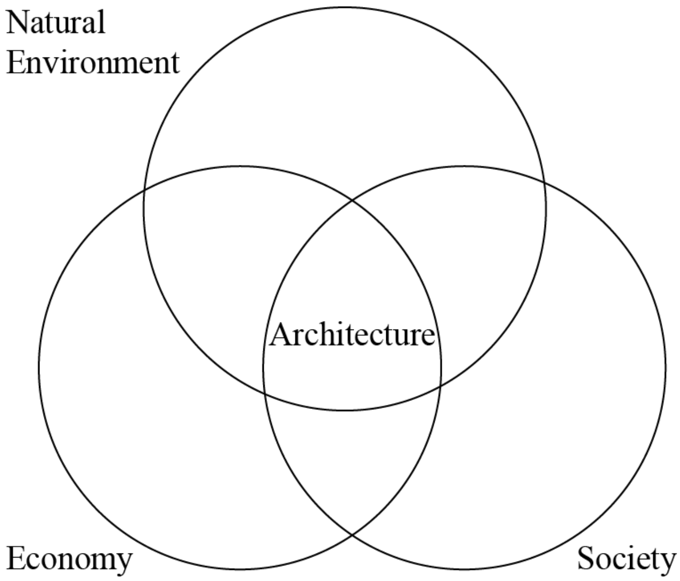


Figure 2.1. Three rings diagram to illustrate connection between the parts of sustainability by Li (2011)

Moreover, it is very critical to reduce energy consumption in long term for achieving a sustainable design (Masood, Abd Al-Hady, & Ali, 2017). Masood *et al* specify some points why so important that reducing energy consumption below.

- Energy is very critical for economic and security reasons for nations and people.

- Every person is responsible for reducing energy usage because it affects the whole, like the inductive method.
- By reducing energy usage, climate change can be slowed.

Furthermore, while designing building, the natural factors related to climatic conditions over the site should be considered because these factors directly affect the human comfort and building design. Givoni (1976) described these climatic elements as solar radiation, air temperature, humidity, wind, and precipitation.

In addition to that, sustainability is a significant issue which should be taken into consideration at the design stage in terms of environmental, economic and social issues; as they improve architectural quality and provide economic advantages (Bragança, Vieira, & Andrade, 2014). There are many definitions of what makes a building sustainable in terms of social, economic and environmental issues. For instance, social issue is about enhancing the quality of life for people. For economic issue, improving wealth and decreasing the cost of maintaining. Moreover, environmental issue is about reducing the effect of buildings on the natural environment (Grierson & Moultrie, 2011). Bragança *et al.* (2014) claim that there are three indicators which have a major influence on sustainability and can be evaluated in conceptual design stage as environmental impacts, energy, and life cycle costs.

2.1.1. Principles of Sustainable Design

According to Shelton (2007), thanks to development of technology and spread of sustainable works, the principles of sustainable design has become more common. Moreover, some strategies have been determined that help architectural projects become more sustainable. These strategies are listed below:

- Orientation and configuration of buildings according to the context
- Window design for solar gain
- Designing microclimates and landscape responsively

- Window design for gaining effective daylighting
- Water management not only for consumers' usage also for landscape and close environment
- Choosing durable and local materials
- Organizing inner and outer relations of building providing natural ventilation

Minimizing the cooling requirement of a building with appropriate architectural design can be achieved basically by minimizing solar and heat gains derived from building envelope. For hot climates, the most critical season is summer so building design should be created according to building thermal performance in this period. Therefore, the design should aim to reduce indoor temperatures and promote natural ventilation.

Givoni (1994) specified the architectural design features affecting the building thermal performance below:

- Building layout
- Orientation of main rooms and windows
- Window size, location, and details
- Shading devices for windows
- Color of the building's envelope
- Vegetation near the building

For sustainable design, water consumption is also an important issue besides energy consumption. While population increases, the consumption of water resources is also increasing. Water demand is changed by additional influences such as land use, urbanization, and climate change (Zimmerman, Mihelcic, & Smith, 2008). Each stressor of influence relates to another forming a complex web, so changes in one stressor will ultimately affect the others (Zimmerman *et al.*, 2008). When designing a system, certain stressors, such as population and urbanization projections are included in the preliminary evaluation. However, other stressors like climate change, are often ignored (Joustra, 2010).

Figure 2.2 shows the comparison of conventional water allocation and appropriation of water in a sustainable building.

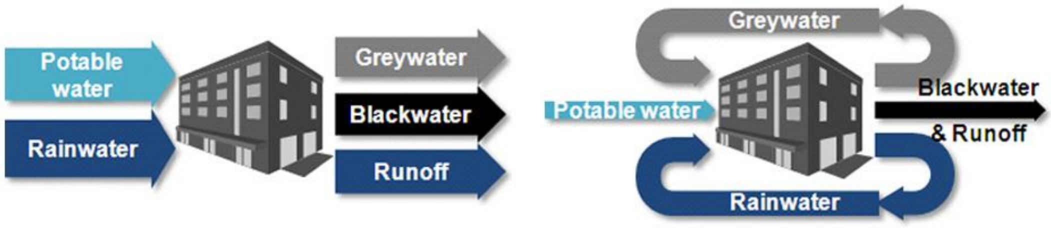


Figure 2.2. Water flow in a conventional structure (left) vs. a sustainable building (right) by Joustra (2010)

2.1.2. Relation Between Design Stages and Sustainable Design

Kibert (2005) points out that the quality of the building can be increased by applying the rules and techniques of sustainable methods. Vernacular architectural methods form the basis of sustainable architecture. In addition to that, the process of the principles of sustainability has also been supported by empirical data. In other words, the experiment has a key role for sustainable designs.

Brophy and Lewis (2011) mention that an architect has a key role in putting sustainable design into practice. That is, an architect can function as bridge between the design and its application. Besides that, showing that the cost will be reduced in time and informing and convincing clients and design team about environmental aspects which are important and necessary elements of sustainable design, may also be a role of the architect for applying the environmentally conscious design. In pre-design stage, climate and location features are the key factors for the relation between the design and context. Moreover, building size and usage are other factors for design. These all affect the energy performance and requirement of buildings. That is, energy usage for cooling and heating is directly related with orientation, daylight penetration, ventilation, material selection, insulation of building. Therefore, although design process is related with different aspects, architect should manage and take into account all of these in early design stage and also inform the client or investor about outputs of the sustainable design.

The terms sustainable building and sustainable design are also being used as ‘green building’ and green design (EPA, 2016). For instance, Brophy and Lewis (2011) described the sustainable strategies as green strategies. Because of that, the term green strategy continued to be used for the clarification in this section. Table 2.1 shows the design process of the building and green strategies at different stages. The key strategy is climate; therefore, the location of the building becomes one of the most important parameters. After these, orientation of the building, the mass of the building such as building size, openings, courtyards, and materials and their application can be stated as green strategies. Brophy and Lewis (2011) categorized design process at different stages which are briefing, initial studies, concept design, preliminary design, developed design, detailed design, tender, supervision at construction, commissioning at construction, operational support, maintenance support, and refurbishment. Table 2.1 presents the clustered stages which are derived from the stages mentioned above.

Table 2.1. *Design Process with Green Strategies summarized from Brophy & Lewis (2011)*

Design Process with Green Strategies	
DESIGN	• Orientation of the building according to the passive strategies, i.e. passive heating, cooling and ventilation • Evaluation of water management • Selection of local materials • Calculation of energy performance • Optimization of the openings regards with adequate daylight and energy consumption • Finalization of the architectural drawings • Determination of construction methods
TENDER	• Convincing the contractors for green design • Specification of the importance of building performance evaluation • Identification of low carbon construction practices
CONSTRUCTION	• Protection of the natural landscape of the construction site • Waste management on the site • Application of the design by good quality of workmanship • Testing of the building envelope • Expression of passive and active systems for the clients and contractors
OPERATION	• Evaluation of the building's environmental behavior • Consideration of the quality for building environment and indoor air • Application of the good quality green materials and sanitary products

The design process is detailed below by investigating conceptual design stage and construction stage.

2.1.2.1. Conceptual Design Stage

Brophy and Lewis (2011) mention that the conceptual design stage has a significant role in starting a project. First of all, building orientation, building relations with environment and organizations of indoor and outdoor spaces are managed. Then, the architectural drawings, which are floor plans, sections and elevations, of these decisions and their alternatives are prepared. After that, the materials and different alternatives are selected. In the lights of this information, costs are calculated. In short, the decisions of the architects, and interdisciplinary works have key roles for holistic success of eco-friendly applications.

The planning session during the predesign stage has critical importance to realize the goal of sustainability because it is the starting point to achieve sustainability. The client has to clearly identify the needs; architects, engineers, and project managers have to figure out the project envelope; and environmental engineer and quantity surveyor should research into sustainability issues and life-cycle costing. Different parties contribute their knowledge into the process to identify the performance goals, such as site issues, water efficiency, indoor environmental quality, and environmentally responsible construction activities (Wu, 2010).

Halliday (2008) proposes that the project should start with high aspirations, or principles of sustainability, and involve the widest range of interests in the design process. In addition, regular progress meetings during the project life cycle have critical importance for the success of sustainable building.

The table (Table 2.2) illustrates the topics, which are practiced and experienced by different approaches of the concept design stage to optimize different design parameters. Brophy and Lewis (2011) discussed these topics as site planning, building form and envelope, and materials.

Table 2.2. *Topics of the Concept Design Stage adapted by Brophy & Lewis (2011)*

Topics of the Concept Design Stage	
Site Planning	• Orientation of the building for optimization of the heating and cooling loads, ventilation, daylight, and shading • Providing water run-off by using soft landscape and vegetation • Designing the surrounding of the building to eliminate the noise and pollution
Building Form & Building Envelope	Designing the form and the facades, • To prevent heat loss • To gain adequate sunlight for daylighting and heating • To provide natural ventilation • To prevent excessive sunlight for overheating
Materials	• Selection of the appropriate and local materials regarding with the climate and environment

2.1.2.2. Construction Stage

According to Anantatmula (2010), sustainable projects are different from conventional projects in terms of technical aspects. That is, to achieve sustainability, the material specifications, and unique building solutions and practices are required. Moreover, if there is an environmental certification goal, extensive documentation and reporting are also required. The typical characteristics of sustainable projects require adjustments of traditional project practices to minimize risks and also to improve the chances of providing the project within acceptable costs. To make this happen, there is a need for cross-discipline coordination on-site selection, design process, construction techniques and building systems in design and project life cycle.

Wu (2010) claims that the construction period is often subjected to all kinds of pollutions, which can influence both the local and natural environments, depending on the nature of the project. Labor, equipment, and materials are of critical importance to improve the overall productivity and reduce waste in the construction period. Basically, green construction is about planning and scheduling. Other than introducing the low-emission vehicles and improving fuel efficiency, sustainable construction aims at planning and scheduling to fulfill the green certification requirements.

Another consideration is the need to minimize site confusion during construction or to protect materials and equipment from corruption during the construction process. Hence, planning and scheduling are needed to achieve the project requirements with high efficiency and low interruption (Glavinich, 2008).

In the concepts of sustainable design and sustainable construction, many parameters, which are energy efficiency, quality management, environmentally friendly materials, should also be considered.

2.2. Bioclimatic Approach for Sustainability

The term 'bio-climatic' means 'of, or pertaining to, the relationship between living things and climate' (Merriam-Webster Dictionary). It was first used in terms of design in the early sixties by Victor Olgyay in his famous book 'Design with climate: bioclimatic approach to architectural regionalism'; where he points out to the need for considering climatic factors in designing spaces that would be thermally comfortable for their occupants. He also developed the bioclimatic chart, based on the dry-bulb temperatures, wind speeds and relative humidity values, in order to identify the limits of the human comfort zone (Figure 2.3). He points out that if climatic conditions are determined to be outside the comfort zone, then corrective interventions are needed (Olgyay, 1963). Comfort zone and the effects on it are illustrated in Figure 2.3.

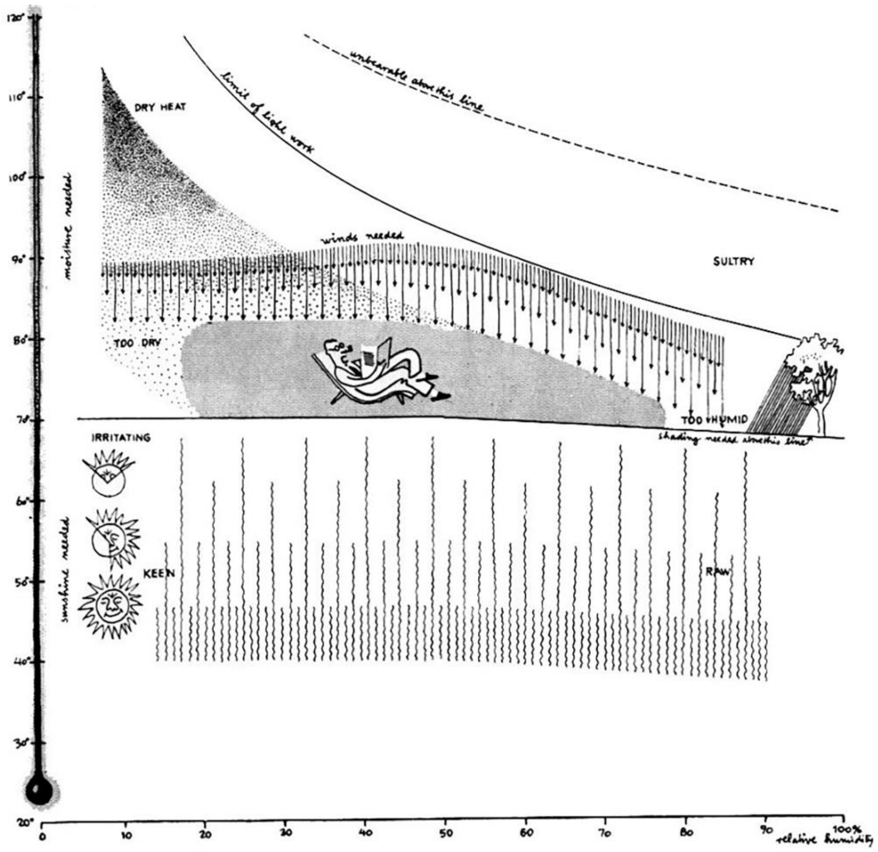


Figure 2.3. Bioclimatic chart proposed by Olgyay (1963) to aid architectural design

Bioclimatic architectural interventions are needed when the prevailing comfort conditions are not within the comfort zone.

In other words, when the conditions are outside of the comfort zone, architectural interventions should be performed. (Manzano-Agugliaro, Montoya, Sabio-Ortega, & García-Cruz, 2015). The most productive and efficient conditions are also defined as comfort zone, which is based on visual, acoustical, psychological and thermal comfort; but the key is the thermal comfort because without optimization of thermal balance, comfort conditions cannot be fulfilled, and human beings cannot be productive.

Major factors which affect human comfort are air temperature, radiation, air movement, and humidity (Olgyay, 1963), and these can be optimized through bioclimatic design strategies. In short, thermal comfort is related with the heat balance between the human body and its surroundings. In other words, it is the optimum thermal sensation of the human being in the current space. This heat balance is supplied with conduction, air movement, evaporation of skin moisture and radiation (Watson & Labs, 1992). Figure 2.4 illustrates these parameters. Three of them depend on individual factors which are metabolism, clothing and skin temperature. Moreover, four of them are related to surrounding environment which are temperature, relative humidity, surface temperature and airspeed. Therefore, in order to provide optimum thermal comfort in spaces, design decisions play an essential role (Brophy & Lewis, 2011).

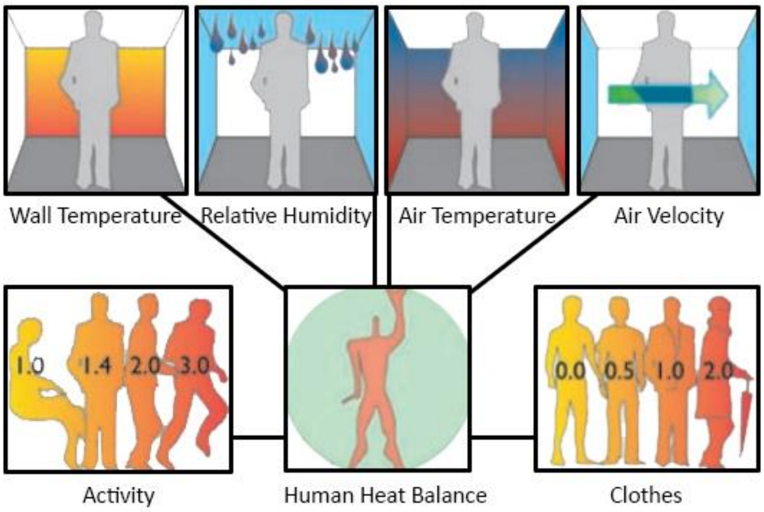


Figure 2.4. The parameters affecting human heat balance demonstrated by Brophy and Lewis (2011)

While Watson (1989) defined the bioclimatic design strategies as minimization of conductive heat flow, infiltration, external air flow and solar gain, promotion of solar gain, ventilation, radiant cooling and evaporative cooling, and providing thermal storage, Canas and Martín (2004) specified the strategies as being high thermal mass, protection against solar radiation, rain, wind and cold temperatures, usage of solar radiation and natural resources, proper building form and town planning.

Olgyay classified the term ‘bioclimatic design’ in 1950s and elaborated in 1960s. Figure 2.5 shows the bioclimatic design and its relations with other disciplines as biology, climatology, technology and architecture. Thanks to these relations, climate balance can be achieved.

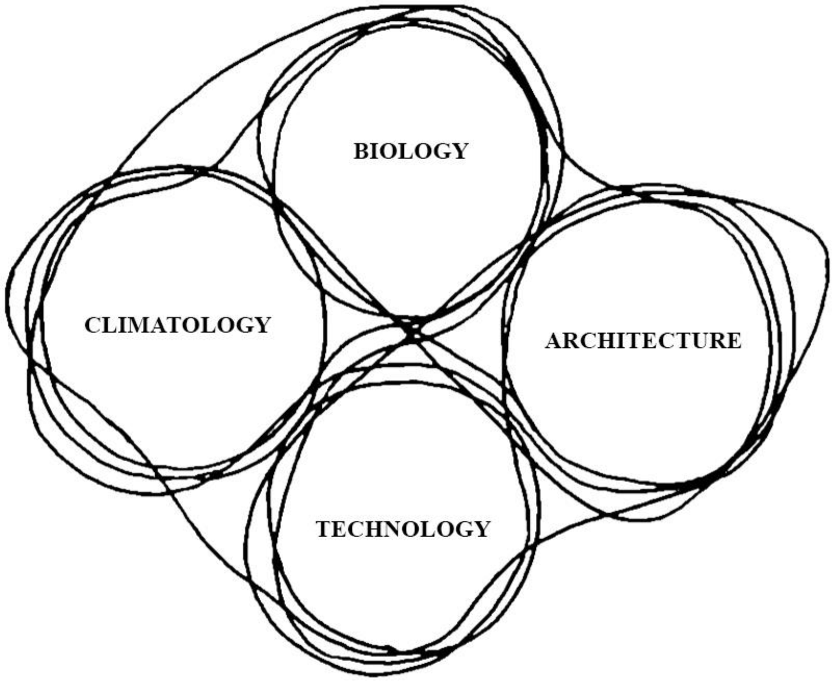


Figure 2.5. Interlocking disciplines of climate design proposed by Olgyay (1963)

When these disciplines are taken into consideration as overall, the optimum relation between the human and climate can be achieved. Then, bioclimatic design helps to manage these interdisciplinary situations and also has been a significant role for bioclimatic design (Szokolay, 2008). In other words, bioclimatic design and its principles help designing environmentally appropriate buildings. That is, the orientation, form and materials of the buildings are arranged with respect to the climatic factors (Hyde, 2000).

In short, to provide comfortable thermal zones in the buildings, active and passive design systems are used together. Passive design systems are examined under the sub-heading of bioclimatic architecture in this study.

2.2.1. Bioclimatic Architecture

Bioclimatic architecture is a current topic for energy efficiency concept in architecture. One of the aims of bioclimatic architecture is to minimize the energy usage by increasing ventilation capacities and energy savings (Zeiler & Boxem, 2009).

Lee, Lee, & Lim (2015) mention that bioclimatic architecture is about using natural energy sources and designing buildings regarding environment. In addition to that, bioclimatic architecture is the method of achieving energy efficient design. Building orientation according to the sun, building shape, building envelope and other factors like these are the design elements of bioclimatic architecture. Moreover, bioclimatic architecture includes principles of passive design. On the other hand, active design is related with technological methods like mechanical systems, which include heat recovery, mechanical ventilation, and floor heating systems, or technological systems using natural sources of energy, such as solar and geothermal energy.

According to Jones (1998), bioclimatic architecture stipulates that the building should be designed by considering the issues which are microclimate, form, and fabric. For instance, in hot climates, indoor spaces can be cooled by using passive and active systems to achieve thermal comfort. Consequently, high energy use and unfavorable environmental effects can appear. That is, it is obvious that there is a relationship between climate change and the behavior of buildings. For this reason, while designing buildings and obtaining the thermal comfort, the environmental impacts should be considered, and these issues should be approached and evaluated together.

Bioclimatic architecture includes the passive architectural design principles. Lee *et al.* (2015) points that while designing passive buildings, thermal insulation and adequate ventilation should be designed and managed to minimize the energy consumption. Hence, selection of the most suitable and efficient materials, and designing the building according to bioclimatic principles are critical for buildings. Yeang & Woo (2010) specify that to realize the passive design strategies, the issues which are low-energy design, the unique climatic and natural features of the building site, and the form of the building should be take into consideration. When designing the building these topics should be evaluated as a whole. For instance, the climate and the topography of the site affect the building form and design decisions. Moreover, the design and the orientation of the building are determined by considering sun control, natural ventilation, and vegetation.

The table (Table 2.3) shows that the environmental control area of passive design techniques includes the light environment, air environment, and thermal environment.

Table 2.3. *Environmental effect of passive design techniques by Lee, Lee, & Lim (2015)*

Design Area	Passive Design Techniques	Environmental control Area		
		Light Environment	Air Environment	Thermal Environment
Building Orientation & Shape	South orientation	natural lighting	-	solar radiation penetration
	Sun shading form	daylight shading	-	solar radiation shading
	Ventilation path	-	natural ventilation	air intake
	Raised roof	-	-	Efficient control of sunlight
	Volume to surface ratio	-	-	efficient control of sunlight
Open Spaces	Atrium	natural lighting	natural ventilation	solar radiation penetration /air intake
	Court yard, light well	natural lighting	natural ventilation	solar radiation penetration /air intake
Opening & Device	Skylight, monitor roof	natural lighting	natural ventilation	solar radiation penetration /air intake
	Clerestory	natural lighting	natural ventilation	solar radiation penetration /air intake
	Daylight duct	natural lighting	-	-
	Light shelves, daylight ceiling	natural lighting	-	-
	Ventilation duct, ventilation tower	-	natural ventilation	air intake
Building Skin	Double skin	-	-	efficient control of sunlight
	Translucent skin	daylight shading	-	solar radiation shading
	Louver, sun screen	daylight shading	-	solar radiation shading
	Closed facade	-	-	efficient control of sunlight
Building Planting	Green roof, landscaped ramp	-	-	soil insulation
	Green wall	-	-	soil insulation
	Water space	-	-	heat exchange

In short, the goal of the bioclimatic architecture is creating the spaces by nature-friendly and economic matters to achieve healthy, comfortable, and energy efficient living areas (Tundrea & Budescu, 2013).

2.2.1.1. Bioclimatic Design Interventions

Bioclimatic interventions are based on reducing energy need while providing thermal comfort. They can help enhance thermal comfort, thus reducing and balancing heating and cooling demands in buildings (Tejero-González, Andrés-Chicote, García-Ibáñez, Velasco-Gómez, & Rey-Martínez, 2016). Gonzalez *et al.* (2016) point that traditional bioclimatic interventions are more sustainable practices instead of the current generic techniques. It goes without saying that vernacular architecture that is based on passive design principles is the result of bioclimatic design concerns. For thousands of years people have used environmental factors to obtain the best solutions for providing thermal comfort within (Canas & Martín, 2004). These vernacular methods have varied depending on site conditions, location, climatic conditions, local materials and cultural norms.

There is a synthesis between technical sustainability which depends on energy, materials, water, etc., and place-based locally centered design. Local values reflect the past, which worked well. Cultural or human heritage in buildings can be viewed through the context of history in the built works of past generations (Clarke, 2008). Sustainability has been thought with issues of energy and resource consumption, and minimization of human impacts on the environment.

The approach of Ken Yeang to the architectural design is to build by considering environmental strategies for the climatic and cultural context. By this way, bioclimatic architecture is achieved and applied by passive design principles and innovations (Kassim, 2006).

Clarke (2008) also points that the understanding of heritage provides the designer with the conceptual tools from the past geological areas and human history and different layers of site's natural history. In other words, context of history and environment provides a guiding path to the designer. This path reflects the connection between the works of past generations, socio-cultural heritage and environmental impacts. Thanks to that, natural heritage and cultural heritage can be separated, and information of the geographical character of the site can be found. The climate which affects each site individually can be found with these deeper layers. It can be seen that the living layer of natural history which is still sitting across previous layers and human history. That is, Clarke points that sustainability issue can be achieved not only determining energy usage, environmental values and new technologies but also continuity of social and cultural values and also minimum intervention of traditional methods.

2.2.1.2. Strategies of Bioclimatic Architecture

Watson & Labs (1992) states that bio-climatic design principles aim at providing thermal comfort in occupied spaces of the buildings, for all seasons. For instance, in winter, the behaviors of the buildings are regulated to gain heat from the sun; on the contrary, in summer, they are formed to provide heat loss. To solve this contrast, interventions should be designed according to the local climates. In other words, the principles which were promoting ventilation or solar gain operated effectively in both summer and winter.

Webster-Mannison *et al.* (2013) specify some strategies to define and solve the energy problems of the buildings, and to create a vision on climate-based designs. The aim of these essential strategies is to provide designers with environmentally aware approaches. Because there is no absolute solution for this issue, designers should solve the problems according to the unique characteristics of building environment.

Some of these principles are specified by Webster-Mannison *et al.* (2013) below:

- Enhance daylighting by:
    - Controlling glare
    - Using light shelves
    - Increasing the use of daylight
    - Using shades for glazing
    - Using high performance glazing
- Augmenting natural ventilation by:
    - Increasing interior air movement
    - Using natural ventilation
    - Using fans
    - Re-designing the building according to stack effect principle
    - Creating atria
    - Thermal chimneys
- Building envelope optimization by:
    - Insulating roof, walls and ground
    - Using local materials for insulation

In addition to that, Brophy & Lewis (2011) clarify the key factors of sustainable design as building structure, building envelope, daylight, heating and cooling. These factors are described in detail below:

- Building structure: Re-use, local and long-life materials may be selected.
- Building envelope: The materials may be tested in terms of performing air permeability and air tightness. Open areas for lighting and thermal performance may be arranged.

- Daylight: Openings may be designed regarding efficient daylight usage.
- Heating: Building plan and façade may be designed to use maximum solar gain.
- Cooling: Façade and shading systems may be designed to obstruct become thermal mass and to allow natural ventilation.

Hyde (2013) mentions that with the development of the new technology and also enlarging the building spaces, the buildings except for residential ones have been fitted with mechanical systems to provide indoor thermal comfort due to not only complexity of the building program but also the dense urban context. In Table 2.4, the comparisons of the bioclimatic buildings and conventional buildings, and their general characteristics are presented.

Table 2.4. *General features of the bioclimatic buildings and conventional buildings stated by Hyde (2013)*

Bioclimatic Buildings / Traditional	Conventional Buildings / Current
• Optimally orientated • Use fresh air • Daylight • Solar-heated • Naturally ventilated • Highly shaded • Well insulated	• Deep plan • Glass façades • Mechanically lit • Fully air conditioned • Reliant on fossil fuel energy

While bioclimatic buildings are part of the traditional ones, conventional buildings are current types of buildings.

Basic principles are determined in order to create a sustainable basis. In addition to these general characteristics, it is necessary to use local parameters to design a building in accordance with bioclimatic principles. In addition, environmental impacts should be re-examined at the beginning of the design because ecosystems are non-stable dynamic structures. (Yeang, 1996). Thus, relationships between architecture and ecosystem can be achieved (Hart, 2011). Yeang (2010) specified the strategies of bioclimatic architecture. Firstly, the strategy is applied to achieve the relations between the human interference and natural environment. Second strategy is to harmonize the building structure and functions with the ecosystems of the site. The other strategy is designing the landscape not only for the building but also for the surroundings of the site. The last strategy is to consider designed system in the context of the global biosphere.

Figure 2.6 illustrates the strategies of climate control by applying four heat flow opportunities, i.e., conduction, convection, radiation and evaporation, in the summer and winter conditions. The nine strategies, which are minimization of conductive heat flow, external air flow, solar gain, infiltration, and promotion of ventilation, radiant cooling, solar gain, and evaporative cooling, are matched with the heat flows and applications in different seasons (Watson &Labs, 1983).

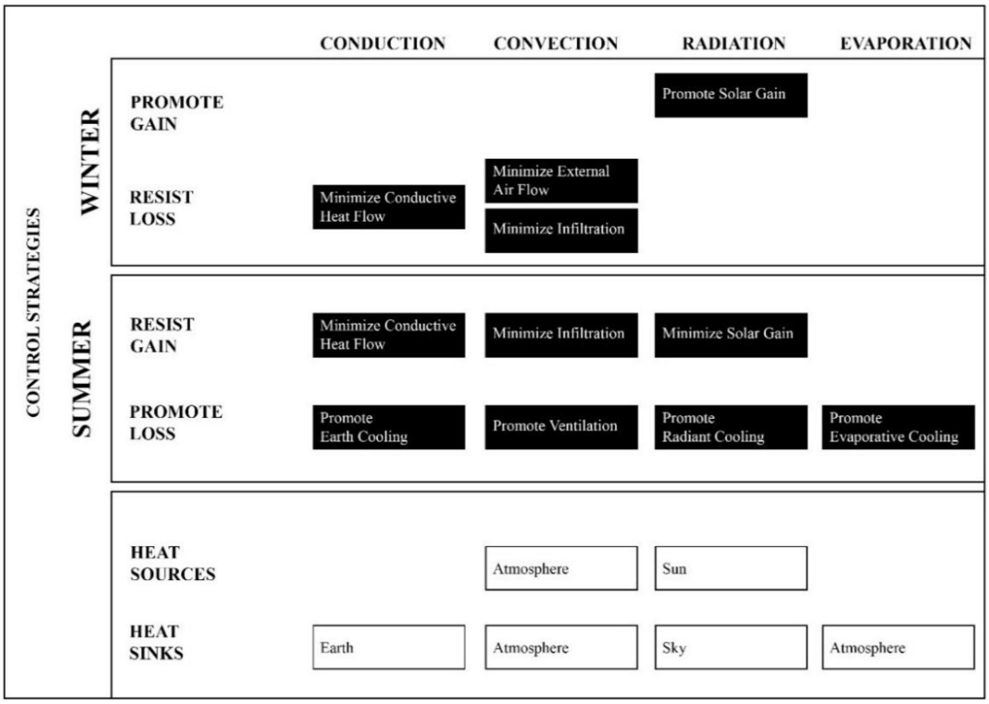


Figure 2.6. Strategies of climate control identified by Watson & Labs (1992)

Moreover, the figure shows the relations between the heat flows, heat sources and heat sinks. While these heat sources are identified as atmosphere and sun, heat sinks are given as earth, atmosphere and sky.

Tengku Robert Hamzah and Ken Yeang have been practising sustainable design methods both for the architectural projects and theorical issues since 1970's. For these practices, they examined topics related to climate and culture of the building site (Couzens, n.d.). Hamzah & Yeang have applied these principles into practice. For instance, Solaris Building in Singapore constructed in 2010, was designed with respect to local climate and ecosystem. As can be seen from the section in Figure 2.7, the atrium was designed to obtain adequate daylight and fresh air. This atrium also provides passive cooling by promoting ventilation to apply passive cooling. The roof of the atrium was covered by operable glasses with louvere type shadings. This roof is convertible and it is operated by climatic sensors to promote stack ventilation and to protect the inner spaces from the rain. The rain screen walls were operated by the same system. Moreover, the inner spaces were vegetated to maintain the relations between the natural and cultural environment (Widera, 2014).

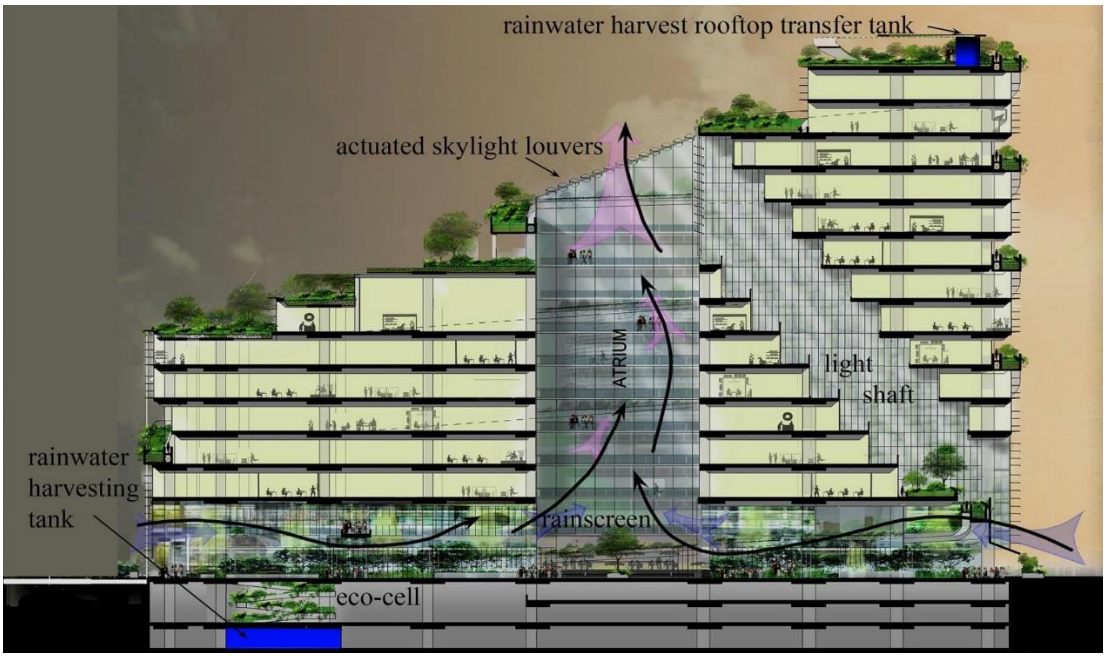


Figure 2.7. Section of Solaris Building illustrated by Hamzah & Yeang (Widera, 2014)

The other example is the school project constructed in Khan Younis, Gaza in 2014 by Michael Collins Associates (MCA). Figure 2.8 illustrates the section of the building which was designed according to bioclimatic principles and these principles were applied at minimum cost (Widera, 2014).

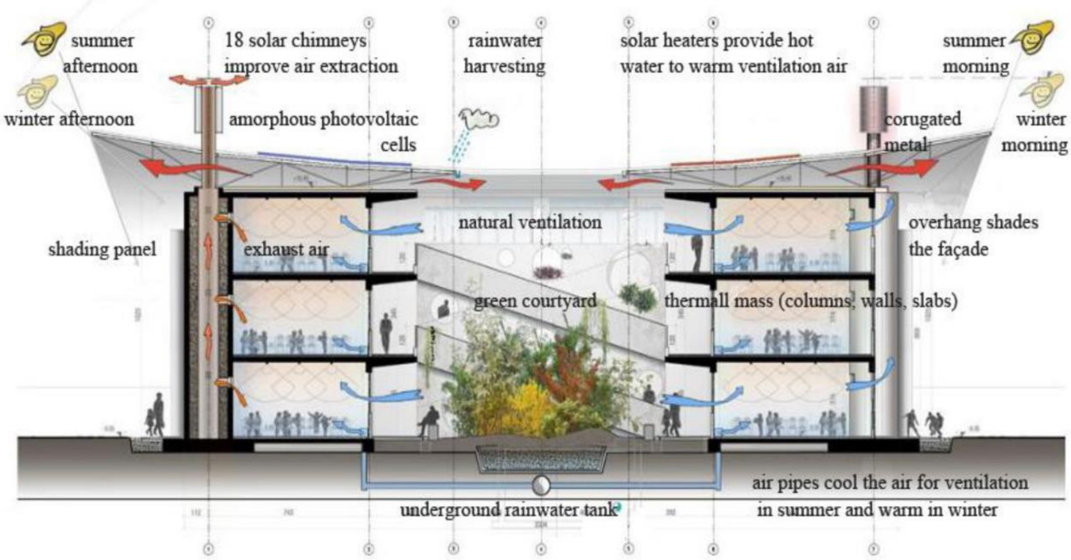


Figure 2.8. Section of Kuwait School illustrated by MCA (Widera, 2014)

2.2.2. Passive Cooling in Hot and Humid Climate

The temperature characteristics of Mediterranean climate are hot and humid that average high levels from 30 ºC to 40 ºC. Lower night temperature is useful for ventilation and cooling (Mercer, Tuan, & Radford, 2007). Natural ventilation is a basic passive cooling system. Cross ventilation and natural ventilation are needed for practicing passive cooling. In addition to that, ventilation stacks are used to remove hot air from inner parts of buildings in summers. Green walls and controlling water usage are also other useful strategies. Mercer *et al*. (2007) also state that green walls and shading elements are useful for controlling the sun and natural light for buildings.

Yeang and Woo (2010) described the passive cooling as decresing and optimizing the indoor temperature by using natural energy sources to realize the thermal comfort. Building form, orientation of building, window size and number, shading devices, and building envelope are the issues affecting the building behaviour. In other words these considerations are applied to minimize the heat gain, to control the sun light, and to promote the natural ventilation. Brophy and Lewis (2011) also mention that building orientation and minimization of solar gains by using shading elements are important for reducing cooling energy and improving thermal comfort in southern latitudes. However, while applying these strategies, adequate daylight is needed. Moreover, the design of the immediate surrounding is important. Using heat-absorbent materials, vegetation, ground cover planting and water decreases overheating in building.

While designing buildings in hot and humid climates, progressive and preferential design approach should be determined. In all passively cooled buildings, five core strategies were described by Dekay & Brown (2014); which are listed below:

- Locating outdoor rooms helps in controlling sun light and wind.
- Thermal buffer zones provide the balance between outdoor and indoor temperature and conditions.
- Stack ventilation provides cooling rooms by movements of cool air. When warm air rises, cooler air spreads from lower areas.
- One of the most effective strategy is placing shades in different layers. That is, it is the idea of enveloping the building which can be related to double skin materials strategy.

In addition to that, Dekay & Brown (2014) stated that the buildings can be cooled passively by the room organization, interior and exterior spaces, and building systems.

Moreover, Givoni (1994) classified passive cooling systems according to natural sources, which derive cooling energy for the buildings, as comfort ventilation, nocturnal ventilative cooling, radiant cooling, direct evaporative cooling, indirect evaporative cooling, soil cooling, and cooling of outdoor spaces.

Figure 2.9 illustrates these three main strategies and their sub-headings. Building form, promotion of natural ventilation, buffer zones are related with the room organizations.

Night cooled thermal mass in the buildings such as columns and beams; rooms which gain adequate sunlight and promote ventilation; courtyards, and wind catchers are the elements of passive strategies in interior and exterior spaces. Arrangements of thermal mass and openings, and shading layers are evaluated with the building systems.

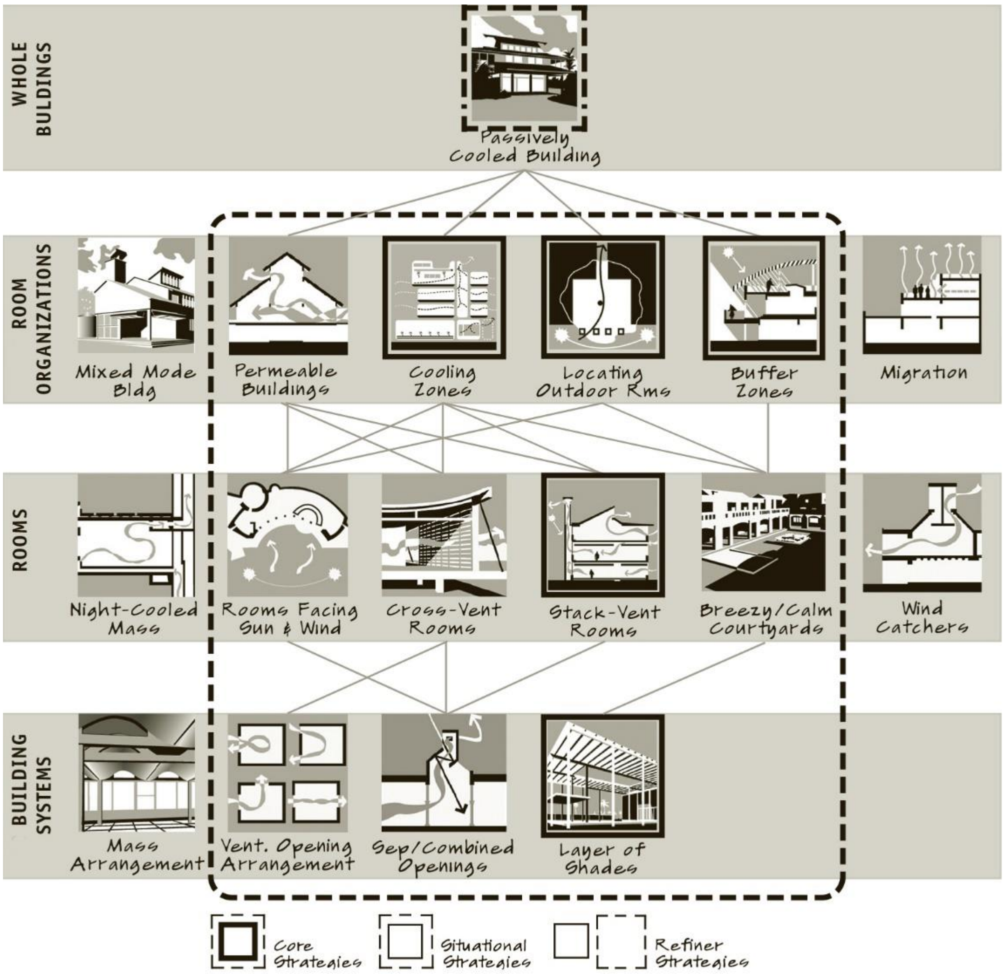


Figure 2.9. The strategies of passively cooled building in hot and humid climate specified by Dekay & Brown (2014)

Additionally, passive solar cooling is used for cooling indoor spaces without using mechanical equipment in hot and humid climates (Yeang & Woo, 2010). These strategies are determined as operable windows, wing walls, thermal chimneys, and sunrooms. All these strategies are based on promoting natural ventilation in an efficient manner. Figure 2.10 illustrates these strategies.

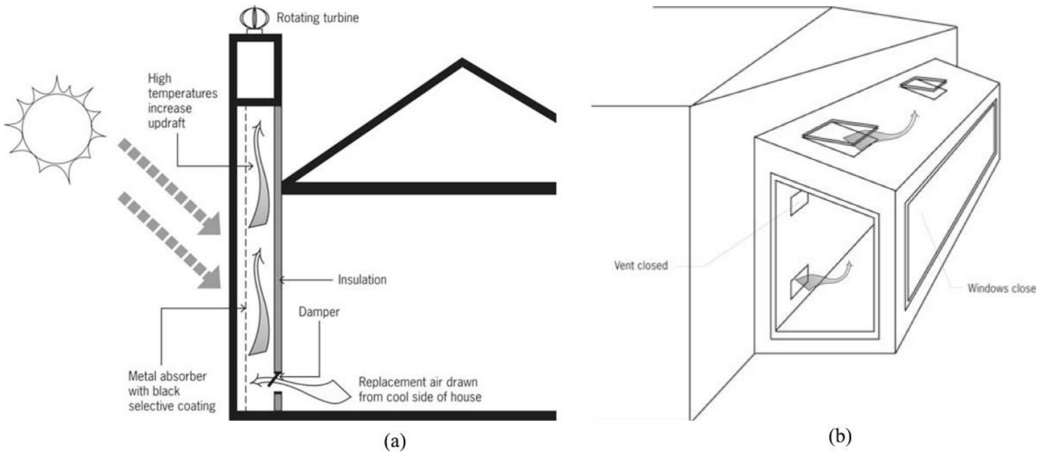


Figure 2.10. Thermal chimney (a), Sunroom (b) illustrated by Yeang & Woo (2010).

2.2.3. Natural Ventilation

Natural ventilation is one of the key factors of passive cooling systems. The meaning of the word ventilation is circulation of air (Merriam-Webster, 2019). Ventilation methods are used for supplying fresh air for interior spaces, and cooling the interior of the buildings when outside air is cooler than the interior, and for increasing the evaporation rate of the human skin (Watson & Labs, 1992).

Brophy & Lewis (2011) mentioned that natural and night ventilation are effective strategy to sustain thermal comfort in summer, for buildings. When the strategy is not sufficient, some additional mechanical systems i.e. mechanical cooling and ventilation can be applied. As a result of natural ventilation, thermal comfort can be achieved by using less energy. That is, the energy consumption of the building and, of course, operation costs can be decreased by natural ventilation.

The principle of natural ventilation is based on the air flow between the indoor and outdoor. Natural forces manage this flow. For example, stack ventilation which is one of the natural ventilation strategies can be achieved by pressure differences. Heated air has lower pressure so lower pressured air passively rises and is removed from the building passively. Moreover, thermal masses of the building i.e. concrete columns and beams can be cooled at night by using natural ventilation. That is, natural ventilation can be applied according to the need and context of the building.

Best solution of obtaining cool air in hot and humid climate is nigh ventilation which is using the cold air from night time. In day time, ground level air is warm, however, ground level and above are getting cool at night (Hazbei, Nematollahi, Behnia, & Adib, 2015).

Hazbei *et al.* (2015) also remarks that this situation provides cooling the air and then, because cool air has higher density than warm air, it goes down to lower levels. This movement cools the roof firstly, and then, the cool air spreads to other parts. Finally, when it reaches the ground floor, it rests there. Because of that, this strategy can be used for warm climates.

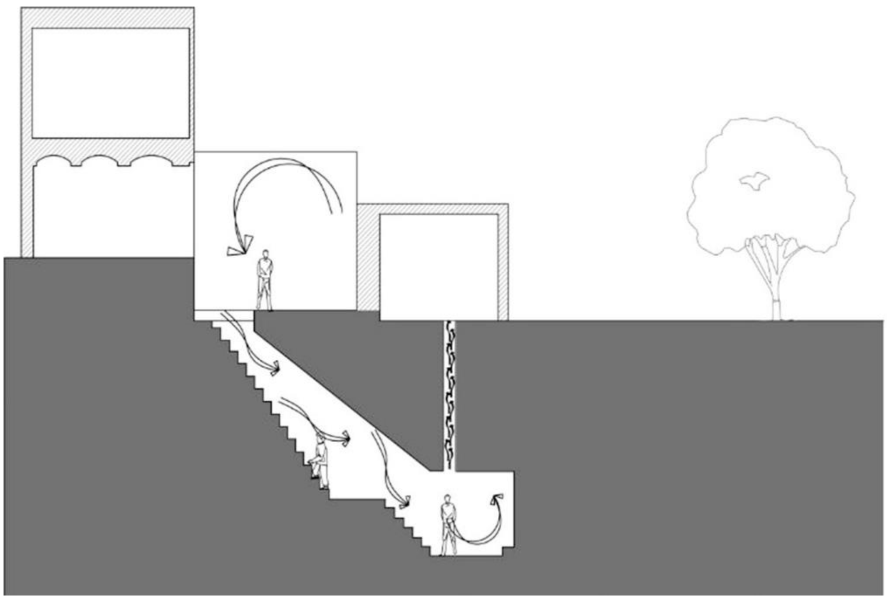


Figure 2.11. Getting cool air from underground space illustrated by Hazbei et al (2018)

The strategy above can be applied for night ventilation. However, an underground space can help for storage of cool air to use it in day time as can be seen in Figure 2.11. Figure 2.12 shows the difference of air temperature between outdoor or aboveground and underground spaces, which are called *shavadon* in Farsi.

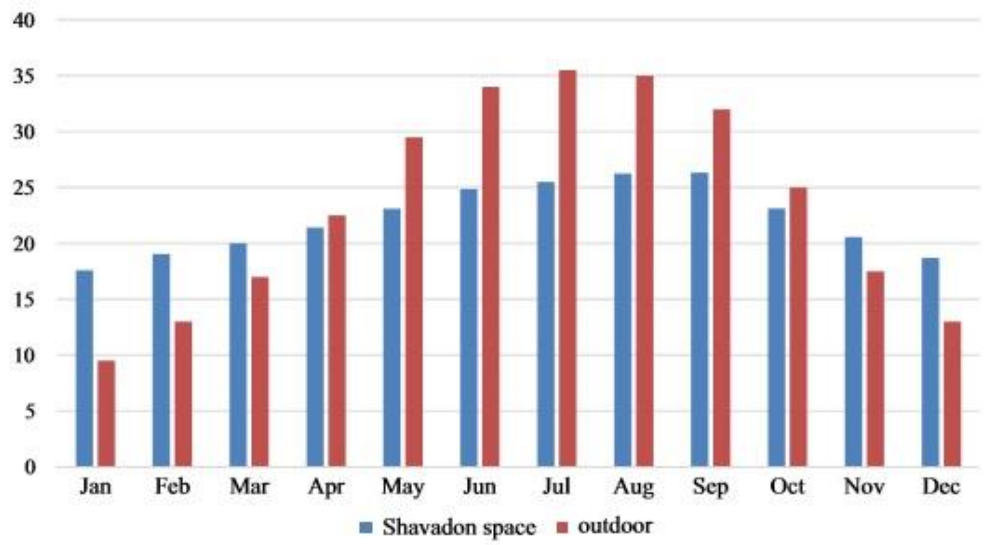


Figure 2.12. The comparisons of air temperatures of underground space and outdoor prepared by Hazbei et al (2018)

For tall buildings, natural ventilation strategies can be studied in three categories (Omrani, Garcia-Hansen, Capra, & Drogemu, 2017). These three types of strategies are illustrated in Figure 2.13 and they are listed below:

- In type A, there is no vertical void which connects each floor. Wind is key factor of natural ventilation for this situation.
- In type B, with a central void and large openings at the facades, natural ventilation is progressed by using air flow. However, in this situation, lower parts are exposed high air force when opening the windows.

- In type C, to prevent negative effects of type B, each central void part has separated each other. Thanks to that, high air force is not occurred at lower parts.

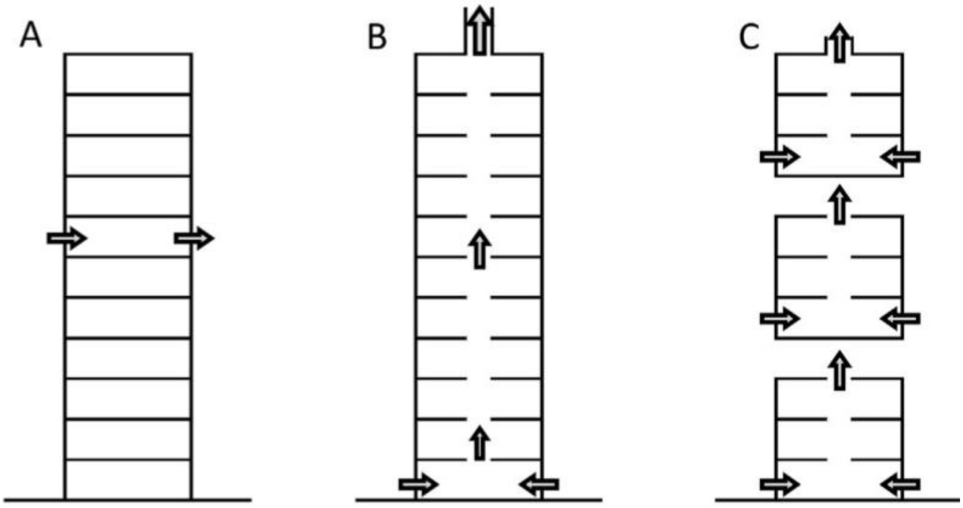


Figure 2.13. The illustration of tall buildings' natural ventilation strategies prepared by Omrani *et al* (2017)

2.3. Evaluating Bioclimatic Strategies thru Building Performance Simulations

With the development of the computers and software, building performance simulation (BPS) tools have also been improved in recent years. They create the bridge between the designers and clients by demonstrating the performance of the buildings. In other words, the impacts of interventions in operation periods can be established and evaluated through simulation tools. Therefore, the outputs of BPS can provide enough proof to convince the clients to invest on more energy efficient building strategies (Partridge, 2013).

Ralegaonkar & Gupta (2010) mentions that one of the main problems of architecture is that designers focus on basic plan, shape and interior materials instead of external conditions. Building energy demand, which is related with thermal comfort, heat, light, and natural ventilation in accordance with air and moisture movement may highlight the relationship between natural environment and design decisions. Lighting, vertical transportation (lifts/escalators), and energy usage for cooling and heating are the main design requirements which have to be taken into consideration for a sustainable building. In addition to that, materials should be chosen by giving importance to their thermal, moisture and sound performance as well as being local produce. Moreover, solar gain is affected by building elements such as walls, doors, roofs and most importantly windows. The factors which affect the cooling and heating energy usage are described by Ralegaonkar & Gupta (2010) below:

- Building area, orientation and usage type
- Relationship between walls and windows
- Density of walls and windows
- Shading components and systems

Brophy & Lewis (2011) suggested that before starting renovation, firstly, the thermal performances of the existing building should be evaluated. The main aim of the renovation is to transform the conventional buildings into bioclimatic ones. In other words, interior weather is optimized by using bioclimatic interventions instead of mechanical systems (Hyde, 2013). The thermal performances are depending on the building envelope, openings such as doors and windows, ground floor and roof. Besides the performances of material features and applications, the surrounding of the buildings should also be evaluated. That is, microclimatic conditions such as topography, surrounding vegetation, prevailing wind and its strength, potential of obtaining sunlight should be examined. Then, obtaining the outputs from these data, the effective interventions can be studied, tested, evaluated and applied. In addition to that, Hyde (2013) mentioned that sustainability and its holistic effects on the cities can be examined by ecological design. To decrease the pollution and to enhance the environmental performance of the building, retrofitting and renovation strategies play a significant role. With the renovations of buildings, not only thermal comfort for occupants but also the savings for energy and water consumption can be provided. That is, the renovations have great potentials beside the façade elevations and aesthetics. Building performance tools enables the foresights for business sectors, investors and occupants (Partridge, 2013).

Performance of the buildings can be improved by different sustainable solutions and methods. These may be achieved not only in material scale but also in building scale. Moreover, performance decisions can be made by making simulations and visualizations in design stage for different scales from material to mechanical systems (Koukkari & Bragança, 2018).

While designing sustainable building, different factors are achieved from design phase to construction phase. In figure 2.14, the performance of all phases is illustrated.

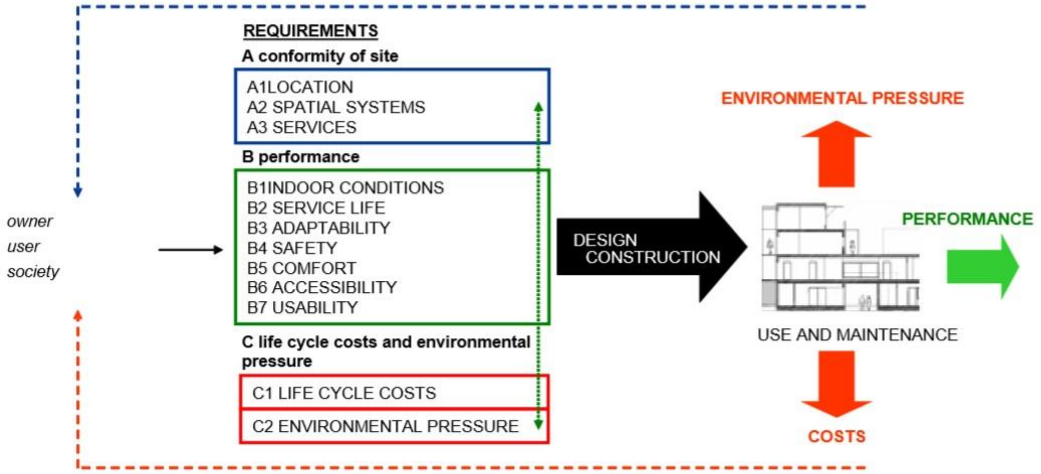


Figure 2.14. Performance analysis of the building in building scale represented by Kokkari & Bragança (2018)

BPS tools provide reliable predictions about the buildings' behavior and performance instead of generic regulations. In other words, by using a simulation tool, the best solution or the best way of application can be generated. This situation gives opportunities to the designer in the early design or pre-design stages. Different computational tools enhance interaction between different disciplines, and these tools can guide the project in all design stages (Brophy & Lewis, 2011). Table 2.5 shows how building models and level of analysis are utilized during different project stages.

Table 2.5. *Building modelling and level of analysis in different project stages proposed by Brophy & Lewis (2011).*

Project Stages	Building Model Detail	Level of Analysis
Concept Design	Site location, building orientation, prevailing wind direction	Evaluation of orientation and level of solar exposure
Preliminary Design	Building geometry, concept drawings, construction method	Evaluation of design schemes, intermediate analysis
Developed Design	Building geometry, detailed façade design, construction method, detailed drawings, engineering drawings	Evaluation of energy performance, detailed analysis
Detailed Design	Detailed Building Model	Estimation of energy performance
Construction	Detailed Building Model	Examination of the changes and the details of construction
Operation	Detailed Building Model	Comparisons of estimated and actual building

2.3.1. Integration of Bioclimatic Interventions and Energy Simulation Software

To achieve sustainable buildings, simulation and energy analysis are important for designers in designing forms and components effectively. Building energy simulation provides analysis of the energy performance of a building by using computer modeling and simulation techniques. There are different simulation tools which can help predict different points of building behavior. These are energy performance, acoustical performance, fire movement, structural performance, life-cycle assessment, etc. (Aksamija, 2015).

Figure 2.15 illustrates the effect of design decisions on building performance and relationships between the decisions and project stages. Moreover, uncertainties about building are also be shown in the different stages of architectural design.

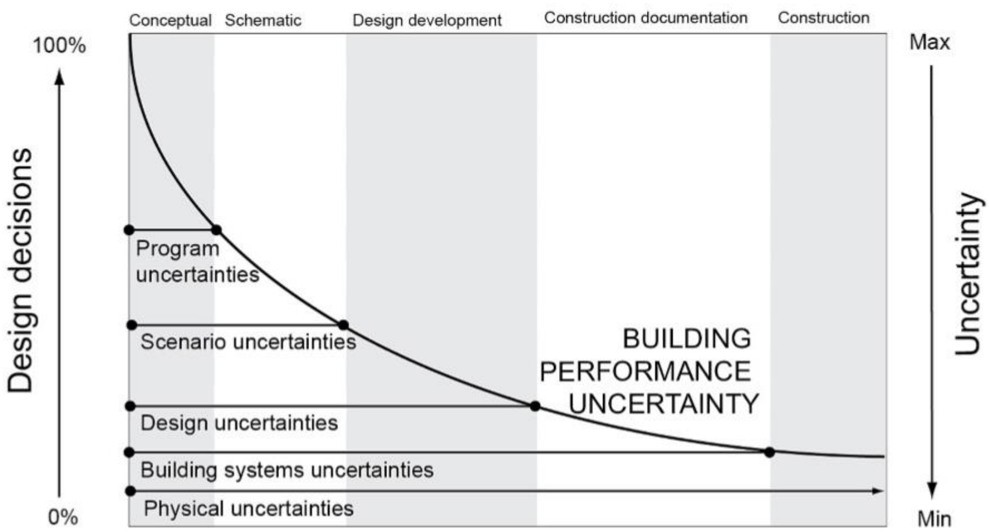


Figure 2.15. The effects of design decisions and effects on building performance uncertainties for each design stages of architectural design demonstrated by Aksamija (2015)

When realizing successful sustainable design, it is believed that not only designers can show different alternatives of designs for clients but also these alternatives can be compared (Danatzko, Sezen, & Chen, 2013). Obtaining realistic design alternatives require detail analysis on different energy types and environmental inputs. In addition to that, materials, including structural materials, are also critical issue for analyzing and optimizing the building.

Aksamija (2015) points that energy performance simulation tools enable different data for designers. For instance, they provide prediction of the thermal behavior of buildings in their environment, simulation of the impact of daylight and artificial light inside buildings, calculation of the effect of various building components and estimation the capacity of equipment for thermal and visual comfort.

Designing the building while taking into considering the sustainable principles at the design stage, helps to reduce the negative impacts of the construction, as well as the cost of the project (Bragança, Vieira, & Andrade, 2014). Figure 2.16 demonstrates the relationship between the environmental impacts, cost and time at the design, construction and use phases.

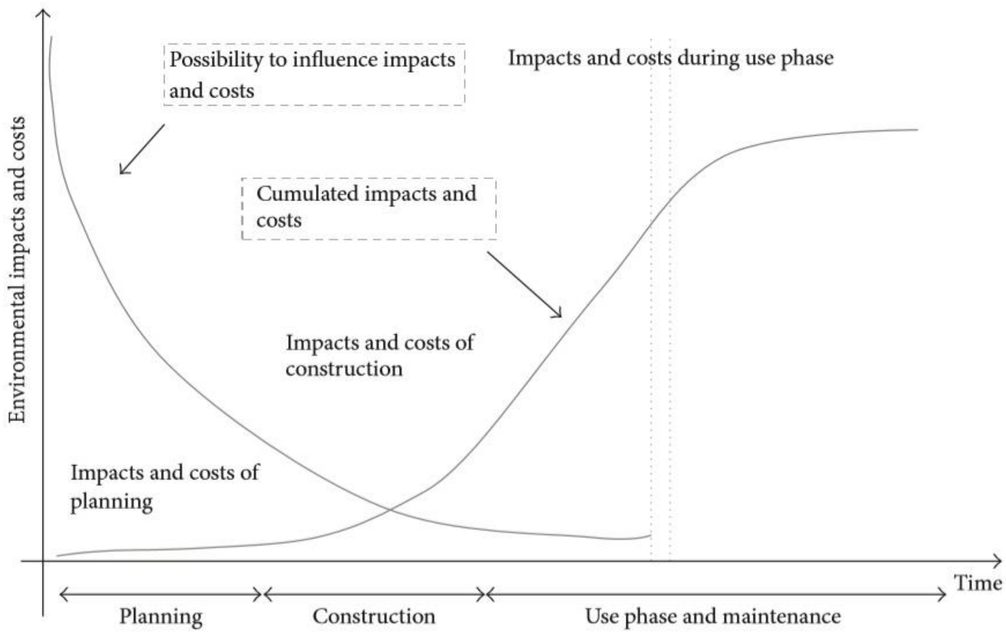


Figure 2.16. The effects of design decisions and effects on life cycle impacts and cost are shown by Bragaça et al (2014)

Hamilton and Watkins (2009) described the term BPS as evidence-based design (EBD) as the tool which creates awareness and predictions about the results of decisions, researches and practices. In other words, EBD gives an opportunity to evaluate the design, and then helps to convince the clients because of presenting the results of design decisions. EBD can be approached by determining and describing the situation of the source. Then, design can be generated according to the outputs from former situation. Thanks to the design predictions and outputs, confidence is provided. There are also some thoughts that this design tool has deficiencies about research and its application into the practice. On the contrary, using this tool gives clarity in forecasting the benefits of the renovations and retrofits (Hyde & Rajapaksha, 2013).

When looking at the office buildings instead of residential and conventional ones, Hyde & Rajapaksha (2013) stated that because most of the existing commercial buildings were not designed having regard to environmental impacts, these buildings have negative effects on the environment. Besides that, to obtain thermal comfort for the occupants, energy demand has also been increased. Because of that, there is need for solutions to improve the thermal performance of the buildings. At this point, EBD can useful because EBD generates the solutions and outputs for renovations in terms of energy. First of all, the existing building and its performance is identified and monitored for the renovation. Then, the interventions and renovation strategies are determined according to the climate, and the surrounding of the building. Thirdly, according to this data, design decisions are generated. Finally, the model of renovations is tested and evaluated. This situation provides evidence for increasing the reliability of the interventions.

Consequently, it is obvious that there is need for designing low energy buildings which provide thermal comfort by an environmentally aware approach. Existing buildings are spending much energy in present state and this energy usage will continue increasingly. Most of these buildings are 20 to 30 years old. Because of that, renovation is a better alternative than destroying old ones and constructing new ones, for decreasing the energy consumptions of buildings (Webster-Mannison, Beeson, & Healey, 2013).

By using energy simulation software, reliable performance outputs can be generated from different renovation strategies. These strategies can be evaluated, tested and compared by architects according to his/her design decisions and creativity.

2.3.2. Building Performance Simulations to Compare Energy Efficient Renovations Building

Main reasons of applying bioclimatic architecture are reducing energy consumption and increasing thermal comfort. However, bioclimatic design is critical for dense urban texture in hot and humid climates for its cost and effectiveness. Active solutions may be more cost effective because of lighting and air conditioning improvements. Cost is incurred by economic scale, availability of materials in market and risks. For instance, the advantages of greening a roof may be too small to achieve energy savings (Sun, Gou , & Lau, 2018).

Francis (2014) states that because building industry is changing rapidly by the effects of becoming more complex and multidisciplinary, the view of the occupants is also changing in the matter of buildings. This change increases the importance of building renovations for energy usage because of the cost increase, the upward trend of the savings, and the rapid developments of the technology. While these changes are occurring in the industry, landholders and users are starting to consider the issue of energy efficiency. This issue is related not only with the sustainability but also with '*image, brand, value and quality'*. Thus, the overall approach of the sustainability and energy usage issues are reconsidered by the evaluation of the financial performance of the building, building value, and building performance as a whole.

In this section, to compare the building before renovation and after renovation, two examples are given below.

One of the building which is located in London was renovated in 2012. This building which is called the Foundry Studios has BREEAM Excellent rating. Thanks to renovation, this old industrial building reduced its energy usage by 50% after changes and interventions.

For reducing energy usage, the skin of the building, i.e. walls, floors, and roof, were insulated by a thick layer of recycled newspaper. Moreover, natural light and natural ventilation were promoted. To generate the electricity, photovoltaic panels (PV) are installed at the roof level. By using building management systems, the mechanical systems for heating and cooling can be controlled with and internet-based monitor. Figure 2.17 shows these passive and active architectural interventions in the Foundry Studios building.

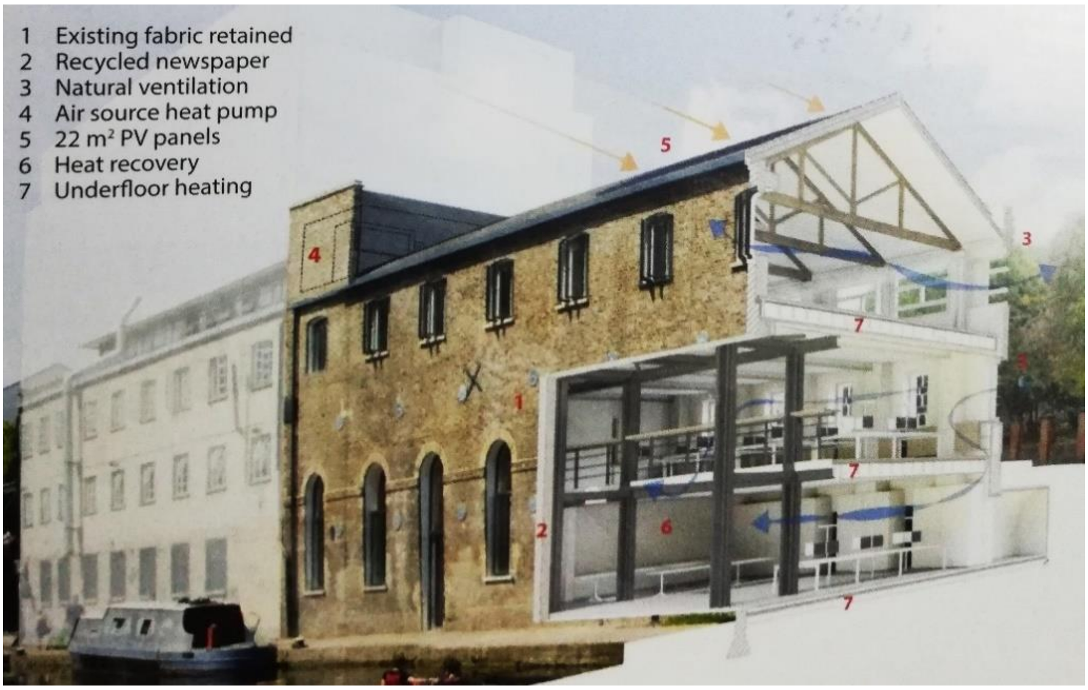


Figure 2.17. The illustration of the renovations and interventions compiled by Penoyre & Prasad (2014)

Table 2.6 shows the comparisons of the pre-renovation data, post-renovation data, and actual data in terms of total energy usage and carbon emission. In addition to that, the remarkable amount of energy saving can be seen in the table.

Table 2.6. *The comparisons of existing and renovated building shown by Penoyre & Prasad (2014)*

	Total Energy (kWh/m²/yr)	Carbon (kg CO_2 /m²/yr)
Pre-Renovation Data (Estimated)	221	22
Post-Renovation Data (Predicted Energy Model)	63.66	31.83
Actual Data (Post-occupancy Data)	115	57.5

The other building which is also located in London was renovated in 2011. This building which is called the Mildmay Community Centre aims at creating comfortable spaces with using much less energy than traditional building type. This aim is achieved by reducing annual energy usage by 80%. This great amount of decrease is achieved by highly insulated building skin, triple-glazed openings, newly added spaces such as balcony and platforms on the façade, and PV panels. These interventions can be seen in Figure 2.18. That is, active and passive design strategies are used together not only for reducing energy usage but also generating electricity.

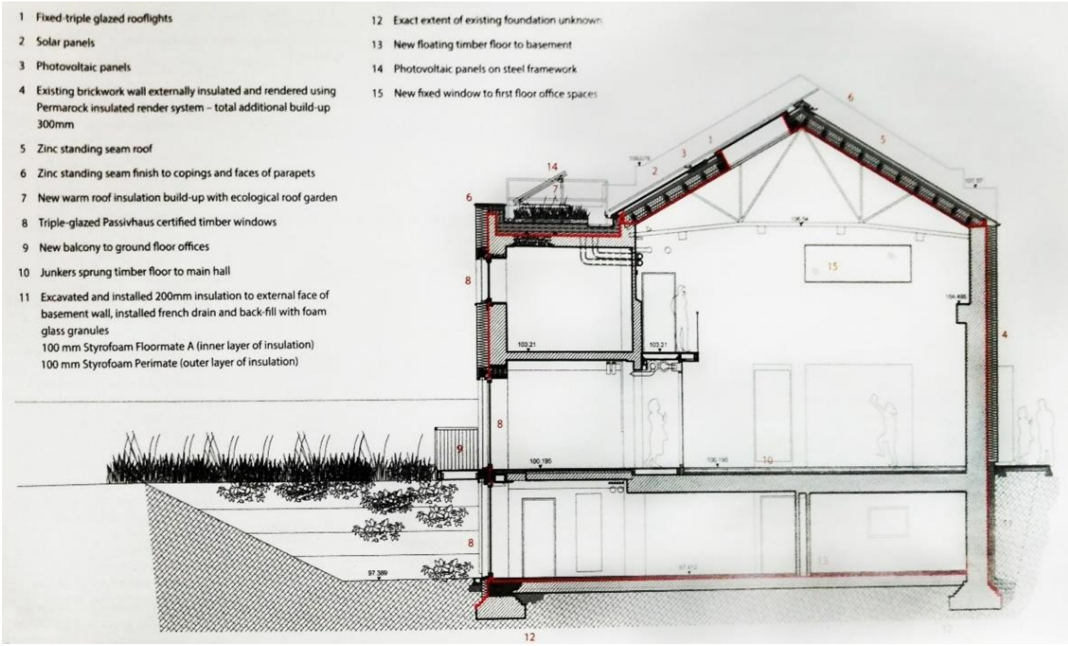


Figure 2.18. The section of the renovated building shown by Penoyre & Prasad (2014)

The comparisons of the data of existing building and renovated buildings are shown in the table (Table 2.7).

Table 2.7. *The comparisons of pre-renovation and post-renovation data illustrated by Penoyre & Prasad (2014)*

	Total Energy (kWh/m²/yr)	Carbon (kg CO_2 /m²/yr)
Pre-Renovation Data (Estimated)	580	
Post-Renovation Data (Predicted Energy Model)	20.8	10.4
Actual Data (Post-occupancy Data)	66.5	25

CHAPTER 3

MATERIALS AND METHOD

In this chapter, materials determined for the research and methods applied for the study are clarified under two subheadings. In the material section, the data of the building selected as case study, the simulation software used for modelling the building and calculating the energy consumption, and finally weather data of Alanya are explained in detail. The procedure is classified step by step and then, simulations of existing building and renovated ones are examined.

3.1. Material

The features and data of the case study building, identification of the simulation software, and the weather data of Alanya are the materials of this study. These are described in detail under the following sections separately.

3.1.1. Case Study Building

In this section, the data of the selected building are explained to analyze the case study, which is an important building in Alanya, i.e., the Alanya Municipality Building, which was constructed in 1991 and located in the center of the city by the seaside. The building was designed by the famous Turkish architect Vedat Dalokay studied architecture at Istanbul Technical University and city planning at Sorbonne University in Paris with Le Corbusier and August Perret who are the pioneers of the modern architecture. After returning to Turkey, he established an architectural office in Ankara (Naz, 2005). Because Dalokay tried to re-examine the traditional architectural attitudes in modern context, he has the respectable place not only in the history of

Turkish architecture but also in Pakistani architecture. Although he encountered the political obstacles, they could not be changed his architectural view (Pekol, 2011).

Inspired by Alvar Aalto, Frank Lloyd Wright, and especially Le Corbusier, Dalokay adopted modernism and rationalism like most architects of his time. Since his architectural attitude was considering society, it was aimed that social and cultural relations were organized in his project (Naz, 2005). In many of his projects, he has achieved a modernist line with symbolic expressions. To create these symbolic expressions, he emphasized the use of geometry. This is why he placed emphasis on the structure ("Dalokay Mimarlık Atölyesi'nde", 1991).

Figures 3.1 and 3.2 below show photographs of Alanya the municipality building.

Figure 3.1. A view of the Alanya Municipality building from the seaside (Retrieved from http://www.alanya.tv/tr/AlanyaBelediyesi)

Figure 3.2. A view of the Alanya Municipality building facing the city

The geographical coordinates of the building site are 36° 32' N, 32° 00' at sea level. The municipality building is located on the İzzet Azakoğlu Street which is parallel to one of the biggest roads in Alanya, i.e. Atatürk Caddesi, and at the end of the RıhtımStreet; which passes through the touristic part of the town where historical places from the Seljuk era such as the Red Tower, the shipyard, and the arsenal building are located. The building site is also the starting point of the beaches in the eastern part of Alanya peninsula. Figure 3.3 illustrates the location of the building.

Figure 3.3. The location of Alanya Municipality

The building of Alanya Municipality has a reinforced concrete structure with brick exterior walls, and, the windows are double glazing with aluminum frame. The building consists of two blocks: the first is the main building which has four floors above ground and one basement, and the other is an annex building which has three floors. In this study, only the main building was modelled, tested and simulated.

At the center of the building, there is an atrium with the skylights. This atrium provides not only visual connection but also the circulation between the spaces. All floors are used as office areas, and each floor has toilets both at the right and left sides of the stairs. The building has a pitched unoccupied roof with copper sheeting. The roof has no heating, ventilation, and air conditioning (HVAC) systems.

Because the building houses the municipality services, there is a high and continual traffic of people during the working hours. This situation requires that interior thermal comfort should be achieved continually. The critical point thermal comfort is cooling because of the of the climate conditions in Alanya. The weather data is given in more detail in the next section. The building is cooled by split and separate air conditioners by using electricity. In addition to that, natural ventilation is used for getting fresh air by opening the windows. The figure (Figure 3.4) shows the section of the building. The total usage of the spaces and their relations can be seen from the drawing.

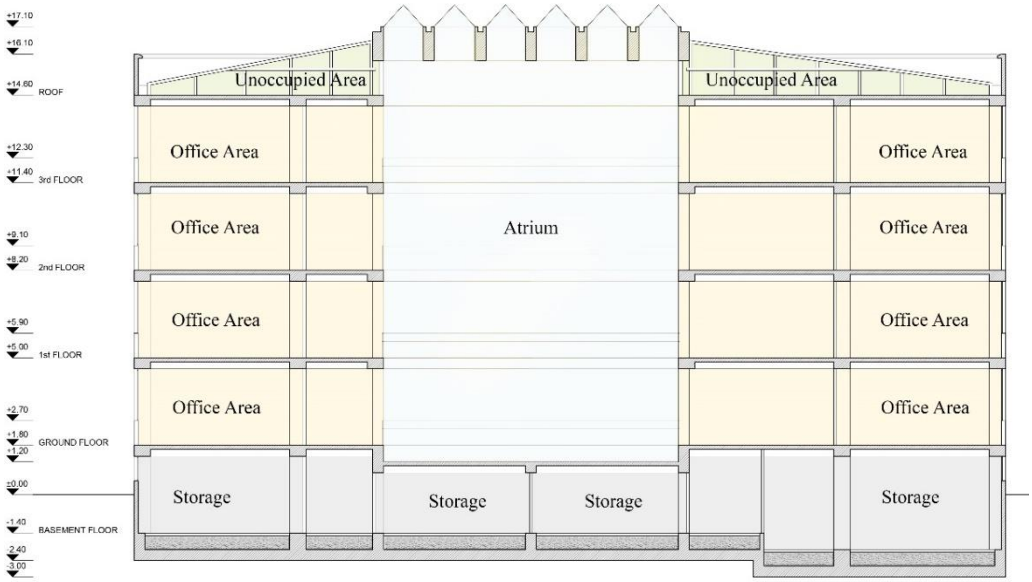


Figure 3.4. The section of the building of Alanya Municipality (Redrawn by Author)

The building consists of a storage floor whose area is 888.91 m², a ground floor 1279 m² and three typical floors 774.11 m² each. That is, the total area of the building is 4490.24 m².

Split air conditioners are used in the building. That is, there is no central cooling and heating system. 62 air conditioners were observed in the building. However, these air conditioners are used in different types such as wall type, free-standing and ceiling type. These air conditioners have been used for different years. In other words, they were taken singularly as needed and used in the building. The images of air conditioners can be found in the appendices.

3.1.2. Simulation Software

DesignBuilder software which is an advanced modelling tool for simulation is used for modelling the existing building. In addition to that, energy simulations of the building are executed by using the EnergyPlus engine which is plugged into the DesignBuilder software.

DesignBuilder software offers to import DXF formatted files. This file format can be prepared by using AutoCAD software, which helps to create 2D and 3D drawings. This situation provides the base for creating 3D model. After developing the 3D model, technical and renderer outputs can be generated. These outputs related to building performance are energy consumption, CO2 emissions, thermal comfort, daylight availability and cost. In other words, DesignBuilder provides accurate data about energy consumption of heating and cooling, comfort, solar gains, mechanical and natural ventilation, etc. throughout the design process in both naturally ventilated and air-conditioned buildings. Figure 3.5 shows the interface of the software.

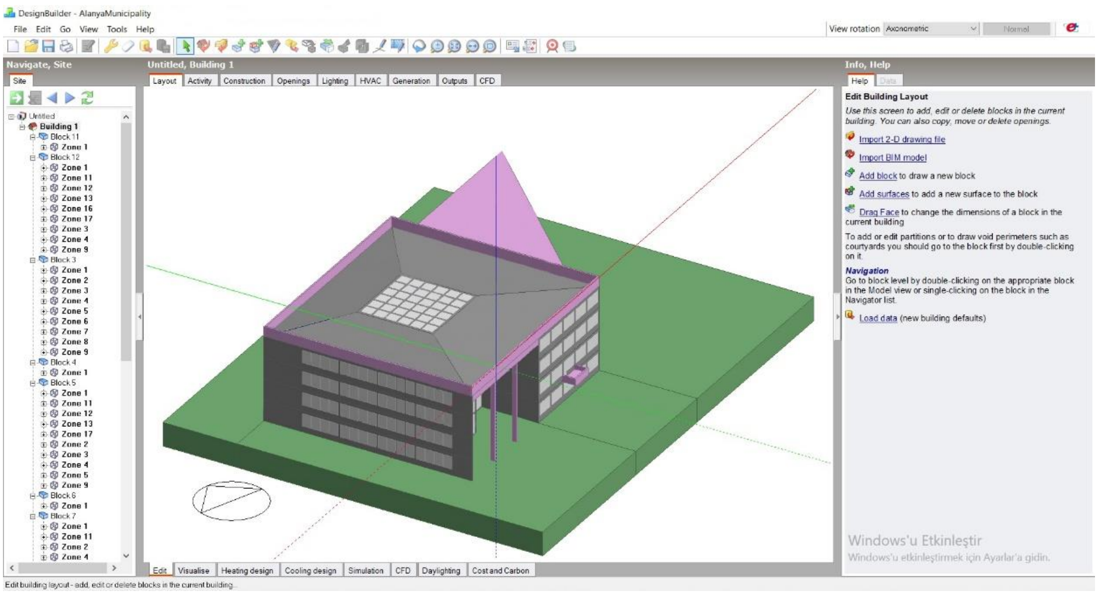


Figure 3.5. The interface of the software

Moreover, Climate Consultant software which converts EPW format raw climate data into different types of graphics is used for illustration of some weather data of Alanya. In addition to that, AutoCAD is used for showing the design of interventions and for the preparation of 2D plan drawings of existing building. Lastly, Microsoft Excel is operated to create the graphs of results.

3.1.3. Weather Data

For the simulation, the weather data of Antalya is used because Antalya has the closest weather data to Alanya. The reason of this situation is that there is no weather data file of Alanya with EPW format.

As can be understood from the Figure 3.6, Alanya has a unique microclimate. The main reason of this situation is that the Taurus Mountains are very high and very close to the city. In this way, the city is protected from cold winds coming from the northern part of Taurus Mountains, and the higher temperatures and humidity cannot be dispersed. One of the most important examples of this is the fact that unlike other Mediterranean cities, many tropical fruits can be grown in Alanya. Especially in banana cultivation, Alanya is at the forefront (Biner, Temirkaynak, & Oten, 2009). This is why the weather of Alanya is considered to be hot and humid despite the fact that is it located in the subtropical climatic zone.

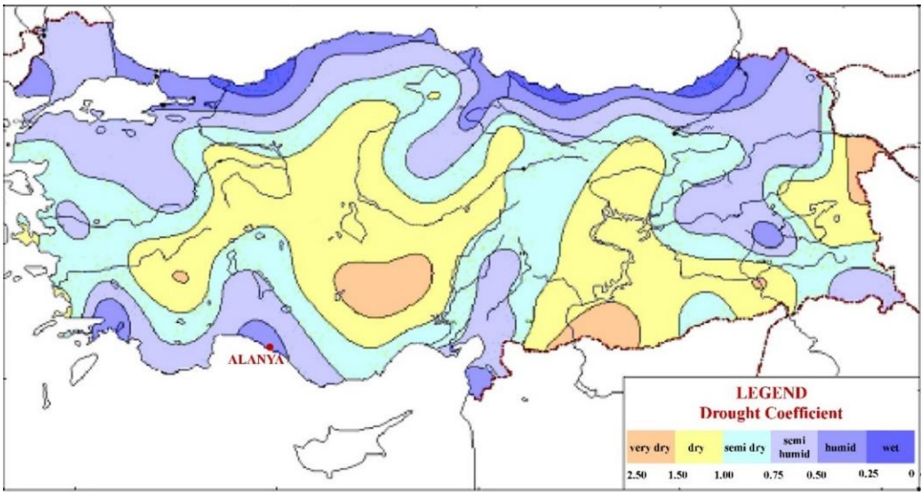


Figure 3.6. Climate classification of Turkey by Aydeniz Method (Sensoy, 2004).

Figure 3.7 which is taken from Climate Consultant software shows the temperature range and comfort zone of Alanya. This software uses the EPW format weather files. The values of temperature range and comfort zone are generated according to ASHRAE 55-2004 standards.

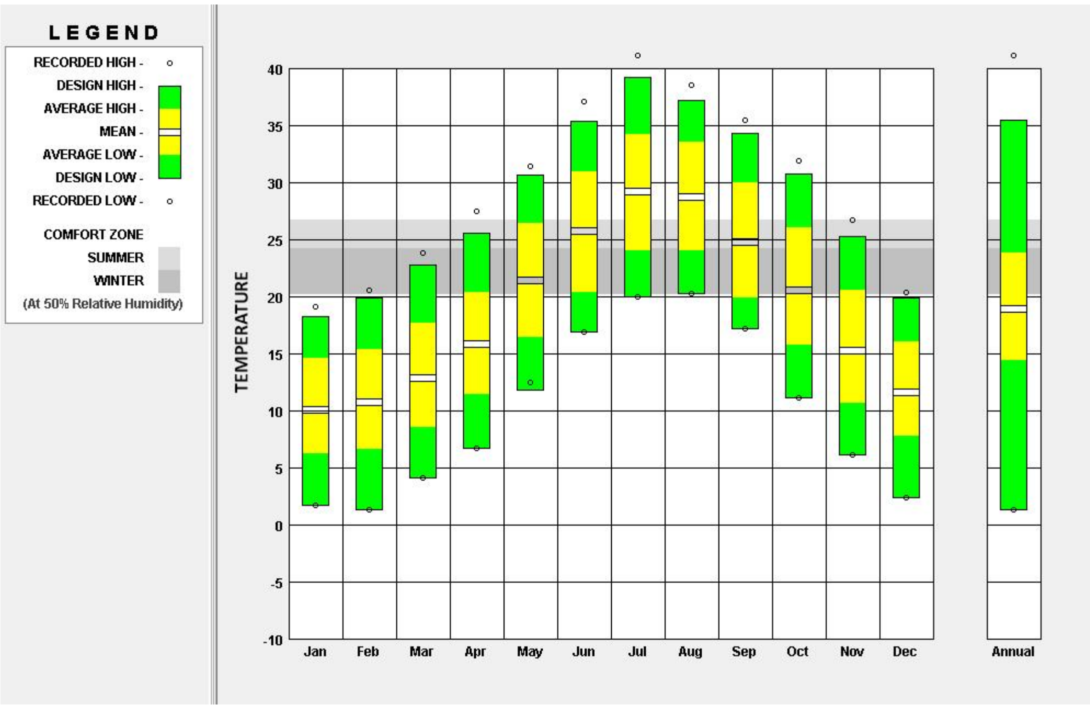


Figure 3.7. Chart showing the temperature range and comfort zone produced by Climate Consultant software

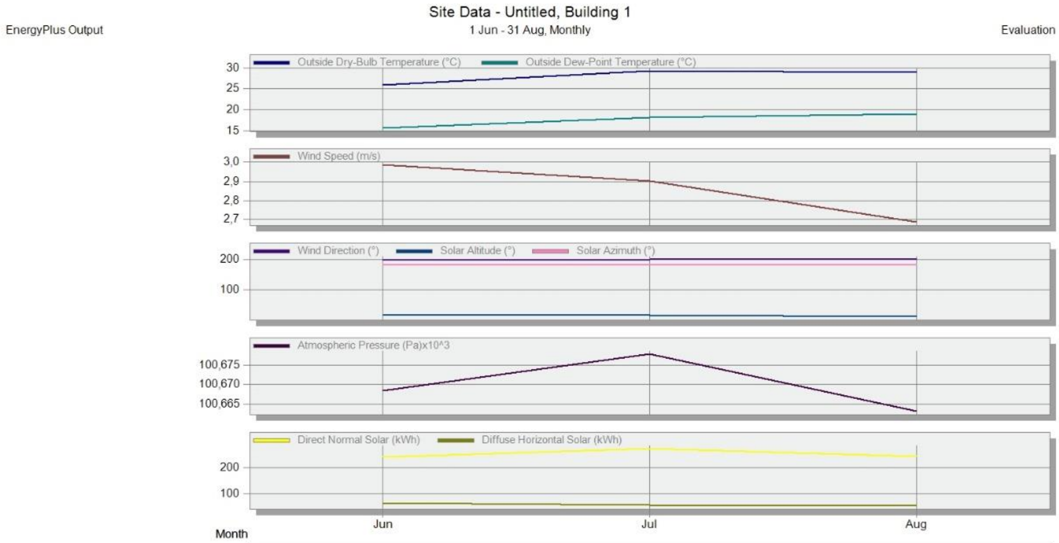
In summer months especially in July and August, it can be seen from the chart that the air temperature is much higher than comfort zone.

Climate Consultant software also provides guidelines for users. These guidelines and design proposals are created by using the features of weather data which is uploaded to the software. These proposals are listed below:

- Window overhangs and operable windows can be used to reduce or eliminate the air conditioning.
- Double pane high performance glazing (Low- E) can be applied.

- Operable walls and shaded outdoors are effective for hot climates.
- Effective natural ventilation- cross ventilation decreases the use of air conditioning.
- Light colored flat roofs can be effective for hot regions.
- Building should be designed to minimize the overheating.
- To minimize conducted heat gain, light colored building material and cool roof can be used.
- Traditional passive buildings in hot climates use small openings to prevent excessive sun light and night ventilation to cool the mass.
- Long narrow building floorplans promote cross ventilation.
- Sunny protected outdoor spaces such as courtyards and verandas can extend living areas in hot climate.
- Plantation provides thermal control; however, trees should not be planted in front of passive solar windows. They can be planted beyond 45 degrees from each corner.

Figure 3.8 illustrates the energy simulation data is taken from the EnergyPlus software databases. Because the main focus is reducing the cooling energy demand, it is expected that the data of Antalya gives similar results to the case in Alanya. The simulation is run for the three months, i.e. June, July, and August which have the highest mean temperature values.



Month	Jun	Jul	Aug
Outside Dry-Bulb Temperature (°C)	25,80	29,22	28,76
Outside Dew-Point Temperature (°C)	15,54	18,14	18,98
Wind Speed (m/s)	2,99	2,90	2,68
Wind Direction (°)	198,85	201,95	200,10
Solar Altitude (°)	17,16	15,87	10,44
Solar Azimuth (°)	184,39	183,11	183,46
Atmospheric Pressure (Pa)x10^3	100,67	100,68	100,66
Direct Normal Solar (kWh)	238,81	271,61	241,99
Diffuse Horizontal Solar (kWh)	67,93	58,91	55,04

Figure 3.8. The weather data of Antalya taken from EnergyPlus software weather databases

3.2. Method

The objective of the study is to determine, test, select and demonstrate how bioclimatic interventions and passive cooling strategies are effective for designing a sustainable building. Because of that, to apply the interventions, municipality building which is one of the most crowded buildings in Alanya is selected. Moreover, because the building is a governmental building, the results of the study may reach to the decision makers. In other words, some architectural decisions related with bioclimatic interventions and traditional construction practices may be taken into consideration while not only designing or constructing new projects but also renovating existing building. The empirical data obtained from energy simulation may help which architectural decisions are appropriate and applicable for Alanya, which is located in the south of Turkey, and has a hot and humid climate. Figure 3.9 illustrates the structure of the methodology.

In this context, the research method adopted is clarified below:

Step 1: Determining the building as a case study and collecting necessary data, i.e. images and architectural drawings.

Step 2: Modelling the existing building by using Design Builder software which is an advanced modelling tool for simulation.

Step 3: Renovating the building virtually by changing the building envelope, i.e., roof and facades, to control the sunlight and to decrease the heat absorption by the roof, and by rescheduling the ventilation to prevent intake of hot air in summer days.

Step 4: Making simulation of the existing model and the renovated models for the summer days; between 1^{st} of June and 31^{st} of August *(three months)*.

Step 5: Analysing and comparing the outputs of simulation with regards to consumption of energy for cooling.

Step 6: Combination of the most effective simulation results which are taken from different interventions.

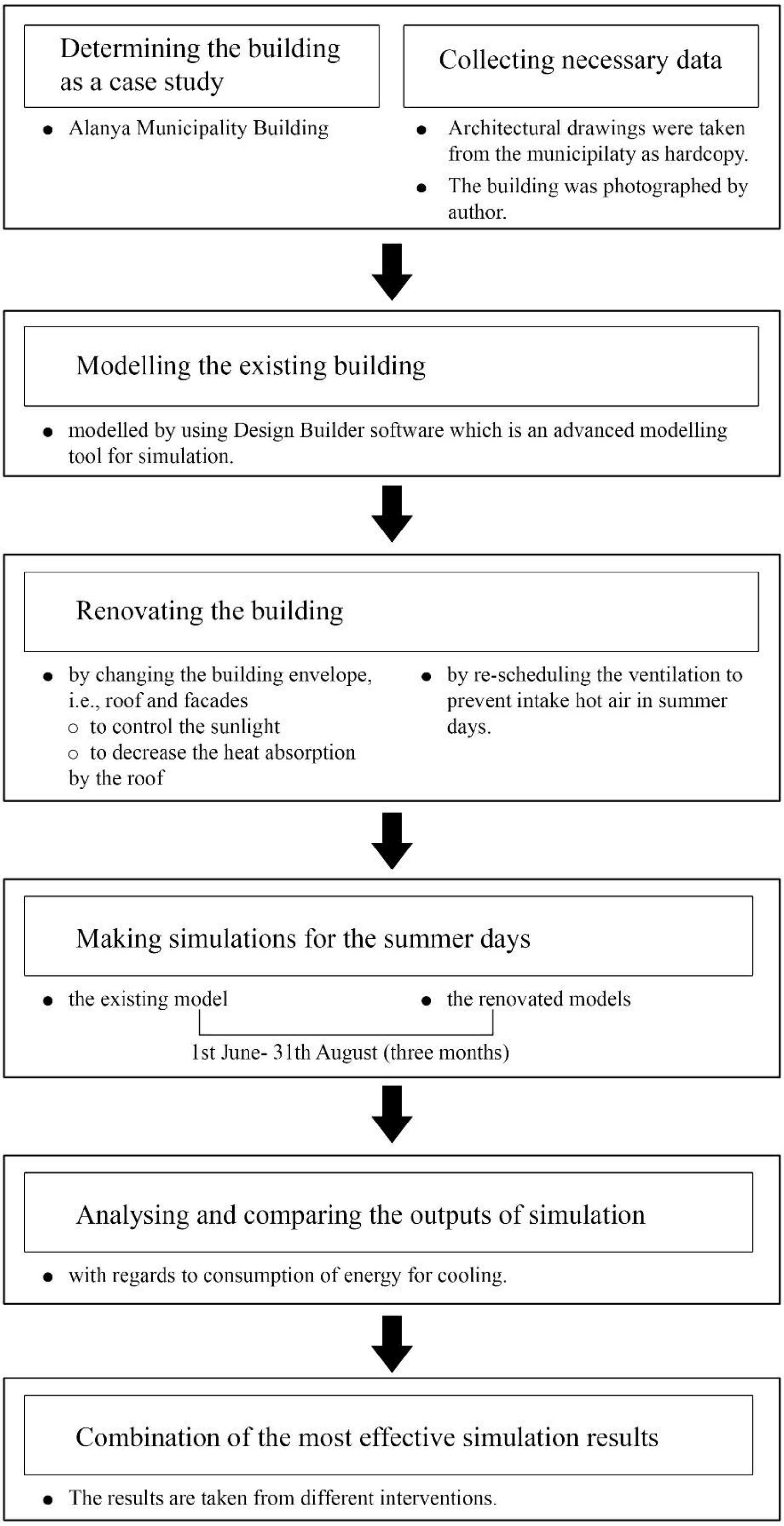


Figure 3.9. The structure of the adopted methodology

Decreasing the energy usage of the existing building for cooling is aimed by renovations which are related with building envelope and natural ventilation. Table 3.1 shows all interventions in more detail.

Table 3.1. *All interventions applied for reducing cooling energy demand prepared by Author*

<table>
<tr><td rowspan="7">R1</td><td colspan="4">ROOF</td></tr>
<tr><td>R1.1</td><td colspan="3">Green roof</td></tr>
<tr><td>R1.2</td><td colspan="3">Glazing change of the skylights</td></tr>
<tr><td>R1.3</td><td colspan="3">New roof design</td></tr>
<tr><td>R1.4</td><td colspan="3">New roof design + projection</td></tr>
<tr><td>R1.5</td><td colspan="3">New roof design + glazing</td></tr>
<tr><td>R1.6</td><td colspan="3">New roof design + projection+ glazing</td></tr>
<tr><td rowspan="7">R2</td><td colspan="4">SHADING</td></tr>
<tr><td rowspan="2">R2.1</td><td>R2.1.1</td><td>Overhang+ Sidefins</td><td>0.50 meters</td></tr>
<tr><td>R2.1.2</td><td>Overhang+ Sidefins</td><td>1.00 meters</td></tr>
<tr><td rowspan="2">R2.2</td><td>R2.2.1</td><td>Louvre</td><td>0.50 meters</td></tr>
<tr><td>R2.2.2</td><td>Louvre</td><td>1.00 meters</td></tr>
<tr><td rowspan="2">R2.3</td><td>R2.3.1</td><td>Overhang+ Sidefins+ Louvre</td><td>0.50 meters</td></tr>
<tr><td>R2.3.2</td><td>Overhang+ Sidefins+ Louvre</td><td>1.00 meters</td></tr>
<tr><td rowspan="4">R3</td><td colspan="4">GLAZING</td></tr>
<tr><td>R3.1</td><td colspan="3">ISICAM – clear double glazing</td></tr>
<tr><td>R3.2</td><td colspan="3">ISICAM K – thermal double glazing</td></tr>
<tr><td>R3.3</td><td colspan="3">ISICAM K+ – thermal triple glazing</td></tr>
<tr><td>R4</td><td colspan="4">Creating courtyard instead of atrium which is at the center of the building</td></tr>
<tr><td>R5</td><td colspan="4">Rescheduling natural ventilation as night ventilation</td></tr>
<tr><td>R6</td><td colspan="4">Courtyard + the most efficient interventions of shading and glazing+ night ventilation</td></tr>
<tr><td>R7</td><td colspan="4">New roof design + the most efficient interventions of shading and glazing+ night ventilation</td></tr>
</table>

There are five main interventions which are related with roof, shading, glazing, courtyard and ventilation. One of the last two interventions is combination of new designed courtyard, night ventilation and the most efficient interventions tested for roof, shading and glazing. The other one is combination of new designed roof, night ventilation and the most efficient interventions tested for roof, shading and glazing.

Under the roof renovation (R1), newly added green roof, changed glazing types of skylights and newly designed roof and their combination with shading and glazing are tested. Different types and dimensions of shading devices are tested to control the solar gain under the shading renovation (R2). The glazing type of the existing situation are changed and simulated under the glazing renovation (R3). Renovation 4 (R4) shows the effects of creating courtyard instead of atrium on the cooling demand of the building. Night ventilation is tested in the renovation 5 (R5). Renovation 6 (R6) and renovation 7 (R7) are the combination of all efficient interventions for reducing cooling demand.

3.2.1. Simulation Software

The 3D Model of the existing building; i.e. base case, was drawn in the DesignBuilder software to obtain the actual energy simulation outputs. DesignBuilder software generates the simulation outputs by using the EnergyPlus engine.

The starting point of the study is modelling the existing building for energy simulation. After modelling the building by using DesignBuilder, the data about materials and occupied hours of the building were arranged and these are mentioned in the following paragraphs.

Features of the base case regarding cooling period, activity, occupancy schedule, materials of walls and floors, and HVAC remained unchanged in the subsequent cases where bioclimatic interventions were integrated one by one in order to isolate their individual impacts on the cooling load. Firstly, the building was identified as generic office building in DesignBuilder software. This means that the schedule of the occupancy of the building is between 07:00 AM and 19:00 PM. In addition to that, the schedule of the cooling system is also defined as same as the schedule of occupancy. The cooling setpoint and setback temperatures are arranged as 24 °C - 28 °C respectively, according to ASHRAE standards. That is, the cooling system is started when the inside air temperature is 28 °C and stopped when 24 °C. The rate of seasonal coefficient of performance (SCOP) assigned as 4.50 because this value represents same value of A+ air conditioner. Table 3.2 shows the relation between and SCOP rate and the energy efficiency class label. Coefficient of performance (COP) represents the ratio between the number of units of heat produced by the air conditioner by using 1 unit of energy (Daşdemir & Keçebaş, 2015). For instance, the air conditioner with the COP rate 4.50 uses 1 kilowatt (kW) energy to produce 4.5 kW of heat.

Table 3.2. *The relation between energy efficiency class and SCOP value expressed by Daşdemir & Keçebaş (2015).*

ENERGY EFFICIENCY CLASS	SCOP
A+++	SCOP ≥ 5,10
A++	4,60 ≤ SCOP < 5,10
A+	4,00 ≤ SCOP < 4,60
A	3,40 ≤ SCOP < 4,00
B	3,10 ≤ SCOP < 3,40
C	2,80 ≤ SCOP < 3,10
D	2,50 ≤ SCOP < 2,80
E	2,20 ≤ SCOP < 2,50
F	1,90 ≤ SCOP < 2,20
G	SCOP < 1,90

Natural ventilation is promoted by opening windows manually at working hours. Because of that, the operation schedule of natural ventilation is identified as the hours between 07:00 AM and 19:00 PM at workdays. The value of air change per hour (ach) represents the amount of air exchange for natural ventilation and heat loss. The volume and use of space require different amount of ach. For the municipality buildings, this amount should be determined between 4 to 10 ach (Engineering ToolBox, 2005). For this study, ach value of natural ventilation is taken as 10.

Data about roofs, openings and walls of existing building is listed below:

The exterior walls are composed of four layers (outermost layer to innermost layer) of 3cm thick plaster, 20cm thick brick, 5cm thick thermal insulation (Herapor) and 2cm thick plaster. The thermal conductivity of insulation material (Herapor) is 0.047 W/mK (Acarla, 2013).

For the window, clear double glazing with 13mm air gap was used. The roof is made of a timber structure that is covered with copper sheets; 8cm thick insulation (conductivity 0.04W/mK; specific heat 840J/kg-k; and density 12kg/m3) was applied on the flat surface under the pitched roof, so a cool roof system was created. The section of the building is illustrated in Figure 3.4.

In the light of these data, the energy consumption and ventilation behavior of the existing building are tested and simulated.

3.2.2. Bioclimatic Interventions

After the simulation of existing building, in order to reduce the energy demand for cooling the building, seven main different renovation strategies, which are mentioned in Table 3.1, were applied and simulated. These can be grouped according to the ventilation schedule and three building envelope components: roofing, shading and glazing. Six proposals for changing the roof covering and design, six proposals for different shading strategies for the windows, three proposals for changing glazing type of windows, one proposal for creating a courtyard one for night cooling, one for the combination of courtyard and the other efficient interventions, and the last one proposing the combination of newly designed roof and other efficient interventions. These strategies and their impacts are explained in detail below.

3.2.2.1. Renovation Strategy 1 (R1)

The first main strategy is about changing the roof design and roof covering. There are six interventions are tested for roof.

Green Roof (R1.1)

The first strategy is about changing roof coverings. It is aimed at decreasing the energy consumption for cooling by applying a green roof instead of the existing roof. Figure 3.10 illustrates the section drawing of the proposed roof.

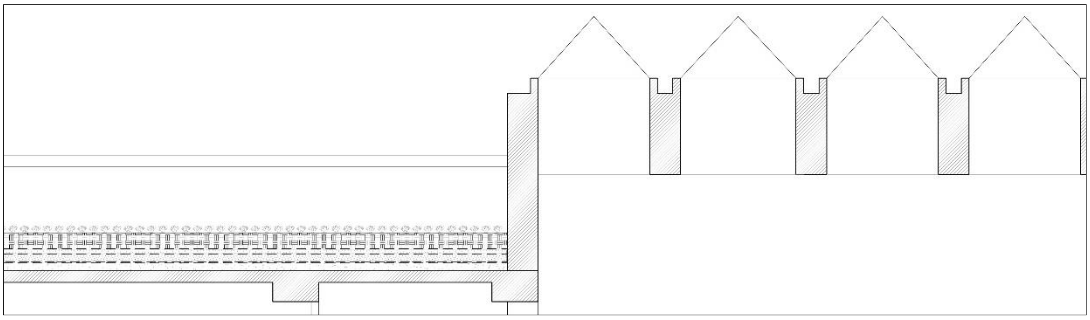


Figure 3.10. Section of the proposed green roof for R1.1

The roof layers of the renovated model are illustrated in Figure 3.11 and they are listed below (outermost layer to innermost layer):

- Plants – (height of plants are 10cm)
- Vegetational soil – 20cm (conductivity (W/m-k) = 0.3; specific heat (J/kg-k) = 1000; density (kg/m3) =1000)
- Drainage board
- Protection mat
- Thermal insulation – 8cm (same features with existing one)
- Geotextile
- Waterproof membrane
- Geotextile
- Sloping concrete – 10cm
- Reinforced concrete slab

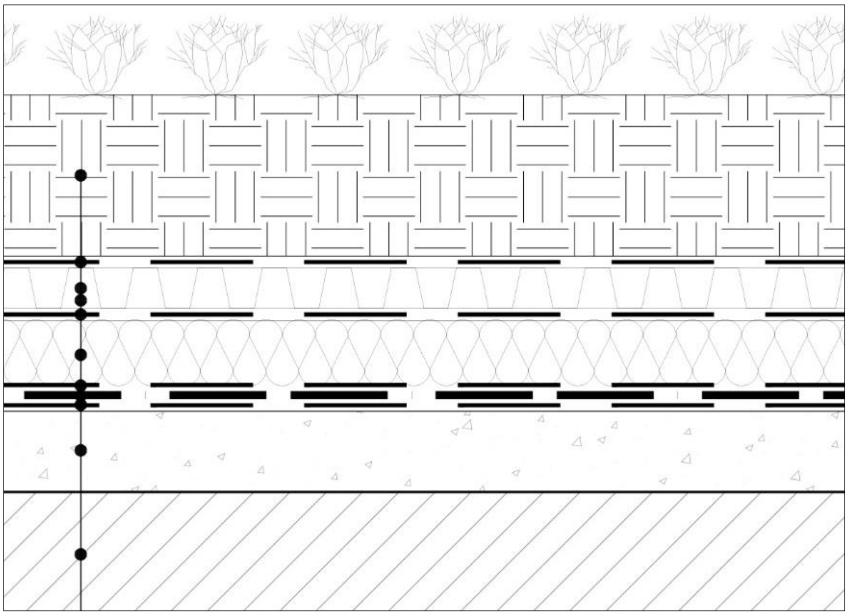


Figure 3.11. The layers of the proposed green roof

Glazing change of the skylights (R1.2)

For the second renovation, the material of the skylights is changed. In existing situation, itis 4 mm polycarbonate sheeting. For the simulation, thermal properties of the existing material are determined in DesignBuilder. The thermal properties are listed in Table 3.3. The exact thermal values of the existing material -polycarbonate- is not known so the values of the materials are taken from makrolon of Sheffield Plastics. It is assumed that the values of these materials are similar.

Table 3.3. *Thermal properties of 4 mm polycarbonate used in existing building.*

Properties	Existing Building
Total solar transmittance	0.849
Direct solar transmittance	0.808
Light transmittance	0.885
U-value (ISO 10292/ EN 673) (W/m2-K)	5.392
U-value (ISO 15099/ NFRC) (W/m2-K)	5.452

To control the daylight coming in from the skylight, new glazing is assigned instead of existing ones, from ISICAM systems, which offer solutions for thermal control in living areas. The section of the skylights is illustrated in Figure 3.12. When researching the products of ISICAM, it is claimed that K series is produced with Şişecam Solar Low-E Glass with high quality heat and solar control coating. Moreover, it also claimed that K series provide maximum thermal insulation and solar control so energy consumption for cooling and heating is reduced. Therefore, this material available in Turkey for thermal control and has been selected for proposed renovation in R1.2. The properties of the ISICAM K are listed in Table 3.4.

ISICAM K is a double-glazing window composed of Şişecam Solar Low-E glazing at outer layer, 12mm air gap, and Şişecam clear glazing at inner layer. To investigate the performance of the window system composed of different glazing and air gaps, the performance calculator can be operated from Şişecam Düzcam website.

Table 3.4. *Thermal properties of ISICAM K series glazing which is calculated in performance calculator of Şişecam Düzcam website linked from http://www.sisecamduzcam.com/tr/faaliyet-alanlarimiz/mimari-camlar/performans-hesaplayici*

Properties	ISICAM K
Total solar transmittance	0.410
Light transmittance	0.720
U-value (ISO 15099/ NFRC) (W/m2-K)	1.600

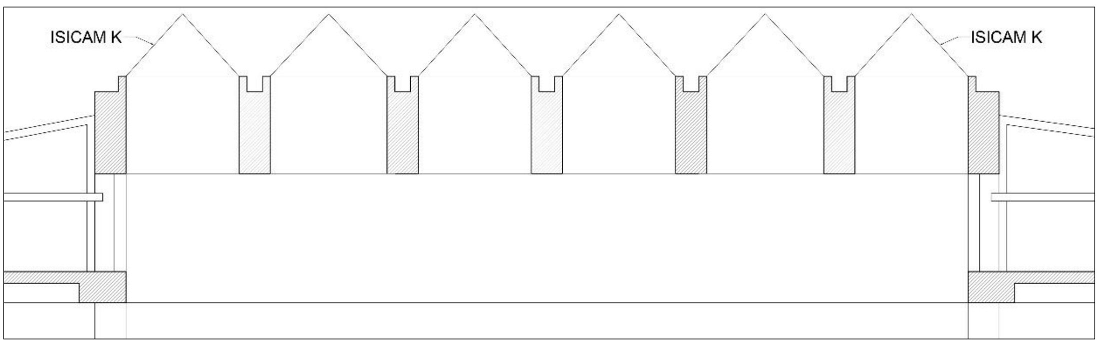


Figure 3.12. The section of the proposed skylights

New roof design (R1.3)

For the third renovation proposal regarding the roof, to control the sunlight and promote the natural ventilation, a new roof design is proposed. The last three interventions about roof are also generated with this design. Figure 3.13 and 3.14 present the 3D images, taken from DesignBuilder, and show the existing skylights and proposed roof design. The layers of the proposed roof are listed as (outmost layer to innermost layer): white plaster (2 cm- to protect from overheating), thermal insulation (8 cm- same features with existing one), reinforced concrete slab (15 cm) and plaster (2 cm).

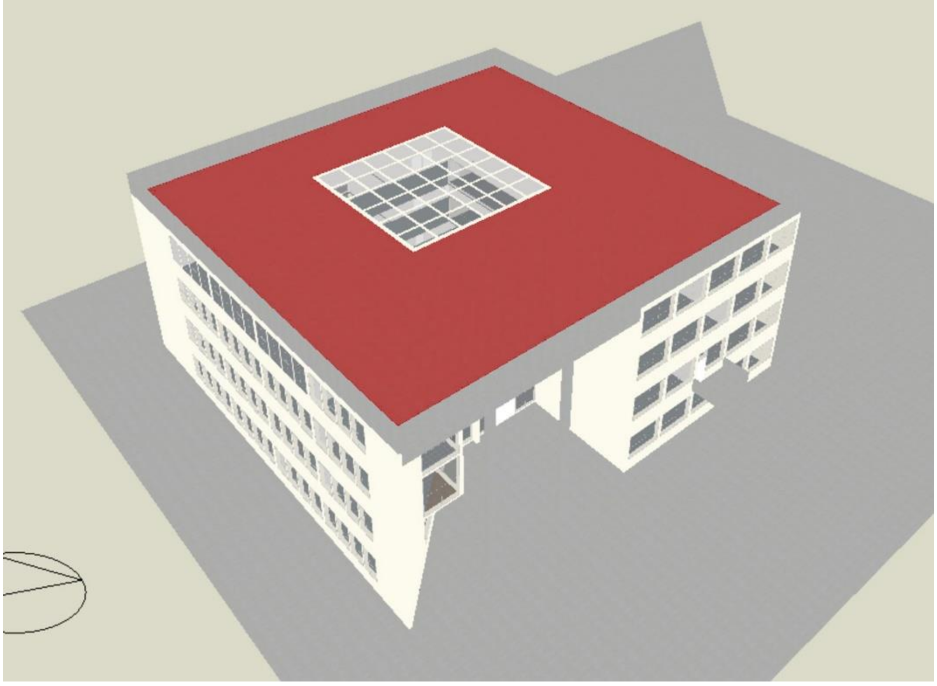


Figure 3.13. 3D view of the existing skylights drawn in DesignBuilder

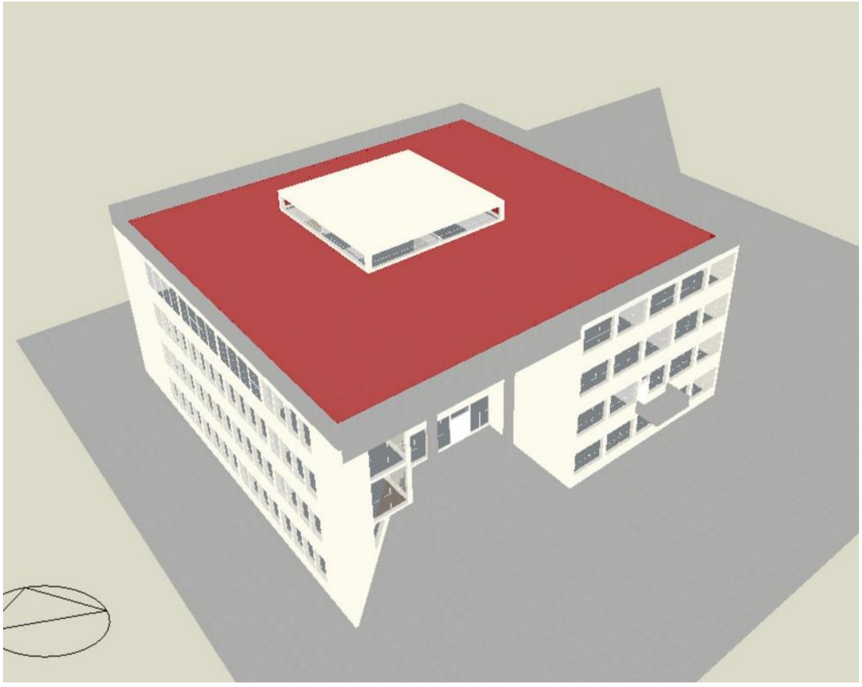


Figure 3.14. 3D view of the new roof drawn in DesignBuilder

The atrium at the center of the building is overheated during the day due to the openings of the skylights which are fixed –and cannot be opened to exhaust the heated air-. Therefore, when designing this proposal, it is aimed not only to prevent overheating because of the greenhouse effect, but also to remove heated air by using the bioclimatic principle of stack ventilation. Figure 3.15 illustrates the section of this intervention.

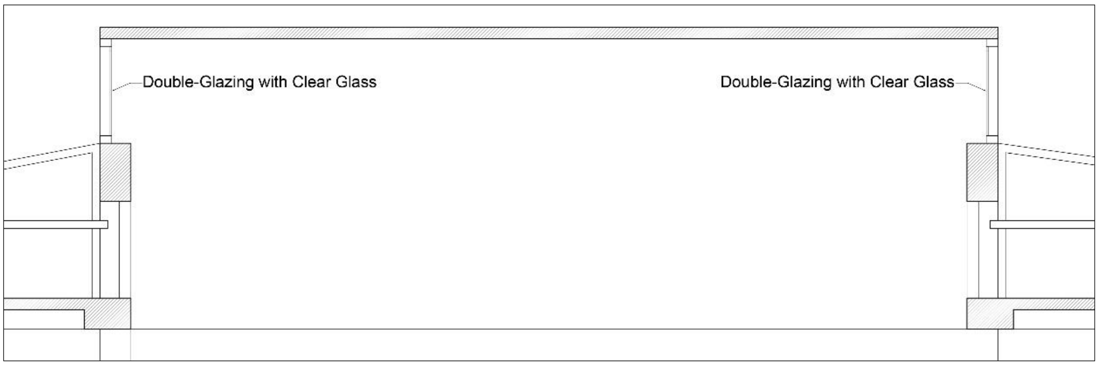


Figure 3.15. The section of the proposed roof for Renovation 1.3

New roof design + projection (R1.4)

For this renovation, the slab of the new flat roof is extended by 1 meter from each edge. To observe the effects of 1-meter projections on cooling demand, and to compare the results of proposed roof and this intervention, they are simulated individually. Figure 3.16 shows the section of this intervention.

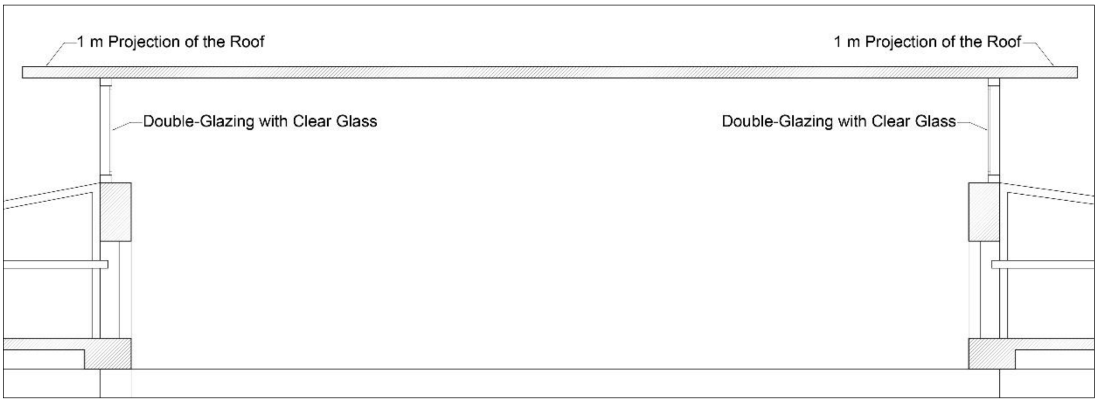


Figure 3.16. The section of the proposed roof for Renovation 1.4

New roof design + glazing (R1.5)

The proposed renovated roof (R1.3) is improved by changing the glazing type. Double glazing with clear glass is used in existing situation. For this renovation, ISICAM K, which is examined in detail in terms of energy performance, is used instead of clear double-glazed windows. Figure 3.17 shows the section of Renovation 1.5. In short, it is tried to improve Renovation 1.4 in terms of thermal performance.

Figure 3.17. The section of the proposed roof for Renovation 1.5

New roof design + projection + glazing (R1.6)

The last intervention on the roof design is the combination of R1.4 and R1.5. In other words, 1-meter projection and ISICAM K series glazing are added to this new roof design. All of these six interventions applied on the roof are simulated and compared; and the most efficient one is selected for the renovation.

The section of this intervention is illustrated in Figure 3.18.

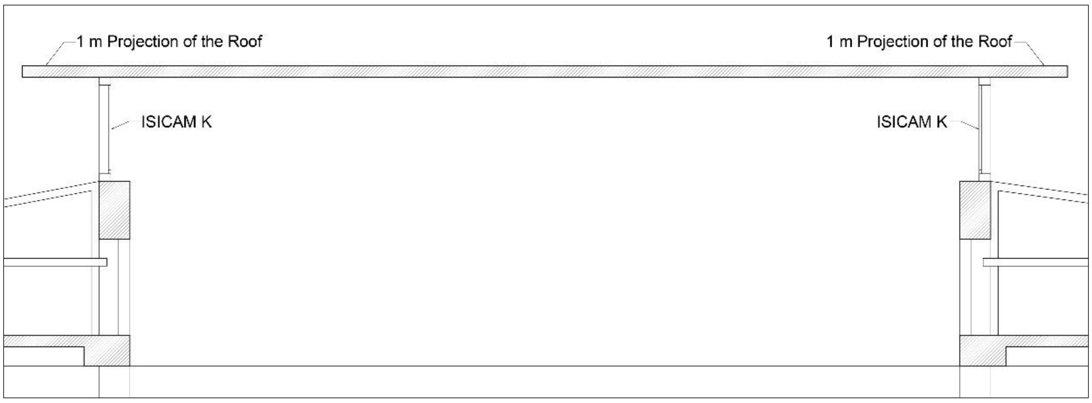


Figure 3.18. The section of the proposed roof for Renovation 1.6

3.2.2.2. Renovation Strategy 2 (R2)

In this main strategy, the interventions show how different types and dimensions of shadings are effective to reduce energy consumption for cooling. In Figure 3.19, the types of shadings are illustrated. In the following six interventions, three different types of shading devices, whose dimensions are 0.50 meters and 1-meter, are tested. In this way, the effects of different types of shading and their dimensions can be tested individually.

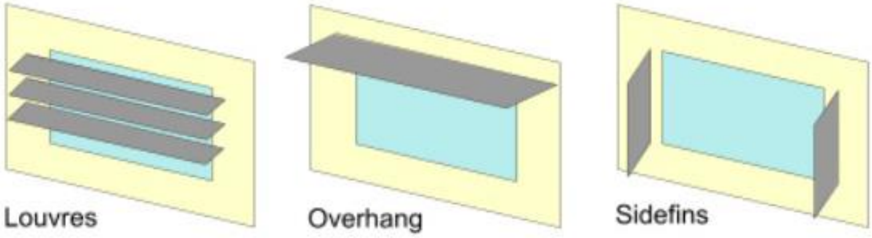


Figure 3.19. Shading devices which are used for renovation strategies

Because the existing building was oriented through the south-east direction, overhangs and sidefins are used together to control the sunlight. That is, the building cannot gain solar light from south, east or west, directly. Therefore, the combination of the shading is used. The combination of overhang and sidefins, louvres type shading, and the combination of these three shading is tested. These interventions are explained in more detail below.

Overhang + sidefins (R2.1)

To control the solar gain and to prevent direct solar light, firstly, overhang and sidefins shading types are used together. Moreover, two different dimensions of these shadings are also tested. The building is located at an angle of 22°. Therefore, these are applied on southeast, northeast and southwest facades of the building. In Figure 3.20, the orientation of the building can be seen.

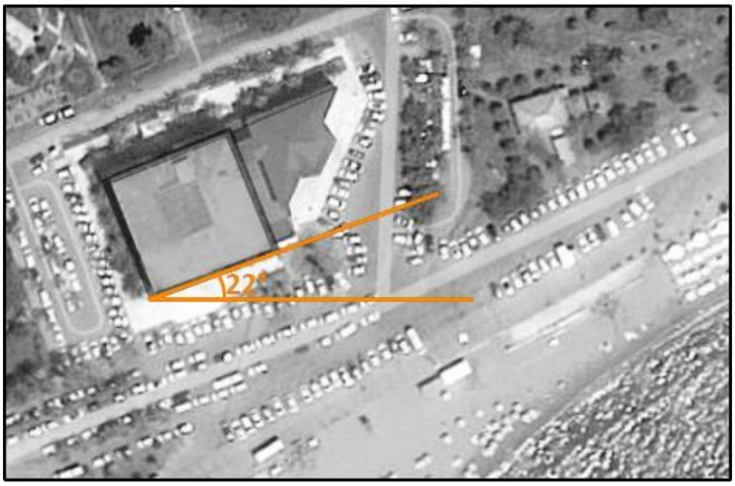


Figure 3.20. The orientation of the building

In this section, two shadings with different depth are examined. The first one, which has 0.50 meters depth, is shown in Figure 3.21.

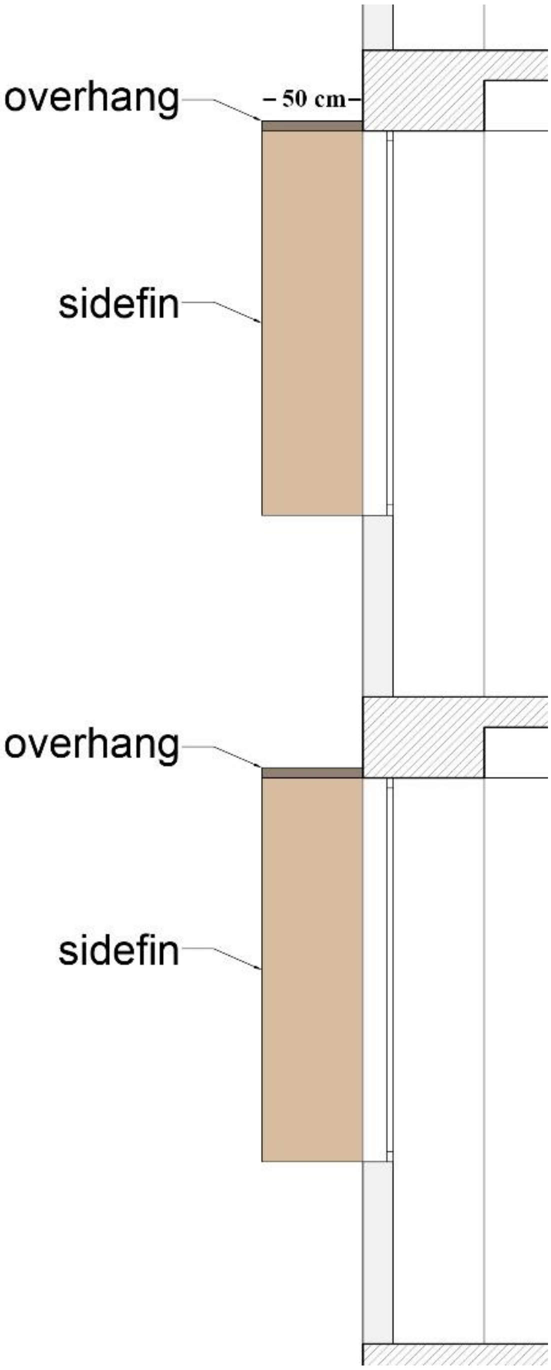


Figure 3.21. The section of the proposed shading devices for Renovation 2.1.1

The other intervention has 1-meter deep shading devices. It is illustrated in Figure 3.22.

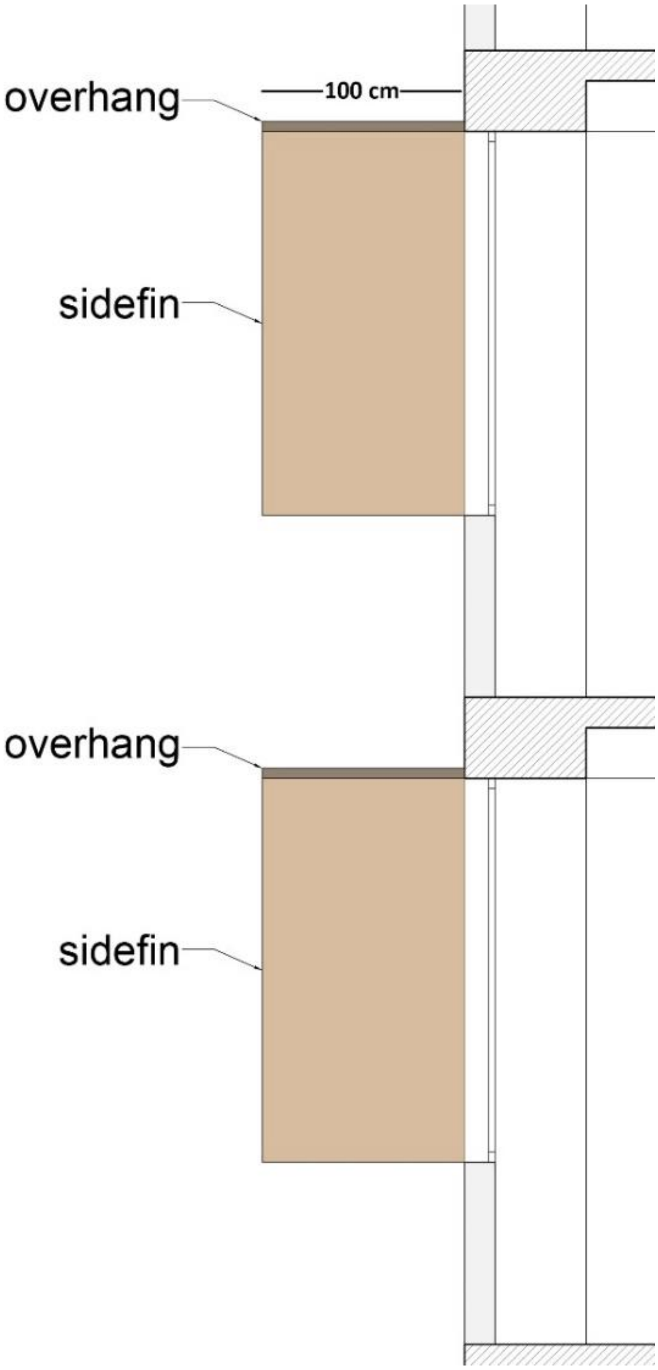


Figure 3.22. The section of the proposed shading devices for Renovation 2.1.2

The materials of the shadings are determined as wood panels with 4 cm thickness.

Louvre (R2.2)

The second intervention about shading is using louvre type shading device. In this intervention, shadings are applied in two different dimensions to test and compare the energy performance for cooling. Figure 3.23 and 3.24 show the sections of louvre type shadings with different lengths of projections which are 50 cm and 100 cm.

The properties of these two shadings are demonstrated in Figure 3.23 and 3.24. These shadings are mentioned in DesignBuilder software as 0.5 m and 1 m projection louvre. Blade depth is changed in these situations, but the other parameters remain the same.

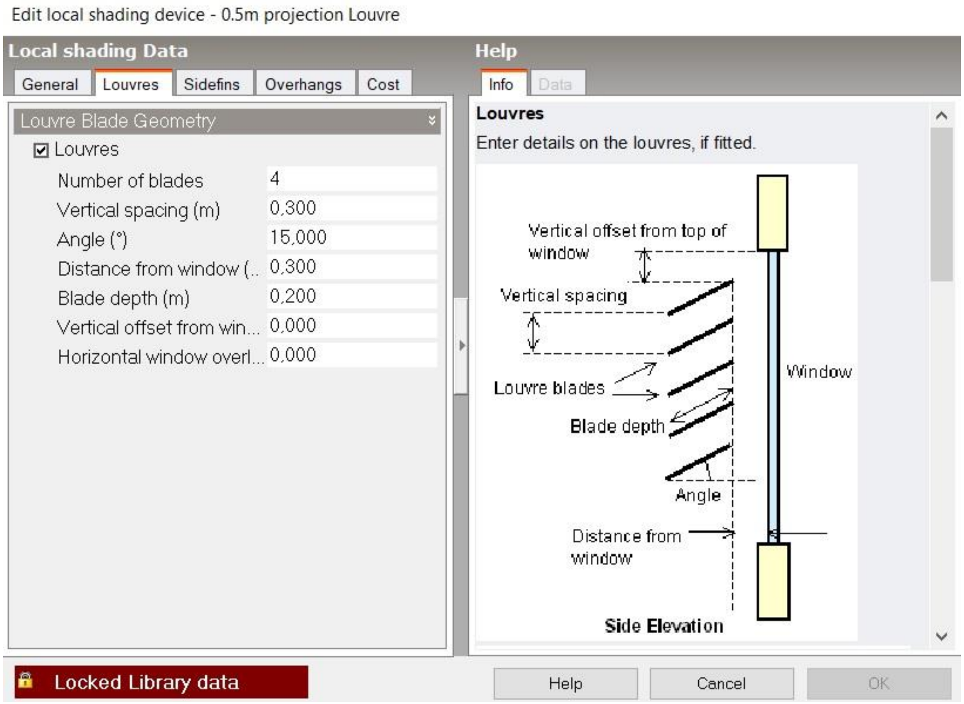


Figure 3.23. Model data of 0.5m projection louvre

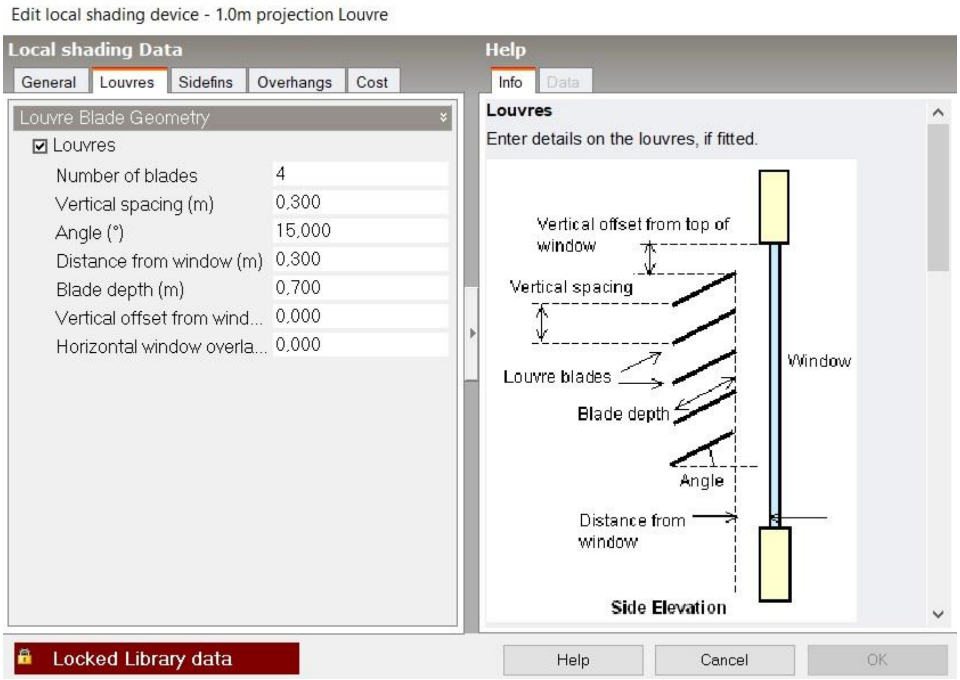


Figure 3.24. Model data of 1.0m projection louvre

Figure 3.23 and 3.24 helps to demonstrate the parameters of louvre type shading. These parameters can be arranged according to the demand of designers. After the model data is determined as in figures above, these two are applied and simulated to calculate the effects on the cooling demand of building. Moreover, Figure 3.25 shows the section drawings of these interventions.

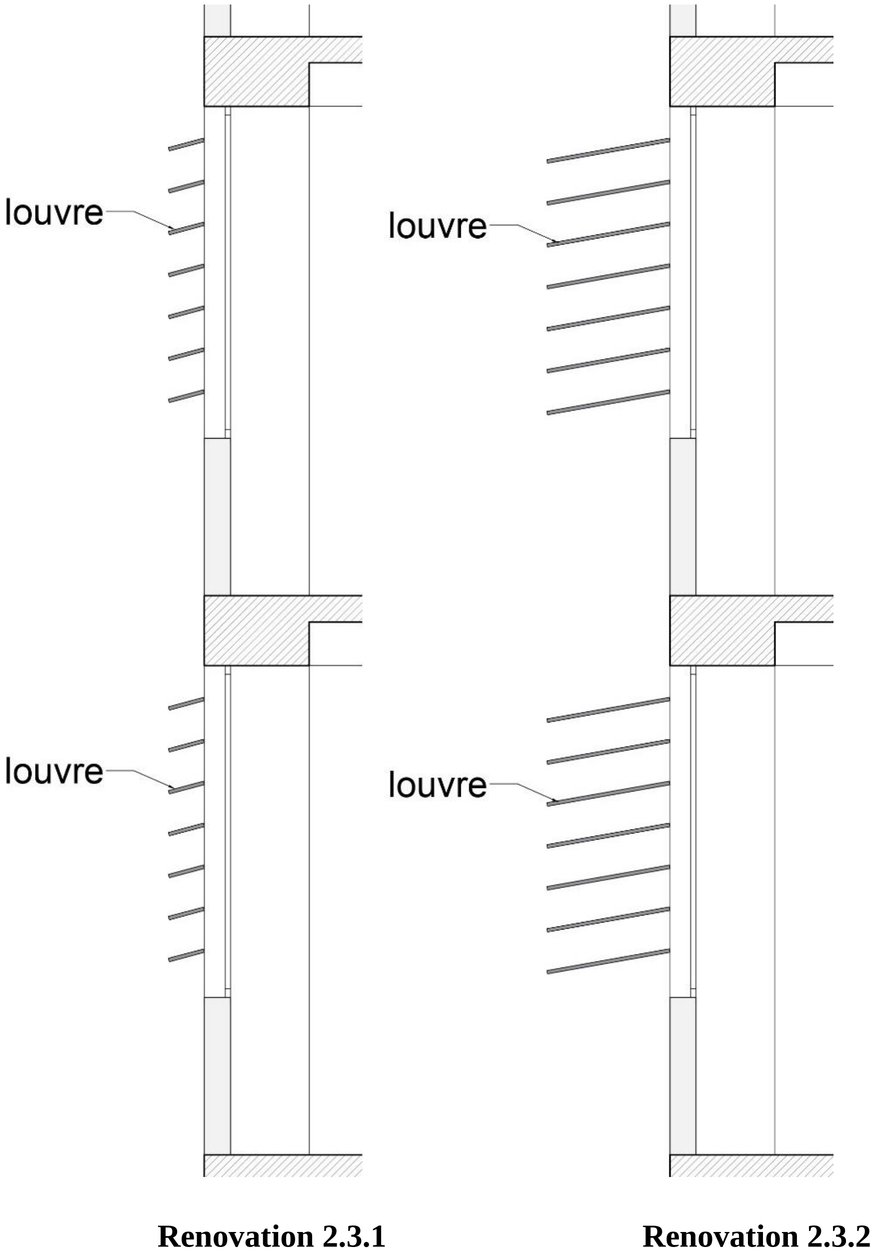
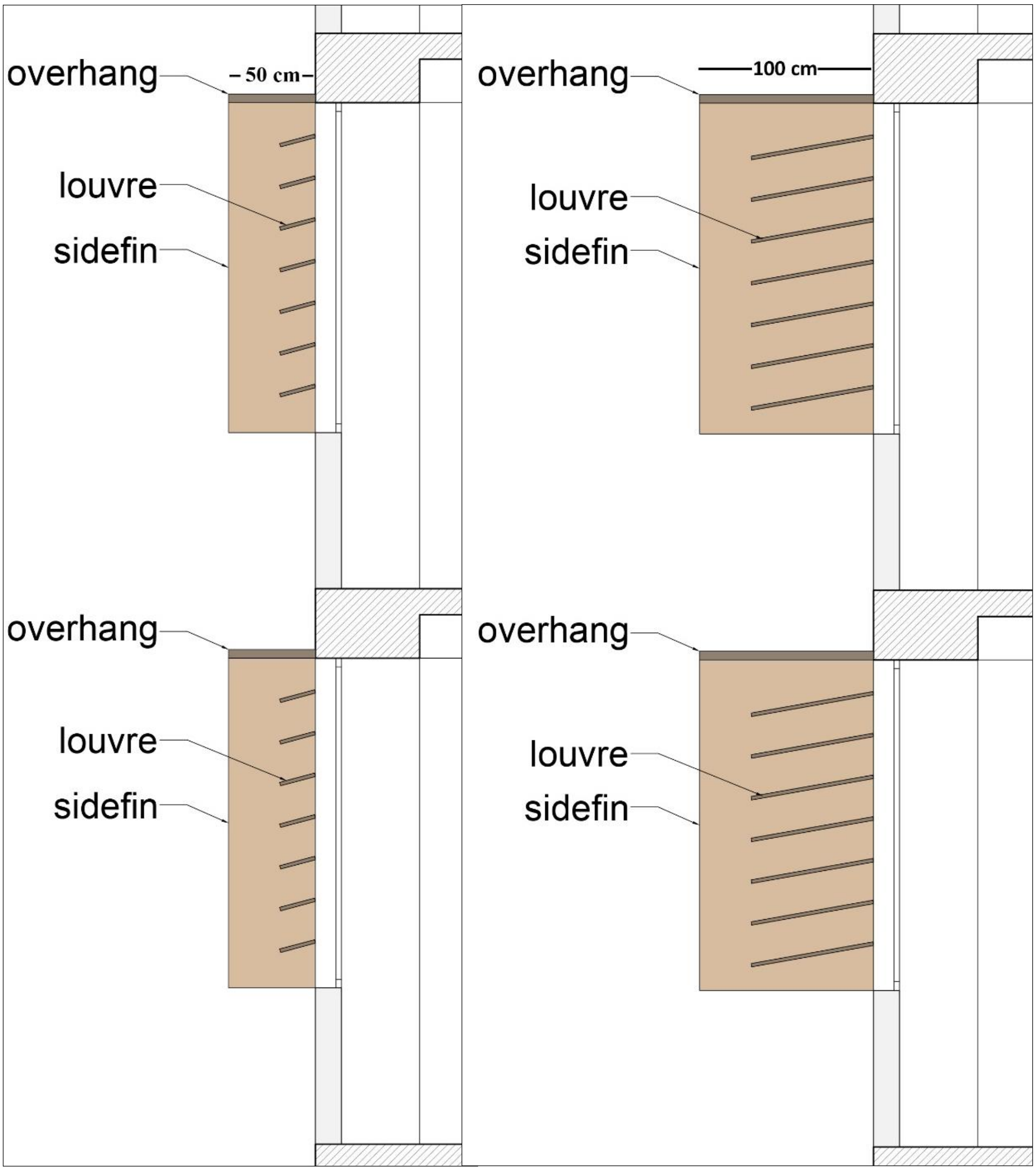


Figure 3.25. The section drawings of Renovation 2.2.1 (blade depth 0.20m) and Renovation 2.2.2 (blade depth 0.70m)

Overhang + sidefins + louvre (R2.3)

In this intervention, three different types of shading are combined to obtain maximum sunlight control. There are also two different projections with different lengths for testing. Figure 3.26 illustrates these two interventions with two projections, which are the combination of three different shading types.



Renovation 2.3.1 **Renovation 2.3.2**

Figure 3.26. The section drawings of Renovation 2.3.1 and Renovation 2.3.2

3.2.2.3. Renovation Strategy 3 (R3)

This renovation strategy is about observing the effects of glazing types on energy consumption. In this strategy, two different types of ISICAM series are used instead of existing glazing. In addition to that, to obtain the actual data after the simulations, and to test the energy performance of the existing clear double glazing, ISICAM clear double glazing is also simulated. In other words, to achieve reliable comparisons, it is checked whether the thermal behaviours of existing windows and clear double glazing of ISICAM series are similar or not.

In this section, three types of glazing, which are ISICAM clear double glazing, ISICAM K, and ISICAM K+, are examined to reduce the cooling demand of building.

ISICAM- clear double glazing (R3.1)

In first intervention, the existing glazing type is changed with ISICAM clear double glazing as mentioned above. The aim of this renovation is to test the similarities in the thermal behavior of existing glazing and the intervention. Table 3.5 below gives information on the existing and renovated glazing types; while Table 3.6 lists the various glazing properties.

Table 3.5. *Glazing types*

Glazing Layers	Existing Building	R3.1
Outermost pane	Clear 4mm	Şişecam Clear 4mm
Air Gap	12mm Air	12mm Air
Innermost pane	Clear 4mm	Şişecam Clear 4mm

Table 3.6. *Glazing properties*

Properties	Existing Building	R3.1
Total solar transmittance	0,742	0,740
Light transmittance	0,801	0,820
U-value(W/m²K)	2,725	2,900

ISICAM K- thermal double glazing (R3.2)

In this section, ISICAM K series glazing types, which are double glazing window composed of Şişecam Solar Low-E glazing at outer layer, 12mm air gap, and Şişecam clear glazing at inner layer, are used for windows to increase the thermal performance of the building. Glazing types are listed in Table 3.7, while glazing properties are given in Table 3.8.

Table 3.7. *Glazing types*

Glazing Layers	Existing Building	R3.2
Outermost pane	Clear 4mm	Şişecam Solar Low-E 4mm
Air Gap	12mm Air	12mm Air
Innermost pane	Clear 4mm	Şişecam Clear 4mm

Table 3.8. *Glazing properties*

Properties	Existing Building	R3.2
Total solar transmittance	0.742	0.410
Light transmittance	0.801	0.720
U-value(W/m²K)	2.725	1.600

ISICAM K+ - thermal triple glazing (R3.3)

Triple glazed windows have better thermal performances, so to improve the thermal performance of the building, the existing windows are changed with triple glazed ones.

While Table 3.9 shows the glazing types, glazing properties can be seen in Table 3.10.

Table 3.9. *Glazing types*

Glazing Layers	Existing Building	R3.3
Outermost pane	Clear 4mm	Şişecam Solar Low-E 4mm
Air Gap	-	16mm Air
Pane 2	-	Şişecam Clear 4mm
Air Gap	12mm Air	16mm Air
Innermost pane	Clear 4mm	Şişecam Solar Low-E 4mm

Table 3.10. *Glazing properties*

Properties	Existing Building	R3.3
Total solar transmittance	0.742	0.330
Light transmittance	0.801	0.640
U-value(W/m^2K)	2.725	0.700

While triple glazed windows have great advantages because of their thermal performances, there are also some disadvantages. In other words, triple glazed windows improve the thermal comfort more than double glazed ones for the spaces which are close to the windows. However, they are expensive, and they require stronger hinges and frames (Portatec, 2018). In the lights of the information above, the interventions are applied and then, the simulations are run.

3.2.2.4. Renovation Strategy 4 (R4)

In this intervention, the courtyard is created instead of the atrium at the center of the building. That is, the atrium space redesigned as an open-air courtyard. Courtyards have been used for centuries for social and cultural interactions, and environmental benefits (Almhafdy *et al*., 2013a). Huang *et al*. (2014) claims that courtyards have a great potential to passively cool the buildings. Therefore, reducing the cooling demand of the building is aimed at while applying this bioclimatic intervention.

While creating the courtyard, the area of the space, which is required to cool, is decreased. In addition to that, cross ventilation is promoted. Moreover, overheating which is caused by fixed skylights can be prevented by creating courtyard at the center of the building. Finally, by using 20x40 cm wooden purlins at the roof, it is tried to prevent courtyard from direct solar light. Figure 3.27 demonstrates the section drawing of the intervention while Figure 3.28 shows the image taken from 3D Model drawn in DesignBuilder.

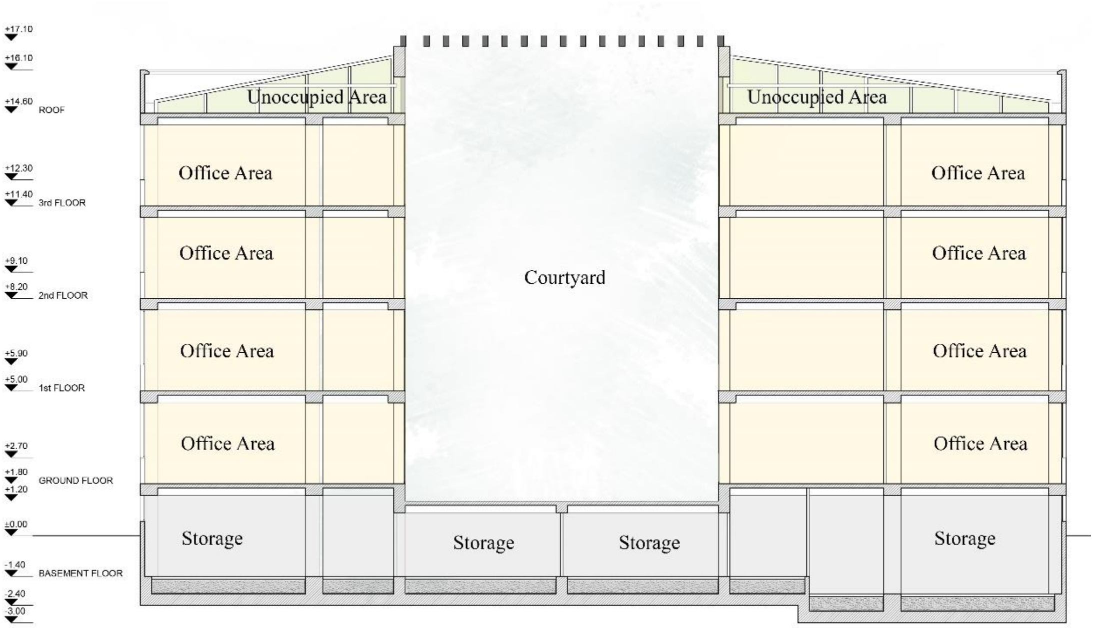


Figure 3.27. The section drawings of the propose courtyard for Renovation 4

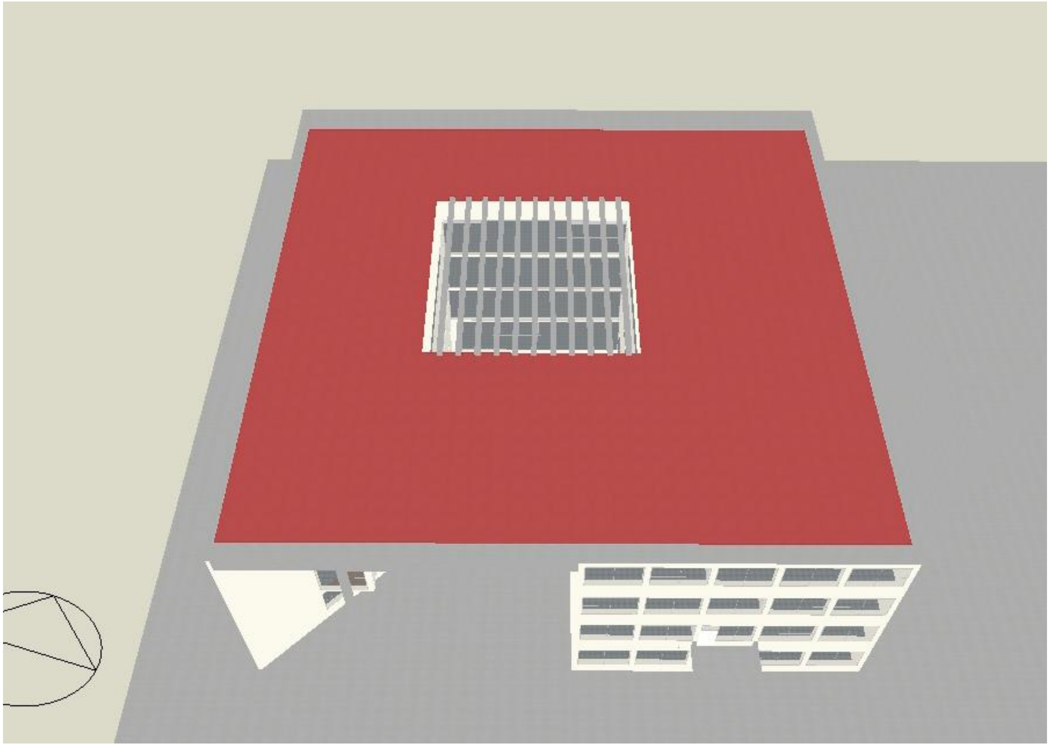


Figure 3.28. 3D Model of Renovation 4 produced in DesignBuilder

3.2.2.5. Renovation Strategy 5 (R5)

In renovation strategy 5, night ventilation is promoted as the next important bioclimatic intervention. This issue is examined in literature review chapter and according to the studies, it is one of the most efficient strategies for hot and humid climates. The reason why night ventilation is quite efficient for passive cooling is that the outside temperature in hot and humid climates is always higher than thermal comfort range in daytime. In existing case, natural ventilation is promoted manually and there is no other system serving to it. Because of these reasons, the schedule of natural ventilation is rearranged according to the outside dry-bulb temperature. Figure 3.29 and 3.30 demonstrate the dry-bulb temperature of Antalya hourly. These figures are taken from Climate Consultant software. While arranging the new schedule, these data are used as guidelines.

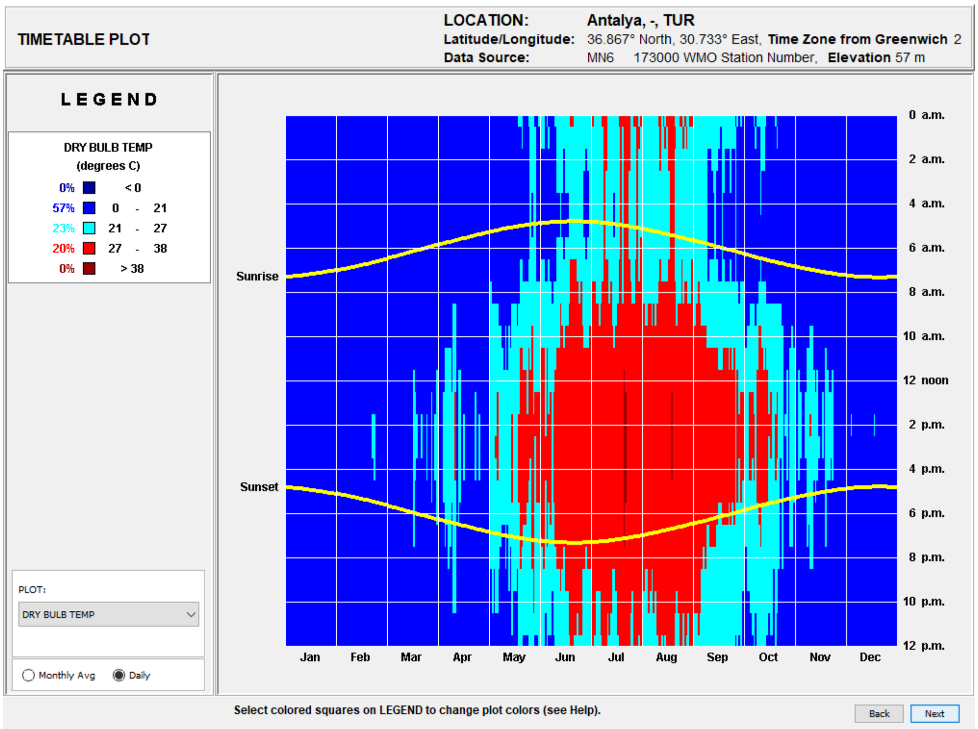


Figure 3.29. Daily Dry Bulb Temperature of Alanya

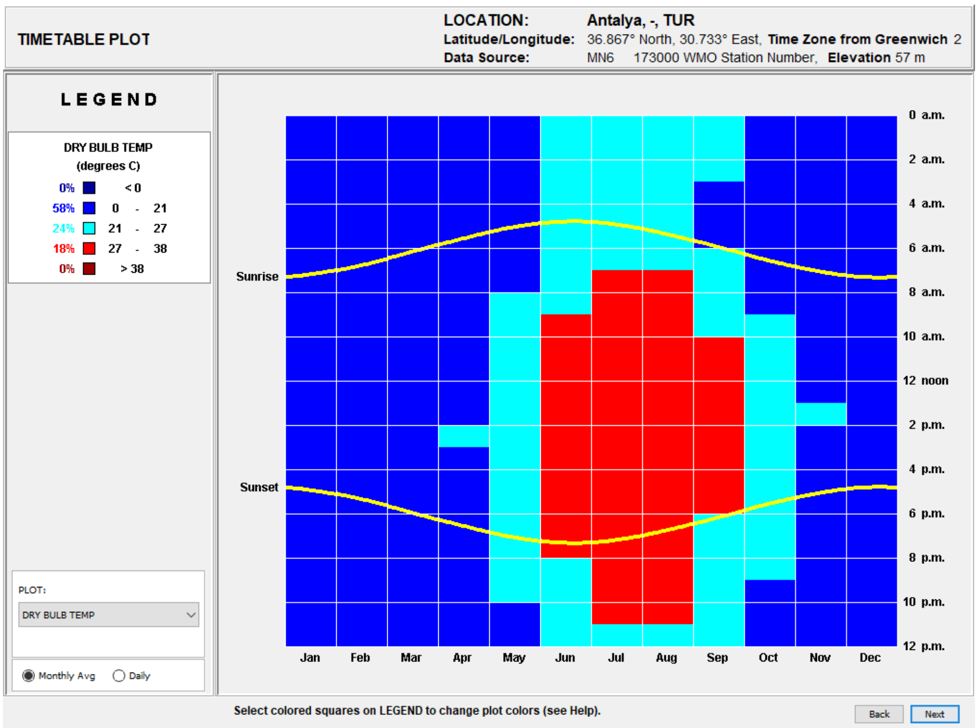


Figure 3.30. Monthly Dry Bulb Temperature of Alanya

From the figures (Figure 3.29 and 3.30), it can be understood that the outside dry bulb temperature never become less than the thermal comfort requirements during the office hours of the municipality. Because of that, when promoting natural ventilation in daytime, the fresh but warmer air coming from outside can raise the temperature inside. For the simulation of existing situation, the schedule of natural ventilation is specified between the hours 07:00 am and 07:00 pm. This situation causes increasing energy demand for cooling. Therefore, the arrangement of schedule of natural ventilation can help to decrease cooling energy demand. New schedule of natural ventilation is generated from the figures above. It can be seen that outside dry bulb temperature decreases under the thermal discomfort value between the hours 11:00 pm and 07:00 am. For this reason, the schedule of natural ventilation is arranged between these hours. Consequently, night ventilation is promoted.

3.2.2.6. Renovation Strategy 6 (R6)

Five main bioclimatic interventions up to now are applied and tested individually. For the last two interventions, the most efficient ones in terms of energy performance are combined for optimization of the building in the matter of cooling energy demand.

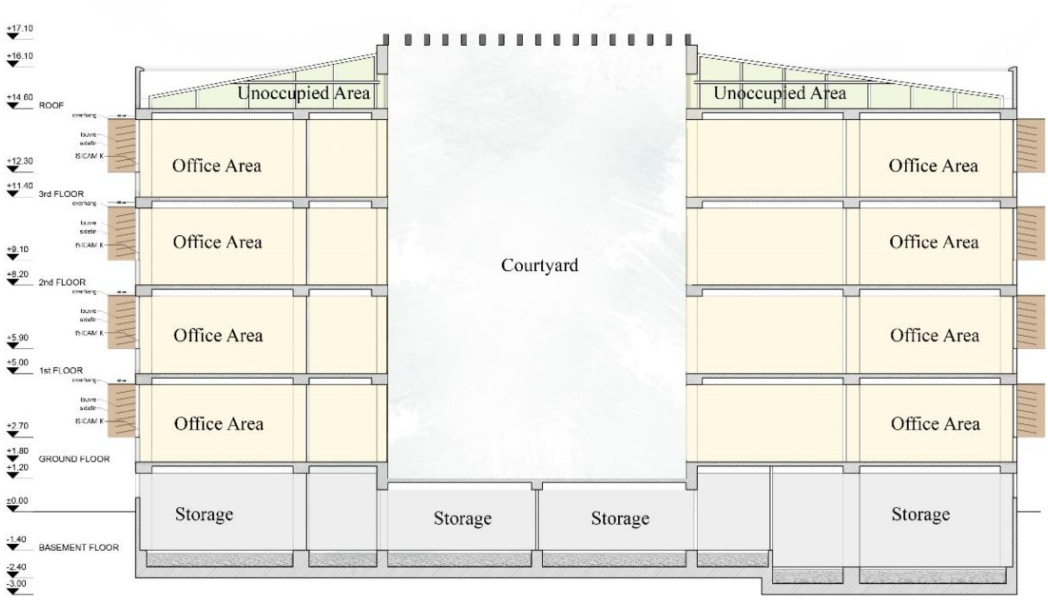


Figure 3.31. The section drawing of the combined interventions for Renovation 6

The proposed courtyard and a new roof design proposal are used for both of last two strategies. In renovation strategy 6, in addition to the proposed courtyard, ISICAM K series glazing types are used instead of existing ones. Moreover, the combination of overhang, sidefins, and louvre type shadings are applied to the windows. Lastly, night ventilation is introduced in the building. In short, in this strategy, the interventions which are R2.3.2, R 3.2, R4, and R5 are combined and simulated concurrently. Figure 3.31 illustrates the section drawing of this intervention.

3.2.2.7. Renovation Strategy 7 (R7)

The last intervention is the combination of new roof design and other strategies. In other words, R1.6, R2.3.2, R3.2, and R5 are applied and simulated. Figure 3.32 shows the section drawing of this intervention.

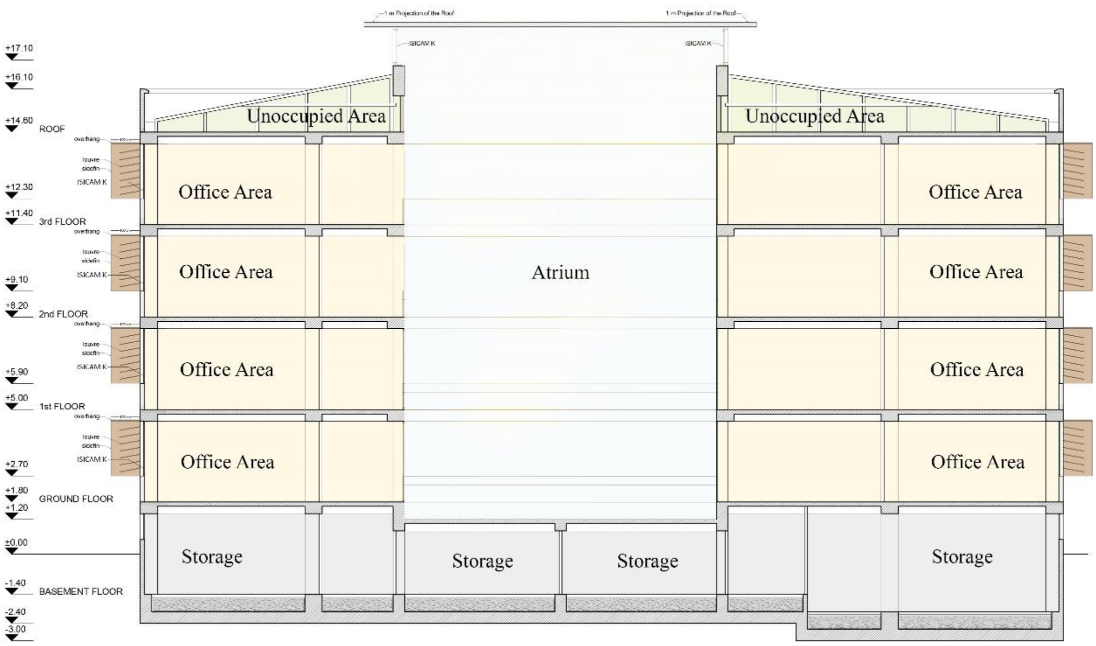


Figure 3.32. The section drawing of Renovation 7 (Drawn by Author)

CHAPTER 4

RESULTS AND DISCUSSIONS

Simulation results of each renovation strategy are presented in this chapter. The results of each strategy mentioned in method section above are examined in different sections. Thereby, it can be seen that how these interventions are effective for decreasing cooling demand for the existing building in hot and humid climate.

4.1. Simulation Results of Existing Building

The building was modeled as it exists with the characteristics given in the previous section and then simulated to determine its cooling energy consumption during the three hottest months; i.e. the days between 1st June to 31th August. The amount of electric energy consumed to cool it was found to be 122024.84 kWh as can be seen in Table 4.1. In order to reduce the energy demand for cooling the building, nineteen different renovations strategies were applied and simulated. These are grouped as seven main strategy. The impacts of these strategies are explained in detail below.

Table 4.1. *Cooling energy consumption in existing building*

Summer month	**Cooling Energy Consumption in Existing Building (kWh)**
June	32689.14
July	43294.70
August	46041.00
TOTAL	122024.84

4.2. Simulation Results of Existing Building

In this section, the results of the energy simulation for the six proposed interventions for the roof are given separately. The results obtained for each intervention with regard to the energy consumption are also compared individually with the base case data.

4.2.1. Bioclimatic Interventions

The first strategy about the roof is about changing roof coverings. It is aimed at decreasing the energy consumption for cooling by applying a green roof instead of the existing roof. Table 4.2 shows the energy consumption for both monthly and total cooling.

Table 4.2. *Cooling energy consumption in R.1.1*

Summer month	**Cooling Energy Consumption for R.1.1 (kWh)**	**Reduction in Consumption (%)**
June	32536.95	0.47
July	42784.98	1.18
August	45562.39	1.04
TOTAL	120884.32	0.93

The simulation results for the building in terms of total energy consumption for cooling show that 120884.32 kWh are consumed. Hence, by applying this strategy, the energy demand of the building was decreased by 1140.52 kWh for three months. That is, 0.93% energy conservation was achieved.

4.2.2. Simulation Results of R.1.2

The second strategy about the roof is about changing glazing of the skylights. By changing the existing glazing with ISICAM K series glazing, this intervention is simulated. Table 4.3 shows the energy consumption of this strategy for cooling.

Table 4.3. *Energy consumption of R.1.2*

Summer month	Cooling Energy Consumption for R.1.2 (kWh)	Reduction in Consumption (%)
June	30906.01	5.45
July	41427.16	4.31
August	44121.36	4.17
TOTAL	116454.53	4.56

It is simulated that 116454.54 kWh energy are consumed for the cooling. As a consequence, total energy consumption was decreased by 5570.31 kWh at the days between 1st June- 31th August by applying R.1.2 strategy. In other words, 4.56% energy conservation was achieved.

4.2.3. Simulation Results of R.1.3

For the Renovation 1.3, roof is redesigned to control the direct sunlight and promote the natural ventilation. By this way, the design is simulated. Hence, 8853.32 kWh energy was saved for three months as it can be seen in Table 4.4. Hereby, energy consumption was decreased by 7.26%.

Table 4.4. *Energy consumption of R.1.3*

Summer month	Cooling Energy Consumption for R.1.3 (kWh)	Reduction in Consumption (%)
June	29868.84	8.63
July	40283.37	6.96
August	43019.31	6.56
TOTAL	113171.52	7.26

4.2.4. Simulation Results of R.1.4

Renovation 1.4 was applied to the flat roof of the new design with the 1-meter projection in each direction.

Table 4.5. *Energy consumption of R.1.4*

Summer month	Cooling Energy Consumption for R.1.4 (kWh)	Reduction in Consumption (%)
June	29601.48	9.45
July	39995.43	7.62
August	42687.13	7.26
TOTAL	112284.04	7.98

When obtaining the simulation results of this intervention, it can be seen that 9740.80 kWh energy was saved for three months. Table 4.5 demonstrates monthly and total energy consumptions. In this way, energy consumption was decreased by 7.98%.

4.2.5. Simulation Results of R.1.5

In the Renovation 1.5, the existing glazing types were changed with ISICAM K glazing types in the new roof design. Table 4.6 shows the simulation results.

Table 4.6. *Energy consumption of R.1.5*

Summer month	Cooling Energy Consumption for R.1.5 (kWh)	Reduction in Consumption (%)
June	29602.01	9.44
July	40034.06	7.53
August	42742.24	7.16
TOTAL	112378.31	7.91

By applying this strategy, 9646.53 kWh energy for cooling was saved. In other words, there is a decrease by 7.91%.

4.2.6. Simulation Results of R.1.6

The last strategy of the roof is the combination of new glazing system, 1-meter projection and new roof design. Table 4.7 illustrates the monthly energy consumption for cooling.

Table 4.7. *Energy consumption of R.1.6*

Summer month	Cooling Energy Consumption for R.1.6 (kWh)	Reduction in Consumption (%)
June	29459.72	9.88
July	39875.94	7.90
August	42578.63	7.52
TOTAL	111914.29	8.29

This strategy saves 10110.55 kWh energy. Moreover, it is achieved that 8.29% energy was saved by applying this strategy.

4.3. Simulation Results of R.2

The results of the energy analysis about six different shading types are given in this section. They are gathered three different sub-headings which are R2.1, R2.2, R2.3 because three different type of shadings are applied.

4.3.1. Simulation Results of R.2.1.1

For the first strategy about shading, 0.5 meters length overhang and sidefins type shading are applied for the windows. The results of this intervention can be seen in Table 4.8.

Table 4.8. *Energy consumption of R.2.1.1*

Summer month	Cooling Energy Consumption for R.2.1.1 (kWh)	Reduction in Consumption (%)
June	31237.50	4.44
July	41794.29	3.59
August	44517.56	3.31
TOTAL	117549.35	3.67

When applying this intervention, 4475.49 kWh energy was saved. That is, %3.67 energy saving was achieved.

4.3.2. Simulation Results of R.2.1.2

In this strategy, 1-meter length shadings which are overhang and sidefins are used and simulated. Table 4.9 shows the monthly and total energy consumption results.

Table 4.9. *Energy consumption of R.2.1.2*

Summer month	**Cooling Energy Consumption for R.2.1.2 (kWh)**	**Reduction in Consumption (%)**
June	30310.40	7.28
July	40808.55	5.74
August	43458.56	5.61
TOTAL	114577.51	6.10

In the light of this data, the energy demand of the building was reduced to 114577.51 kWh. Hence, energy consumption was decreased by 7447.33 kWh by using this strategy; i.e. 6.10% energy conservation was achieved for three summer months.

4.3.3. Simulation Results of R.2.2.1

Louvre type shadings with 0.5 meters length are applied for the windows in this strategy. The simulation results can be seen in Table 4.10.

Table 4.10. *Energy consumption of R.2.2.1*

Summer month	**Cooling Energy Consumption for R.2.2.1 (kWh)**	**Reduction in Consumption (%)**
June	31087.16	4.90
July	41608.80	3.89
August	44067.43	4.29
TOTAL	116763.39	4.31

As a result, energy demand for consumption was decreased by 5261.45 kWh by using this strategy. In other words, this value represents the decrease of energy usage by %4.31.

4.3.4. Simulation Results of R.2.2.2

In this strategy, unlike the previous one, the lengths of louvre type shadings were increased to 1 meter. The energy demand of this strategy can be seen in Table 4.11.

Table 4.11. *Energy consumption of R.2.2.2*

Summer month	Cooling Energy Consumption for R.2.2.2 (kWh)	Reduction in Consumption (%)
June	31087.16	4.90
July	41608.80	3.89
August	44067.43	4.29
TOTAL	116763.39	4.31

When applying this intervention, 8746.09 kWh energy was saved. That is, %7.17 energy saving was achieved.

4.3.5. Simulation Results of R.2.3.1

The combination of three shading types with 0.5 meters length are applied in this strategy. Table 4.12 illustrates the energy consumption of renovated building.

Table 4.12. *Energy consumption of R.2.3.1*

Summer month	Cooling Energy Consumption for R.2.3.1 (kWh)	Reduction in Consumption (%)
June	30093.06	7.94
July	40580.14	6.27
August	43052.17	6.49
TOTAL	113725.37	6.80

The energy demand of the building was reduced to 113725.37 kWh. Therefore, when applying this strategy, energy consumption was decreased by 8299.47 kWh by using this strategy. Hence, 6.80% energy conservation was achieved.

4.3.6. Simulation Results of R.2.3.2

The last strategy about shadings is the combination of three shading types with 1-meter length. Table 4.13 shows the energy simulation results.

Table 4.13. *Energy consumption of R.2.3.2*

Summer month	Cooling Energy Consumption for R.2.3.2 (kWh)	Reduction in Consumption (%)
June	29233.61	10.57
July	39722.03	8.25
August	42163.63	8.42
TOTAL	111119.27	8.94

In the light of this data, the energy demand of the building was reduced to 111119.27 kWh. Hence, energy consumption was decreased by 10905.57 kWh by using this strategy; i.e. 8.94% energy conservation was achieved for three summer months.

4.4. Simulation Results of R.3

To observe the effects of glazing types on energy demand of the building, the energy simulation results of three different glazing is tested in this chapter.

4.4.1. Simulation Results of R.3.1

To make the comparisons between ISICAM glazing series and the existing window glazing more reliable, firstly, clear double glazing from ISICAM was tested as the glazing materials of the building. The results of the simulation can be seen in Table 4.14.

Table 4.14. *Energy consumption of R.3.1*

Summer month	Cooling Energy Consumption for R.3.1 (kWh)	Reduction in Consumption (%)
June	32692.46	0.01
July	43282.32	0.02
August	46019.72	0.04
TOTAL	121994.50	0.02

After the simulation, the difference of the energy demand between the ISICAM clear double glazing and existing glazing is obtained as 30.34 kWh; i.e. %0.02 energy consumption change is occurred. Because of that, it can be said that the thermal behavior of these two glazing types are similar.

4.4.2. Simulation Results of R.3.2

In this strategy, ISICAM K series glazing types are applied and tested. The energy consumption results for cooling are given in Table 4.15.

Table 4.15. *Energy consumption of R.3.2*

Summer month	Cooling Energy Consumption for R.3.2 (kWh)	Reduction in Consumption (%)
June	30136.61	7.81
July	40462.53	6.54
August	43063.12	6.47
TOTAL	113662.26	6.85

By this strategy, 8362.58 kWh energy was saved. This means that %6.85 energy conservation was achieved.

4.4.3. Simulation Results of R.3.3

ISICAM K+ thermal triple glazed windows are applied instead of existing ones in this strategy. The results of these strategies can be seen in Table 4.16.

Table 4.16. *Energy consumption of R.3.3*

Summer month	**Cooling Energy Consumption for R.3.2 (kWh)**	**Reduction in Consumption (%)**
June	29475.21	9.83
July	39629.23	8.47
August	42222.52	8.29
TOTAL	111326.96	8.77

The energy demand of the building was reduced to 111326.96 kWh. Hence, energy consumption was decreased by 10697.88 kWh by using this strategy; i.e. 8.77% energy conservation was achieved for three summer months.

4.5. Simulation Results of R.4

In this strategy, the courtyard is designed instead of the atrium. Table 4.17 shows the results of the simulation.

Table 4.17. *Energy consumption of R.4*

Summer month	**Cooling Energy Consumption for R.4 (kWh)**	**Reduction in Consumption (%)**
June	28578.53	12.57
July	37840.96	12.60
August	40595.28	11.83
TOTAL	107014.77	12.30

The results show that the energy demand was decreased to 107014.77 kWh. Therefore, 15010.07 kWh energy was saved. By this way, energy consumption was reduced by %12.30.

4.6. Simulation Results of R.5

In renovation strategy 5, night ventilation is promoted. Table 4.18 shows the results of the simulation.

Table 4.18. *Energy consumption of R.5*

Summer month	**Cooling Energy Consumption for R.5 (kWh)**	**Reduction in Consumption (%)**
June	16024.08	50.98
July	19324.47	55.37
August	20506.65	55.46
TOTAL	55855.20	54.23

In the light of this data, the energy demand of the building was decreased to 55855.20 kWh. Hence, energy consumption was decreased by 66169.64 kWh by using this strategy; i.e. 54.23% energy conservation was achieved for three summer months.

4.7. Simulation Results of R.6

In this strategy, R2.3.2, R 3.2, R4, and R5 are combined together because of their high percentage energy saving. The results of the renovation 6 can be seen in Table 4.19.

Table 4.19. *Energy consumption of R.6*

Summer month	**Cooling Energy Consumption for R.6 (kWh)**	**Reduction in Consumption (%)**
June	10415.78	68.14
July	13059.69	69.84
August	14103.20	69.37
TOTAL	37578.67	69.20

By applying renovation 6, the total energy demand for summer months was decreased to 37578.67 kWh. That is, 84446.17 kWh energy was saved. In other words, the energy consumption for cooling was reduced by %69.20.

4.8. Simulation Results of R.7

In this strategy, R1.6, R2.3.2, R3.2, and R5 are applied and simulated to reduce energy demand of the existing building. Table 4.20 demonstrates the results of the renovation 7.

Table 4.20. *Energy consumption of R.7*

Summer month	Cooling Energy Consumption for R.7 (kWh)	Reduction in Consumption (%)
June	9947.46	69.57
July	12635.78	70.81
August	13742.65	70.15
TOTAL	36325.89	70.23

When considering this strategy and the simulation results, the total energy demand was decreased to 36325.89 kWh for summer months. Hence, energy demand was reduced by 85698.95 kWh. In other words, %70.23 energy saving was achieved.

4.9. Evaluation of All Strategies

While evaluating the results of all strategies explained in detail above, firstly, the strategies are compared among themselves. In other words, there are several interventions in the section of roof, shading and glazing, so they are evaluated individually. Then, the most efficient ones of them and the other strategies are presented all together.

Hence, six roof strategies are compared firstly. Then, six shading strategies are evaluated. After that, three glazing strategies are examined. Lastly, seven different strategies are evaluated and discussed.

Firstly, the data of six strategies belonging to the roof is presented in Table 4.21 below.

Table 4.21. *Three months energy simulation results of existing building and roof renovations.*

Cooling Energy Consumption for Roof Strategies (1st June- 31st August)		
Strategies About Roof	Energy Demand in (kWh)	Reduction in Demand (%)
Existing building	122024.84	-
Green roof (R1.1)	120884.32	0.93
Glazing change of the skylights (R1.2)	116454.53	4.56
New roof design (R1.3)	113171.52	7.26
New roof design + projection (R1.4)	112284.04	7.98
New roof design + glazing (R1.5)	112378.31	7.91
New roof design +projection+ glazing (R1.6)	111914.29	8.29

As shown in the Table 4.21, most efficient strategy is Renovation 1.6 which is composed of the new roof proposal with 1-meter eaves and ISICAM K series glazing type. Green roof instead of copper covered roof provides 0.93% decrease for energy consumption. The main reason why the lower value belongs to green roof is that the existing roof system is an insulated cool roof, so it is already a good application for preventing the roof from overheating. For this case, green roof also provides decreased consumption. The reason why the new roof proposal is the most effective for energy saving is not only preventing the atrium from direct sun light, but also enabling for hot air release from the roof.

Secondly, the energy demand of shading strategies which are in different lengths and types are presented in Table 4.22.

Table 4.22. *Three months energy simulation results of existing building and shading renovations.*

Cooling Energy Consumption for the Strategies about Shading Devices (1st June- 31st August)		
Strategies About Shading Devices	Energy Demand in (kWh)	Reduction in Demand (%)
Existing Building	122024.84	-
Overhang+ sidefins *0.50 meters* (R2.1.1)	117549.35	3.67
Overhang+ sidefins *1.00 meters* (R2.1.2)	114577.51	6.10
Louvre *0.50 meters* (R2.2.1)	116763.39	4.31
Louvre *1.00 meters* (R2.2.2)	113278.75	7.17
Overhang+ sidefins+ louvre *0.50 m* (R2.3.1)	113725.37	6.80
Overhang+ sidefins+ louvre *1.00 m* (R2.3.2)	111119.27	8.94

When analyzing Table 4.22, it can be said that for shading devices, louvre type is more efficient than combination of the shadings types which are overhang and sidefins because it decreases the penetration of daylight to inside. Because of that, when these three types of shadings are applied together to windows, the best outcome is achieved. In addition to that, it can be understood that the length of the shadings has important role for sunlight control. However, to ensure that the view does not become obstructed, maximum 1-meter length of shadings have been tested. As a result, while 0.50-meter shading devices provide 3.67 to 6.80% energy conservation, 1-meter shading depth help to reduce energy consumption from 6.10 to 8.94%.

Thirdly, thermal behaviors of three different glazing types are compared in Table 4.23 below.

Table 4.23. *Three months energy simulation results of existing building and different glazing types tested.*

Cooling Energy Consumption for Glazing Strategies (1st June- 31st August)		
Strategies About Glazing	Energy Demand in (kWh)	Reduction in Demand (%)
Existing Building	122024.84	-
ISICAM *clear double glazing* (R3.1)	121994.50	0.02
ISICAM K *thermal double glazing* (R3.2)	113662.26	6.85
ISICAM K+ *thermal triple glazing* (R3.3)	111326.96	8.77

Using ISICAM thermal glazing types instead of clear glazing causes 6.85 to 8.77% reduction in energy consumption. As mentioned before, R3.1 is simulated for testing the similarities between the existing glazing type and ISICAM clear double-glazing type. The results show that they are acting very similar so it can be said that the simulation outputs of other ISICAM glazing types can be compared with the existing situation.

The data based on simulations carried out to determine the energy consumption for cooling the existing building as well as for each energy saving strategy is presented in Table 4.24 below.

Table 4.24. *Three months energy simulation results of existing building and all renovations.*

Cooling Energy Consumption for All Strategies (1st June- 31st August)		
Strategies	Energy Demand in (kWh)	Reduction in Demand (%)
Existing Building (Base case)	122024.84	-
New roof design +projection+ glazing (R1.6)	111914.29	8.29
Overhang+ sidefins+ louvre *1.00 m* (R2.3.2)	111119.27	8.94
ISICAM K *thermal double glazing* (R3.2)	113662.26	6.85
Courtyard (R4)	107014.77	12.30
Night cooling (R5)	55855.20	54.23
Combination of R4+ R2.3.2+ R3.2+ R5 (R6)	37578.67	69.20
Combination of R1.6+ R2.3.2+ R3.2+ R5 (R7)	36325.89	70.23

From the table above it can be seen that decreasing energy consumption for cooling was achieved by each intervention individually and in combination too. In Figure 4.1, the graph shows the simulation outputs to compare total energy consumption of existing building and renovations.

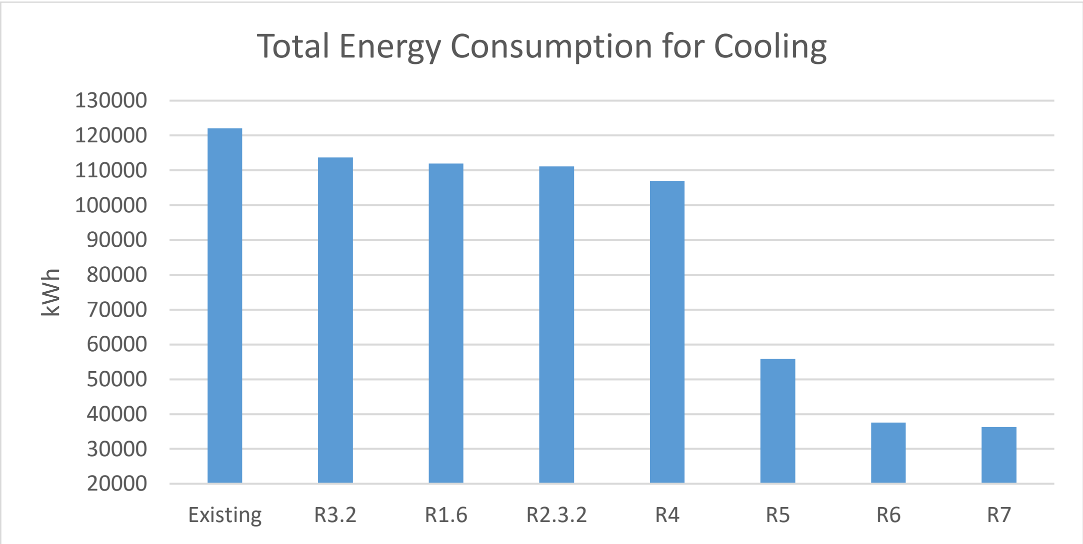


Figure 4.1. Total energy consumption of all situations

When analyzing Figure 4.1, it can be said that rescheduling the natural ventilation is the most effective intervention for decreasing the energy consumption in this study. The reason is that the weather of Alanya in summer is extremely hot and humid. In other words, dry bulb temperature of outside is always higher than thermal comfort range in summer months in working hours of municipality. Because of that, it can be understood that promoting the natural ventilation when the value of outside temperature is in the thermal comfort range is the best individual way for this study. Moreover, controlling the sunlight and preserving the building from overheating help to decrease energy consumption for cooling. When these strategies are applied together as in R6 and R7, the reduction in energy consumption as compared to the existing building case as low as 69.20 and 70.23%, respectively. As a result, when the roof was redesigned, the glazing types were changed, shading devices were used, and finally the night ventilation was promoted, the greatest amount of decrease (i.e. 70.23%) in the energy demand was achieved.

CHAPTER 5

CONCLUSION

During the past few decades, when the effects of climate change started to be felt, the terms sustainable design and passive design started to gain popularity in the realm of architectural design (Watson, 1989). It is a widely accepted fact that climate change is the result of increasing greenhouse gas emissions in the atmosphere, which are produced by the increasing consumption of fossil fuels. This state of affairs is manifesting itself in the form of global warming; hence, there is need to decrease energy consumption or change the type of energy resources to mitigate the risks of global warming (Xu, Huang, Liu, & Zhang, 2016).

While economic and social consciousness are increasing, people's demand for thermal comfort has also been increased. The main effect which causes increasing energy consumption is also the effort of providing thermal comfort that is for space heating in winter and space cooling in summer (Li, Yang, & Lam, 2012).

Energy consumption issue should also be addressed by renovating existing building to environmentally conscious one by employing bioclimatic strategies. The aim of this research was to implement the most effective interventions and observe changes in selected building by using energy simulation program and applying sustainable bioclimatic principles.

As a case study, the Alanya Municipality Building was selected for renovation. The reason why Alanya was chosen is the city's hot and humid climate, where energy use for cooling is extremely high. Moreover, the motivation behind choosing municipality building was to present outputs and reports to the decision makers and to demonstrate to them the role of architects in reducing the energy consumption.

For hot and humid climates, controlling sunlight and preventing the building from overheating are the key strategies for cooling. In addition to that, organizing the natural ventilation especially night ventilation and stack ventilation is highly effective for obtaining thermal comfort with less energy consumption. Therefore, the renovations were designed to apply the bioclimatic interventions which are about promoting these ventilation strategies, and reducing the heat gains.

In this study, the renovation methods were applied not only individually but also in combination. By this way, it is tested that when parameters change, the energy behavior of the building was affected by these changes. In short, in this research, these interventions were examined individually, and then they were combined to obtain the most effective proposal for the existing building which is located in hot and humid climate.

As a conclusion, this study demonstrates how the bioclimatic interventions that have traditionally been used for many years, namely basic architectural design decisions, which are environmentally conscious, and contextually effective in reducing the cooling energy of the existing buildings. In order to achieve the effects of these interventions, numerical data and predictions about building performance should be generated. Because of that, this aim was achieved by testing and simulating the existing building by using energy simulation software.

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APPENDICES

A. SIMULATION SETTINGS

In this section, the settings of the simulation software are presented. Firstly, activity tab of the software is demonstrated. In the software, the tabs about activity, construction, opening, and HVAC have the key properties and settings for the simulation. The settings in these tabs affect the results directly, and also, they provide arranging the parameters of existing situation and different interventions applied for reducing the cooling demand of the building. Moreover, the model option tab is also illustrated in this section. The settings in this tab provide determining the HVAC setting whether it is simple or detailed. In addition to that, natural ventilation setting in this tab specifies whether it is scheduled and calculated. These settings should be arranged according to the building behavior.

Firstly, the settings in activity tab are presented. These settings are about the building usage and general properties of building. In other words, the settings in this tab is about the density of occupancy, the activity schedule of the building, and environmental control. Environmental control settings provide controlling of the setback temperatures for cooling, heating, and natural ventilation. Because of that, these settings remain same for all renovation strategies.

Secondly, construction tab shows the all material properties for the walls, slabs, floors, and roof of the building. That is, when changing the materials, the settings in this tab should be changed. In the opening tab, the material properties of glazing which is used for windows, skylights, and doors can be arranged. The properties of the frames and dividers of the windows, skylights, and doors are also assigned in this tab. Moreover, the aperture properties of openings can be specified in this tab when the natural ventilation of the model is determined as calculated. However, in this study, natural ventilation is assigned as scheduled. In addition to that, shading devices can be added in this tab. Lastly, in HVAC tab, templates can be selected. Nevertheless, the settings of these templates can be changed. The properties of mechanical ventilation, heating, cooling, and natural ventilation can be set in this tab.

In short, the settings of the renovation strategies, and the existing building are presented in this section. In other words, this section shows the material properties of roof, and window glazing. In addition to that, the properties of shading devices, and the schedules of natural ventilation are presented in detail below.

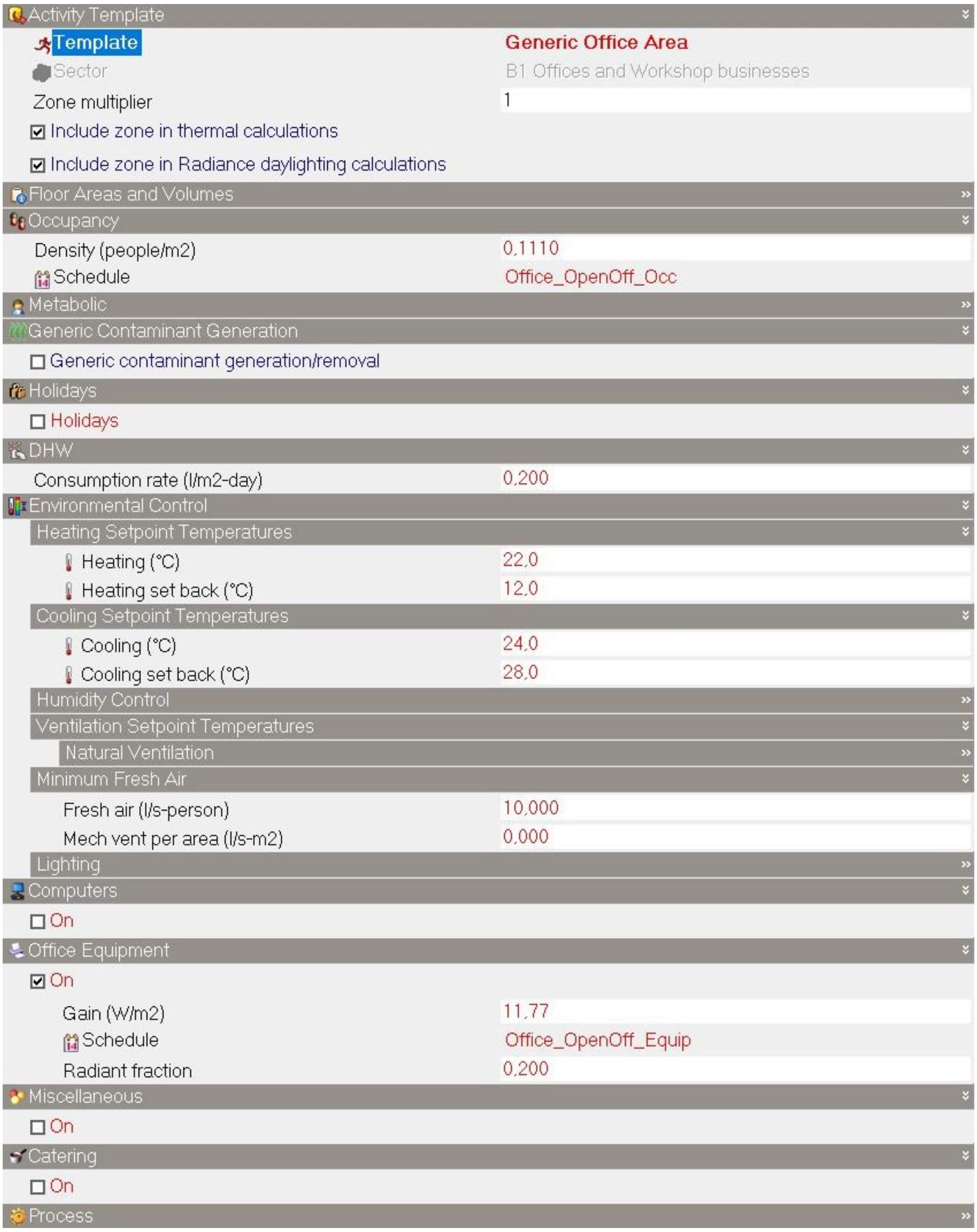


Figure A.1. Data of activity tab which was used for all simulations

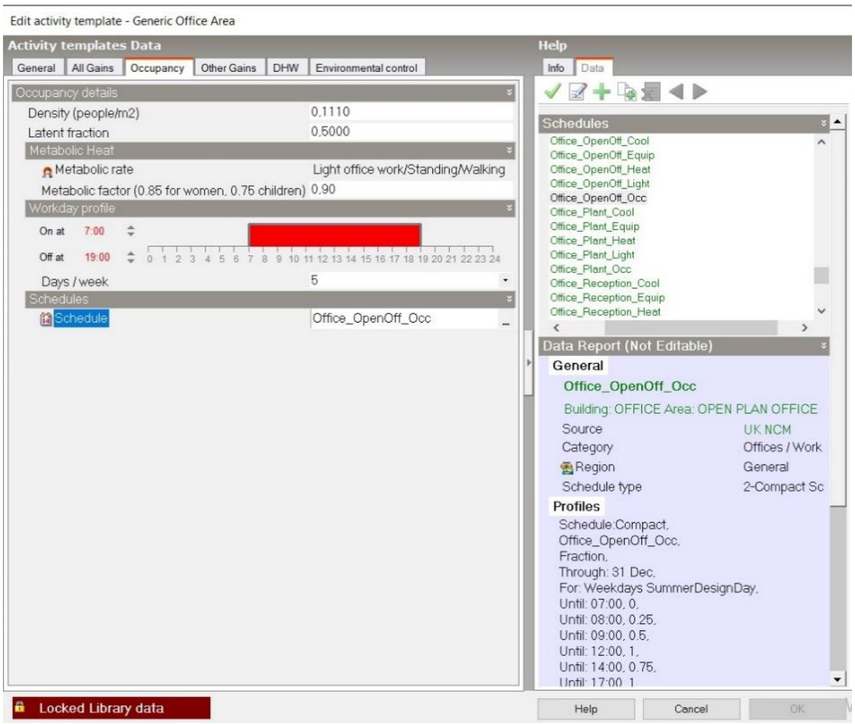


Figure A.2. Occupancy schedule of the building which was used for all simulations

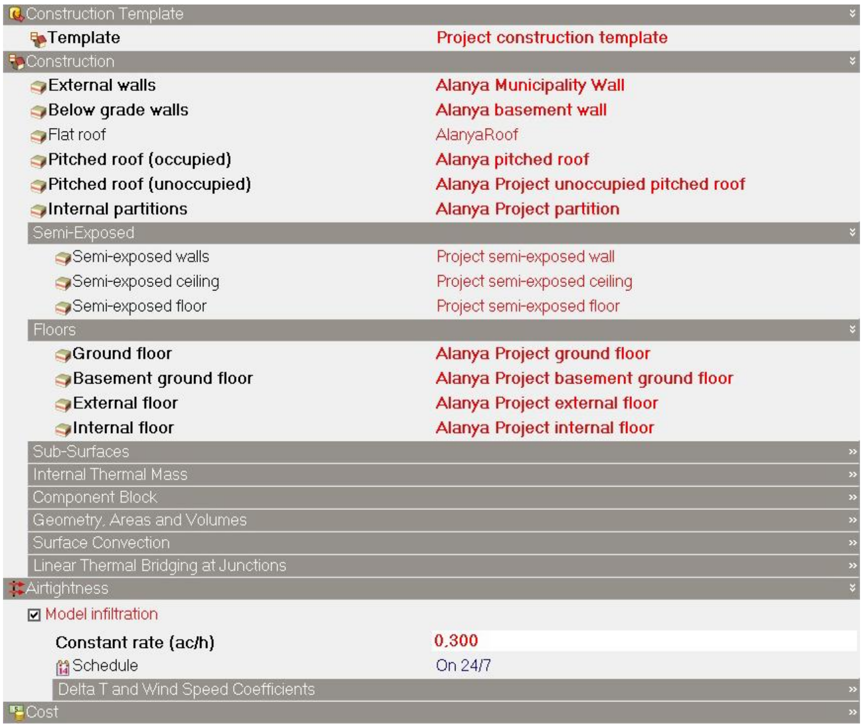


Figure A.3. Construction materials which were used for all strategies except for green roof

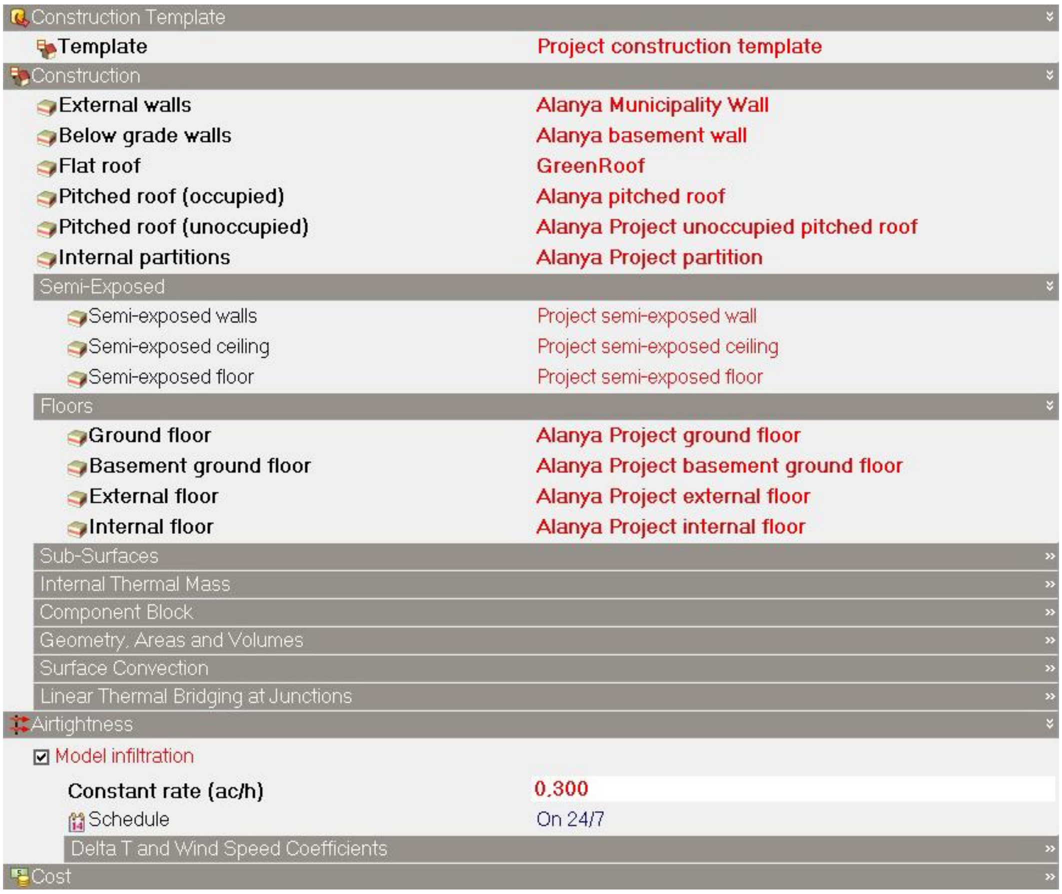


Figure A.4. Construction materials which were used for green roof strategy (R1.1)

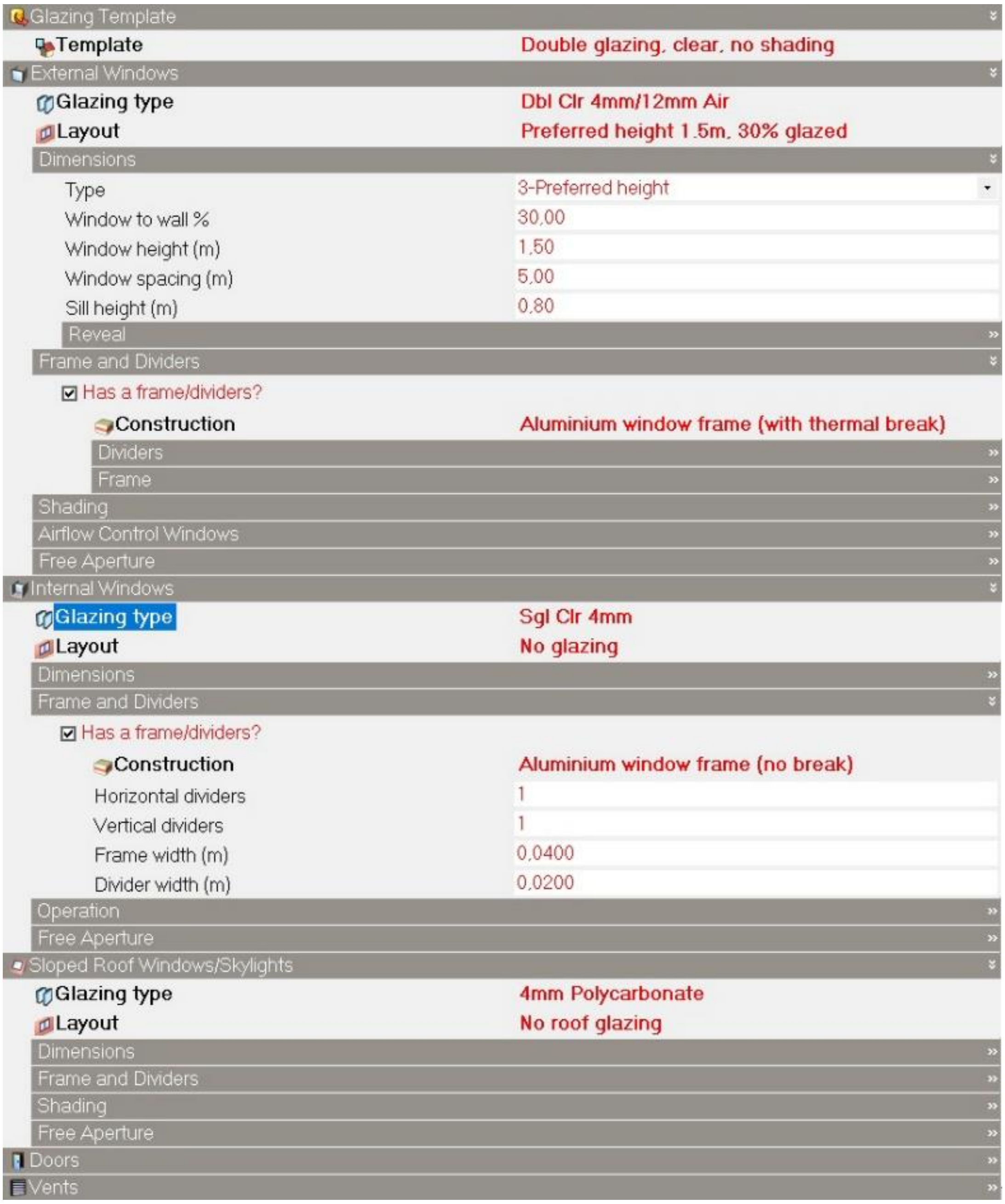


Figure A.5. Properties about the openings of existing building

Figure A.6. Opening properties of the renovated roof glazing for the renovation (R1.2)

Figure A.7 illustrates the properties for the shading renovation (R.2.3.2) in opening tab of the simulation software. The settings of other renovations about the shadings are applied like this way.

Figure A.7. Opening properties of the shadings for the renovation (R2.3.2)

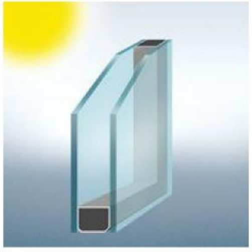
Figure A.8. Opening properties of the first glazing strategy (R3.1)

Figure A.9. Opening properties of the renovation about glazing (R3.2)

Figure A.10. Opening properties of the triple glazed windows (R3.3)

ŞİŞECAM
DÜZCAM

Performans Hesaplayıcı



Isıcam® Sistemleri

DIŞ CAM	:	Şişecam Renksiz Düzcam 4 mm Renksiz
BOŞLUK	:	12 mm Ara Boşluk (Hava)
İÇ CAM	:	Şişecam Renksiz Düzcam 4 mm Renksiz

Gün Işığı Değerleri (EN 410)	Gün Işığı Geçirgenliği	: %82
	Gün Işığı Dışa Yansıtma	: %15
	Gün Işığı İçe Yansıtma	: %15
Güneş Enerjisi Değerleri (EN 410)	Güneş Enerjisi Direkt Geçirgenliği	: %74
	Güneş Enerjisi Dışa Yansıtma	: %13
	Güneş Enerjisi Soğurma	: %13
	Güneş Enerjisi Toplam Geçirgenliği (Solar Faktör / g)	: %78
	Gölgeleme Katsayısı	: 0,90
	UV Geçirgenlik	: %53
Isı Geçirgenlik Katsayısı (EN 673)	U Değeri W/(m^2K)	: 2,9
Gürültü Yalıtım Değeri (EN 12758)	Rw (C; Ctr) dB	: 29 (-1; -4)

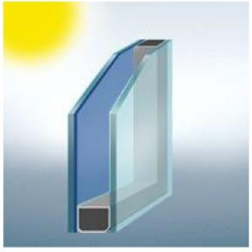
Bu ünite ile;
- Isı Kontrolü
sağlanmaktadır.

"Gün Işığı" ve "Güneş Enerjisi" değerleri, EN 410 standartlarına uygun olarak laboratuvar ortamında ölçülmüş spektral veriler kullanılarak hesaplanmıştır.
Isı geçirgenlik katsayısı olan U değeri EN 673 standardına uygun olarak hesaplanmıştır. U değeri hesabında kullanılan yayınım (emisivite) değerleri, laboratuar ortamında EN 12898'e uygun olarak ölçülmüştür.
Potansiyel ısıl kırılma riskleri veya ilgili yapı yönetmelikleri nedeniyle ısıl işlem görmüş cam ürünlerinin kullanılması gerekebilir. Bu dokümanda ısıl kırılma risklerine yönelik herhangi bir hesaplama bulunmamaktadır. Bu konu ile ilgili sorularınız için lütfen Trakya Cam Sanayii A.Ş. ile irtibat kurunuz.
Cam kombinasyonunun özellikleri, teknik ve diğer veriler, bu belgenin oluşturduğu tarih itibari ile geçerlidir ve dökümanın içerdiği bilgiler herhangi bir uyarıya gerek olmaksızın Trakya Cam Sanayii A.Ş. tarafından değiştirilebilir.
Bu doküman bilgilendirme amaçlıdır. Dökümanda verilen değerler ile fiili değerler arasında, kullanım yerindeki koşullara bağlı olarak farklılıklar oluşabilir. Bu farklardan dolayı Trakya Cam Sanayii A.Ş. hiçbir şekilde sorumlu tutulamaz.

Figure A.11. Thermal properties of clear double-glazed window which were used for R.3.1 calculated from http://www.sisecamduzcam.com/tr/faaliyet-alanlarimiz/mimari-camlar/performans-hesaplayici

ŞİŞECAM
DÜZCAM

Performans Hesaplayıcı



Isıcam® Sistemleri

DIŞ CAM	:	Şişecam Solar Low-E Cam 4 mm Nötral (2. Yüzey)
BOŞLUK	:	12 mm Ara Boşluk (Hava)
İÇ CAM	:	Şişecam Renksiz Düzcam 4 mm Renksiz

Gün Işığı Değerleri (EN 410)	Gün Işığı Geçirgenliği	:	%72
	Gün Işığı Dışa Yansıtma	:	%10
	Gün Işığı İçe Yansıtma	:	%11
Güneş Enerjisi Değerleri (EN 410)	Güneş Enerjisi Direkt Geçirgenliği	:	%41
	Güneş Enerjisi Dışa Yansıtma	:	%29
	Güneş Enerjisi Soğurma	:	%31
	Güneş Enerjisi Toplam Geçirgenliği (Solar Faktör / g)	:	%44
	Gölgeleme Katsayısı	:	0,50
	UV Geçirgenlik	:	%10
Isı Geçirgenlik Katsayısı (EN 673)	U Değeri W/(m^2K)	:	1,6
Gürültü Yalıtım Değeri (EN 12758)	Rw (C; Ctr) dB	:	29 (-1; -4)

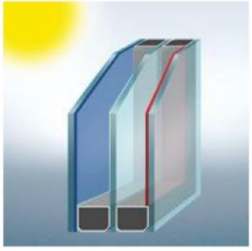
Bu ünite ile;
- Isı ve Güneş Kontrolü
sağlanmaktadır.

"Gün Işığı" ve "Güneş Enerjisi" değerleri, EN 410 standartlarına uygun olarak laboratuvar ortamında ölçülmüş spektral veriler kullanılarak hesaplanmıştır.
Isı geçirgenlik katsayısı olan U değeri EN 673 standardına uygun olarak hesaplanmıştır. U değeri hesabında kullanılan yayınım (emisivite) değerleri, laboratuar ortamında EN 12898'e uygun olarak ölçülmüştür.
Potansiyel ısıl kırılma riskleri veya ilgili yapı yönetmelikleri nedeniyle ısıl işlem görmüş cam ürünlerinin kullanılması gerekebilir. Bu dokümanda ısıl kırılma risklerine yönelik herhangi bir hesaplama bulunmamaktadır. Bu konu ile ilgili sorularınız için lütfen Trakya Cam Sanayii A.Ş. ile irtibat kurunuz.
Cam kombinasyonunun özellikleri, teknik ve diğer veriler, bu belgenin oluşturduğu tarih itibari ile geçerlidir ve dökümanın içerdiği bilgiler herhangi bir uyarıya gerek olmaksızın Trakya Cam Sanayii A.Ş. tarafından değiştirilebilir.
Bu doküman bilgilendirme amaçlıdır. Dökümanda verilen değerler ile fiili değerler arasında, kullanım yerindeki koşullara bağlı olarak farklılıklar oluşabilir. Bu farklardan dolayı Trakya Cam Sanayii A.Ş. hiçbir şekilde sorumlu tutulamaz.

Figure A.12. Thermal properties of thermal double-glazed window which were used for R.3.2 calculated from http://www.sisecamduzcam.com/tr/faaliyet-alanlarimiz/mimari-camlar/performans-hesaplayici

ŞİŞECAM
DÜZCAM

Performans Hesaplayıcı



Isıcam® Sistemleri

DIŞ CAM	:	Şişecam Solar Low-E Cam 4 mm Nötral (2. Yüzey)
1. BOŞLUK	:	16 mm Ara Boşluk (Hava)
ORTA CAM	:	Şişecam Renksiz Düzcam 4 mm Renksiz
2. BOŞLUK	:	16 mm Ara Boşluk (Hava)
İÇ CAM	:	Şişecam Low-E Cam 4 mm Nötral (5. Yüzey)

Gün Işığı Değerleri (EN 410)	Gün Işığı Geçirgenliği	:	%64
	Gün Işığı Dışa Yansıtma	:	%12
	Gün Işığı İçe Yansıtma	:	%14
Güneş Enerjisi Değerleri (EN 410)	Güneş Enerjisi Direkt Geçirgenliği	:	%33
	Güneş Enerjisi Dışa Yansıtma	:	%31
	Güneş Enerjisi Soğurma	:	%37
	Güneş Enerjisi Toplam Geçirgenliği (Solar Faktör / g)	:	%39
	Gölgeleme Katsayısı	:	0,45
	UV Geçirgenlik	:	%5,6
Isı Geçirgenlik Katsayısı (EN 673)	U Değeri W/(m^2K)	:	0,7
Gürültü Yalıtım Değeri (EN 12758)	Rw (C; Ctr) dB	:	35 (-1; -6)

Bu ünite ile;
- Isı ve Güneş Kontrolü
sağlanmaktadır.

"Gün Işığı" ve "Güneş Enerjisi" değerleri, EN 410 standartlarına uygun olarak laboratuvar ortamında ölçülmüş spektral veriler kullanılarak hesaplanmıştır.
Isı geçirgenlik katsayısı olan U değeri EN 673 standardına uygun olarak hesaplanmıştır. U değeri hesabında kullanılan yayınım (emisivite) değerleri, laboratuar ortamında EN 12898'e uygun olarak ölçülmüştür.
Potansiyel ısıl kırılma riskleri veya ilgili yapı yönetmelikleri nedeniyle ısıl işlem görmüş cam ürünlerinin kullanılması gerekebilir. Bu dokümanda ısıl kırılma risklerine yönelik herhangi bir hesaplama bulunmamaktadır. Bu konu ile ilgili sorularınız için lütfen Trakya Cam Sanayii A.Ş. ile irtibat kurunuz. Isıl kırılma risklerine karşı ortadaki düzcamın temperli olarak kullanılması veya düşük demirli düzcam olması önerilmektedir.
Cam kombinasyonunun özellikleri, teknik ve diğer veriler, bu belgenin oluşturduğu tarih itibari ile geçerlidir ve dökümanın içerdiği bilgiler herhangi bir uyarıya gerek olmaksızın Trakya Cam Sanayii A.Ş. tarafından değiştirilebilir.
Bu doküman bilgilendirme amaçlıdır. Dökümanda verilen değerler ile fiili değerler arasında, kullanım yerindeki koşullara bağlı olarak farklılıklar oluşabilir. Bu farklardan dolayı Trakya Cam Sanayii A.Ş. hiçbir şekilde sorumlu tutulamaz.

Figure A.13. Thermal properties of thermal triple glazed window which were used for R.3.3 calculated from http://www.sisecamduzcam.com/tr/faaliyet-alanlarimiz/mimari-camlar/performans-hesaplayici

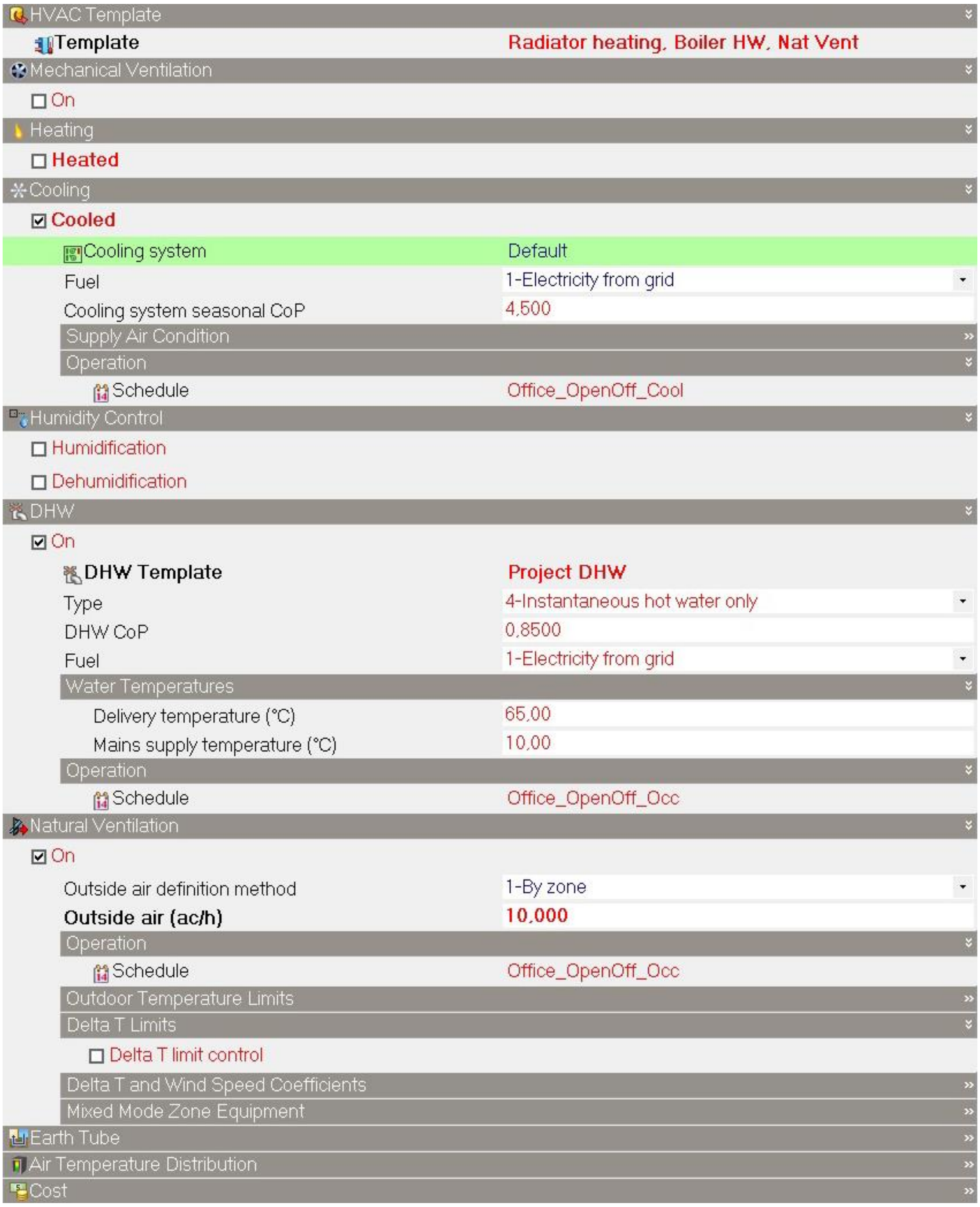


Figure A.14. HVAC settings of existing situation

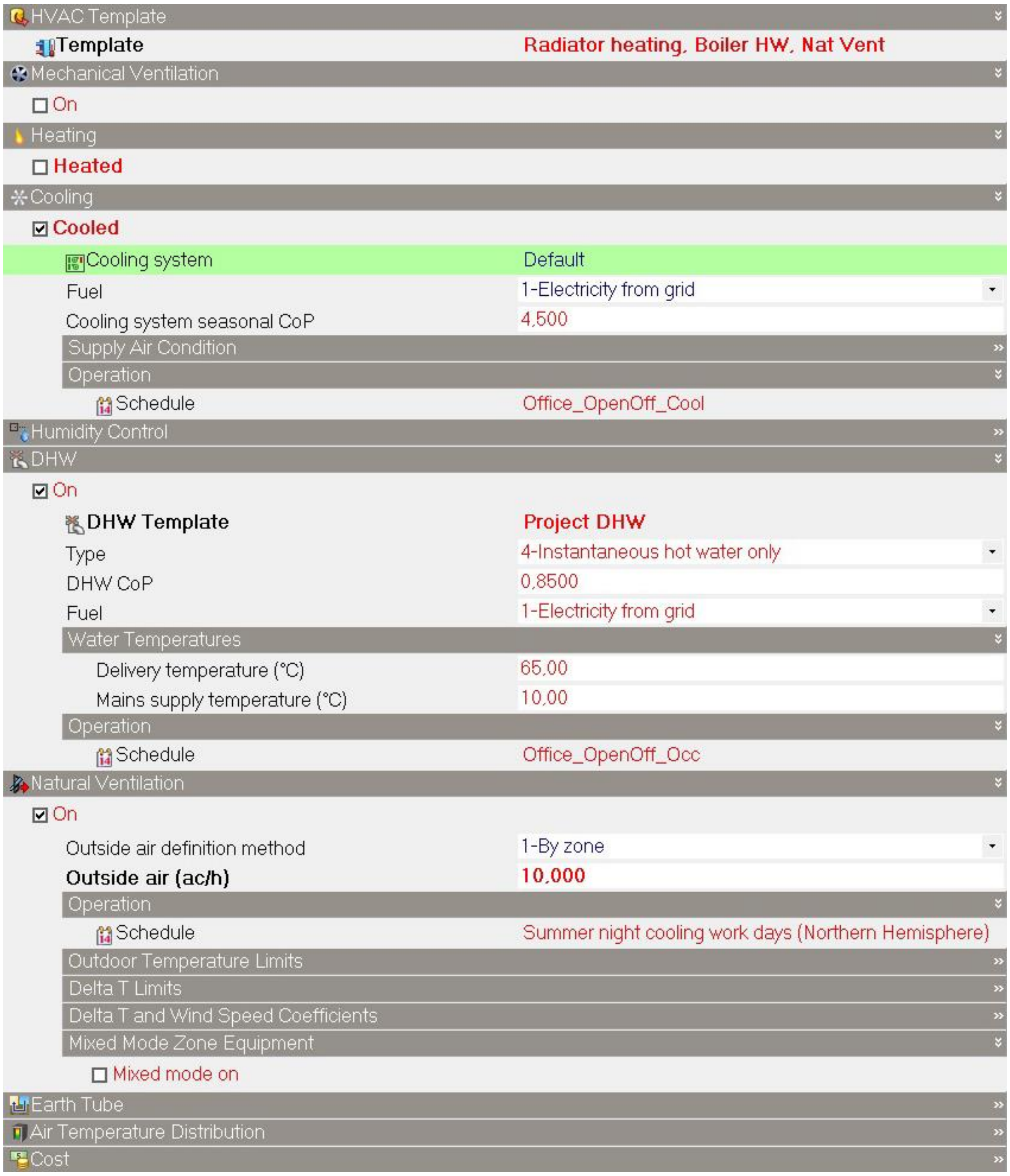


Figure A.15. HVAC settings of night ventilation strategy (R5)

B. ENERGY CONSUMPTION RESULTS

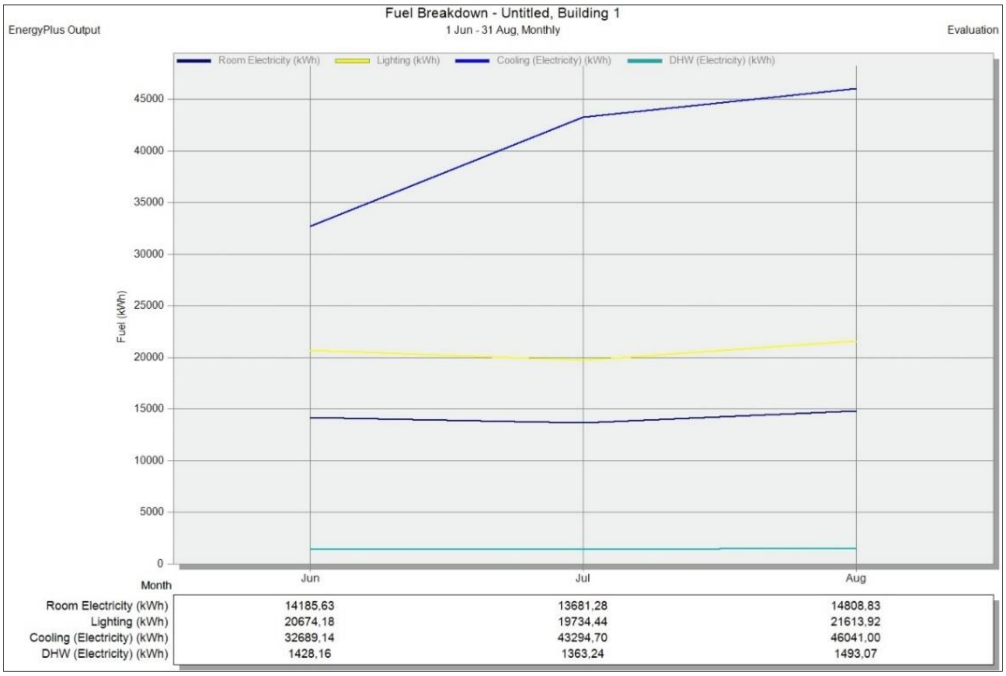


Figure A.16. Energy consumption results of existing situation

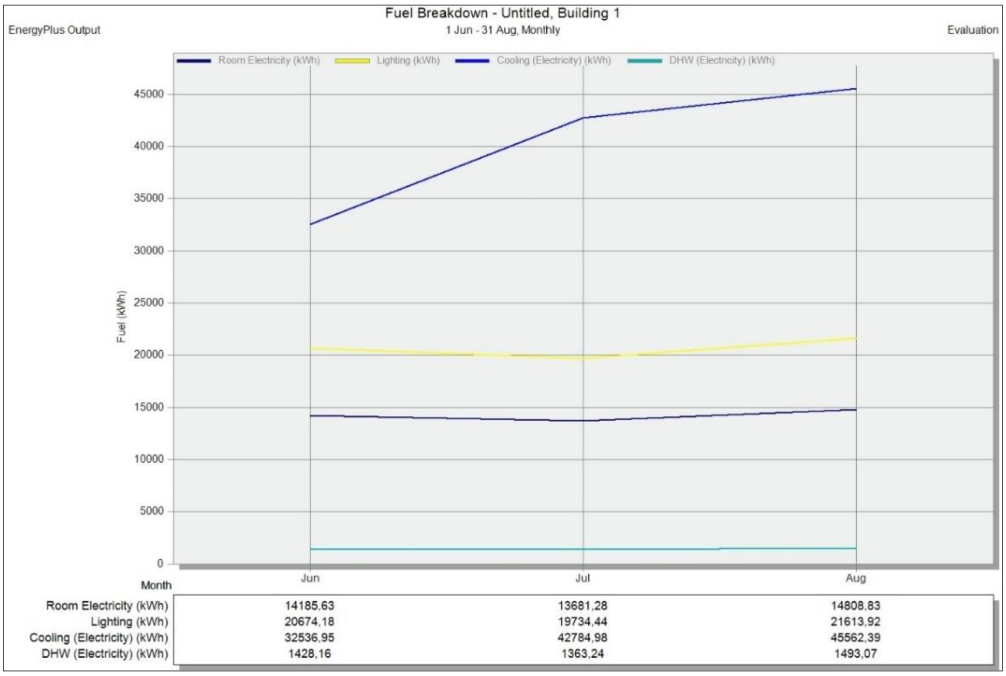


Figure A.17. Energy consumption results of R1.1

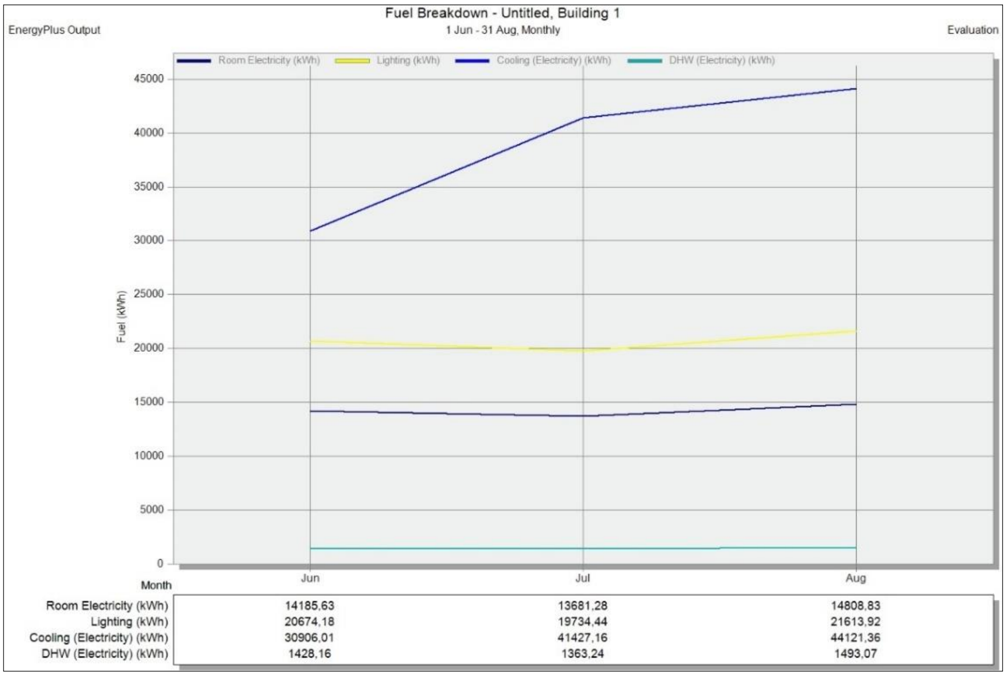


Figure A.18. Energy consumption results of R1.2

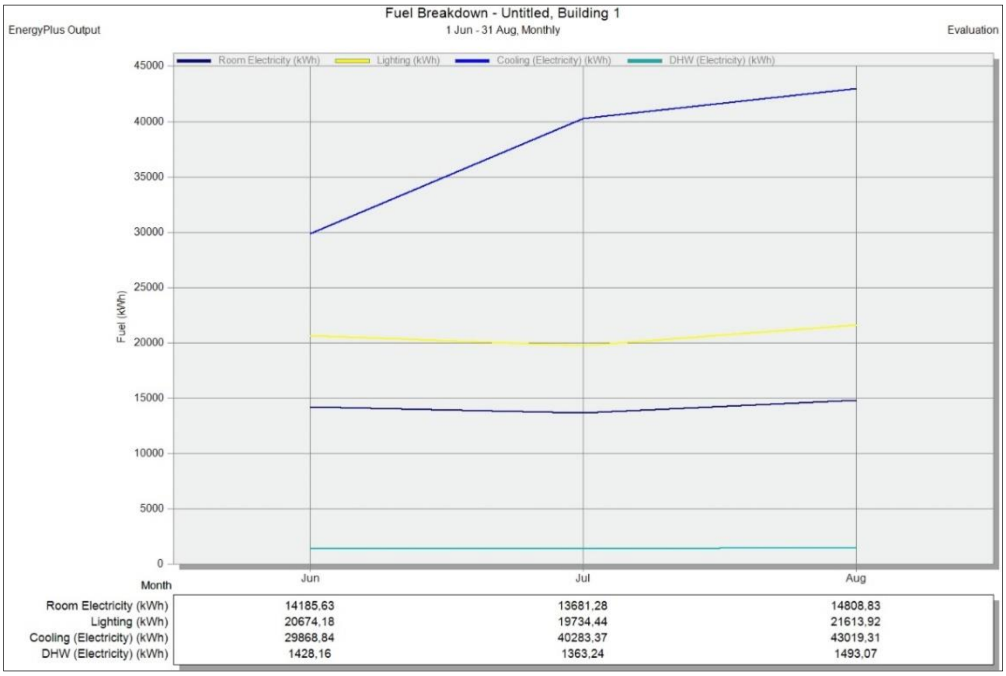


Figure A.19. Energy consumption results of R1.3

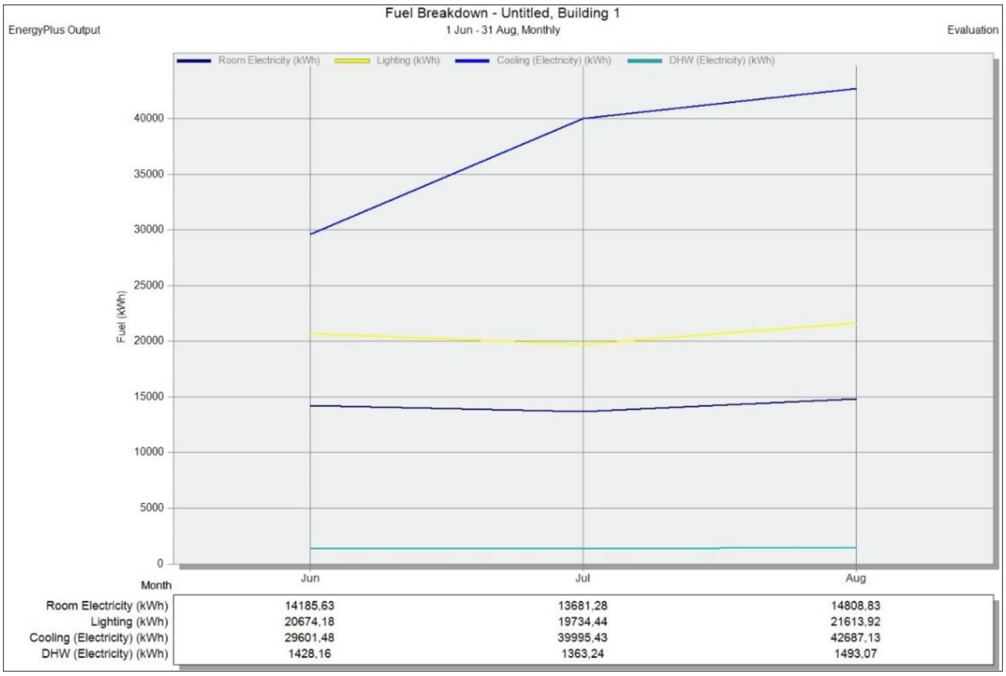


Figure A.20. Energy consumption results of R1.4

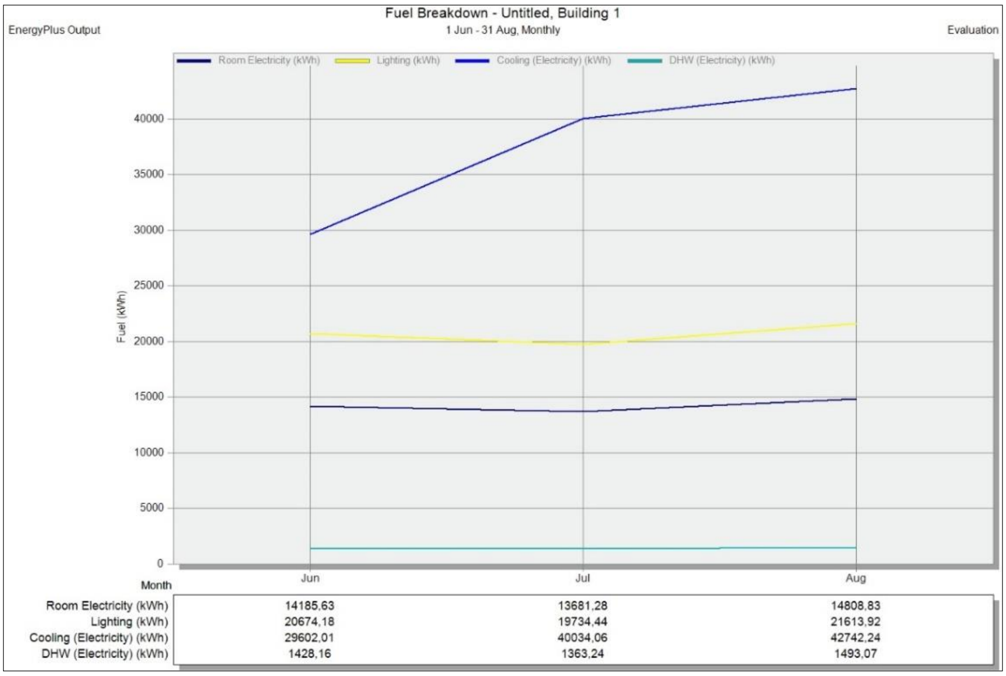


Figure A.21. Energy consumption results of R1.5

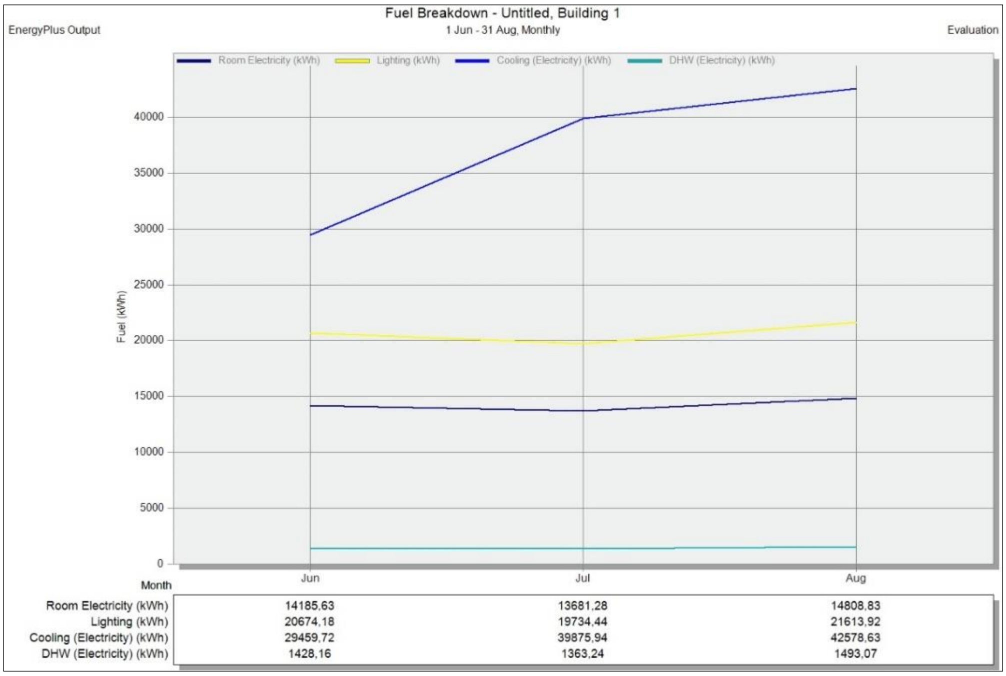


Figure A.22. Energy consumption results of R1.6

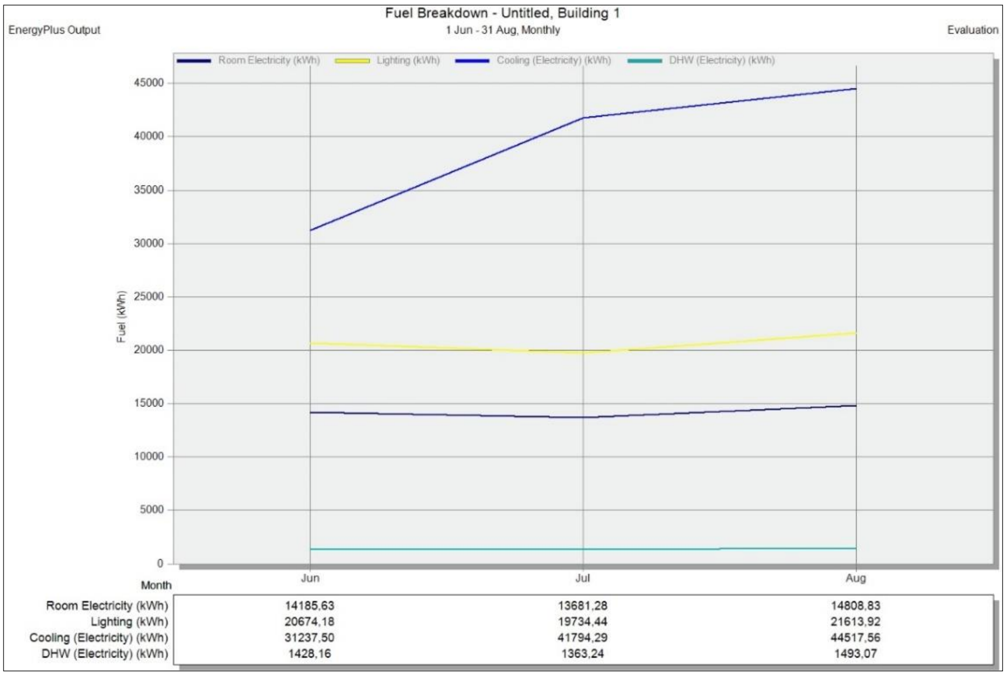


Figure A.23. Energy consumption results of R2.1.1

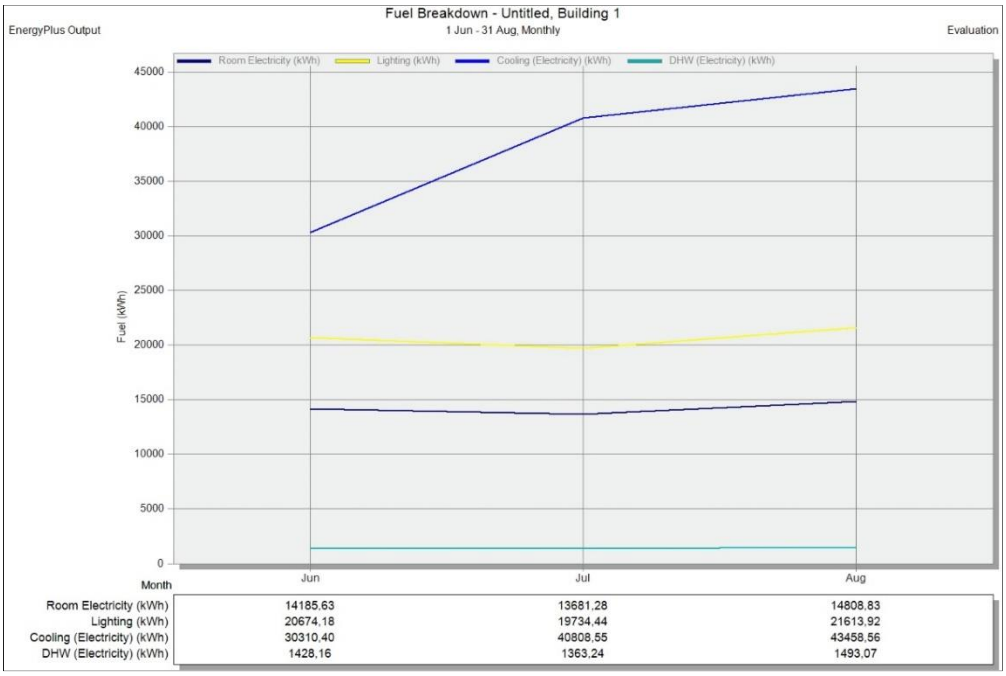


Figure A.24. Energy consumption results of R2.1.2

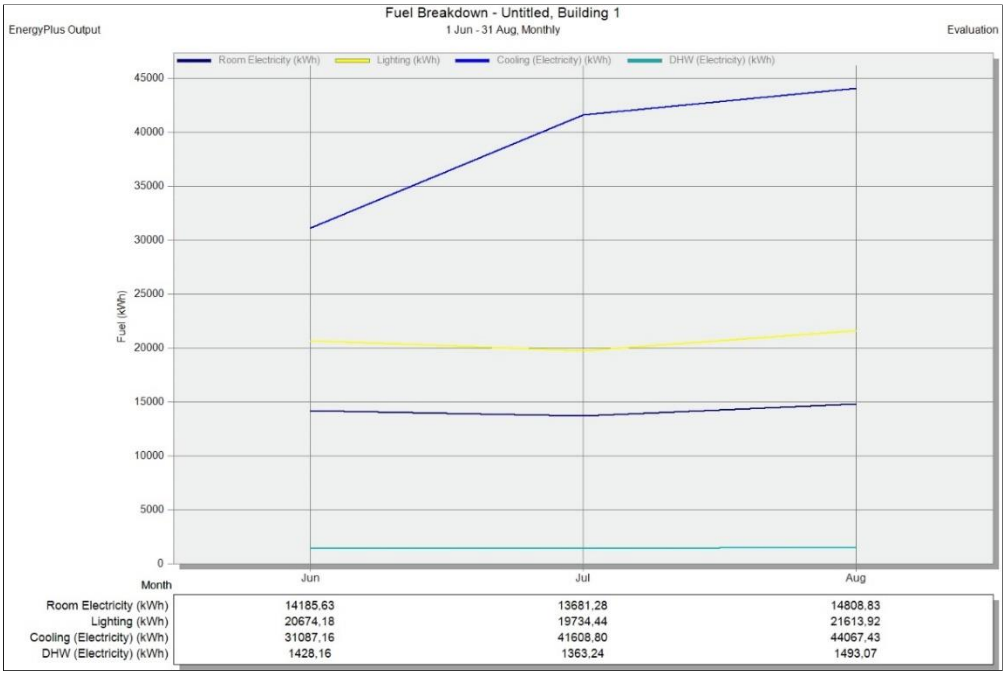


Figure A.25. Energy consumption results of R2.2.1

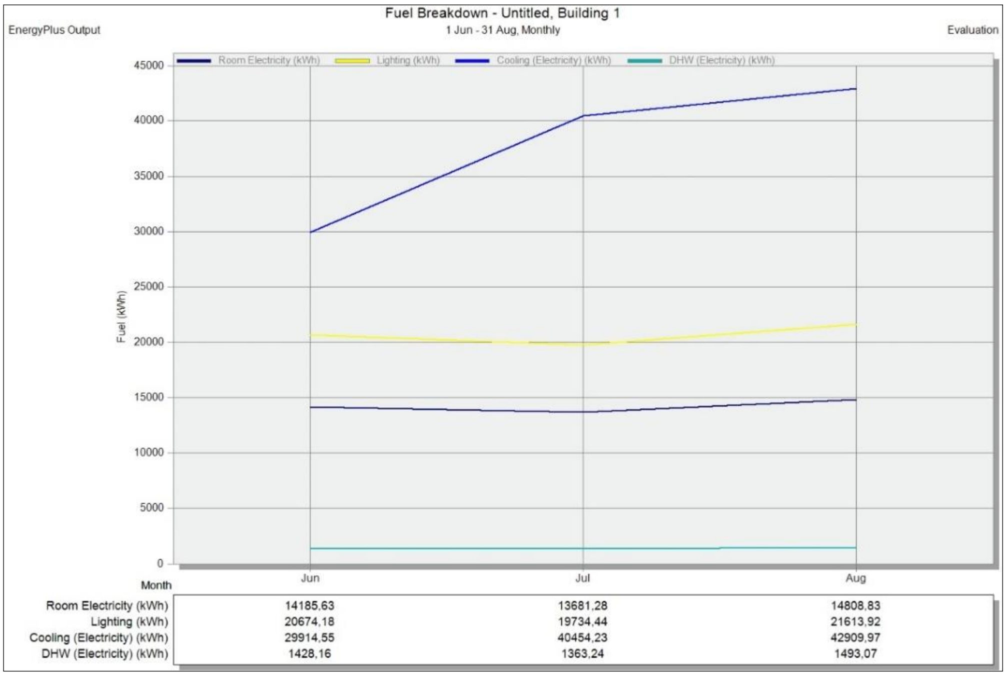


Figure A.26. Energy consumption results of R2.2.2

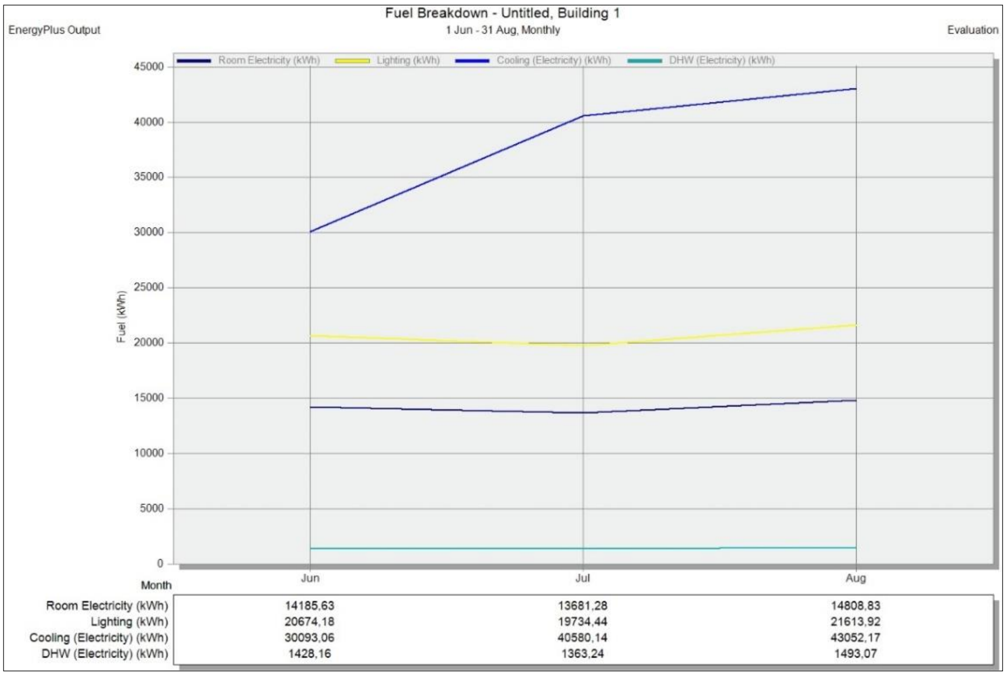


Figure A.27. Energy consumption results of R2.3.1

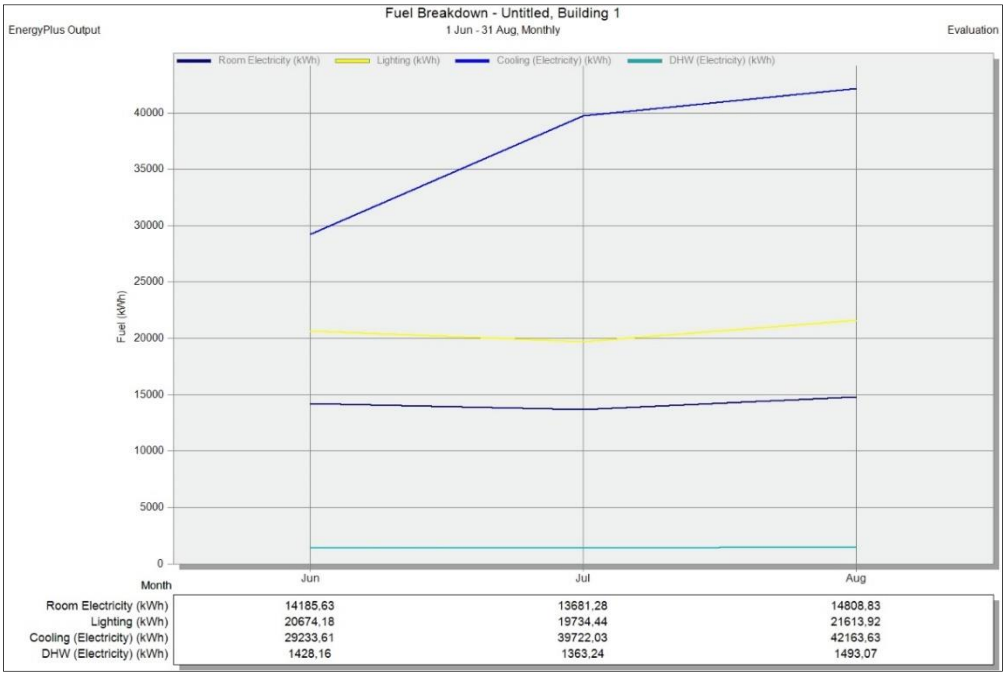


Figure A.28. Energy consumption results of R2.3.2

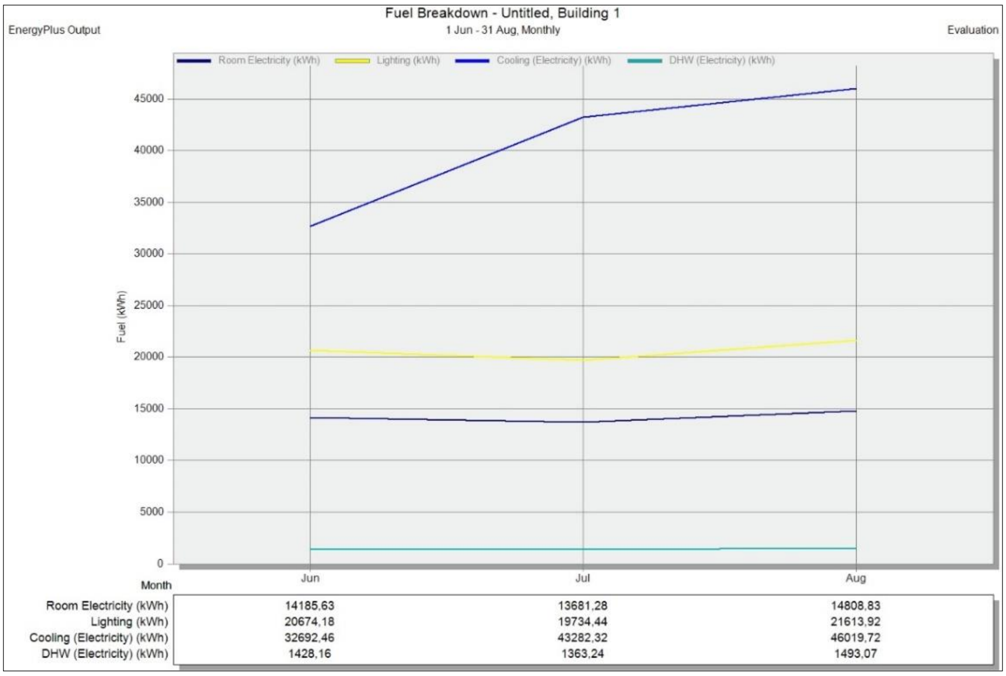


Figure A.29. Energy consumption results of R3.1

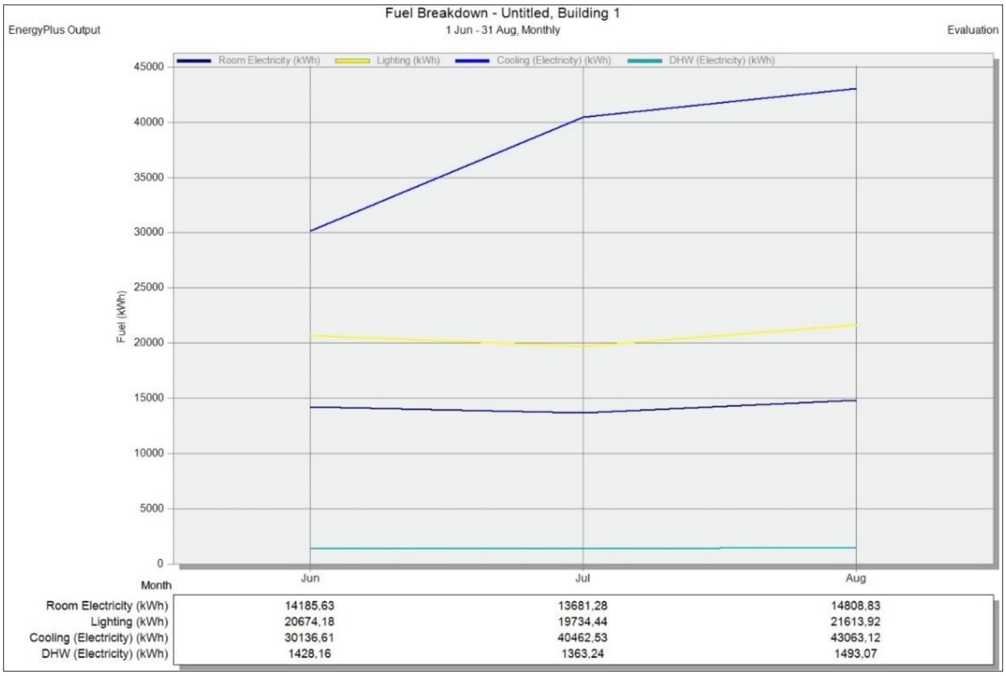


Figure A.30. Energy consumption results of R3.2

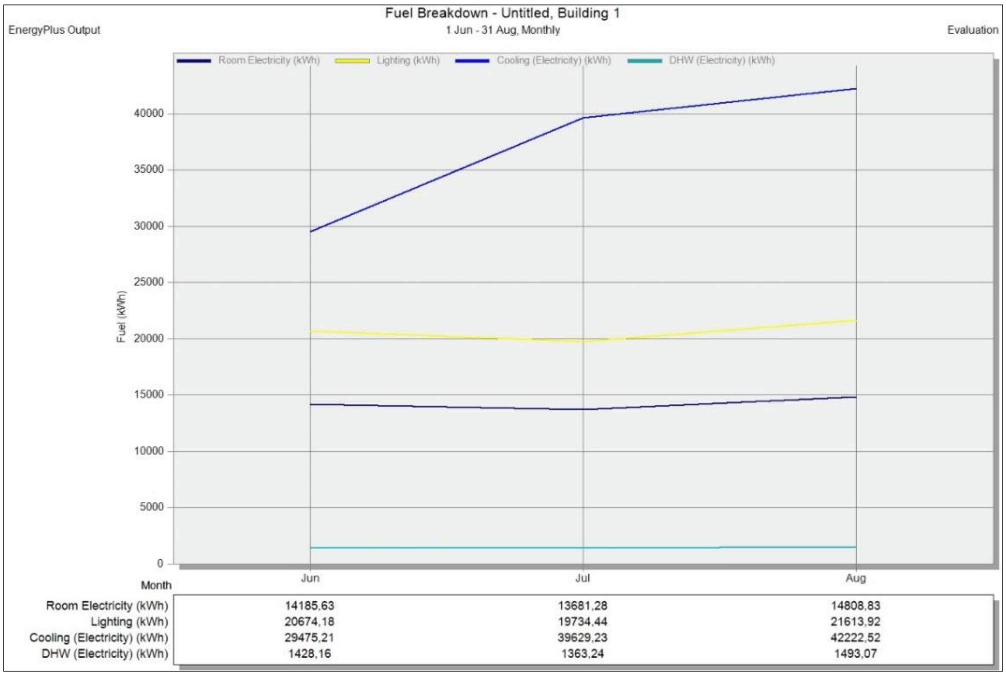


Figure A.31. Energy consumption results of R3.3

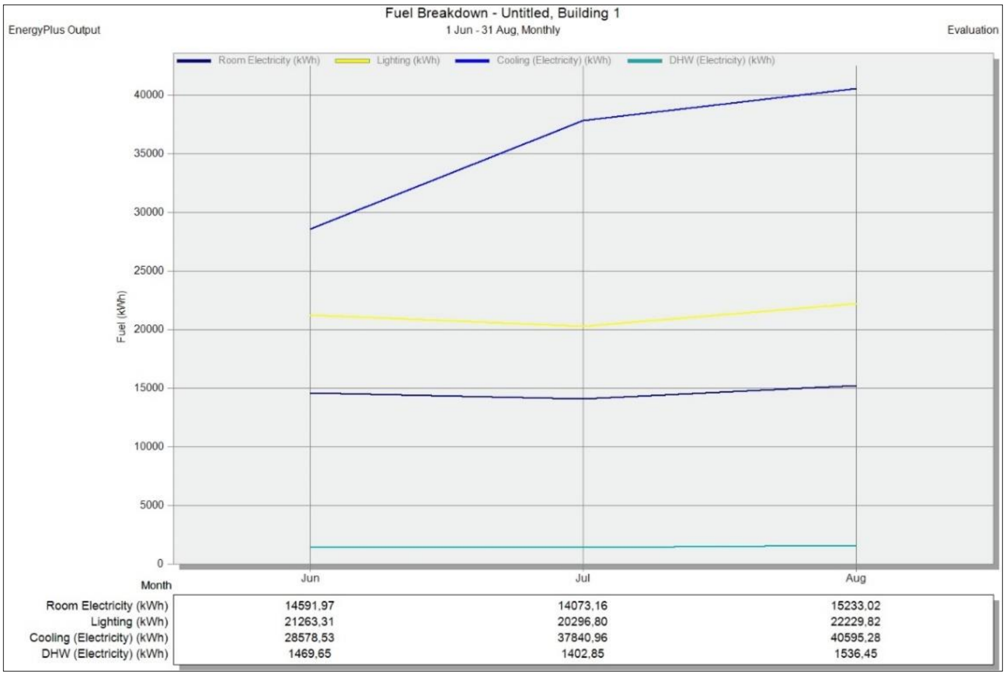


Figure A.32. Energy consumption results of R4

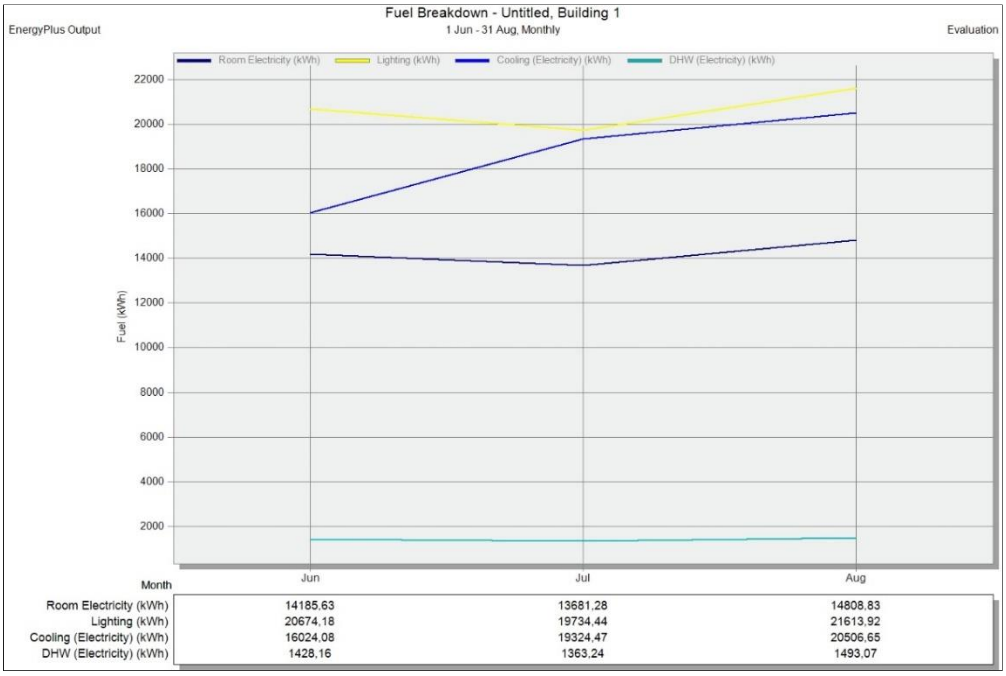
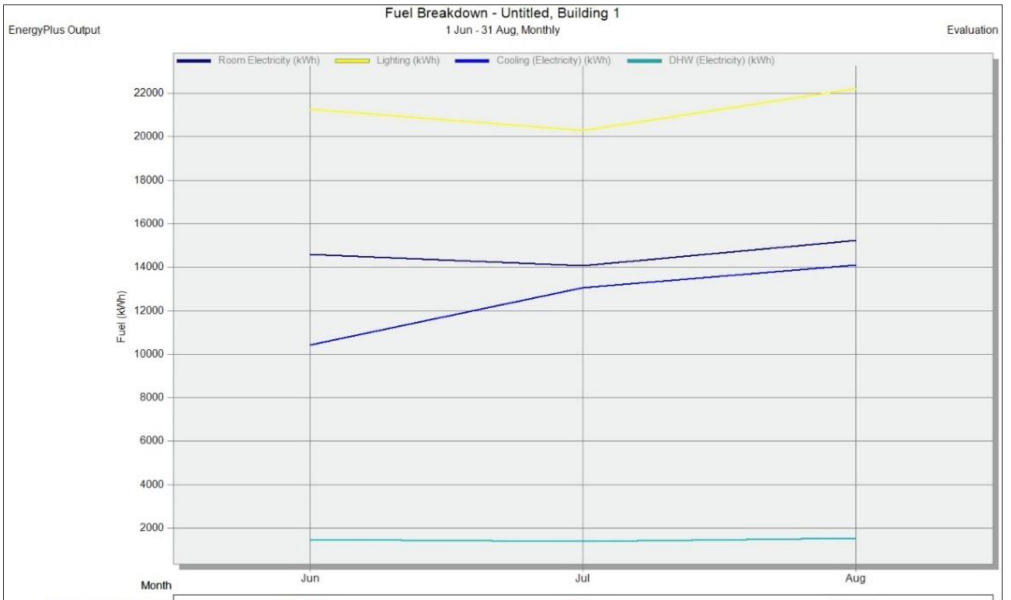
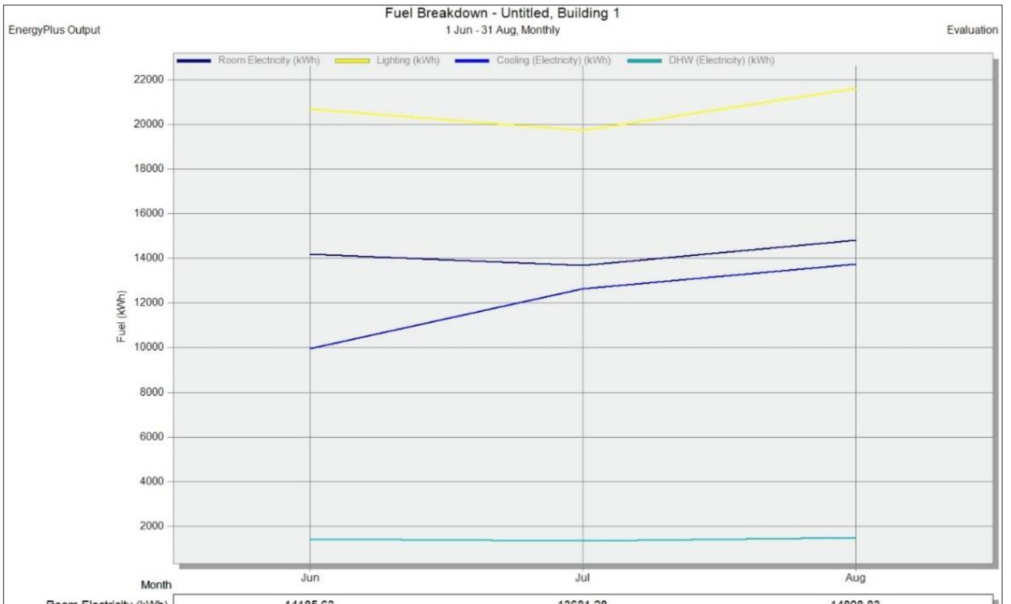


Figure A.33. Energy consumption results of R5



Month	Jun	Jul	Aug
Room Electricity (kWh)	14595,05	14076,13	15236,23
Lighting (kWh)	21267,77	20301,05	22234,49
Cooling (Electricity) (kWh)	10415,78	13059,69	14103,20
DHW (Electricity) (kWh)	1469,97	1403,15	1536,78

Figure A.34. Energy consumption results of R6



Month	Jun	Jul	Aug
Room Electricity (kWh)	14185,63	13681,28	14808,83
Lighting (kWh)	20674,18	19734,44	21613,92
Cooling (Electricity) (kWh)	9947,46	12635,78	13742,65
DHW (Electricity) (kWh)	1428,16	1363,24	1493,07

Figure A.35. Energy consumption results of R7

C. THE IMAGES OF ATRIUM AND AIR CONDITIONERS

Figure A.36. The image of atrium

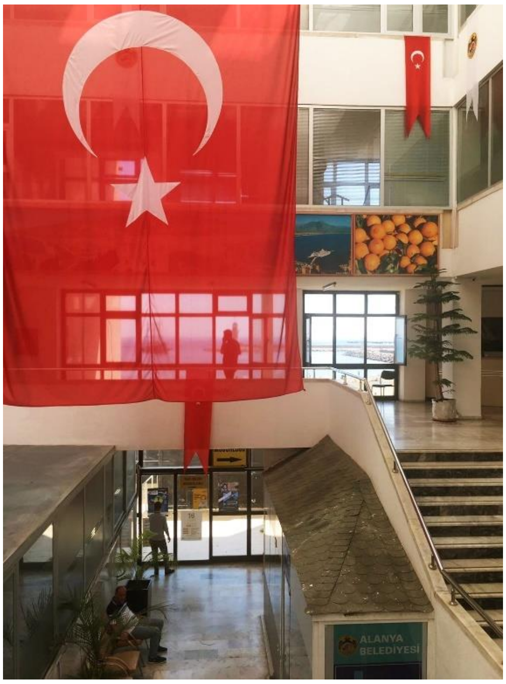


Figure A.37. The image of atrium

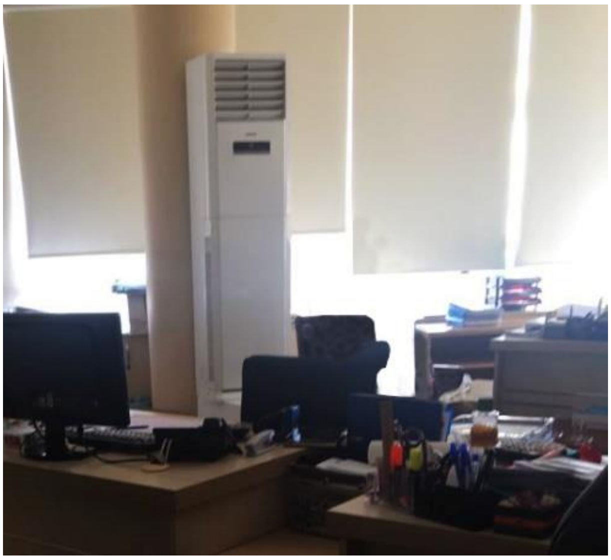


Figure A.38. The image of free-standing air conditioner

Figure A.39. The image of air conditioning units

Figure A.40. The image of air conditioning units

D. FLOOR PLANS

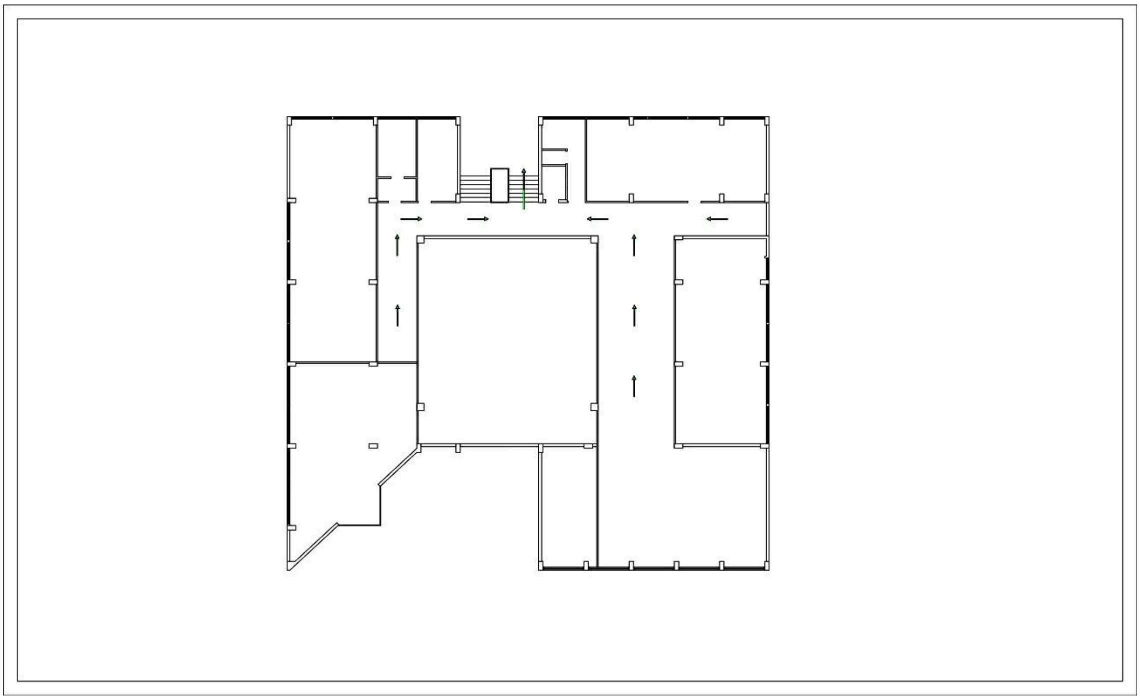


Figure A.41. Basement Floor Plan

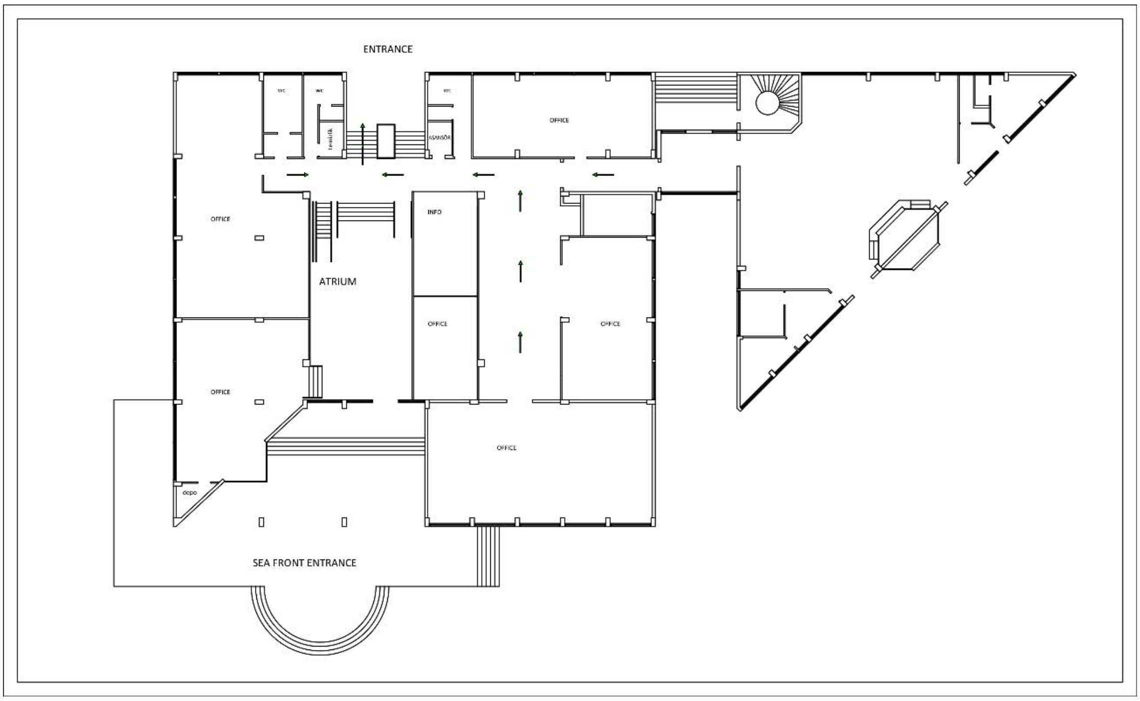


Figure A.42. Ground Floor Plan

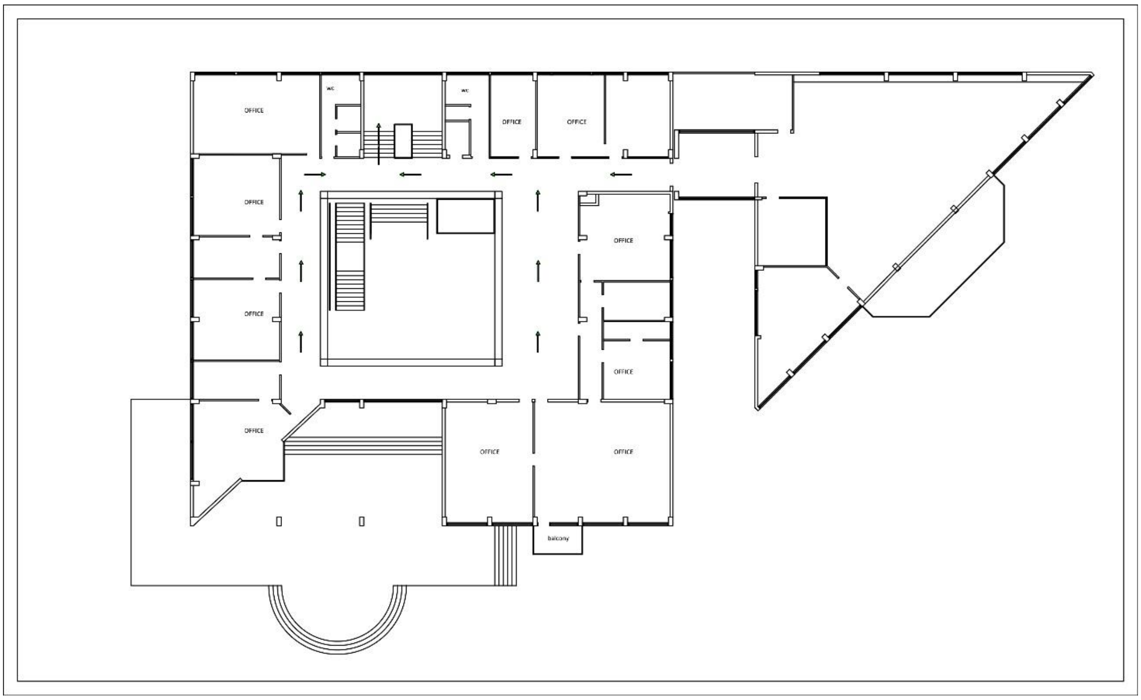


Figure A.43. First Floor Plan

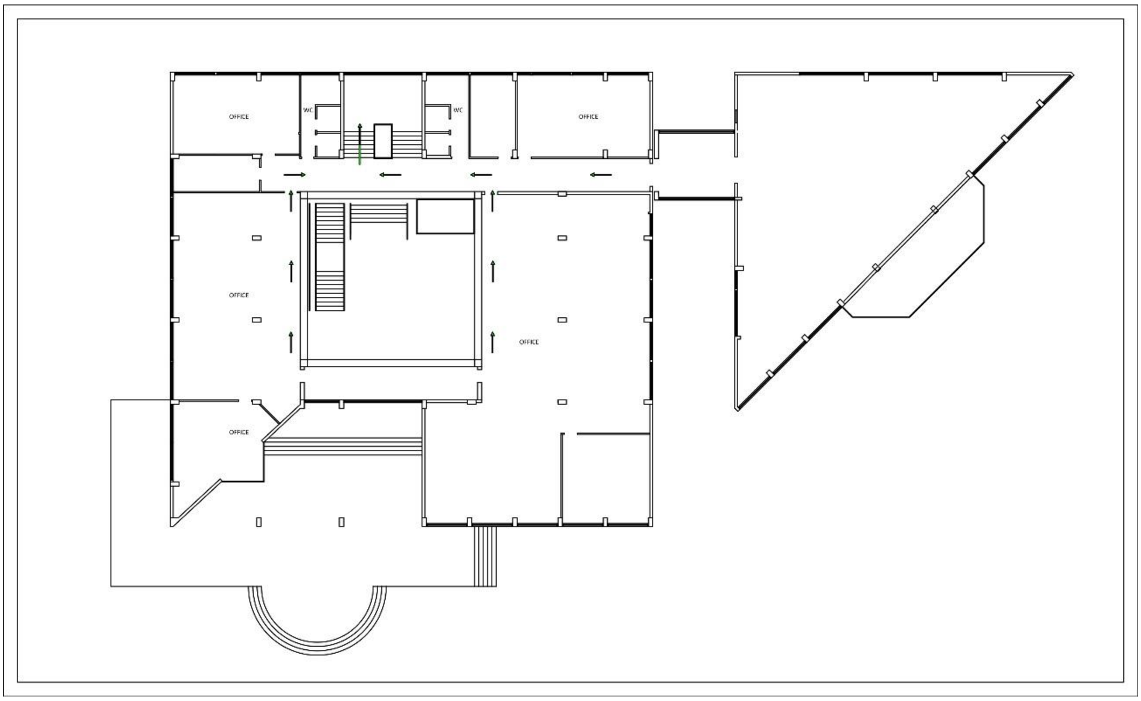


Figure A.44. Second Floor Plan

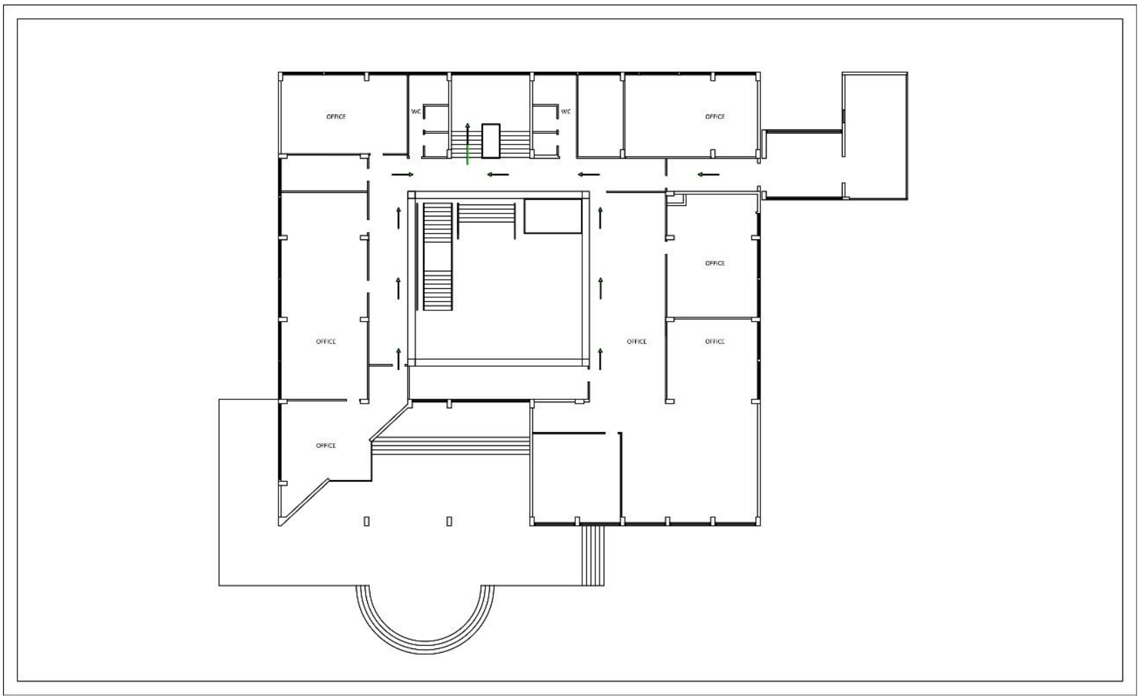


Figure A.45. Third Floor Plan