ISTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

AN ESTIMATION APPROACH for THERMAL PERFORMANCE of ATRIUM BUILDINGS through a CASE STUDY

M.Sc. Thesis by
Ayşe Miray Gemi, B.Arch

Department: **Architecture Faculty**

Programme: **Environment Control and Building Technology**

December 2006

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Ayşe Miray Gemi, B.Arch

(502041701)

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Supervisor (Chairman): Prof. Dr. A. Zerrin YILMAZ

Members of the Examining Committee Assc. Prof. Dr. Alpin Köknel YENER

Prof. Dr. Ursula EICKER (S.A.S)

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ATRİUM YAPILARININ ISIL PERFORMANSLARININ DEĞERLENDİRİLMESİNDE ÖRNEK UYGULAMALI BİR YAKLAŞIM

YÜKSEK LİSANS TEZİ

Mimar Ayşe Miray Gemi
(502041701)

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Tez Danışmanı : **Prof. Dr. A. Zerrin YILMAZ**

Diğer Jüri Üyeleri **Doç. Dr. Alpin Köknel YENER**

Prof. Dr. Ursula EICKER (S.A.S)

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FOREWORD

Energy issue is a vital problem for the World. At present, the world's energy demand is by large covered by the use of fossil energy, which causes the environmental damage. The great energy potential of atrium buildings should be realized and used as a design option to prevent our world from the immediate threat of climate change. In this work, thermal performance of atrium buildings is introduced and an approach is purposed. The application of the approach is shown on a case study building.

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LIST OF ABBREVIATIONS

IEA	: International Energy Agency
BMS	: Building Management System
BCS	: Building Community System
NFPA	: National Fire Protection Association
IBC	: The International Building Code
BSRIA	: Building Services Research and Information Association
ASHRAE	: American Society of Heating, Refrigerating and Air-Conditioning Engineers
TRNSYS	: Transient System Simulation Program
CFD	: Computer Fluid Dynamic
SHGC	**:** Solar Heat Gain Coefficient

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LIST OF SYMBOLS

U	**:** Heat transfer coefficient
Ib	**:** Beam Solar Radiation
g	**:** Solar Heat Gain Coefficient
$\mathbf{T_{sol}}$	: Solar Transmittance
$\mathbf{Rf_{sol}}$	: Solar Reflectance
$\mathbf{T_{vis}}$	**:** Visible transmittance
ρ	**:** Reflectance
α	**:** Absorptance
τ	**:** Transmittance

ATRİUM YAPILARININ ISIL PERFORMANSLARININ DEĞERLENDİRİLMESİNDE ÖRNEK UYGULAMALI BİR YAKLAŞIM

ÖZET

Son yıllarda teknolojik gelişmeler ve değişen ihtiyaçlarla birlikte binaların enerji tüketimleri geniş çapta artış göstermiştir. Bunun yanında binaların enerji ihtiyaçları ise halen büyük oranda fosil enerjilerden karşılanmakta ve inşaat sektörü, diğer kullanıcılarla kıyaslandığında bu sınırlı enerjinin tüketimi üzerinde azımsanmayacak bir paya sahip olmaktadır. Bununla birlikte binaların, gelecekte dünyamızı tehdit eden küresel ısınma etkisini ve hava kirliliğini azaltmak için fosil kaynakları kullanmayı bırakıp enerji etkin olarak tasarlanması gerektiğinin genel bir anlayış olduğu gözükmektedir. İşte bu yüzden doğaya saygılı tasarım konusunun mimarlar ve mühendisler tarafından göz önünde bulundurulması önem kazanmıştır.

Bu tezin konusu genellikle ticari yapılarla bütünleşmiş olarak tasarlanan atrium yapılarının enerji etkinliğini inceleme altına almaktır. Bu tez örnek bir bina üzerinde atriumların ısıl performanslarının değerlendirilmesine bir yaklaşım önermektedir. Örnek bina yazarın lisansüstü eğitiminin bir kısmını yürüttüğü Stuttgart, Almanya'da yer almaktadır. Çalışma atriumların ısıl davranışlarını tahmin edebilmek ve doğru bir enerji korunumlu tasarım yapabilmek için özellikle pasif güneşsel tasarım parametrelerine eğilmiştir. Ayrıca bu çalışmada, atriumların bütünleştirildiği ana binaları için enerji tasarrufu potansiyeli de inceleme altına alınmıştır. Isısal tahmin, binaların bütün enerji ihtiyaçlarının ve istenen iç hava sıcaklığının sağlanması için gereken yüksek ekonomik giderleri optimize edebilmek için onların tasarım aşamasında enerji tüketimlerini hatasız bir biçimde değerlendirilebilmesinde gereklidir.

Bu çalışmanın amacına atriumun enerji etkin tasarım değişkenlerinin örnek bir bina üzerinde incelenmesiyle ulaşılmıştır. Farklı çözüm önerileri ve bu önerilerden elde edilen sonuçlar uygun değerde çözümlere ulaşabilmek adına karşılaştırılmıştır. Binanın performansının değerlendirilmesi için günümüzde kullanım alanını giderek arttıran bilgisayar tabanlı enerji simülasyon programlarından biri olan TRNSYS 16 bina simülasyon programı kullanılmıştır.

AN ESTIMATION APPROACH for THERMAL PERFORMANCE of ATRIUM BUILDINGS THROUGH a CASE STUDY

SUMMARY

In recent years, the technological development and changing requirements have created an increasing on the energy consumption of the buildings extensively. The energy demand of the buildings is by large covered by the use of fossil energy presently and the construction sector has a wide percentage on the consumption of this restricted energy source comparing with the other consumers. However, there seems to be a common understanding that the building must be stop to use fossil sources and designed energy efficient in the future, in order to prevent the enormous impact of the building on the global environment, like air pollutant and global warming. Therefore, it has been important to take into consideration the environmental respectively design issue by architects and engineers.

The objective of this dissertation is to analyze energy efficiency in atrium spaces which is generally integrated to commercial buildings, although energy conservation is generally not a main reason for integrating an atrium in a building design. It is an approach to estimations of atrium's thermal energy performance on a case study. The building which is taken as case study is located in Stuttgart, Germany since the writer studied as an exchange student during some part of her master's study there. The study especially tends to describe passive solar design parameters in atria in order to predict its thermal behavior and to achieve saving energy by true design concept. Furthermore, energy saving potential of atria for its integrated building has been analyzed. Thermal prediction is required to assess energy consumption accurately in building at the design stage in order to optimize the overall energy requirement and gross economic cost of providing the desired indoor temperature.

Aim of the work is achieved by analyzing design concept of atrium on the case study building and setting different variations and comparing the results to obtain the optimum solution. Energy analyses are carried out simulating the building by computer based simulation tool TRNSYS 16.

1. INTRODUCTION

1.1 Climate, Energy and Buildings

Energy issue is a vital problem for the World. At present, the world's energy demand is by large covered by the use of fossil energy, which causes the environmental damage. However, there seems to be a common understanding that our energy supply to a much larger extent must be based on renewable energy systems in the future. Major reasons for this are environmental issues, like global warming and local air pollution. Other strong reasons for focusing on renewable sources are the decreasing the limited energy sources. Limited fuel resources are being depleted, and some countries are becoming increasingly dependent upon oil and gas importation [1, 2]. The Royal Commission on Environmental Pollution has recommended that if they are to avoid damaging and potentially disastrous climate change, the UK needs to cut its CO2 emissions by 60% by 2050 [3].

Buildings are most of the energy consumer all over the world. Le Corbusier considered buildings 'machines for living in'. Modern buildings have indeed become increasingly complex, involving technologically advanced building materials, and mechanical systems for controlling interior air quality, thermal comfort, lighting and acoustics. These systems which exclusively rely on the utilization of non-renewable energy are often expensive to install and energy-intensive in operation [4]. In other words, in terms of the way they are arranged and serviced, and the methods by which they are constructed, have an enormous impact on the world's eco-system. The creation and operation of buildings accounts for save 50 percent of all energy resources consumed across the planet, making the construction industry "the least sustainable industry in the world" [5]. According to a UK Research Study, it is obvious that about a half of all UK energy consumption and a similar proportion of carbon dioxide emissions are associated with buildings [6].

To prevent the enormous impact of the building on the global environment, it is important to minimize their energy demand and cover it through the generation of renewable energy. In order to reduce CO2 emission of buildings and to ensure environmental conversation the following energy strategy must be adopted for all new developments:

• Reduce energy demand for buildings to a minimum

• Meet this demand with the most efficient services and appliances

• Maximize the use of low carbon or renewable energy supplies

• Reduce the need to travel and promote walking and cycling in preference to motorized transport [3].

Earth receives energy annually from the sun equivalent to 178,000 terawatt years which is around 15,000 times the present world-wide energy consumption. Of that, %30 is reflected back into space, %50 is absorbed and re-radiated, and 20% powers the hydrological cycle. Only 0.6 % powers photosynthesis from which all life derives and which created our reserves of fossil fuel [2]. Using solar energy instead of limited energy sources can be a good solution for environmental damage.

The other important subject is to make environmental respectively design or energy efficient design. Energy efficient buildings help to improve external air quality and to reduce the effects of global warming. Architects must design their buildings with this consideration.

1.2 Energy Efficient Design Strategies

Environmental design is not new. The cold environment of 350.000 years ago led our European ancestors to built shelters under limestone cliffs. More recently, English cob cottages and Doha homes, both built of earth, demonstrate vernacular responses to light and heat. The rise of science in the Renaissance led to the Industrial Revolution which has enabled environmental engineers to produce reasonably comfortable conditions in almost any building in almost any climate. Some of the most visually architectures of our era have taken technology and have pushed it to the limits of its capabilities. The engineering systems associated with this architecture, however, have required high-grade energy to deal with the environmental problems resulting from the building design. What we need to do now is to reduce a building's reliance on fossil fuel-derived high-grade energy yet still provide comfort inside for the occupants [1].

In the recent years, environmental design come into prominence again and there is an increasing need to find ways in order to improve the energy efficiency of buildings. The need to improve the energy efficiency of buildings is clear and is primarily a question of good energy conscious building design, both in the construction of new buildings and in the retrofitting of energy saving features to the existing building.

Improving energy efficiency is one of the most cost-effective ways of reducing greenhouse gas emissions. A building can be designed to use 50% to 70% less energy than a typical building, when the way it functions as a whole and the method in which building systems interact are considered at the concept stage. The key approach in energy-efficient design is that the building is considered to be more than just cladding and structure, but that all elements contribute to the performance of the building particularly in terms of interacting with the climate [7].

Energy efficient building design means requiring the minimum amount of energy for heating, cooling, equipments and lighting that is required to maintain comfort conditions in a building. The energy efficient buildings must adjust their self by utilizing natural resources of lighting, heating and cooling or by avoiding from them if they make no benefit for building environment. These are the renewable energy sources like solar, wind. Furthermore, the mechanical systems in this building have to be controlled being compatible with the passive systems if it is required. An important factor impacting on energy efficiency is the building envelope. This includes all of the building elements between the interior and the exterior of the building such as: walls, windows, doors, roof and foundations. All of these components must work together in order to keep the building warm in the winter and cool in the summer [8].

In order to achieve energy efficiency in modern buildings it is generally applied new methods and strategies, however these all new strategies base on the old passive solar energy strategies. Double façades, sun spaces and atria could be given as example for new strategies. This study focuses in particular on atrium buildings. It is very important to have an understanding of the thermal behavior of buildings to provide the required comfort conditions, to improve the energy performance of the built environment. Furthermore, atrium buildings can be used as an energy efficient design approach to reduce energy consumption of commercial building. Therefore, it is tried to make an approach to an estimation of thermal performance of atrium buildings in the study and this approach is evaluated on a case study by means of a simulation tool.

Atrium buildings offer great potential for energy conservation by providing passive cooling in summer and passive heating in winter. The large volume of air in atriums can also be exploited to reduce nonrenewable energy use. Recognition of the significance of the energy-conserving potential of atriums has been increasing in recent years. IEA, Energy Conservation in Building and Community Systems (BCS) program recognized the need for guidance in the design of large spaces in buildings and launched a project called Energy-Efficient Ventilation of Large Enclosures (IEA Solar Heating and Cooling Task XI and IEA Annex 26) [9,10].

Atria have been a design element in buildings for centuries and are today commonly found in commercial structures throughout the world. However, energy conservation is seldom a primary reason for using an atrium in a building design, but other reasons can strongly influence the energy use characteristics of the atrium and of the adjacent building spaces [9]. If the primary reasons for constructing an atrium or sunspace are aesthetic or commercial and energy-use is ill-considered, the result can easily be an increase in energy consumption of the building [11].

It is not true that the incorporating the atrium in a building design leads automatically to reduce energy consumption of the whole building. There are lots of studies show that the atriums could be a very huge energy consumers for their main building, if energy isn't be taken into consideration in construction of atrium. As an example can be given a systematic study of atrium performance which is conducted in U.S and analysed saving energy potential of atrium by comparison with the same building without an atrium; however, as it can be seen in Figure 1.1, optimizing on the design can reverse this situation. Therefore atrium must be designed based on the passive solar energy principles in order to achieve energy saving with atrium spaces in whole building [11, 12]

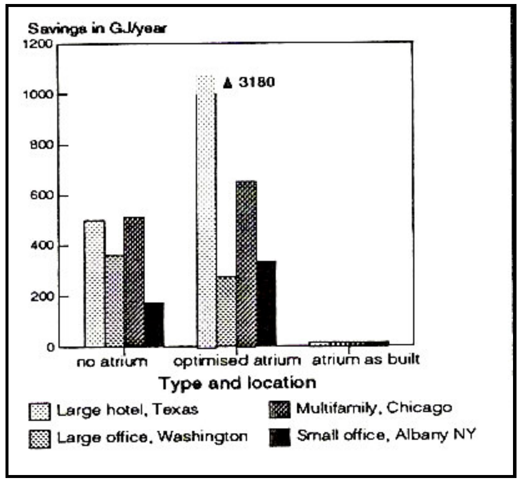


Figure 1.1: Energy savings of commercial buildings with and without atrium [11].

The prediction of temperature distribution in atriums is very important in order to design energy efficient atrium buildings to effectively control indoor climate. This will not only reduce energy consumption, but will ultimately help in adopting appropriate design measures for maintaining comfort conditions. There are basically two approaches to the determination of temperature stratification; experimental and analytical. Experimental approaches are expensive and time-consuming. Computer simulation, if suitable tools are available, could be very expedient for the building designer. [13]

1.3 Energy Performance Prediction of Atrium Buildings

Application of passive solar techniques to atrium buildings and optimization of design requires information and attention to the details of design and construction on the design phase. Nowadays, design tools are available to analyze the thermal behavior of buildings in detail and give recommendations for design strategies. [14]

The prediction of the energy performance of a atrium is a complex matter. The thermal process and air flow process interact. This processes depend on the geometric, thermo-physical, optical and aerodynamic properties of the various components of atrium spaces. Although public domain energy simulations have been used for simulating the thermal behavior and performance of buildings for a long time, this computer tools are some handicaps for predicting the thermal behavior of atriums, because they do not account for temperature stratification mass flow or radiative heat transfer between zones. Therefore, during the simulation, there should be defined acceptable assumption.

This thesis tries to model temperature and energy consumption of an atrium building by using dynamic building simulation program, TRNSYS, as a design tool in order to achieve estimation on thermal performance of atrium.

1.4 Objectives of the Work

The aim of this thesis is to analyze thermal performance of atrium buildings in order to achieve energy efficient design of atria and incorporate it properly to the commercial buildings. In this respect, major issues of atriums thermal behaviour are analyzed and evaluated its thermal performance on a case study building in Esslingen, Germany, by using a dynamic simulation program TRNSYS 16. In case study, different variations are applied and compared the result to find optimum design concept for atrium buildings in terms of its thermal performance.

In detail, the current thesis includes the following chapters:

The first chapter is introduction. It tries to highlight the importance of energy for present and future and clarify the significant portion of buildings on energy consumption all over the world. Then is particularly explained importance of atrium building in order to achieve energy-saving in commercial buildings and touched on energy prediction issue of atrium briefly.

The second chapter is Fundamentals of Thermal Performance of Atrium and aims in describing atria as energy efficient design approach and includes a detailed thermal analysis on the atrium spaces in consideration of energy efficiency and try to show some accepted design criteria for atrium spaces.

The 3rd chapter includes building energy simulation used in the current thesis. First is explained how building energy simulation tools aid to design better energy efficient buildings. The building energy simulation program TRNSYS used to achieve this study is also briefly described.

The 4th chapter, an Estimation Approach for Thermal Performance of Atrium Buildings through a Case Study, composes the main chapter of the study. It proposes an application of thermal energy strategies of atrium spaces on a case study building in Esslingen, Germany. First, it defines the case study building and its existing energy strategy. After that, the thermal performance of atria, which is highlighted in Chapter 2 is evaluated with different possible design concepts by using of TRNSYS and compared with each other to obtain the best solution.

The last chapter of the thesis is the 5th chapter and it includes the conclusion and recommendation for future works related to atria type buildings.

2. FUNDAMENTALS OF THERMAL PERFORMANCE OF ATRIUM

This chapter aims in describing atria as energy efficient design approach and includes a detailed thermal analysis on the atrium spaces in consideration of energy efficiency and try to show some accepted design criteria for atrium spaces.

2.1 Introduction

Atrium (a'treem), as a term is used for an interior court in Roman domestic architecture and also a type of entrance court in early Christian churches, which were playing an important role as uncovered, internal patios [15]. Besides, in Turkey and Anatolian architecture, almost all mosques and houses comprise essentially of an enclosed courtyard providing a private living and worshiping space which is opened to outside conditions and at the same time separated from outside. With this characteristic they provided a temperate climate and were playing an important role as protected, private outdoor spaces.

Today atrium means an enclosed multi-storied space that is open vertically to multiple stories. Atria are typically used as key architectural features in main entries, public circulation areas or as special destinations within a building. Atrium design often involves skylights and generous glazing areas that provide an infusion of natural light which make them a prominent building areas well suited to serve ceremonial and social functions. Among the reasons for including an atrium in a building design are to create a dramatic entry or central space, to increase the amenity for the building users, to provide more perimeter space and to facilitate circulation [9, 15].

NFPA 92B the current standard for smoke control in large spaces defines atrium as a large volume space created by a floor opening or series of floor openings connecting two or more stories that is covered at the top of the series of openings and is used for purposes other than an enclosed stairway; or other mechanical and utility service to the building. IBC defines Atrium similarly as an opening connecting two or more stories other than enclosed stairways, elevators, hoist ways, escalators, plumbing, electrical, air-conditioning or other equipment, which is closed at the top and not defined as a mall [15].

In many ways, atrium buildings have been an attractive design element for centuries constructed with different forms and structures. Today, atria can be frequently met in commercial buildings because of the architectural reasons and its influence on the occupants physically and psychologically. Moreover, they enhance prestige of the company. However, it is not considered the energy conservation potential of atrium. In view of the fact that the there is an increasing need to find ways in order to improve the energy efficiency of building, atrium should be designed and constructed energy conscious.

2.1.1 From Energy Point of View

Public buildings adopted uncovered atria at a larger scale. With the emergence of new technologies for the production of metal and glass in the 19th century, glass covered atria, conservatories and arcades became popular, their use spreading to northern Europe and beyond. The indoor climate in these spaces was originally maintained throughout the year by passive means, but with developments in air-conditioning and an increased use of glass on building facades, passive atria, conservatories and arcades became less common and much experience in their use was lost [11].

The 1950s brought a revival of the atrium as a commercial amenity in offices, shopping malls and hotels, initially in North America and then in Europe. Most of these atria were fully mechanically air-conditioned so that they could be used all year. In such cases the energy use can be quite high. Consequently most atrium buildings were not as energy efficient as they could be and they became an enormous waster of large quantities of energy. For amenity and convenience, glazed areas have been increased. Buildings were oriented to capture view without consideration of energy implications. After the energy crisis in 1970s, people became more conscious of energy conservation and environmental issues. Atrium buildings gained a bad reputation and were labeled as “energy wasters” [11, 16].

In recent years atria had gained very common popularity in building design. As a result of this regeneration, the energy-saving potential of atria based on passive solar principles has been reconsidered and applied to advantage, typically in commercial buildings like office buildings, hotels and shopping centres.

In practice, atria are rarely incorporated in designs for the main purpose of energy saving. The motivation is more likely to be architectural. Accepting that the atrium is now very common feature in large public and commercial building, it becomes all the more important to ensure that it does not commit the building to a lifetime of high energy consumption [12].

It is helpful to consider the evolution of an atrium from an open space. The open space would provide the parent building with daylight, natural ventilation and, if south-facing, useful passive solar gains. All of this function is potentially energy saving. If the open space is now glazed over to form an atrium, these original functions must not be jeopardized [12].

To ensure that the presence of an atrium space does not increase the energy consumption of the parent building, and that the original benefits of the open court are preserved, the following points must be observed. The daylighting levels in the glazed space must be maximized by the use of reflective finishes and clear glazing. This allows the surrounding rooms to be daylit and obviate the need for daytime artificial lighting in the atrium. The atrium must have a supply of fresh air which will permit natural ventilation of the surrounding rooms (if fire regulations permit). Shading and high rates of ventilation must be provided in summer to prevent overheating of the atrium and subsequent overheating of the surrounding spaces (Figure 2.1) [9].

If the original function of the open space are preserved and the atrium does not increase the energy consumption of the whole building, it could be consider the potential environmental benefits of the atrium space.

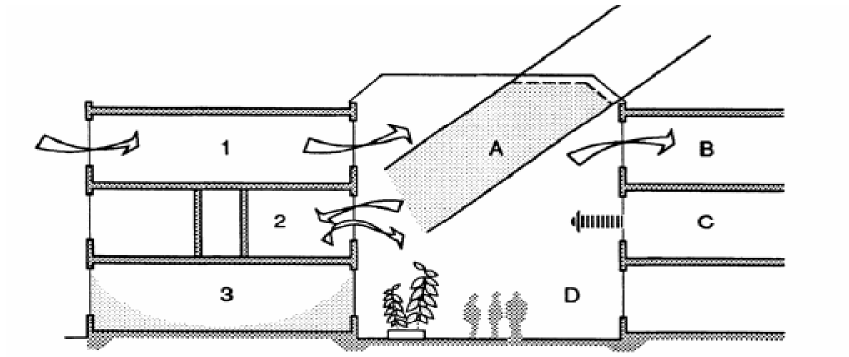


Figure 2.1: The environmental benefits of an atrium compared with an open court. 1: cross-ventilation, 2: single sided ventilation, 3: daylight, A: sun in winter, shade in summer, B: pre-heated ventilation, C: reduced conduction loss, D: useful space [9].

The following advantages are often quoted:

-Provision of a semi-outdoor space with protection from cold and wet weather. An atrium is a pleasant all weather gathering place providing shelter from the more extreme climate conditions outside. The atrium replicates a desirable outdoor environment by providing the benevolent aspects of the outdoor environment; natural light, moderate temperatures while sheltering us from the harsher elements of extreme temperatures, rain, and winds.

-The conversion of open courts to daylit and protected space, which can be used for circulation, restaurants, recreation in commercial buildings

-The possibility of using the atrium as a useful sink for warm extract air, or as a pre-heater for ventilation air.

-The reduction of heat loss from building surfaces which would otherwise be exposed to winter weather.

-The reduction of maintenance costs to facades otherwise exposed to the weather.

-The enhanced use of daylighting so that for the majority of the year no electric lighting is required during the office hours.

-The provision of vast and entertaining interior gardens.

-The provision of links, both within one building and between streets [11].

On the other hand, there are some disadvantages of atria that the designer must take into account in order to avoid its harmful effect on energy consumption of the whole building. These problems can be described as follows:

-Added fire and smoke risks.

-The provision of ventilation to spaces which would otherwise be open to ambient air.

-The loss of daylight to rooms adjacent to courtyards, caused by roof structures.

-The risk of cross contamination in hospital atria, and the spread of odors in glazed malls.

-The cost of glazing.

-The risk of overheating [11].

It is obvious that there are essentially many disadvantages of atrium beside its advantages. However, atrium building always becomes an attractive design element for centuries. We incorporate atrium buildings with architectural and energy consideration.

It can be mentioned some basic reasons for incorporation of atrium in building as follows [16]:

1. An urban and architectural role: This has been one of the most dominant factors from the inception of modern atrium buildings. The atrium is used by architects and planners as a versatile urban design element [17]. It is the ability of atrium buildings to deal with complex and unusual site shapes which makes them so useful in urban design. National Gallery of Art, Washington DC is a good example, which has designed by I. M. Pei and completed in 1978. The building is located in an awkward site: its radial avenues crossing gridded streets produce many wedge-shape areas. The new building as an extension to the old gallery had the urban-design task of relating to the present gallery, aligning with the Mall Avenue and acting as the last definer of the processional route of Pennsylvania Avenue before it enters the

influence of the Capitol itself. The overall site shape is too graceless to produce a strong building form .The architect resolved the problem by shearing the site in two, creating two sharp triangles which heighten the sharpness of the convergence of two avenues. (Figure 2.2) Furthermore, Professor Sir Leslie Martin and Lionel March in their book- "Land Use and Built Form" proved that the same floor area could be delivered in relatively low buildings by arranging them around the perimeter of a site using Fresnel square. (Figure 2.3) The Fresnel square is a square divided into concentric rings of decreasing width, but of equal area. Furthermore the area of each ring equals the area of square at centre (Figure 2.4) [16].

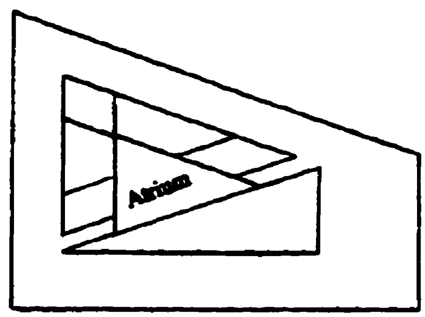


Figure 2.2: Site plan of atrium building at Washington DC [16]

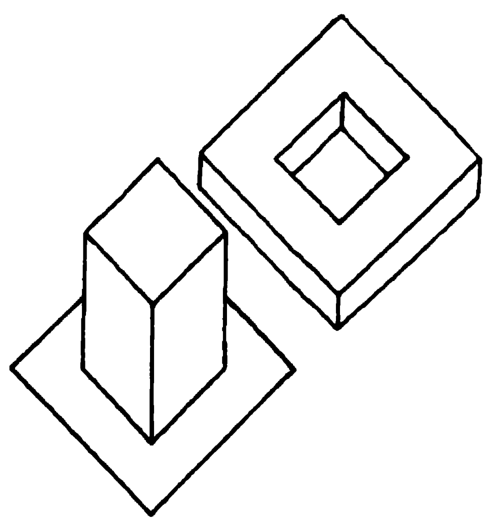


Figure 2.3: Illustration of efficient land use [16]

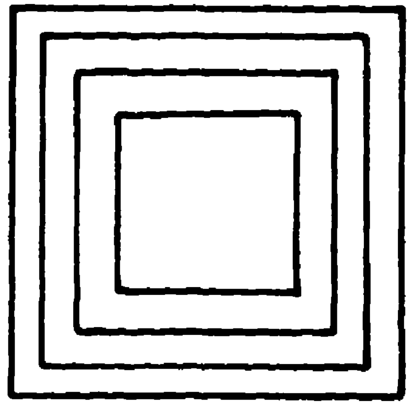


Figure 2.4: Fresnel square [16]

2. Visual Connection with outdoor: Atrium provides the occupants in atrium and also in its adjacent spaces an opportunity to view to the outdoor thanks to its glazed area. While in deep plan offices without atrium can not view to outdoors, with atrium they can benefit the outdoor environment in wide range [16].

3. Profitability: Market studies show that the buildings with atriums are very attractive and have higher occupancy rates, increased sales and are capable of generating higher rental rates. [16].

4. Energy Conservation: Atriums offer great potential for energy conservation through daylighting, passive heating and passive cooling.

2.1.2 Classification (Types)

An atrium is defined as a glazed space, which is thermally separated from adjacent spaces, and which or often not, or only partially, heated. Adjacent space is defined as the buildings adjacent to the atrium. The exterior envelope is the part of the atrium envelope that faces the ambient. It can be totally glazed or partly opaque. The intermediate boundary is the part of the atrium envelope that faces the adjacent spaces. It can be glazed, opaque, and/or partially open.

The shape and geometry of an atrium is both the product of and the reason for the adjoining occupied portions of the building. Inhabited by office workers, residents, or other uses, these spaces are impacted greatly by the configuration of the atrium space. The configurations can refer to the shape in two or three dimensions, the scale or the layout of the surrounding spaces and how they are connected to the atrium [15].

Atrium buildings could be of unlimited shapes and configurations. Furthermore, same forms and configurations have been defined by different academicians with various names. According to Hastings there are five basic types of atriums based on configuration. It can be seen in Figure 2.4. On the other hand, this basic form of atrium can be seen in categorization of Saxon as well. Saxon classifies atria based on the number of contacted face of atrium to adjacent building.

2.1.2.1 Hasting's Types

Core atrium: The classic atrium type providing a glazed courtyard in the centre of the building surrounded by adjacent spaces on all sides. The external envelope of the atrium is limited to the area of the roof glazing (Figure 2.5.a).

Integrated atrium: An integrated atrium is a glazed space that is positioned in the building such that only one side faces the exterior. It may or may not have a glazed roof (Figure 2.5.b).

Linear atrium: The linear atrium covers an open space between two parallel building blocks ending with glazed gables on both sides (Figure 2.5.c).

Attached atrium: The attached atrium is a glazed space added to the external wall of the building envelope (Figure 2.5.d).

Envelope atrium: The envelope atrium is characterized by an entirely enclosed building covered by glass representing a "house in- house" concept. The large external envelope glazing may include one facade of the building (Figure 2.5.d) [9].

2.1.2.2 Saxon's Types

Single-sided or conservatory atrium abuts one side of the occupied portion of the structure (Figure 2.5.d). Two sided-atrium(two open sides) abuts two sides of the occupied portion of the structure (Figure 2.5.f). Three-sided atrium (one open side) abuts three sides of the occupied portion of the structure (Figure 2.5.b). Four-sided atrium (no open sides) abuts four sides of the occupied portion of the structure (Figure 2.5.a). Linear atrium (open ends) sandwiched between two occupied portions of structure (Figure 2.5.c) [16].

Another classification stated by Yoshino is as follows: [18]

1. Tower type with high ceiling

2. Large volume with wide floor area,

3. Small volume with low ceiling, and

4. Greenhouse type with extensive glazed area. (Figure 2.6)

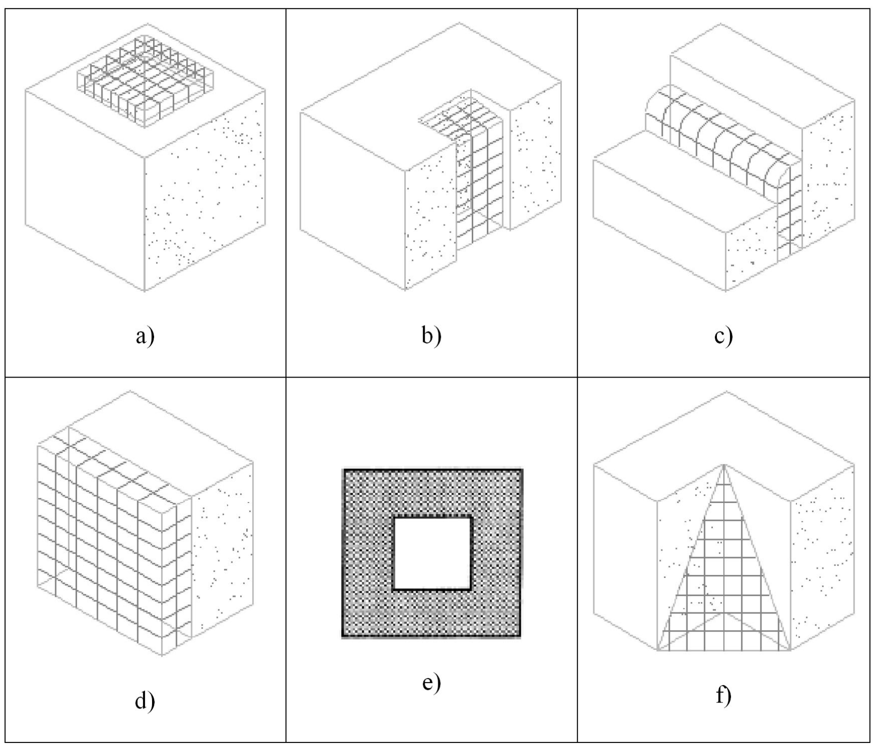


Figure 2.5: Atrium Types according to the relationship between main building and atrium space [9, 16]

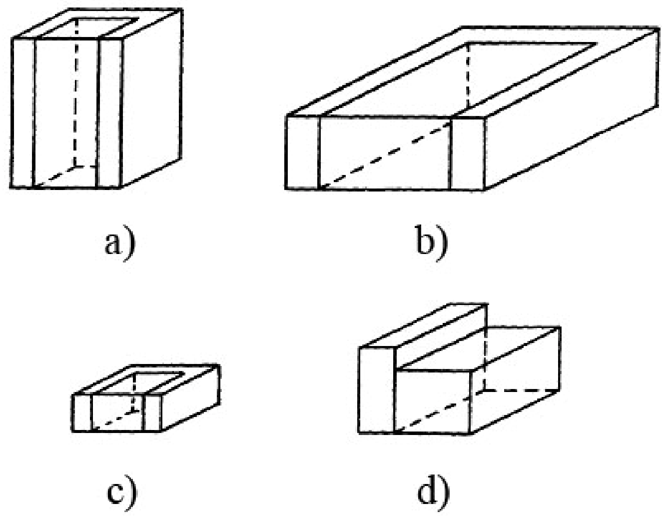


Figure 2.6: Atrium types according to the Yoshino's classification; a) tower type with high ceiling, b) large volume with wide floor area, c) small volume with low ceiling, d) greenhouse type with extensive glazed area [18]

Atrium buildings are also categorized based on spatial connections between adjacent building and atrium space, which can be seen in Figure 2.7 [18].

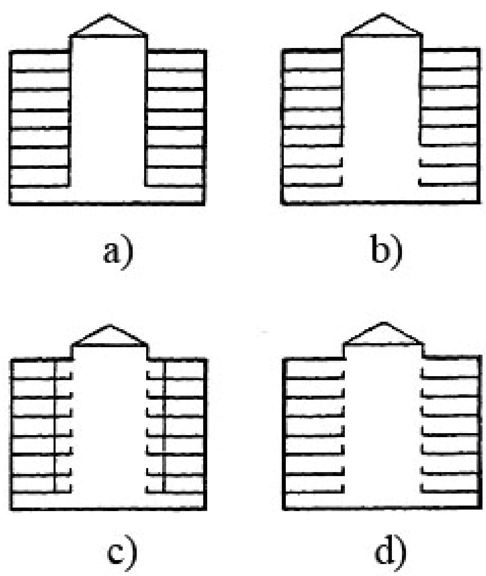


Figure 2.7: Atrium types based on spatial connection to adjacent building; a) totally separated, b) open to only lower floor, c) open to corridors, d) Totally open [18].

In recent years, atrium buildings are designed and constructed in complex forms, thanks to new construction technologies and new trends in architecture. Therefore it is necessary to make a classification of complex type of atria. (Figure 2.8) This has been done by Saxon as follows;

1. Bridging: Atrium connects several occupied portions of structure.

2. Podium: Atrium sits at the bottom or below an occupied portion of structure.

3. Multiple Laterals: Atrium spaces scattered throughout plan on single or multiple stories.

4. Multiple Vertical: Atrium spaces scattered throughout height of tower structure [15, 16].

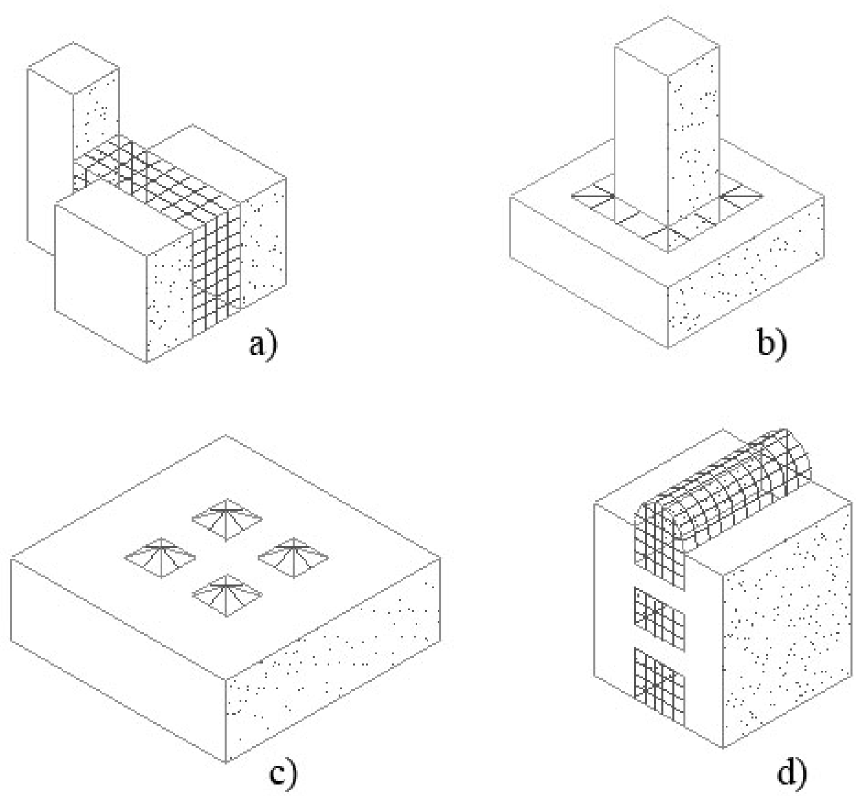


Figure 2.8: Complex Types according to the Saxon [16]

The most important geometrical parameters of atrium spaces are the relationships between length, width, and height. Therefore, it might be beneficial to quantify these geometrical parameters in a single number. Bednar used section aspect ratio and plan aspect ratio, while Baker used well index, room index, and aspect ratio in order to characterize the geometry of atriums [12, 19].

These are defined as follows:

1. Sectional aspect ratio (SAR) = Height/Width,

2. Plan aspect ratio (PAR) = Width/Length

3. Well index (WI) = Height (Width + Length) / (2-Length-Width)

4. Room index (RI) = (Length-Width) / Height (Length + Width)

5. Aspect ratio (AR) = Length-Width/Height^2

Based on SAR and PAR atrium spaces could be categorized as follows:

1. Linear, if PAR < 0.4.

2. Rectangular, if 0.4 <PAR< 0.9

3. Square, if 0.9 < PAR = 1, and

1. Shallow if SAR< 1, and

2. Tall and/or if SAR > 2,

The AR is used to compare atriums with daylight admitting areas of the same size, but different heights [12, 19].

Each type of atrium has various properties like exterior glazing area, sectional and plan aspect ratio, and connection area with adjacent space. As a result of that, this all various types affect atriums thermal performance in terms of interacting with the climate. Therefore, it is very important to determine proper atrium type depending on the climate and thermal and architectural requirements. In following chapter, fundamentals of atrium thermal behaviour will be explain and in addition, the affect of atrium type will be mentioned in some cases considered with the fundamentals.

2.2 Fundamentals of thermal behaviour of atrium

An atrium is a space consisted of large glass walls and roof; therefore, indoor thermal environment is greatly influenced by the outdoor conditions. If there is no air conditioning system, the atrium space can easily get overheated during the day due to solar radiation. At night, the indoor temperature rapidly falls due to large heat loss through the glass. If the space is conditioned, the conditioning load could be much higher than that of other buildings. There is also a possibility of a large vertical temperature gradient in the atrium space. The area under the roof could be very hot all year round, while the occupied zone temperature on the floor could be even lower than the comfort level during the winter [20]. The temperature in an unconditioned atrium will depend on the relative amounts of solar gains and transmission losses. The energy balance of atrium can be seen in Figure 2.9 [21].

It is difficult to predict the thermal behavior of an atrium at the beginning the design process of the project. However, some parameters can have an impact on the indoor environment. These parameters are architectural considerations depending to the knowledge of the architect.

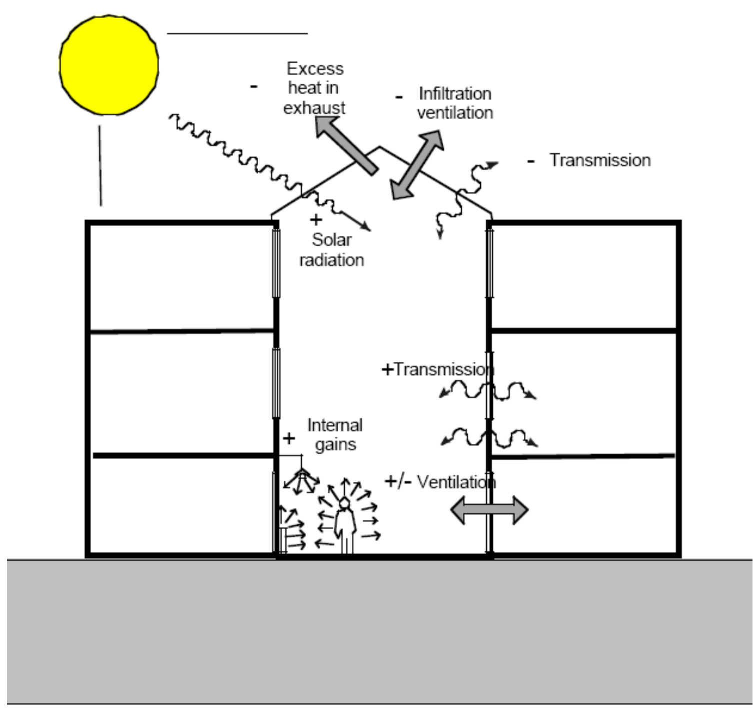


Figure 2.9: Energy Balance in Atrium [21]

If we mention about the thermal behavior of atrium, it involves the following two natural phenomena:

1) Greenhouse effect: Short wave radiation from the sun passes through glazing to warm interior surfaces. The re-radiated heat in the form of long wave radiation is not able to pass back through the glass. This effect is of benefit in the winter and a liability in the summer [22].

2) Stack effect: The stack effect is the result of convection within an open space. The warmer, less dense, more buoyant air rises to the top of the space, and tries to exit. This results in a positive pressure at the top of space and a negative pressure at the bottom. Wind movement over the openings will enhance the suction effect. If the air cannot exit, then this results in the stratification of air by temperature especially apparent in a tall closed volume. Combined with the buoyancy of air warmed by the greenhouse effect there will be strong stratification of air by temperature in a tall closed volume, and an equally strong upward draught when openings are made [16, 22].

Working with these two effects makes climate-control simple; working against them can be costly or even impracticable [16]. There are lots of studies, which are concerned with the thermal behavior of atrium buildings in some respects. However, the result of these studies varied widely. It seems clear that the energy performance of atrium buildings depends upon some parameters. These are geographical location and climate, orientation, ratio of atrium size to adjacent building size, type and function of atrium, thermal nature of adjacent spaces, adaptation of cooling and heating strategies, envelope constructions and operation hours, temperature set point and equipment efficiency. In order to understand thermal performance of atrium and to specify an energy efficient design strategies compatible with different climate and environment, first we have to analyze the thermal behavior of atrium. This part of study tries to highlight the major thermal behaviors occurring in atrium buildings.

2.2.1 Temperature Stratification and Stack effect

One important characteristic of large glazed spaces such as atrium is that the air temperature is not always homogeneous but can increase with the height of the atria.

This phenomenon is called temperature stratification. Warm air tends to rise and cold air to fall. If the air flow is dominated by the natural convection process, thermal stratification can be established. However, this thermal stratification can be destroyed partially or completely by other air flow currents, including a strong mechanical supply jet flow or a cross ventilation due to winds. The temperature stratification depends on the thermal condition, height of enclosed space and particularly on the distribution of the solar and internal gains. The air movements in the atrium and between the outside or adjacent zones also have a significant influence on stratification [23, 25].

The temperature stratification in large enclosures is due to the following effects: A volume of air which is heated and then reaches a higher temperature than its surrounding will be affected by a driving force, due to density differences between the warm air and the cold air (the warm air is lighter than the cold one), which will tend to displace it in the vertical direction from bottom to the top (known as stack effect).The higher temperature in the volume can be caused by a heat source of a machine, a personal computer for example as well as heated surfaces (by the sun). Outdoor climate influence also significantly stack effect in atrium buildings. It is more pronounced in cold climates, because of greater temperature differences between indoor and outdoors [23, 24].

Depending on the thermal situation, we can define four main temperature distributions in large enclosures (Figure 2.10)

1. Constant in the height.
2. Increasing linearly
3. no linear profile, increasing swiftly in the lower part
4. No linear profile, increasing swiftly in the upper part

Profile 1 is typical for complete mixed situation. Profile 2 is typical in atria where the heat sources are uniformly distributed in the space and its surfaces. Profile 3 represents the common case whether either central heat source or source generates a column of heated air which rises rapidly to the roof prior to mixing and tends to pool at the upper level, or heat sources are distributed only in the upper part (internal shading under the roof for example). Profile 4 represents the case where heat sources are close to the floor level [23].

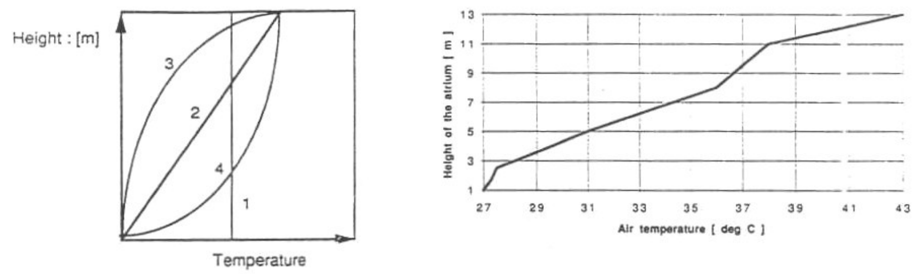


Figure 2.10: Typical vertical temperature profiles [23]

The temperature stratification has a considerable influence on thermal comfort and energy consumption for summer and winter condition differently. In winter, temperature stratification is a disadvantage because the atrium will require more heat in order to obtain comfortable conditions on the ground level. However, because of greater temperature gradients, hot air at the top increases heat loss through the roof. Therefore, it is advisable to recirculate the hot air collected at the top to the bottom with the help of fans. During the summer, temperature stratification can be seen as positive for the comfort of the occupied zone at the ground level, but can also lead to overheating problems if the upper part is occupied or in adjacent spaces. Stratification of the temperature in the summer is not very often sufficient to provide comfortable conditions at the ground level and natural ventilation must be used. The stratification is then reduced [13, 23].

The stratification of the temperature in atria is relevant when the following conditions are fulfilled:

- Height of the volume is important. In atrium configuration with a small height no important stratification is taking place, especially when the vents are opened and the space naturally ventilated.

- Heat transfer to the air from the heat source in the upper part or linearly distributed through the height of the volume.

- Hatches (vents) for natural ventilation opened or closed (or partially) and ventilation system of atrium have significant effect.
- Volume with small air movements is important
- The internal shading devices will tend to create some stratification.

The natural ventilation of the atria by openings vents at different levels will decrease the stratification depending on the efficiency of the piston flow. If the peak temperature of the upper part of the atrium is not increased by the internal shading devices which tend to create stratification, the upper occupied zone or the rooms at that level of the adjacent building will not become more uncomfortable than they would be with complete mixing [18]. Some experimental and numerical studies shows that the most significant variables affecting stratification are outdoor air temperature, sun position, and global radiation, while wind speed is less significant compared with the other variables. The temperature stratification increases as outdoor air temperature, height and solar radiation increase. However, for similar outdoor conditions, it is greater in the atriums with higher SAR [9, 23]. Moreover, combined with the buoyancy of air warmed by the greenhouse effect there will be strong stratification of air by temperature in a closed atrium and an equally strong upward draught when openings are made [16].

Traditional ventilation systems by mixing utilize supply jets to create a strong global circulation in a ventilation space. This can result in a rather uniform air temperature distribution. This is why those most existing cooling load calculations assume that the zonal air temperatures are uniform. This assumption can simplify significantly the heat transfer calculation. The zonal air temperature is the same as the exhaust air in that zone. Heat conduction through walls, floor and ceiling can then be calculated easily. However, the assumption of uniform air distribution is not true in ventilation by displacement. Thermal stratification is a result of utilizing the buoyancy flows in this air distribution method. The associated contaminant concentration stratification is also the main reason why the displacement ventilation becomes a good option for some buildings. Air is supplied at the floor level and is controlled to behave as gravity current. Global air circulation is minimized. Cool and fresh air is distributed by gravity currents into the lower occupied region of the room or building. The cool air is heated by heat sources or the floor in the room, rising as thermal plumes and boundary layer flows along the warm surfaces. During this process, the supply fresh air becomes “old” and perhaps polluted, which rises to the upper zone of the room. The air temperature is no longer uniform vertically in the room. Apart from thermal plumes and thermal boundary layers, the air temperature is rather uniform horizontally [25].

2.2.2 Heat transfer through glazing (greenhouse effect)

Short wave radiation from the sun passes through glazing to warm interior surfaces. The re-radiated heat in the form of long wave radiation is not able to pass back through the glass. This effect is called greenhouse effect in atria and is a benefit in the winter and a liability in the summer. Because of its large glazed areas, atrium spaces are affected more by outdoor climate conditions, for example in high temperatures during the day and rapid heat loss during the night, and may have several problems such as over-heating in summer and mild winter, and cold drafts and condensation on glass in winter [16, 22].

The greenhouse effect can be achieved by the proper design alternatives. The thermal transmittance, orientation, inclination and solar radiation transmittance of the external glazing of atrium influence this effect significantly. The proportion of exterior glazed area to adjacent wall area is also very important and it depends on the configuration and type of atrium, which has been mentioned in this chapter before.

Typically, a high proportion of the exterior envelopes of atrium are glazed and the height is considerable compared to conventional built spaces. Therefore, it is difficult to meet criteria for U-values of exterior walls and roof specified by common standards for commercial building by a majority. Thus overall heat loss and gain will be higher in atriums compared with conventional building envelopes. The conductive and convective heat transfer through the glazed surface of atrium is highly dependent upon the temperature and pressure gradient (due to the stack effect and wind) between indoors and outdoors. Apart from this, glazed area will also allow large amounts of radiative heat transfer.

A glazed roof is also a significant different feature of atrium buildings, because of the extensive areas exposed to the solar radiation. A large glazed roof will admit solar radiation during the day and allow radiative heat loss during the night. On the one hand, solar radiation in winter will help to reduce heating loads and, on the other hand, it will increase cooling loads in summer. Radiation heat loss at night may be utilized as a cooling strategy in summer, whereas it will increase heating loads in winter [19]. The solar incident angle is high in summer and low in winter. The intensity of solar transmission received at a surface is a function of the angle of incidence. Solar transmission will be a maximum, when the angle of incidence is 90o. Therefore, when designing the roof of atriums, the inclination and the orientation should be considered in order to take best advantage of solar radiation in winter and refuse the undesirable solar gain in summer. This could be done by designing the slope and orientation of roofs such that the glazed surface is close to 90o with the solar incident angle [16].

The useful solar heat gain which is obtained by greenhouse effect during the cold days has also a great effect on the temperatures of adjacent building and reduces its heating demand. The solar heat gain through the exterior glazing may contribute to the adjacent building energy demand by a proper design concept.

There are some factors which ensure the effective use of greenhouse effect in the adjacent buildings;

- The ratio of external glazing area of the atrium to the wall area of the parent building which is protected by the atrium.

- The thermal transmittance of the separating wall between atrium and parent building. This will normally be dominated by the amount of glazing in the wall [12].

The proportion of exterior glazed envelope to intermediate envelopes of atrium spaces depends upon the configuration and types of atriums, which has been told in this chapter previously.

The adjacent wall between atrium and parent building has mostly higher U-values compared with exterior walls of atrium, because these walls are constructed with reduced insulation or no insulation at all. Moreover, their glazing areas are constructed with single-glazed openable windows, in order to benefit from the passive heating and cooling acting in atrium space (like solar gains, natural ventilation). The atrium loses or gains to/from adjacent spaces depend on the temperature gradient between them. However, because of lower temperature gradients between atrium spaces and adjacent spaces, heat transfer through intermediate envelopes will still be less than through exterior envelopes, provided atrium spaces are used as buffer zones [16, 18, 23]

2.3 Design Criteria for Different Conditions

In previous chapter, two natural phenomena of atrium have been analyzed, of which the designer should be aware for providing comfort condition in atrium spaces. Energy efficient atrium design should be done by considering these two phenomena. However, atrium's performance will be changed depending on climate of the site in which atrium is placed. Therefore some design criteria must be determined for different climate conditions. The other important factor affecting design criteria is thermal nature of building use as defined by Saxon. The climate condition is the obvious deciding factor for atrium design. In cold season atrium must work as a heat collector to provide freely heat from sun to the building and in warm season conversely must reject heat. In this respect, atrium's thermal strategy should be specified by considering the interaction of building use and climate conditions. We can analyze it for cold climate and tempered warm climate as winter and summer condition, respectively.

2.3.1 Winter Conditions

In winter, atrium can be passively warmed by admitting large amounts of solar radiation through the large glazed area and by storing this useful gain with the help of high thermal massive walls and floors. Even if the entering of solar radiation into the space depends on the thermal properties of glazed materials, it is also important to save and use large amount of the heat inside atriums. The rapid heat loss during cold nights can be avoided by stored heat in thermal mass of atrium space.

Furthermore, use of an atrium as a buffer space, which is a transition space between the indoor and outdoor environments, could provide energy saving in winter.

An atrium acts as a buffer reducing transmission losses from adjacent spaces to the ambient and may also provide heat to adjacent spaces. A buffer atrium will be designed to admit sun freely and will therefore generally be at least five degrees warmer than outside air temperature in warming season. Furthermore, an atrium displaces auxiliary heating by solar gain transfer from atrium to the adjacent spaces. [9, 16] In order to achieve this, we have to stress some important parameters like orientation or inclination and thermal properties of external glazing, thermal properties of material used for interior space of atrium, operating system for ventilation and heating and insulation.

There are three way for utilizing the sun; Heat collection, conservation and distribution. First, if we consider energy collection, atrium envelope will be very important for collecting the useful heat gain from sun in winter. The temperature in atrium spaces depends on some physical parameters of atrium space, like type of atrium, external glazing properties of atrium and separated wall glazing properties of atrium which is between adjacent building and atrium. For example, for external glazing properties, it can be mentioned orientation, inclination and solar transmission.

Even if the atrium is without auxiliary heating, the temperature in the atrium will be above the ambient temperature. Based on the study on atrium of Baker, N. and Steemers K. in their book "Energy and Environment in Architecture", the increment in temperature in atria depends on a number of factors.

1. The ratio of wall area of the parent building protected by the atrium to the external glazing area of the atrium. This ratio is defined as protectivity which varies from about 0.25 (case A) to about 3 (case C) (Figur 2.11).

2. The thermal transmittance of the separating wall between atrium and parent building. This will normally be dominated by the amount of glazing in the wall.

3. The thermal transmittance of the external glazing of the atrium.

4. The orientation, inclination and solar radiation transmittance of the external glazing of the atrium [12].

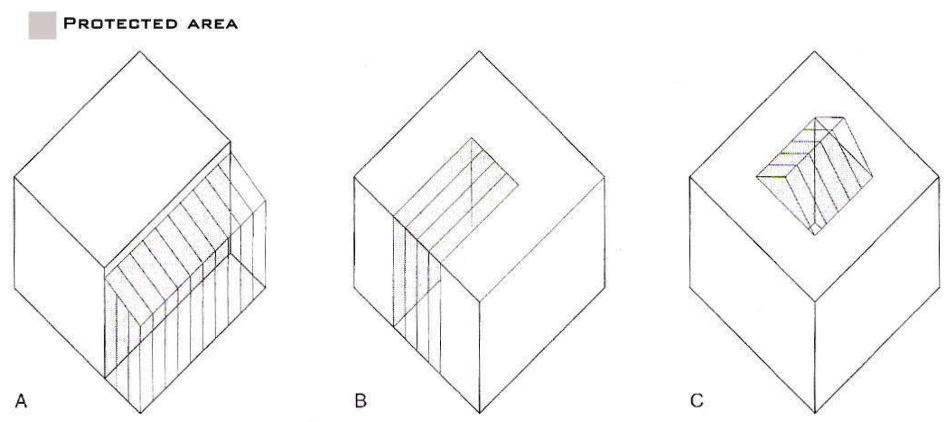


Figure 2.11: The ratio of external glazing to the protected area (or separating wall) [12].

Due to the low thermal capacitance and high thermal transmittance of glass, temperatures in the atrium respond quite quickly to the ambient conditions, resulting in a steady state calculation such as this being useful. The calculator can be used to indicate typical daytime conditions, by using indoor daytime set-point temperature and average daytime outdoor temperature [12].

Short-term averages may be calculated as follows:

Daytime average: $T_{day} = (1.7T_{max} + 0.3T_{min}) / 2$ *

Night-time average: $T_{night} = (0.3T_{max} + 1.7T_{min}) /2$ *

*T_{max}, T_{min} are the average daily maximum and minimum temperatures respectively.

In the study, it has been used a more detailed model, which takes account of solar gains and the exchange of air between the atrium and the parent building, in order to come close to the real temperature estimations in atrium. The calculations have been conducted on an unheated atrium case in the UK (Figure 2.14) [12].

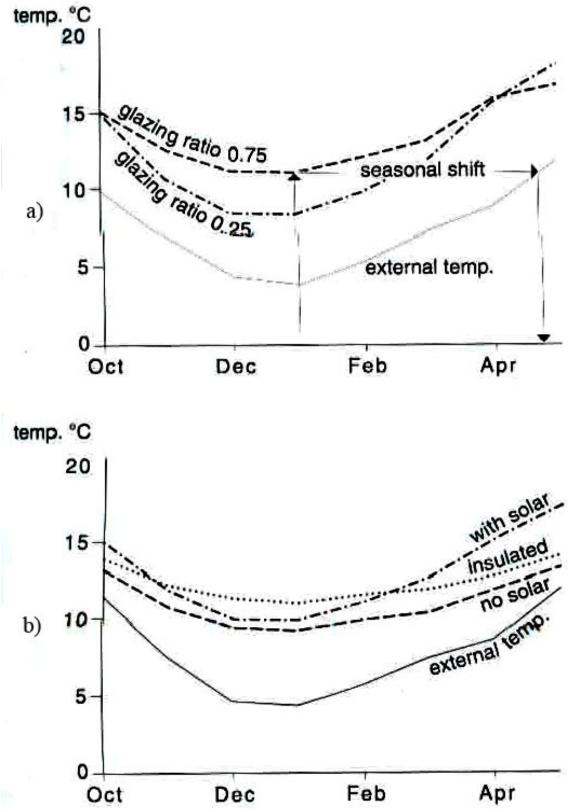


Figure 2.12: Predicted monthly temperatures for a typical core atrium [12].

Figure 2.12(a) shows the effect of the glazing ratio of the separating wall. The seasonal shift indicates the climatic equivalent inside the atrium. It can be seen that the atrium temperature has a climatic conditions rather than the environmental standards. The high glazing ratio of separating wall (75%) influences the atrium temperature in a good way. Figure 2.12(b) shows contribution made by solar gain and compares this with the effect of an opaque insulation roof. Solar gain does not influence the temperature significantly and the effect of insulation roof is higher than the glazed atrium especially in cold winter days due to the poor solar radiation. However, it has to be considered the relative amount of south-facing and non-south-facing atrium glazing in order to determine the exact performance. According to this study, two useful concepts when considering the performance of an atrium are the protectivity and the solarity. The protectivity is defined as the ratio of the separating wall area to the atrium external envelope area. The solarity is defined as the ratio of south-facing glazing to the total area of glazing in the external atrium envelope [12].

For transferring of solar gain through the glazing, the orientation and inclination are very important factors. The predominant orientation of the atrium aperture should be south, and the glazing should be vertical (to reduce the risk of overheating in summer) [9]. Moreover, if it is, then a south-facing envelope can be shaded most easily to exclude higher-angle sun in summer [16].

The atrium glazing properties significantly affect atrium energy consumption if the atrium is heated to a temperature near the comfort zone. During the heating season the U- value of the atrium glazing is a more significant factor than the solar transmission. Double low-e glazing is especially effective in northern latitudes. For example, parametric studies of the atrium in the ELA building, in Trondheim, Norway with north and south facing glazing, show about a 50 % reduction of atrium heating energy requirements when the U-value of the glazing is reduced from 2.1 to 1.0 and the solar gains are kept constant. For the total building, this improvement in U-value results in about a 5 % drop in heating energy requirements [44]

A comparison of glazing options for the ELA atrium was made by the designers prior to construction. The results indicate that the double, low emissivity glazing produces about a 10 % improvement in building heating energy consumption compared to other glazing options, and about a 20 % improvement compared to an open well (non-atrium) building when the atrium is to be heated to 15oC. A double low-e glazing in the atrium is found to be the best alternative as it can be seen in Figure 2.13 [44, 18].

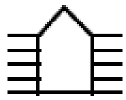
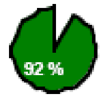
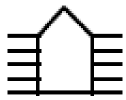
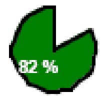
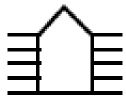
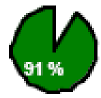
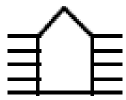
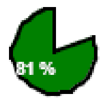
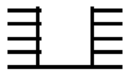
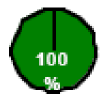
A			92%	Double glazing in roof and gable walls, single in facades.
B			82%	Double low-E glazing in roofand gable walls, single in facades.
C			91%	Double glazing in all
D			81%	Double low-E glazing in roofand gable walls, double in facades.
E			100%	No glass roof, triple glazing in facades.

Figure 2.13: Energy consumption for heating the ELA building in Trondheim for different glazing alternatives [18].

Appropriate building form for winter strategy can be low-rise and well-spaced generally, because of the low (by world standarts) development densities permitted. Since the low sun angles in winter, down to 10 degrees above the horizon (especially in northern latitudes), are sought in building, it is desirable to have glazed adjacent walls to the atrium facing within 20 degrees of noon. If only roof-glazing is possible, a south-facing monitor form permits collection of the most sun [16]

As mentioned before, temperature increment in atrium depends on some parameters. As a result of the temperature increment in atrium heat losses from the parent building reduces and can be provided tempered fresh air to reduce the ventilation heating load. Even when air is being dumped from the parent building, the increase in atrium temperature reduces heat losses compared with the case where the air is dumped direct to the outside. It means that there is a kind of heat-recovery effect. As with atrium temperatures, the energy saving is strongly dependent upon the critical parameters of the atrium, like protectivity and solarity, and the size of the atrium relative to the parent building as explained before [12].

Ventilation of atrium in winter is desirable. Still air will stratify with cold air ponding at the level people pass through, and with any warm air pressing against the roof and cooling. If the atrium and occupied space are uncoupled for normal ventilation, effective air-mixing can be achieved by using a low-velocity fan to pull air down a duct [16].

Another study in U.K can be seen on Figure 2.14, which considers how heating energy consumption varies depending on a number of ventilation options. The biggest step is the difference between an independently ventilated atrium (b) and having no atrium at all (a). Here the saving is all due to the reduced conductive losses through the separating wall. The modelled building has a rather high protectivity ratio of about 2.5, which accounts for this significant effect. Energy saving can be increased by ventilation coupling between the atrium and the parent building. The ventilation pre-heat mode (c) is particularly appropriate for atria of high solarity, when during sunny hours the atrium temperature might go unnecessarily high without the ingress of ambient air. The ventilation dumping mode (d) causes slight savings but carries the advantage of higher atrium temperature, particularly appropriate on cloudy winter. At first sight the recirculation mode (e) should be ruled out on grounds of air quality, since there is no obvious source of fresh air. However, unavoidable infiltration through the atrium envelope takes place over 24 hours (and is allowed for in this simulation), whilst the building is typically occupied for about 10 hours. Furthermore, atria often contain large quantities of green plants which absorb CO2 and other contaminants. The notion of the atrium being in symbiosis with the building is an attractive one, but must be treated with some caution. In practice, a mix of all three modes (c), (d) and (e) could probably be used to advantage, controlling the temperature swings and air quality. This would certainly demand fairly sophisticated automatic controls [11, 12].

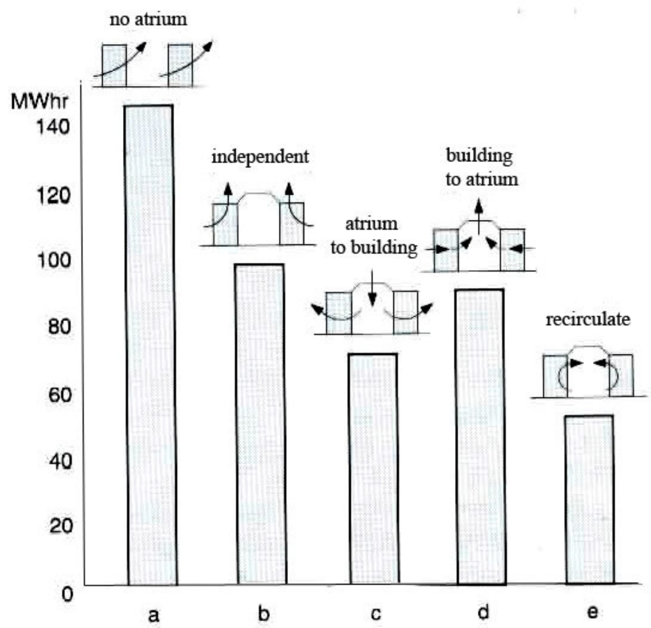


Figure 2.14: Annual heating energy consumption for a building with different ventilation strategies.[12].

In another study shows the ventilation effect depending on the air flow direction between the heated building and atrium as seen Figure 2.15. In the case of "From building to atrium" it can be obviously seen increment of temperature in atrium, due to the using of heated air through the adjacent building. Compared with the previous study, other case (from atrium to building) can be accepted because of his energy saving potential for the adjacent building however there can not be maintained good conditions as the first case.

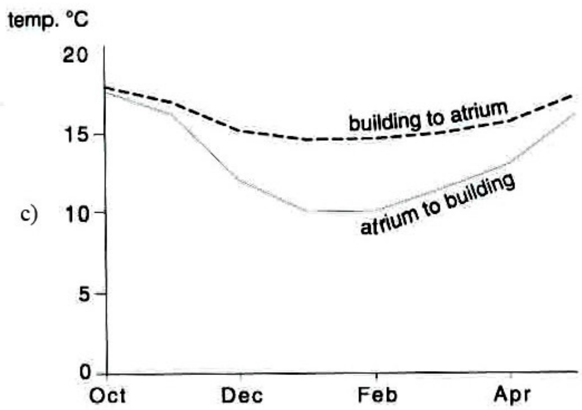


Figure 2.15: Predicted monthly temperatures for a typical core atrium [12].

For energy conservation and distribution, one of the considerable precautions is using thermal mass in atrium walls and floor. Collected solar radiation must be stored in the interior mass of building components exposed directly to the sun in winter. Thermal mass allows for storage of the solar energy entering the building. It thus reduces temperature fluctuations during winter, while during summer it helps to delay the temperature transfer from the outside to the inside. Different materials have a different thermal capacity. The materials of the atrium façade play a role on the thermal inertia of the building. This fact leads to a time delay of heat transfer to the atrium interior. The flow of heat through the atrium envelope is particularly exploited in atrium space or in heavy weight adjacent buildings for heating or cooling purposes. Thermal mass elements of the atrium can be slabs, beams or adjacent walls. Transparent elements on the atrium façade act as solar collectors and interior opaque elements like adjacent walls as heat storage sinks. Heat transfer from massive elements to the air is done by radiation, convection and conduction [9, 21].

A Swedish study by Goran Lundquist (in Camera Solaris, Stockholm, 1980) shows a benefit of two degrees in overnight low temperature where thermal capacity is provided, and a converse reduction of two degrees in periods of peak temperature [16].

Another important precaution is night insulation, in order to avoid undesirable infiltration and transmission losses from the atrium exterior envelope. Because of high glazing area, atrium will lose out heat in a wide range comparing with the other conventional commercial building. Therefore it is very significant to install night insulation to the building envelope.

Night-time heat losses are reduced by using good quality thermal materials in the envelope glazing and in the walls and windows separating the atrium from the rest of the building [9]. The amount of insulation required in atrium envelope depends on the comfort needed in the atrium and the insulation provided in the atrium envelope. High insulation in the atrium envelope will always be desirable in winter season, especially in cold climates. It is least important on sun-facing façades, but particularly important on roofs: heat migrates more rapidly upwards than side ways, as warm air presses against the roof (stack effect). Open night skies in winter can suck radiant heat from an atrium, cooling it to below outside temperature. An alternative to insulated glazing, which has lower light transmission if thermally efficient, is the use of night-shutters. These can be of fabric or folding sheet material, and will be very cost-effective [16].

Atrium type has an important role to act as a buffer space or its adjacent space. Linear or core type atrium have more spaces adjacent to their atria then the buildings with other types of atria. In these, the potential for the atrium to act as a buffer is substantial since it can affect a greater portion of the building. For example integrated atria type may perform well but do not substantially buffer the building as a whole, since they are connected to only a small portion of the building.

2.3.1.1 The effect of atrium on the heating energy load of adjacent spaces

An unheated atrium or buffer-space affects the heating load of the adjacent building in two ways: -By reducing the convective heat losses through the separating wall -By reducing the ventilation heat losses. This is more complex than it may seem since the reduction of conductive loss is strongly influenced by the geometry of the atrium, and the effect on ventilation heat loss is dependent on the mode of ventilation coupling between atrium and the adjacent building. [12]

Whilst the heating energy savings look very encouraging, it must be pointed out that heating energy forms a relatively small portion of total energy costs of larger buildings. The largest savings are often to be made in lighting, cooling, fan, and pump energy, and usually all requiring expensive on-peak electricity [11]. Therefore, it will be highlighted the design criteria of atrium for summer condition in the following part.

2.3.2 Summer Conditions

The cooling energy demand has increased in Europe. The demand for room and packaged air conditioners has grown with 20% between 1999 and 2002. The annual report summary of BSRIA on the West European room and packaged air conditioning market in 2003 confirms these conclusions. On the other hand, the Kyoto protocol binds the developed countries to reduce the collective emissions of six key greenhouse gases—among which CO2—at least by 5% by 2008–2012. This protocol encourages the governments amongst others to improve energy efficiency and to promote renewable energy. Therefore, counterbalancing the energy and environmental effects of air conditioning is a strong requirement for the future. Solar energy can also be used to induce convection to ventilate and/or cool a building. This usually referred to as Passive Cooling or Passive Ventilation. Passive cooling may contribute to the Kyoto requirements by reducing the need for cooling energy while providing a good thermal comfort. By the use of solar energy for buildings, if applied effectively, can result in energy saving and reduce CO2 emissions. Atrium is a good strategy to manage the passive cooling in commercial buildings. Carefully designed atria for commercial buildings can be used to induce passive ventilation through an office complex by suitable location of inlet and extract opening. In office buildings, the use of passive cooling techniques combined with a reduced cooling load may result in a good thermal summer comfort and therefore save cooling energy consumption [26, 27]

The performances of these passive cooling techniques depend on multiple building and environmental parameters. Firstly, climatic parameters (temperature difference inside-outside, average outdoor temperature range), building characteristics (thermal inertia of the building and convective heat transfer between ventilation air and thermal mass) and technical parameters (ventilation rate by night and control strategy) define the performance of natural night ventilation [26]

In cooling season the main concern is to prevent overheating. It is difficult to reduce air temperatures in the atrium below ambient temperature throughout the day. However it is possible to reduce the temperatures in atrium by taking some effective precautions. Atrium needs to behave as a shading device and store of cool air. There are three passive measures, in descending order of effectiveness, may be employed to attain this: shading, ventilation, and incorporation of thermal mass. [9, 12, 16]

Shading is the first method of defence reducing the ingress of solar gain. Sun must be excluded, except for ‘accent lighting’, and so glazing must either be fully shaded or polar-oriented. Shading provides a way of rejecting solar gains as soon as they enter the atrium (or even before with external devices), thereby reducing heat buildup. Shade can also reduce the effective temperature, as experienced by an occupant, by up to 8K. It saves the person from direct sun beam and reduces glare, which is of psychological benefit during times of stress. [12,16].

Ideally the shading should be movable. Fixed shading, or tinted glazing, will also reduce daylighting levels all year round. Furthermore, atrium envelope provides a structure upon which to install movable shading devices. The reason for recommending movable shades for thermal consideration must be stressed. The problem is that the sky brightness varies over a wide range. On cloudy days in winter, the atrium glazing should provide a minimum reduction to the sky illumination, in order to maintain the daylighting in the rooms and indeed, to provide enough light in the atrium for planting. Furthermore, in cold winter days, shading may obstruct utilizing useful solar gain. The ingress of direct sunbeams would be welcome. However, on a sunny day in summer, the situation is reversed. With the sky brightness twenty times greater, there is now no shortage of daylight and the presence of direct sun will overheat the atrium in general, and increase surface temperatures of both plant and human occupants. Obviously if there is sufficient shading in summer, then there must be too much in winter. Movable shading is the answer [11, 12].

If movable shading cannot be adopted, it is better to reduce the glazing area by having opaque well-insulated areas in the atrium envelope. If fixed shading is applied to the south-facing slopes, the shading function is maximised. If applied to north-facing roof slopes, this allows useful winter solar gains but performs less well to prevent summer overheating. A good compromise for relatively cool climates is where steep-angled south-facing glazing is left unshaded, and the shallow-angled north-sloping atrium envelope is opaque insulation. Alternatively, geometrically selective louvers and overhangs can shade summer sun and admit winter sun [12].

The performance of external shading certainly is better. However, when shading devices are positioned well away from and above occupants, re-emission of heat by radiation and convection is far less significant. If devices are light coloured and well ventilated, then internal shading can be effective. However, as told in previous chapter, internal shading devices can cause significant temperature stratification problem. [12, 23]

Ventilation is the other means by which summer temperatures can be limited. An atrium can induce natural ventilation and avoid undesirable solar gains. Natural ventilation can provide high rates of air change for zero energy cost. The ventilation of the atrium can also induce cross-ventilation of the adjacent occupied spaces [11, 12]. Furthermore, the ability to open windows and "let fresh air enter" would improve environmental quality for employees [28].

Natural ventilation is the use of outdoor air flow into buildings to provide ventilation and space cooling in summer time. In moderate climates, one promising approach to reduce the energy demand of office buildings for air conditioning without reducing comfort is passive cooling by night ventilation. Natural ventilation provides fresh air to ensure safe, healthy and comfortable conditions for building occupants without the use of fans and ensure free cooling without the use of mechanical systems. Furthermore it reduces building construction costs and operation costs, when carefully designed. The operating energy consumption can be reduced, which is required for air conditioning and circulating fans. Further benefits include no fan noise and in some cases elimination of the mechanical cooling system.

Air movements through a space can be introduced in a variety of ways:

1) with operable windows, ventilation can be driven by wind or thermal buoyancy (or stack effect) to ventilate a single side of a building or to cross ventilate the width of a building; 2) stack-induced ventilation uses a variety of exterior openings (windows in addition to ventilation boxes connected to under floor ducts, structural

fins, multi-storey chimneys, roof vents, etc.) to draw in fresh air at a low level and exhaust air at a high level and 3) atria enables one to realize a variant of stack ventilation, where the multi-storey volume created for circulation and social interaction can also be used to ventilate adjacent spaces. [29]

Advanced stack-ventilated buildings have the potential to consume much less energy for space conditioning than typical mechanically ventilated or air-conditioned buildings [45]. Stack ventilation effect can be achieved with use of atrium space. In this sense, atrium spaces can be a good instrument with their convenient form in order to overcome overheating problem in summer and maintain indoor air quality. Therefore natural ventilation is a critical factor in determining the environmental performance of atria. The inclusion of atria in modern developments is often used to enhance the lighting levels within a building and to provide a comfortable transit area. However, they can be problematic with overheating in the summer and can be excessively cold in the winter. They can also be expensive to run in terms of energy [9].

The purpose of an atrium ventilation system is to ensure the lowest possible indoor temperature in summer and to remove moisture and other pollutants in winter with the lowest possible energy consumption. For a natural ventilation system, thermal buoyancy and wind are the driving forces, and these forces can effectively be used in atria if the system is designed and executed in a proper manner as to obtain sufficient ventilation capacity and suitable regulation possibilities [30].

Buildings can be shaped and oriented to allow for maximum exposure to summer breezes, while the walls, interior layout and window placement are important for efficient circulation of these breezes [7]. However, in most cases, breezes cannot be relied upon, and thus the limiting case for design will be to provide sufficient stack-effect ventilation. In the critical hot summer days with no wind, a sufficient ventilation capacity shall then be obtained by the thermal buoyancy alone, and therefore the greatest importance will be attached to thermal buoyancy. [11]

Natural ventilation by thermal buoyancy (stack-effect) is the air exchange between two or more zones with different air densities. These differences can be due to different temperatures or different moisture contents. In an atrium, the temperature differences will dominate; therefore, moisture differences will not be taken into account [30]. Natural ventilation can be facilitated by a stack effect and by proper placement of air inlets and outlets. Inlets should be placed at the bottom of the atrium (and/or induced cross circulation should be included), and sufficient exhaust air vents should be placed at the top [9] However, it must be emphasized that this works only when the average temperature of the air in the stack is greater than the external air temperature. In summer conditions, this may already be too hot. Furthermore, the driving pressure is dependent on the average temperature of air column, not the maximum. Heating up the top of the stack only will not be very effective [11].

Two kinds of buoyancy driven ventilation can be identified. They are mixing ventilation and displacement ventilation, and are defined by the position of the openings. Figure 2.16 shows the effect of openings at the top only of atrium, called mixing ventilation. Warm air leaves the atrium, reducing the pressure and allowing cool air to enter via the same opening, which then falls to the floor. This results in the air temperature at floor level being above ambient temperature. However, this type of ventilation leads to a relatively uniform vertical temperature distribution. On the other hand, Figure 2.17 shows the effect of displacement ventilation provided by openings at the top and bottom. For displacement ventilation, driven by stack effect, openings will be required at the top and bottom of between 5% and 10% of the roof glazing area of a top-lit atrium [12]. Warmed air escapes through high openings or vertical airshafts and cooler air enters the lower openings. High and low openings can promote stack effect cooling. Summertime heat gains and overheating in the atria are reduced by using openings at the top and bottom. Measured results of some researches show that the location of the openings greatly influences the ventilation efficiency. The measured air change rates for cases with open vents both at top and bottom are seven to eight times larger than the air-change rate for cases with openings only at the top when the atria are naturally ventilated [9]. Furthermore, with displacement ventilation, temperature increments at ground level will be much higher [12]. If it is considered that the occupation is located largely on ground floor, displacement ventilation has a large impact on thermal comfort and energy consumption.

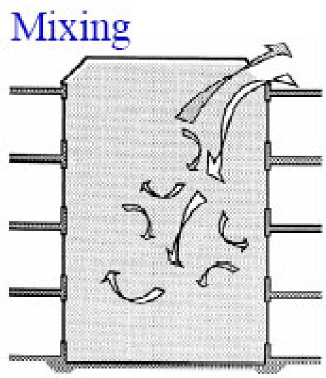


Figure 2.16: Mixing ventilation [12].

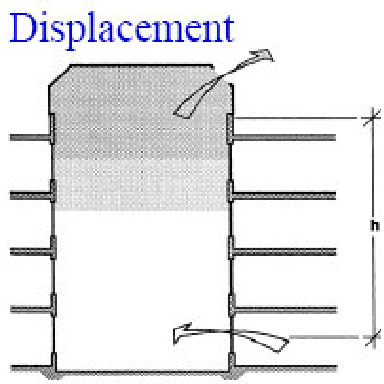


Figure 2.17: Displacement ventilation [12].

At night, heat retained by massive elements in the atrium will cause a greater temperature difference between atrium and cool night air and it enhance the stack effecting atrium [11]. In this respect, natural ventilation can be used by driven the stack effect or wind to provide useful night cooling atrium at night. Night ventilation is one of the interesting and promising passive cooling techniques. It cools down the exposed building structure, which is warmed throughout the day-time by solar radiation and high air temperatures. As a consequence, heat may accumulate the next day and temperature peaks will be reduced and postponed consequently [26]. Furthermore, night-time convective cooling of building mass structure can be achieved by cross ventilation, with air passing from the ambient through the adjacent spaces and out via the atrium space. It may be possible than to achieve the comfort condition during the morning, following ventilation overnight when the air temperature is below the daily average [11,12].

One of the key elements of good climate-sensitive design involves the choice of appropriate materials for energy absorption. In many climates, ambient temperature varies in a daily pattern, with maxima during the middle of the afternoon and minima overnight or in the early morning. Maximum solar input also occurs during the middle of the day. By choosing suitable building materials with appropriate 'thermal mass' (the accepted term for the overall effect of the amount of the material combined with its thermal capacity) heat can be stored and temperature fluctuations reduced, resulting in more acceptable thermal conditions [21, 31]. In this respect, the thermal mass of the building is the major influence in reducing overheating [28].

In atria, thermal mass is only effective if it can be cooled by night cooling [12]. In other words, natural night ventilation is only suitable in buildings with sufficient accessible thermal mass (75–100 kg/m2). As a rule of thumb, IEA Annex 28 (1997) and Van Paassen et al. (1998) recommend a maximum of 20–30 W/m2 heat gains in heavy constructions. The thermal mass stores heat from sun in the winter and moderates summer temperatures to reduce peak loads on the building [26] Since the cooling of thermal mass depends on the stack effect, the height of the atrium is an advantage in setting up strong buoyancy driven [11]

A combination shading and natural ventilation with thermal mass can keep the temperature increment to within 3K or 4K above ambient [11].

2.3.2.1 The effect of atrium on the cooling energy load of adjacent spaces

Natural ventilation in atria by stack effect can provide high rates of air change for zero energy cost. The ventilation of the atrium can also induce cross-ventilation of the adjacent spaces. However, it must be emphasised that this works only when the average temperature of the air in the stack is greater than the external air temperature. [11,12]

The affect of atrium on its adjacent building has greatly influenced by the ventilation strategy between the spaces. If there is no convective connection between atrium space and adjacent space, the cooled atrium air can not be reached to adjacent space, which is heated during the day due to the internal gains and solar gains. In terms of thermal relationship between atrium and offices, there are considered three energy-saving strategies for atrium, although each of these influences the others;

2.3.2.2 Energy Saving Strategies for Atrium

- **Buffer space (insulation);** it is a free running or partially conditioned space between occupied zones and the exterior. This buffering can be enhanced by using thermal mass and shading in naturally ventilated atrium in summer to reduce sol-air temperatures, therefore reducing the cooling load on the office buildings [28]. In Figure 2.18 a, it can be seen displacement ventilation driven by stack effect. In this case there is no air flow coupling between offices and atrium. It means that atrium works as a buffer space for office rooms in hot summer days, because of its cool air compared with outside.

- **Natural ventilation;** this can be achieved using an atrium to create a stack effect through a building so that occupied areas can be naturally ventilated in summer instead of air conditioned. It can be done by different ventilation solutions [28]. In Figure 2.18 b, offices can be cooled by conventional window opening to atrium. In this case offices can be cooled more effectively. In Figure2.18 c, collected heat in adjacent spaces during the day time can be removed by opening two-sided windows (cross-ventilation) in offices and the air is extracted by stack effect from atrium top openings. Therefore, we can obtain the best solution by using the third ventilation concept. This ventilation strategy is generally used in night cooling and very effective for offices. The high thermal mass can be cooled by this way.

- **The "Plenum" Atrium;** it can be achieved by using the atrium as a supply, extract, or recirculation plenum integrated into the building's air-conditioning system. Perhaps the most significant energy-efficient mode for atria in modem commercial schemes is as a plenum integrated into the engineering systems of a building, given that natural ventilation strategies are likely to be limited to buildings with total internal heat gains of less than 40 to 50 W/m2. The success of a plenum atrium depends on the ability of the design team to identify and exploit opportunities for including the particular energy patterns of an atrium into the overall energy strategy of a project. Below are shown some common examples:

The supply plenum--fresh air is drawn through the atrium, where it is preheated by solar gains and heat losses from the building before entering the air-handling plant. The exhaust plenum--stale air from the building's air handling systems is exhausted into the atrium, where it provides a tempered buffer space that then reduces heat flow from the adjacent occupied spaces. The heated buffer space--waste heat from the building is "dumped" into the atrium to provide a tempered buffer space. This reduces building heat loss and gives added amenity value at no extra energy cost [28].

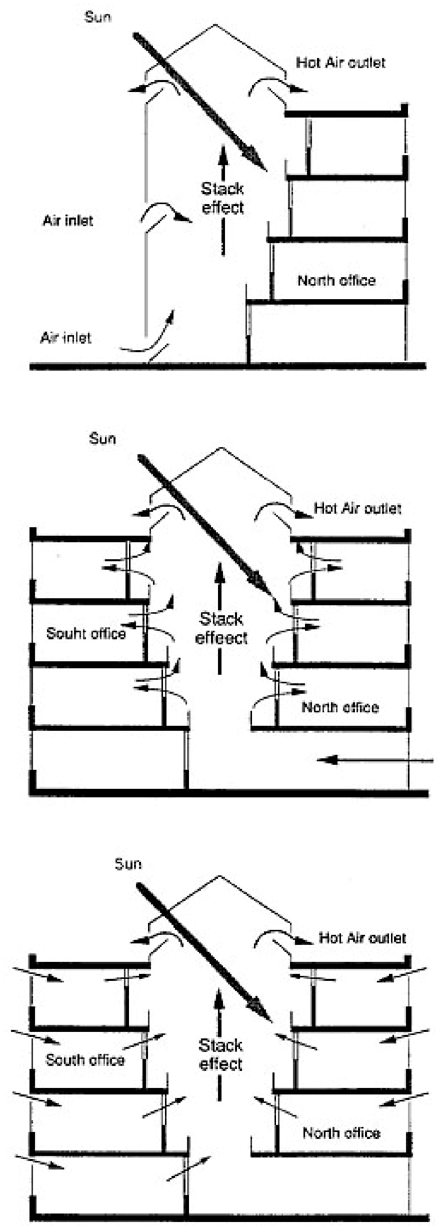


Figure 2.18: Different ventilation strategies. [12].

2.3.3 Space Conditioning

The outdoor climate is a major factor that suggests the appropriate thermal strategy for atrium buildings, followed by the thermal nature of the building; it means that whether it is heat deficit or heat surplus. According to Saxon, based on the thermal strategy, there are basically three types of atrium buildings [16], which are as follows:

1. warming atrium

2. cooling atriums, and

3. convertible atriums

For warming atrium and cooling atrium, the design strategies have been already explained. However, the convertible atrium must be designed adaptable to warm condition in summer and cold condition in winter (Figure 2.19).

The convertible atrium should work very much as a warming atrium in winter, but have more substantial defences against over-heating in summer. This is the case even when full comfort is not sought in the atrium itself, since solar impact on the atrium interior will lead to heat build-up in the occupied space, and to impractical ventilation rates in the atrium. The basic need is for external shading to the atrium glazing. This can be fixed to admit low-angle sun in winter but to exclude high-angle sun in summer, or it can be operable. Operable (movable) shading is able to deliver more benefits, but at higher cost: it provides winter-night insulation and admits more daylight. Such shading shutters may be able to substitute for some of the insulation capacity of the envelope [16].

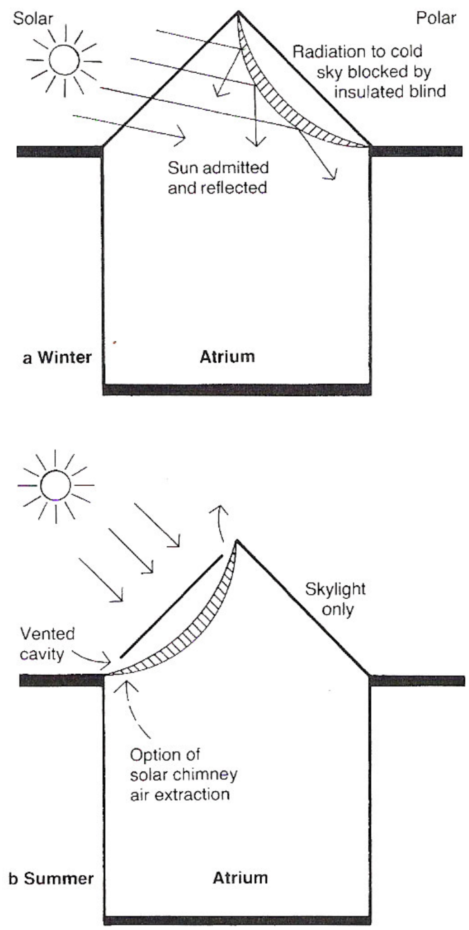


Figure 2.19: The convertible atrium; a) a passive device, an insulated blind hanging from the atrium apex. In winter it substitutes for double glazing and acts as a solar reflector, b) in summer it is moved to the solar side and excludes direct sun

As mentioned earlier, use of atriums as an energy efficient design element with passive cooling in summer and passive heating in winter is the most energy conserving strategy. However, if partial or full conditioning is required, it is still possible to build energy efficient atrium buildings through more efficient operation and design of mechanical system.

It should be stated at the outset that most atrium buildings above domestic scale cannot operate without mechanical and electrical systems. Making use of the passive thermal advantages of atria often involves coupling them with artificial heating, cooling and ventilation systems. An atrium building is not therefore, except of most benign climates and on a small scale, a candidate for a complete 'natural energy' approach. In very hot climates its best service is to improve the performance of a totally artificial environment system. An atrium building can be 'selective', using natural energy techniques to the reasonable limit for the building purpose and location, and then completing the task with mechanical, electrical and electronic systems [16].

There are several methods of environmental control designed and implemented to avoid the large vertical temperature gradient or to keep the occupied zone thermal comfort. Yoshino et al. (1995) showed widely used thermal environment control methods for the atrium space [18].

1. Occupied zone control: Conditioned air is diffused downward from wall of lower floor level of atrium or from ceiling of lowest floor level. Floor cooling or heating system can be installed or spot control by stand alone cooler can be used.

2. Treatment of hot air stored in the area under the roof can be achieved by natural ventilation, mechanical ventilation, or fan coil unit for cooling

3. Solar radiation control devices can be blind inside of glass roof or cloth suspended from roof

4. Other methods can be air-curtain system for thermal separation between atrium space and adjacent rooms or air-curtain system for avoiding upward air flow. Diffusing warm air on glass surface can be also an efficient method [18]

Although all the control method mentioned above could adapt successfully to any atrium design project, engineers who do not have much experience cannot be sure whether those systems would work well as they want before the real system operation. Therefore, computer based simulation programs for buildings can be used to predict the atrium performance with different combination of passive strategies and mechanical conditioning systems.

2.4 Summary

The energy saving and the temperature conditions of an unconditioned atrium can vary quite widely and are dependent upon some configurations, which has been tried to highlight in this chapter. These configurations are a result of atrium's thermal and physical structure, orientation and location in the site and other passive solar strategies like shading and natural ventilation. Furthermore, it should be taken into consideration that the climate condition and building use has great impact on thermal performance of atrium buildings. Because of this reason, the main thermal behaviours of atrium has been analysed and given some examples of existing studies. After that, the passive solar design strategies responding different climate and type of atria have been clarified. As atria are not automatically energy-saving features with natural precautions, beside the passive solar techniques, it should be considered the mechanical equipment of atrium maintained compatible with passive systems. Therefore, it is very important for designer to be aware of the fundamentals of atrium's thermal performance to be able to design energy efficient atrium. Moreover, in computer based building simulations, these parameters can be applied using different variation. Therefore it must be known, how the parameters affect the thermal behaviour of atrium. In chapter 4, will be analysed the critical parameters for atria and tried to obtain best solution.

3. COMPUTER BASED ENERGY PERFORMANCE SIMULATION FOR BUILDINGS

3.1 Introduction

Most commercial buildings designed today will use more energy to operate, and cost more to design and construct than necessary. Significant energy savings could be achieved with little or no increase in first cost if energy-efficient design technologies were used. Research into integration of building systems indicates that by considering energy performance early in the design process, energy savings between 30% and 50% of current energy consumption rates are technically and economically feasible. However, most building design teams do not adequately consider the energy impacts of design decisions to achieve these savings

These facts illustrate the capability and the importance of passive solar building design with respect to conservation of both energy and money. The idea of passive solar is simple: take advantage of natural processes like radiation, conduction and convection and avoid them, when undesired. But applying passive solar effectively does require information and attention to the details of design and construction. The built environment is rather complex and involves many interactions. Even when we limit ourselves to energy, environmental and comfort issues, real building design questions are usually too complicated to be solved using simple rules or design guidelines. One way of dealing with this complexity is by using computer modeling and simulation [32]. Design tools are available to analyze the thermal behavior of buildings in detail and give recommendations for design strategies. It is therefore necessary, that design tools have a reliable and accurate means of predicting the solar radiation on surfaces. Since solar radiation on a surface is often greatly influenced by self-associated facade obstructions, neighbor buildings and the surrounding landscape, a prerequisite of solar modeling is the ability to predict shaded and insolated parts as a function of solar position and geometry.

3.2 Modelling

The thermal interactions between a building and its environment are complex because of several sub-systems interacting with each other. Continuous energy transfer processes take place among the building's inter-connected parts such as rooms, walls, windows, duct linings, etc. This complexity comes from the dynamic behaviour of the system responding to the instant changes [33]. Basically, the building envelope transmits heat to and from the inside and outside environments. Modelling a building properly requires that a simulation program adequately addresses fundamental heat transfer processes such as conduction through the solid materials in the building envelope, convection between the envelope and the surrounding air, and radiation between the envelope and the inside and outside environments. Highly nonlinear equations are thus necessary to represent interrelated energy exchanges among the building parts and most of them are dependent not only on the material properties of the envelope but also the inside and outside environmental conditions [34].

Forward modelling starts with detailed description of the system being modelled and establishes the building model based on a physical description. A reliable energy performance assessment requires the use of complicated algorithms. For the advanced modelling and calculations, the building location, geometry, construction details, orientation of walls and windows, occupancy, local climate, operating schedules, HVAC system type, etc. are the required input information that affects energy flow in buildings. Figure 4.1 shows the main elements of building energy simulation and the interactions between them [35].

3.3 Simulation Tools

Nowadays, design tools are available to analyze the thermal behaviour of buildings in detail and give recommendations for design strategies. The most well-known ones are BLAST, DOE-2, TRNSYS, ENERGYPLUS, and ESP-r.

BLAST (Building Loads Analysis and System Thermodynamics) performs hourly simulations of buildings, air handling systems, and central plant equipment in order to provide accurate estimates of a building's energy needs to mechanical, energy and architectural engineers. The zone models of BLAST, which are based on the fundamental heat balance method, are the industry standard for heating and cooling load calculations. BLAST output may be utilized in conjunction with the LCCID (Life Cycle Cost in Design) program to perform an economic analysis of the building/system/plant design [36].

DOE-2 is an hourly, whole-building energy analysis program calculating energy performance and life-cycle cost of operation. It can be used to analyze energy efficiency of given designs or efficiency of new technologies [36].

TRNSYS is an energy simulation program whose modular system approach makes it one of the most flexible tools available. TRNSYS includes a graphical interface, a simulation engine, and a library of components that range from various building models to standard HVAC equipment to renewable energy and emerging technologies. TRNSYS also includes a method for creating new components that do not exist in the standard package. This simulation package has been used for more than 25 years for HVAC analysis and sizing, multizone airflow analyses, electric power simulation, solar design, building thermal performance, analysis of control schemes [36].

ENERGYPLUS is a new generation building energy simulation program that builds on the most popular features and capabilities of BLAST and DOE-2. EnergyPlus includes innovative simulation capabilities including time steps of less than an hour, modular systems simulation modules that are integrated with a heat balance-based zone simulation and input and output data structures tailored to facilitate third party interface development. Other planned simulation capabilities include multizone airflow, and electric power simulation including fuel cells and other distributed energy systems [36].

ESP-r is an integrated modelling tool for the simulation of the thermal, visual and acoustic performance of buildings and the assessment of the energy use and gaseous emissions associated with the environmental control systems and constructional materials. In undertaking its assessments, the system is equipped to model heat, air, moisture and electrical power flows at user determined resolution. The system is designed for the UNIX operating system, with supported implementations for Solaris and Linux, and is made available at no cost under an Open Source license [36].

For the present study simulation tool TRNSYS is chosen for the calculations due to its flexible nature. TRNSYS will be explained below in detail.

3.4 TRNSYS program overview

The simulation program, by which the atrium calculations have been conducted, is called TRNSYS. The following section gives a brief survey of TRNSYS with emphasis on the simulation of buildings.

TRNSYS simulation tool is used in the present study for modelling the system and calculating the results. TRNSYS is an acronym for a 'transient simulation program'. It is originally developed in 1972-73 by the University of Wisconsin Madison Solar Energy Lab and the University of Colorado Solar Energy Applications Lab and became available since 1975. It is written in FORTRAN language [37].

TRNSYS is a transient system simulation program with a modular structure. The modular structure of TRNSYS gives the program tremendous flexibility, and facilitates the addition to the program of mathematical models not including in the standard library. In TRNSYS, a system is described in a special input language that connects components together. The file containing the system description is called DECK. External data files, i.e. weather data, can be assigned to the simulation in the DECK. Each component of a system is associated with a TYPE number, which identifies the components function (i.e. TYPE 16 is the solar radiation processor), and a UNIT number which distinguishes the component from all other components in a system. A component receives three types of information: INPUTS, PARAMETERS and TIME. INPUT variables may vary with time and are generally OUTPUTS from other components. PARAMETERS are assumed to not vary throughout the whole simulation. Time is a TRNSYS internal variable and is neither an INPUT nor a PARAMETER. The information flowing out of a component are called OUTPUTs. For creating a DECK two different graphical interfaces, PRESIM and IISIBAT, can be used for assistance [14].

The components are configured and assembled using a fully integrated visual interface known as the TRNSYS Simulation Studio, and building input data are entered through a dedicated visual interface (TRNBuild). The simulation engine then solves the system of algebraic and differential equations that represent the whole system. In building simulations, all HVAC-System components are solved simultaneously with the building envelope thermal balance and air network at each time step. The program typically uses 1-hour or 15-min time steps but can achieve 0.1-sec time steps.ser-selectable (e.g. hourly and monthly) summaries can be calculated and printed [38].

TRNSYS provides different methods to simulate the thermal behavior of a building. The first one is a very simple Degree-Day model (TYPE 12). A more detailed method is offered by a one zone model (TYPE 19). where all the structural components are modelled according to the ASHRAE transfer function approach. The most accurate way to calculate the energy balance of a building is by Multi-Zone model. This method calculates the heat transfer between the zones (up to 25) by solving the coupled differential equations using matrix inversion techniques. The walls, ceilings and floors are modelled based on the ASHRAE transfer function approach. Moisture balances are performed in addition to the energy balances. TYPE 56 represents a non-geometrical building model. In general, the following inputs are needed: ambient temperature, ambient humidity ratio, incident radiation for each existing orientation of external surfaces, incident beam radiation for each existing orientation of external surfaces, incident angle for each existing orientation of external surfaces, the orientation of external surfaces and the volume and capacity of a thermal zone, other specific inputs, i.e. for control [14, 37].

The heat flows in TYPE 56 is based on energy balances. In order to reduce computing time the walls of a building are modelled according to the transfer function relationships of Mitalas and Arseneault [Mitalas and Arseneault, 1967] defined from surface to surface. Long wave radiation and convective heat transfer are calculated using the star network approach developed by Seem [Seem, 1987]. Moisture balances are performed in addition to the energy balances [14].

Type 56 provides a large list of optional OUTPUTs for each thermal zone, like air temperature, ventilation, infiltration, convective and radiative gains, humidity ratios etc. The required PARAMETERs concern the building description. Due to the complexity of a building description with multiple zones, a separate preprocessing called TRNBuild is performed first to create ‘PARAMETER’ files which are used by TYPE 56 during the simulation as shown in Figure 3.1. 3D graphical interface called TRNSCAD can be used to create or only digitalize the geometry of a building. TRNSCAD writes an output file, which is further processed by TRNBuild, an interactive input program. In TRNBuild the building description is completed by specifying the characteristics of the building walls and windows and data like ventilation, infiltration, gains, heating mode and cooling mode. Also, the desired outputs are specified within TRNBuild. Then, the output file of TRNBuild is processed by the program BID. BID generates three files: one file (*.trn) containing the transfer functions for the walls, a second file (*.bld) containing the remaining building description and a third file (*.bui) for user information only. The first two output files from BID are used as parameters by TYPE 56 in the actual TRNSYS DECK [14]

IISiBat, which can be roughly translated from French as "Intelligent Interface for the Simulation of Buildings," is a general simulation environment program that has been adapted to house the TRNSYS simulation software. The name of the environment program, IISiBat has been changed by upgrading TRNSYS 15 to 16 as Trnsys Simulation Studio which has an integrated preprocessing utility that allows the TRNSYS user to graphically create TRNSYS input files by connecting inputs and outputs of icons that represent TRNSYS components (Figure 3.2).

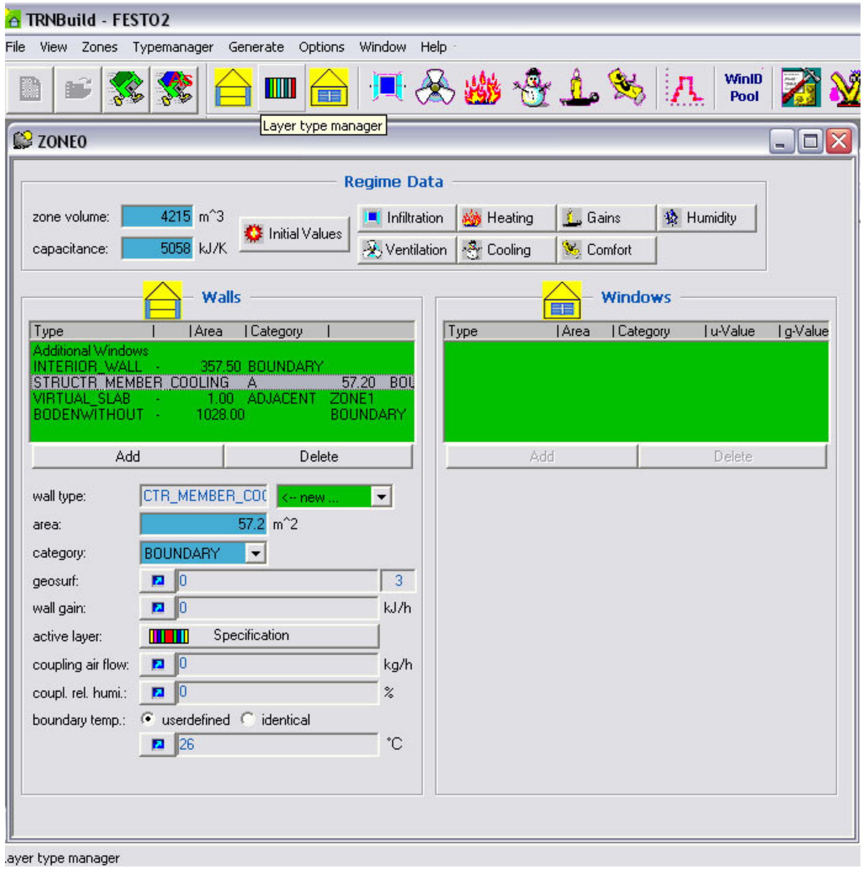


Figure 3.1: Snapshot of TRNBuild

The information flow diagram in Trnsys Simulation Studio is a schematic representation which all components are interconnected in a system. The main Trnsys Simulation Studio window contains many icons represents a different system component (e.g., Fan Coil, shading device, solar collector, etc.) with lines connecting them. All the required input information is shown as an arrow directed into it and information calculated, output, as an arrow out of it. The user drags the necessary icons into the Assembly Window then creates links between the components. The lines connecting the icons represent the pipes and wires that connect the physical components. The components contain all the parameters, inputs and output of the component. Each input to a component must be matched to an output of another component, a constant or a variable defined by an equation. The output can be used as an input to any other components, including the component itself [39].

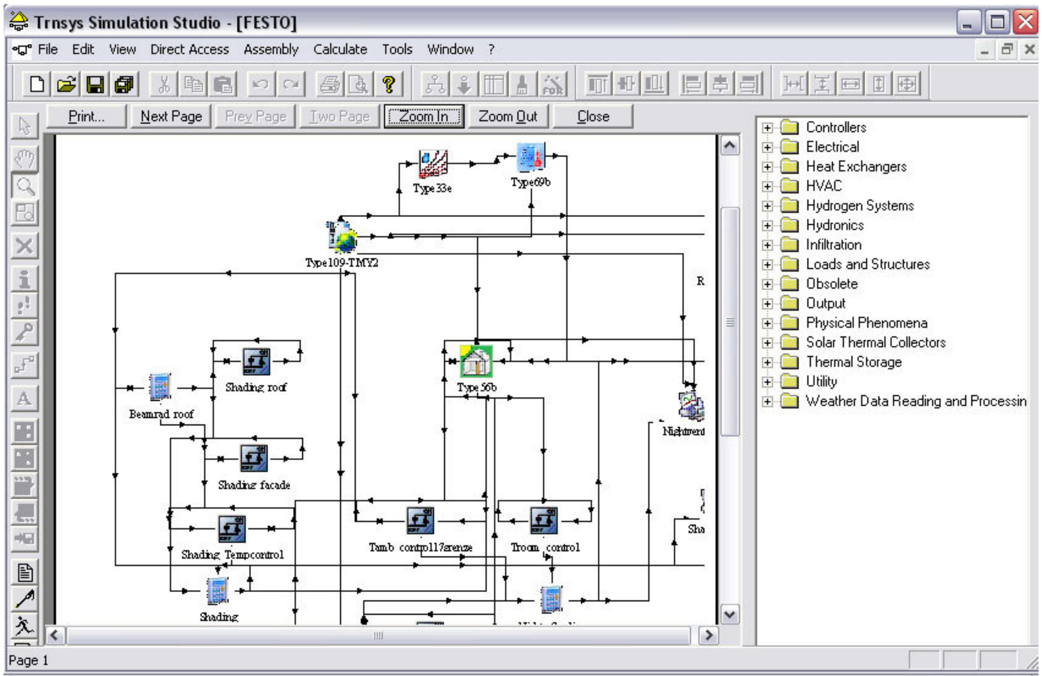


Figure 3.2: Snapshot of Trnsys Simulation Studio

With a program such as TRNSYS, the entire problem of system simulation reduces to a problem of identifying all the components that comprise the particular system and formulating a general mathematical description of each [39].

3.5 Potential difficulties on estimating the energy performance of atrium by means of existing simulation tools

The use of simulations in the design process of the atrium had a large impact with respect to choice of window glazing, solar shading and ventilation rates (Jacobsen and Jensen, 1999). Physical characteristics of atriums affect the indoor environment conditions, thermal loads. Furthermore, the sizes and forms of atrium spaces lend themselves to complex skylight shapes and surface areas that result in excessive solar heat gains in summer and high heat losses in winter. The impact of the roof shape and atrium physical parameters on the atrium thermal and energy performance has not been well understood. Therefore, it is needed a design tool special for atria take full advantage of atrium potential, improve thermal performance, and optimize the total energy consumption for heating and cooling.

Prediction of thermal and energy performance of atriums is strongly related to the availability and accuracy of prediction tools and modeling techniques. Atriums are known to be subject to significant temperature stratification due to their large size and high solar heat gains through their fenestration, particularly in summer. Temperature stratification influences thermal comfort and increases thermal loads of the mechanical system. Atriums also have complex air flow patterns, due to buoyancy effect and to the interaction among the atrium space, the adjacent spaces, the mechanical system, and the outside environment. Prediction of temperature stratification and airflow pattern needs accurate and detailed modeling techniques. CFD may be used to predict temperature stratification and air flow pattern under steady state and known boundary conditions. However, CFD models are not practical for dynamic simulations since they require excessive calculation time and powerful hardware [40]. Furthermore, CFD can calculate only for a specific time. It makes the calculating annual performance and energy demand of atrium impossible. Therefore, zonal thermal models should be used to predict annual performance of atrium.

In this study TRNSYS is used to predict the thermal performance of atrium as zonal thermal simulation. In following chapter, an application on a case study building is proposed and discussed the results.

4. AN ESTIMATION APPROACH FOR THERMAL PERFORMANCE OF ATRIUM BUILDINGS THROUGH A CASE STUDY

Understanding and application of principles of atrium's thermal energy performance is very important in order to determine the true design concept for atrium spaces. In chapter 2, it has been defined the fundamentals of atrium energy performance. In this chapter this principles is estimated on a case study building.

4.1 Introduction

As explained previous chapters, with the evaluation on technology, popularity and attractiveness of atrium building has been increased and it started to use as a common design element in architecture by using new materials like glass and steel. Wide using of glass and steel enhanced the glazing area of atrium buildings. Moreover, conditioning of atrium is achieved by operating the mechanical system. This new system leads to increasing both of investment and operating cost. However, the basic energy potential of atrium has been missed. Nowadays, the energy potential of atrium has come into prominence again. The true energy efficient atrium design should be environmentally conscious and minimize the energy consumption of the whole building, while still providing desirable comfort conditions to its occupant. This aims can not be achieved only considering the whole energy efficient building design criterion. On the other hand, with the application of a complex management system to the whole building can not solve the energy problems of the atrium. It can only provide by understanding the thermal behavior of atrium spaces, which is different than common office buildings. It is also not true for atria to apply the common regulations and standards accepted for commercial building. Therefore, earlier explained strategies will be applied in this chapter on a case study building.

This chapter describes an approach for the estimation of the atrium's thermal energy performance in order to achieve a true atrium design. The proposed approach is carried out on a case study building in this work. Therefore, before the clarifying of the approach the case study building and its existing energy strategies are going to be described first as follows.

4.2 Description of case study building

The building, which is taken as a case study in the present work has been designed for the company FESTO by Jaschek Architecture Office. It started to build in year 2001 and has been completed in 2001 (Figure 4.1). The building is located in Berkheim, Esslingen, a city with 90.000 inhabitants, is placed 25 km far from Baden-Württemberg's provincial capital, Stuttgart. The building serves as administration and office building of the company FESTO. The case study building has been designed and constructed as user-friendly concept, to which is contributed with natural luminance, acceptable acoustic, comfortable climate.

Figure 4.1: FESTO Technology Centre, Esslingen, Germany

The building is divided into the 3 V-shaped structures, which is connected with an entrance to the polygonal strap over the north-sided extension building. Between the splayed parts of the structure is formed the three courtyards, which is opened to the outdoor. The courtyards (atria) of the V-shape's are covered. As a result of the different topographic position of the 3 V-shape, for every 3V's comes into being different performance. As you seen in figure 4.2, every atrium has variable orientations and lighting and consequently an individually character. In this work, third atrium placed on the left side of plan has been chosen to apply the approach.

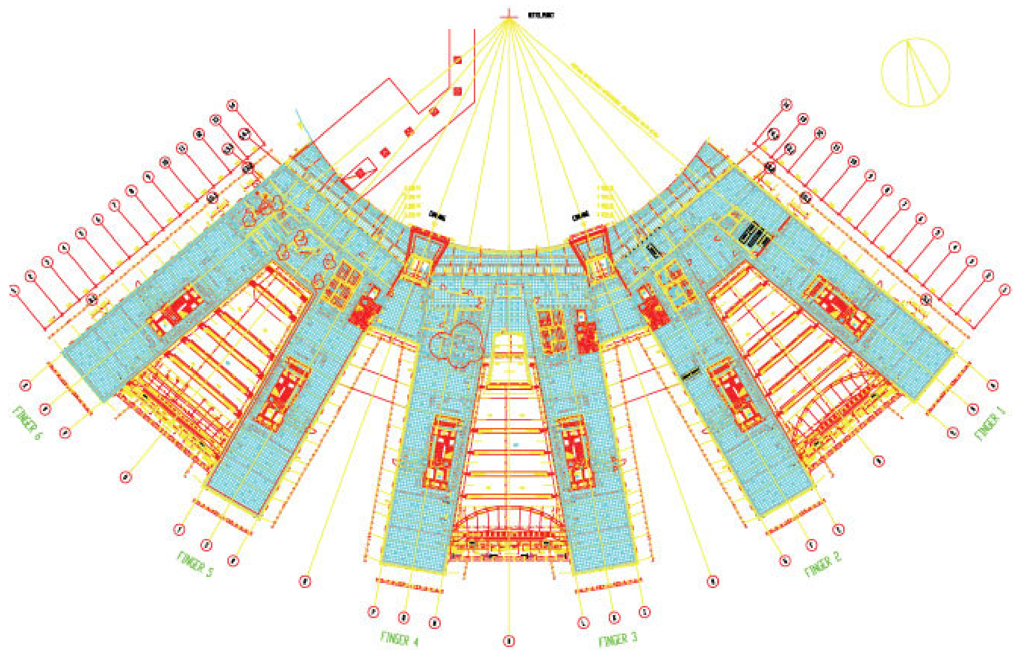


Figure 4.2: The plan of case study building

The plans of the ground floor, first floor, second floor and third floor are very similar. The offices are placed around the atrium spaces called as "finger". Open plan offices are distributed along the external walls. Stairs, elevators and restrooms are located on the centre of office blocks. Atrium space has a floor area of 1028m2. The sections are given in figures 4.3 and 4.4.

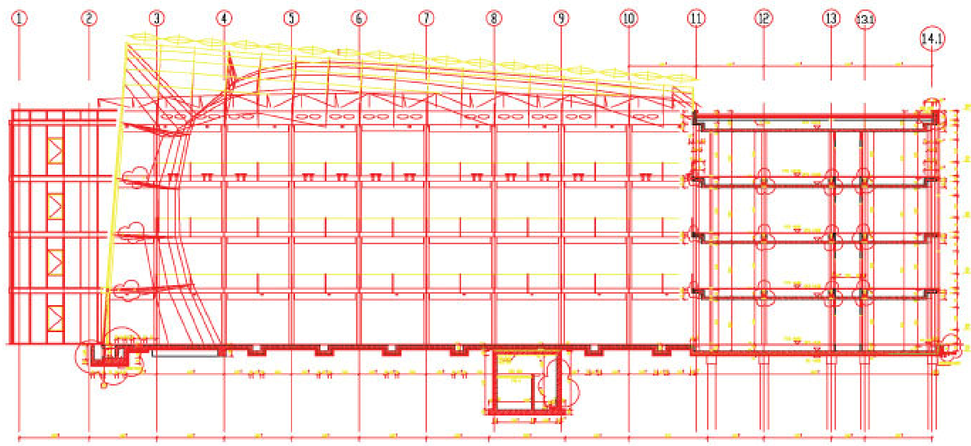


Figure 4.3: A long side section of atrium

The three covered atrium have a form of an inclined cylinder-section. The main construction is an orthogonal steel-framed shell, which is propped up by the tension of a curved cable structure. This construction is over the south façade and extends from the roof level to the ground floor. The fenestration of the inclined south façade has been fixed by the steel profiles. In each floor level of façade, a catwalk has been attached to the façade, which connects the two office blocks to each other. It gives an opportunity to the users to go next to the glass structure. The slab of the catwalks is semitransparent from steel structure and gives a clear view to the outside (Figure 4.5)

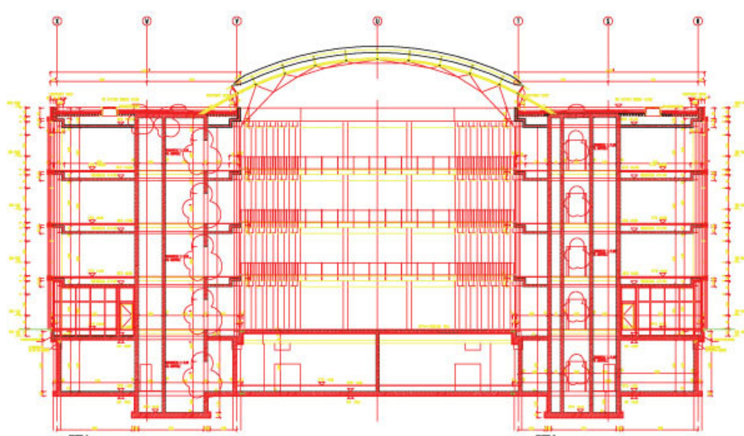


Figure 4.4: A short side section of atrium

Figure 4.5: Atrium Space

The cladding of the atrium's roof has been achieved with 3-layer pneumatic ETFE-Foil Cushions. The cladding system comprises 3 layer of the UV stable copolymer Ethylene Tetre Fluoro Ethylene (ETFE) welded into foils. Pneumatic cushions are restrained in aluminium extrusions and supported by a lightweight structure. The cushions are inflated with low pressure air to provide insulation and resist wind loads. The cushions are self-supporting due to the resulting pressure in the space of cushions. The maximum dimension is approx. 28 x 2,50 m per unit (Figure 4.6).

Figure 4.6: Roof structure of atrium space; ETFE Foil cushion

The cushions are manufactured from between two and five layers of the modified copolymer Ethylene Tetra Fluoro Ethylene (ETFE). This cladding system combines exceptional light transmission and with high insulation. Each layer can incorporate different types of solar shading enabling the designer to optimize the aesthetic and environmental performance of the building envelope. It can react to the sun and change its transmission and insulation throughout the day [41, 42]

ETFE (Ethylene TetrafluoroEthylene) is a fluorocarbon-based polymer (a fluoropolymer), a kind of plastic. It was designed to be a material with high corrosion resistance and strength over a wide temperature range. An example of its use is as pneumatic panels to cover the outside of the football stadium Allianz Arena or the Beijing National Aquatics Centre- the world's largest structure made of ETFE film (laminate) [43].

By changing the pressure in cushions, the position of middle foil cushions change. As a result of this, there is generated a sun protection. If the system in the function of "Shading devices off", it means that the Light transmission of the roof is 50%. There is still a view to the sky in this position. In the function of "Shading devices on", the middle foil layer is under pressure. Positive and negative Layers generate a closed form, with a 93% shading rate on the top-side (Figure 4.7)

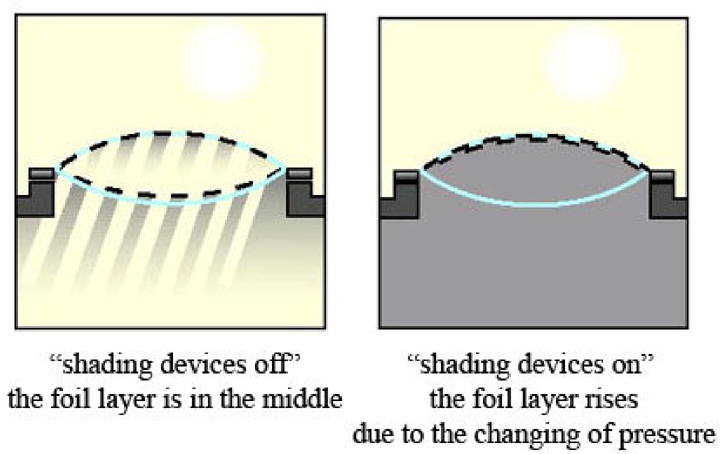


Figure 4.7: Working principle of the ETFE Foil cushion

As well as roof structure, on the main façade (southwest), the exterior shading devices has been installed to exclude direct sun beam if it is needed. The shading devices of this façade are “sails” including 6 separated pieces. They are rolled up hydraulically by rods. All the shading devices are controlled depending on the temperature and beam radiation.

4.3 Definition of Simulation (Boundary Conditions)

Modelling can be seen as the process of re-expressing the building design in a manner suitable simulation [32]. As explained in previous chapter (3), TRNSYS Simulation Studio allows the TRNSYS user a chance to create graphically TRNSYS input files by connecting inputs and outputs of icons that represent TRNSYS components. However, because of the complexity of defining building parameters with TYPE56 multi-zone component in TRNSYS Simulation Studio, interactive and user-friendly TRNBuild environment is used instead. The all information about the building structure characteristic such as walls, windows and roof properties and climatic data of the building like ventilation, infiltration, internal gains, heating and cooling mode were based on the building real data collected, calculated and entered to the program. Up to the desired results, outputs were also selected.

The simulations have been applied in first step of calculations only on the atrium space which is placed between finger 5 and 6. The atrium space has been horizontally divided into the 4 zones. Each zone level corresponds to the each office floors level. The building is schematically illustrated in the figure 4.8. The office building as called fingers, and basement has been defined with a boundary conditions, which is variously accepted for summer period calculations and winter period calculations, 26ºC and 22 ºC respectively. In second step of calculations, one of the adjacent fingers called finger 6 has been simulated, in order to determine impact of atrium space on the energy consumption of office buildings.

Each walls and windows between adjacent offices and atrium is constructed from same type of walls and glazing. Five types of wall are used in the atrium and office building in total. Thicknesses of walls are taken from the technical drawings and the properties are defined based on the technical information, which has been taken from the project owner, the firm FESTO. The real properties have been given in TRNSYS using the material list. For insulation levels, the German building regulations are followed. The overall U-values of each wall is calculated by TRNSYS using default convective heat transfer coefficient for inside: 11 kJ /h m^2 K and for outside: 64 kJ /h m^2 K.

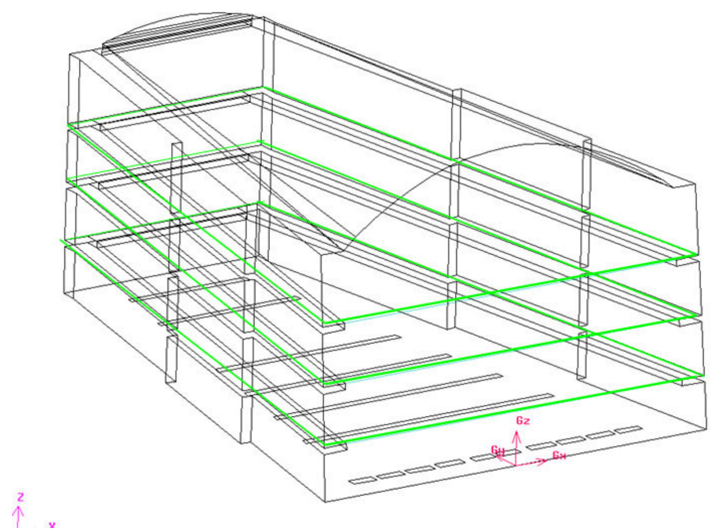


Figure 4.8: Schematically illustrated atrium building and defining the zones in TRNSYS

The details of the external fenestration, internal walls, floor, ceiling and other technical properties are shown in Table 1,2,3,4,5 respectively.

The atrium space is divided into 4 thermal zones vertically. Where there are no surfaces in reality, the thermal zones are bounded by fictive surfaces which do not absorb or reflect solar radiation; thus enabling solar radiation modelling in side the atrium. These surfaces are properly defined as “fictitious wall” using TRNSYS material library. This materiel is able to transmit the solar radiation directly. Adjacent spaces are taken into account assuming fixed thermal conditions.

Table 4.1: External and internal glazed surfaces

Windows							
Types		**Area (m2)**	**U-value (W/m2K)**	**(SHGC) %**	**T-sol %**	**Rf-sol %**	**T-vis %**
Main Façade (Southeast)		581	1.4	0.622	0.462	0.237	0.749
Vertical Roof of atrium	**North**	26.1	1.4	0.320	0.260	0.218	0.659
	East	50.7					
	West	50.7					
ETFE-Foil Cushion		933	2.3	0.320	0.259	0.615	0.455
Adjacent Windows		1483	1.7	0.605	0.521	0.355	0.782
Offices Façades		329	1.4	0.622	0.462	0.237	0.749

Table 4.2: Adjacent walls

Walls					
Layers	**Thickness**	**Conductivity**		**Specific Heat**	**Density**
	[m]	**[kJ/hmK]**	**[W/mK]**	**[kJ/kgK]**	**[kg/m3]**
Light concrete	0.18	0.432	3.48	0.84	350
U-value	0.599 W/m2K				

Table 4.3: Ground Floor of atrium and offices

Floor					
Layers	**Thickness**	**Conductivity**		**Specific Heat**	**Density**
	[m]	**[kJ/hmK]**	**[W/mK]**	**[kJ/kgK]**	**[kg/m3]**
Natural Stone (Granit)	0.03	12.56	3.48	0.84	2800
Plaster Underfloor	0.005	1.69	0.47	1	1400
Anhydride pavement	0.02	4.320	1.2	1	2100
Concrete slab	0.18	4.068	1.13	1	1400
Anhydride pavement	0.01	4.320	1.2	1	2100
Insulation	0.16	0.14	0.04	0.9	80
U-value	0.223 W/m2K				

Table 4.4: Ceiling of Offices

Floor					
Layers	**Thickness**	**Conductivity**		**Specific Heat**	**Density**
	[m]	**[kJ/hmK]**	**[W/mK]**	**[kJ/kgK]**	**[kg/m3]**
Natural Stone (Granit)	0.05	12.56	3.48	0.84	2800
Plaster Underfloor	0.005	1.69	0.47	1	1400
Anhydride pavement	0.02	4.320	1.2	1	2100
Concrete slab	0.18	4.068	1.13	1	1400
Anhydride pavement	0.01	4.320	1.2	1	2100
U-value	2.637 W/m2K				

The area of each wall according to direction and position is calculated as necessary inputs to simulation. Geometric properties of office building are summarized in the table 4.5 below.

Table 4.5: Geometrical properties of atrium and office block

Atrium V3					Office
Total Volume m3	**19745**				**11184**
Atrium Building	Zone0	Zone1	Zone2	Zone3	Office floor
Zone Volume (m3)	4215	4215	4215	7100	2796
Total area (m2)	1028	1028	1028	1028	682
Interior Wall Area (m2)	306	306	306	359	344
Adjacent wall area	277	277	277	277	131
Main Façade Area (m2)	114	114	114	239	329
Roof Area (m2)	126 m2; Vertical façade/ 933 m2; Horizontal roof (ETFE Foil Cushion)				

First, basecase atriums are selected in order to compare different design options and select the optimum design that meets the user specified requirements for energy efficiency. Basecase is also representative of real atriums. In following section will be defined the operating system of basecase, which is currently operated in real building. After that, it will be determined different design options to see the relative change in performance due to a change in design with respect to the basecase. The notion of the basecase holds only for relative design performance outputs, such as energy use and peak loads. The characteristics of the basecases are as follows.

Interaction of an Atrium with its Adjacent Spaces: The atrium space has walkways (galleries) along internal walls at each floor level to facilitate circulation to the atrium adjacent spaces. The atrium space is closed to the adjacent spaces. The windows on adjacent walls are not openable. The atrium space communicates with its adjacent spaces via doors that remain closed most of the time. Therefore, in simulation, it is assumed that the heat gain/loss via air change from/to the adjacent spaces is zero.

Occupancy hours: The office is accepted to be occupied from 05:00 to 20:00 during the weekdays including Saturday based on the information taken from real operation hours of building FESTO. Therefore the occupancy hours for atrium have defined during this time.

Boundary conditions of adjacent spaces: Offices and Basement floor has been assumed with a boundary condition defined based on a schedule. During the summer period, 24℃ in occupancy hours and 28℃ for unoccupied periods like during weekends and nights. Basement floor has been assumed to be 23℃ constantly. During the winter period, 22℃ in occupancy hours and 18℃ for unoccupied periods like during weekends and nights. Basement floor has been assumed to be 21℃ constantly.

Internal Gains: It is accepted that the internal gains occur during the occupancy hours. For non-occupied hours, gain from persons, lighting and other devices are zero. The gain per person is chosen from the TRNSYS gain list according to ISO 7730 as 90W/person sensible heat described as an activity “standing light work or working slowly”. Gain from computer is also chosen from TRNSYS list as 230W PC with color monitor, per monitor. It assumed that number of computer is only 3 due to the no working activity in atrium. However, depending on the observation some workers or guests could use their notebook in atrium. For the artificial lighting system, the power densities are assumed to be 5 W/m2 with a 30% convective part.

Infiltration: Infiltration rate for air leakage is assumed to be 0.1 ach.

Ventilation: Ventilation rate has been taken based on the real building data. The fresh air is supplied to the atrium via mechanical and natural ventilation from convectors located in front of main façade, on the floor of atrium. The air is supplied with an air flow rate 6000 m3/h. Operating hours for ventilation system is from 05:00 to 20:00 during the weekdays including Saturday based on the information taken from real operation hours of building FESTO. Supply air temperature is adjusted as outside temperature.

Air flow coupling between thermal zones: The supply air temperature is given to the ground floor and air flow connection of this air between the other 3 zones can be achieved by using "air flow coupling" property, which is possible to define in TRNBuild. The Ach rate of supply air has been used for defining the correct rate.

Heating system: First of all, the transmission heat losses are minimized. The external walls, roof, floor are very well insulated. Heating system is on whenever the heating is needed (September- May term). Climatisation is achieved through the supply air. The air is supplied to the atrium from the convectors located on the ground floor; during the working hours with a constant ventilation rate (6000 m3/h) Set temperature of heating system is taken as 22ºC between 05:00-20:00 hours including Saturday and for non-occupant hours and Sunday is 18ºC. Other system components for heating are structural member heating in the staircase walls and under floor heating.

Cooling System: Cooling system is implemented during the cooling season which is June-July-August term (between 3625-5832 hours of the year). Cooling system is on between 05:00-20:00 hours during weekdays and Saturday. Set temperature of cooling system is assumed to be 22ºC whenever the cooling system on. It is taken as 26 ºC for non-occupant hours and on Sunday.

TRNBuild saves the information about the building as *.bui file and also calculates the ASHRAE transfer functions for walls which are required by the TYPE 56 as *.trn file. One of the TRNBuild output file of this case study simulation can be seen in Appendix A as an example. After generating these two files for the case study building in TRNBuild they were assigned to TYPE 56 multi zone component of TRNSYS using TRNSYS Simulation Studio.

In the TRNSYS Simulation Studio the following components, which are necessary to simulate the building are connected together.

TYPE 109-TMY2: This component serves the main purpose of reading weather data at regular time intervals from a data file, converting it to a desired system of units and processing the solar radiation data to obtain tilted surface radiation and angle of incidence for an arbitrary number of surfaces. In this mode, Type 109 reads a weather data file in the standard TMY2 format. The TMY2 format is used by the National Solar Radiation Data Base (USA) but TMY2 files can be generated from many programs, such as Meteonorm. This data file distributed with TRNSYS 16 that was generated using Meteonorm is distributed under license from Meteotest.All files were generated using default options in Meteonorm V 5.0.13. The "TMY2" output format is used because it is easily read by Type 89 and Type109. [36]

TYPE 69b: This component determines a fictive sky temperature as an output, which is used to calculate the long-wave radiation exchange between an arbitrary external surface and the atmosphere. [36]

TYPE 33: This component is called as psychometrics. It calculates humidity ratio, wet bulb temperature, and enthalpy, density of the air-water mixture, density of dry air only, relative humidity (as percentage), dry bulb temperature and dew point temperature depending on the inputs it takes [36].

TYPE 2d: This component is a differential controller. It generates a control function which can have a value of 1 or 0. The value of the control signal is chosen as a function of the difference between upper and lower temperatures Th and Tl, compared with two dead band temperature differences DTh and DTl [36].

TYPE 56: The TYPE 56 is the Multi-Zone Building Model which models the thermal behaviour of a building having up to 25 thermal zones. The building description files which are generated by TRNBuild are read by this component [36].

Inputs and outputs of the TRNSYS components below are connected in order to simulate building. Results are obtained from the output files of TRNSYS and analyzed [36].

4.4 Application of Simulation on Case Study Building

The energy performance of atrium buildings depend on multiple building and environmental parameters, as explained in the Chapter 2.

In this part, the base case explained in previous chapter is applied. First interior temperatures of every thermal zone in atrium are calculated depending on the current operating system but without applying passive atrium strategies. The fresh air is supplied to the first zone directly in outside temperature by 1.45ach for first zone, because of the fresh air requirement in the space. It is note that the ventilation system is operated in occupancy hours, which is described previously. Moreover, the heating and cooling energy are assumed by a mode supplied fresh air. The temperatures are free floating.

Results are printed first for hottest two weeks between 18 July and 31 July for the city Esslingen in order to see the temperature gradient between the zones clearly. Moreover, the calculation has been carried out for the total summer period. Results of the basic case are given in the Fig. 4.9 and Fig. 4.10. As it can be seen in figure 4.9, the temperatures are increasing in the higher levels of atrium. The zone 0 is lowest thermal zone of atrium. Zone 1, 2, 3 mean the first, second, third floor, respectively. In hottest days the outside temperature is higher than zone 0 and 1. However the temperatures of zone 2 and 3 reach to highest values. However, it must be emphasized, that the occupation is located largely on ground floor. In figure 4.10, the free-floating temperature of basic case can be seen for summer period (June-July-August). The result shows that the temperature gradient for basic case is very high, especially for hottest summer days. The ground floor which is important for occupants in terms of thermal comfort, is swinging between 20°C and 30°C. The temperature of ground floor is rising 1735 hours above 25°C in summer period. It means that the ground floor is over the comfort conditions with a range of %75 of the summer period. Average and maximum temperatures of each zone can be seen in Table 4.6.

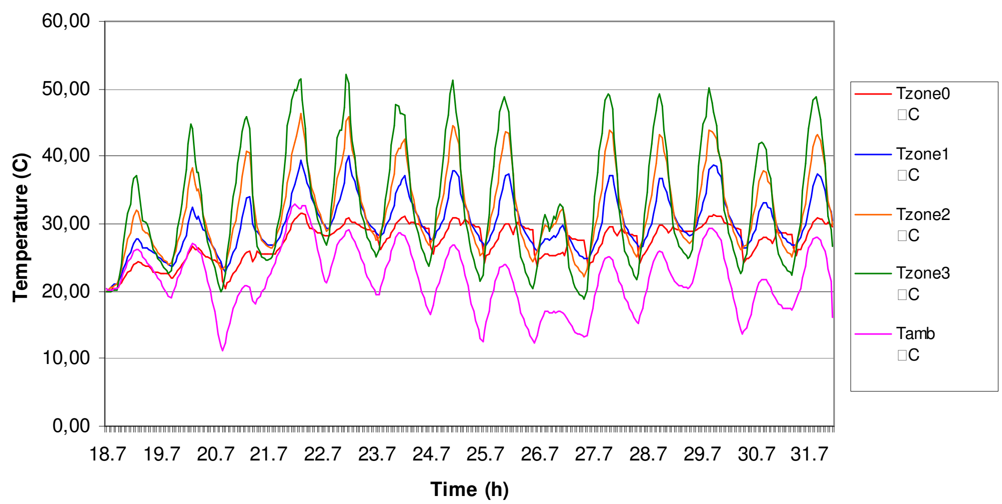


Figure 4.9: Outdoor and indoor free-floating temperature in Basecase in hottest two week (18 July-31 July)

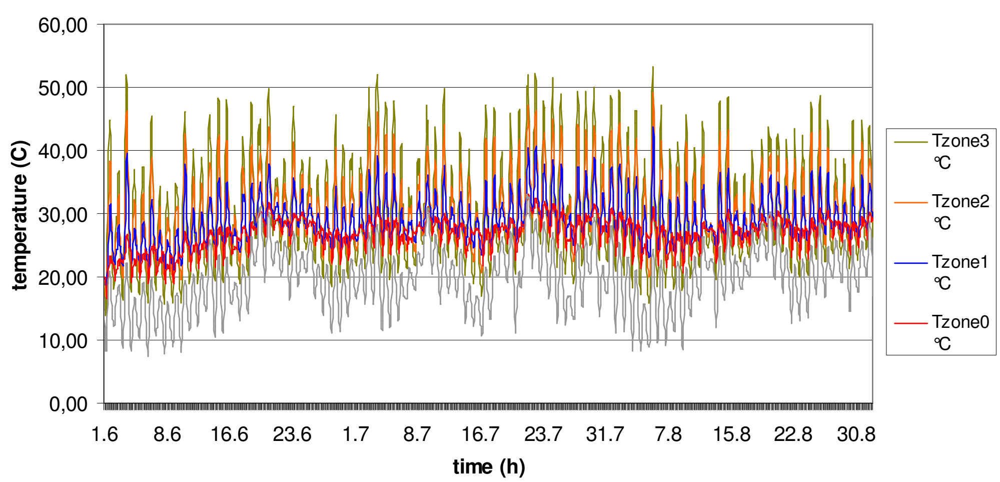


Figure 4.10: Outdoor and indoor free-floating temperature in Basecase in summer period (June-July-August)

After temperature calculations, sensible cooling energy demand calculations are carried out for basic case (Figure 4.11). Set temperature is defined as 22℃ for ground floor to calculate cooling energy demand. Cooling energy in summer period is calculated 18598,9 kWh for basic case.

Table 4.6: Maximum and average indoor outdoor temperatures in cooling season

(Cooling Season)	T_ambient	T_Zone0	T_Zone1	T_Zone2	T_Zone3
Average (°C)	19,61	26,85	28,92	30,26	30,73
Max (°C)	32,98	33,07	43,59	49,11	53,34

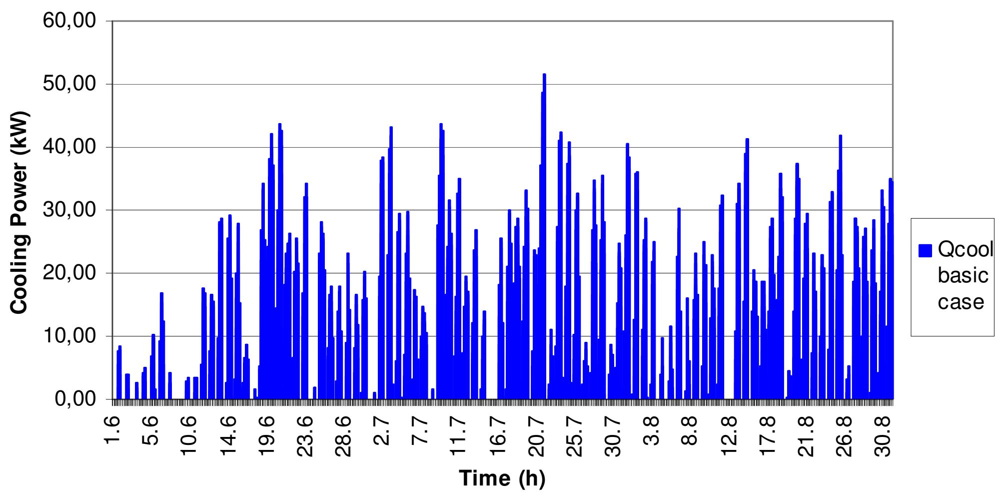


Figure 4.11: Hourly variation of sensible cooling demand of basic case

In order to make true decisions, year-round performance of atrium has be obtained and considered. Thermal behaviors of the base atrium cases are also analyzed for the winter time where heating is necessary. First of all calculations are carried out while the heating system is off and the temperatures are free floating in order to see the true passive performance of atrium. Results of this basic case are given in the Fig. 4.12 and Fig. 4.13. Firstly, the calculation has been carried out for coldest two weeks between 7 January and 21 January for the city Esslingen in order to see the temperature gradient between the zones clearly (Figure 4.12). In extreme cold days, the temperature can be lower than night temperatures, due to the fact that the fresh air is supplied directly by outside temperature to the ground floor. Therefore, there can be obviously seen the great effect of supply air temperature on temperature of atrium. However, atrium temperatures always are above the outside temperatures because of the high internal gains. Therefore, atrium can be used as a buffer space for office blocks with its tempered air, even without any passive precaution. Secondly, the calculation has been carried out for the whole heating season (September-May) seen in Figure 4.13.

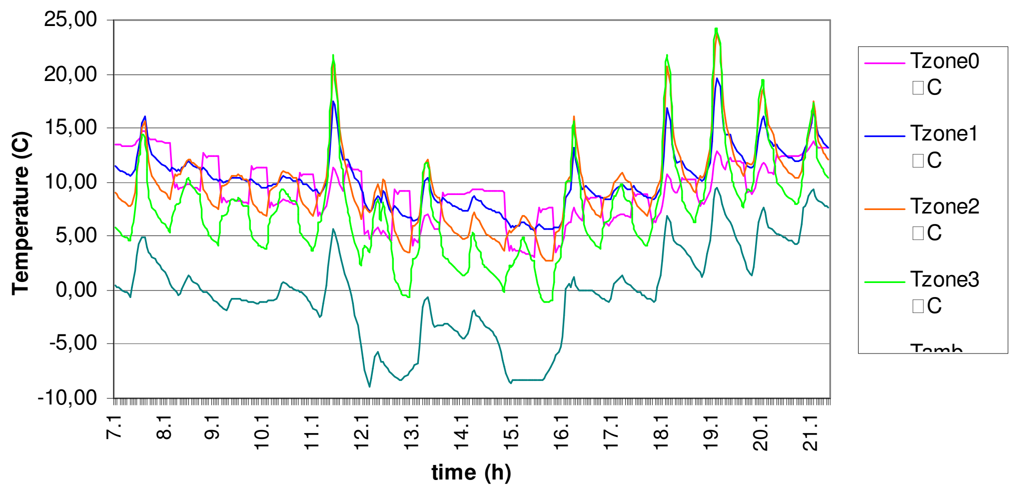


Figure 4.12: Outdoor and indoor free-floating temperature in Basecase in coldest two week (7 January-21 January)

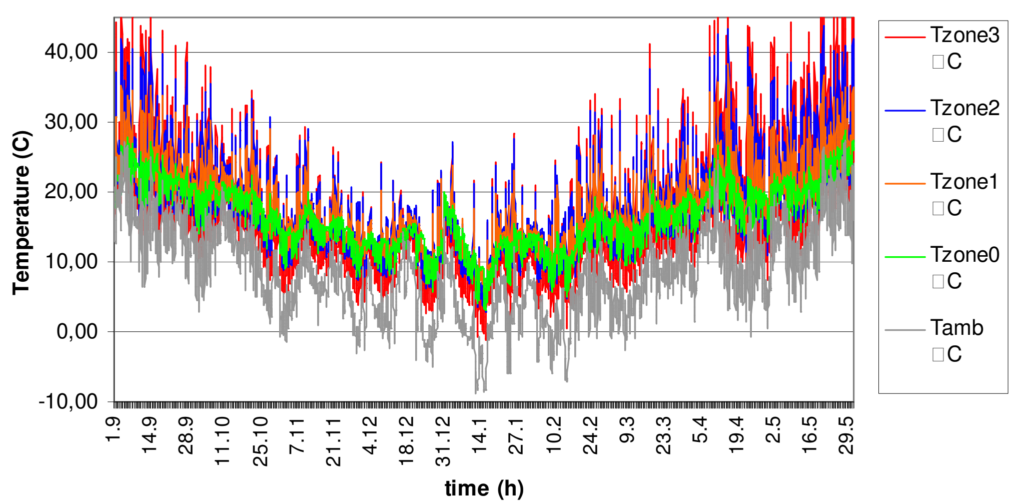


Figure 4.13: Outdoor and indoor free-floating temperature in Basecase in winter period (September-May)

The ground floor which is important for occupants in terms of thermal comfort, is swinging between 5°C and 25°C (Figure 4.14). The average temperature is 16,32°C as seen in Table 4.7. The temperature of ground floor falls down below 18°C 4029 hours in winter period. It means that the ground floor is under the comfort conditions with a range of %61. Average and minimum temperatures of each zone can be seen in Table 4.7.

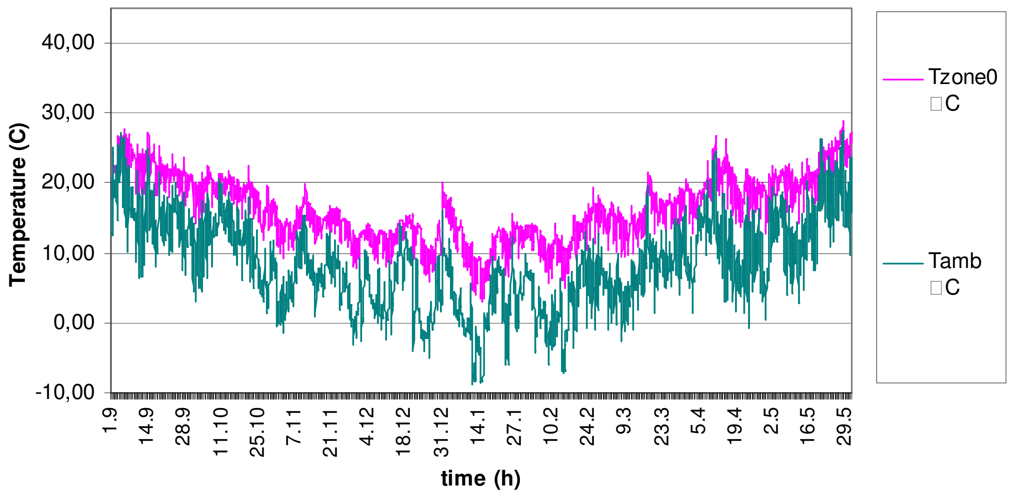


Figure 4.14: Outdoor and indoor free-floating temperature of ground floor of Basecase in winter period (September-May)

Table 4.7: Minimum and average indoor outdoor temperatures in heating season

(Heating Season)	**T_ambient**	**T_Zone0**	**T_Zone1**	**T_Zone2**	**T_Zone3**
Average (°C)	8,40	16,32	17,65	17,89	16,79
Min (°C)	-8,90	3,08	5,53	2,76	-1,12

After temperature calculations, sensible heating energy demand calculations are carried out for basic case (Figure 4.15). Set temperature of heating system is defined 22°C in occupancy hours for ground floor to calculate heating energy demand. Occupant hours fro atrium has been described in previous section. Set temperature is

18℃ except of occupancy hours, which is defined in previous chapter. Heating energy in winter period is calculated 85908,8 kWh for basic case.

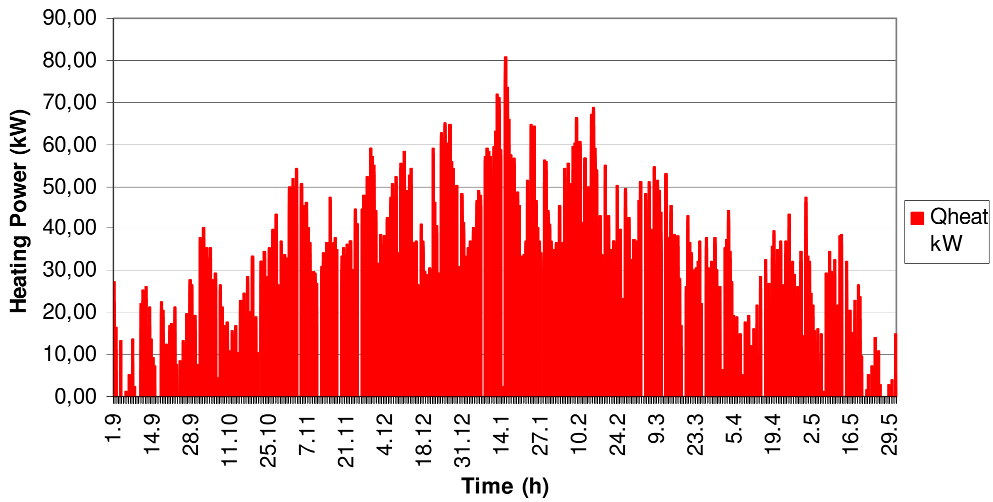


Figure 4.15: Hourly variation of sensible heating demand of basic case

If it is possible to use as alternative passive cooling system "earth to air heat exchanger", heating load can be substantially reduced by preheated air supplied to atrium.

4.5 Analyzing the passive control strategies on Atrium of Case Study Building

After the application of simulation on case study building as basic case, passive control strategies will be applied on the basic case and the temperatures and energy demand of atrium space will be analyzed.

Different features were used to obtain the goals for the energy efficient atrium building: natural ventilation, night cooling, applying high thermal mass, useful solar heat gain through the appropriate selected glazing, heat recovery by ventilation, automated control of night cooling, solar shading, low energy equipment, etc. Application of passive systems and the line of its automation are explained in following part.

4.5.1 Summer Period calculations

In summer, passive control systems on the envelope of atrium which can be classified as solar control and natural ventilation control are the most important passive control strategies for energy efficient and healthy building design. They are usually provided by operable windows for natural ventilation and external shading devices. Therefore the atrium buildings designed by passive solar strategies should benefit from the opportunity offered by these passive control systems and building automation system should also control these systems to achieve the most efficient building energy management.

The use of adaptable building envelope devices can lead to considerable energy savings, if they are controlled correctly. They should be adjusted to recognize and respond instinctively and constantly to environmental change. Unfortunately, field studies show that occupants very rarely adjust these devices unless they are threatened by discomfort and for instance once they make an adjustment they very rarely re-adjust the blinds for the rest of the day. To minimize the both energy use and discomfort it is desirable to automate the building envelope elements and to link them to internal and external stimuli. The proper types of these control systems should be designed specific to each building at the design stage to get maximum energy efficiency from the building [44].

4.5.1.1 Night Time Convective Cooling and Using Thermal Mass

It was anticipated that during the day in summer, internal temperatures would rise to 25 C or 26 C. Useful convective cooling is therefore promoted when the external temperature drops below 21C, which occurs frequently at night during the summer period. Ventilation is operated with 1.45Ach in daytime. The movement of air (in the absence of wind) is driven by buoyancy forces reversing the daytime air movement pattern under downdraught cooling. The night cooling is controlled via the 10 piece of convector at lower ground level and the air is filtered and supplied from there. Convective cooling relies on large air change rates. When night ventilation is initiated, it is assumed that the all high level vents are fully opened and air change rate is 2.5Ach. In this way the benefits can be genuinely regarded as ‘free’ cooling.

4.5.1.2 Results for night cooling strategy

The performance of natural night ventilation is analyzed based on the achieved indoor air temperatures. Different natural ventilation strategies has been applied and compared with the base case which is operated without night cooling. The effect of the different night cooling strategies on temperature of atrium can be seen in figure 4.16. In this figure there are two different night cooling strategies. “Night 1” is operated continuously between 21:00-05:00h regardless of climatic condition of indoor and outdoor. “Night 2” is controlled depending on indoor and outdoor temperatures. Control criteria for this night cooling are shown below in table 4.8. In order to activate the system both of the criteria must be ensured at the same time.

Table 4.8: Control criteria for night cooling operated by automation “night2”

Control criteria	**Limits for “active”**	**Limits for “non-active”**
Average room temperature	Troom>22 ºC	Troom<20 ºC
Outside temperature	21ºC >Tamb>17ºC	16ºC >Tamb; Tamb>21ºC

In figure 4.16, the effect of two different night strategies is monitored for special two weeks, which has a mild days as well as hot days, in order to see the performance of two strategies in possible various conditions during the summer period. If we check the day-time peak-temperatures, there is no difference between two cases. However, first case “Night1” reaches in cold nights very low temperatures, because of the permanent operating of free cooling during the night. It reduces also early morning temperatures below the comfort condition. Furthermore, in mild days where the indoor air temperature is swinging between 18-22C, second case performs better. In figure 4.17 it can be seen the indoor temperatures for each zone by operating “night2”. Therefore, the second case controlled by automation system has been chosen for following calculations. Except of extreme hot days, temperatures of ground floor are almost in comfort range for this second type of night cooling as seen in figure 4.17. However, it is still not sufficient; therefore it is needed more passive control strategies like thermal mass and shading.

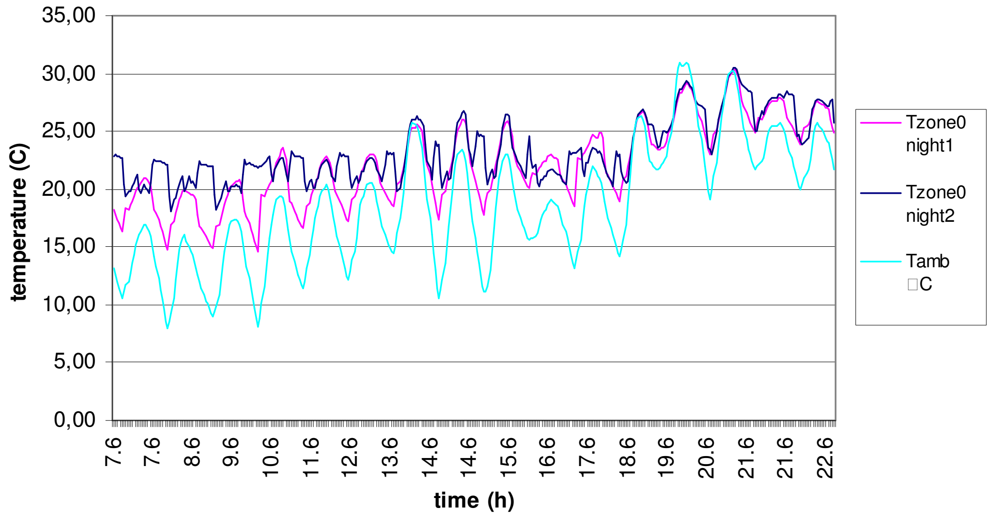


Figure 4.16: Outdoor and indoor air temperature of zone0 for 7-22 June with different night ventilation strategies

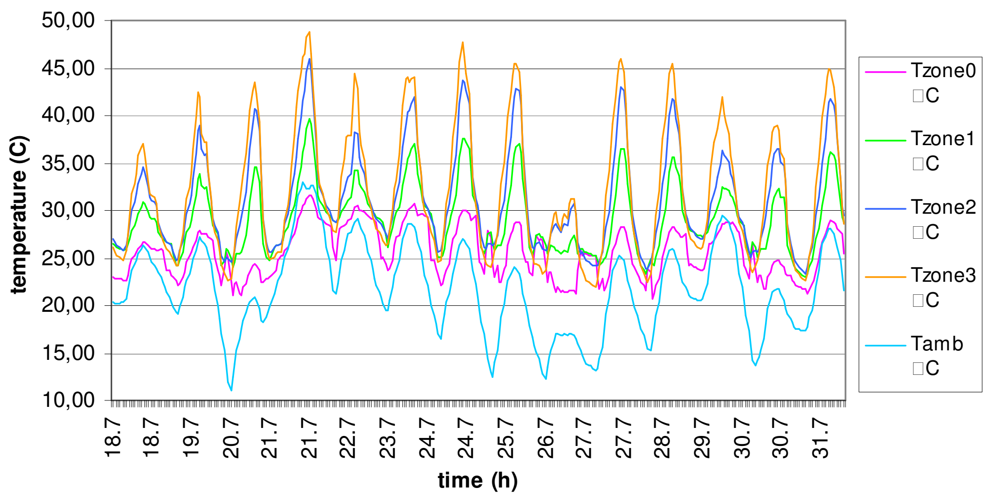


Figure 4.17: Outdoor and indoor air temperature of thermal zones of atrium by automated night ventilation in hottest two week (18July-31July)

As mentioned in previous chapter, natural night ventilation can be successful only with a sufficient thermal mass. Natural night ventilation cooled down the inside air and exposed opaque parts, which had stored the heat of the previous day, from midnight p.m. till 6 a.m. As a result, excess heat accumulated in the ceiling and slabs of adjacent corridors the following day and the air temperature peaks by day decreased. Therefore, second case which is determined in night cooling calculation as effective cooling, has been calculated again by high thermal mass. Heavy concrete with high conductivity and density is used as the high thermal mass in calculation. In figure 4.18, it is obvious, that the night cooling with thermal mass reduce the peak temperatures by between 3C and 8 C in zone 1. However, without thermal mass, there is just small difference like 1C between basiccase. This results show that the night cooling can be effective just with using thermal mass. Furthermore, thermal mass has the effect of reducing great temperature swinging between day and night, and temperature gradient between thermal zones when compared with figure 4.17 (Figure 4.19). In spite of impact of thermal mass on reducing temperature gradient during the night, it can not be effective for day time temperatures as well as night time. It is because of the high solar radiation entering through the large glazing into the building. It can be prevent by using solar shading in large glazing envelope.

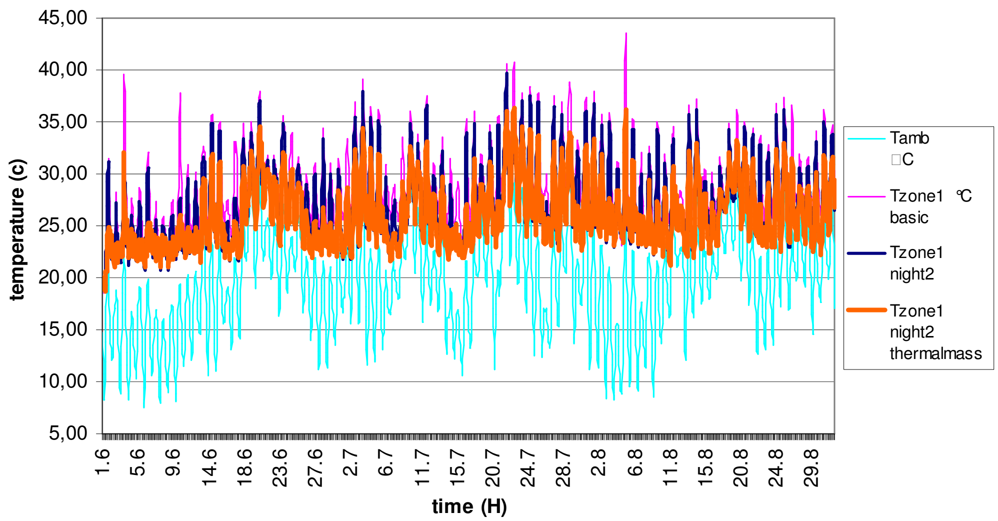


Figure 4.18: Outdoor and indoor air temperature of zone 1 by effect of thermal mass with automated night ventilation in summer period.

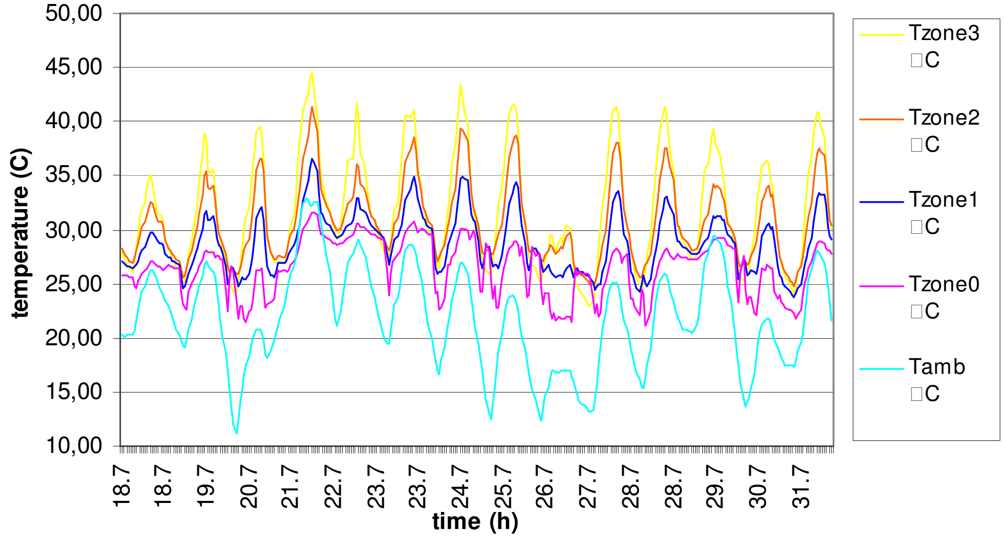


Figure 4.19: Outdoor and indoor air temperature of thermal zones of atrium by night ventilation "night2" with thermal mass in hottest two week (18July-31July)

A comparison of night cooling with thermal mass can be seen in table 4.9. It shows that average and maximum temperatures for each zone. The temperature of ground floor is rising 1067 hours above 25°C in summer period. It means that the ground floor is over the comfort conditions with a range of %45.

Table 4.9: Maximum and average indoor outdoor temperatures of cases "night2" with and without thermal mass in cooling season

Case Type	(Cooling Season)	T_ambient	T_Zone0	T_Zone1	T_Zone2	T_Zone3
Non-ventilated case	Average (°C)	19,61	26,85	28,92	30,26	30,73
	Max (°C)	32,98	33,07	43,59	49,11	53,34
Night2	Average (℃)	19,61	23,98	27,02	28,90	29,60
	Max (℃)	32,98	31,58	39,70	45,97	48,86
Night2 With high thermal mass	Average (℃)	19,61	24,65	26,81	28,61	29,37
	Max (℃)	32,98	30,65	36,61	41,30	44,53

Thermal mass and night cooling has an impact on cooling energy demand by reducing peak temperatures and temperature swinging in atrium. In figure 4.20, introduction of natural night ventilation to the building by using thermal mass resulted in reduction total cooling energy demand compared to non ventilated basic case. In other word it provides lowest indoor air temperature which is closest to the set point temperature of the cooling system. The maximum difference on sensible cooling energy demand is between ventilated and non-ventilated case as %30, as a result of the significant difference of the temperature values for these types (Table 4.10)

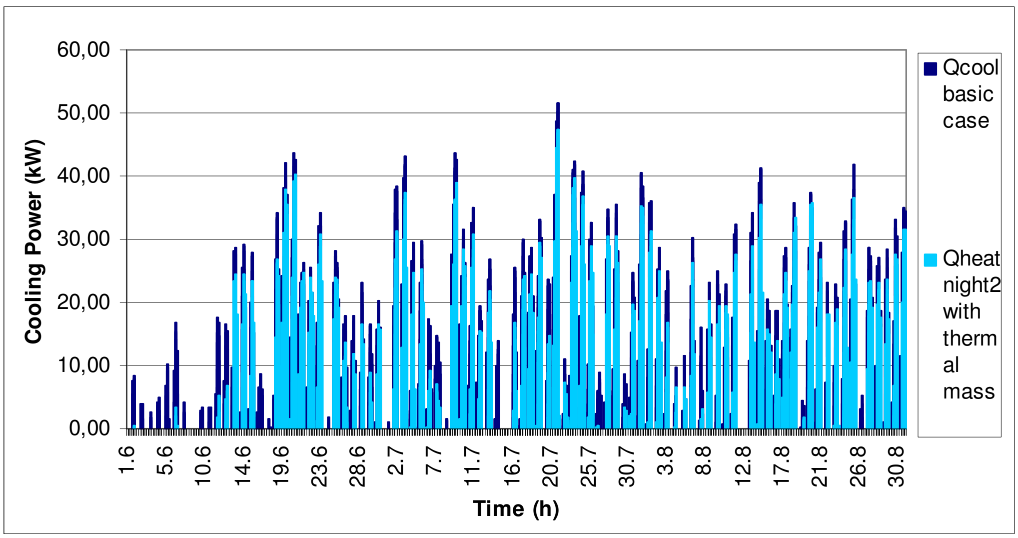


Figure 4.20: Hourly variation of sensible cooling demand of case with night cooling and thermal mass compared with basecase.

Table 4.10: Summary of the results obtained for ventilated and base case of Atrium

Summer Period (June-July-August)	**Sensible Cooling Energy (kWh)**	**CoolingLoad (kWh/m2)**
Without night ventilation (basic case)	18598,9	18
Night ventilation and thermal mass	13212,36	12.8

4.5.1.3 Shading

To investigate the effect of the external shading devices, a number of simulations were performed in the present work. For these simulations, it has been assumed that the case study building has been shaded during the day by external shading devices and their effect on indoor air temperature and cooling energy demand were analyzed. Shading strategy has been applied on the basecase. However, it is depending on a number of control criteria. As described before, there are two shading line in atrium. One of them is the shading devices of this façade called “sails” and the other is roof cladding which consist of ETFE-Foil Cushion. Solar shading coefficient of the devices has been assumed to be 0.7 for the main façade and 0.5 for the roof structure.

4.5.1.4 Results for shading strategy

Firstly, indoor air temperatures are calculated for two shading strategy. In first case, shading devices assumed to be active between 11:00-18:00h permanently regardless of climatic conditions. In second case, it has been also assumed that the shading devices controlled by building automation system during the day. The boundary conditions for automated shading are as in table 4.11. In order to activate the system both of the criteria must be ensured in same time. Secondly, some comparison with the non-shaded basic case has been made.

Table 4.11: Control criteria for shading

Different conditions	**Control criteria**	**Limits for “active”**	**Limits for “non-active”**
Summer	Average room temperature	Troom > 23 ºC	Troom < 21 ºC
	Beam Radiation on horizontal	I_b > 50 W/m2	10 W/m2 > I_b
Winter	Average room temperature	Troom > 23 ºC	Troom < 21 ºC
	Beam Radiation on horizontal	I_b > 200 W/m2	10 W/m2 > I_b

In the figure 4.21 and 4.22, it can be seen how different shading strategies effects indoor air temperature of atrium. The case where the shading devices is active between 11:00 and 18:00h continuously regardless of temperature and radiation.

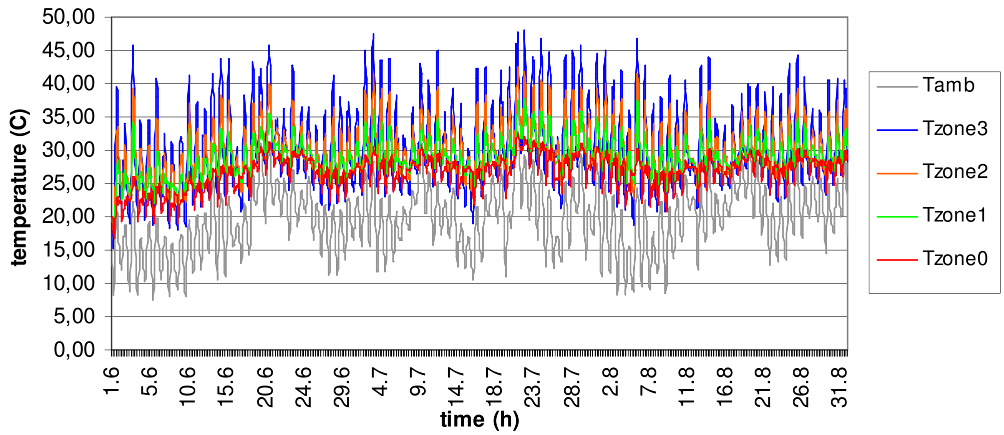


Figure 4.21: Outdoor and indoor air temperature of thermal zones in permanent-shaded case activated between 11:00-18:00h in summer season

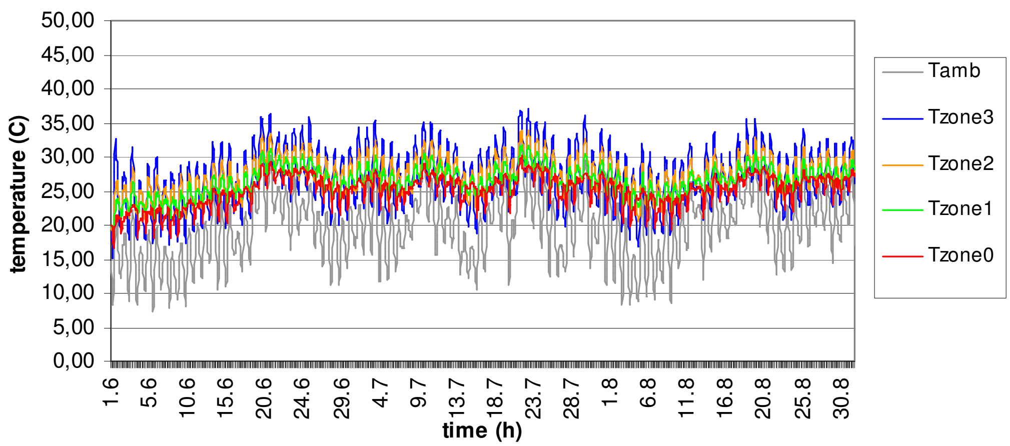


Figure 4.22: Outdoor and indoor air temperature of thermal zones in shaded case controlled temperature- and radiation-dependent in summer season

A comparison of indoor air temperatures of zone 1 obtained with two different shaded cases and non-shaded case (basic case) can be seen in the figure 4.23. Using shading devices lowered down the indoor air temperatures compared to non-shaded case. However, it must be emphasized that the shading strategy responding to various climatic conditions can reduce significantly the indoor temperatures in atrium space. Some days the temperature difference can be over 5 ºC.

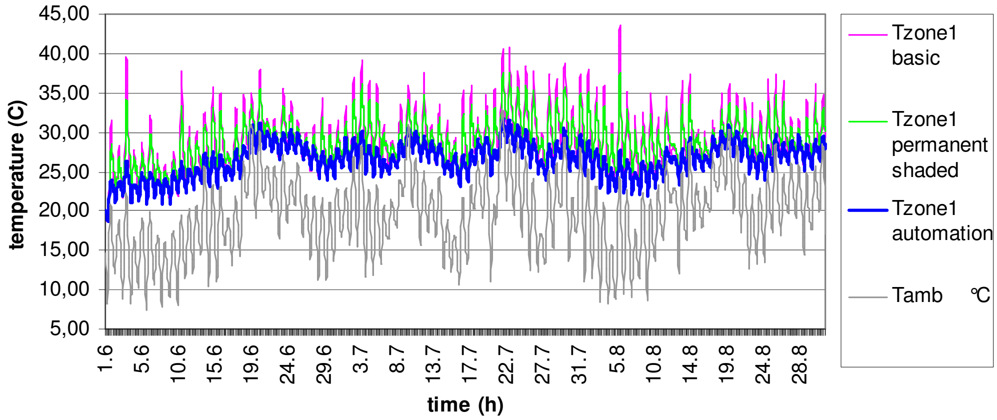


Figure 4.23: Outdoor and indoor air temperature of zone 1 in different shaded cases compared with base case.

In case controlled by an automation system, the maximum indoor temperature of zone 1 decrease from 44ºC to 32ºC compared with basic case. However, permanent shaded case can decrease only from 44ºC to 38ºC. This is almost same for other thermal zones. In Zone 3, the decreasing range of maximum and average temperatures by shading can be stronger due to the large glazing are of top floor with roof structure. (Table 4.12)

Table 4.12: Maximum and average indoor outdoor temperatures of shaded and base cases in cooling season

Case Type	(Cooling Season)	T_ambient	T_Zone0	T_Zone1	T_Zone2	T_Zone3
Non-shaded case	Average (°C)	19,61	26,85	28,92	30,26	30,73
	Max (°C)	32,98	33,07	43,59	49,11	53,34
Shaded 11-18h permanent	Average (°C)	19,61	26,78	28,94	30,30	30,74
	Max (°C)	32,98	32,53	37,63	42,52	48,08
Shaded By automation	Average (°C)	19,61	25,15	26,52	27,16	26,97
	Max (°C)	32,98	30,12	31,74	33,91	37,00

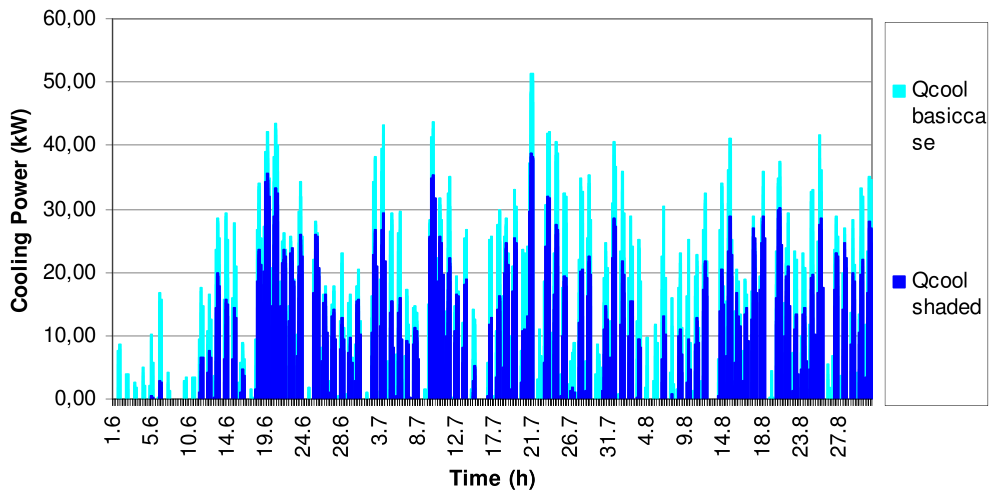


Figure 4.24: Hourly variation of sensible cooling demand of shading case compared with basecase.

The cooling loads are analyzed for this case, which is shown in Figure 4.24. As simulation results (table 4.13) indicate, 31% reduction in sensible cooling energy demand is achieved in summer cooling period by effective using of shading devices.

Table 4.13: Summary of the results obtained for shaded and non-shaded cases in Atrium

Summer Period (June-July-August)	**Sensible Cooling Energy (kWh)**	**CoolingLoad (kWh/m2)**
Non-shaded case	18598,91	18,09
Shaded 11-18h permanent	17126,18	16,66
Shaded By automation	12976,31	12,62

4.5.1.5 Combined Strategy

In order to prevent overheating in atrium effectively during cooling season, all of the passive strategies must be operated compatible. For that reason, the passive strategies explained evaluated separately in previous application, will be applied in this section as combined case to prevent overheating and reduce cooling energy demand. Shading, night ventilation and thermal mass are three important passive means for summer. Best alternatives determined for shading and night ventilation previously is combined with each other. These are automated night ventilation by using thermal mass on building structure and automated shading device operated depending on temperature and beam radiation intensity.

4.5.1.6 Results for combined strategy

The effect of combined case on the reduction of the maximum indoor temperature for zone 0 is shown more clearly in Fig. 4.25. It can be read from the table that without night cooling and shading the indoor temperature will reach 33℃. With natural night ventilation, this temperature reduce by about 3℃ for 2,5 air change per hour. With shading, this temperature reduce by about 3,5-4℃ and with combination both of them, the temperature reduce by about 4-5℃. It is obvious that making combination of all passive strategies results best performance for summer indoor air temperatures.

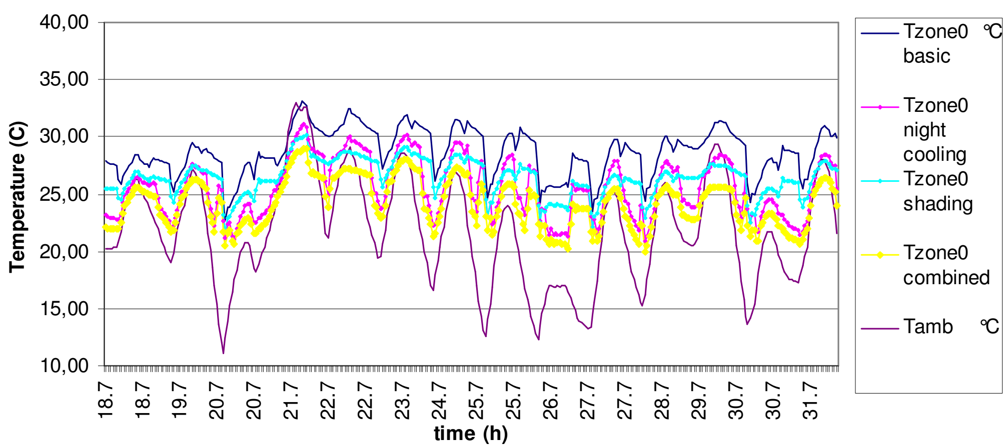


Figure 4.25: Outdoor and indoor air temperature of zone 0.

In hottest day combined case reduce indoor air temperature from 32,5 to 28 compared with basic case. Appropriate using of passive strategies can reduce temperature gradient between thermal zones, as it can be seen in Fig. 4.26. When compared with basic case, combined case reduces peak temperatures by about 4℃, 13℃, 16℃, 17℃ for zone0, zone1, zone2, and zone3, respectively.

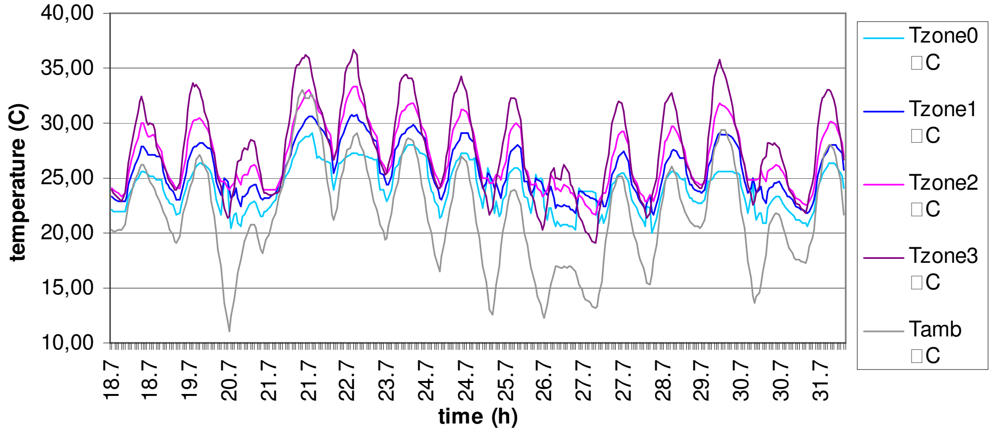


Figure 4.26: Outdoor and indoor air temperature of thermal zones of combined case in hottest two week (18 July-31 July)

After calculating temperature, cooling load of combined case has been calculated. Comparison of each case which has been carried out previously including base case, are reflected on fig. 4.27.

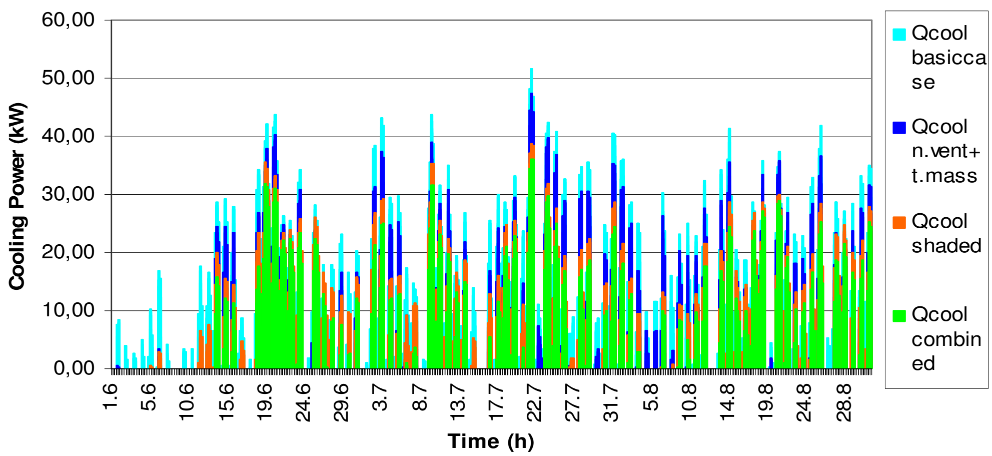


Figure 4.27: Hourly variation of sensible cooling demand of each case

The results of individual strategies have been summarized in table 4.14 below. As seen in table, introduction of combination of natural night ventilation and shading to the building resulted in reduction total cooling energy demand compared with non-ventilated, non-shaded and basic case. Combined case results in 4C reduction in average and maximum temperatures for zone 0 (ground floor of atrium) operated without air conditioning system. In other words it provides lowest indoor air temperatures for each thermal zone which is closest to the set point temperature of the cooling system.

Table 4.14: Summary of the results for summer period for atrium

Thermal zone	Case Type	AverageTemp (°C)	MaxTemp (°C)	Sensible Cooling Energy (kWh)	CoolingLoad (kWh/m2)
Zone 0 (1028 m2)	**Basic**	26,85	33,07	18598,91	18,09
	Night-cooled	24,65	30,65	13212,36	12,85
	Shaded	25,15	30,12	12976,31	12,62
	Combined	22,98	29,03	9213,15	8,96
Zone 1	**Basic**	28,92	43,59		
	Night-cooled	26,81	36,61		
	Shaded	26,52	31,74		
	Combined	24,42	30,71		
Zone 2	**Basic**	30,26	49,11		
	Night-cooled	28,61	41,30		
	Shaded	27,16	33,91		
	Combined	25,47	33,30		
Zone 3	**Basic**	30,73	53,34		
	Night-cooled	29,37	44,53		
	Shaded	26,97	37,00		
	Combined	25,95	36,73		

Table 4.15 shows that the proportion and number of hours over 25°C for ground floor of atrium. Although the cooling loads for night ventilated and shaded case is almost same, proportion of hours over 25C of shaded case is much more than ventilated case because of the high night-time temperatures. It can be seen that the night ventilation has a great effect on temperature during non-occupied hours and it affect also the temperatures of the occupied hours. By combining night ventilation

and shading, it can be obtained very low proportion of hours over 25C (20%). It is important to emphasize that the temperatures are calculating without cooling system.

Table 4.15: Proportion and number of hours over comfort condition for applied cases during summer period for atrium

Case Type	Number of hours over 25,00°C in Zone 0	Proportion of hours over 25,00°C for summer period
Base case	1735h	78%
Night ventilated	1067h	48%
Shaded	1332h	60%
Combined	458h	20%

4.5.2 Winter Period calculations

In winter, there are some useful precautions in order to save energy and increase atrium temperatures. The thermal properties of glazing are very important to benefit useful heat gain and to avoid cold outside temperatures. Furthermore inclination and orientation are also very considerable. Using of thermal mass and pre-heated ventilation or heat-recovery systems have great impact on reducing energy consumption of building and improving comfort conditions in winter.

Thermal mass is one of the considerable precautions for energy saving. Thermal mass provide to storage of the solar energy coming into the building in sunny winter days. This reduces large temperature swinging during winter. As it is shown in fig. 4.28, introduction of thermal mass into the building structure helps to increase temperatures about 2C approximately compared with base case. In fig. 4.29, it can be seen temperature distribution in each thermal zone for case with increased thermal mass. It has been calculated the same case but additionally shaded when the temperature and beam radiation exceed the boundary condition. It affects temperatures especially during early and late winter. In fig. 4.30, useful shading keep the temperatures in winter almost same, however in warm days during spring and autumn draws it down to comfort condition.

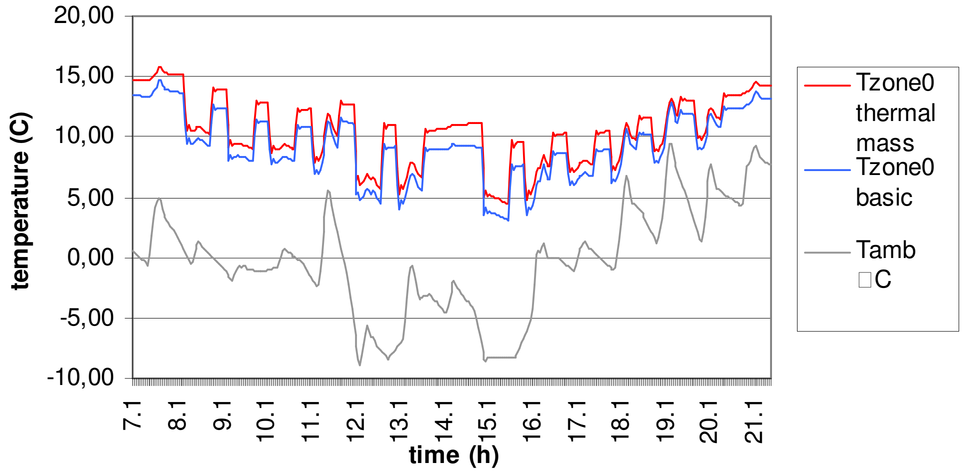


Figure 4.28: Outdoor and indoor air temperature of zone 0.

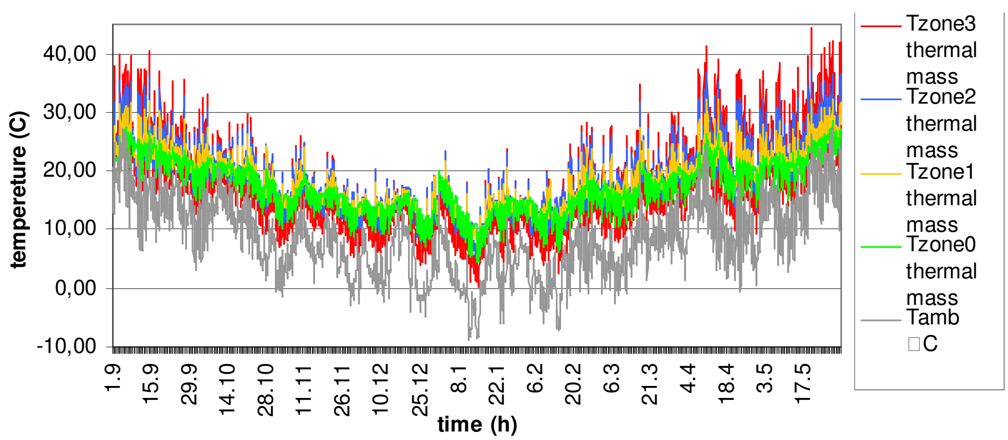


Figure 4.29: Indoor air temperatures of atrium for case with thermal mass

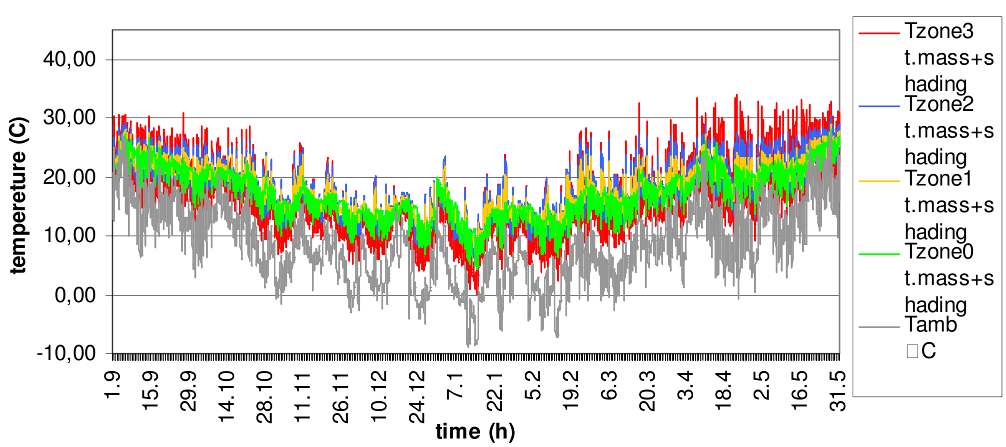


Figure 4.30: Indoor air temperatures of atrium for shaded case with thermal mass.

In every case evaluated by now, 100% fresh air with outside temperature is supplied to atrium during occupancy hours. In order to reduce ventilation losses, heat recovery system has been implemented to the building ventilation system. It saves preheated air and mixes it with fresh air when the outside temperature is cold. The control and working strategy is as given in table 4.16.

Table 4.16: working principle of heat recovery

Heat recovery mode	Outside air	Fresh outside air	Preheated air in atrium
Active	IF x<18°C	%30	%70
Non active	IF x>=18	100%	-

Using preheated air in ventilation system reduces ventilation losses. Therefore, it affects temperatures of atrium significantly, as it is shown in Fig. 4.31. Effect of heat recovery on indoor temperature of zone 0, can be seen clearly in Fig 4.32. Ventilation by heat recovery results in increasing of temperature about 5C when compared with basic case and 3C when compared basic case with thermal mass. Due to the high temperatures, atrium can act as buffer space perfectly for its adjacent rooms for winter period.

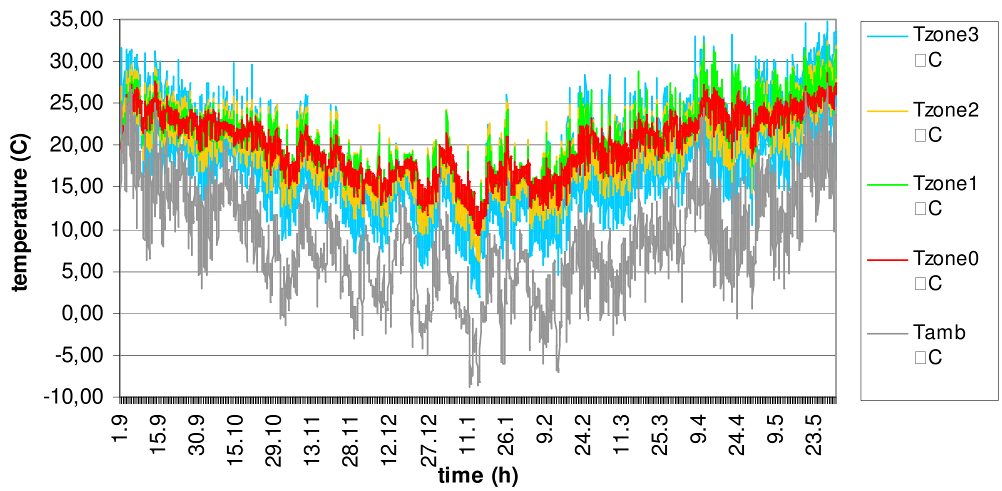


Figure 4.31: Indoor air temperatures of atrium for heat recovery case with thermal mass

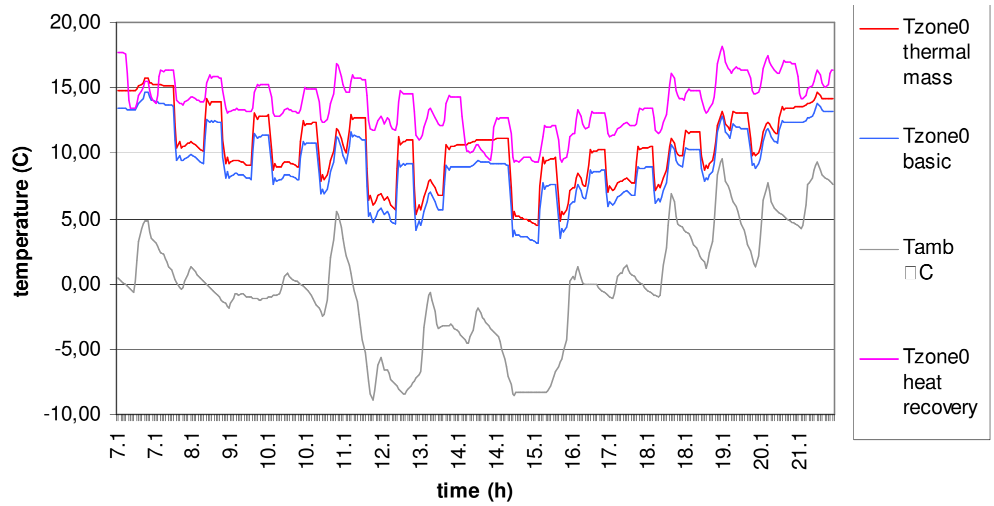


Figure 4.32: Comparison of indoor air temperatures of different strategies for zone0 during coldest weeks.

Improvement on ventilation by heat recovery keeps temperatures from reaching high values in warm days during early and late winter, whilst increasing it close to set temperature of heating system. It can be achieved by adjusting the ventilation mode depending on the outside temperature, which is explained in table 4.16 previously. It can be seen in Figure 4.33, which shows the temperatures of zone 1 for basic case and heat recovery case during the winter period. The results of cases applied for winter period is summarized in table 4.17.

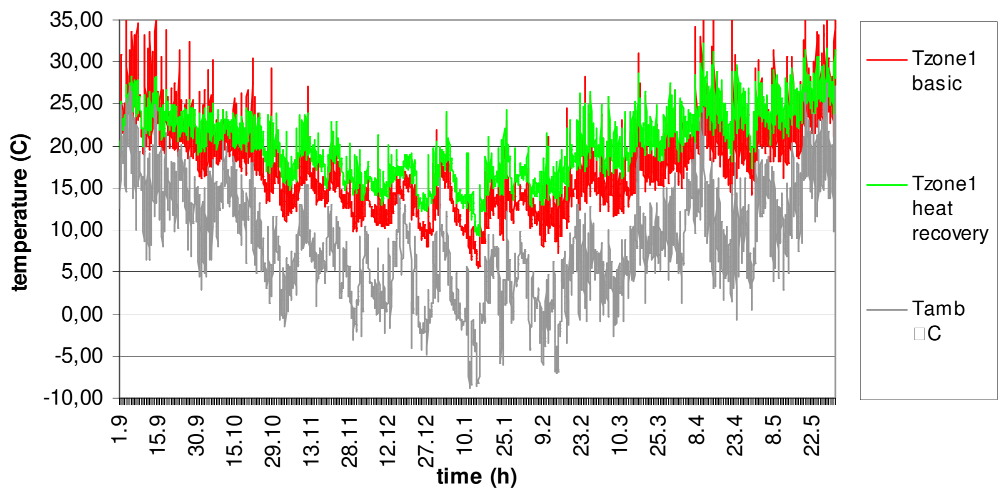


Figure 4.33: Comparison of indoor air temperatures of heat recovery mode with basic case for zone1 during winter season.

Table 4.17: Summary of the results for winter period for atrium space

Thermal zone	Case Type	Average Temp (°C)	MinTemp (°C)	Sensible Heating Energy (kWh)	HeatingLoad (kWh/m2)
Outside air		8,40	-8,90	--------	--------
Zone 0 (1028 m2)	**Basic**	16,32	3,08	85908,78	83,56
	+Thermal Mass	17,10	4,43	76608,91	74,52
	+ Shaded	17,03	4,43	77286,75	75,18
	+Low-e glazing	17,27	4,59	75018,81	72,97
	+Heat recovery	19,99	9,26	33435,66	32,52
Zone 1	**Basic**	17,65	5,53		
	+Thermal Mass	18,27	6,88		
	+ Shaded	17,86	6,88		
	+Low-e glazing	18,23	7,17		
	+Heat recovery	20,15	9,26		
Zone 2	**Basic**	17,89	2,76		
	+Thermal Mass	18,31	4,56		
	+ Shaded	17,69	4,56		
	+Low-e glazing	18,35	5,27		
	+Heat recovery	19,34	6,06		
Zone 3	**Basic**	16,79	-1,12		
	+Thermal Mass	16,94	0,27		
	+ Shaded	16,24	0,27		
	+Low-e glazing	17,33	1,39		
	+Heat recovery	17,70	1,87		

The proportion of hours under comfort condition can be seen in Table 4.18. By using heat recovery system, the proportion reduces from 61% to 33% in comparison with basic case.

Table 4.18: Proportion and number of hours under comfort condition for applied cases during winter period for atrium

Case Type	Number of hours under 18°C in Zone 0	Proportion of hours under 18°C for winter period
Base case	4029,00	61%
Thermal mass	3735,00	57%
Useful shaded	3749,00	57%
Low-E	3649,00	55%
Heat Recovery	2207,00	33%

4.5.3 Annual analyze

The passive energy strategies can be applied during the whole year. It can be achieved by adjusting these strategies according to the climatic conditions and comfort requirements. Passive means have been controlled by an automation system which has already applied to winter and summer calculation and the results have been discussed. For annual analyze passive strategies of winter and summer has been potentially integrated by automation system. As it can be seen in Table 4.19, first thermal mass with night ventilation system is calculated for the whole year. Energy saving is 14% in this case. By using just effective shading devices, energy saving is almost same as in previous case. Application of all passive systems like shading, night ventilation and heat recovery strategies, the results can be 59% reduction on total load in comparison with basic case.

Table 4.19: Summary of the annual results for atrium space

Annual Load	Cooling Load (kWh/m2)	Heating Load (kWh/m2)	Total Load (kWh/m2)
Basic	18,09	83,56	101,65 (100%)
Thermal mass **Night cooling**	12,85	74,52	87,37 (86%)
Shaded	12,62	75,18	87,80 (86%)
Shaded **Night ventilated (Thermal mass)** **Heat recovery system**	8,96	32,52	41,48 (41%)

4.6 Analyzing effect of thermal performance of atrium on adjacent spaces

Including an atrium as an energy-saving feature demands an understanding of the role of the atrium in the annual energy performance of the whole building. This requires some basic knowledge of the load and occupancy profiles of the various parts of the building and the ability to interpret these profiles as energy use patterns. As mentioned before, an atrium provides an additional insulation layer between office blocks and the external climate. Apart from the obvious improvement in U-value, this buffering can be enhanced by

⇒ using the atrium to capture solar gains, thus increasing its ambient temperature in winter, and

⇒ using thermal mass and shading in a naturally ventilated atrium in summer to reduce sol-air temperatures, therefore reducing the cooling load on the office buildings [28]

Boundary conditions for office blocks are assumes as follow:

Interaction of the office blocks with atrium: The atrium space has walkways (galleries) along internal walls at each floor level to facilitate circulation to the atrium adjacent spaces. The windows on adjacent walls are not openable. The adjacent walls include %90 glazing. U-value of the adjacent wall is 1.7 W/m2k Therefore, the heat gain/loss via air change from/to the adjacent spaces is assumed to be zero in simulation.

Occupancy hours: The office is accepted to be occupied from 05:00 to 20:00 during the weekdays including Saturday based on the information taken from real operation hours of building FESTO.

Boundary conditions of adjacent spaces: Basement floor has been assumed to be 23℃ during the winter and 21℃ during the summer constantly.

Internal Gains: It is accepted that the internal gains occur during the occupancy hours. For non-occupied hours, gain from persons, lighting and other devices are zero. The gain per person is chosen from the TRNSYS gain list according to ISO 7730 as 75W/person sensible heat described as an activity “seated light work, typing”. Gain from computer is also chosen from TRNSYS list as 230W PC with color monitor, per monitor. It assumed that number of computer is 30. For the artificial lighting system, the power densities are assumed to be 10 W/m2 with a 30% convective part.

Infiltration: Infiltration rate for air leakage is assumed to be 0.1 ach.

Ventilation: Ventilation rate has been taken based on the real building data. The fresh air is supplied to each office floor via mechanically. The air is supplied with an air change rate 0.95 1/h. Operating hours for ventilation system is from 05:00 to 20:00 during the weekdays including Saturday based on the information taken from real operation hours of building FESTO. Supply air temperature is adjusted as outside temperature.

Heating system: First of all, the transmission heat losses are minimized. The external walls, roof, floor are very well insulated. Heating system is on whenever the heating is needed (September- May term). Climatisation is achieved through the supply air. Set temperature of heating system is taken as 22ºC between 05:00-20:00 hours including Saturday and for non-occupied hours like during Sunday and nights is 18ºC.

Cooling System: Cooling system is implemented during the cooling season which is June-July-August term (between 3625-5832 hours of the year). Cooling system is on between 05:00-20:00 hours during weekdays and Saturday. Set temperature of cooling system is assumed to be 22ºC whenever the cooling system on. It is taken as 28 ºC for non-occupied hours.

In order to evaluate effect of atrium on energy consumption of its adjacent office building, there will be carried out cases with no atrium, with buffer atrium and plenum case atrium.

The temperature increment of the atrium has two main energy benefit for itself an its adjacent building. Firstly it reduces the heat losses from the parent building via the wall separating the heated building form the atrium. This buffer effect allows a larger fraction of glazing to be used in this wall [11].

Secondly, the atrium offers the possibility of providing pre-heated/cooled ventilation or "make up" air to the climatised building. This means of thermal energy saving is particularly appropriate to larger buildings since ventilation heat loss assumes a greater proportion of the total heat loss than in smaller building. Furthermore, where in a normal building ventilation air would have to be mechanically handled and pre-heated/cooled, to avoid the local chilling effect of cold incoming air in winter and overheating of hot incoming air in summer, the atrium climate will provide the opportunity of "natural" ventilation to the surrounding rooms by casual window opening. This can be called as plenum effect [11]

Results of different of cooling and heating and total energy demands and loads have been summarized in Table 4.20, which shows the second floor and ground floor of office block. Highest cooling loads for two office floors have been obtained in case without atrium. By incorporating of non-optimized atrium to office buildings results in 61% reduction on cooling loads. This great reduction can be explained as a result of admitting high solar radiation through the adjacent wall exposed to the warm outside conditions which has no shading device and large glazing area. Operating of the plenum type reduce the cooling loads by 67% compared with basic case. The energy saving in plenum type is greater than other types because of the cooled atrium by extract air coming from offices and recirculation of this air in whole building operating system according as air quality of space.

Highest heating loads for two office floors have been obtained in case without atrium. Incorporation of non-optimized atrium into the building results in 8% reduction on heating load of offices. By optimizing the atrium, it is obtained 21% reduction and by using plenum type atrium for optimized case, the results can be 55% reduction. It is because of the effect of pre-heated atrium on its adjacent building as a buffer space and recirculation of this pre-heated air in air-conditioning system of the whole building according as air quality of space.

Total loads for two office floors have been obtained for all cases. The case without atrium has highest heating loads in comparison with other cases. Incorporation of non-optimized atrium with office building resulted in 40% reduction on total loads of office floors. By optimizing atrium, it is achieved a 46% reduction. By using plenum atrium, which creates an effective ventilation connection between atrium and offices can result in 62% reduction on total cooling loads.

Table 4.20: Summary of the annual results for office block

Energy and load for offices	**Sensible Cooling Energy (kWh)**		**Cooling Load (kWh/m2)**		**Sensible Heating Energy (kWh)**		**Heating Load (kWh/m2)**		**Total Load (kWh/m2)**	
Case/Thermal zone	**Offc0**	**office2**	**Offc0**	**Offc2**	**Offc0**	**Offc2**	**Offc0**	**Offc2**	**Offc0**	**Offc2**
without atrium (adjacent to outside)	47393	48051	69,5	70,5	29287	29444	43,0	43,2	**112,5**	**113,7**
buffer; with base case atrium	17375	19244	25,5	28,2	26725	27033	39,2	39,6	**64,7**	**67,8**
buffer; with optimized atrium	16673	17868	24,5	26,2	23218	24004	34,0	35,2	**58,5**	**61,4**
plenum; with optimized atrium	15078	15960	22,1	23,4	13226	13636	19,4	20,0	**41,5**	**43,4**

Furthermore, temperatures of atrium space have been calculated with two different relationship strategies between atrium and office blocks. These strategies are plenum and buffer atria. The calculations have been conducted for hottest two weeks during summer period and coldest two weeks during winter period. As it can be seen in Fig. 4.34 and 4.35 shows the temperatures variation of atrium zones depending on the different relationship between atrium and office blocks.

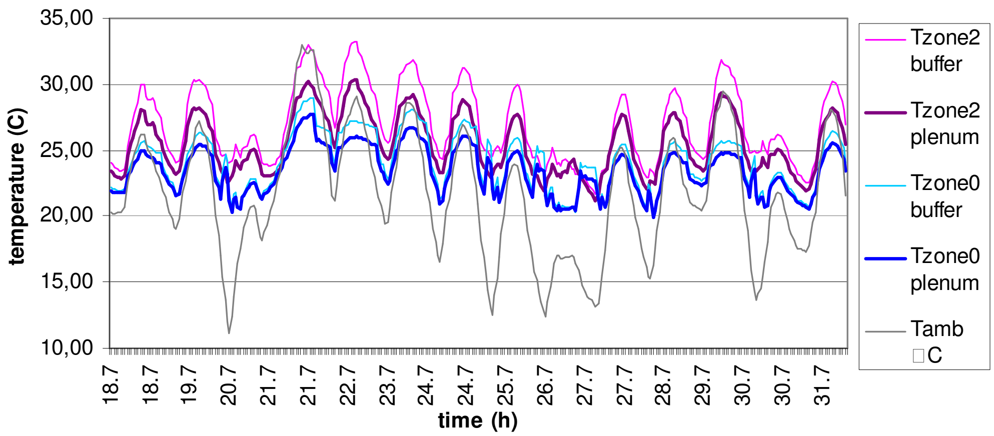


Figure 4.34: Comparison of indoor air temperatures of atrium by buffer effect and plenum effect atrium for hottest two week.

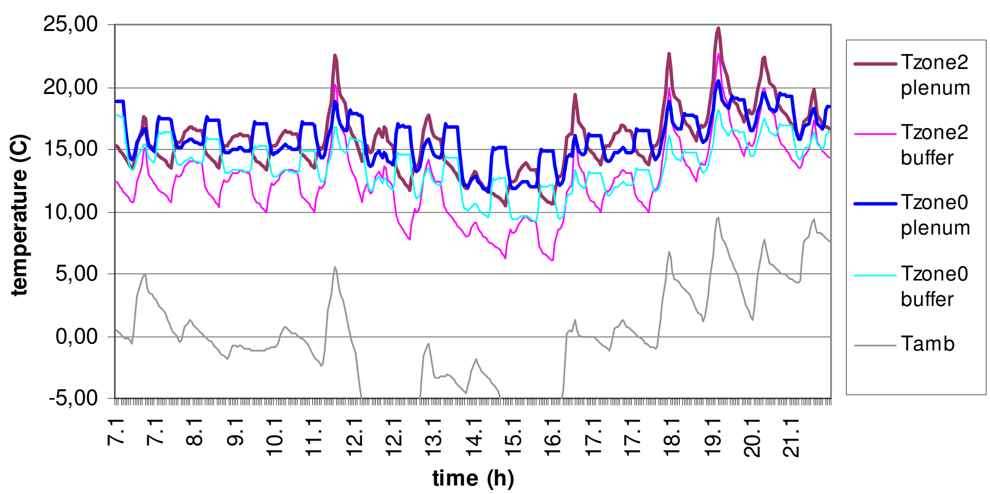


Figure 4.35: Comparison of indoor air temperatures of atrium by buffer effect and plenum effect atrium for coldest two week.

In summer calculation, plenum type atrium has more comfortable conditions, as seen in Fig. 4.34. The temperatures are lower compared with buffer type, because of using the extract air of offices as a supply air to atrium. It creates a pre-cooled air in atrium. Especially the temperatures in higher levels are higher like Zone 2. It means plenum type reduce the temperature gradient of atrium because of the extract air supplied to the atrium from each floor of office. In winter calculation, plenum atrium type has higher temperatures compared with buffer type, as seen in Fig. 4.35. Temperature differences can be 3C, especially during the cold days. Although the ventilation connection between offices and atrium is just during the occupied hours in plenum type, because of the high day temperatures, the night-time temperature does not reduce so much like other case.

4.7 Results of Case Study

The approach for estimation the thermal performance of atrium has been defined in Chapters 2. In this chapter this approach has been applied to a case study building located in Stuttgart, Germany. Firstly, the case study building has been described. Then, the boundary condition of atrium is defined. After that, the application of simulation has been conducted by using TRNSYS. Calculation has been carried out based on the real building data and operating system for atrium. However, there has been used no passive strategies on atrium. Therefore, the case has been called as basic case. The free-floating temperatures without air-conditioning system and cooling-heating loads have been obtained separately for the year round performance of the atrium. For summer period, the result shows that the temperature gradient for basic case is very high, especially for hottest summer days. The temperature of ground floor is rising in %75 of the summer period above 25°C. In winter calculation, atrium temperatures always are above the outside temperatures because of the high internal gains. However, the temperature of ground floor falls down below 18°C in %61 of winter period. When compared with summer period results, atrium can be maintained easier for winter period without using any passive control systems accept of good thermal insulation and can be used as a buffer space for office blocks with its tempered air, even without any passive precaution.

After the application of the simulation on case study building, passive control strategies have been applied on basic case of atrium in order to evaluate effect of passive strategies on thermal performance of atrium. Summer Period calculation and

Winter Period calculation has been conducted separately and finally winter and summer strategies which give the best performance for atrium, have been integrated to obtain annual performance of atrium.

In summer period calculation, the performance of natural night ventilation, application of thermal mass, shading and combined strategies has been analyzed respectively. For defining the true night ventilation strategy, different natural ventilation strategies has been applied and compared with non-ventilated case. In "Night 2" working automatically depending on indoor and outdoor temperatures has been obtained the best performance. Except of extreme hot days, temperatures of ground floor are almost in comfort range for this type. However, it is still not sufficient; therefore it is needed more passive control strategies like thermal mass and shading. The results show that the application of thermal mass reduces the peak temperatures by between 3C and 8 C. However, without thermal mass, there is just small difference like 1C between basiccase. This results shows that natural night ventilation can be successful only with sufficient thermal mass. The temperature of ground floor is rising above 25°C in %45 of summer period for this case. Furthermore, Thermal mass and night cooling has an impact on cooling energy demand by reducing peak temperatures and temperature swinging in atrium. Introduction of natural night ventilation to the building by using thermal mass resulted in 30% reduction total cooling energy demand compared to non ventilated basic case, as a result of the significant difference of the temperature values for these types

In spite of impact of the thermal mass on reducing temperature gradient during the night, it can not be effective for day time temperatures as well as night time. It is because of the high solar radiation entering through the large glazing into the building. It can be prevent by using solar shading in large glazing envelope. To investigate the effect of the external shading devices, a number of simulations were performed. Application of shading devices in different strategies lowered down the indoor air temperatures compared to non-shaded case. However, it must be emphasized that the shading strategy responding to various climatic conditions can reduce significantly the indoor temperatures in atrium space. Some days the temperature difference can be over 5 ºC. By application of automated shading device results in 3C reduction in maximum indoor temperature of zone 0. However, permanent shaded case reduce maximum indoor temperature of zone just 0.5C. The reduction is increasing with the height of the atrium. For example, in Zone 3, the decreasing range of maximum and average temperatures by shading is stronger due to the large glazing are of top floor with roof structure. Using shading devices controlled by automation system reduce sensible cooling load by 31%.

In order to obtain best performance of atrium and reduce cooling load, the passive energy strategies must be operated compatible. Therefore, a combination of best results obtained for each passive strategy has been conducted. Combining the passive strategies results in 4C reduction on average temperatures of ground floor, while night ventilation reduce 1,2C and shading 1,8C average temperatures. The proportion of hours over 25C decreases also in combined case to 20%. It is important to emphasize that the temperatures are calculating without cooling system. Appropriate using of passive strategies can reduce temperature gradient between thermal zones. When compared with basic case, combined case reduces peak temperatures by about 4℃, 13℃, 16℃, 17℃ for zone0, zone1, zone2, and zone3, respectively. It is obvious that making combination of all passive strategies results best performance for summer indoor air temperatures. Introduction of combination of natural night ventilation with thermal mass and shading to the building has also significant effect on reduction in total cooling energy demand compared with non-ventilated, non-shaded and basic case. It can be obtained 50% energy saving in combined case.

Secondly, passive strategies for winter period have been evaluated. In winter, there are various passive energy strategies to obtain best performance in atrium building. These are optimizing the thermal properties of glazing, selecting appropriate orientation and inclination for admitting useful solar gain inside the building. These precautions could not be taken because of the difficulties to change these parameters of the case study building which is already constructed. Using of thermal mass and pre-heated ventilation or heat-recovery systems have great impact on reducing energy consumption of building and improving comfort conditions in winter.

Application of thermal mass into the building structure increase temperatures about 2C approximately compared with base case and reduces large temperature swinging during winter. It has been calculated the same case but additionally shaded when the temperature and beam radiation exceed the boundary condition. Useful shading keep the temperatures in winter almost same, however in warm days during spring and autumn draws it down to comfort condition.

By incorporation of heat recovery system to the whole building ventilation system, the ventilation losses have been reduced. Therefore, it affects temperatures of atrium significantly. Ventilation by heat recovery results in increasing of average temperature of ground floor about 5C when compared with basic case. Due to the high temperatures, atrium can act as buffer space perfectly for its adjacent rooms for winter period. Improvement on ventilation by heat recovery keeps temperatures from reaching high values in warm days during early and late winter, whilst increasing it close to set temperature of heating system. It can be achieved by adjusting the ventilation mode depending on the outside temperature. Including of heat recovery system to the ventilation system has a great effect on heating load. It can be achieved 61% energy saving by applying all the passive systems including heat recovery for winter period. The proportion of hours under 18C is 61% of winter period in basic case. By incorporating of thermal mass to the building structure, this proportion reduces to 57%, using heat recovery system additionally reduces it from 61% to 33%.

In order to evaluate year-round performance of atrium, passive energy strategies have been applied during the whole year. It can be achieved by controlling passive energy strategies by automation system. In case with thermal mass and automated night cooling during the whole year, energy saving is 14%. By using just effective shading devices, energy saving is almost same as in previous case. The results show that the application of all passive systems like shading, night ventilation and heat recovery strategies save 59% of total energy load in comparison with basic case.

After the evaluating the performance of atrium and total loads of atrium, the role of thermal performance of atrium on the performance and energy load of its adjacent space has been analyzed. Ground floor and second floor of an office block has been calculated. In order to understand the effect of different atrium strategies on adjacent space, various cases have been carried out like no atrium, with buffer atrium and plenum atrium.

The results show that the highest cooling and heating loads for two office floors are in case without atrium. By incorporating of non-optimized atrium to office buildings results in 61% reduction on cooling loads and in 8% reduction on heating load of offices. By optimizing the atrium, it is obtained 21% reduction on heating load. Operating of the plenum type reduce the cooling loads by 67% and heating loads by 55% compared with basic case. It is because of the effect of pre-cooled and -heated atrium on its adjacent building as a buffer space and recirculation of this air in air-conditioning system of the whole building. Consequently, total loads of office floors were reduced 40% by incorporation of non-optimized atrium with office building; 46% by optimizing atrium this atrium and; 62% by implementation the plenum atrium, which creates an effective ventilation connection between atrium and office floors. The results indicate that the plenum type has greatest energy saving potential compared to other types.

Furthermore, temperatures of atrium space have been calculated with two different relationship strategies between atrium and office blocks. These strategies are plenum and buffer atria. The calculations have been conducted for hottest two weeks during summer period and coldest two weeks during winter period. In summer and winter calculation, plenum type atrium has more comfortable conditions. The temperatures are lower during the summer period compared to buffer type, because of the pre-cooled air in atrium. In winter calculation, plenum atrium type has higher temperatures compared to buffer type. Temperature differences can be 3C. It is because of the pre-heated air coming to the atrium.

5. CONCLUSION

In the present work thermal performance of atrium buildings is evaluated. An estimating approach to thermal performance of atrium buildings is proposed then the application of this approach is achieved on a case study building.

Energy issue is a vital problem for the World. At present, the world's energy demand is by large covered by the use of fossil energy, which causes the environmental damage. Countries are trying to encourage for using the renewable energy sources. Moreover, they are looking for a way to reduce the energy consumption and to prevent our world from the immediate threat of climate change. Buildings are great energy consumers and have an important role on energy context so that they have a priority in the many countries policies.

Beside the construction cost, operating cost of buildings is very high. By saving energy in building in operating process can be very effective way to meet the future aim from environmental point of view. The building energy regulation in many countries is tried to improve by governments for this environmental threat on our world. In order to limit the energy consumption of buildings, the goals and precautions must be taken by designing building environmental friendly and energy conscious. Therefore, this issue is started to be taken into account in developed country.

Nowadays, the atria have gained popularity in commercial buildings. Designer and engineers have been started to design and build with an increasing frequency. Atriums have also been reported to increase the marketing values of many buildings, beside their psychological and physiological effects on increasing the morale of people. However, the major reason for incorporating the atrium spaces into the building is architectural but it should not be missed that the atrium buildings have a great energy potential. It should be realized and used as a design option to achieve energy efficiency.

In this work, thermal performance of atrium buildings is introduced and an approach is purposed. The application of the approach is shown on a case study building. The principles of this method are the reduction of the heating and cooling loads of atrium, the use of passive cooling and heating and enhanced control of automation system of the building. Furthermore, this study aims to reduce the heating and cooling loads of the adjacent office building of atrium by incorporating of atrium with true design concept.

According to the approach, major factors of thermal behaviour of atrium have been analyzed. Atriums thermal behaviour depends on a number of factors. The energy saving and the temperature conditions of an unheated atrium can vary quite widely and are dependent upon some configurations, which are a result of atrium's thermal and physical structure. These are type of atrium, external glazing properties of atrium and separated wall glazing properties of atrium which is between adjacent building and atrium. For example, for external glazing properties, it can be mentioned orientation, inclination and solar transmission. The outdoor climate is also an important factor that suggests the appropriate thermal strategy for atrium buildings. Because of this reason, the major thermal behaviours of atrium has been also analysed and given some examples of existing studies. After that, the passive solar design strategies responding different climate and type of atria have been clarified. Beside the passive solar techniques, it should be considered the mechanical equipment of atrium maintained compatible with passive systems. Furthermore, automation ways for maintaining passive solar strategies has been discussed in order to specify appropriate passive solar energy strategies responding to the different climatic conditions.

Passive control systems on building envelope, which complement the passive solar intelligent building approach, are the most important passive control strategies for energy efficiency and healthy building design. Sun control and natural ventilation control assist enhancing the interior air temperatures and consequently lower the building energy loads also contribute the occupant's comfort. External shading devices intercept solar beams before they enter the building and prevent overheating in the cooling season and also local discomfort. External shading is a good solution to all these problems. Natural night ventilation can be used to prevent overheating problems during summer. This ventilation technique, driven by wind and stack effect, cools down the exposed building structure at night and reduces and postpones consequently the temperature peaks by day.

Atria are not automatically energy-saving features. Therefore, it is very important for designer to be aware of the fundamentals of thermal performance of atrium to be able to design energy efficient atrium. It must be known, how the parameters affect the thermal behaviour of atrium. In computer based building simulations, these parameters can be applied using different variation Therefore, the critical parameters were analysed for atria to obtain best solution.

It is difficult to predict the thermal behavior of an atrium at the beginning the design process of the project. In order to deal with this complexity, the using computer modeling and simulation has been increased in recent years. However, there are also some difficulties by prediction of thermal performance of atria by using simulation tools due to their various parameters interacting with each other in a complex way. Therefore, there must be done some assumptions. In the present work the analysis was performed by TRNSYS simulation tool due to its flexible nature within the presence of hourly meteorological input data. TRNSYS has a modular system approach, which allows users to completely describe and monitor all interactions between the components.

After the definition of approach, it has been applied to a case study building located in Esslingen, Stuttgart, Germany. In the present study, firstly the current real building data has been analyzed, which is called as base case and does not include any passive solar energy strategies. Summer and winter period calculation has been conducted and very high free-floating temperatures and total energy load has been obtained. Especially extreme hottest and coldest day the free-floating temperatures can be very uncomfortable.

After the application of simulation on case study building, passive solar energy strategies has been analyzed, that has been theoretically discussed in previous chapter. The building has already been constructed so it wasn’t possible to apply all the energy efficient design strategies explained before. Therefore, passive solar intelligent concept has been applied to determination of the most suitable design concept for winter and summer by application and control of the natural ventilation system, shading system and thermal mass and heat recovery system for summer and winter period.

Natural night ventilation is an energy efficient way to improve thermal summer comfort. In the present study, natural ventilation is used at night which is working depending on the inside and outside temperature. Night ventilation cooled down the indoor air and they got closer to the outside temperature values. Installation of natural night ventilation to the building resulted in reduction total cooling energy demand compared to non ventilated case. In other word it provides lowest indoor air temperature which is closest to the set point temperature of the cooling system. In order to make the night ventilation effective, thermal mass has been incorporated to the design. Appropriate using of night cooling with thermal mass can reduce temperature gradient between thermal zones and reduce peak temperatures during the day because of its energy absorbing capacity. Using effective night ventilation system lowered down the proportion of hours over comfort condition from 78% to 48% for summer period. The difference on sensible cooling energy demand is between ventilated and non-ventilated cases as %31, as a result of the significant difference of the temperature values for these types.

For summer period external shading devices are proposed for the case study building as another passive energy parameter on building envelope and their effects are investigated. It is accepted in the present study that shading system is controlled by building automation system during the day and it is activated depending on the beam radiation on horizontal and atrium air temperature, during the cooling period. Simulation results indicate that with proper shading strategies, indoor air temperatures have been significantly reduced. Using shading devices lowered down the proportion of hours over comfort condition from 78% to 60% for summer period. Proper control of solar heat gain reduced consequently the cooling energy demand and the cooling load compared to non-shaded case. As simulation results indicate, 31% reduction in sensible cooling energy demand is achieved in summer cooling period by effective using of shading devices.

In order to prevent overheating in atrium effectively during cooling season, all of the passive strategies must be operated compatible. For that reason, the passive strategies, has been applied as combined case to prevent overheating and reduce cooling energy demand. Simulation results indicate that with proper combination of all passive strategies, indoor air temperatures have been significantly reduced. Pssive energy strategies lowered down the proportion of hours over comfort condition from 78% to 20% for summer period. Introduction of combination of natural night ventilation with thermal mass and shading to the building reduced consequently the cooling energy demand and the cooling load compared to basic case. As simulation results indicate, 50% reduction in sensible cooling energy demand is achieved in summer cooling period by effective combination of passive means. It is quite effective compared with only ventilated, only shaded and basic case.

In winter, some useful precautions have been conducted in order to save energy and increase atrium temperatures. Thermal mass, pre-heated ventilation or heat-recovery systems, useful winter shading and low-e glazing on the façade and roof of atria have been applied and analyzed in winter calculations. helps to increase temperatures about 2K approximately compared with base case. In order to reduce ventilation losses, heat recovery system has been implemented to the building ventilation system. Ventilation by heat recovery results in increasing of temperature about 5K. Operating the shading system doesn't change the heating loads. However, it has a great effect on preventing the high solar radiation during the early and late winter. Furthermore, improvement on ventilation by heat recovery keeps temperatures from reaching high values in warm days during early and late winter, whilst increasing it close to set temperature of heating system it can be achieved by adjusting the ventilation mode depending on the outside temperature. Using of thermal mass into the building structure lowered down the proportion of hours under comfort condition from 61% to 57% for summer period and introduction of heat recovery system to the building ventilation system additionally lowered down the proportion of hours under comfort condition from 61% to 33% for summer period. This results in 61% reduction total cooling energy demand consequently. The results shows that the combined case with the all passive means reduce significantly heating loads. However the ventilation losses have great impact on heating loads. Therefore, heat recovery systems are considerable for winter design strategies.

The effect of atrium on thermal performance and energy loads of its adjacent building is very important. The incorporation of an atrium into the building can lead to increase energy consumption of the whole building. Atria are not automatically energy savers and it is significant to be aware of effect of the atrium on adjacent building. Therefore, in second step calculation, it has been obtained the energy demand of two office floor by applying various atrium conditions, in order to evaluate effect of atrium on energy consumption of its adjacent office building. There will be carried out cases with no-atrium, with buffer atrium and plenum case atrium. Highest total loads for two office floors have been obtained in case without atrium. Incorporation of non-optimized atrium with office building resulted in 40% reduction on total loads of office floors. By optimizing atrium, it is achieved a 46% reduction. By using plenum atrium, which creates an effective ventilation connection between atrium and offices can result in 62% reduction on total cooling loads.

These results show that the energy savings can be achieved by applying and intelligent controlling of passive solar strategies in atrium building and also in its adjacent building. The result of the whole calculation shows that the application the strategies is not only sufficient, but also the controlling of it according to the various climate condition can be more effective in terms of energy saving. Reducing the thermal load in building by means of passive solar methods can also reduce construction costs, bring significant amounts of savings by making more energy efficient buildings and reduce the enormous impact of buildings on the environment. It must be emphasized, that the atrium can behave variously in different time of the year. Therefore, atria must be designed by passive solar energy strategies adjusted seasonally. It can be achieved by intelligent building management systems.

It is obvious that atrium application requires a series of passive strategies for better energy performance. Therefore, the final decision for a building design with atrium should be done after the life-cycle economic evaluation. Furthermore, this economic evaluation should certainly include the lighting energy analysis to mention of energy efficient atrium design. In another climate for better energy performance, there may be different strategies and may be still the energy performance will not be good enough, for example in hot climates. Then, there may be defined the method of passive means according to this climate differently. For atria, it is very difficult to specify a concrete design guide. Because they are influenced greatly by outdoor conditions and many different processes like thermal or air flow has been interact, because of its complex structure and form. Therefore, there is a great need to use the computer simulation program, suitable for atria.

For future studies, the air flow modeling programs can be coupled to the thermal energy simulation program. So, the effect of complex air flow pattern with incorporation of thermal process can be seen and better energy performance for atria could be evaluated.

Furthermore, application of other passive cooling and heating strategies based on the other natural resources can be implemented to the operating system of atrium. For instance, geothermal energy can cool and heat the supply air to the atrium which is used nowadays on atrium systems frequently. In real building, structural member cooling on the some part of adjacent walls and underfloor cooling and heating system is currently operating. The energy demand for operating this system is covered by about 70% from natural resources.

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APPENDIX A

One of the TRNBuild output file of the case study simulation can be seen below as an example. Properties of the building are given in special TRNBuild format. Transfer function coefficients which are necessary for the whole building simulation is calculated by TRNBuild and the results can be seen end of this section.

****
****
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* TRNBuild 1.0.84

****
****
****

* BUILDING DESCRIPTIONS FILE TRNSYS

* FOR BUILDING:

C:\Program Files\Trnsys16\MyProjects\FESTO_with office_summer_full.inf

* GET BY WORKING WITH TRNBuild 1.0 for Windows

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* C o m m e n t s

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*--
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* P r o j e c t

*--
----

*+++ PROJECT

*+++ TITLE=FESTO

*+++ DESCRIPTION=UNDEFINED

*+++ CREATED=UNDEFINED

*+++ ADDRESS=UNDEFINED

*+++ CITY=UNDEFINED

*+++ SWITCH=UNDEFINED

*---
----

* P r o p e r t i e s

*---

PROPERTIES

DENSITY=1.204 : CAPACITY=1.012 : HVAPOR=2454.0 : SIGMA=2.041e-007 : RTEMP=293.15

*--- alpha calculation -------------------

KFLOORUP=7.2 : EFLOORUP=0.31 : KFLOORDOWN=3.888 : EFLOORDOWN=0.31

KCEILUP=7.2 : ECEILUP=0.31 : KCEILDOWN=3.888 : ECEILDOWN=0.31

KVERTICAL=5.76 : EVERTICAL=0.3

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TYPES

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*

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* L a y e r s

*---

LAYER HEAVYCONCR

CONDUCTIVITY= 6.12 : CAPACITY= 0.84 : DENSITY= 2200

LAYER GRANITEGNE

CONDUCTIVITY= 12.56 : CAPACITY= 0.84 : DENSITY= 2800

LAYER ANHYDRITES

CONDUCTIVITY= 4.32 : CAPACITY= 1 : DENSITY= 2100

LAYER UNTERBOEDE

CONDUCTIVITY= 1.69 : CAPACITY= 1 : DENSITY= 1400

LAYER CONCRETE_SLAB

CONDUCTIVITY= 4.068 : CAPACITY= 1 : DENSITY= 1400

LAYER MINERALD04

CONDUCTIVITY= 0.14 : CAPACITY= 0.9 : DENSITY= 80

LAYER FICTITIOUS

RESISTANCE= 0.044111

LAYER GLAS

CONDUCTIVITY= 2.88 : CAPACITY= 1 : DENSITY= 2500

LAYER PLASTERBOA

CONDUCTIVITY= 0.576 : CAPACITY= 0.84 : DENSITY= 950

*---

* I n p u t s

*---

INPUTS SHADING_FASSADE SHADING_DACH NIGHTCOOLING SOLLTEMP_SOMMER TEMP0 TEMP1 TEMP2 TEMP3

*---

* S c h e d u l e s

*---

SCHEDULE WEEK

HOURS =0.0 5.0 20.0 24.0

VALUES=0 1. 0 0

SCHEDULE WEEKEND

HOURS =0.0 1.0 24.0

VALUES=0 0 0

SCHEDULE OCCUPANCY

DAYS=1 2 3 4 5 6 7

HOURLY=WEEK WEEK WEEK WEEK WEEK WEEK WEEKEND

*---

* W a l l s

*---

WALL INTERIOR_WALL

LAYERS = GLAS MINERALD04

THICKNESS= 0.005 0.016

ABS-FRONT= 0.6 : ABS-BACK= 0.6

HFRONT = 11 : HBACK= 11

WALL VIRTUAL_SLAB

LAYERS = FICTITIOUS

THICKNESS= 0

ABS-FRONT= 0 : ABS-BACK= 0

HFRONT = 11 : HBACK= 11

WALL BODENWITHOUT

LAYERS = GRANITEGNE UNTERBOEDE ANHYDRITES CONCRETE_SLAB ANHYDRITES MINERALD04

THICKNESS= 0.03 0.005 0.02 0.18 0.01 0.16

ABS-FRONT= 0.6 : ABS-BACK= 0.6

HFRONT = 11 : HBACK= 11

WALL INTERN_MASSIVE

LAYERS = HEAVYCONCR

THICKNESS= 0.18

ABS-FRONT= 0.6 : ABS-BACK= 0.6

HFRONT = 11 : HBACK= 11

WALL STAIRCASEWALL

LAYERS = HEAVYCONCR

THICKNESS= 0.3

ABS-FRONT= 0.6 : ABS-BACK= 0.6

HFRONT = 11 : HBACK= 11

WALL INT_BOARD

LAYERS = PLASTERBOA

THICKNESS= 0.12

ABS-FRONT= 0.6 : ABS-BACK= 0.6

HFRONT = 11 : HBACK= 11

WALL DECKE

LAYERS = GRANITEGNE UNTERBOEDE ANHYDRITES CONCRETE_SLAB ANHYDRITES

THICKNESS= 0.05 0.005 0.02 0.18 0.01

ABS-FRONT= 0.6 : ABS-BACK= 0.6

HFRONT = 11 : HBACK= 11

*---

* W i n d o w s

*---

WINDOW FOLIE

WINID=15009 : HINSIDE=11 : HOUTSIDE=64 : SLOPE=90 : SPACID=1 : WWID=0.77 : WHEIG=1.08 : FFRAME=0.15 : UFRAME=3 : ABSFRAME=0.6 : RISHADE=0 : RESHADE=0 : REFLISHADE=0.5 : REFLOSHADE=0.5 : CCISHADE=0.5

WINDOW FASSADE1

WINID=2104 : HINSIDE=11 : HOUTSIDE=64 : SLOPE=90 : SPACID=1 : WWID=0.77 : WHEIG=1.08 : FFRAME=0.15 : UFRAME=5 : ABSFRAME=0.6 : RISHADE=0 : RESHADE=0 : REFLISHADE=0.5 : REFLOSHADE=0.5 : CCISHADE=0.5

WINDOW GABLE1

WINID=2004 : HINSIDE=11 : HOUTSIDE=64 : SLOPE=90 : SPACID=1 : WWID=0.77 : WHEIG=1.08 : FFRAME=0.15 : UFRAME=8.17 : ABSFRAME=0.6 : RISHADE=0 : RESHADE=0 : REFLISHADE=0.5 : REFLOSHADE=0.5 : ;

CCISHADE=0.5

WINDOW ADJACENTWIN

WINID=13001 : HINSIDE=11 : HOUTSIDE=11 : SLOPE=90 : SPACID=1 : WWID=0.77 : WHEIG=1.08 : FFRAME=0.1 : UFRAME=8.17 : ABSFRAME=0.6 : RISHADE=0 : RESHADE=0 : REFLISHADE=0.5 : REFLOSHADE=0.5 : ;

CCISHADE=0.5

*---

* D e f a u l t G a i n s

*---

GAIN PERS_ISO05

CONVECTIVE=216 : RADIATIVE=108 : HUMIDITY=0.139

GAIN LIGHT01_01

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 CONVECTIVE=0 : RADIATIVE=18504 : HUMIDITY=0
GAIN LIGHT01_02
 CONVECTIVE=0 : RADIATIVE=18504 : HUMIDITY=0
GAIN LIGHT01_03
 CONVECTIVE=0 : RADIATIVE=18504 : HUMIDITY=0
GAIN LIGHT01_04
 CONVECTIVE=0 : RADIATIVE=18504 : HUMIDITY=0
GAIN PERS_ISO04
 CONVECTIVE=180 : RADIATIVE=90 : HUMIDITY=0.11
GAIN COMPUTER04
 CONVECTIVE=690 : RADIATIVE=138 : HUMIDITY=0
GAIN LIGHT02_05
 CONVECTIVE=0 : RADIATIVE=24552 : HUMIDITY=0
GAIN LIGHT02_06
 CONVECTIVE=0 : RADIATIVE=24552 : HUMIDITY=0
*----------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------------------------------
* O t h e r  G a i n s
*----------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------------------------------
*----------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------------------------------
* C o m f o r t
*----------------------------------------------------------------------------------------------------
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*----------------------------------------------------------------------------------------------------
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* I n f i l t r a t i o n
*----------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------------------------------
```

```
INFILTRATION INFILATRIUM
 AIRCHANGE=INPUT 2.4*NIGHTCOOLING+0.1
INFILTRATION INFIL_NORMAL
 AIRCHANGE=0.1
INFILTRATION INFIL_OFFICE
 AIRCHANGE=SCHEDULE -0.285*OCCUPANCY+0.95
*---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
* V e n t i l a t i o n
*---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
VENTILATION ATRIUM_ANLAGE
 TEMPERATURE=OUTSIDE
 AIRCHANGE=SCHEDULE 1.45*OCCUPANCY
 HUMIDITY=OUTSIDE
VENTILATION GEBAEUDE_ANLAGE
 TEMPERATURE=INPUT 1*TEMP0
 AIRCHANGE=SCHEDULE 0.285*OCCUPANCY
 HUMIDITY=OUTSIDE
VENTILATION VENT1
 TEMPERATURE=INPUT 1*TEMP0
 AIRCHANGE=SCHEDULE 1.2*OCCUPANCY+0.3
 HUMIDITY=OUTSIDE
VENTILATION VENT2
 TEMPERATURE=INPUT 1*TEMP1
 AIRCHANGE=SCHEDULE 1.2*OCCUPANCY+0.3
 HUMIDITY=OUTSIDE
VENTILATION VENT3
```

```
 TEMPERATURE=INPUT 1*TEMP2
 AIRCHANGE=SCHEDULE 1*OCCUPANCY+0.3
 HUMIDITY=OUTSIDE
*---------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------
* C o o l i n g
*---------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------
COOLING COOL_0
 ON=SCHEDULE -6*OCCUPANCY+28
 POWER=999999999
 HUMIDITY=100
*---------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------
* H e a t i n g
*---------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------
*
*---------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------
* Z o n e s
*---------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------
ZONES ZONE0 ZONE1 ZONE2 ZONE3 OFFICE0 OFFICE2
*---------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------
* O r i e n t a t i o n s
*---------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------
ORIENTATIONS NORTH SOUTH EAST WEST HORIZONTAL NNW SWW
SSE
```

*

*++
+++
+++
++++++++++++++++++++

BUILDING

*++
+++
+++
++++++++++++++++++++

*

*---
----

* Z o n e ZONE0 / A i r n o d e ZONE0

*---

ZONE ZONE0

AIRNODE ZONE0

WINDOW=FASSADE1 : SURF= 2 : AREA= 114.8 : EXTERNAL : ORI=NORTH : FSKY=0.5 : ESHADE=INPUT 0.75*SHADING_FASSADE

WINDOW=ADJACENTWIN : SURF= 34 : AREA= 131.2 : ADJACENT=OFFICE0 : BACK : COUPL=3254 : ORI=WEST

WALL =INTERIOR_WALL : SURF= 1 : AREA= 146 : BOUNDARY=SCHEDULE -6*OCCUPANCY+28

WALL =VIRTUAL_SLAB : SURF= 10 : AREA= 100 : ADJACENT=ZONE1 : BACK

WALL =BODENWITHOUT : SURF= 24 : AREA= 1028 : BOUNDARY=23

WALL =INTERN_MASSIVE : SURF= 4 : AREA= 249 : INTERNAL

WALL =INTERN_MASSIVE : SURF= 3 : AREA= 57.2 : BOUNDARY=SCHEDULE -3*OCCUPANCY+26

REGIME

GAIN = PERS_ISO05 : SCALE= SCHEDULE 25*OCCUPANCY

GAIN = LIGHT01_01 : SCALE= SCHEDULE 1*OCCUPANCY

INFILTRATION= INFILATRIUM

VENTILATION = ATRIUM_ANLAGE

CAPACITANCE = 5058 : VOLUME= 4215 : TINITIAL= 20 : PHINITIAL= 50 : WCAPR= 1

*---

* Z o n e ZONE1 / A i r n o d e ZONE1

*---

ZONE ZONE1

AIRNODE ZONE1

WINDOW=FASSADE1 : SURF= 6 : AREA= 114.8 : EXTERNAL : ORI=NORTH : FSKY=0.5 : ESHADE=INPUT 0.75*SHADING_FASSADE

WALL =INTERIOR_WALL : SURF= 7 : AREA= 277 : BOUNDARY=SCHEDULE -4*OCCUPANCY+26

WALL =VIRTUAL_SLAB : SURF= 9 : AREA= 100 : ADJACENT=ZONE0 : FRONT : COUPL=INPUT 12600*NIGHTCOOLING

WALL =VIRTUAL_SLAB : SURF= 5 : AREA= 300 : ADJACENT=ZONE2 : FRONT

WALL =INTERN_MASSIVE : SURF= 25 : AREA= 249 : INTERNAL

WALL =INTERN_MASSIVE : SURF= 8 : AREA= 57.2 : BOUNDARY=SCHEDULE -3*OCCUPANCY+26

REGIME

GAIN = PERS_ISO05 : SCALE= SCHEDULE 4*OCCUPANCY

GAIN = LIGHT01_02 : SCALE= SCHEDULE 1*OCCUPANCY

INFILTRATION= INFIL_NORMAL

VENTILATION = VENT1

CAPACITANCE = 5058 : VOLUME= 4215 : TINITIAL= 20 : PHINITIAL= 50 : WCAPR= 1

*---

* Z o n e ZONE2 / A i r n o d e ZONE2

*---

ZONE ZONE2

AIRNODE ZONE2

WINDOW=FASSADE1 : SURF= 11 : AREA= 114.8 : EXTERNAL : ORI=NORTH : FSKY=0.5 : ESHADE=INPUT 0.75*SHADING_FASSADE

WINDOW=ADJACENTWIN : SURF= 47 : AREA= 131.2 : ADJACENT=OFFICE2 : BACK : COUPL=3254 : ORI=WEST

WALL =INTERIOR_WALL : SURF= 12 : AREA= 146 : BOUNDARY=SCHEDULE -6*OCCUPANCY+28

WALL =VIRTUAL_SLAB : SURF= 14 : AREA= 300 : ADJACENT=ZONE1 : BACK : COUPL=INPUT 12600*NIGHTCOOLING

WALL =VIRTUAL_SLAB : SURF= 15 : AREA= 700 : ADJACENT=ZONE3 : FRONT

WALL =INTERN_MASSIVE : SURF= 26 : AREA= 249 : INTERNAL

WALL =INTERN_MASSIVE : SURF= 13 : AREA= 57.2 : BOUNDARY=SCHEDULE -3*OCCUPANCY+26

REGIME

GAIN = PERS_ISO05 : SCALE= SCHEDULE 4*OCCUPANCY

GAIN = LIGHT01_03 : SCALE= SCHEDULE 1*OCCUPANCY

INFILTRATION= INFIL_NORMAL

VENTILATION = VENT2

CAPACITANCE = 5058 : VOLUME= 4215 : TINITIAL= 20 : PHINITIAL= 50 : WCAPR= 1

*---

* Z o n e ZONE3 / A i r n o d e ZONE3

*---

ZONE ZONE3

AIRNODE ZONE3

WINDOW=FASSADE1 : SURF= 17 : AREA= 239.4 : EXTERNAL : ORI=NORTH : FSKY=0.5 : ESHADE=INPUT 0.75*SHADING_FASSADE

WINDOW=GABLE1 : SURF= 20 : AREA= 50.7 : EXTERNAL : ORI=WEST : FSKY=0.5 : ESHADE=INPUT 0.75*SHADING_FASSADE

WINDOW=GABLE1 : SURF= 21 : AREA= 50.7 : EXTERNAL : ORI=EAST : FSKY=0.5 : ESHADE=INPUT 0.75*SHADING_FASSADE

WINDOW=GABLE1 : SURF= 22 : AREA= 26.1 : EXTERNAL : ORI=SOUTH : FSKY=0.5 : ESHADE=INPUT 0.75*SHADING_FASSADE

WINDOW=FOLIE : SURF= 23 : AREA= 933.7 : EXTERNAL : ORI=HORIZONTAL : FSKY=1 : ESHADE=INPUT 0.5*SHADING_DACH

WALL =VIRTUAL_SLAB : SURF= 16 : AREA= 700 : ADJACENT=ZONE2 : BACK : COUPL=INPUT 12600*NIGHTCOOLING

WALL =INTERIOR_WALL : SURF= 18 : AREA= 277 : BOUNDARY=SCHEDULE -4*OCCUPANCY+26

WALL =INTERN_MASSIVE : SURF= 27 : AREA= 316 : INTERNAL

WALL =INTERN_MASSIVE : SURF= 19 : AREA= 57.2 : BOUNDARY=SCHEDULE -3*OCCUPANCY+26

REGIME

GAIN = PERS_ISO05 : SCALE= SCHEDULE 4*OCCUPANCY

GAIN = LIGHT01_04 : SCALE= SCHEDULE 1*OCCUPANCY

INFILTRATION= INFIL_NORMAL

VENTILATION = VENT3

CAPACITANCE = 8400 : VOLUME= 7000 : TINITIAL= 20 : PHINITIAL= 50 : WCAPR= 1

*---

* Z o n e OFFICE0 / A i r n o d e OFFICE0

*---

ZONE OFFICE0

AIRNODE OFFICE0

WINDOW=FASSADE1 : SURF= 30 : AREA= 61.9 : EXTERNAL : ORI=SWW : FSKY=0.5

WINDOW=FASSADE1 : SURF= 31 : AREA= 239 : EXTERNAL : ORI=NNW : FSKY=0.5

WINDOW=FASSADE1 : SURF= 32 : AREA= 29.1 : EXTERNAL : ORI=SSE : FSKY=0.5

WINDOW=ADJACENTWIN : SURF= 33 : AREA= 131.2 : ADJACENT=ZONE0 : FRONT : ORI=WEST

WALL =BODENWITHOUT : SURF= 28 : AREA= 682 : BOUNDARY=23

WALL =STAIRCASEWALL : SURF= 29 : AREA= 104.5 : BOUNDARY=SCHEDULE -3*OCCUPANCY+26

WALL =INT_BOARD : SURF= 35 : AREA= 96.4 : BOUNDARY=IDENTICAL

WALL =INT_BOARD : SURF= 36 : AREA= 249 : INTERNAL

WALL =DECKE : SURF= 37 : AREA= 682 : BOUNDARY=IDENTICAL

REGIME

GAIN = PERS_ISO04 : SCALE= SCHEDULE 60*OCCUPANCY

GAIN = COMPUTER04 : SCALE= SCHEDULE 30*OCCUPANCY

GAIN = LIGHT02_05 : SCALE= SCHEDULE 1*OCCUPANCY

INFILTRATION= INFIL_OFFICE

VENTILATION = GEBAEUDE_ANLAGE

COOLING = COOL_0

CAPACITANCE = 3355.2 : VOLUME= 2796 : TINITIAL= 20 : PHINITIAL= 50 : WCAPR= 1

*---

* Z o n e OFFICE2 / A i r n o d e OFFICE2

*---

ZONE OFFICE2

AIRNODE OFFICE2

WINDOW=FASSADE1 : SURF= 38 : AREA= 61.9 : EXTERNAL : ORI=SWW : FSKY=0.5

WINDOW=FASSADE1 : SURF= 39 : AREA= 239 : EXTERNAL : ORI=NNW : FSKY=0.5

WINDOW=FASSADE1 : SURF= 40 : AREA= 29.1 : EXTERNAL : ORI=SSE : FSKY=0.5

WINDOW=ADJACENTWIN : SURF= 41 : AREA= 131.2 : ADJACENT=ZONE2 : FRONT : ORI=WEST

WALL =DECKE : SURF= 42 : AREA= 682 : BOUNDARY=IDENTICAL

WALL =STAIRCASEWALL : SURF= 43 : AREA= 104.5 : BOUNDARY=SCHEDULE -3*OCCUPANCY+26

WALL =INT_BOARD : SURF= 44 : AREA= 96.4 : BOUNDARY=IDENTICAL

WALL =INT_BOARD : SURF= 45 : AREA= 249 : INTERNAL

WALL =DECKE : SURF= 46 : AREA= 682 : BOUNDARY=IDENTICAL

REGIME

GAIN = PERS_ISO04 : SCALE= SCHEDULE 60*OCCUPANCY

GAIN = COMPUTER04 : SCALE= SCHEDULE 30*OCCUPANCY

GAIN = LIGHT02_06 : SCALE= SCHEDULE 1*OCCUPANCY

INFILTRATION= INFIL_OFFICE

VENTILATION = GEBAEUDE_ANLAGE

COOLING = COOL_0

CAPACITANCE = 3355.2 : VOLUME= 2796 : TINITIAL= 20 : PHINITIAL= 50 : WCAPR= 1

*---

* O u t p u t s

*---

OUTPUTS

TRANSFER : TIMEBASE=1.000

AIRNODES = ZONE0 ZONE1 ZONE2 ZONE3 OFFICE0 OFFICE2

NTYPES = 1 : TAIR - air temperature of zone

AIRNODES = OFFICE0 OFFICE2 ZONE0

NTYPES = 31 : QCOOL - sensible cooling demand of zone (positive values)

*---

* E n d

*---

END

***** WALL TRANSFERFUNCTION CALCULATIONS *****

---------- WALL TYPE INTERIOR_WALL ----------

THERMAL CONDUCTANCE, U= 8.61907 kJ/h m2K; k-Wert= 1.70161 W/m2K

TRANSFERFUNCTION COEFFICIENTS

K	A	B	C	D
0	9.0098330E+00	8.3316910E+00	2.1305549E+01	1.0000000E+00
1	-3.9076499E-01	2.8737695E-01	-1.2686481E+01	
SUM	8.6190680E+00	8.6190680E+00	8.6190680E+00	1.0000000E+00

---------- WALL TYPE VIRTUAL_SLAB ----------

THERMAL CONDUCTANCE, U= 22.67008 kJ/h m2K; k-Wert= 3.04137 W/m2K

TRANSFERFUNCTION COEFFICIENTS

K	A	B	C	D
0	2.2670083E+01	2.2670083E+01	2.2670083E+01	1.0000000E+00
SUM	2.2670083E+01	2.2670083E+01	2.2670083E+01	1.0000000E+00

---------- WALL TYPE BODENWITHOUT ----------

THERMAL CONDUCTANCE, U= 0.83375 kJ/h m2K; k-Wert= 0.22282 W/m2K

TRANSFERFUNCTION COEFFICIENTS

K	A	B	C	D
0	3.5824932E+00	2.2478087E-08	1.3547031E+02	1.0000000E+00
1	-8.4648992E+00	2.6136800E-04	-3.3750206E+02	-1.7772943E+00
2	7.0721717E+00	6.3343245E-03	3.0093242E+02	1.0267102E+00
3	-2.5182796E+00	1.6495053E-02	-1.1704370E+02	-2.2608587E-01
4	3.8134989E-01	8.5295291E-03	1.9298231E+01	1.6200840E-02
5	-2.0564381E-02	9.9525086E-04	-1.1455248E+00	-3.8358495E-04
6	3.6971403E-04	2.4656023E-05	2.3043266E-02	1.3685785E-06
7	-1.1621149E-06	1.0889499E-07	-7.2680115E-05	
8	7.5911365E-10	6.8087838E-11	5.5867466E-08	

SUM	3.2640312E-02	3.2640312E-02	3.2640312E-02	3.9148676E-02

---------- WALL TYPE INTERN_MASSIVE ----------

THERMAL CONDUCTANCE, U= 34.00000 kJ/h m2K; k-Wert= 3.62473 W/m2K

TRANSFERFUNCTION COEFFICIENTS

K	A	B	C	D
0	1.2000075E+02	2.8432985E+00	1.2000075E+02	1.0000000E+00
1	-1.1598489E+02	1.4744129E+01	-1.1598489E+02	-3.8245345E-01
2	1.7374694E+01	3.5990935E+00	1.7374694E+01	6.4916009E-03
3	-1.7329707E-01	3.0748872E-02	-1.7329707E-01	-7.3579938E-07
4	1.4079176E-05	1.9093353E-06	1.4079176E-05	
SUM	2.1217272E+01	2.1217272E+01	2.1217272E+01	6.2403741E-01

---------- WALL TYPE STAIRCASEWALL ----------

THERMAL CONDUCTANCE, U= 20.40000 kJ/h m2K; k-Wert= 2.88625 W/m2K

TRANSFERFUNCTION COEFFICIENTS

K	A	B	C	D
0	1.2000014E+02	1.6512178E-02	1.2000014E+02	1.0000000E+00

1	-1.8676537E+02	1.1706481E+00	-1.8676537E+02	-9.7058995E-01
2	8.0794911E+01	2.6607769E+00	8.0794911E+01	2.0108906E-01
3	-9.6879514E+00	6.9521472E-01	-9.6879514E+00	-6.8096277E-03
4	2.2241477E-01	2.0464009E-02	2.2241477E-01	1.9338584E-05
5	-4.8342021E-04	4.3891988E-05	-4.8342021E-04	
6	4.3980179E-08	3.6173466E-09	4.3980179E-08	
SUM	4.5636598E+00	4.5636598E+00	4.5636598E+00	2.2370881E-01

---------- WALL TYPE INT_BOARD ----------

THERMAL CONDUCTANCE, U= 4.80000 kJ/h m2K; k-Wert= 1.08696 W/m2K

TRANSFERFUNCTION COEFFICIENTS

K	A	B	C	D
0	2.4191776E+01	2.6202525E-02	2.4191776E+01	1.0000000E+00
1	-3.2556541E+01	6.8982419E-01	-3.2556541E+01	-7.5998832E-01
2	1.0701362E+01	7.9117821E-01	1.0701362E+01	9.3276510E-02
3	-7.4732821E-01	8.7039586E-02	-7.4732821E-01	-1.0162299E-03
4	5.6401739E-03	6.6247451E-04	5.6401739E-03	3.6277682E-07
5	-1.5601245E-06	1.5975439E-07	-1.5601245E-06	
SUM	1.5949071E+00	1.5949071E+00	1.5949071E+00	3.3227232E-01

---------- WALL TYPE DECKE ----------

THERMAL CONDUCTANCE, U= 17.20232 kJ/h m2K; k-Wert= 2.63662 W/m2K

TRANSFERFUNCTION COEFFICIENTS

K	A	B	C	D
0	9.2200512E+01	4.8006207E-02	1.6086502E+02	1.0000000E+00
1	-1.2866743E+02	1.9784862E+00	-2.4359071E+02	-7.8056856E-01
2	4.5966970E+01	3.0699011E+00	9.7117313E+01	1.0834696E-01
3	-3.9422726E+00	5.0292888E-01	-8.8894704E+00	-1.8380405E-03
4	4.9226180E-02	7.6342895E-03	1.0488050E-01	1.9707113E-06
5	-4.3309580E-05	6.5912133E-06	-7.3930256E-05	
SUM	5.6069633E+00	5.6069633E+00	5.6069633E+00	3.2594233E-01

************* REQUIRED INPUTS *************

*InpNR Label UNIT INPUT DESCRIPTION

* 1 TAMB C AMBIENT TEMPERATURE

* 2 ARELHUM % RELATIVE AMBIENT HUMIDITY

* 3 TSKY C FIKTIVE SKY TEMPERATURE

* 4 ITNORTH kJ/hr.m^2 INCIDENT RADIATION FOR ORIENTATION NORTH

* 5 ITSOUTH kJ/hr.m^2 INCIDENT RADIATION FOR ORIENTATION SOUTH

* 6 ITEAST kJ/hr.m^2 INCIDENT RADIATION FOR ORIENTATION EAST

* 7 ITWEST kJ/hr.m^2 INCIDENT RADIATION FOR ORIENTATION WEST

* 8 ITHORIZONT kJ/hr.m^2 INCIDENT RADIATION FOR ORIENTATION HORIZONTAL

* 9 ITNNW kJ/hr.m^2 INCIDENT RADIATION FOR ORIENTATION NNW

* 10 ITSWW kJ/hr.m^2 INCIDENT RADIATION FOR ORIENTATION SWW

* 11 ITSSE kJ/hr.m^2 INCIDENT RADIATION FOR ORIENTATION SSE

* 12 IBNORTH kJ/hr.m^2 INCIDENT BEAM RADIATION FOR ORIENTATION NORTH

* 13 IBSOUTH kJ/hr.m^2 INCIDENT BEAM RADIATION FOR ORIENTATION SOUTH

* 14 IBEAST kJ/hr.m^2 INCIDENT BEAM RADIATION FOR ORIENTATION EAST

* 15 IBWEST kJ/hr.m^2 INCIDENT BEAM RADIATION FOR ORIENTATION WEST

* 16 IBHORIZONT kJ/hr.m^2 INCIDENT BEAM RADIATION FOR ORIENTATION HORIZONTAL

* 17 IBNNW kJ/hr.m^2 INCIDENT BEAM RADIATION FOR ORIENTATION NNW

* 18 IBSWW kJ/hr.m^2 INCIDENT BEAM RADIATION FOR ORIENTATION SWW

* 19 IBSSE kJ/hr.m^2 INCIDENT BEAM RADIATION FOR ORIENTATION SSE

* 20 AINORTH degrees ANGLE OF INCIDENCE FOR ORIENTATION NORTH

* 21 AISOUTH degrees ANGLE OF INCIDENCE FOR ORIENTATION SOUTH

* 22 AIEAST degrees ANGLE OF INCIDENCE FOR ORIENTATION EAST

* 23 AIWEST degrees ANGLE OF INCIDENCE FOR ORIENTATION WEST

* 24 AIHORIZONT degrees ANGLE OF INCIDENCE FOR ORIENTATION HORIZONTAL

* 25 AINNW degrees ANGLE OF INCIDENCE FOR ORIENTATION NNW

* 26 AISWW   degrees   ANGLE OF INCIDENCE FOR ORIENTATION SWW

* 27 AISSE   degrees   ANGLE OF INCIDENCE FOR ORIENTATION SSE

* 28 SHADING_FA any   INPUT

* 29 SHADING_DA any   INPUT

* 30 NIGHTCOOLI any   INPUT

* 31 SOLLTEMP_S any   INPUT

* 32 TEMP0   any   INPUT

* 33 TEMP1   any   INPUT

* 34 TEMP2   any   INPUT

* 35 TEMP3   any   INPUT

************* DESIRED OUTPUTS *************

*OutNr Label   Unit   ZNr Zone   Surface   OUTPUT DESCRIPTION

*   1 TAIR   1 C   1 ZONE0   air temperature of zone

*   2 TAIR   2 C   2 ZONE1   air temperature of zone

*   3 TAIR   3 C   3 ZONE2   air temperature of zone

*   4 TAIR   4 C   4 ZONE3   air temperature of zone

*   5 TAIR   5 C   5 OFFICE0   air temperature of zone

*   6 TAIR   6 C   6 OFFICE2   air temperature of zone

*   7 QCOOL 5 kJ/hr   5 OFFICE0   cooling demand

*   8 QCOOL 6 kJ/hr   6 OFFICE2   cooling demand

*   9 QCOOL 1 kJ/hr   1 ZONE0   cooling demand

*** THERMAL CONDUCTANCE OF USED WALL TYPES ***

WALL INTERIOR_WALL	k-Wert=	1.702 W/m2K
WALL VIRTUAL_SLAB	k-Wert=	3.041 W/m2K
WALL BODENWITHOUT	k-Wert=	0.223 W/m2K
WALL INTERN_MASSIVE	k-Wert=	3.625 W/m2K
WALL STAIRCASEWALL	k-Wert=	2.886 W/m2K
WALL INT_BOARD	k-Wert=	1.087 W/m2K
WALL DECKE	k-Wert=	2.637 W/m2K

RESUME

She was born in 1981 in Istanbul. She finished the high school in Üsküdar Anadolu Lisesi, Istanbul, 1999. She earned her bachelors degree in Architecture in 2004 from Dokuz Eylül University. Same year, she started her master’s degree in Environmental Control and Building Technologies Program in Istanbul Technical University. She studied in Stuttgart University of Applied Sciences during 2005-2006 in the framework of Erasmus Exchange Program.