Effect of Atrium on Thermal Comfort

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ABSTRACT

Regarding sustainable development and energy consciousness in architectural area, a primary concern of this research is to achieve a thermal comfort environment in atria which lie in a transition between composite and hot-humid climates, hence to improve thermally the internal built environment and promote optimum use of passive atrium performance.

The present thesis is based on a quantitative approach and has focused on the thermal performance of an educational atrium building. Coloured building, which is the field study, is a part of the architecture department at Eastern Mediterranean University in Famagusta, North Cyprus. Overheating is the main problem of its existing atrium that has a profound impact on the thermal and energy performance of the building. To support the theoretical framework and discover the gap, brief reviews of similar recent researches done so far are included. In combination with the data gathered, observation, measurements on site, photography, and maps are also collected; data used was validated to create dynamic thermal modelling of the existing atrium building via TAS software so to estimate the comfort zone in terms of thermal conditions.

The comparison of Coloured building simulations confirmed that indoor thermal comfort is directly affected by external temperature, internal air circulation, solar radiation, relative humidity, and the height of the atrium building. Consequently, the most suitable atrium form in a hot humid climate, which can provide comfort zone for its occupants, would be the one with a three to five meter height for atrium tower, having proper outlets on the highest part of the atrium tower, and covering atrium roof by solid material instead of transparent ones such as glass.

Keywords: Atrium, Thermal Comfort, Building Problem in Hot Humid Climate, TAS Software, Energy Saving

ÖZ

Mimari alanlarda sürdürülebilir gelişim ve enerji bilinci göz önünde bulundurulduğunda, bu araştırmanın yapılmasının temel nedenleri arasında, çeşitli ve sıcak-nemli iklimler arasında yer alan bir atriumda, termal konfor olan bir çevre oluşturarak, içte inşa edilen çevreyi termal olarak geliştirmeyi ve pasif atrium performansını en uygun şekilde kullanmayı amaçlamaktadır.

Bu tez nicel bir yaklaşım temelinde ve eğitimsel bir atrium binasının termal performansı konusu üzerine yazılmıştır. Bu çalışmanın araştırma alanı olan Renkli Bina, Kıbrıs'ın Gazimağusa şehrinde bulunan Doğu Akdeniz Üniversitesi, Mimarlık Fakültesi'nin bir parçasıdır. Binanın termal ve enerji performansı üzerinde önemli bir etkisi olan atrium ile ilgili en büyük problem ise aşırı ısıtmadan kaynaklanmaktadır. Teorik temeli destekleyebilmek amacıyla, benzer konularda yapılan araştırmalar da dahil edilmiştir. Veri toplanmasına ek olarak, gözlem, ölçümler, fotoğraf çekimleri ve haritalar da toplanmıştır; kullanılan veriler atrium binasının dinamik termal modellemesini oluşturabilmek ve termal koşulları açısından rahatlık alanını hesaplayabilmek amacıyla TAS yazılımı kullanılarak doğrulanmıştır.

Renkli bina benzeşmelerinin karşılaştırılması sonucunda, dış sıcaklık, iç hava sıcaklığı, güneş radyasyonu, bağıl nem ve atrium binasının boyu gibi etkenlerin, iç termal konforunu doğrudan etkilediği saptanmıştır. Bu sebeplere bağlı olarak, sıcak iklimlerde kullanıcılara rahatlık alanı sunabilecek en uygun atrium biçimi, kulenin yüksek kısımlarında uygun çıkışlara sahip olup tavanı cam gibi saydam maddeler yerine daha katı maddelerle kaplı olan ve bunlara ek olarak kule boyunun 3-5 metre arasında olan atrium biçimi olduğu gözlemlenmiştir.

Anahtar Kelimeler: Atrium, Termal Konfor, Sıcak-nemli İklimlerde Bina Problemi, TAS Yazılımı, Enerji TASarrufu

This thesis is dedicated to my parents who have supported me with their endless love in all the way since the beginning of my studies.

Also, this thesis is dedicated to my beloved brother who has always helped me and believed that I could do it.

Finally, this thesis is dedicated to all those who believe in the richness of learning.

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Though only my name appears on the cover of this dissertation, a great number of people have contributed to its production. I would like to express my deep appreciation to all the kind people around me who have contributed to the conduction of this thesis and because of whom my graduation would be the one that I will cherish forever.

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Most importantly, none of this would have been possible without the love and patience of my parents. My immediate parents, to whom this dissertation is dedicated to, has been a constant source of love, concern, support and strength all these years. Therefore, I would like to express my heart-felt gratitude to my dear parents, Efat Yousefiyan and Rahim Amiri. Moreover, I wish to express my love and gratitude to my beloved brother, Amir Amiri for his understanding and encouragement all through my studies.

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INTRODUCTION

1.1 Research Background

Nowadays with the growing effect of greenhouse and lack of non-renewable energy in the world, designers and architects, especially in the vast modern countries, are making an all-out effort to decrease the negative effects of using non-renewable energy so to conserve the human environmental comfort via the construction of sustainable buildings. The growth in constructing sustainable buildings would lead to an increase in the thermal performance and a decrease in energy consumption of the buildings as well.

Several scholars such as Atif (1994), Bednar (1986), Göçer, Aslihan, and Özkan (2006), Höppe (2002) are united in the belief that reviving the atrium is one of the most significant key factors in developing architectural history, especially during the recent decades. Revival of atrium has been known as a social centre and has been used broadly in the ancient Greek particularly at Roman houses, up to the present time. This glass-enclosed space within a central building can offer a spatial soul and heart. It has been proven that atrium buildings have a direct effect on marketing value of buildings, and both psychology and physiology of occupants` moral as well.

Furthermore, in the various studies it has been confirmed that the crucial role of atria leads to having a decline in energy consumption by keeping human thermal comfort

(Taleghani, Tenpierik, and van den Dobbelsteen, 2012). Thermal behaviour in atria is an important aspect of energy utilization in building which is primarily related to lighting, cooling, heating, and also reduction of thermal stratification; due to the fact that to the way of designing the glazed atrium, a large public space, with more amenities, is very sensitive. Failures or mistakes in the early stage of designing atrium occur frequently which cause some consequential effects on both energy and indoor thermal performance of the building.

As a result, atrium has become a focal component in many large-scale luxury new buildings. However, overheating and over-lighting are the main design problems of atrium which designers are dealing with (Chenvidyakarn, 2007; Defxlnw, and Born, 1987; Sharples and Shea, 1999). The importance of thermal comfort in atria, mentioned also in the literature review section, is to help the new atrium buildings to reduce their energy consumption and produce comfortable environment for users.

1.2 The Problem Statement

Hot and dry climate conditions in Famagusta, North Cyprus affect the temperature to increase which consequently has a direct effect on the comfort of indoor environment. In his research, Humphreys (1994) has noted that an unexpected excessive temperature causes reactions in people`s behaviours. In this regard, results of various investigations presented that developing an appropriate environment with thermal convenience in educational buildings is a significant subject which directly impacts the students` learning capacity the same way as their teachers. Additionally, the studies have mentioned that although acclimatization and cultural factors can decrease the effect of undesirable temperature on occupants, they are usually susceptible to the undesirable temperature. Discomfort situation makes students represent more aggressive behaviours and less capable of focusing on their work (Feriadi, Wong, Chandra and Cheong, 2003; James and Christian, 2012; Kwok, 1998; Wong, and Khoo, 2003).

Hence, in order to achieve indoor thermal comfort in an educational atrium building at hot climate, it is important to understand heat loss, air stratification, temperature, solar radiation, humidity percentage, wind profile outside and inside of the building, proper orientation, and also form of the building.

1.3 Aim and Objectives of the Research

A remarkable challenge in the contemporary researches is to find out the effective strategies to overcome the discomfort condition of each climate while declining energy utilization (Berkovic, Yezioro, and Bitan, 2012; Höppe, 2002; Zain, Taib, and Baki, 2010). Despite today`s technological breakthroughs in computer simulation of the buildings to assess proper daylight, heating and cooling transfer, and also ventilation, it is problematic to regulate a user’s metabolism or clothing. This describes why people in a same place may perceive temperature with remarkable differences (Gregerson, 2010). The thermal building simulation software would contribute to architects and designers in the designing process at its initiation. Therefore, better understanding of the latest design guide principles in the early design stages would have positive and noticeable impacts on both planers and architectures` decisions besides improving indoor comfort of the built environment.

In this review, the way of improving the existing thermal condition of the selected building in a hot and dry climate would be taken into consideration. Therefore, the goal of this investigation is to examine the thermal environmental performance of atria in buildings, plus doing a research on finding a suitable atrium form for this climate.

The main objectives of this study are as follows:

1) To find out the reasons why an atrium has become popular in the recent years
2) To realise the merits and demerits of using atrium form
3) To discover how environmental conditions may affect the atrium buildings
4) To understand the problem of atria in hot and dry climate
5) To find out the current thermal condition in atrium buildings and adjacent spaces (via dynamic thermal simulation software)
6) To compare the thermal conditions of atrium space and classrooms with thermal standards (via ASHRAE standard)
7) To determine preferred and acceptable temperature range in the atrium space and adjacent zones

Therefore, this study is an effort in collecting building problems by focusing on hot regions and providing some precautions related to those problems for planners, architects and others who work with planning and design of the built environment in hot climate zones.

1.4 Research Scope and Limitation

This research sheds more light on the concept of offering internal thermal comfort to build environment through reducing energy consumption with the passive solar strategies used in the Coloured Building which belonged to the department of Architecture at the Eastern Mediterranean University in Famagusta, North Cyprus. The research was carried out during the academic year 2012 - 2013.

Although the present research carefully fulfilled achieving its objectives, there were some limitations as well. Firstly, lack of time for conducting this research caused to have a limitation in comparing the field measurement parameters to the computer ones knowing that these parameters can affect the thermal performance of the Coloured Building. Secondly, although considering all types of atrium, this research focused on only a four sided atrium. Moreover, the simulation of the selected atrium building was conducted on the real size and additionally to create each simulation, only the apertures which have openable windows were considered. To understand the thermal position of the Coloured Building in comfort zone, the thermal position of the highest and the lowest parts of atrium space, which were key spaces in the Coloured Building Atrium, were represented by bioclimatic charts. Next, the analysis of TAS software has been done in relation to the weather data in Famagusta. The analysis result of dynamic simulations were based on several parameters such as global radiation (W), ambient air temperature (°C), building heat transfer (W), surface temperature (°C), wind velocity (m/s), wind direction (°), the amount of air flow in and flow out (kg/s), and relative humidity (%). Finally, the atrium form did not change its characters except for its tower height.

1.5 Research Methodology

In this experimental research, action method of research was employed to define the importance of thermal comfort in atrium building. To support the theoretical part, data has been totally gathered from the previous researches, articles, books, and internet sources in this specific area. The primary quantification data of the field study was obtained through field measurements and observations. To evaluate and compare the thermal performance of the selected building, TAS software was used so to reach the highest building thermal performance through several simulations with various parameters. TAS software is one of the most powerful computer programs in predicting the dynamic thermal simulation. The outcomes of this research are based on the results of the TAS simulations analysis and environmental data monitoring.

1.6 Organization of the Thesis

The following research is composed of three chapters. The first chapter is an introduction to the research subject and its significant key role in achieving a sustainable approach in architecture plus solving the problems of field study in terms of thermal comfort, and stating the aims and objectives for gathering the required data while being more focused. Then, the comprehensive information about the definition, historical development, architectural functions, various factors which affect the design of atrium, plus thermal performance and passive solar strategies of atrium form were discussed based on reviewing the literature. Chapter 2 includes the TAS simulations of the selected building and their gained results by finding and comparing simulations with each other.

Finally, in the conclusion section of the research, the major findings of the simulations results and the literature review have been summarized. Obtained data and future research suggestions can contribute to increase the well-being of the future atrium buildings on hot humid climate, particularly on the area of limitations of this research.

1.7 Historical Development

1.7.1 Atrium Definition

An atrium, the singular form of atriums[1] or atria[2], is derived from a Roman`s name. The early atrium buildings were an open square or rectangular courtyard located at the heart of a building in a richly ornamented room (Fig. 1). Besides in early Christian churches, atria were served as the front entrance courtyard. However, at present time, modern atrium is a skylighted court located immediately after the main entrance door.

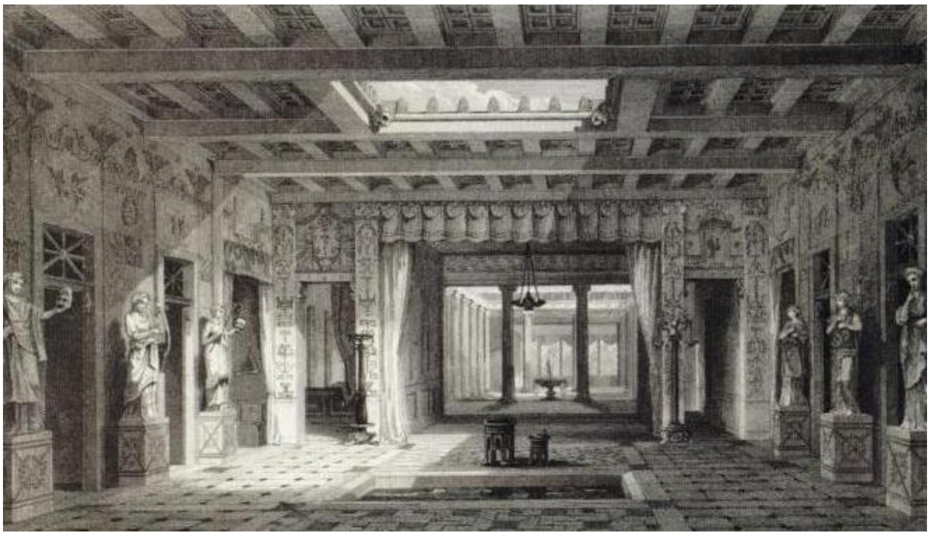

Figure 1: One of the Pompian Houses with the Ornamented Atrium Space

(Source: Amery, C., & Curran, B. (2002). p.100)

In this regard, numerous ancient authors had focused on the anatomical definition of the atrium component. In Robertson`s book, "Greek and Roman Architecture" (1969, p.302), he said that Marcus Vitruvius Pollio (c. 80-15 BCE.) who is known for his ten volume work, De Architectura and Marcus Terentius Varro (c. 116-27 BCE.), has called atrium the '*Cavum Aedium*` which means the "hollow of the house"; the term

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[1] The term atriums is acceptable in the modern English language usage as being the plural of atrium.

[2] The plural form of atrium in Latin is atria.

Cavum Aedium was defined by Varro as “the roofed-over area inside the house walls which is left open for the use of everyone”. This description means that the atrium was used as a waiting room to accommodate visitors and clients.

From the point of view of *Cavum Aedium*`s construction, Vitruvius, mentioned in his third chapter of the book VI, on architecture, five different types of *Cavum Aedium* in terms of column and wall design can be distinguished as follows:

Corinthian Atrium: The compluvium[3] frame was supported by a number of columns which were small peristyles.

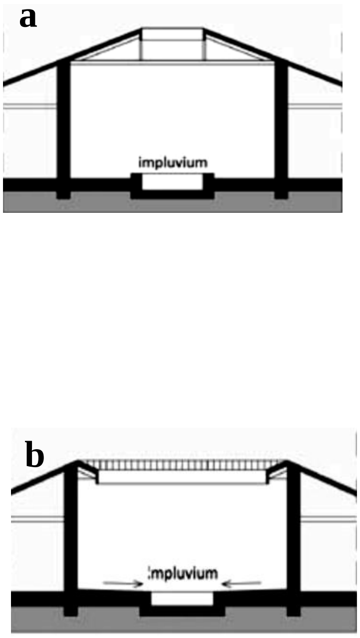

Figure 2 : (a) Displuviate Atrium, (b) Tetrastyle Atrium

(Source: KAVAS, K. R., 2012)

Displuviate Atrium: This typology was appropriate for winter residence because the opening in the roof sloped outward, and the rainwater was thrown off toward the walls and then to gutters (Fig. 2a).

Tetrastyle Atrium: This one was used for a short span, in which the frame of the compluvium was supported by four columns at the angles, whereas none of other columns were carried the roof (Fig. 2b).

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[3] **Compluvium** (skylight) is "The opening in the roof of a court, atrium, or cavcedium of a Roman house. The roof sloped toward the comphivium from the surrounding walls, discharging its rain water into the impluvium (tank or reseiToir) in the court beneath it" from Sturgis, R. (Ed.). (1901). *A dictionary of architecture and building: biographical, historical, and descriptive* (Vol. 1). The Macmillan Company, p.368.

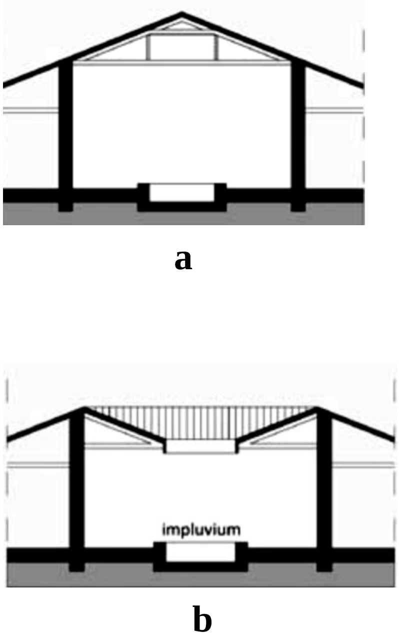

Figure 3: (a) Testudinate Atrium, (b) Tuscan Atrium

(Source: KAVAS, K. R., 2012)

Testudinate Atrium: The one in which was no opening in the roof. It might be the earliest form of atrium, where it was used just for a sitting room or there was an upper story on it (Fig. 3a).

Tuscan Atrium: It seems that the most prevalent type of atrium roof which was used in Roman houses was Tuscan Atrium. It was shaped by no columns to support the roof, so the roof loads were carried by crossbeams. The compluvium was a four-sided skylight opening. It is originally from the early Italian feature (Fig. 3b).

Both Vitruvius and Varro in their investigations represented most remarkable testimony on the origins of the atrium which was an Italian characteristic. Varro indicated that the Tuscan atrium, from the Etruscan city of Atria, located in the Po valley, was driven by Romans in terms of the spatial convention and is taken from the both the word and the place, Tuscan (McKay, 1998, p.16). Vitruvius used the term “atrium” properly in place of Varro’s cavum aedium. However, he did not mention that the atrium was an Etruscan heritage from Atria; instead he used atrium as an architectural characteristic devoted specifically to the Romans and Etruscans which was unfamiliar to Greeks (Robertson, 1969, p.302).

A considerable aspect of atrium is its spatial organization in the building. Kostof noted it being interesting that “Atrium-house” in Roman architecture is distinguished by two items from Greek Atrium-House: “highly regimented composition” and “a feeling for inwardness” (Kostof, 1985, pp.197-199).

Generally, atrium is associated with the previously mentioned vital central opening surrounded by solid form; it has a crucial role in the circulation inside the building and acts as a welcoming area for occupants. So it seems that an atrium as an interior plaza is a highly sociable space for gathering.

1.7.2 Historical Development of Courtyard

Courtyards are the purest and greatest sustainable features can be seen in the primitive and traditional settlements. Mofidi (2007) believed that the form of primitive constructions was based on the local materials, human experience, acclimatization, and direct perception of climate condition (Mofidi and Medi, 2007).

A courtyard form is one of the few architectural features related to comfort and protection. Substantially, a courtyard applies to any exterior space defined by building elements, with a direct connection to interior spaces almost on every side, increasing the inside-outside exchange changes. Courtyard has been used normally in ancient residential housing forms. Probably, the reason behind primitive human beings extremely preferring using a courtyard in their houses was to have both natural access and privacy at the same time.

With the development in urban settings, the courtyard concept has become a key character in architectural design. Bednar (1986) asserted that the origin of courtyards has been traced back to at least 3000 B.C in the archaeological remains of Ur. Mesopotamia.

Figure 4: The Main Courtyard of Tabatabaei House, in Kashan, Iran

(Source: http://www.flickr.com)

The various types of courtyard houses have been widely built in many parts of the world in contradictory climates and cultures, from the most primitive civilizations in China, to the Middle East, especially Iran, and North Africa (Fig. 4).

Keister (2005) stated that protection was the primary purpose of the early courtyards; they were surrounded by tall walls, making a barrier to protect the interior part from the undesirable viewpoints and also animals, while making a shield to against the weather variation as well (Keister, 2005, p.3). In later civilizations, the social centre in buildings used frequently in castles, monasteries, grand palaces, and the palazzo, was defined to be the courtyard. From that time on, atrium has become a new possibility for courtyard form and was extremely used in the historiography of Greek and Roman dwellings; for instance Pompeii is one of the most famous towns where its archaeological witnesses are a cultural heritage for accommodation of many atrium houses in itself.

While holding differences, many authors, however, believe that the terms atrium and courtyard mean the same; the similar point between these two is their having visual and physical access from an open-space to the adjacent rooms. The different between an atrium and a courtyard is the accessibility percentage of its space to the surrounding building elements. Atrium is that court positioned next to the entrance door. The exterior atrium-house walls were isolated from outside with windows and few doors so to keep noise and dirt away. Circulation in an atrium, in contrary to a courtyard which is around the building, takes place inside. The interior movement of atrium is clearly shown in Mansart`s building, the plan of Le Grand Commun at Versailles (Fig. 5).

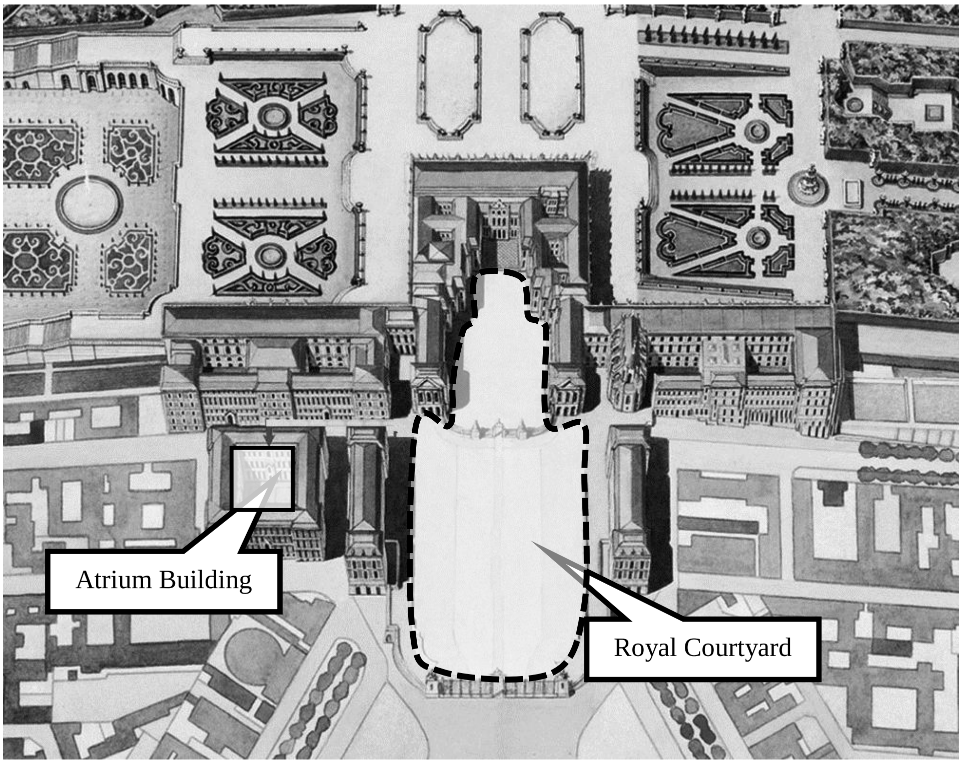

Figure 5: The Comparison between Atrium and Courtyard in Versailles Palace, France

(Source: http://www.lemoniteur.fr/181-innovation-chantiers/article)

1.7.3 Historical Development of Atrium

Since early decades in the 19th century, the concept of the definition of atrium has been changed. Throughout the Industrial Revolution, atrium form, however, kept its original space containing natural light and air from the side or above; which now is incorporated a glazed wall or roof.

The glazed atrium is being known as a key feature in many forms of the recent buildings and also an environmentally stimulating area in the “Modern Architecture”. Taleghani, Tenpierik, and van den Dobbelsteen (2012) asserted that an atrium is a part of the transitional space. Because of the lack of non-renewable energy besides the limitation in using renewable energy sources, designers tend to investigate on passive and efficient building forms such as courtyards or atria.

An overview of several conducted researches such as Hung, and Chow (2001), and Bendar (1986), on architectural aspects of atrium represents that the revolution of atrium can be generally divided into three periods as follow:

- 19th century
- 20th century
- Late 20th century

19th Century

In the late 18th to 19th century, the period of Industrial Revolution, a transition toward the mechanized manufacturing brought a notable development in glass and iron usage techniques as substantial components in architecture, especially in

European countries. The new technology brought a new era in construction so that the majority of buildings were built from iron and glass.

Bednar (1986) in his comprehensive book, *The New Atrium*, stated that new roofs are frequently covered with two developed spatial models, the atrium and the arcade. In combination with them, traditional masonry systems are also consumed to support the building. In this regards, Cleveland Arcade in Ohio is one of the primitive arcade atria which was built in 1890 by John Eisenmann and George Smith. The two nine-storey buildings, which are used for office usage, are connected to each other by an arcade skylight. Illustrated in Figure 6, the height of the arcade atrium is around 30 meters spanned by iron and glass enclosed arcade (Wikipedia, n.d.).

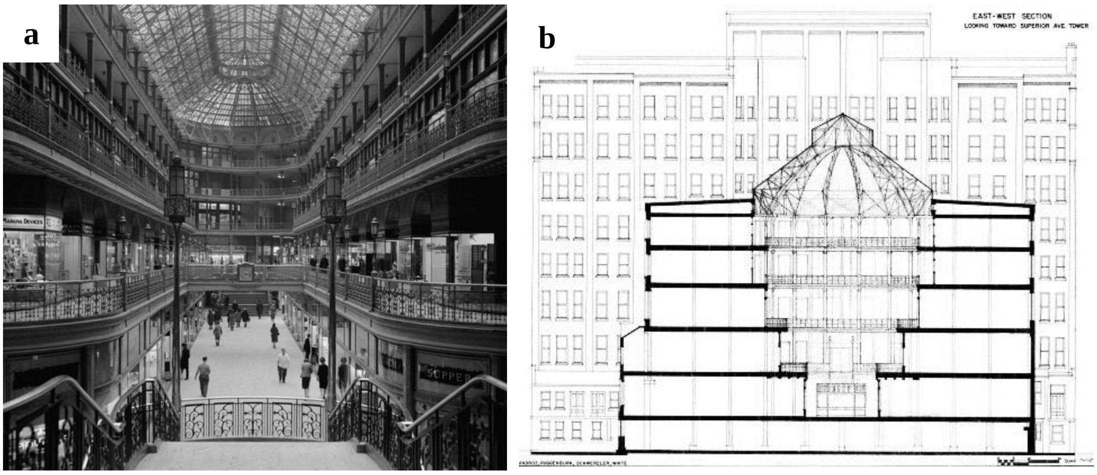

Figure 6: Interior Space of the Arcade in Cleveland with its Lateral Section

(Sources: (a) http://arquitecturamashistoria.blogspot.com; and (b) http://www.virtualtourist.com)

According to Bednar`s research (1986), The Consuls Office at the Bank of England was the new spatial atrium type at that time, which was built during 1792 to 1794 by John Soane. This trend was continued with the Reform Club which was built by Sir Charles Barry in London, in the early 18th century. The building was the first well-known atrium in which the roof was covered by a vault metal structure in-filled with glass. Thus, for the first time the glazed atrium usage was eliminated from the weather factors and made the outdoor natural light penetrate into indoor spaces (Fig. 7).

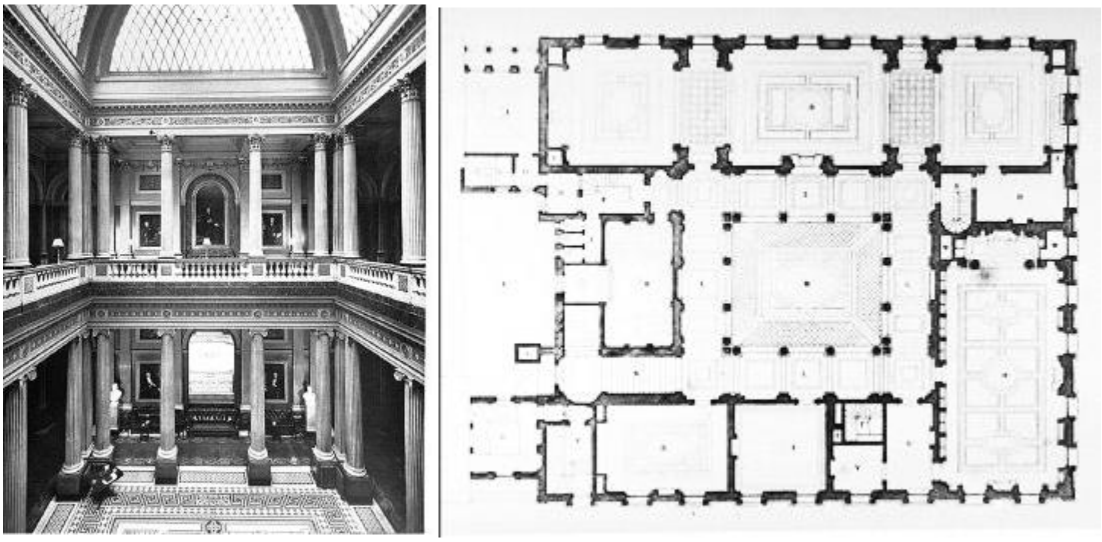

Figure 7: Internal View of the Reform Club with its Plan

(Source: http://www.studyblue.com)

A new opportunity was created for the huge public buildings by integrating open and glazed spaces. The new atrium feature with iron and glass structure was used extremely in train stations, exhibition halls, malls and conservatories (e.g. Crystal Palace, in London, by Joseph Paxton in 1850-51). England and France are among the countries which devoted many of these constructions to themselves.

Even though, atrium buildings had been popular in the early 19th century, they were neglected for last two third of this century. The main problem why architectures and designers began to wane using atrium forms was the fire hazard; iron, glass and steel utilized in the structures were unable to withstand the heat of urban fire (Bendar, 1986; Ahmad, & Rasdi, 2000; Hung & Chow, 2001).

Early 20th Century

An atrium concept developed quickly during the late nineteenth and early twentieth centuries. The second epoch of the atria forms took place in The United States, especially North America; while in European countries the atrium usage was fading away. The construction method, integrating masonry materials into glass and iron structures, was the same like the first period. For abolishing new materials` fire weakness, structures were covered by masonry buildings.

In the book "*The New Atrium*"(1986), it is represented that the oldest famous atrium building which was erected by General Montgomery Meigs in Washington D.C., is the Pension Building during 1882 to 1887 (Fig. 8). At that time, the building was the greatest brick building in the world which was set as prior to the following atrium buildings. The influential advantage of this building was its saving energy consumption.

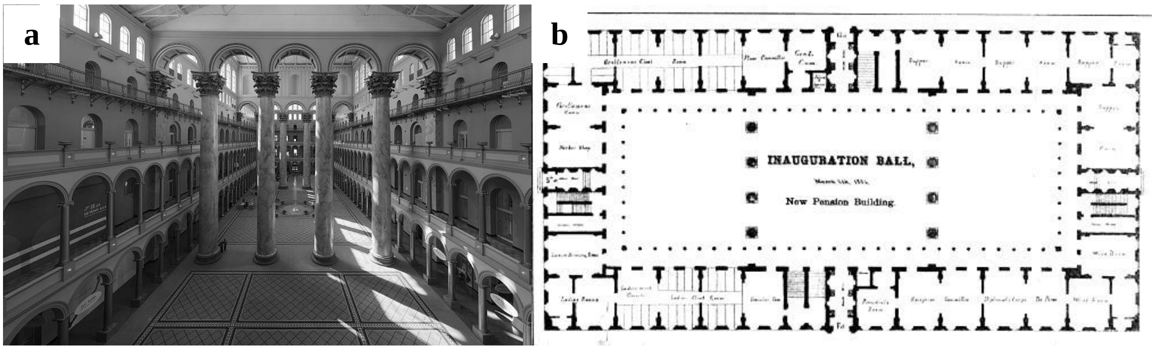

Figure 8: Internal View of the Pension Building's Opening, and the Buildings' Floor Plan

(Sources: (a) http://boards.straightdope.com; and (b) http://ornamentalplaster.blogspot.com)

The features considered by General Meigs in this building were:

- The reduction in lighting consumption by using daylighting for each office
- The suitable view points
- The thick masonry structure acted as a thermal mass, thus it decreased heating and cooling demand
- All windows were double glazing windows
- The roof was covered by an uncommon insulation system
- Using natural ventilation per 2 minutes
- Using steam radiators for heating

Looking at the Pension Building, it can be asserted that in 20th century, it was the first time when designers had paid attention to reduce energy consumption; they had tried to invent a new system to contribute to the energy supply and so to have a cleaner environment in their future constructions.

In contrary to the previous period, the buildings in this era consisted of several levels which were around the four-sided atrium space. In 1905, this trend was sustained by Frank Lloyd Wright`s Larkin Office Building in Buffalo, New York. Particular characteristics of the atrium buildings were their usage of vertical and horizontal accesses as a sculpture, accommodating shops and offices in a ground floor and their behaving as an interior plaza in order to gather people flow.

Eventually, this era`s movement finished by F. L. Wright`s (1959) Gardner Museum in Guggenheim Museum in New York (Hung, W. Y. et al., 2001). By the end of the 20th century, skyscrapers were equipped by atriums which had become better shelters with that long focal court.

Late 20th Century

As reiterated, the deployment of new technologies have soared energy consumption and the oil`s price. In consequence, numerous researches have been focused on this field to find a sustainable method to decrease the usage of energy.

The history of atria proceeded after a short dormancy in the United States. In the 1960s, the third approach was reached to its apogee by two atrium buildings: Hayatt Regency Hotel in Atlanta and Ford Foundation Headquarters.

Figure 9: The Interior Design of the Hayatt Regency Atlanta, Atlanta, Georgia

(Source: http://www.stonehilltaylor.com)

Hayatt Regency Hotel designed by John C. Portman, is the first atrium hotel which has a huge interior landscape like the urban park. It is illuminated by both clerestory glazing and top lit. The 22-story building has enclosed the rectangular court vertically (Fig. 9).

The other atrium building, Ford Foundation Headquarters, which was designed by Roche and Dinkeloo, was known as the transitional zone between the inside and outside. The atrium of this office building is located at a corner with a glass-side wall toward the street. These two successful tall buildings with the central and corner atria are inspired by the high constructions afterwards as a key form of space (Fig. 10).

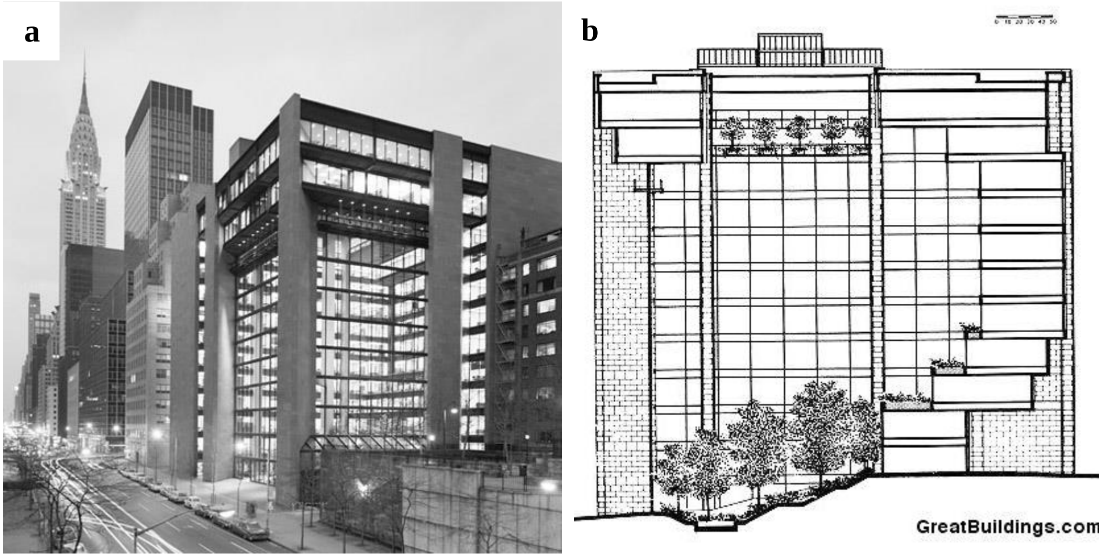

Figure 10: Section of Ford Foundation Headquarters Atrium, New York, New York, 1968

(Sources: (a) http://www.pivotdublin.com; and (b) http://canilive12.blogspot.com)

The modern atrium has new abilities such as being the buffer zone, or the environmental concept, improving the aesthetics and helping economic while giving the occupants feeling of the space.

1.8 The Role of Atrium in the Building

As mentioned before, the primitive function of atrium was the demand for family safety, creating a meeting or gathering space for household, its rituals-social, political, and religious functions, and being profitable at the same time (Gazda, 1994, p. 29).

In contrast to the past, the invention of atrium or sunspace led to a considerable amount of assistance toward an open space. Undoubtedly, atrium buildings are the most common features which are used for the communal purposes in large contemporary public buildings. Bednar (1986) noted that atrium has a high flexible function in incorporating any kind of building and acts as the social central space. Moreover, the marketing value and the identity of buildings would increase in the top glazed public spaces.

Bednar (1986) and Saxon (1994) were both agreed on a belief that one of the most consequential design values of atria is their urban aspect; atrium positively contributes to old building conservations, and energy efficiency while it revitalizes old buildings as well. Hence, some fundamental aspects of atrium usage are described as follows.

1.8.1 Urban Design Aspect

It has been stated by Saxon (1994) that "exterior and interior public space, defined by built form, is the foundation of good urban design". The nature of atrium is to accommodate a flow of people in itself and provide some facilities for public use. In many cases, designers have attempted to make an atrium pattern which fulfils many functions taken place outside like plazas and park.

Findings indicate that atria are the kind of transition space which their circulation and access design have a substantial effect on building`s movement and its design`s success. The research done by Pitts, Saleh, and Sharples (2008) represented that the transition spaces have a key role in impressing and guiding the users in the building`s design; this sort of space takes more volume of the building`s area. In 2004, other

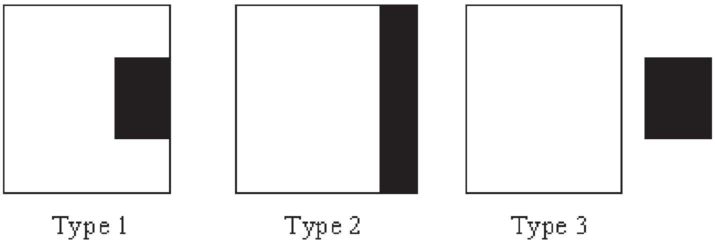

Figure 12: Different Types of Transitional Spaces
(Source: Chun, Kwok & Tamura, 2004)

scholars, Chun, Kwok, and Tamura, noted that transition spaces can be classified into three types. The first category is the transition space which is surrounded by the building, next group is the one attached to the building, and the third type is the one that is separated from the building; atrium belonged to the first type (Fig. 11).

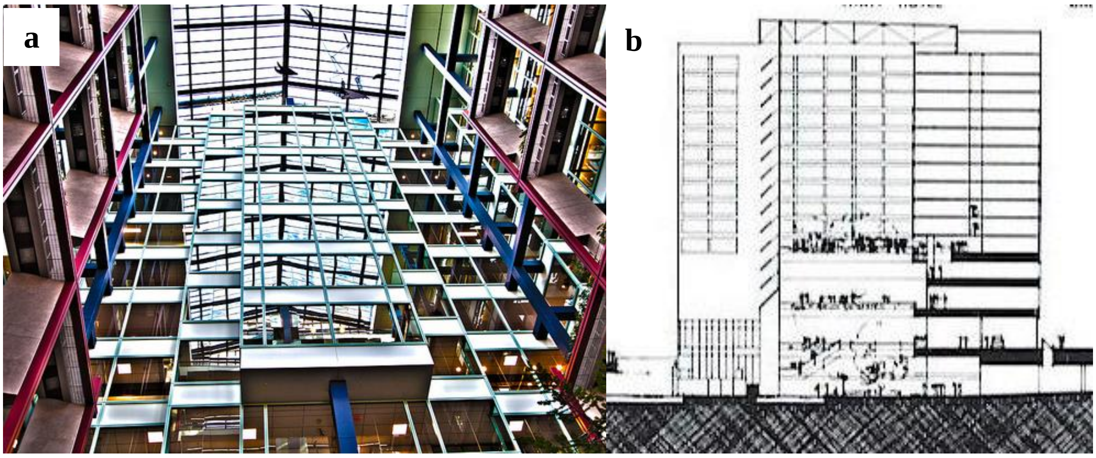

Figure 11: The Hercules Plaza Atrium in Wilmington, U.S.A

(Sources: (a) http://www.flickr.com; and (b) Bednar, 1986)

Sometimes atria link downtown to the interior space of the buildings or sometimes it acts as a plaza to connect a number of buildings in one point. In *The New Atrium* which was written by Bednar (1986), the best example among the transitional buildings is discussed to be Hercules Plaza in Wilmington by Kohn Pedersen Fox Associates, Delaware; and Crystal Court of IDS Centre in Minneapolis is the stated to be a successful instance for the plaza atrium (Fig. 12).

Another urban design value of atria is the atrium façade directed toward the street facade. Due to the fact that street facades have a high definition in urban spaces, an atrium facade is particularly mentioned to be a significant item. Atria which have the shared surfaces with the street, give panoramic views of the city to occupants. Thus, both the visual relation and the transition between indoor and outdoor of the atrium building are compatible with its urban context. It becomes more highlighted as the atrium building does not intrude the harmony of the street, in particular commercial atrium buildings which are located in the commercial district. Atria add the new interior plaza to outdoor plazas and increase the vitality of the street.

Nevertheless, there are some problems which have impacts on the relationship between the urban spaces and the atrium building. Recently, there have been many skyscrapers built which tend to use an atrium within them. An atrium causes these skyscrapers to be self-centred buildings with various attractive functions. That is why these buildings separate the interior and exterior of buildings and allows users to enter into the fresh indoor city.

Nowadays, atria have extended their role in the landmark of the cities and have situated instead of open public plazas. The atrium, although removes the negative climate conditions, pulls people inward into buildings and they will become far away from the real world, going toward the built environmental spaces. Then it should be considered by the designers and architects to pay equal attention to the inner and outer areas of atria constructions.

1.8.2 Architectural Aspect

As previously referenced, atria are being incorporated into the high rise buildings at a high frequency; this can be seen especially in luxurious hotels, huge office premises and shopping malls. The beneficial point of the atrium is its being attached properly to various building types. Accordingly, it offers creative shapes for buildings.

Since 1970s, the glazed openness at the central buildings has given the perception of space to occupants by bringing natural light and fresh air. While people are waiting in the building, they need to sit or entertain themselves. Thus, the modern atria were designed to act as a social environment, providing everything for users to feel confident in the built environment. Moreover, atria are essentially flexible spaces and are known as the leisure place. Saxon (1994) discussed that an atrium can house diverse activities, provide a location for gathering people, exchanging information, and offer an excellent viewpoint to look around; what is more, atrium is even able to supply the occupants with cinema, children's playground and sport facilities in the centre of the buildings. Consequently, the quality of atrium attributes to increase dramatically user rates and lend excitement and drama to the space.

While everyone would prefer to spend more time in the built environment, there are definite demerits. The foremost drawback is security. When a large population enter into the atrium buildings with different culture, it is natural that not only users can experience problems but also the place itself. Therefore, building designers have to divide the space into the public and private part. Their design should consider lower levels, such as the ground floor, for public usage like entertaining facilities and retail shops or banks; and the upper levels should be devoted to the office places and residential regions. Indeed, the ground level can be connected to outside very easily and make the transition faster or without any difficulty.

As mentioned earlier, daylight is the fundamental item for most atrium buildings. The form of building, the atrium roof structure and its proper orientation are the key architectural points which architects have to pay attention in the early design stage. Littlefair and Aizlewood (1997) described how to penetrate natural light into the atrium by removing excessive solar heat gain. Their research showed that a shallow atrium shape will be brighter than a deeper one with rectangular shape. Additionally, it revealed that the central rectangular atrium can be said to be the best form of atrium shape; however, the linear one performs the same, so it depends on the adjoining building's height.

According to the investigation on the atrium roof form by Yunus, Ahmad, and Zain-Ahmed (2010), the roof structure reduces daylighting around 55% for all kinds of roofs which they analysed them. It was evident that the structural flat roof had the least impact on roof transmittance. Therefore, in order to reach a high performance in atrium space, it is needed to consider the most efficient form and roof structure besides choosing a proper direction to receive more sun rays (Fig.13).

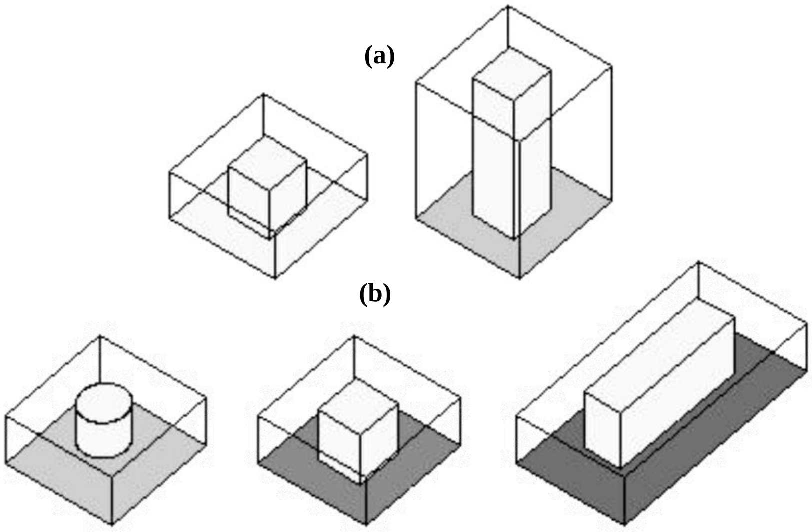

Figure 13: (a) A Shallow Atrium is Brighter than a High One with the Same Plan; (b) a Circular Atrium Base is Brighter than a Square One, Assuming All Three has a Same Roof Aperture Area

(Source: Yunus, Ahmad, and Zain-Ahmed, 2010)

1.8.3 Conservation Aspect

Conservation and preservation of old buildings contributes to the definition of public realm, for it is both necessary and beneficial during urban design strategy and history of the city. By integrating atrium to the existing constructions, it provides not only a new life but also it adds a new useful space to the existent buildings.

By covering the historic courtyard buildings, atrium offers a new service possibility for buildings. The great advantage of an atrium is its easily adjoining to different building forms. This possibility helps to present and preserve the original buildings` facades and connect an old building to the new ones by keeping its historical façade.

In order to preserve the historical part of a city or revive the urban fabrics left unused for a long time, atria can perform as the buffer transitional zone to accommodate, refurbish and extend the old structures. The new atrium part is able to relate several buildings by the central court or revive the historic urban fabric by attracting people to come in and spend their time there.

It seems to be fair to say that the new glazed roof in an old building is designed to give quality to the building again. The conservation of the historic fabric by the adopted atrium respects to the traditional context, contributes the urban economic, reuses the historical urban part, and renovates the building`s exterior while giving a new function and interior to the building. In this regards, the bank of Nova Scotia Headquarters in Toronto was designed by WZMH Partnership in 1988. A dramatic 14-storey high glazed atrium connects the old 27-storey building to the new 68-storey office tower (Fig. 14).

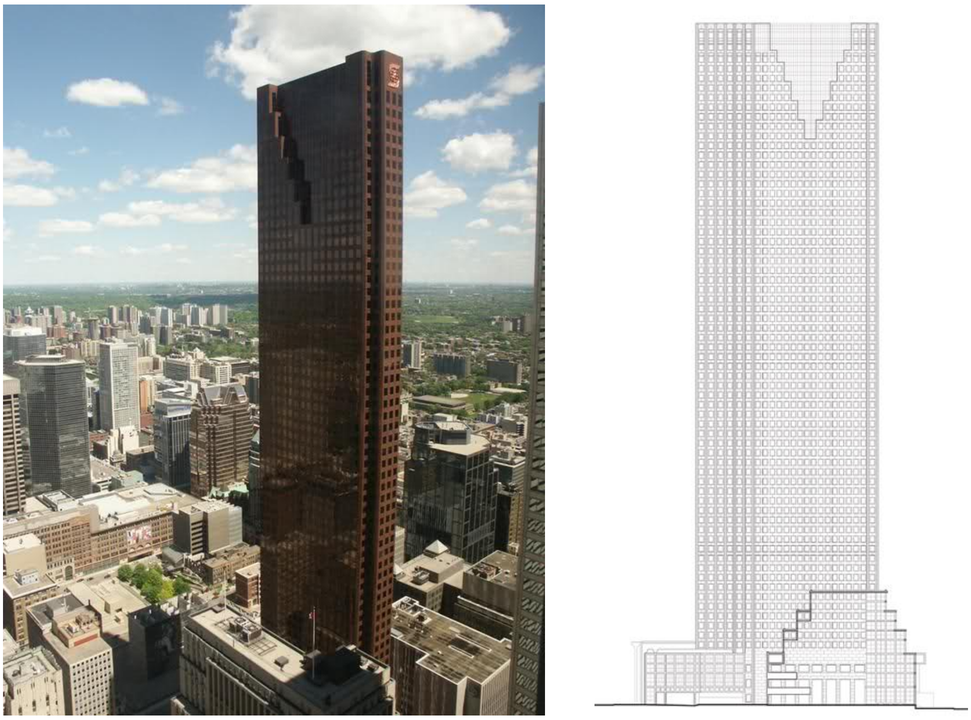

Figure 14: The General View and Section View of Bank of Nova Scotia, by WZMH Partnership, Toronto

(Source: http://www.wzmh.com)

1.8.4 Environmental Atrium

The internal situation of the glazed atrium is another key point in pulling people in and keeping them inside the building. The primitive theory of atrium building is its being responsive to psychological, emotional, cultural, social, and aesthetic requirement. In addition, the interior sector of the atria needs to create a unique quality in order to stimulate the outdoor environment by removing the harsh natural environment and setting up a sense of space, while gaining profit from natural light and bringing in vegetation within the building.

Atria can become significant circulation nodes to provide a welcoming entrance. The horizontal and vertical accesses act as the sculptures in the central atria and it would be more effective if they are built by rich materials and colours. Moreover, utilization of the interior architectural features like planting, art installations, sculptures, fountains, waterfalls and lighting can enhance the quality of atrium space.

In the 20th century, urban densities and world population grew quickly. The fact led designers to see incorporation of an atrium form as an excellent opportunity for increasing the quality of environmental sustainability in large buildings (Parker, and Wood, 2013, p.140). The passive atrium idea can provide desired conditions for the building inside through natural energy resources, such as daylighting, wind, passive solar gain, and evaporating cooling in order to adopt buildings properly to their local climates.

Based on the study from Ho (as cited in Hung et al. 2001), atrium building form has a direct effect on the internal thermal environment. Generally among the various forms of the atrium, both linear and central atria significantly decrease the temperature fluctuations and keep temperature performance near to the comfortable.

By covering the courtyard, direct sunlight can be controlled and the internal temperature would be higher than the building`s outside. The researches which have been conducted on the influence of the street canopy on human thermal comfort revealed that vegetated or glass canopies are capable of decreasing heat stress of the outdoor spaces drastically. Moreover, of the benefits of roofing the spaces are to provide shade for pedestrians, balance humans` thermal comfort, raise property values, provide protection from wind discomfort and make access to the solar radiation available in winter (Saxon, 1986; Mayer, Kuppe, Holst, Imbery,and Matzarakis,2009; Enete, Alabi, and Chukwudelunzu, 2012). Saxon in his book *'Atrium Building Development and Design'* added this type of positive points and called it the "buffer effect".

According to the investigation done by Göçer et al. (2006), atria are the buffer zones which are located between inside and outside sections of buildings. Automatically, the glazed roof affects air stratification by the daylight and heat gained through the solar systems. It is proven that the most fraction of energy consumption belongs to the heating load in cooling seasons. In addition, reduction of in the cooling energy consumption can be supplied by controlling sunlight, using external shading for the glazed part, and also considering some openings at the top and bottom of the atria.

Daylighting use is particularly a beneficial issue for the atrium form. It offers the perception of space, a comfortable view, and has a major effect on energy-saving. As seen in the Figure 15, a comparison between the accessibility of daylight in a traditional building and an atrium can be seen (Hung & Chow, 2001). The reflectance of the atrium walls and the size of the glazed atrium incorporated within the artificial light have a significant impact on electrical consumption.

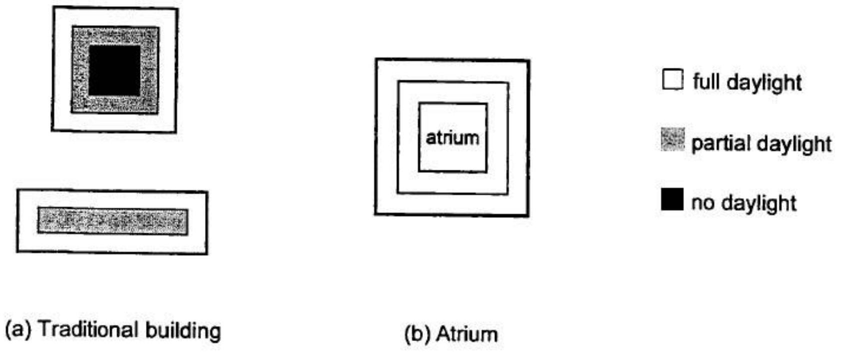

Figure 15: The Accessibility of Daylighting in both a Traditional Building and an Atrium

(Source: Hung, and Chow, 2001)

Furthermore, the glazed atrium`s size is another design consideration which may cover the whole beneficial points of the atrium. The huge glazed atrium roof overheats the inner side of atrium space in summer. It is stated in Laouadi, Atif, and Galasiu`s inquiry (2002) that the cooling load consumption was reduced meaningfully by decreasing the fenestration surface area more than 48%. In winter, increasing heat loss and air stratification had caused discomfort for occupants and also had enhanced the heating load consumption; however, the atrium and its adjacent spaces were ventilated by air stratification without an air conditioning system (Göçer et al., 2006). Therefore, understanding the accurate percentage of glazing size is one of the important issues in the early design level; ignoring this issue can increase glare which affects the visual comfort of users, too. Besides, keeping the balance between the volume of heat loss and the amount of glazing is a crucial aspect in utilizing the passive atrium idea.

On the other hand, the improper roof structure and usage of unsuitable shading devices increase the artificial light usage, because they reduce noticeably the natural light penetration in the atrium space.

1.8.5 Energy Conservation

As previously indicated, one of the generic strategies in reducing energy consumption of the buildings meaningfully is the use of glazed atrium. Historically, the ancient atrium made use of natural energies to heat, cool, and ventilate. Nowadays, because of the lack of fossil resources and increase in global warming, it is truly a mistake not to use natural resources.

As reviewed, an atrium is inherently designed to eradicate seasonal climatic variation and enhance the pleasant interior situation by keeping both wind and precipitation out, providing a natural lit as well. Further to increase energy efficiency of atria, Bednar (1986, p.81) has hypothesized that the atrium form has mainly five advantages which cause it act as the co-ordinated energy systems:

Daylighting: The integration of atrium form into the design of buildings brings about using energy sources for free. Penetration and distribution of natural light are the prevailing aspects of atria which positively affect the cost of electricity. As it is obvious that designers are unable to count only on natural light for the illumination of atrium buildings, so they supply artificial light with natural light.

On the other hand, the reduction of energy consumption by daylighting is quite limited unless passive solar system combines with the atria to use proper daylight. Meanwhile, passive heating and cooling may well be enlarged if architects do not consider how to control them (Hunn, 1996, 382). Minimizing uncomfortable situations and insulating glazed parts of the atrium can be recommended to save energy owing to a decrease in energy expenditure.

Passive Cooling and Heating: The careful design of atria can contribute not only to heating or cooling but also it is important in highlighting the energy efficiency of the atrium buildings in a meaningful way. Among passive energies used in atria, passive cooling is the major energy directly addressed; it is established trough shading devices, convective cooling, thermal mass, and thermal convection (Bednar, 1986, p.90). Cooling huge enclosed atrium buildings is more expensive than heating them. Both ways, heating and cooling naturally cannot influence the whole atrium efficiently. These solutions require the mechanical system to incorporate the natural cooling or heating systems to act effectively.

Thorough reviewing passive cooling in the atria forms, it is noted that the importance of heating for office and commercial buildings is less than its cooling and lighting aspects.

Ventilation: The primitive aim of ventilation whether mechanical or natural, for indoor spaces, is to achieve the thermal environment and higher quality of air. Cross-ventilation and additionally vertical ventilation of the high rise buildings are the advantages of atria which are normally provided by the differential pressure on the windward sides of a building (Fig. 16).

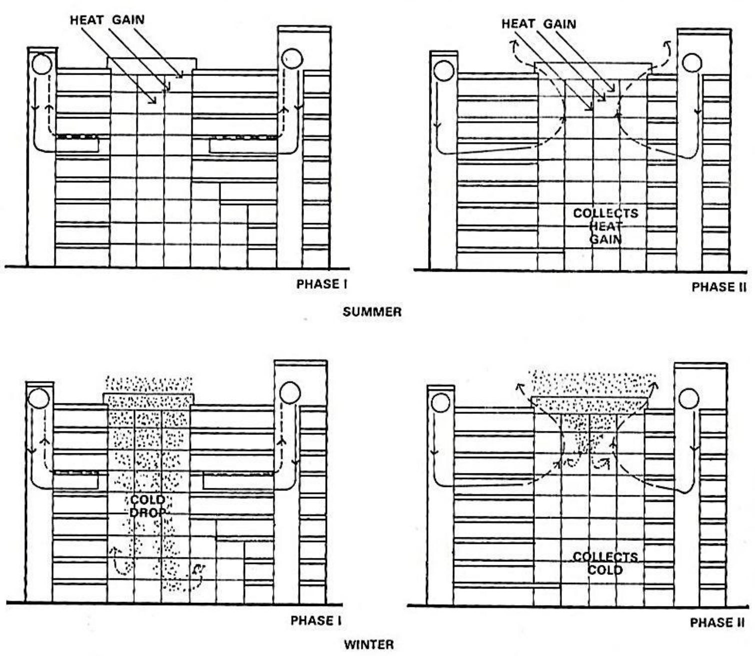

Figure 16: Air Flows throughout the Year in Butler Square, Minneapolis

(Source: Bednar, 1986)

In this regards, Santamouris (2012) asserted that the wind effects decline directly from the glazed parts of the atria while stack effect becomes significant by the height of the atria. In order to prevent the stack effect, designers consider several openings at the top of atrium well to lead exhausted air outside of the buildings. Thus, fresh air of the outdoor ambience comes into the atrium buildings from the lower openings. Due to this fact, size and location of openings are very influential design parameters which can control the ventilation rates (Santamouris, 2012, p.52).

Microclimates: Some components as illustrated in vegetation, water features, materials, layouts and even sitting landscape make the aesthetics of interior space better. Plants and water features strengthen cooling and humidity through evapotranspiration. Moreover, greenery leads to the contribution toward optimization of energy usage by absorbing air pollution and refreshing the atrium atmosphere.

Thereupon, atrium plays the role of a thermal buffer zone because the external envelopes of the atrium space will have less connection with the outward. Subsequently, the heat loss is reduced and solar gain is grown. These reasons cause the interior ambient temperature of atrium buildings to be always higher than the common ones.

1.8.6 Economic Aspect

In the 1980s, the glazed pattern of atrium became more popular with the development of materials. Economics is the first factor of the atria form which designers, particularly building owners consider in their decisions.

Although the construction period and the used material of atrium buildings are less than the other type of buildings, designing and constructing the roof structure part are very hard and sensitive. The research of Sharples and Shea (1999) on the effect of atrium roof construction on daylight levels in atria has concluded that one of the most influential parts of the atrium design is its roof structure. Roof structure can decline the daylight entering into the building or reduce overheating, glare and atrium`s adjacent spaces which have a direct effect on energy consumption then on the economic sector. It is certainly true that an atrium concept has been known as the environmental preserving measure which has a dramatic impact on energy costs of buildings. To achieve maximum passive benefits[4] of the atria while minimizing energy usage, there should be focus on well-designed atrium buildings.

Creating skylight, although is very expensive, contributes to the return on an investment. The largest energy cost of a building, especially in official and

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[4] The passive benefits of an atrium building are such as natural ventilation, daylighting, passive cooling and solar heating.

commercial types, has been devoted to the artificial lighting. Integrated daylighting to the artificial lighting is one of the basic components of atria which reduces greatly the electrical consumption around one-half to two-third of the ordinary buildings.

The economic aspects of atrium buildings were categorized into four parts by "*The New Atrium*" book (Bednar, 1986): financing, construction cost, profitability, and operating cost. Profitability means gaining extremely high rental rates, and occupancy rate. As mentioned previously, designers should improve the quality of atrium space by using greenery, luxurious art elements and materials, well-designed elevators and stairs routs, and other features so that a memorable and drama space is created.

According to previous investigations, atrium has proven its having the highest value in marketing. Most of the official and commercial buildings generally tend to an atrium form because it has the notion of attracting users and inviting them to come inside of buildings. Atria increase rental rate and tenants are also satisfied with paying more to have a shop or office through the interior atrium plaza. Another point is that atrium is a multi-functional space which has a high ability to accommodate various activities. One of the fascinating amenities of atria is its providing linking to different parts of these complexes by sky bridges.

1.8.7 Fire Safety

As remarked earlier, the main issues why European designers put away the atrium concept during the 1980s were the lack of stability and heat tolerance of the modern material, particularly the glazed covering. Normally, the atrium is composed of large glazed areas which do not have enough fire resistance qualities. Therefore the atrium space should be designed so that the flames would not be able to touch the glazed features and behave as fire barriers; that is to prevent the broken glasses which are falling into the inner area due to the heat of fire.

Despite the multi benefits of atrium design in architecture, major atrium hazards have potential fire risks and lack smoke control management. The large opening surrounded by several levels of tall buildings decreases fire control systems in efficiency compared to non-atrium buildings.

Inherently, an atrium form is not the main source of fire hazard, because any fire in the simple atrium can rapidly be detected. The problem occurs when the atrium building acts as a mixed functional space. Hansell (1994) in his book reached to this fact that most death caused by fire was traced back to be caused actually by smoke rather than heat (as cited in Hung, 2001). The unique open area of atria brings more oxygen for fire and permits flames, smoke, and hot gases to distribute from the fire location to other areas of the atrium building. The best options then would be considering fire-resistant and unbroken boundary for atrium space which restrict the atrium use.

In order to overcome the fire problem, there are some general guidelines and standards to prevent the fire and smoke spread partly. However, there are not specific fire measures for atrium buildings, so it is be possible to use and adopt similar measures from conventional buildings to atrium buildings. Coupled with the existent standards, a clear understanding of the space function and also its users` demands can help to select the appropriate type of fire resistance systems to be used in atria.

1.9 Design Analysis of Atrium Building

In the contemporary architectural world, the atrium concept has been so far varied from the ancient one. Because of the industrial development, the wide range of atrium structures has been available for designers to enhance energy efficiency and promote interior quality of the built environment. In order to reach this aim, designers should consider the suitability atrium type which completely adapts to the local climatic conditions (Fig. 17).

1.9.1 Classification of the Atrium Types

An atrium type is defined by its location in the building. Totally, it is located in the centroidal interior space of a building which is surrounded by several stories and covered by glazed surfaces. The atrium`s centroidal can be differentiated from courtyards, street canopies or the arcade type (Bednar, 1986). Typical atrium configurations can be formed by the simple shapes like four sided, cylinders or the

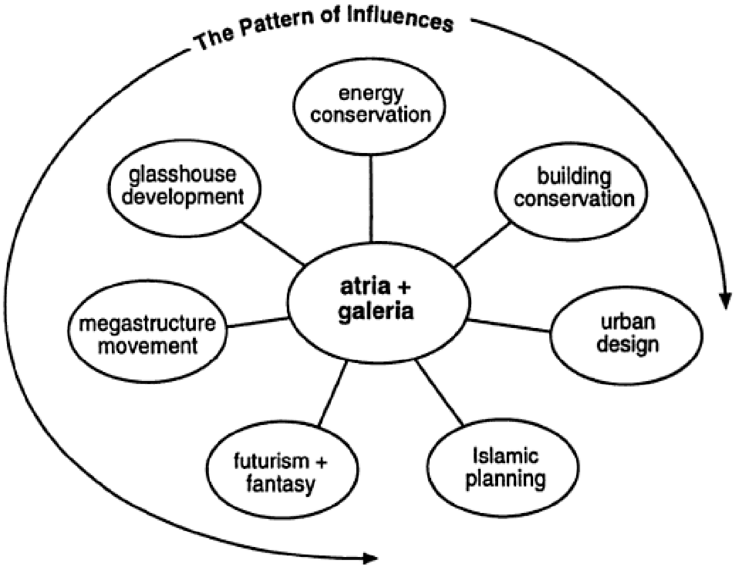

Figure 17: The General View on Atrium Design Approaches and Affecting Parameters

(Source: Ahmad, and Rasdi, 2000)

mixture of both of them. Even the atrium roof has its own character; it can be built in a dome, rectangular or pyramid form. Moreover, the glazed part of the atrium can be located on top, buildings` sides or a compound of both.

As previously alluded, studies of atrium buildings represented that the key factors of designing an atrium are its form and structure. However, the well understanding of these elements has led designers to improve their building designs, there is a lack of knowledge in atrium structure and form`s performance. The atrium can be classified by its usage, and structure which it will be explained in the following sections.

1.9.1.1 Type of The Atrium by Use

In this regards, several of researches used the study by Morgan, Ghosh, Garrad, Pamlitschka, De Smedt, and Schoonbaert (1999), and also Hansell, and Morgan (1994) as a main source of atrium type in terms of usage. Morgan et al (1999) found that the atrium usage divided into four groups which are suitability for managing smoke and protecting fire, easily.

Sterile Tube Atrium

The sterile tube atrium is based on the restriction of usage and design process. The atrium courtyard is separated from the adjacent space by the prepared facades; these facades use as the fire resistant obstacles in order to keep fire and smoke from distributing through adjacent spaces.

An atrium acts only as the orientation and circulation area which would be built by non-flammable materials for lower levels (Fig. 18).

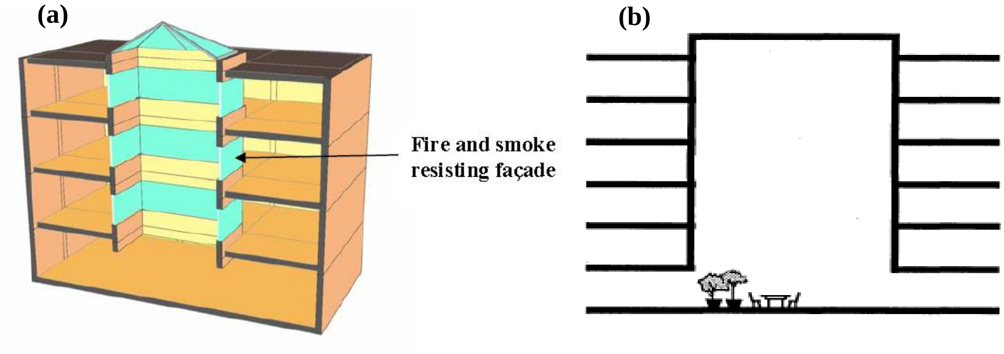

Figure 18: The Sterile Tube Atrium

(Sources: (a) Harrison. R., 2004; (b) Bastings, 1988)

Closed Atrium

The closed atrium is nearly the same as the sterile tube one, but the difference is the facade materials may not essentially be non-flammable and this type permits the atrium space to have a function (Fig.19).

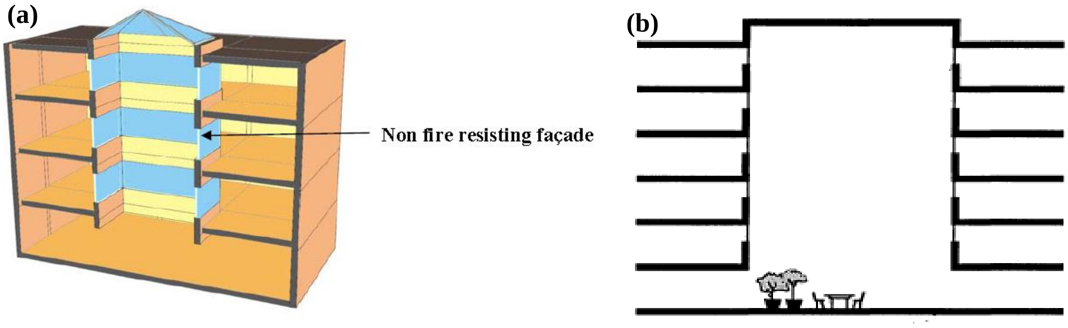

Figure 19: The Closed atrium

(Sources: (a) Harrison. R., 2004; (b) Bastings, 1988)

Partially Open Atrium

The sterile tube and closed atrium designs have a restricted use. Due to have a bit more flexibility, the partially open atrium is designed with the connection between the atrium well and the part of lower levels. On the upper levels, the non-flammable resisting facades are used to separate the atrium well and the upper adjacent levels (Fig. 20).

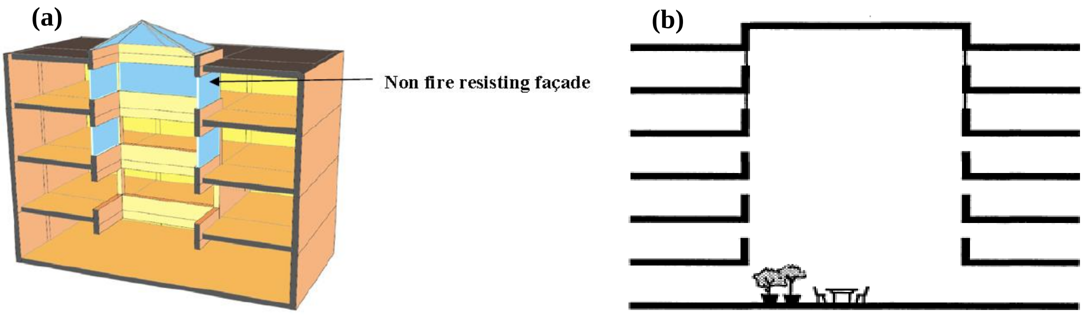

Figure 20: The Partially Open Atrium

(Sources: (a) Harrison. R., 2004; (b) Bastings, 1988)

Fully Open Atrium

As illustrated in Figure 21, a fully open space atrium among the previous explained types has the less restriction. It is connected directly to the adjacent spaces without any non-fire resisting facades. Thus, it creates a large opening for multi functions.

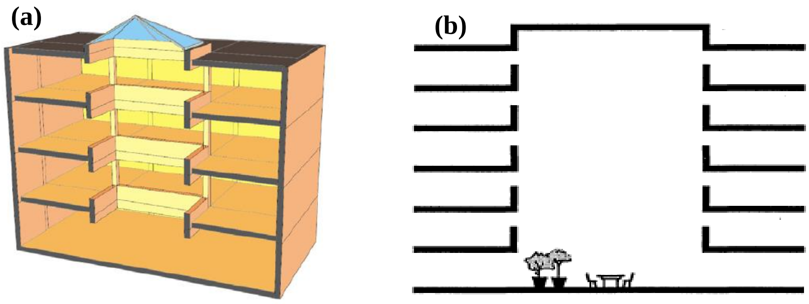

Figure 21: Fully Open Atrium

(Sources: (a) Harrison. R., 2004; (b) Bastings, 1988)

1.9.1.2 Type of The Atrium by Configuration

The shape of atria can be influenced mainly by social potential although the site orientation and project economy have their own places in forming the atria. In 1983, after analysing around 30 atria, Saxon concluded that there are totally nine types of the atrium which are generally divided into the simple form and the complex one.

Simple Form

The atrium form is composed of single sided, double-sided, triple sided, four-sided, and linear atria. As reviewed, the atrium has high flexibility to be applied to different kind of constructions. Hence, simple forms of the atrium can integrate to the small, single buildings as well as large complexes (Fig. 22).

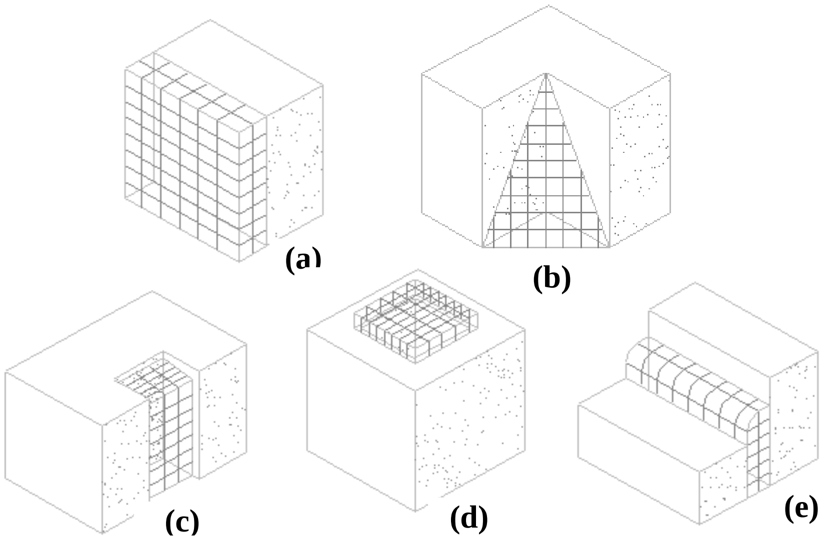

Figure 22: The Simple Forms of Atria: (a) Single Side, (b) Double Sided, (c) Triple Sided, (d) Four Sided, (e) Linear Atrium

(Source: Saxon, 1983)

Complex Form

The second group of atrium in terms of configuration is the complex form. Generally, it is the integration of more than one type of simple atrium which is used in tall buildings and high density development. The bridging, podium, multiple laterals and multiple vertical are the most usable forms (Fig. 23).

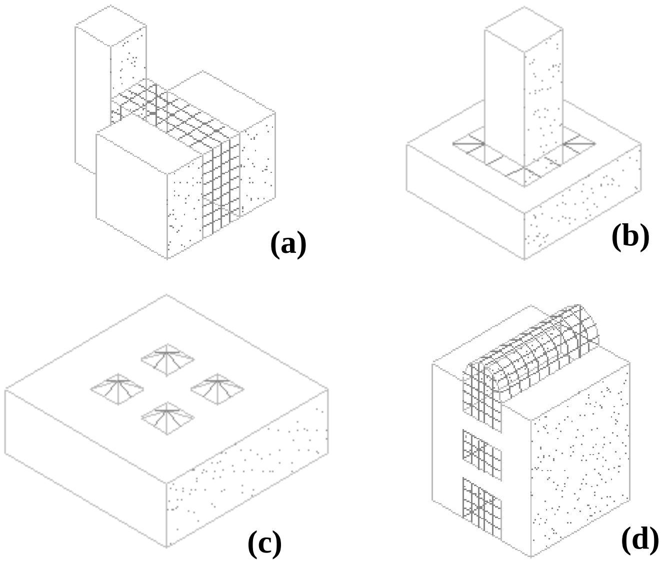

Figure 23: The Complex Forms of Atria. (a) Bridging, (b) Podium, (c) Multiple Lateral, (d) Multiple Vertical

(Source: Saxon, 1983)

1.10 Design Analysis

The design of an atrium with the aim of reaching the maximum level of energy saving depends on several items; these include the roof construction, the glazed roof percentage, the building orientation, the shape of atrium well, the height of an atrium, the materials used in the atrium, the adjacent spaces, etc. The major items which have the significant effects on energy consumption of the atrium are roof structure, shape and height of the atrium. In the following subsets, each item will be developed by discussing on its impacts on the atria.

1.10.1 Roof Construction

A glazed roof, the external skin of the atria, is backed up by the structure which is the major design element in architecture. The careless design of the roof structure brings several major problems in terms of both engineering and energy consumption.

The structure can be positioned internal and external to the glazed surfaces. Consequently, the building has an expose construction which is visible from inside or outside. For an instance, one of the comprehensive external structures of atrium buildings is Lloyd's building in London which was built by Richard Rogers Partnership from 1978 to 1986. This insurance building is the kind of bridging atrium which plays as the orientation and transitional zone among three towers; it is covered by the 12,000 square metres large barrel-vaulted glass skylight with 60-metre height posing on the rectangular space (Fig. 24).

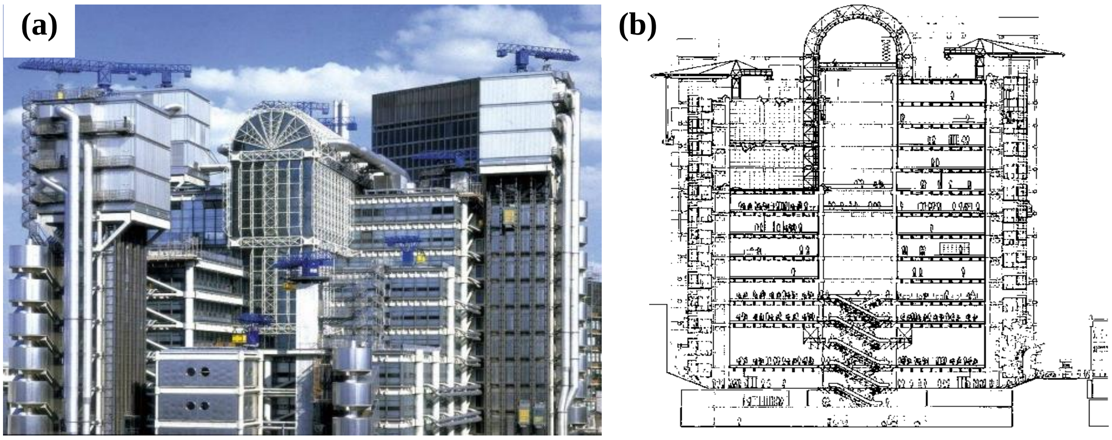

Figure 24: (a) The External View of Lloyd`s Atrium Building, (b) Atrium Section

(Source: (a) http://brst440.commons.yale.edu, (b) http://www.archdaily.com)

Additionally, the internal structure of atria is illustrated by The Co-operative Group HQ in Manchester (Fig.25).

Figure 25: The External View of Co-Op HQ Atrium Building, Manchester

(Source: http://www.building.co.uk)

In 2012, 3DReid designed a sustainable office block with a huge triangular central atrium. The 16 storey building has balconies for each level which overlook the atrium; it offers wide views to the social internal space without internal columns. The atrium span is around 16.5 meters covered by the double glazed and the steelwork. “The structure is fully exposed so that the building is clear and honest and legible in how the concrete and steel come together” said 3D Reid divisional director Mike Hitchmough (Fig. 26).

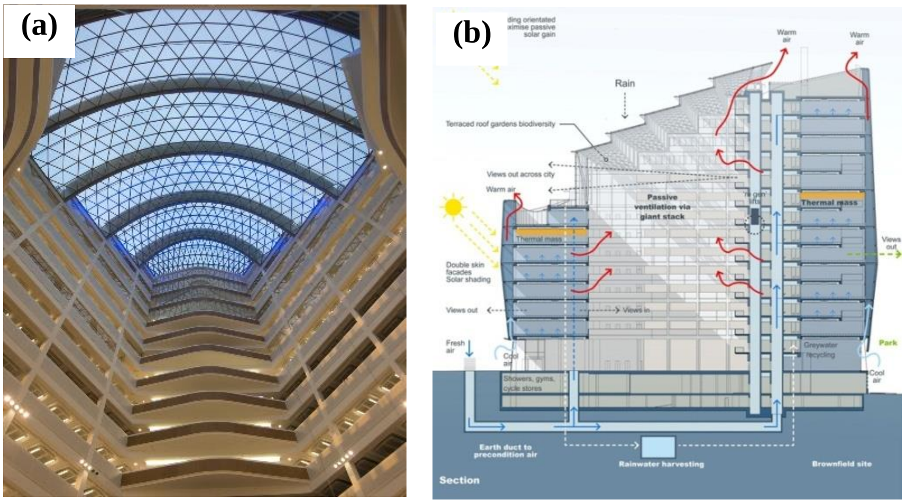

Figure 26: (a) Each Office Level has a Panaroma Outlook through the Balconies, (b) A Secion through the Co-Op HQ`s Atrium

(Source: http://www.bdonline.co.uk)

1.10.2 Shape and Height of The Atrium

The proportions of an open interior court, particularly it`s shapes and height are the core contributors to save energy, reduce dark points, and spread sunlight equally into the atria. As reviewed, the area, subsequently heat loss would be outstretched by increasing the atrium proportion and consequently the need for heating and cooling the atrium buildings is grown, too.

Rennie and Parand (as cited in Yunus et al., 2010) asserted that the shape and height of atria have an impact on daylight performance. By analysing several stimulations, they discovered that generally there are two basic categories from the view point of atrium proportion, the circular atrium well with shallow borders and the four-sided atrium well with tall borders; the result demonstrated that the internal situation of the shallow atrium is better than the deep atrium, and the circular shape received more daylight than the rectangular one. It would be made apparent when the result of the double height atrium well is compared with the low height atrium; the first one reduced the daylight around 5% at the atrium well. Furthermore, Rennie and Parand (1998) suggested that in the tall buildings or skyscrapers, designers should consider the smaller size for windows which are located on the upper levels due to decrease the direct daylight from the top-lit.

In brief, with the evidences stated in several investigations (Sharples and Shea, 1999; Yunus, 2007; Sharples and Lash, 2007; Yunus et al., 2010), the four sided atria especially square shape with the flat glazed roof are the most common atrium form which distribute daylight in an equal manner than the other atria well shapes. Additionally, the wider atrium well can be caught more vertical daylight than the narrow one.

1.10.3 Development in Atria Roof Structure and Fabric

The widespread use of various structures in atrium roofs is based on the innovative technology in construction materials. By the development in concrete and steel framework, architects and engineers are able to cover huge spans of buildings without using columns which are given the panoramic view of internal space. Nowadays, the atria are one of the most favourite architectural components which are used greatly in multi-storey hotels, office buildings and shopping centres. The well-designed of roof structure consists of climate, daylight, fire and smoke management, safety, acoustic, security, and aesthetics. Figure 27 is shown the various structural roof types; considering the usage, objectives, size, materials, and the other complex factors determine the type of atrium roof (Stroud Foster & Harington, 1990).

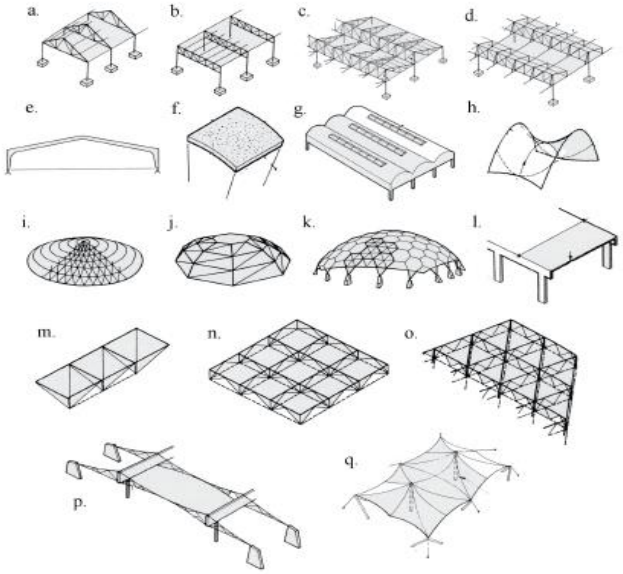

Figure 27: Atrium Structural Roof Configurations:

a.Trussed; b. Girder; c. Northlight; d. Monitor; e. Portal Frame; f. Shell; g. Barrel; h. Saddle; i. Grid Dome; j. Polygonal Dome; k. Geodesic Dome; l. Slab; m. Space Frame; n. Flat Grid; o. Lattice; p. Suspended; q. Membrane

(Source: Stroud Foster & Harington, 1990)

The Other research by Boubekri (as cited in Sharples, and Lash, 2007) underlined that penetrating daylight into the atria wells has significantly affected by the roof structure. His analyses were represented that the flat top roof receives the most daylight although the saw tooth roof admitted a bit less than that one. Additionally, Dewey and Littlefair (1998) stated that the worst type of atrium roof is dome which is caused gloomy inside of the space although Laouadi and Atif (2001) found that a dome form admits the maximum percentage of low sunlight in winter.

On balance, the ideal forms for atrium roof are the rotational forms like dome, lantern and pyramid. The flat roof, supported by lattice or truss structures, has the flexibility to use in which height is limited or where the connection to the existing building is difficult. The slope shape usually uses to take the precipitation away from the atrium building and also it removes the snow load from the glass surface due to prevent the glass from breaking and falling into the atrium space; basically the truss roof system utilizes to support this kind of roof.

In 2002, the eight-story atrium of Endesa’s headquarters in Madrid, Spain was designed by Kohn Pedersen Fox (KPF). It is the flat glass atrium which is well-known in terms of energy efficiency, the dynamic use of new technologies, and environmental conscious. The atrium has the key element to the Endesa building; it plays as the social and transition space for the office space. The height of atrium is around 32 m which is enclosed 3,000 m^2 central area (Fig. 28).

Furthermore, dome or arched roof is inherently aesthetics and reminds occupants of the plaza for gathering. It has the ability to cover each size of atrium openings. Structurally, it is very efficient and minimizes bending stresses.

Figure 28: External View of the Headquarters for Spanish Energy Utility Provider Endesa Fuses

(Source: http://kpf.com)

However, during winter in the cold zone, the arched form admits more sunlight, it causes the snow to be melt, where on the upper curved area; then during the afternoon, melted snow turns into the ice near the glass level of the atrium roof and increases its load. Therefore, these extra loads break the glass part which is very harmful and dangerous for occupants.

The Reichstag dome is one of the sustainable cases which famous as the rebirth landmark of Berlin in Germany (Fig. 29a). It is the new dome of the German parliament which is refurbished by Foster & Partners in 1999. The dome is completely made of glass and steel which permits users to look directly into the chamber of the German parliament. The dome structure is composed of 24 main steel ribs and covered 3,000 m^2 areas by 24 panes of glass for each row (Fig. 29b).

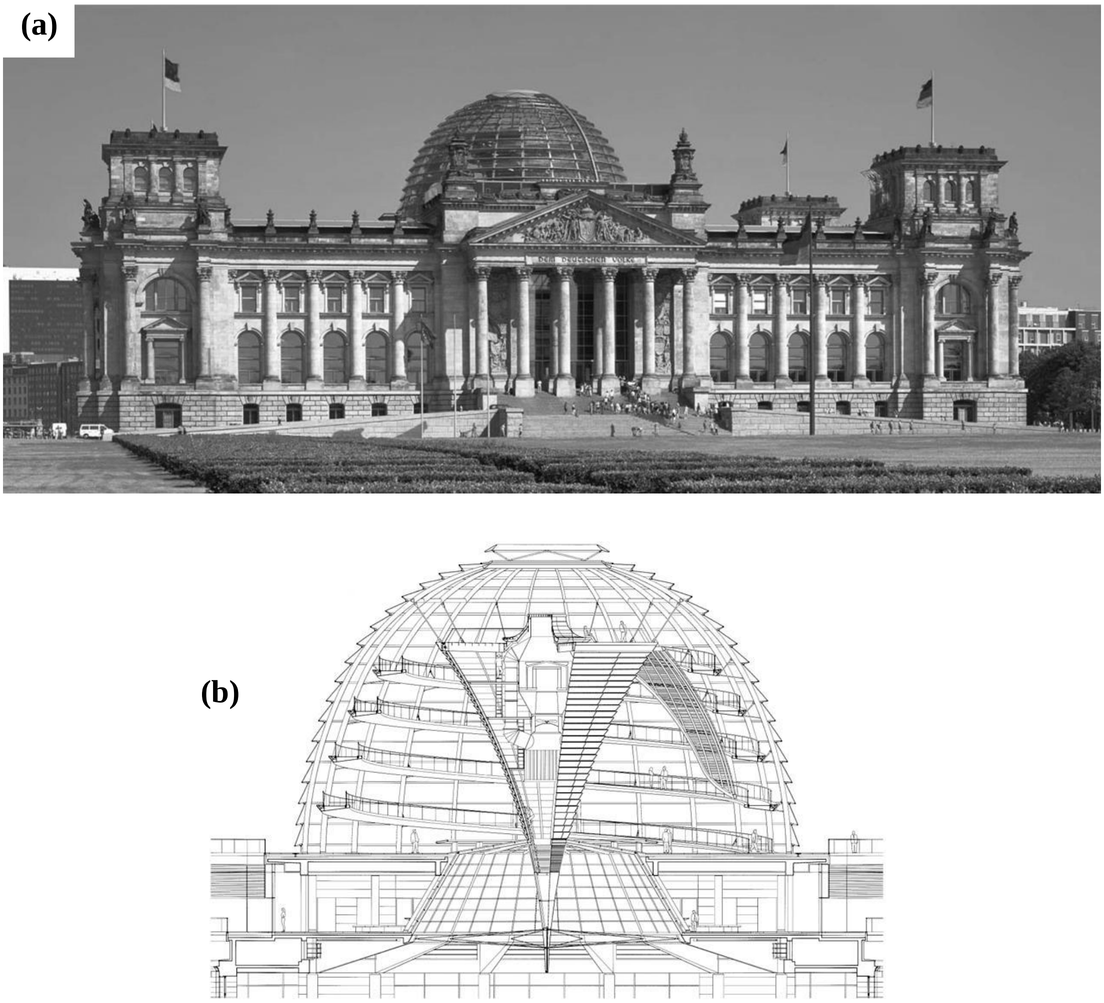

Figure 29: (a) The Entrance View of New German Parliament, (b) The Section of the Reichstag Atrium, Berlin, Germany

(Source: http://www.fosterandpartners.com)

Pyramid forms are essentially steady structures under the vertical load and increase the efficiency and safety of the roof structure. The frame chosen for covering and holding glass components can be a simple one. The point which designers should consider in pyramid roof form is that the roof has to be flat without any projections. The comprehensive example of pyramid atrium roof is the Louvre pyramids in Paris constructed by I.M. Pei. The main large pyramid is the new entrance to the Louvre Museum complex and the new galleries (Fig. 30).

Figure 30: A General View of the Main Louvre Pyramid Seen from the Top of the Inverted One

(Source: http://crystalsimages.photoshelter.com)

1.11 Thermal Comfort

In the human environment, one of the most fundamental considerations which affect human performance and also its health is thermal comfort. Despite focusing on the aesthetic aspect of buildings, a comfort zone should be provided through increasing the quality of indoor air, light, acoustic, and hygiene which is very essential.

Researchers have identified variety definitions for thermal comfort. The simplest, as well as the easiest in understanding the meaning of comfort, is the absence of discomfort. The generic and acceptable definition of thermal comfort supposed by ASHRAE is “that condition of mind which expresses satisfaction with the thermal environment”. This definition reveals that thermal comfort is a wide area and is impossible to define it in absolute terms. When in a built environment more than 90% of its occupants assert their feeling comfortable, it means that the interior situations of the built environment can create thermal comfort which is well adapted to each individual (Table 1).

Table 1: Optimum Operative Temperature and its Acceptable Temperature Range

(Source: Drawn by an Author, Based on ISO 7730, and ASHRAE 55 date)

	Season	Cloth	Operative Temperature Rage (°C)	Operative Temperature (°C)
ISO 7730	Summer	0.5	24.7	23-26.4
	Winter	0.9	22.2	20-24.3
ASHRAE 55	Summer	0.5	24.5	23-26
	Winter	0.9	22	20-23.5

At present, with the growth in technology, more than two third of people prefer to spend the major part of their time in an enclosed environment. Therefore, comfort conditions of enclosed environments are of great importance.

Feeling comfort depends directly on human sensation and indoor climatic factors of a built environment; human sense organs consist of the eyes, brain, ears, tactile sensors, nose, and heat sensors. Besides, Franger (1970), in his analyses of thermal comfort, described that occupants` thermal perception from the built environment would can be influenced by metabolism, air temperature, thermal radiation, air velocity, humidity, and the clothing level. Consequently, the combination of those mentioned factors with the social, cultural, sexual, and age parameters of users would be the response of users to the buildings` thermal environment. These multiple and complex factors are categorized by Brager, and de Dear (1998) into three major groups; cognition, context, and demographics respectively. Besides they added that the built environment even has interaction with the users in terms of indoor air quality, acoustics, and lighting.

It is important to point out that the value of the above factors can be seen clearly in the built area as well as understanding users' satisfaction by the increase in saving energy in the buildings and offering design strategies to provide human comfort economically.

1.11.1 Human Comfort

The need for an internal environment`s comfort for humans dates back to 1919, when human comfort and building`s energy consumption had been affected by the local climate conditions; hence, the interest of installing air conditioners developed rapidly among the buildings, exclusively in tall buildings.

However, analysing human comfort is rather difficult; it is one of the main issues which architects pay attention to. If the occupants` comfort in buildings was meaningless, architects would create series of shelters without any facilities as having fenestrations, low ceilings, or small areas.

Human comfort has been generally influenced by environmental factors. That means when occupants feel comfort from the visual, thermal, acoustic, physical and psychological aspects. To be precise, sunlight is one of the determined factors affecting human comfort which assist people in perceiving their surrounding space. Openings or fenestrations essentially permit users to have contact with outside while providing visual comfort and having both physiological and psychological benefits (Fig. 31).

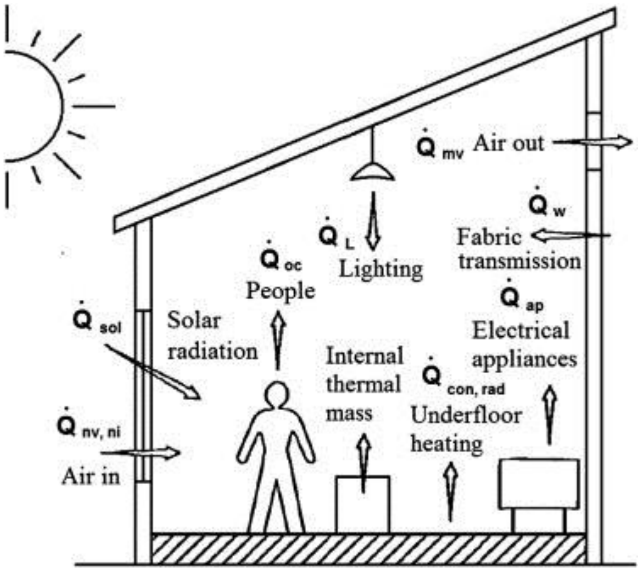

Figure 31: Parameters Affecting Internal Thermal Comfort of the Building

(Source: Counsell, J. M., Khalid, Y. A., & Brindley, J., 2011)

1.11.2 Comfort Zone

Feeling comfortable in the built environment is rather hard to achieve. The term “comfort” means satisfaction of something, so it addresses psychological satisfaction as much as physiological satisfaction. Therefore, providing a comfort zone to make everybody satisfied, which depends on wide variations of human mind changing from one person to the other, is difficult. Various researches and experimentations are undertaken to find out conditions in which a determined range of occupants feel thermally comfortable (Fig. 32). For defining occupants’ perception of thermal comfort, Predict Mean Vote (PMV) and Predict Percentage of Dissatisfied (PPD) are the basic indoor comfort indexes.

Omandy and Ezratty (2012), in their literature review had present that human thermal comfort can be estimated by measuring ambient air temperatures and perception. In this regards, in 1970, Professor Fanger who is master on the health effects of the

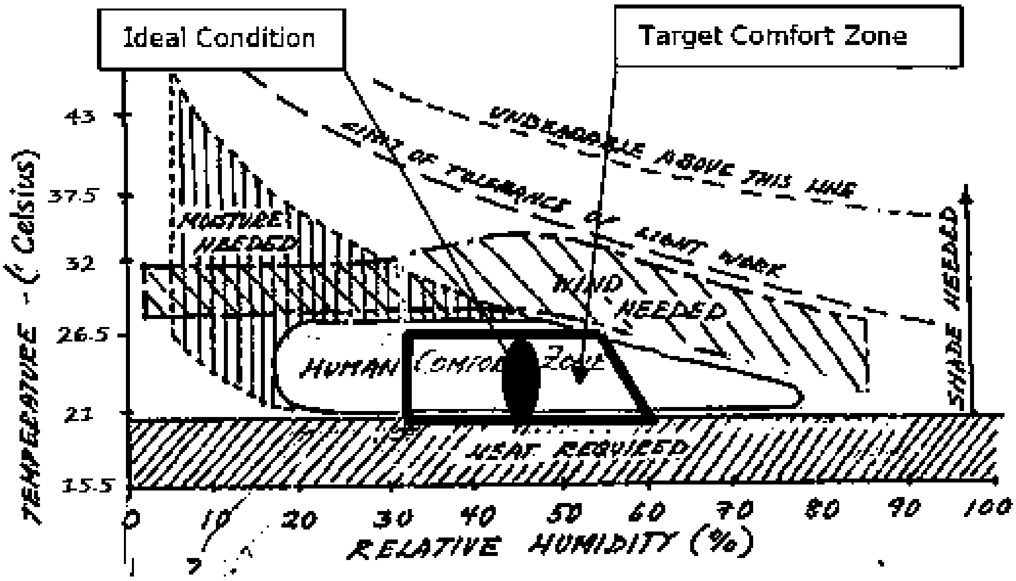

Figure 32: Human Comfort Zone

(Source: http://www.greengaragedetroit.com)

thermal comfort in indoor environments, developed some psychological experiments which are called Predict Mean Vote (PMV) and Predicted Percent Dissatisfied (PPD) for analyzing thermal variables. The Fanger`s comfort scales was confirmed by the American Society for Heating, Refrigerating, Air-conditioning Engineers (ASHRAE, 2009).

Figure 33 demonstrates the PMV index which is the result of the degree of human comfort with various considered items in different air temperature, air velocity, and relative humidity. This scale represents the satisfaction of a large group of people`s responses to the comfort situations of the indoor buildings. The comfort zone in Franger`s scale is between +1 and -1. The second index is Predicted Percent Dissatisfied (PPD). PPD is a function of PMV; it shows the percentage of people who were dissatisfied with the indoor thermal comfort of the buildings. Fanger related PPD to PMV as shown in Fig. 33.

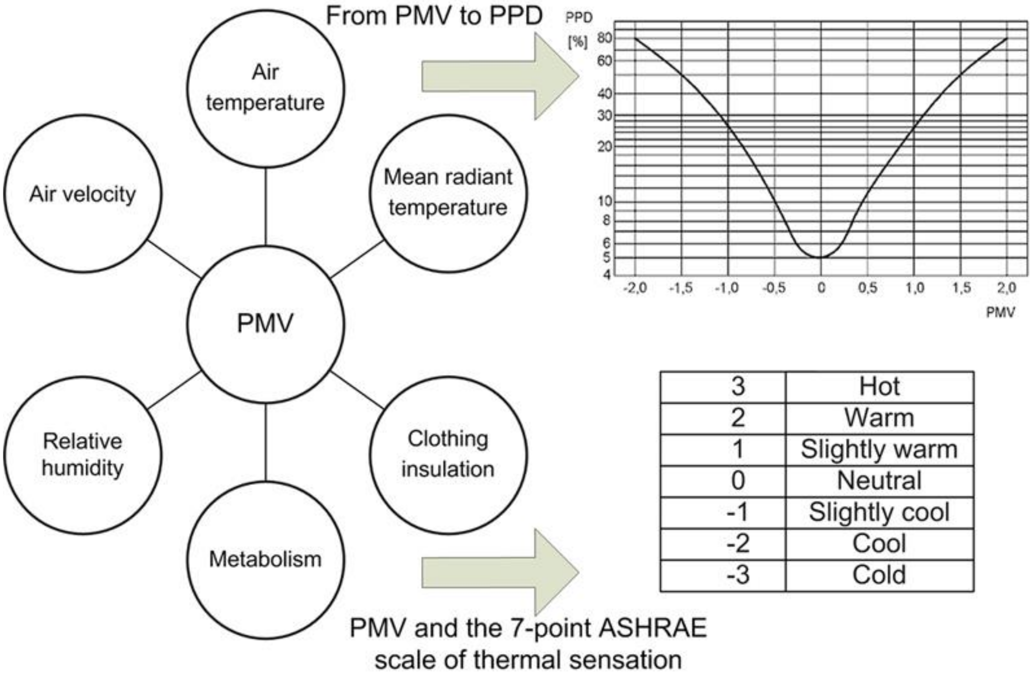

Figure 33: PMV, its input Parameters, its Relation to PPD, and its Expression on the ASHRAE 7-point Scale of Thermal Sensation

(Source: http://www.bioscience.org)

1.12 Literature Review

1.12.1 Passive Solar Strategies of Atrium

Daylighting, heating, and cooling are passive design strategies of an atrium, which are called passive solar designs. Passive solar design means the process of collecting, storing and distributing solar energy. In order to provide a good atrium design, it is essential to analyse carefully the interactions of the daylight, heating and cooling requirements with not only the atrium space but also the adjacent spaces. When these design strategies work properly in combination with each other, the yearly cost of consumed energy would significantly reduce and the indoor space situations would become very close to the human comfort zone.

The main goals regarding why atria are chosen as a base of passive solar strategies are to block out the heat produced by sunlight, to avoid greenhouse effect, to ventilate the building impressively in hot summer days, and to have it perform as a solar collector in the winter time so to heat the interior spaces of the buildings. To respond appropriately to the thermal environment of atrium buildings, the atrium design should consider carefully the local site details and its climate conditions. By considering the local context conditions, atrium would be able to act as a good thermal buffer zone between the outside and inside spaces, due to making a thermal balance.

1.12.1.1 Daylighting in Atrium

The simplest daylight strategy as the source of light in atrium buildings is to cover large areas of the building with glass; whether the roof, wall, or the combination of both. The two superiorities of entering daylight into the building compared to other advantages of the atria are making inside of the building full of light, and eliminating the heat and poor quality of artificial light. What proved true in the numerous investigations on atrium daylighting are having advancement in socialization and interaction of the people, reviving the indoor space especially in deep-plan buildings, preparing impressive spaces, increasing the great benefit of direct solar gain, contributing to resolving the general problems of acclimatization and natural ventilation (Bednar 1986; Saxon 1986; Bryn 1993; Hung et al., 2001).

Through daylight design for buildings by Baker and Steemers (2002, p. 25), the architectural and historical role of daylight has become the bridge between romance and prosaicness. The strong needs for having aesthetic and reducing the usage of artificial lighting in the modern architecture have caused integration between daylight quality and its quantity which offers architects to reach a remarkable and sustainable architecture.

In addition to increasing the quality of daylight in the atrium space, some general daylight rules covered in Saxon`s book, *Atrium Buildings-Development and Design* (1983, pp.66-68) are summarised as follows:

- Providing suitable diffuse surfaces for adjacent atrium borders to reflect and transmit daylight into the down spaces of atrium
- Penetrating natural light into buildings without interrupting the thermal strategy of the atria
- Diffusing the direct sunlight to distribute light equally through the atrium space
- Having an appropriate combination between natural light and artificial one by control and arrangement
- Receiving the maximum daylight by a proper orientation of atrium form, structure`s orientation, and by means of a light shelf

In this regards, 1 Bligh Office Tower in the centre of Sydney is one of the successful examples in using the efficient daylight in atria (Fig. 34).

Figure 34: A General View of 1 Bligh Office Tower

(Source: http://www.archdaily.com)

The office tower, designed in 2011 by Ingenhoven Architects + architectus, received the highest award in the Australian “Green Star”-standard. The thirty storey building is shaped by the solar orientation and view corridors (Fig. 35).

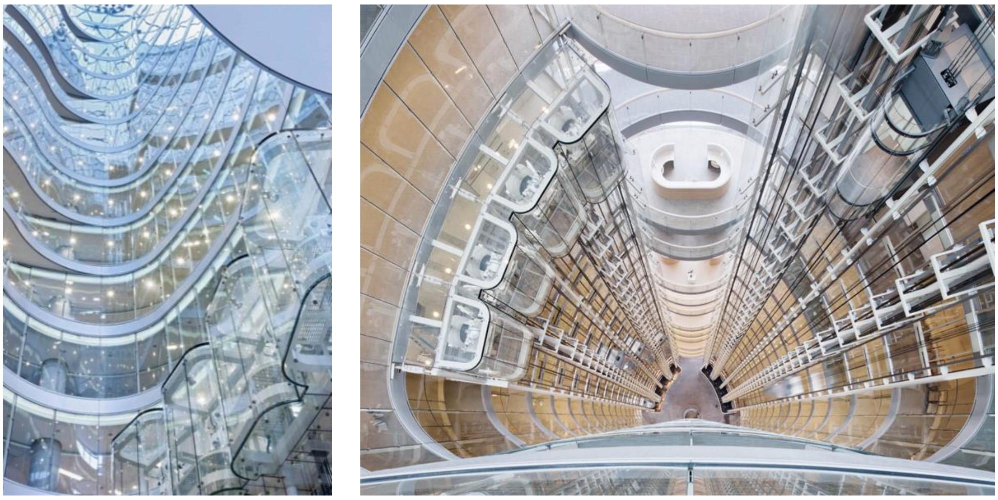

Figure 35: The Interior View of 1 Bligh Street, in Sydney

(Source: http://www.detail-online.com)

As in Göçer et al.`s (2006) research was mentioned, the glazing system on the external surfaces caused a reduction in solar gains and heat loss; moreover, using the transparent materials such as glass for internal atrium space surfaces caused admitting more sunlight into the atrium space. In this case, the transparent materials for internal and external surfaces are not only used to catch more sunlight into the building, but also to offer the widest unobstructed views toward the world famous Harbor Bridge of Sydney.

Alternatively, several studies have been done on the combination of daylighting and thermal strategies in atrium buildings. The result of Demers and Potvin`s research (2007) illustrated that the quality of daylight, reduction in the cooling load, and also decline in the heating load in the atria are directly related to each other. Demers and Potvin reached the point that during the cold seasons, it is important to maximize passive solar heating by admitting a low angle of sunlight, whereas reducing the heat glare effect of the direct sunlight in warm seasons or the seasons between cold and warm. By testing several atrium roof types (opaque, sawtooth, four-sided roof), sawtooth has been proved to have the greatest impact on thermal aspects than the other roofs. Consequently, this research suggests that in order to optimize the thermal comfort through daylight, it is better to consider the angles lower than 60°; otherwise, the sunlight angle which is higher than 60° being to be reflected over 80% of their value.

It is very essential to achieve internal thermal comfort in the atrium space by high quality daylighting. Controlling the diffusion of sunlight and the daylight intensity are key criteria in the lighting design. Among various criteria which affect the increase or reduction of solar gains and glare problems, the light collecting system and the reflectance of the adjacent wall surfaces of the atrium are very important in controlling the daylight problems.

In this regard, Fuziah, Azni, and Shuzlina (2004) found that the highest daylight can be obtained at the centre of the atrium ground floor. Hence, the location, orientation, size, and also well-shading of atrium fenestrations are crucial to provide comfortable indoor space in terms of thermal and lighting aspects. It was suggested that the integration between atrium fenestrations and transparent shading devices is the optimum solution to have an unobstructed visual while reducing the heat gain from atrium fenestrations.

It can be concluded that a design target of atria is to create a thermally comfortable zone while providing sufficient daylight for all indoor atrium spaces with respect to energy saving. It means that these two mentioned items should work together, so to reach a certain quality of life (Demers, and Potvin, 2007).

1.12.1.2 Heating Strategy for Atrium

As argued before, one of the key roles of atria are to act like a buffer which maintain the average stable temperature and reduces thermal transmission for indoor spaces. Atria are able to make a balance between the external environment and the internal spaces of the buildings; moreover, there is no need to heat the atrium space, because they increase the quality of their adjacent environments by distributing the heating load, which takes place through sunlight.

One influential point in designing atrium is the extent to which atrium space and adjacent spaces are well connected to each other. Besser, Rodrigues, and Lau (2011), from their analyses, understood that the absence of connections between mentioned spaces, prevent the distribution of solar heat gains to transmit into the surrounded spaces from the atrium space. The result of analyses on the two-storey atrium building demonstrated that during the cold weather, interior space refresh properly by natural ventilation.

In contrast to the cold seasons, the atrium building cannot supply the fresh air requirements in warm weathers. The main reason is the lack of connection between atrium and adjacent spaces. Even the stack effect does not have enough power to replace the excess heat gained from the atrium space to the surround spaces. It means that the atrium space is not only able to ventilate its space, but also causes its adjacent spaces not to ventilate very well; additionally, heating load and an exhausted air in the adjacent spaces increase to provide an uncomfortable situation for occupants, as well as increasing the need of cooling load.

In order to maximize solar heating usage in the cold seasons and prevent interior atrium spaces from overheating in hot seasons by solar gain, atria apertures should be designed on seasonal and diurnal climatic variation; it is generally suggested that apertures should be oriented toward south. Studies showed that the atrium building which is located toward north or south, has reduced the heating energy consumption around 50%.

1.12.1.3 Cooling Strategy for Atrium

The most proportion of energy consumption of an atrium space belongs to the electricity need which consists of artificial lighting, air condition and ventilation;

generally, the dominate electricity consumption usage for cooling the atrium space among the electricity needs is ventilation.

The glazed part of atria is inherently affected by the outside conditions. By extending the glazing area, however, daylight increases, so it allows a lot of direct sunlight to enter the building and overheat the indoor space. In having the purpose of reaching thermal comfort in atria, natural ventilation at night, and controlling the amount of undesirable sunlight to prevent solar gains, are more fundamental than the other ways.

Geros, Santamouris, KaraTASou, Tsangrassoulis, and Papanikolaou (2005) clearly represented that the natural ventilation strategy at night is an effective strategy which technically can decrease the cooling load produced by air-condition roughly up to 90%. Additionally, efficient air flow, thermal capacity, and different temperature between outside and inside of the building during the night have strong impacts on the natural ventilation.

Atrium has been designed as a solar chimney that increases the air movement. Therefore, the geometry of an atrium tower and its linkage between atrium and adjacent spaces are very remarkable in providing cooling requirements of the building. The correct geometry of an atrium can have a significant influence on exchanging the exhausted and heat flow by the thermal radiation. Moreover, time period also has a remarkable impact on air movement; it is stated that during the daytime, the air movement can be increased in the lower level of the atrium by natural convection (Voeltzel, Carrié, and Guarracino; 2001). Berkovic, Yezioro, and Bitan (2012) stated that in the hot summer days, solar radiation mainly effects human comfort. In this case, the orientation of atrium space is very important to determine the amount of shade which is produced by the atrium geometry for inner part of the building.

Shafqat, and Oosthuizen (2013) used the CFD model[5] to analyse the effect of buoyancy-driven ventilation and its various parameters on the thermal comfort of a three-storey atrium building. The analyses demonstrated that if the height of atrium tower be increased, sufficient air pressure would be produced to induce the air movement from the atrium to adjacent spaces. In contribute with maintaining the equal comfort conditions in each building storey, the inlets and outlets should be considered near the ground and on the top of the side walls, respectively. The point is that this method would be effective only when the opening proportions of the outlet are equal to the inlet openings for each storey. Mainly, the exhausted air flows transmit from the building through the atrium space and go out from the central outlets which are placed on top of the atrium tower.

Karava, Athienitis, Stathopoulos and Mouriki (2012) stated that providing passive solar cooling through night cooling needs the building`s thermal mass which is functional in various climates. If the atrium design was based on the passive solar cooling, the indoor atrium temperature would strongly depend on solar radiation. Experiences of Karava et al. (2012) demonstrated that a tall atrium space with a high-glazed top lit assists the transmission of buoyancy-driven airflows to increase. Additionally, the cooling load saved in the building`s thermal mass can be enhanced by the low streams of internal air flows during the night. Hence, profound ventilation

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[5] CFD is abbreviation of *Computational Fluid Dynamics* which creates a fluid flow and thermal simulation of building before manufacturing to analyses the building behaviour and optimizes designs.

at night with the outdoor temperature is able to reduce cooling demands in the atrium building.

According to Breesch, Bossaer, and Janssens (2005), there are four concerns to achieve: reducing cooling loads of an atrium building, minimizing the heat emission of building`s equipment, using external shading devices particularly in south facade, and reducing the solar heat gains by interior spaces. So, in contribution to passive solar cooling, using shading devices and cross ventilation can be complementary strategies in the atria during the summer time. The point about designing a shading system is that besides controlling the unwanted solar radiation, a poor design of shading devices can decrease the lighting of indoor atrium environments.

1.12.2 Thermal Performance of Atrium

Scientifically, in human body, heat transfers by convection, conduction, and radiation. This transferring continues till the temperature of a human body reaches thermally to a balance situation. In connection with what mentioned, heat loss or heat gain is also defined as when heat penetrates from beyond the building into the interior spaces through its surfaces, and thereafter building gains temperature; it also can happen inversely.

As stated earlier, generally the criteria which determine the thermal performance of a building have been revealed. Among the various criteria, climate has the key role which affects greatly on the indoor thermal comfort of the atria. Maintaining and predicting the thermal behaviour of highly-glazed spaces such as atrium are very difficult although these types of buildings are extremely attractive. The building designers have to keep the heat balance between inside and outside of the building to provide a comfortable built environment for human life. Undoubtedly, thermal comfort is somehow subjective and complex regarding providing satisfaction. Nowadays, predicting the thermal condition of the building before constructing is available using computer simulations. This possibility offers designers and architectures a wide area to analysis their building by various parameters so to reduce the energy consumption of the building.

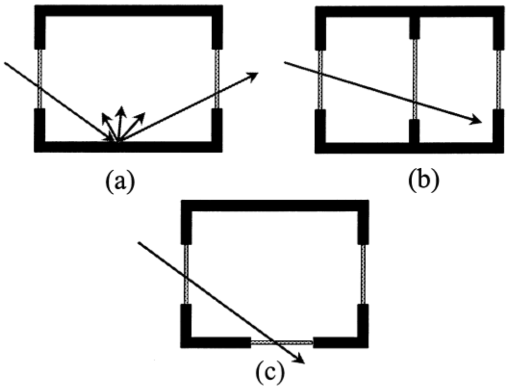


Figure 36: The Different Ways of Reducing the Sunlight heat Entered into the Building (a) Retransmit to Outside; (b) Direct to the Adjacent Spaces; and (c) Direct Retransmission

(Source: Voeltzel, Carrié, and Guarracino, 2001)

In spite of the fact that an accurate orientation of atrium buildings is substantially important, the poor design of it may result in receiving more negative variations of climate which needs the high energy requirements to reach the comfort zone. It should be considered also that solar radiation has shortwaves; technically, when the shortwave enters into the building from glazed surfaces, it changes into longwave solar radiation which is why the interior temperature of the atrium buildings increases. As seen in Figure 36, there would be solutions to reduce solar radiation heat attainment such as keeping the inside brightness by leading direct sunlight toward outside or adjacent areas, or reflecting the sunlight toward outside. An investigation done by Wall (1997) demonstrated that the entered sunlight to the glazed buildings can reflect around 10 to 70 percent of the whole solar radiation.

According to Laouadi, Atif, and Galasiu (2003), design parameters of top glazing buildings can affect the annual energy usage and thermal performance in cold climates; these examined design parameters consist of the proportion of fenestration surface, skylight and atrium form, fenestration types, and the connection between the atrium and its adjacent spaces. Respectively, the findings represented that:

- An atrium with a 100% glazed area has the worst situation among the others (enclosed, three-sided, and pyramid/pitched form). It increases the discomfort situation as well as cooling needs.

- The pyramid skylight in three-sided atrium building is more efficient in cooling load than the other one in the linear atrium. Additionally, to increase the annual heating of the skylight building the U-value of the fenestration and also the solar heat gain coefficient (SHGC) should be considered.

- And finally, the adjacent area of an enclosed atrium needs less cooling load than the three-sided and linear ones; however, producing heat load could be decreased in the linear atrium throughout the year, compared to the enclosed and three-sided ones.

Moreover, it took Laouadi, and Atif`s (1998) attention to compare the results of the field measurements with the ESP-r software − a building performance simulating program − on an enclosed three-storey building with a pyramid skylight. The analysed parameters were predicting the incoming solar radiation and while measuring the indoor temperature of the atrium space. Results belong to only weekends when nobody was using the atrium space with the HVAC system. Some of the results should be highlighted as follows:

- The temperature measurements for both winter time and summer time represents that there is an agreement between the ESP-r predicted results and the field measurements; the difference was around 4°C, however, the predicted temperature was higher than the measured one (around 2-3°C).

- Nevertheless, the best agreement can be seen between the measured and predicted solar radiations, in the summer time; the predicted solar radiation is around 20% under the measured one.

Consequently, the results of both computer simulations and field measurements demonstrated that during the cold seasons the temperature stratification was very weak, compared to the hot seasons when they were pronounced. It becomes clear that the temperature stratification in the glazed atrium spaces mainly depends on solar radiation and electrical lighting.

According to Chenvidyakarn (2007), sunblinds or shading devices, spatial organisation, appropriate materials and textures, and proper building direction, as well as well-designed vegetation are the other parameters which influence thermal comfort. To reduce heat gain by solar radiation, the appropriate insulation should be utilized; Chenvidyakarn recommended that heavyweight and lightweight materials should be used respectably for the buildings which are occupied predominantly in daytime, and the ones occupied during the night.

In addition to using low and high absorptivity surface materials, Wall (1997) had examined the effect of sunlight absorbed on thermal performance of the building, by glazed spaces and other zones, in variable seasons and sunlight angle. There were large differences between absorbing and distributing solar radiation by highly-glazed buildings in summer time and winter time. Dark surfaces attracted around 45% to 60 percent compared to lighter surfaces with attracting 20% to 58 percent in winter. During the winter time, around 90% of the solar radiation was absorbed by both surfaces while in summer time most of the solar radiation was reflected by light surfaces and absorbed by dark ones.

Furthermore, Stec, Van Paassen, and Maziarz (2005) reminded that application of plants is one of the basic passive thermal strategies which composes of several benefits such as improving the space acoustic by absorbing, diffracting and reflecting noise, expanding the relative humidity, producing oxygen well as reducing CO2, increasing thermal insulation, filtering air, increasing the interior quality of atrium space, and finally increasing the psychological positive effects.

In brief with the reasons stated above, to maximize the thermal buffering characteristics of atria, designers must understand the local climatic conditions and know how different atrium types respond to different climates. Building forms and fabrics have to work much closer through the use of modern materials and analytical techniques. The building envelope should therefore be carefully chosen according to the nature of the site and also environmental criteria. Only through this process of selection and adoption can an energy efficient and climatic responsive atrium design be generated.

1.12.3 Natural Phenomena of Atrium

Creating a highly-glazed built environment for human may bring some problems besides their physical and psychological benefits. Consistent with the architects and designers' intention of increasing indoor thermal comfort and also reducing energy consumption in atria, greenhouse and stack effect which are two main natural phenomena, can directly influence the building performance; whether their effects be positive or negative.

1.12.3.1 The Greenhouse Effect in Atrium

Design of a new atrium can act like a greenhouse. The greenhouse effect usually happens in the multi-storey spaces which are equipped by skylight or side wall glazed. Greenhouse effect is caused by trapping the income short-wave sunlight in the atrium space; re-emitting the sunlight through the glass with the long-wave is impossible and increases indoor temperature.

In cold seasons, the greenhouse effect can be used to improve atrium buildings by bringing warmth, helping atria to moderate the interior temperature, protecting interior spaces from extreme differences of diurnal temperature, as well as keeping wellbeing inside on cold days. In order to conserve energy, it is worthy to gain the solar radiation during cold seasons, and store it into massive materials like stones; then, using the stored heat during the following days and nights makes the inside part of the building warm and decreases the heating load (Fig. 37).

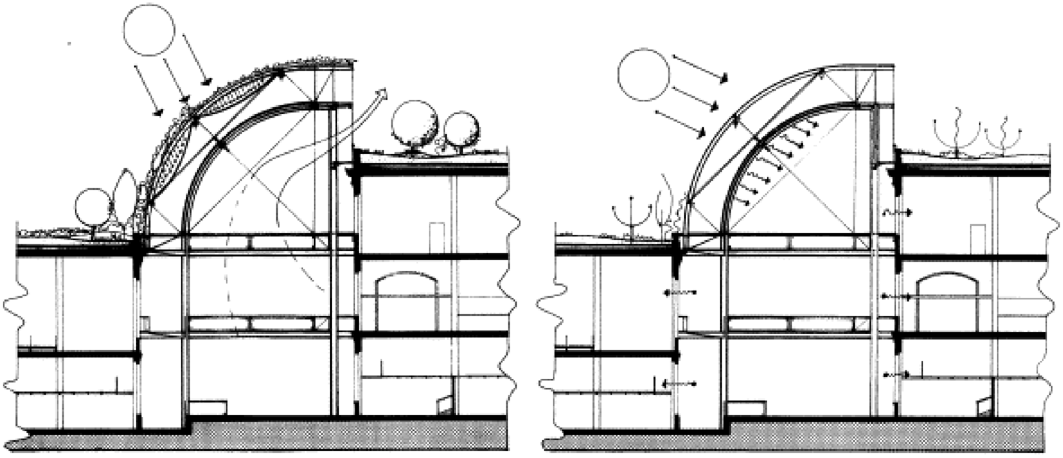


Figure 37: Atrium Sections which Reveal the Thermal Performance during (a) Summer Period, (b) Winter Period

(Source: Ferrante, and Mihalakakou, 2001)

Contrariwise, plants can be extremely hurt by the negative aspect of greenhouse. The air temperature on the higher levels of the atria upsurges rapidly than the lower levels when attracting direct sunlight; and it causes the tall plants damage more quickly than the short ones or shrubs. To prevent the higher air volume from heating more, effective recirculation from upside of the atrium to downside or directing exhausted and warm air to the outside of building should be considered. Additionally, occupants` activities and artificial lighting help significantly in rising the indoor temperature. Therefore, the need for cooling load would increase and energy usage would correspondingly cultivate directly.

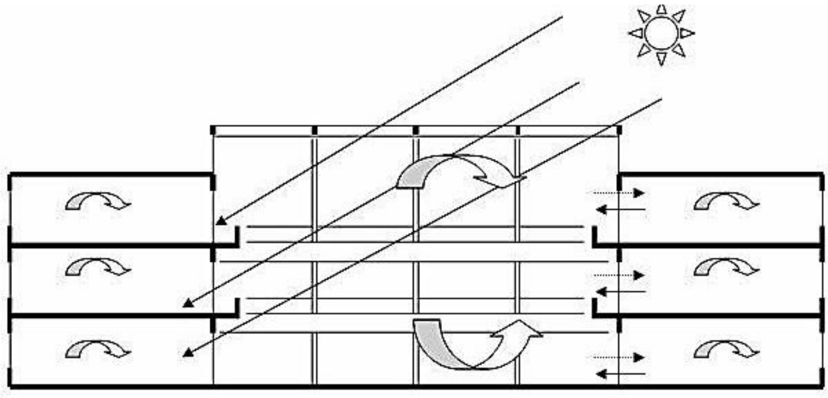
1.12.3.2 The Stack Effect in Atrium

In the atria, stack effect can be increased to promote the indoor air quality of the building for occupants. What is known as ‘stack effect’ ventilation is a driving force of airflow which moves through the building from the lower levels of the atrium to the top levels by the difference in the inside and outside temperature. Stack effect ventilation is kind of natural ventilation which decreases the energy usage and induces an outflow to go up through vertical pressure; then an exhausted inflow to go out through outlets on the top of atrium space to bring fresh air plus remarkable free ventilation and cooling load for both residential and office buildings.

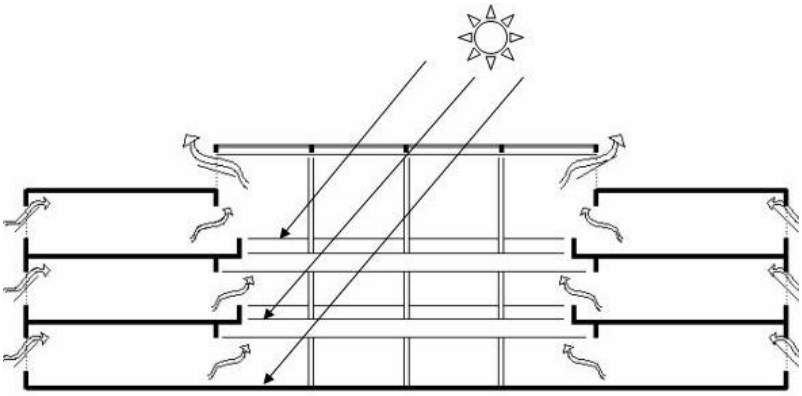
The uniform open space of atrium, with its high glazed roof or side glazed wall, helps to increase the effectiveness of natural temperature stratification, and subsequently the stack effect. Awad, Calay, Badran, and Holdo (2008) believed that high-rise atrium buildings do not usually enlarge the air flow pressure. Outlet and inlet openings which are located in the dominant wind direction enhance the natural ventilation flow. Hence, ventilation flow rates and the stratification interface height should be considered to maximize the benefits of natural ventilation design.

Looking from another point of view, stack effect can contribute to the distribution of fire smoke through vertical access and particularly an atrium space. During the fire hazard in atrium buildings, smoke goes rapidly to the upper levels by stack effect through the open atrium space, stair shafts, and also elevator shafts. Based on Su, Lin, Shu, and Hsu`s (2011) research results, occupants have a short time to evacuate the buildings which are equipped with the outlets posed on top of the building, especially atrium buildings; because stack effect provides invisible hot situations in vertical accesses which are the only way for occupants to evacuate. The experimental results verified that to control smoke during the fire, the opening position should be changed from up to the lower levels or the upper outlets be closed and the lower ones get opened.

In overall, a powerful stack effect offers inflow on lower floors. Effective wind and stack effects are driven from ambient situations, the imbalancement of the mechanical ventilation system, and construction looseness. The important advantages of the well stack effect design are to enhance thermal comfort by providing effective air movement in the harsh climate, maintain the air quality by admitting fresh air in highly isolated buildings, as well as removing heat from inside of the building during the summer time (as seen in Fig. 38). In the figure, percentage of replacing or transmitting air volume between the atrium space and the adjacent space is given as input data.



Winter Time



Summer Time

Figure 38: Stack Effect Ventilation during Winter and Summer Time

(Source: Göçer, Aslihan, and Özkan, 2006)

1.13 Field Study Analysis

1.13.1 The Building

The study has been carried out in the Colored Building, an educational building which is a part of the Architecture Department at the Campus of Eastern Mediterranean University in Famagusta, North Cyprus. This building was selected to investigate the effect of its interior atrium space, adjacent spaces and classes on the thermal comfort during the whole year.

The Coloured building is a three-floor building, with a rectangular shape in plan. The atrium analysed in this study is a four-side form in plan with 10 m × 13 m area, covered by the gable roof that is sited immediately on the truss structures. Each storey contains on average 7 classes and studios. Library, seminar room, archive rooms (with 4.5m height), cafeteria or restaurant, storages, and restrooms besides internal corridors are the physical environment of the building. A notable feature of this atrium is its being emphasised as a social space, and not just as a transitional zone.

The above explanation and also observations of the current position of the field study were recorded in detail and images were taken in order to give a better understanding and a closer view of the building, as well as to realizing the situation of thermal comfort in the Coloured Building. Field visits took several weeks as the building was spacious having more lots of parts and windows (Fig. 39, 40, 41, 42).

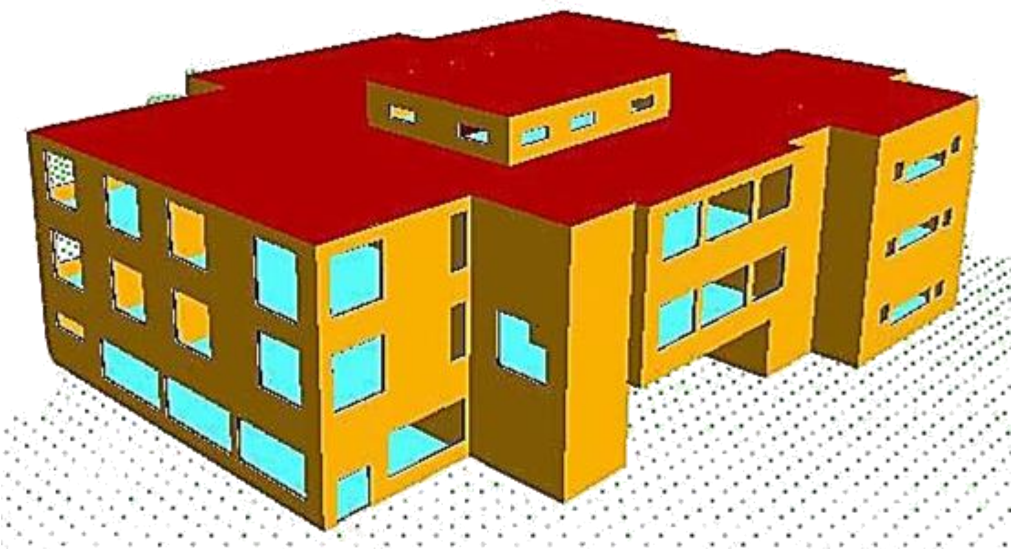


Figure 39: 3D Modelling of Coloured Building via TAS Software

(Source: Drawn by an Author)

Figure 40: Interior Views of the Coloured Building`s Atrium

(Source: Taken by an Author)

Figure 41: External View of Coloured Building Atrium Tower

(Source: Taken by an Author)

Figure 42: Roof Structure of Atrium

(Source: Taken by an Author)

1.13.2 Climate Condition of Famagusta, North Cyprus

Famagusta (Gazimağusa/Mağusa in Turkish), is a coastal city on The Eastern Part of Cyprus (35°12'N, 33°57'E) being 1 m above the coastline. The Mediterranean Sea passes from the east side of the city, and there is a seasonal lake near the city centre (Fig. 43).

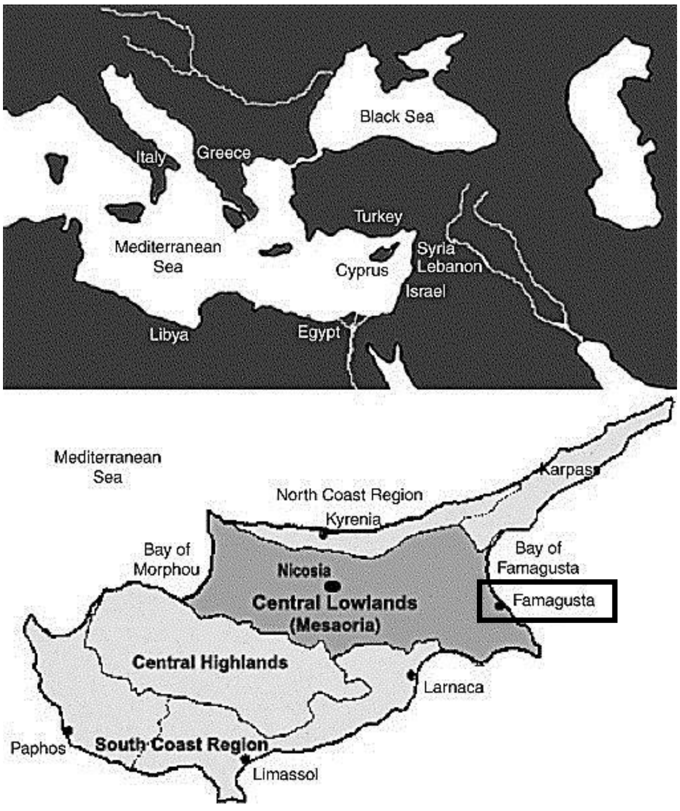


Figure 43: Location of Cyprus and Famagusta

(Source: http\\:www.kktcmeteor.org, 2013)

Bar-Matthews, Ayalon, Gilmour, Matthews, and Hawkesworth (2003) asserted that Asia, Europe, and North Africa`s climate patterns have affected Cyprus climate. According to Köppen climate classification signs, Famagusta lies in the Csa and Bsh climate region − Subtropical climate-Mediterranean and Semi-arid − (Peel, Finlayson, and McMahon, 2007). The average annual temperature in this climate is 19.5 °C, the amount of precipitation is 430 mm, and the average annual solar radiation is around 417.3 Cal/Cm2 (Calories per Square Centimetres). According to

Cyprus meteorological reports, mean relative humidity recorded is approximately 61.6% throughout the year. The hottest month is July when the maximum and minimum mean temperatures are 34 °C, and 22°C; whereas the coldest month is January. For January, maximum and minimum average temperatures are 6°C and 16°C, respectively. An interesting fact is that Cyprus temperature would not usually reach below 0 °C (“Climate and Weather of Famagusta,” 2010) (as seen in Figure. 44).

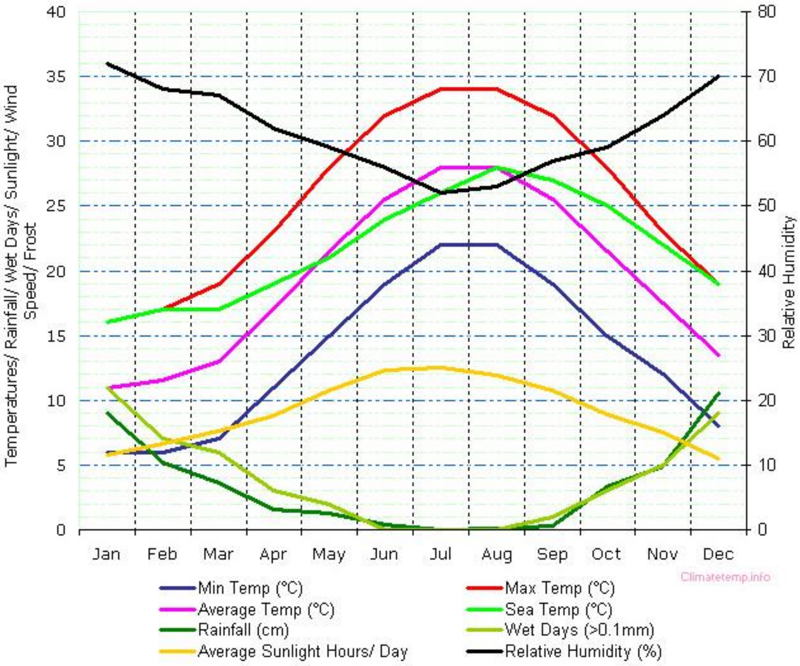


Figure 44: The Annual Graph of Famagusta Climate
(Source: http://www.famagusta.climatemps.com)

For creating building simulations in the present dissertation, the climate database, based on an hourly time-series which include: global radiation, cloud covering factor, internal and external dry bulb temperature of each zone and the selected building, relative humidity, and wind speed and its direction was considered. The weather database utilized is a collection of Famagusta weather reports developed by the American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE); it was the result of the Research Project 1015 and its included information is appropriate for performing building energy calculus based on computational simulations.

1.13.3 The Atrium Building Problems with Hot and Humid Climate

The fundamental purpose of various buildings is to be responsible for safeguarding human life and health, and to protect from the harsh climatic parameters, in addition to providing a comfort zone for working.

Nowadays with the non-renewable resource crisis, building industry has encountered a challenge to minimize its energy consumption while providing a desirable indoor climate for the built environment which is the most important aim of any designer or construction company in the world; even it has been stated in numerous researches to be the only most important goal of an atrium building (Laouadi, 2002; Taleghani, Tenpierik, and van den Dobbelsteen, 2012). A good understanding of human comfort needs and building`s energy efficient, economic, region and comfortable conditions assist architects and planners to erect the atrium building which responses to unifying ecology, technology, biology, and even media parameters in an aesthetic experience.

Employing passive environmental solutions, to adapt appropriately to local climates and take better advantage of natural energy resources, has been found very popular in the recent decades. Providing thermal comfort in atrium buildings is the key factor in the building industry, specifically in rough climates. As stated in the literature, only atrium buildings which admit natural light, serve as eye-catching setting, offer several urban design, being a public plaza, act as a buffer zone to reduce energy transfer from outside to the outdoor environment would be able to achieve passive heating or cooling, ventilation and daylighting (Bednar, 1986; Atif, 1994; Du & Sharples, 2010).

Generally, the hot humid zone is characterised by the high amount of incoming solar radiation, relatively high humidity, and also high environmental temperature. However, Cyprus has a hot humid climate, because of the coastal situation, it has relatively high humidity, heat loss during the cold seasons, as well as gaining highly heat in hot seasons. The quantity of researches focused on the most influential surrounding environmental factors which influence indoor thermal comfort and energy conservation of buildings in hot humid climate. It was found that building form and optical, context and orientation of the building, distance between buildings, and thermophysical[6] properties of the building envelope (Hanna, R., 1997; Yılmaz, Z., 2007; Zain, Z. M., Taib, M. N., & Baki, S. M. S., 2007; Manioğlu, G., and Yılmaz, Z., 2008)

In this present thesis, a current situation of the Coloured building atrium has created unsuitable condition for its occupants in terms of thermal comfort. By considering the thermal comfort review, the observation of building demonstrated that the poor design of atrium roof material, its profile and structure, the lack of strong natural ventilation and stack effect have brought several problems as followed:

- A lack of regulate air circulation to bring fresh air
- The high rate of relative humidity
- The growth of indoor heat gain during the hot seasons

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[6] A Thermophysical property is defined as materials characteristics that are affected by vary items like pressure, composition, and temperature without changing their chemical identity.

- The growth of indoor heat loss during the cold seasons

1.14 Dynamic Thermal Building Simulation

Nowadays with the rapid advancement of technology, various computer software and simulation techniques offer the opportunity to calculate the quantitative aspect of thermal comfort. These computer modelling programs provide widespread facilities that enable designers to predict, analysis, and compare their building simulations under the real design parameters.

Principally, these types of software are designed to give relatively the best design solution due to save energy and provide comfortable environment for human. Among thermal simulation programs, TAS software is a possible method for making building simulation, calculating its thermal performance based on the ASHARE standards, and predicting the comfort zone for building occupants.

1.14.1 An Overview of TAS Application

TAS is abbreviated for Thermal Analyser System which was invented by *Environmental Design Solutions Limited* Company to analysis thermal performance of the building. EDSL TAS (TAS SOFTWARE, 2012) has a modular design which consists of three fundamental programs: the 3D Modeller, Building Simulator, and Results Viewer. This dynamic thermal simulation software predicts internal thermal situation based on the main six parameters (metabolism, air temperature, thermal radiation, air velocity, humidity, and clothing level) that affect thermal comfort. The created simulation is examined under dynamic conditions on an hourly time-series basis. In building dynamic thermal analysis, empiric case comparison can be conducted which is professionally and scientifically accepted, thus the comparison would be used to validate the TAS software.

Laouadi, and Atif (1998) underlined the fact that TAS software usually is not used for analysing atrium buildings. The main reason is that atria are complex parts of the buildings where different parameters play significant roles on the thermal phenomena. Furthermore, atria have complex shapes of fenestration (pyramid, dome, and cylinder); that is why predicting the entered solar radiation, its transmission to the adjacent zones, and the reflection times are very hard to analysis, particularly in large sized atrium spaces.

The objective for selecting this computer software is to reach a high internal thermal environment by increasing the quality of built environment thus to provide better thermal conditions for occupants by considering different variables.

Reviewing all the information given and researches done regarding the atrium building area, it can be realized that there is a gap between the previous studies which is focusing on the atrium performance and its various structures, as well as its efficient form in hot and dry climate. However, there were several researches allocated to the atrium which was located in hot humid climate, but the need for further research can be obtained by the reviews done regarding its combination with other parameters which are going to be considered in the current study.

As mentioned before, in the current research identical attention has been paid on the effect of four-sided atrium on the internal thermal comfort in hot and dry climate. The aim was to find a more systematic and sustainable atrium type which provides a suitable and healthy environment thus to increase the well-being of occupants.

Chapter 2

RESULTS AND ANALYSIS

2.1 Introduction

This chapter of thesis reports descriptions and details besides analysis results of the selected building and its modelling via EDSL TAS software (2012). The same monitored building has been considered to conduct exercises on, with creating several dynamic thermal modelling, each of which has its own particular variables. The purpose of evaluating these simulations throughout a year was to predict the thermal comfort zone for occupants plus finding out the thermal behaviour of the atrium building through numerical results.

To reach these objectives, three parameters were tested: the atrium roof material, height of the atrium tower, and apertures opening percentages. Integration of these various parameters was aimed to contribute to a better design of future atria in hot and dry climate, in order to conserve energy and also provide thermal comfort environment based on human needs.

2.2 Analysis of TAS Simulations for Atrium Building

Based on dynamic simulations, the evaluation of Coloured Building thermal performance was divided into two periods: winter time and summer time. Winter time is composed of the months December and March. Although March is normally categorized in the spring, because of its being a cold season in the country under research, it was considered to be in the winter time. Furthermore, June and

September being subheading of hot weather, were considered to present summer time. It is important to note that the available results were beyond the scope of the present research study, therefore the noon time which is a determined and crucial time, has been chosen for demonstrating in the sections and diagrams.

Coloured Building, a three-storey construction, is composed of 36 zones with several surfaces which are demonstrated in TAS simulation (Appendix B & D). Data had been collected from the day twenty first of each of the specific four months throughout the year during three determined hours[7]. Analytically, climate parameters used in these simulations were:

- Global radiation (W)
- Ambient air temperature (°C)
- Wind speed (m/s)
- Wind direction (°)
- Cloud cover (0-1)
- Relative humidity (%)

Additionally, the considered apertures` opening percentages were 0.0%, 0.1%, and 1.0%[8]. It should be noted that the cooling and heating system through the mechanical system for indoor air temperature values was ignored.

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[7] The four selected days were 21st of March, June, September, and December at 7:00am, 12:00pm, and 19:00pm in each month.

[8] 0.0 percentage means all the apertures are closed; 0.1 means they were open around 10 percent; and 1.0% means that the whole apertures of building were completely open.

2.2.1 General Physical Characteristics of the Simulations

Observation process was done to understand the overall design characteristics of the existing atrium space. The existing atrium space is covered by a single clear glazing roof with 2.5 m of the height of atrium tower. As illustrated in Figure 45, the building entrance door is directed toward south and the longer side of atrium tower is laid from east to west with ten windows, which are posed around the bottom part of atrium tower, the window sizes are 2.00 m × 0.70 m with a 4 mm clear single glazing (Appendix C, No. 10). Each perimeter area (cafeteria, classes, archive rooms, restrooms, storages, and stair boxes) has one to six windows of various sizes (Appendix C).

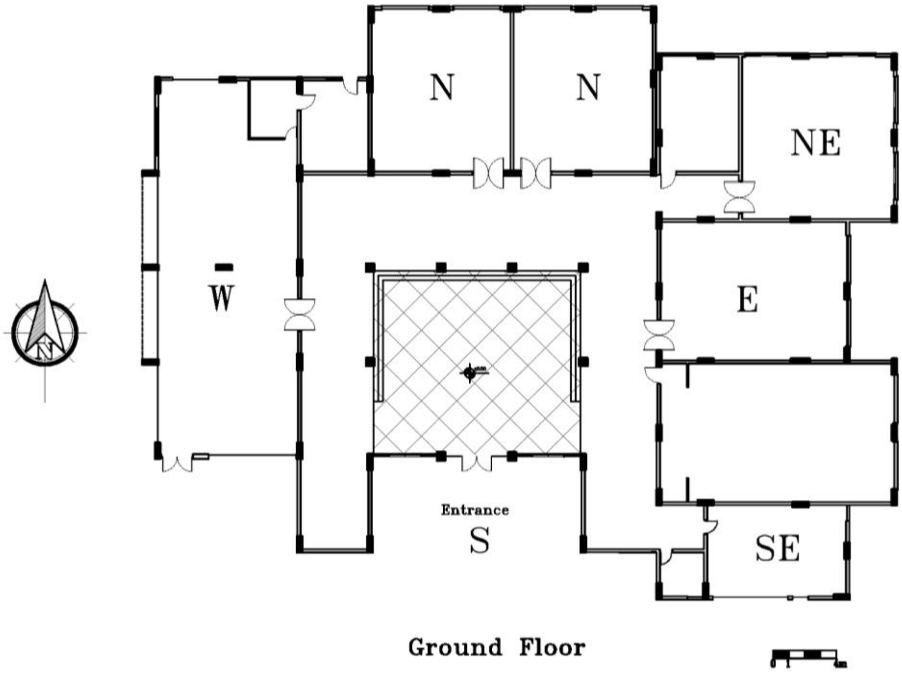

Figure 45: Schematic Drawing Showing Direction for All Zones

(Source: Drawn by an Author through the Given Plans by Architecture Department of EMU, based on the Coloured Building`s plans)

Building elements which follows are the same for all simulations:

- **Envelope:** 200 mm thick brick wall, and Lime Plaster of 15 mm thickness.
- **Internal walls:** 4.30 m height, the distance from external layer to internal one is filled by: 100 mm thick brick, lime plaster layer with a 20 mm thickness, 200 mm thick brick wall, plus the internal layer which is gypsum plastered with a 10 mm thickness. The importance of these walls is to divide areas or zones from each other for the simulation.
- **Floor:** The floor is covered by 20 mm gypsum plaster; then the main structure of floor is made of 300 mm thick reinforced concrete slab that has 40 mm thick terrazzo as floor cover on top.
- **Roof:** It is plastered by gypsum material at bottom, 300 mm reinforced concrete as structure that is covered by 30 mm water insulation.
- **Windows:** Single clear glazing with a 4 mm thickness
- **Doors` glass:** 10 mm thick single clear glazing
- **Aperture Frame:** PVC with a 50 mm thickness

Briefly, the building envelope layers were shown in Table 2 from the interior section to exterior sides.

Table 2: Envelope Material from Internal to External Side

(Source: Drawn by an Author)

Building Element	Material	Thickness (mm)
External Wall	Brick wall	200
	Lime plaster	15
Internal Wall	Brick wall	100
	Lime plaster	20
Floor	Gypsum Plaster	20
	Reinforced Concrete Slab	300
	Water Insulation	30
Roof	Gypsum Plaster	20
	Reinforced Concrete Slab	300
	Water Insulation	30
Atrium Roof	Plastic Made Clear Sheets	10
Windows` Glass	Single clear glazing	4
Doors` Glass	Single clear glazing	10
Aperture Frame	PVC	50

2.2.2 TAS Simulations

In the following parts, the descriptions of each simulation by different modifications are presented. In Table 3, a general view on weather files of Famagusta, (http://kktcmeteor.org, 2013) is represented. For the entire period, all external parameters were the same. It should be noted that the first simulation is the current situation of Coloured Building. Moreover, any kind of shading devices or blinds was not considered for any simulation.

Table 3: Weather Parameters of the Whole Studied Period

(Source: Drawn by an Author; Based on http://kktcmeteor.org)

Date	Time (h)	External Temperature (°C)	Relative Humidity (%)	Global Radiation (W)	Wind Speed (m/s)	Wind Direction (°)	Cloud Cover
March 21st	7:00	16.10	89	315.17	4.50	31	0.03
	12:00	17.80	51	839.69	7.10	60	0.03
	19:00	16.10	76	0.00	1.00	2	0.03
June 21st	7:00	26.40	68	532.65	2.80	35	0.00
	12:00	28.90	74	993.20	3.70	96	0.00
	19:00	28.30	72	0.00	1.90	212	0.00
September 21st	7:00	21.90	59	369.83	2.50	254	0.21
	12:00	29.20	48	833.87	3.70	131	0.21
	19:00	24.20	68	0.00	2.60	214	0.21
December 21st	7:00	14.50	62	82.57	6.90	17	0.24
	12:00	14.70	55	519.86	4.30	9	0.24
	19:00	10.90	62	0.00	1.90	296	0.24

As demonstrated in Table 3, the least external temperature among the four months under study was 10.90°C at night in December and the highest one was 29.20°C at noon time in September. In March 21st, relative humidity reached 89% in the early morning, and it decreased dramatically in September at noon time to 48%. The highest solar radiation was perceived at noon time in June; it was 993.20 (W) that reduced to 0.00 from noon to night. Obviously, the prevailing wind which was also illustrated in the table was N with the maximum speed of 6.90°. Additionally, a Table 4 is represented the general view of six simulations as a brief.

Table 4: Differences of Simulations

(Source: Drawn by an Author; Based on TAS Software Data)

Simulation Name	Duration	Doors & Windows opening percentages	Atrium Windows` Opening (%)	Atrium roof material	Roof height (m)
1	Four Selected Months	100	100	Glazing	2.50
2	Four Selected Months	10	10	Solid	2.50
3	June	10	100	Solid	2.50
4	Four Selected Months	10	10	Solid	5.00
5	June and September	100	100	Solid	5.00
6	March and December	0.00	0.00	Solid	5.00

2.2.2.1 Simulation 1

The entire ceiling area was covered by a single glazing in the first simulation. The glass type property which was used as a roof covering is shown in Table 4. In the present simulation, all apertures such as windows and doors were open 100%.

Table 5: Performance of Single Glazing Window

(Source: Drawn by an Author; Based on TAS Software Data)

Glass Type	Thickness (mm)	Light Transmittance	Solar Transmittance	UV Transmittance (W/m$^{2\cdot}$°C)
Single Glazed-Clear	10	0.890	0.820	5.747

The general view on this simulation, demonstrated that internal temperature was higher than ambient one. Atrium had an average temperature among the other building zones in both hot and cold situations. Zone 9 had the highest humidity percentage and the lowest temperature amongst the other zones. During March, June, and September, external and internal temperatures of atrium roof surface were approximately 10 degrees higher than the ambient temperature. Atrium space had the highest percentage of inlet air among the north and south sides of the Coloured Building. In addition, building needed more wind during the summer time, and gained more solar radiation in winter time. That is why inside thermal environment of atrium building was far away from comfort zone (Appendix E). Studying the influence of certain parameters on simulation 1 is represented as follows:

In the early morning (7:00 am): The prevailing wind direction was N. In September, the amount of air flew which went out of the building was more than the other months, particularly in higher levels. During the whole selected months, air flow through north side was more than the other building sides, especially in the ground floor. Summer time analyses revealed that the internal air temperature of Coloured Building was 3 to 5 degrees greater than the external one, and the inside air temperature reached only 1 degree higher than the external one in the winter time. Additionally, the building missed heat load in March and December; in June and

September it gained extra heat. The average range of internal relative humidity was between 47% and 66% in June and September, however, it was 60% to 90% in March and December.

At noon (12:00pm): There was an increase in the amount of inlet air through ground levels of building from N direction in March and December, and S one in June and September. Observations illustrated that north side of the building was mostly in shadow, besides south and east facades received more solar radiation from morning till noon; so that indoor air measurements of north zones had an air temperature near the outdoor one. South zones were warmer and atrium had the average temperature compared to other zones. In 12:00 pm, prevailing wind pattern illustrated that wind mainly flew from E. Throughout the year it can be seen that humidity was high in the lowest floors, although it was less in the atrium tower. There was a dramatic drop in relative humidity of the building in the external area in June; the change was around 20%, from 74% to 45.30% in the atrium tower. Entirely, the building heat transfer was minus; it means that the building lost its heat. Moreover, atrium tower had the maximum temperature compared to the other zones temperatures.

In the evening (19:00pm): Despite foregoing times, the air entered into the building from south side was more than the other sides, particularly from lower levels. The amount of inlet air had decreased level by level from down floors to upper ones. The temperature of atrium tower was approximately less than the other building zones except for the north ones in winter time, and zones which were located on the second floor. Moreover, atrium tower had the highest degrees in the lower zones in summer time. Wind came from WSW. During the night, the building released its stored heat to the indoor spaces. The relative humidity of the present simulation was 5% to 12%

below the ambient humidity. Atrium had a temperature of 5 to 6 degrees higher than the outdoor temperature.

Furthermore, in the morning time in March, the difference in temperature between north and south sides of the building reached around 7 degrees. A comparison of the internal and external temperatures of the building surfaces demonstrated that the internal temperature of south surfaces were 2°C greater than their external ones. At 19:00, external temperature was 16.10°C. Although, there was no solar radiation, the maximum internal temperature reached to 19.77°C in zone 26, and the minimum one was 16.88°C in zone 20. By monitoring the whole inside and outside temperature measurements during the whole year, the indoor thermal situation of the Coloured Building was found out to be far away from the comfort zone. In hot seasons, June and September, inside section of the atrium space needed wind with around 4 m/s speed and also 50% to 60% relative humidity. Moreover, the building was not even near comfort zone in cold seasons, especially in December; it needed to gain more solar radiation and around 58% humidity to pose in comfort zone (Appendix E).

A summary of the building's performance data is demonstrated in Table 5. There is the maximum mean and the minimum mean of internal and external temperatures, humidity, and resultant temperature of the building shown in the table.

Table 6: Summary of the Performance of Coloured Building-Simulation 1

(Source: EDSL TAS Software)

	Value	Unit	Zone	Day	Hour
Max Air Temp	40.83	°C	Zone 36	175	12
Min Air Temp	4.04	°C	Zone 34	365	6
Max Humidity	97.35	%	Zone 10	20	14
Min Humidity	19.16	%	Zone 36	263	9
Max Resultant Temp	49.3	°C	Zone 36	175	12
Min Resultant Temp	5.19	°C	Zone 36	38	6
Max MRT	57.78	°C	Zone 36	175	12
Min MRT	5.39	°C	Zone 36	31	6
Max External Temp	37.5	°C	External	175	16
Min External Temp	2.7	°C	External	31	6
Max External Humidity	98.00	%	External	28	5
Min External Humidity	21.00	%	External	263	9

It seems that the critical time on June 21st was at noon. At the time, external temperature reached 28.90°C with 74% humidity. However, zone 1, 13, 25, and 36, which compose the whole atrium space, had the maximum temperature, particularly atrium tower with 36.62°C. The lowest temperature belonged to zone 9 on the ground floor through N; it was 28.91°C with the highest humidity around 67%. Noon time had the maximum wind velocity in the day with 3.7 m/s, although the global radiation had its highest range around 1000 W. The difference between internal and external temperature surfaces of atrium zone was 9 degrees. It increased in the north side to reach the temperature of 14 degrees. There was no significant change in the remaining times. Only, the second floor was 2 or 3 degrees warmer than the other floors at night.

In September, the building thermal environment was around 3 degrees greater than outside, except at noon time when the internal building temperature was under or near the external temperature. However, second floor and atrium tower were warmer than the other lower zones at 12:00pm.

On 21st of December, the lowest temperature was monitored in the evening; it was 10.90°C with a 62% relative humidity. Wind direction was NW with 1.90 m/s speed. At noon time, the internal building temperature was around 15°C which was close to the external one, although the global radiation had its highest radiation and was around 520. With the diagrams and comparison of different season days and time periods, it can be concluded that the internal thermal environment of the existing building was dramatically under the comfort zone and it needed to obtain more solar radiation (Appendix E).

2.2.2.2 Simulation 2

In this simulation, the ceiling was coated by a solid material which was the same material used for other ceilings` roof zones. Solid materials` property is presented in Table 6. All apertures such as windows and doors were open 10%. Based on TAS data, internal and external solar absorbance of roof surfaces were 0.400 and 0.900, respectably. The amount of heat that the solid roof could conduct was around 4.12 W/m^{2}·°C. Emissivity amount of inside and outside roof surfaces were 0.900 and 0.950.

Table 7: Properties of Roof Materials

(Source: Drawn by an Author; Based on TAS Software Data)

Roof Fabric	Description	Thickness (mm)	Conductivity (W/m °C)	Density (kg/m^3)
Inner	Plaster 1*4	5.0	0.42	1200.0
2	Density 1 Concrete*4	200.0	1.13	2000.0
3	Concrete Screed*3	60.0	1.28	2100.0
4	Asphalt 1*2	3.00	0.43	1600.0

By monitoring all four months, it was represented that the dramatic difference between internal and external temperatures of building`s surfaces were changed from 10 degrees in the first simulation to 2 or 3 degrees in this one, even in zone 9, which also had a critical position like previous simulations in terms of thermal temperature. In simulation 2, however, the atrium roof being completely covered by solid material, the internal thermal situation of the building did not get better and the inside temperature was a bit more greater than outside. All the results were very close or even similar to simulation 1. The general views of four months within three periods are briefly described as follows.

In the early morning (7:00am): The amount of outlet air in the ground floor was less than upper floors. For instance, the air flow which went out from second floor was 0.053kg/s compared to the ground floor which was 0.007. Flowing air into the building from north side was more than south side in March, June, and December, contrasting September when the air flowing from south was more. The minimum difference was 0.100 kg/s, and the maximum was 0.500 kg/s; generally, south side of building in this simulation had higher inlet air and temperature compared to other sides. In March and December mornings, the internal building temperature was the same or even 1 to 2 degrees under the external one. However, it was becoming 1 to 2 degrees higher than external temperature in June and September. External measurement of solid roof surfaces revealed that they were around 7 degrees higher than the ambient and internal roof surfaces` temperature, except for December when the external surface temperature was even 1 degree lower than the internal one. During March and December, the building transferred most of its heat to outside, although it kept heat in June, and especially September. Relative humidity domain in hot seasons was ranging from 50% to 67% and in cold seasons, it was between 60% and 89%. A prevailing wind came from NW.

At noon (12:00pm): The difference between internal and external roof surfaces reached to its minimum of being 10 degrees in December. The north side of the building was the coldest compared to other orientations. The building lost its heat during the noon time in the whole year. The zones which were located through N had a temperature very close to the external one. Moreover, south side zones had the highest temperature and atrium space was between north and south with an average temperature. Finally, wind mostly came from E direction.

In the evening (19:00pm): Temperature of the atrium tower was approximately greater than the north side and the same as the south one; rarely it was around 1 degree under the south temperature. Wind generally blew from SW. The maximum humidity was 69% in June and the minimum one was 46% in March.

Building performance data of this simulation represented that there was a significant difference between this simulation and simulation 1 (Table 7). By comparing the previous building performances with this one, it can be seen that the internal temperature was decreased. Maximum air temperature in this simulation decreased from 40.83 to 37.37°C, for instance. Also, there was an increase in minimum humidity from 19.16 to 22.94% in zone 36.

2.2.2.3 Simulation 3

Simulation 3 was based on simulation 2, with considering 100% opening for all its apertures. Since the third TAS model had no difference in outcomes with the previous one, what was concluded is not going to be repeated.

2.2.2.4 Simulation 4

In this simulation, the atrium tower height was increased to two times higher than the existing one around 5 m and the roof surface was covered with solid material which was an effective parameter in simulation 2. All apertures were open 10 percent. A comparison of the building performance between simulation 4 and 2 was shown that nothing has changed meaningfully (Table. 8).

Table 8: Summary of the Performance of Coloured Building-Simulation 2

(Source: EDSL TAS Software)

	Value	Unit	Zone	Day	Hour
Max Air Temp	37.79	°C	Zone 36	175	16
Min Air Temp	3.89	°C	Zone 34	31	6
Max Humidity	97.98	%	Zone 10	339	14
Min Humidity	22.94	%	Zone 36	263	9
Max Resultant Temp	38.77	°C	Zone 25	175	16
Min Resultant Temp	6.10	°C	Zone 25	31	6
Max MRT	40.46	°C	Zone 25	175	15
Min MRT	7.68	°C	Zone 6	38	6
Max External Temp	37.5	°C	External	175	16
Min External Temp	2.7	°C	External	31	6
Max External Humidity	98.00	%	External	28	5
Min External Humidity	21.00	%	External	263	9

To follow the general description of this simulation, all evidences were very similar to the second simulation. However, there were some differences which caused this simulation to have a better thermal situation than the previous ones. First of all, increasing the height of atrium part caused the surfaces of the north and south side of internal atrium tower to remove their temperature variances, and have the same temperature. Moreover, increasing atrium height had a significant impact on air circulation compared to the aforementioned simulations. It reduced the pressure of air circulation, besides it increased building heat transfer around 0.100 kg/s in lower and 3.000 kg/s in upper levels. The tall atrium tower decreased the inside temperature around 3 degrees. Consequently, in the following simulations can be monitored that how the internal thermal environment can come closer to comfort zone with a simple variable (Appendix E).

2.2.2.5 Simulation 5 and 6

In order to reach the comfort zone, simulation 5 was considered for summer time, which is in June and September, with 100% opening. Simulation 6 was carried out in winter time, March and December, with 0.0% opening. In the following tables (Table 9, 10 and 11) summary of building performance of simulations 4 to 6 were shown.

Table 9: Summary of the Performance of Coloured Building-Simulation 4

(Source: EDSL TAS Software)

	Value	Unit	Zone	Day	Hour
Max Air Temp	37.73	°C	Zone 35	175	16
Min Air Temp	3.89	°C	Zone 34	31	6
Max Humidity	97.99	%	Zone 10	339	14
Min Humidity	23.46	%	Zone 22	263	9
Max Resultant Temp	38.69	°C	Zone 25	175	16
Min Resultant Temp	6.09	°C	Zone 25	31	6
Max MRT	40.32	°C	Zone 25	175	15
Min MRT	7.68	°C	Zone 6	38	6
Max External Temp	37.5	°C	External	175	16
Min External Temp	2.7	°C	External	31	6
Max External Humidity	98.00	%	External	28	5
Min External Humidity	21.00	%	External	263	9

Table 10: Summary of the Performance of Coloured Building-Simulation 5

(Source: EDSL TAS Software)

	Value	Unit	Zone	Day	Hour
Max Air Temp	37.51	°C	Zone 35	175	16
Min Air Temp	2.89	°C	Zone 34	365	6
Max Humidity	97.69	%	Zone 10	339	14
Min Humidity	21.35	%	Zone 22	263	9
Max Resultant Temp	37.95	°C	Zone 34	175	16
Min Resultant Temp	4.79	°C	Zone 25	365	6
Max MRT	39.14	°C	Zone 34	178	17
Min MRT	5.80	°C	Zone 25	38	6
Max External Temp	37.5	°C	External	175	16
Min External Temp	2.7	°C	External	31	6
Max External Humidity	98.00	%	External	28	5
Min External Humidity	21.00	%	External	263	9

It is impossible to compare these simulations with previous ones. The reason is that simulation 6 and 5 were carried out in separate seasons with different temperate ranges. It is important to mention that although thermal descriptive of these simulations were the same as simulation 4, but in these cases, the thermal performance on inside building finally reached near the comfort zone by decreasing the temperature in September and increasing it in March. For example, zone 36 in simulation 4 was 29.22°C which was reduced to 25 °C in September, and its temperature had increased in March from 18.13°C in simulation 4 to 23.89°C in simulation 6. The temperature and the amount of both inlet and outlet air flow can be monitored in the following sections and diagrams.

Table 11: Summary of the Performance of Coloured Building-Simulation 6

(Source: EDSL TAS Software)

	Value	Unit	Zone	Day	Hour
Max Air Temp	38.98	°C	Zone 34	175	17
Min Air Temp	3.77	°C	Zone 25	31	6
Max Humidity	97.14	%	Zone 10	339	14
Min Humidity	21.50	%	Zone 35	184	16
Max Resultant Temp	40.28	°C	Zone 34	178	17
Min resultant Temp	5.98	°C	Zone 25	31	6
Max MRT	41.62	°C	Zone 34	178	17
Min MRT	7.83	°C	Zone 25	38	6
Max External Temp	37.5	°C	External	175	16
Min External Temp	2.7	°C	External	31	6
Max External Humidity	98.00	%	External	28	5
Min External Humidity	21.00	%	External	263	9

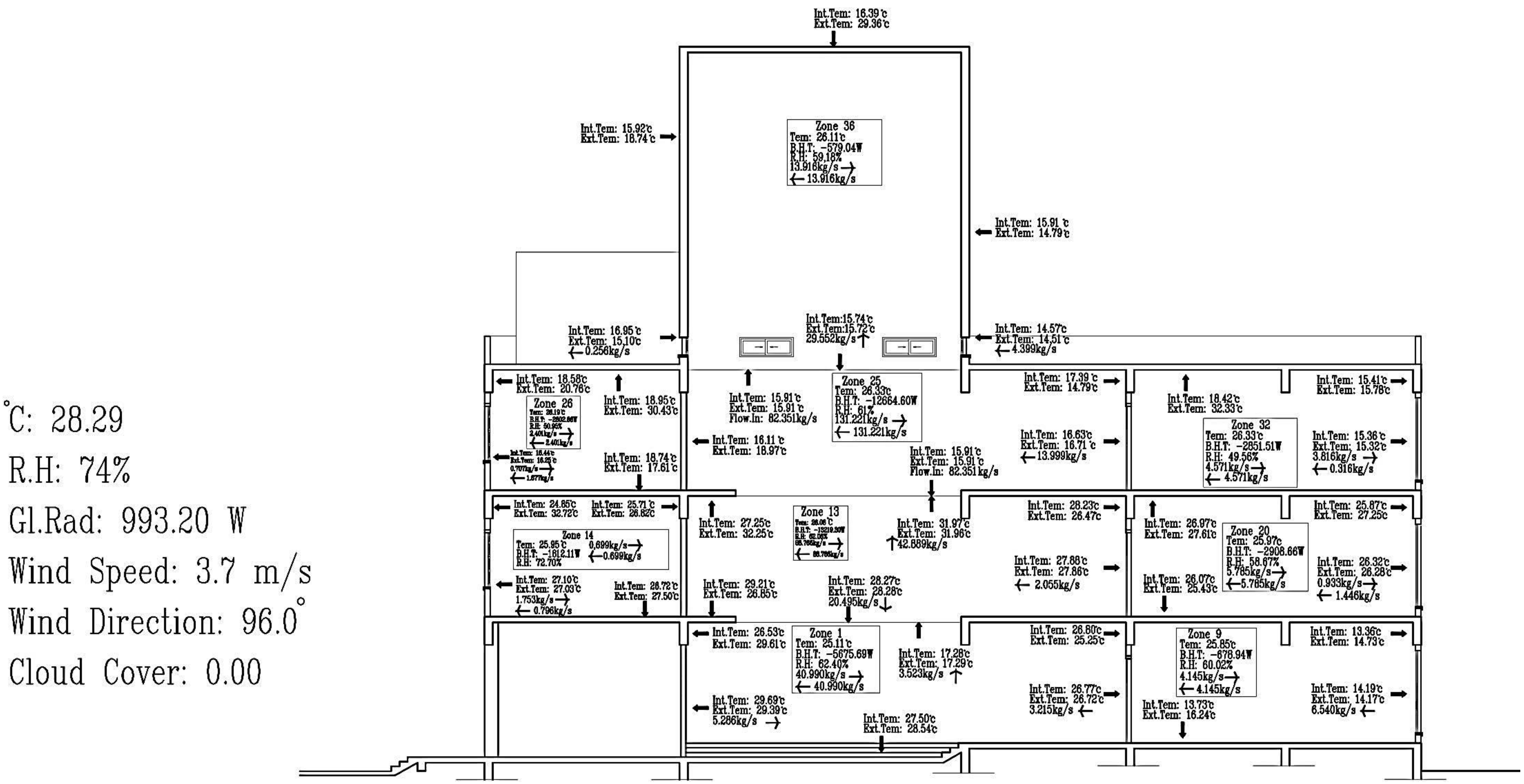

Figure 46: Thermal Performance of Coloured Building on June 21st, Noon Time (Simulation 5)

(Source: Drawn by an Author, Based on TAS Software Data)

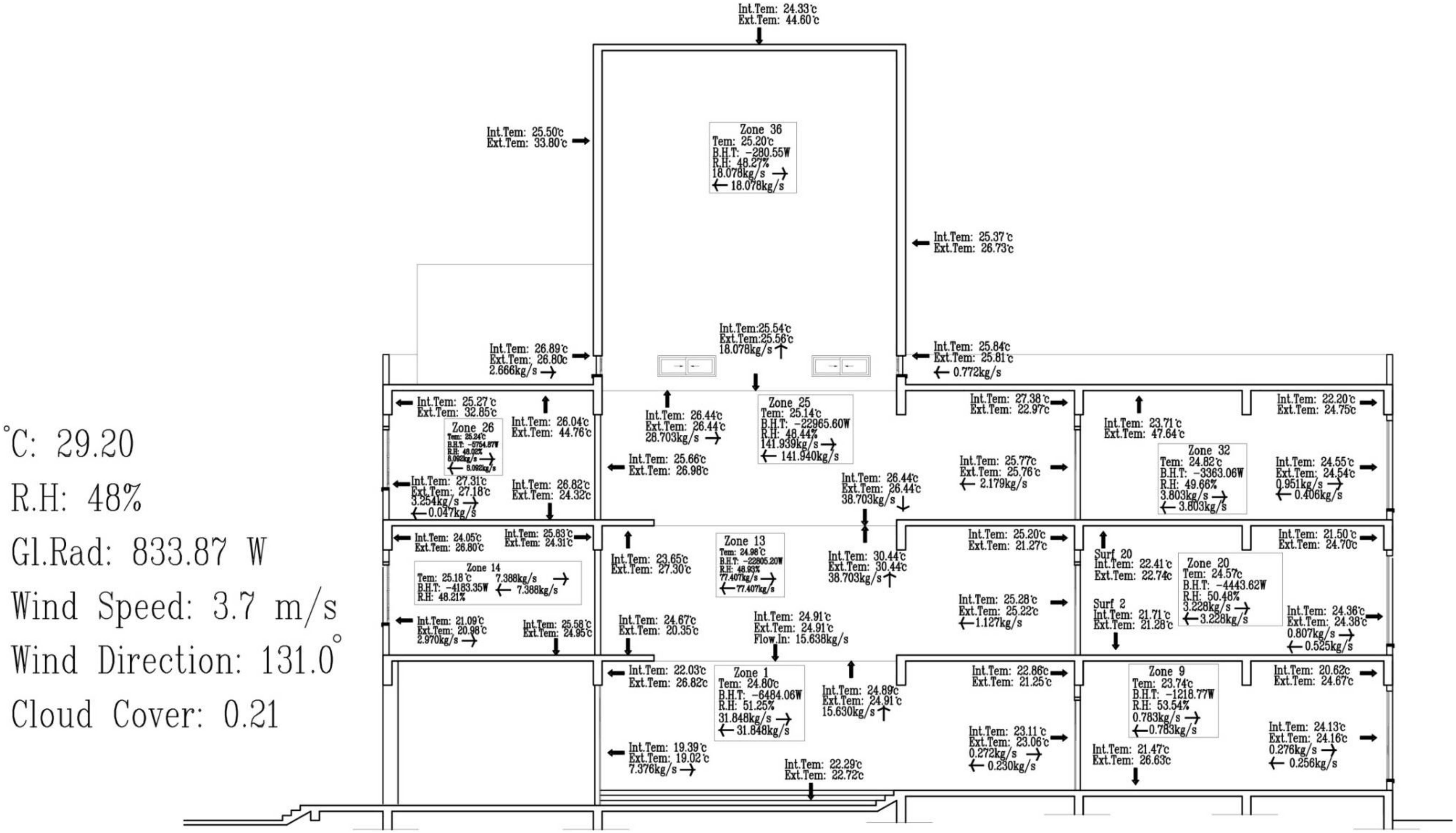

Figure 47: Thermal Performance of Coloured Building on September 21st, Noon Time (Simulation 5)

(Source: Drawn by an Author, Based on TAS Software Data)

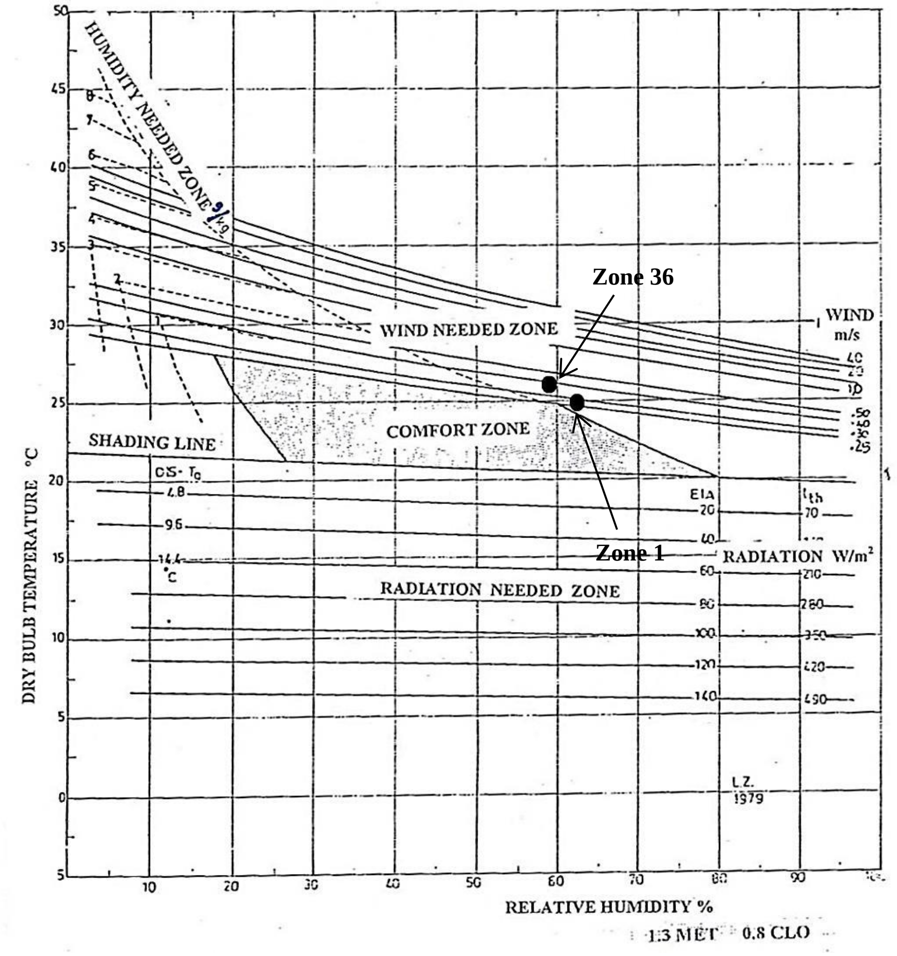

Figure 48: Bioclimatic Chart of Coloured Building on June 21st at 12:00pm (Simulation 5)

(Source: Drawn by an Author, Based on TAS Software Data)

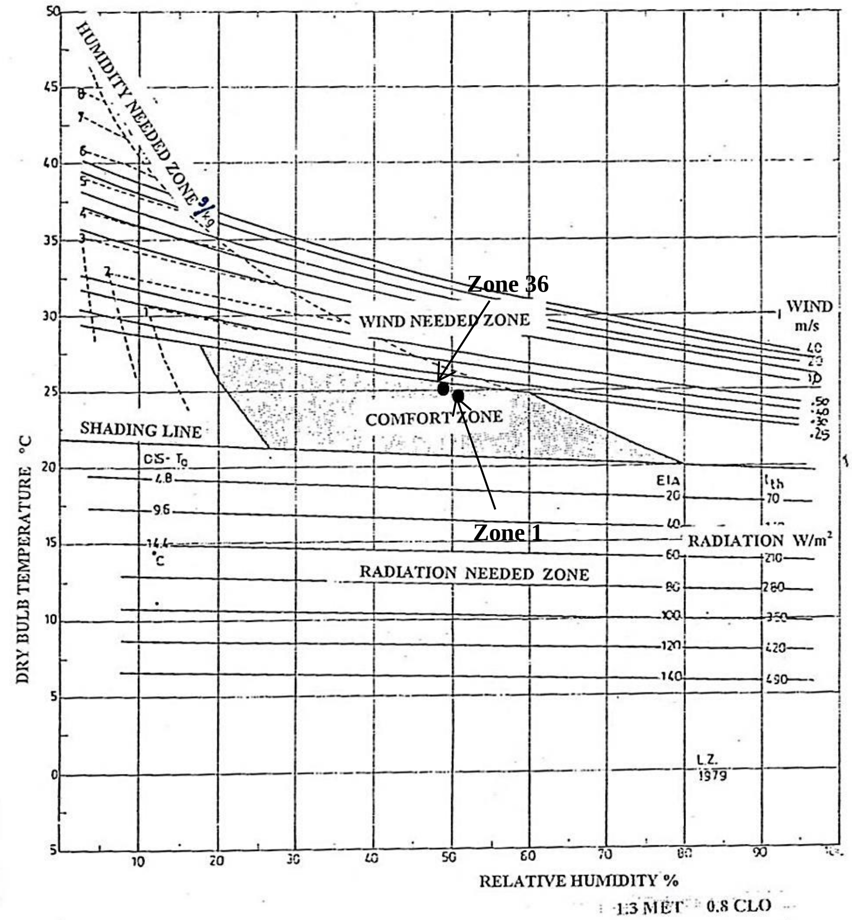

Figure 49: Bioclimatic Chart of Coloured Building on September 21st at 12:00pm (Simulation 5)

(Source: Drawn by an Author, Based on TAS Software Data)

In the former sections and diagrams, it was demonstrated that the highest part of the atrium building, the atrium tower, was in the comfort zone in September by an average of 25 °C. However, zone 36 with around 26 °C was on the comfort edge in June, zone 1 was completely posed in comfort zone both in June and September with having a temperature of 24 to 25°C and 50% to 62% humidity. By 100 percentages opening of all apertures, internal thermal comfort of Coloured Building has changed significantly during a hot time. In simulation 4, the least temperature both in June and September were 28 °C and 27 °C respectably. However, it was shown that in simulation 5, Coloured Building can provide comfort situation for its occupants by decreasing the temperature around 4 degrees.

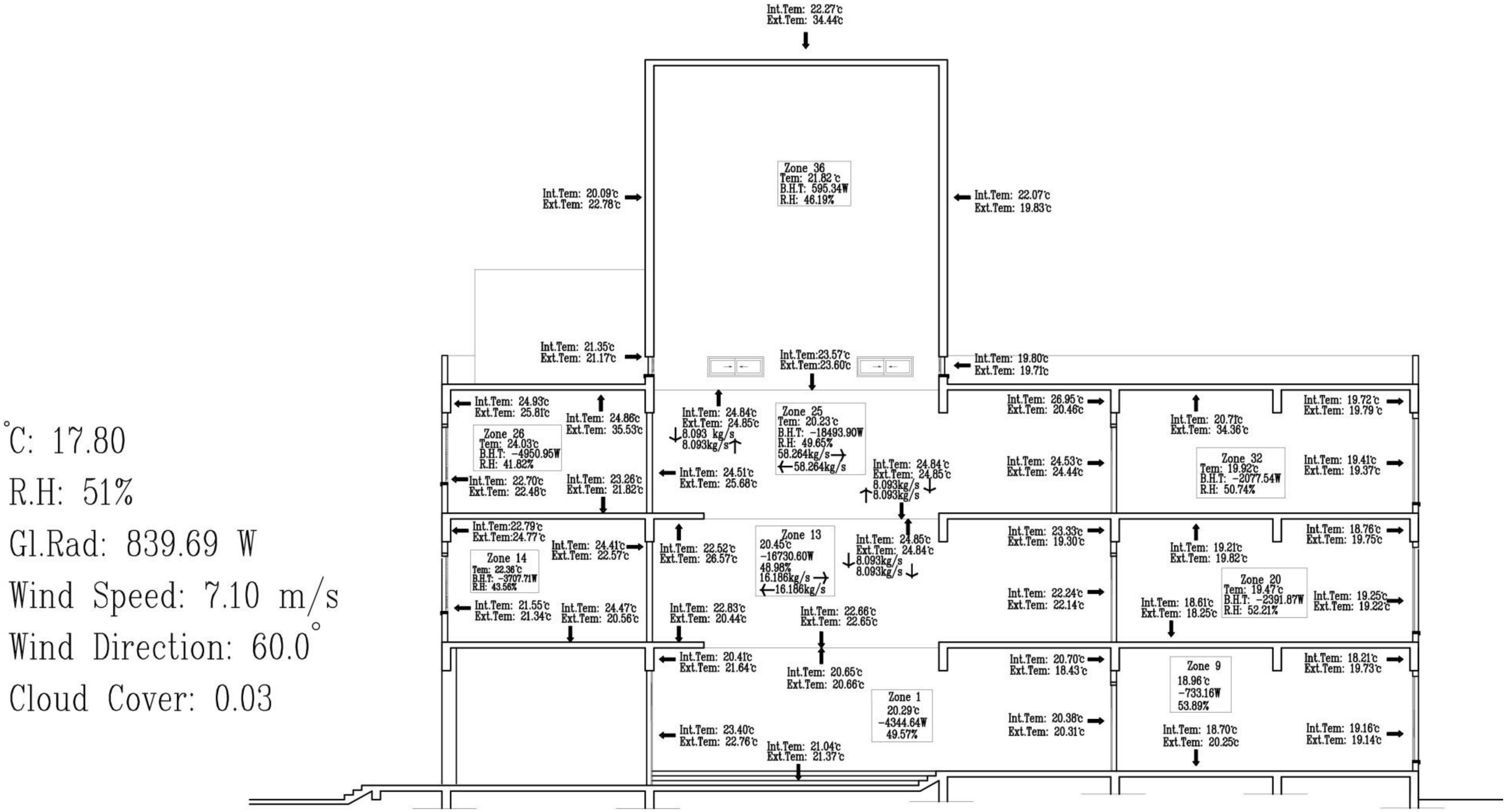

Figure 50: Thermal Performance of Coloured Building on March 21st, Noon Time (Simulation 6)

(Source: Drawn by an Author, Based on TAS Software Data)

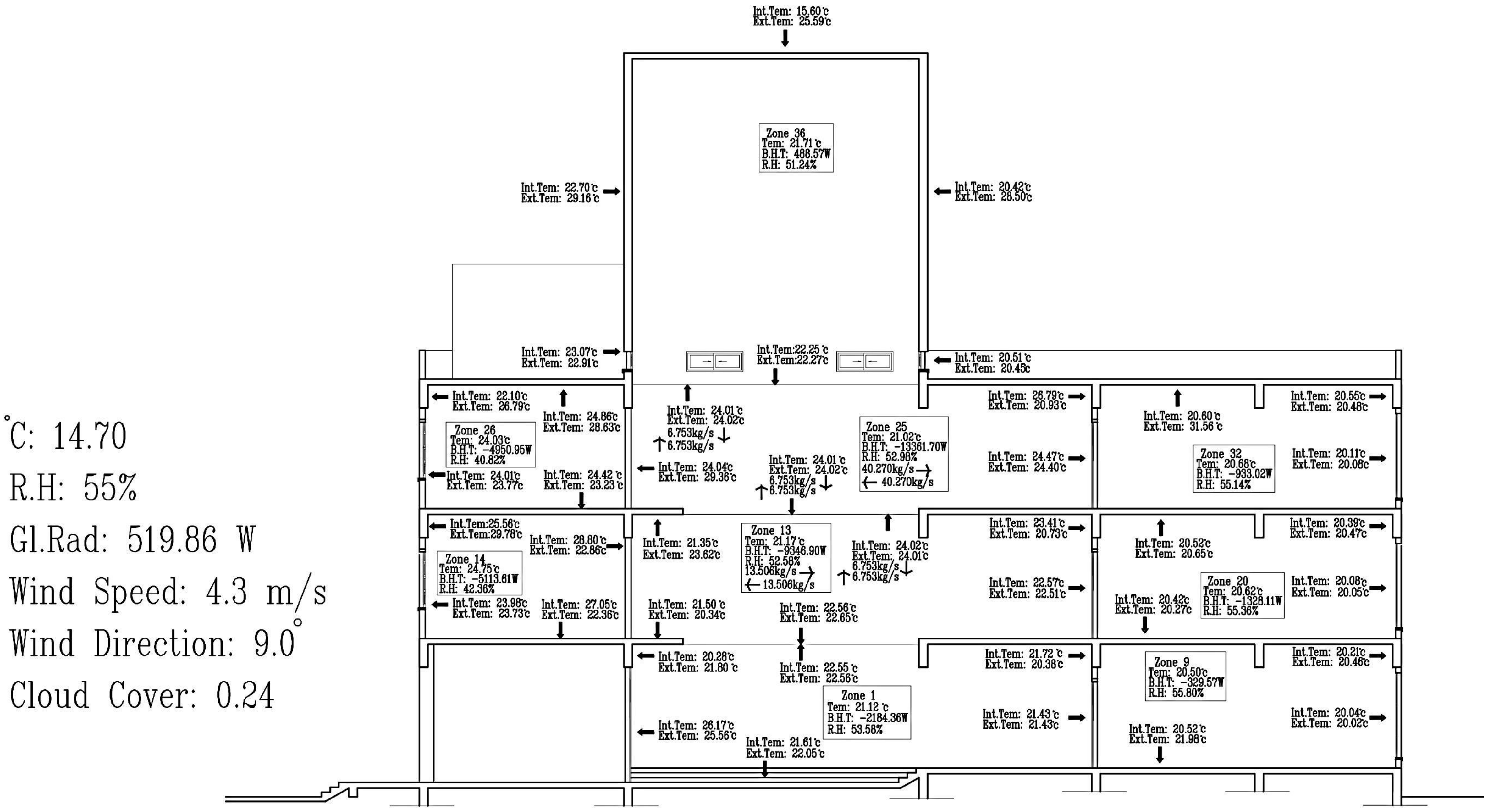

Figure 51: Thermal Performance of Coloured Building on December 21st, Noon Time (Simulation 6)

(Source: Drawn by an Author, Based on TAS Software Data)

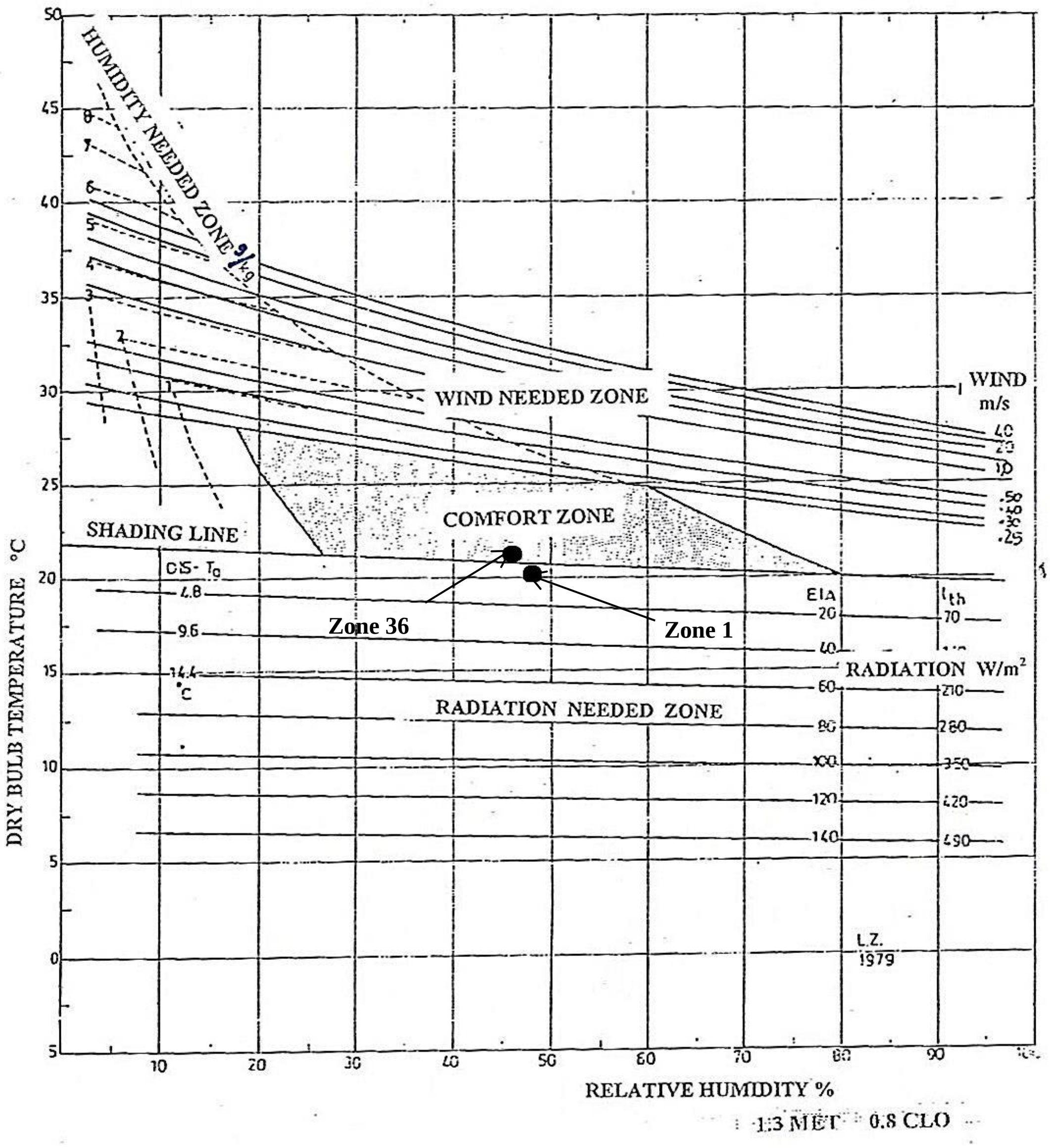

Figure 52: Bioclimatic Chart of Coloured Building on March 21st at 12:00pm (Simulation 6)

(Source: Drawn by an Author, Based on TAS Software Data)

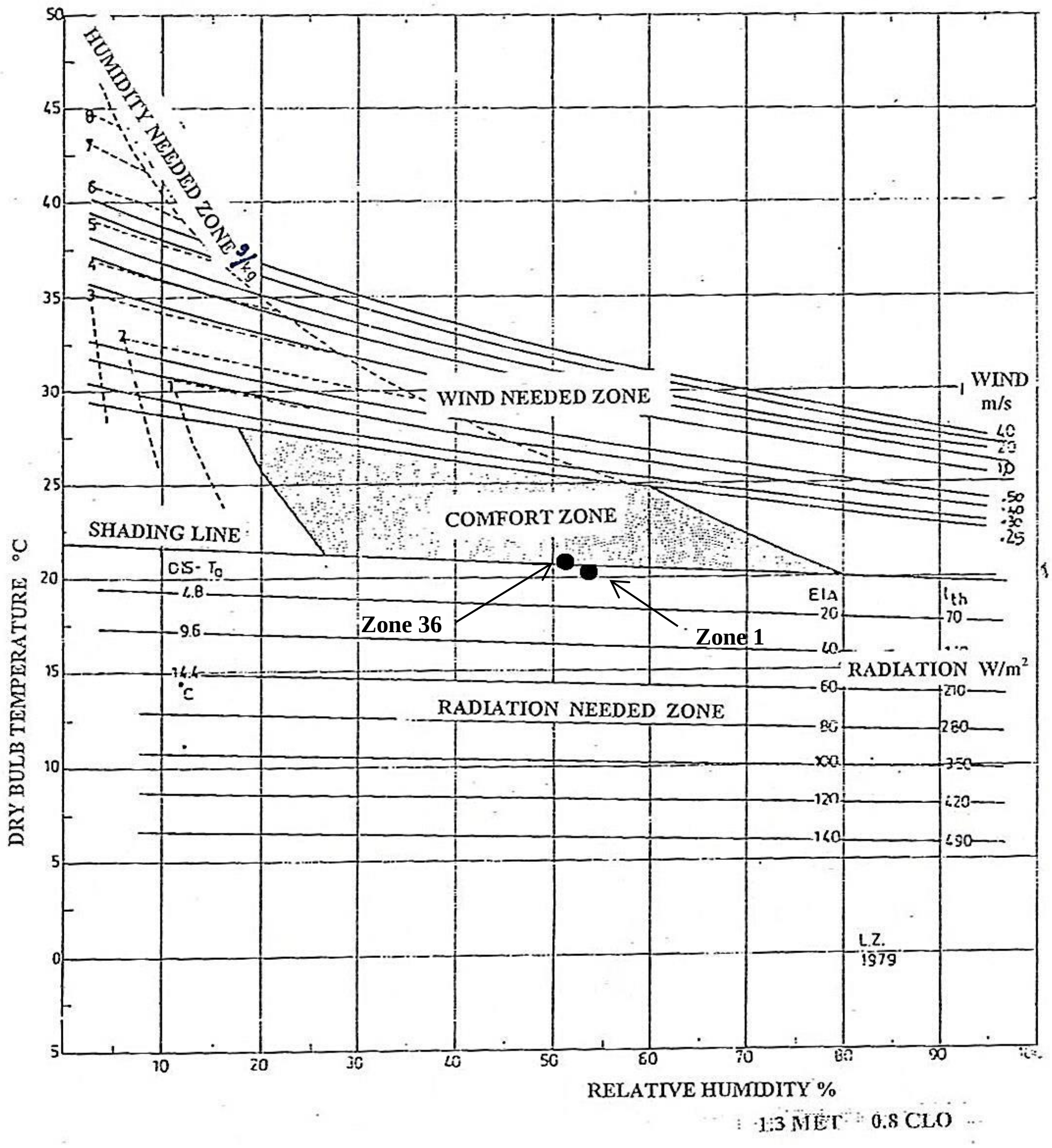

Figure 53: Bioclimatic Chart of Coloured building on December 21st at 12:00pm (Simulation 6)

(Source: Drawn by an Author, Based on TAS Software Data)

With 0% opening of apertures in winter time, internal thermal condition of Coloured Building was getting better than the previous simulations; even though it was not perfect but it was acceptable. Both in March and December, temperatures were around 21°C and a bit higher on June 21st, with no difference in humidity percentages. In this case, it was clearly understood the dramatic increase in temperatures was occurred by closing all apertures. The inside temperature was around 27°C in June and 25°C in September, however, it was around 30°C in simulation 4.

2.3 Results and Discussions

In general, in this chapter, examinations of the six dynamic thermal modelling of Coloured Building via TAS software was described in order to find the thermal comfort zone based on the atrium passive strategies without a mechanical system. The influence of increasing the height of the atrium tower, solar radiation, external temperature, internal air circulation, relative humidity, and apertures opening percentage in thermal performance of the Coloured Building was studied. From the point of view of TAS simulations` results, internal temperature of atrium space should be more than 21 °C with around 53% relative humidity in March and December which were considered as cold periods. During hot periods which mean June and September in the current research, indoor thermal situation of atrium building should be 24 °C with approximately 48% to 60% humidity, although the internal temperature was between 25 °C and 26 °C in simulation 5.

The comparison of the Coloured Building performance of all simulations represented that simulation 1 had the highest temperature among the other simulations which was 40.83 °C in an atrium tower, zone 36. The maximum air temperature was shown that how much a glazed roof and solid one could have a significant impact on decreasing and increasing internal thermal comfort. Moreover, the least air temperature could be seen in simulation 5 which was 2.89 °C in zone 34 at the west side of building; however, simulation 5 was carried out in summer time with 100% apertures opening.

The greatest humidity based on the building performance was 97.99 % in simulation 4, at zone 10, which is located on the ground floor in North side. As mentioned early, the reasons could be that North side of building was always in shadow and zone 10 was located on the ground floor where the amount of inlet air was normally high. The internal temperature would be effect directly on reducing and increasing relative humidity. This manner would be more obvious when monitored the least minimum humidity of the Coloured Building; it was 19.16 % in zone 36 of simulation 1.

By comparing the simulations, first simulation, which was showing the existing Coloured Building situation, had the worst condition in terms of thermal performance. However, simulation 5 had an acceptable thermal condition and simulation 6 was on the comfort border. In hot time, the inside temperature of simulation one was even more than external one, being higher around minimum 3 degrees, and in cold time it was almost the same as the external temperature; in December, sometimes internal temperature notably was under the external one in building zones which were located in north side. Among the examined simulations, simulation 3 had no positive effect on the building thermal performance with a 10 percent aperture opening and solid roof. In simulation 4, the impact of solid atrium roof and increasing atrium tower height can be seen, but then again there was no sign of the comfort condition for occupants. The positive effects of previously mentioned variables caused simulation 5 with having 100% opening apertures to be in the comfort zone in summer time, and simulation 6 to be located very close to comfort zone with closed apertures.

Consequently, it was understood that in the selected four months, March and September had an approximately moderate and acceptable situation, while June and

December had a crucial situation in terms of hot and cold seasons, respectively. Significant fluctuations could be monitored in June and December. Atrium space in summer seasons, particularly in June, acted like a solar furnace and increased the internal temperature by 3 to 6 degrees. So that the atrium roof considered with the solid roof could have a meaningful influence on moderating the temperature in whole the building zones, especially in the atrium space. Solid roof caused reducing the direct incoming solar radiation in June and September, and increasing the internal temperature in March and December by gaining solar radiation. Considering the height of the atrium tower in simulations 4, 5, and 6 proved that the air pressure speed can be reduced by it, although apertures` opening and outlet openings had their own key roles in thermal transition. Finally, the building performance represented that internal temperature has an inverse relation with humidity; it can be seen when the internal temperature in upper zones like 34 to 36 increased, the relative humidity went down directly.

Chapter 3

CONCLUSION

2.1 Conclusion

It is more generic for an atrium to have an environmental advantage, being considered as a buffer zone to moderate internal temperature of atrium and its adjacent spaces. Atrium also is used mostly to control the harsh climate. As discussed before, energy consumption in public buildings, which have lots of occupants, can be decreased dramatically by employing passive solar strategies instead of the mechanical ones. Well-designing of atrium form is very substantial in the early design stages. Failures occurrence in this type of space is normally refer to the lack of knowledge for regarding the specific type.

Based on services literature, the selected atrium is the top four sided atrium which is used frequently to obtain more daylight. This type of atrium may be problematic in hot humid climates such as North Cyprus where is well-known for its direct sun shine. The top glazing atrium helps the building to increase its internal temperature, especially during the hot summer period. This research aimed to improve the internal thermal performance of atrium buildings which would be a beneficial contribution in case of decreasing energy usage and increasing internal thermal quality of the built environment. Considering a collection of researches on atrium thermal performance, there is a gap in researches of the atrium thermal performance in hot humid climate, so that the findings of this thesis would be more important for future atrium constructions in hot climate.

The building chosen for conducting the research was the Coloured Building of Architecture Department in EMU at Famagusta, North Cyprus. To predict thermal performance of the existing atrium building, three research approaches were integrated into analyses part: 1) observation of the existing building 2) on site measurements, and 3) creating dynamic modelling via TAS software. The use of computer simulation software was highly beneficial, because of the difficulty in making the real environment and providing the exact weather condition for each simulation. Besides, field measurements have their own problems and mistakes.

By taking a brief overview on all the represented simulations, it can be concluded that in simulation 1, the current situation of the Coloured Building with the glazing atrium roof had been shown with all apertures considered to be 100% open. And as mentioned before in Chapter 2, the prevailing wind direction was north. Moreover, the internal temperature of the building was higher than the external one, although there was a moderate temperature in the atrium space in both hot and cold periods. The point is that the lower adjacent atrium spaces which were located on the ground floor had the highest humidity percentage and the lowest temperature compare to the upper adjacent spaces. Furthermore, the atrium tower was taller than the other parts of the building with around 17 m height, which is why it had the highest percentage of inlet air among the other parts of the building. Additionally, the building lost heat load in winter period and gained extra heat in summer. One of the influential items at noon time which affected internal temperature of the Coloured Building was that north side was typically in shadow, besides the facades located in south, east, and west were under direct solar radiation from morning till afternoon. Therefore, indoor air measurements in north side had an approximate same temperature as outside. At 12:00, relative humidity was high in the lowest floors in contrary to the atrium tower, the highest part of the building, which has the lowest humidity percentage, throughout the year. During the night, the amount of incoming air from south side was increased, in contrary to morning and noon when the prevailing wind came from north direction. Generally, the temperature of atrium tower was approximately less than the other spaces. At the end, during the night, the building released its stored heat to the indoor spaces.

By monitoring the results of simulation 1, there was a meaningful difference between the north side temperature and the south one. The results of inside and outside temperature measurements during the whole year were prooved that the indoor thermal situation of the Coloured Building was far away from the comfort zone. In June and September, inner part of the atrium space, to reach the comfort zone, it needed to decrease its internal temperature by the effects of a wind, with almost a 4 m/s speed plus 50% to 60% relative humidity. Besides, the internal thermal comfort of the existing building was not even near comfort zone in cold seasons as well, especially in December. Therefore, the internal temperature of the building needed to reach 21 ºC with around 58% humidity to pose in comfort zone.

In simulation 2, a material of atrium roof was considered to be changed from transparent into solid, with 10 percentage opening for all apertures, in order to monitor the new variable effect on internal thermal performance. A prevailing wind was coming from NW and E based on the time. Interestingly, an immediate reaction could be seen in the temperature difference between inside and outside of the building’s surfaces from 10 degrees in the first simulation to 2 or 3 degrees in the second one. The results represented that in the morning the amount of outlet air in the ground floor was less than upper floors and air was coming into the building mostly from north side than south side in March, June, and December. However, the air flow from south was taking place more in September; so that south side of the building in this simulation had higher temperature compared to other sides. During the winter period, the building lost most of its heat, although it kept much heat in summer period, especially September, with a 50% to 67% relative humidity which was less than the winter one. In the same way with the first simulation, at noon time, north side of the building was the coldest part, in contrary to other orientations. It can be said that during the night time, internal building temperature, especially in the atrium tower was more than outside because of using high-weight materials for the building’s elements. These kinds of material normally emit their stored heat to inner part of the building in a long period of time. Consequently, the only advantage of covering atrium roof was the reduction temperature difference between north and south sides of building. Based on bioclimatic charts` results, the internal thermal situation of the building was a bit near to the comfort zone in March and September, but it needed to receive more solar radiation in winter period so to take the internal temperature of the selected building to 21ºC from its average of 15 ºC. The results of simulation 2 represented that the building’s thermal performance was very close or even similar to simulation 1. Therefore, the Coloured Building could not be located in the comfort zone.

In the third simulation, even by changing the opening percentage of all apertures from 10% in the previous one to 100%, thermal performance of the building did not change meaningfully. With no variation in June, this simulation could not reach the comfort zone so that it was considered to create another TAS scenario with new variable parameters.

From simulation 4 to 6, the height of atrium tower was increased two times to become 5 meters. By extending the atrium roof, the interior air pressure decreased and significantly moderated all internal zones` temperature, even building`s surfaces. Additionally, building heat transfer increased compared to previous simulations. In simulation 4, all apertures were opened around 10%. The results demonstrated a positive impact of the deed on internal thermal comfort. It means that varying a parameter was effective, although the Coloured Building could not obtain the comfort zone yet. In September and March, thermal performance of the building was near the comfort zone but internal temperature needed to decrease 5 degrees in summer time and increase approximately the same amount in winter time.

In order to reach internal thermal comfort of the selected building at a short time by TAS simulation, simulations 5 and 6 were taken place separately throughout the summer and winter period respectively. A 100% opening was considered for simulation 5 because the building needed more wind to decrease its internal temperature based on the previous simulations during the hot seasons. The results showed that in June, the building could not reach the comfort zone with having around 27ºC and 58% relative humidity. However, the building finally could obtain the mentioned zone by reaching around 25ºC and 48% humidity in September, at noon time. Simulation 6 was carried out during the winter time which was why all apertures were closed to keep and prevent internal heat load lost. March, among winter months, was when the thermal performance of the building was on the edge of comfort zone and even its atrium tower was in the comfort zone at the time;

however, it should be noted that the thermal situation of the building was also very near to comfort zone in December.

Therefore, the results represented that the selected atrium building, thermally reaches the comfort zone in summer time, but it was very close to comfort zone in winter time by the new modifications. In June, Coloured Building never reached the comfort zone, although its thermal performance was reasonable in September. In cold months, March was in comfort zone near the comfort border with 21ºC and December, thermal performance of Coloured Building was on the comfort border from 20ºC to 21 ºC. Building in December needed receiving more solar radiation for raising the internal temperature.

The analysed simulations and collected data on site demonstrated that an atrium with a glazing roof is not suitable and efficient for hot climates. It has negative impacts on energy cost and thermal comfort of the building. That was why, the selected building reached the comfort zone in the recent simulations via solid atrium roof. The main reason is that the atrium space keeps the solar radiation inside of the building based on greenhouse effect. Although, greenhouse effect is advantageous in cold climates, it makes problems in hot ones. In fact, greenhouse effect has a double side edge: it reduces heating load during the cold period, and increases cooling load in the hot period. The comparison of the last simulations with the former ones revealed that even height of atrium tower and apertures` opening percentage can increase internal thermal environment for the building.

2.2 Suggestions for Future Research

Several areas of research have been determined for future studies, which are figured out while undertaking the current research.

Generally, previous studies have focused on different climates, and mostly are limited to cold and hot humid climates, although there are many problematic areas which need to work on. It would be useful to extend studies on atrium buildings in hot humid climate to find out solutions for atrium form in order to improve the inside thermal quality of the built environment for occupants.

Briefly, in this research, the effect of penetrating solar radiation, internal air circulation, humidity percentage, atrium tower height, and roof material on thermal comfort was chosen to work on. Further research could explore the influence of atrium structure, windows` arrangement, windows` size, various types of shading devices, and different atrium roof forms, with the propose of enhancing internal thermal comfort to provide a comfortable environment for occupants, and reduce energy consumption. Moreover, CFD, a computer simulation program would be used to predict the effect of wind direction on building`s thermal performance.

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APPENDICES

Appendix A: Sample of the Coloured Building Plans

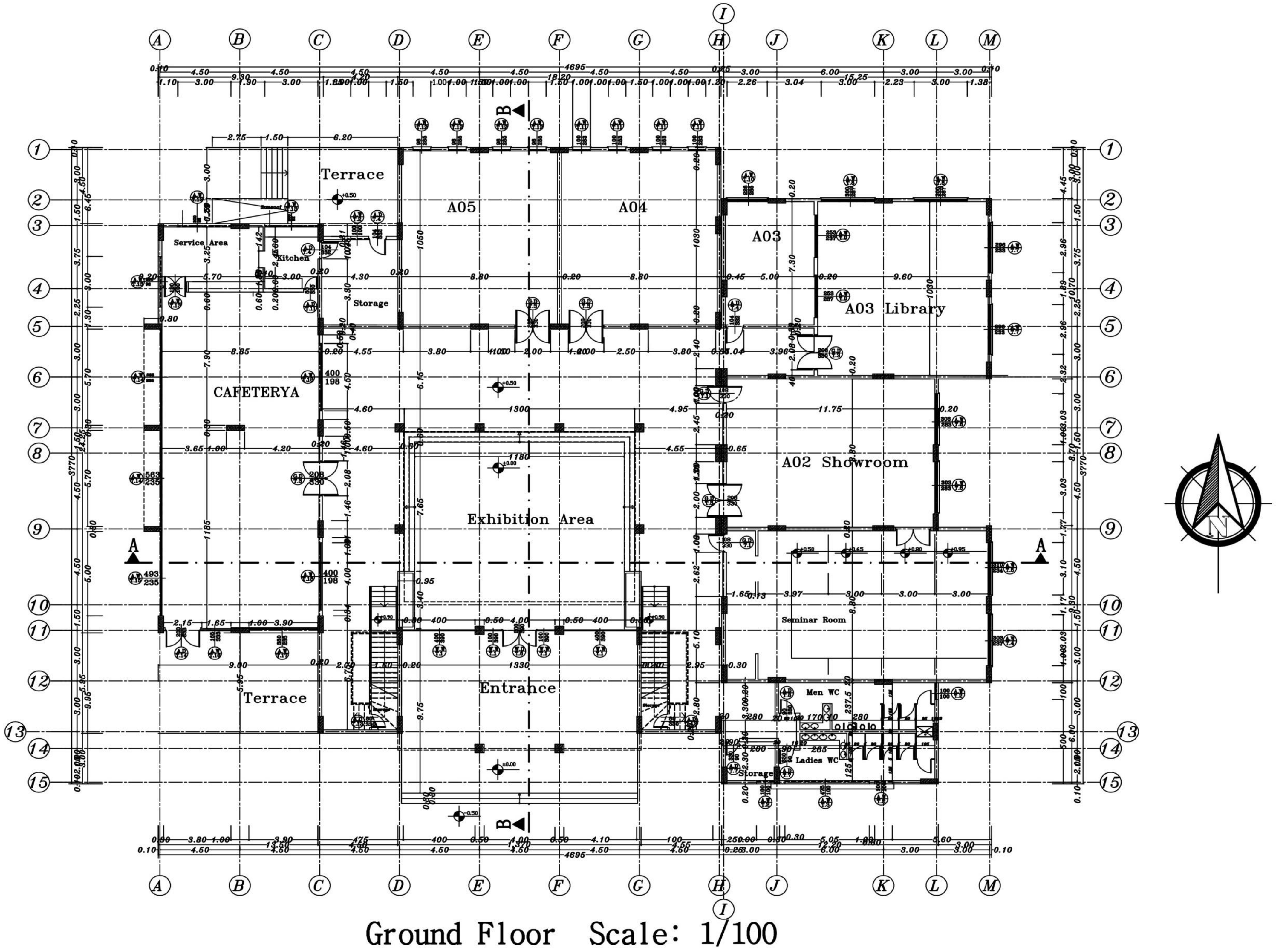


Figure 54: The Ground Floor of the Coloured Building

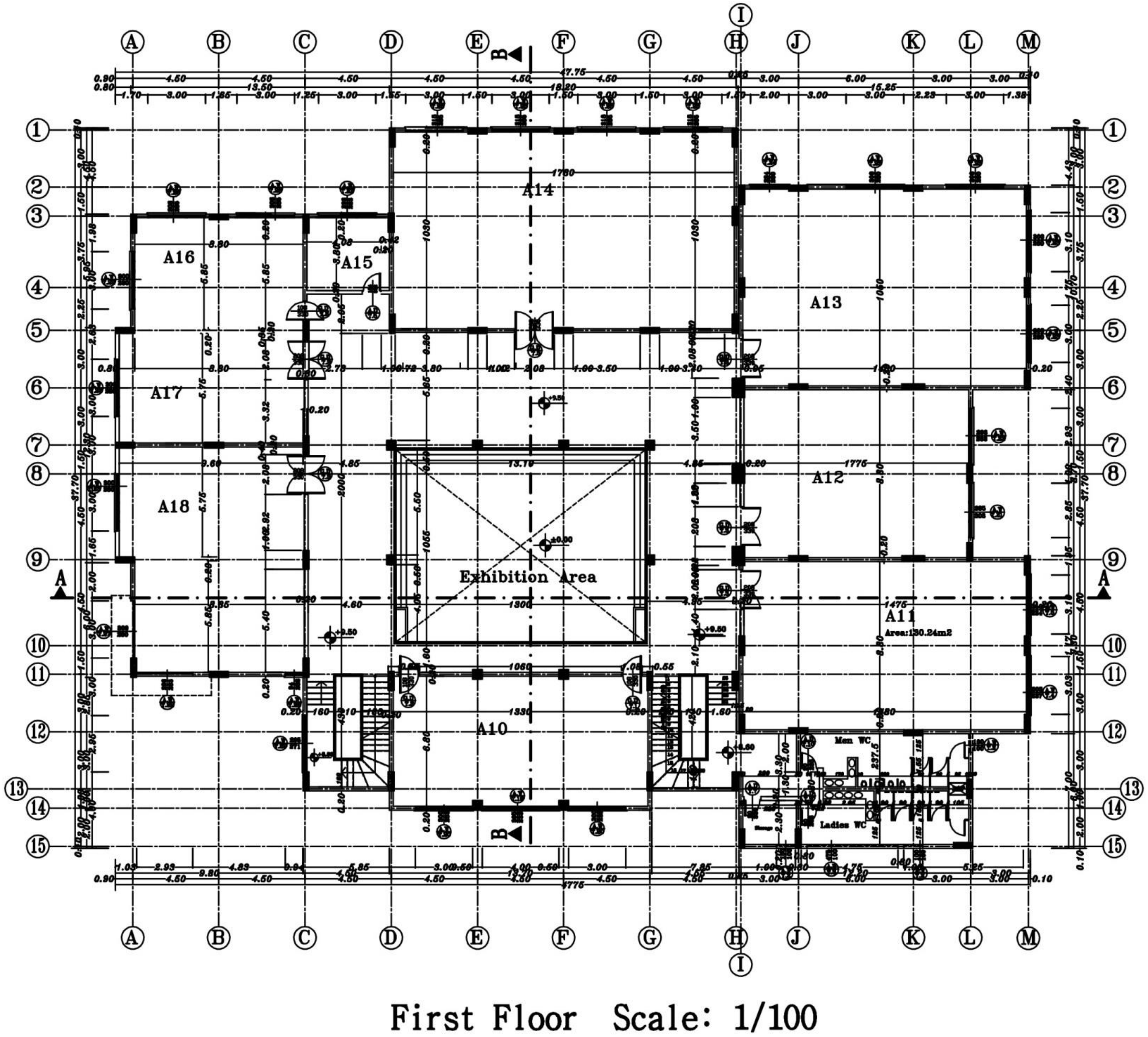
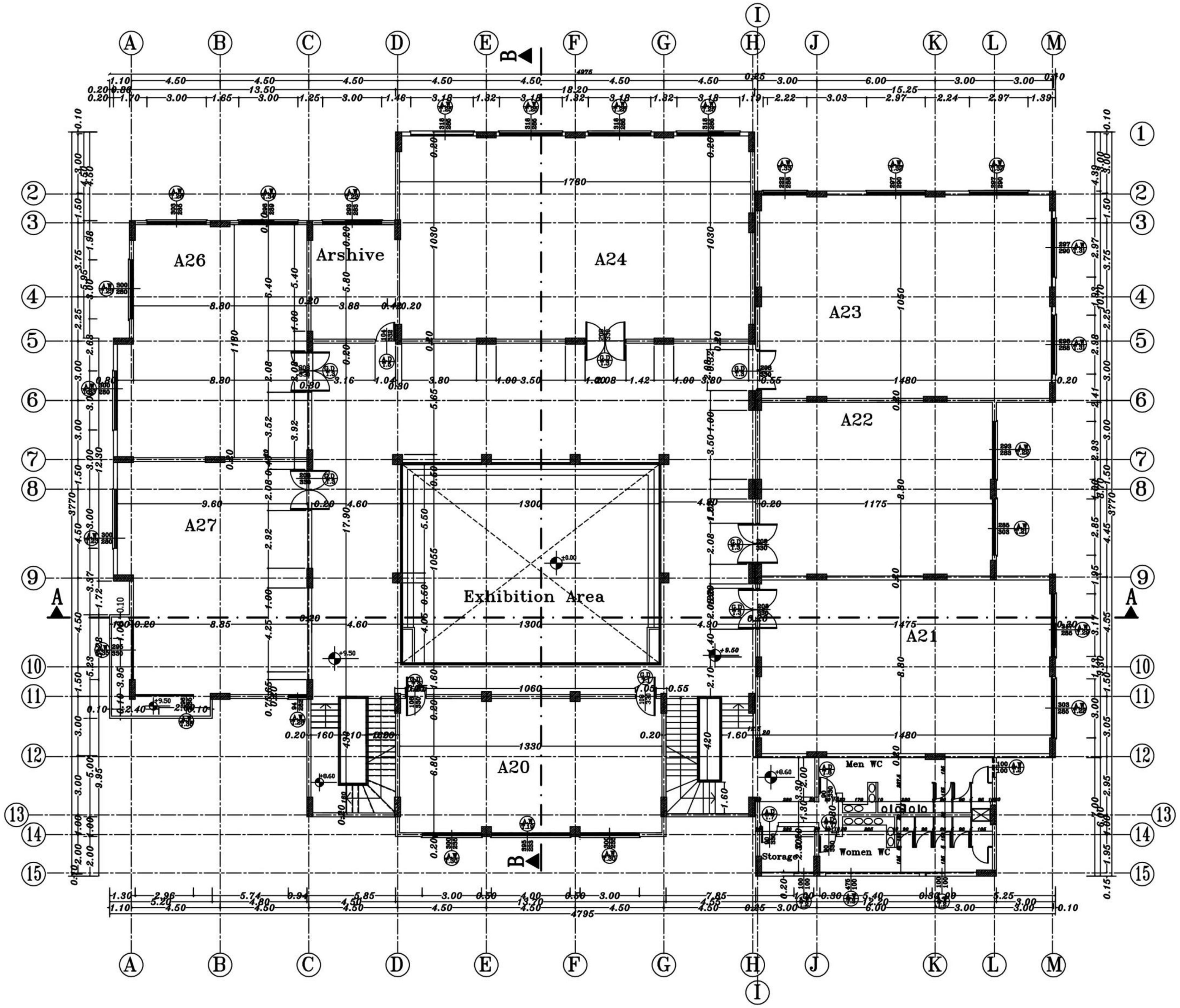


Figure 55: The First Floor of the Coloured Building



Second Floor Scale: 1/100

Figure 56: The Second Floor of the Coloured Building

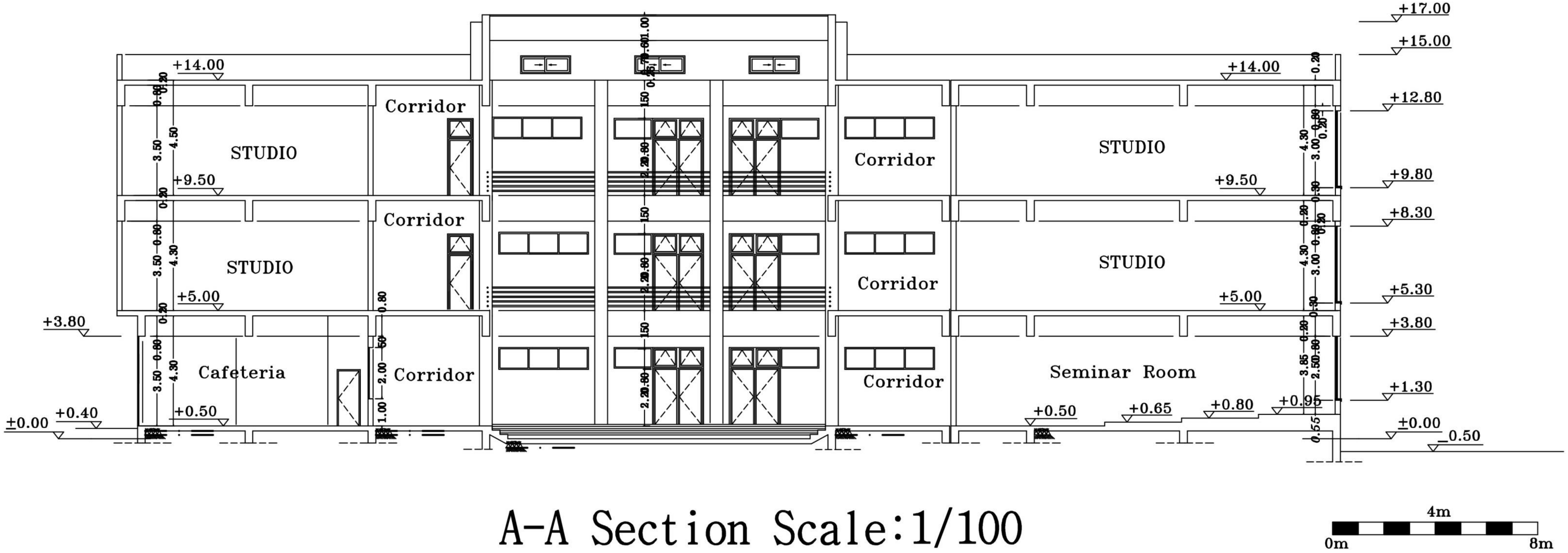


Figure 57: Section A-A of the Coloured Building

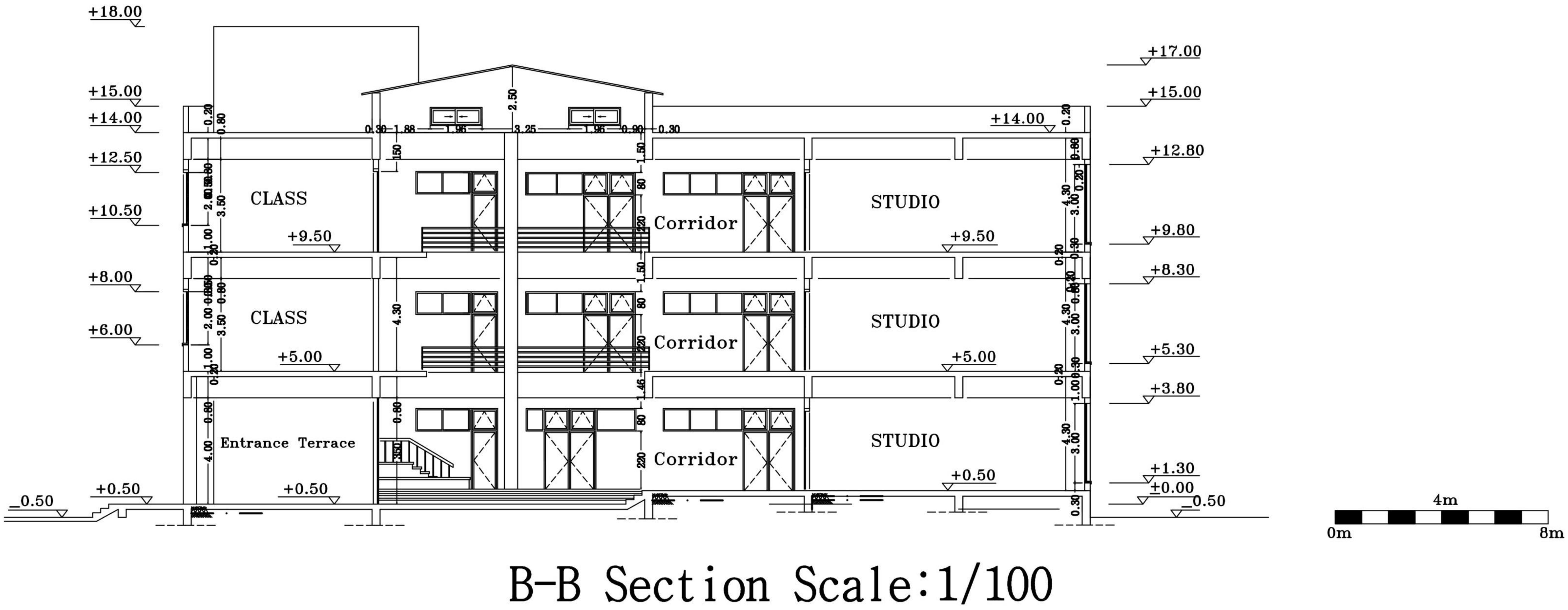
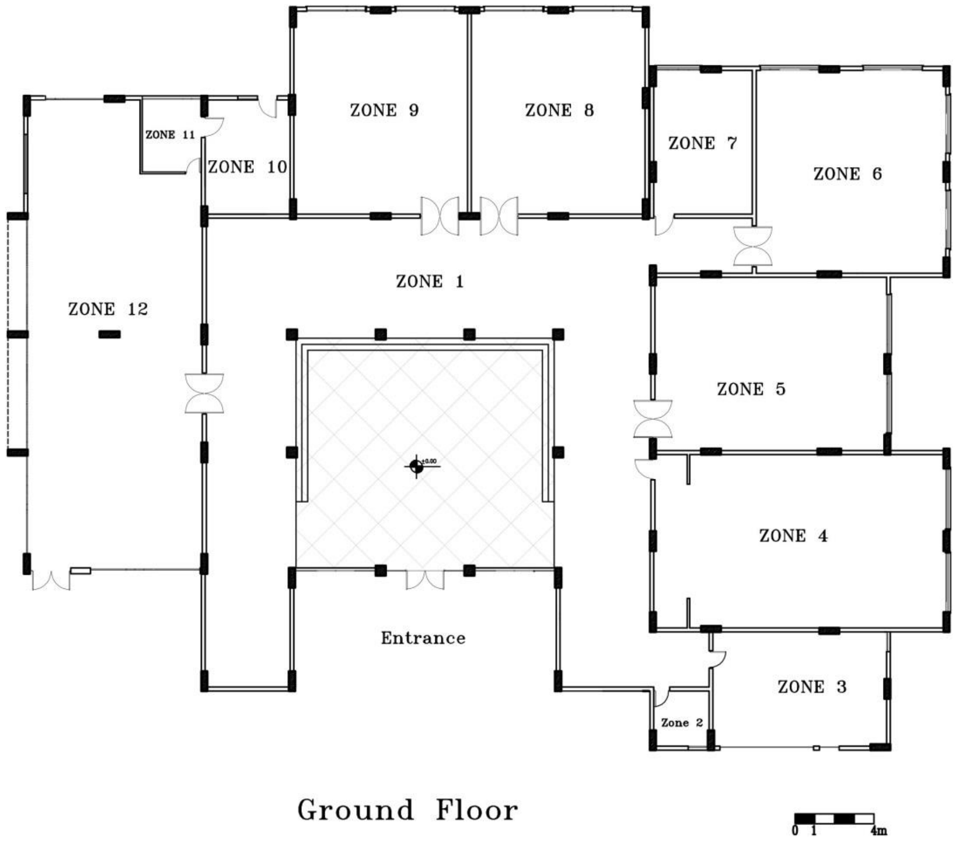
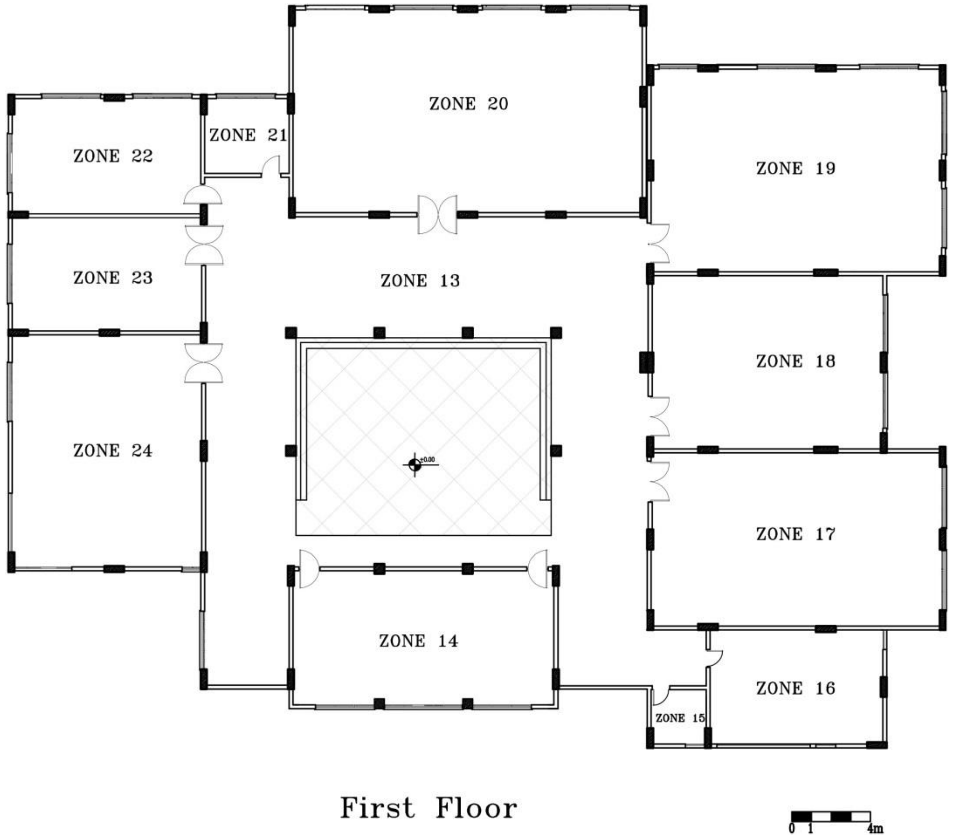


Figure 58: Section B-B of the Coloured Building

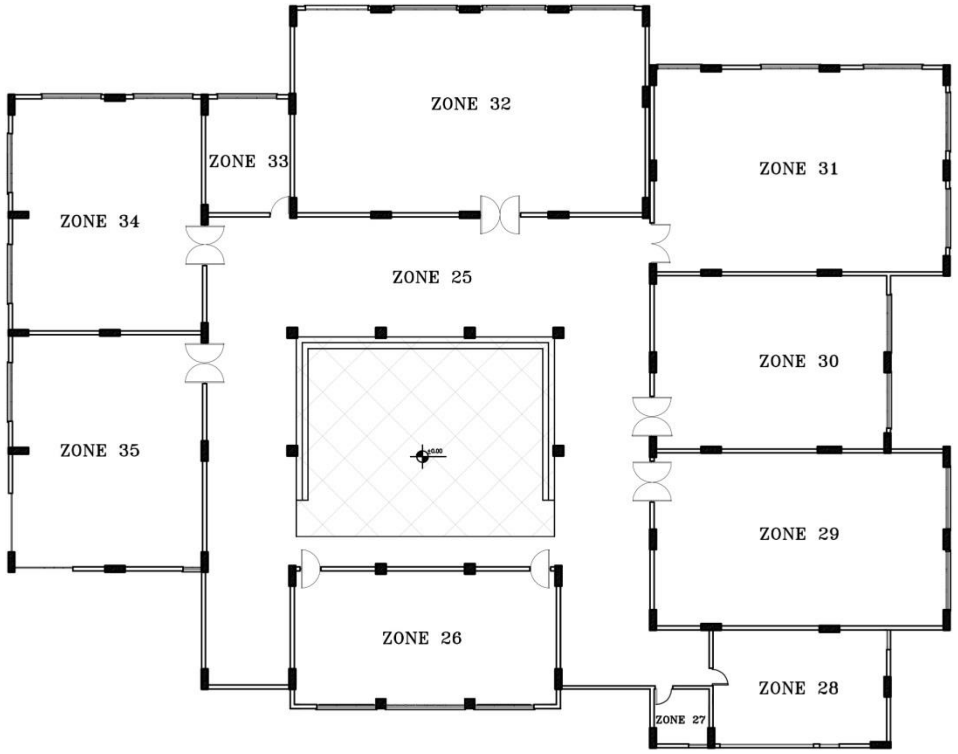
Appendix B: Sample of the Zone Names



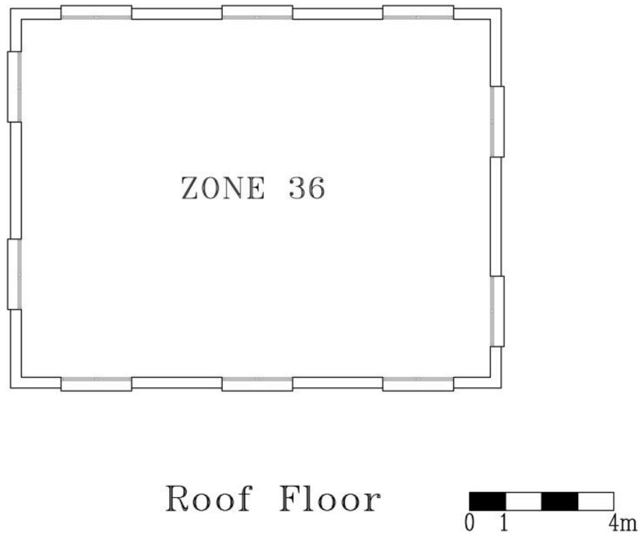
Ground Floor



First Floor

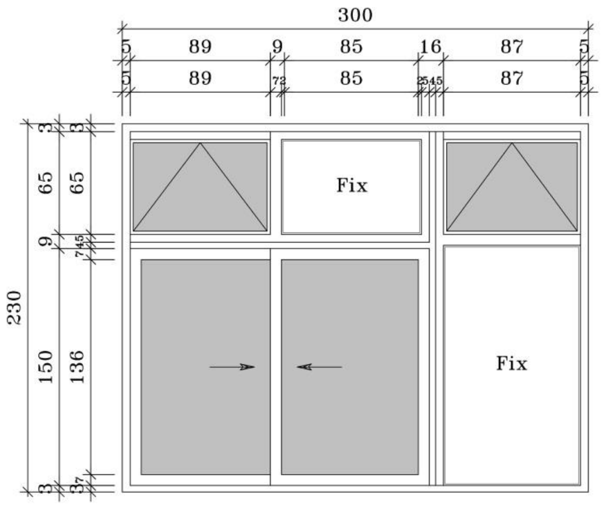


Second Floor



Roof Floor

Appendix C: Sample of Window Types



AL.W
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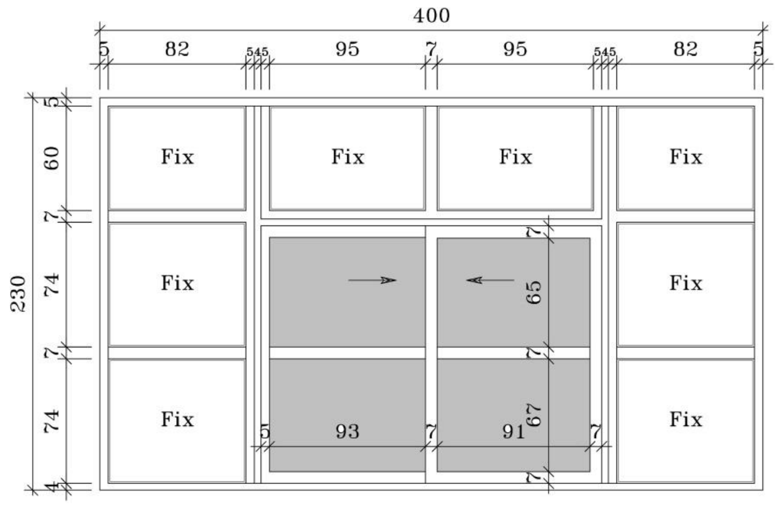

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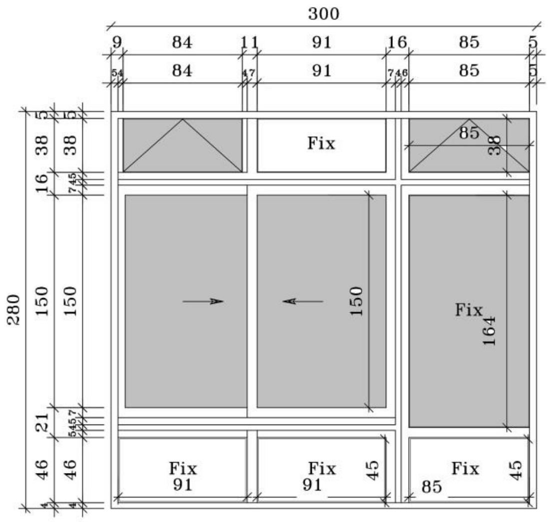

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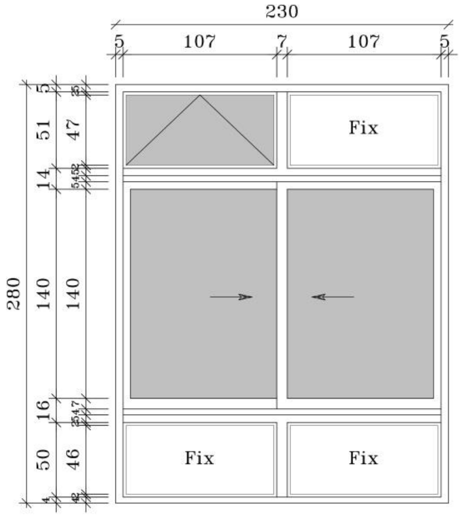

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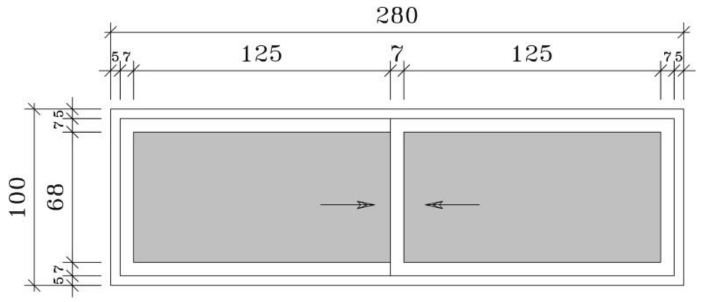

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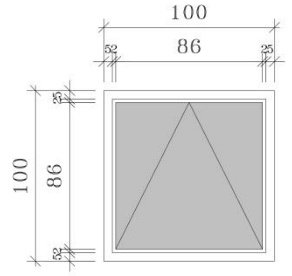

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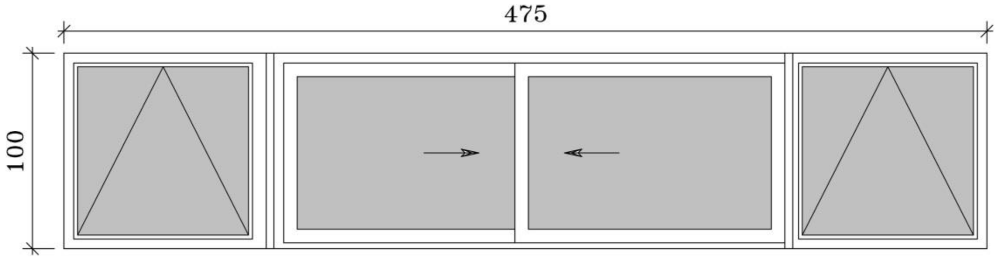

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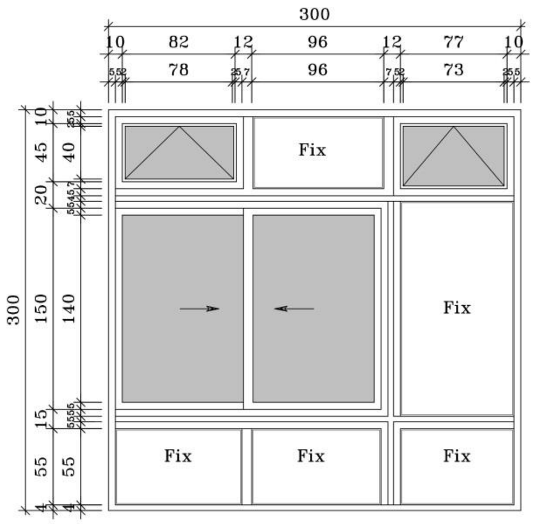

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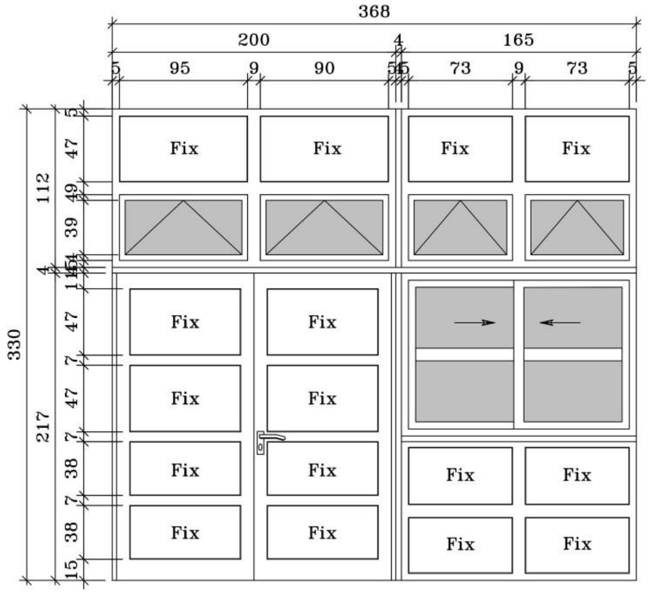

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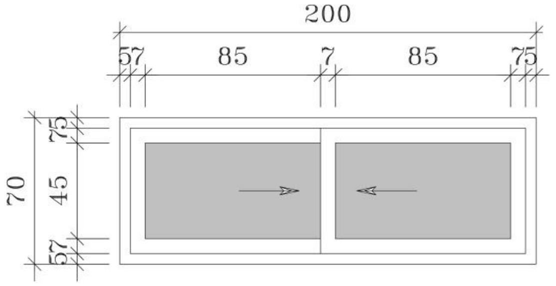

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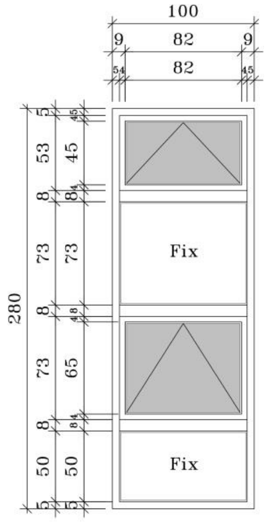

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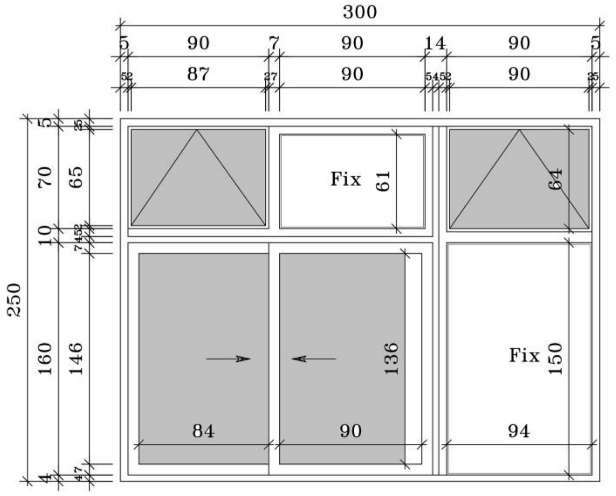

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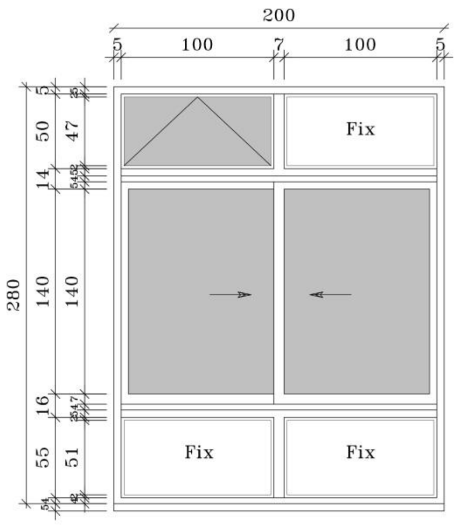

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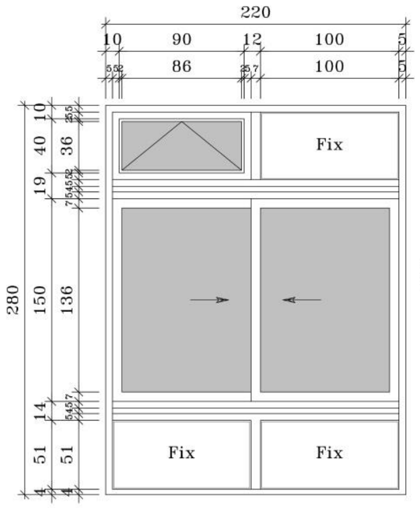

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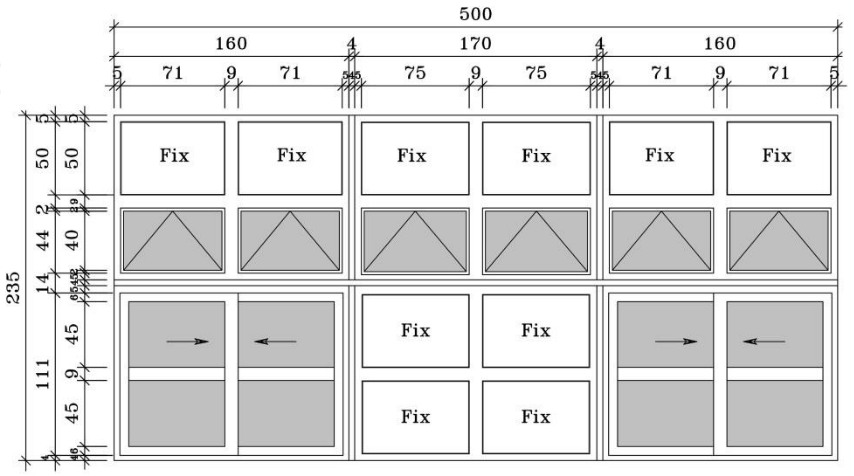

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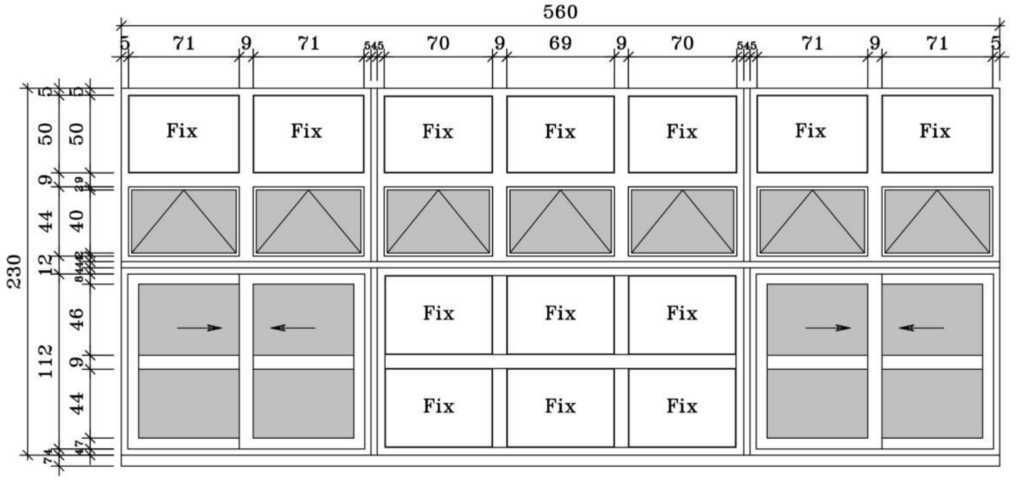

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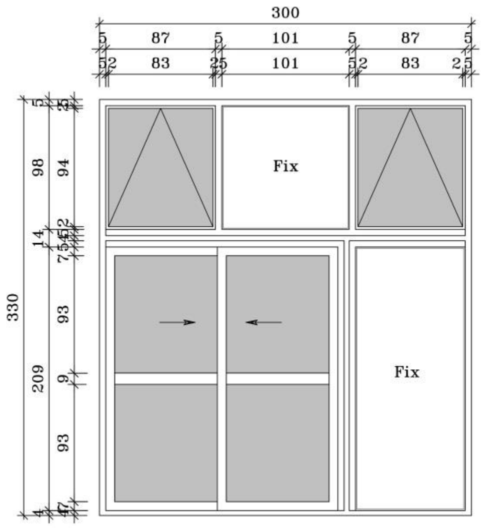

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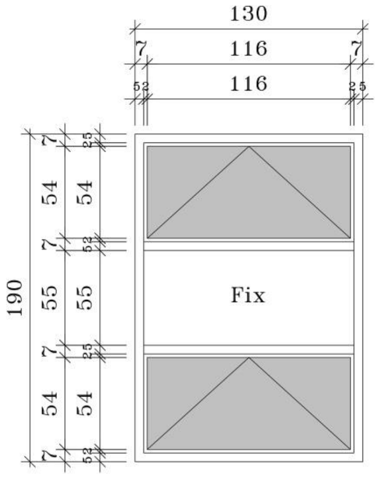

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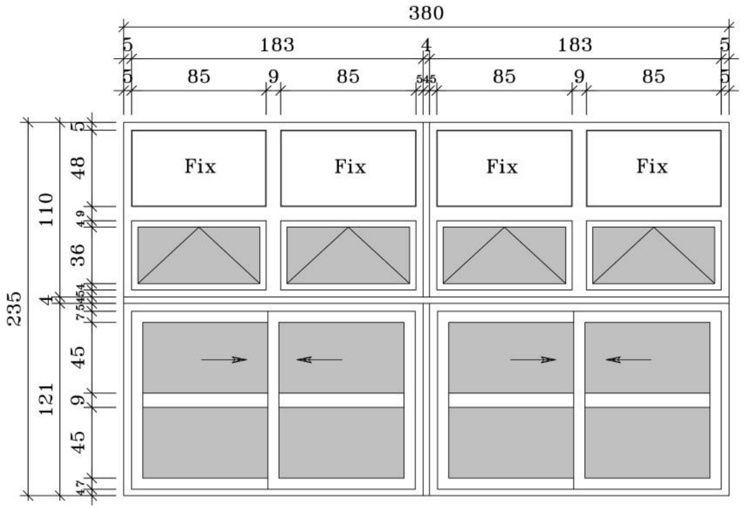

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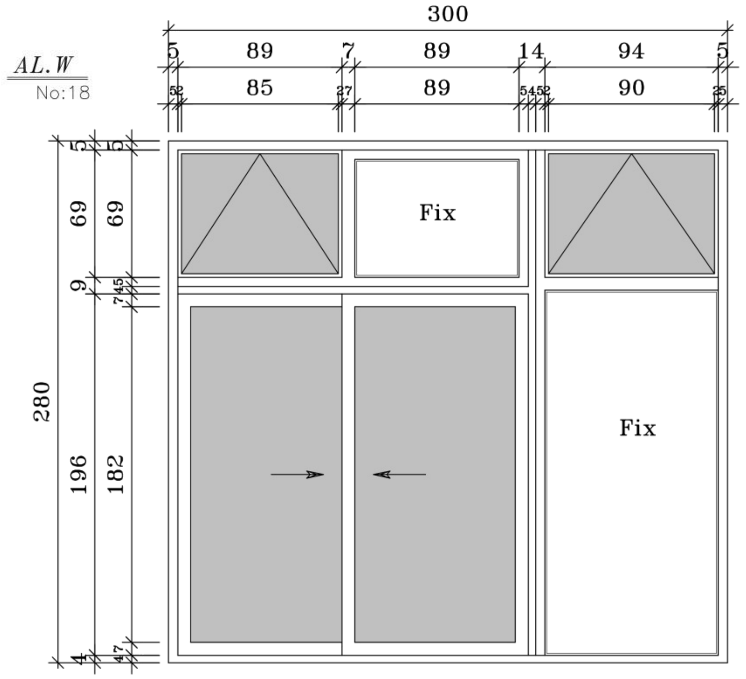

AL.W
No:20

Table 12: Windows' Type
(Source: Drawn by an Arthur)

No.	Type	Window Width	Window Height	Window No.
1	Al.W$_1$	300	230	6
2	Al.W$_2$	400	230	6
3	Al.W$_3$	300	280	12
4	Al.W$_4$	230	280	6
5	Al.W$_5$	280	100	3
6	Al.W$_6$	100	100	6
7	Al.W$_7$	475	100	3
8	Al.W$_8$	300	300	8
9	Al.W$_9$	368	330	1
10	Al.W$_{10}$	200	70	10
11	Al.W$_{11}$	100	280	10
12	Al.W$_{12}$	300	250	6
13	Al.W$_{13}$	200	280	9
14	Al.W$_{14}$	220	280	4
15	Al.W$_{15}$	500	235	1
16	Al.W$_{16}$	560	230	2
17	Al.W$_{17}$	300	330	1
18	Al.W$_{18}$	130	190	2
19	Al.W$_{19}$	380	235	1
20	Al.W$_{20}$	300	280	6

Appendix D: Sample of Surfaces

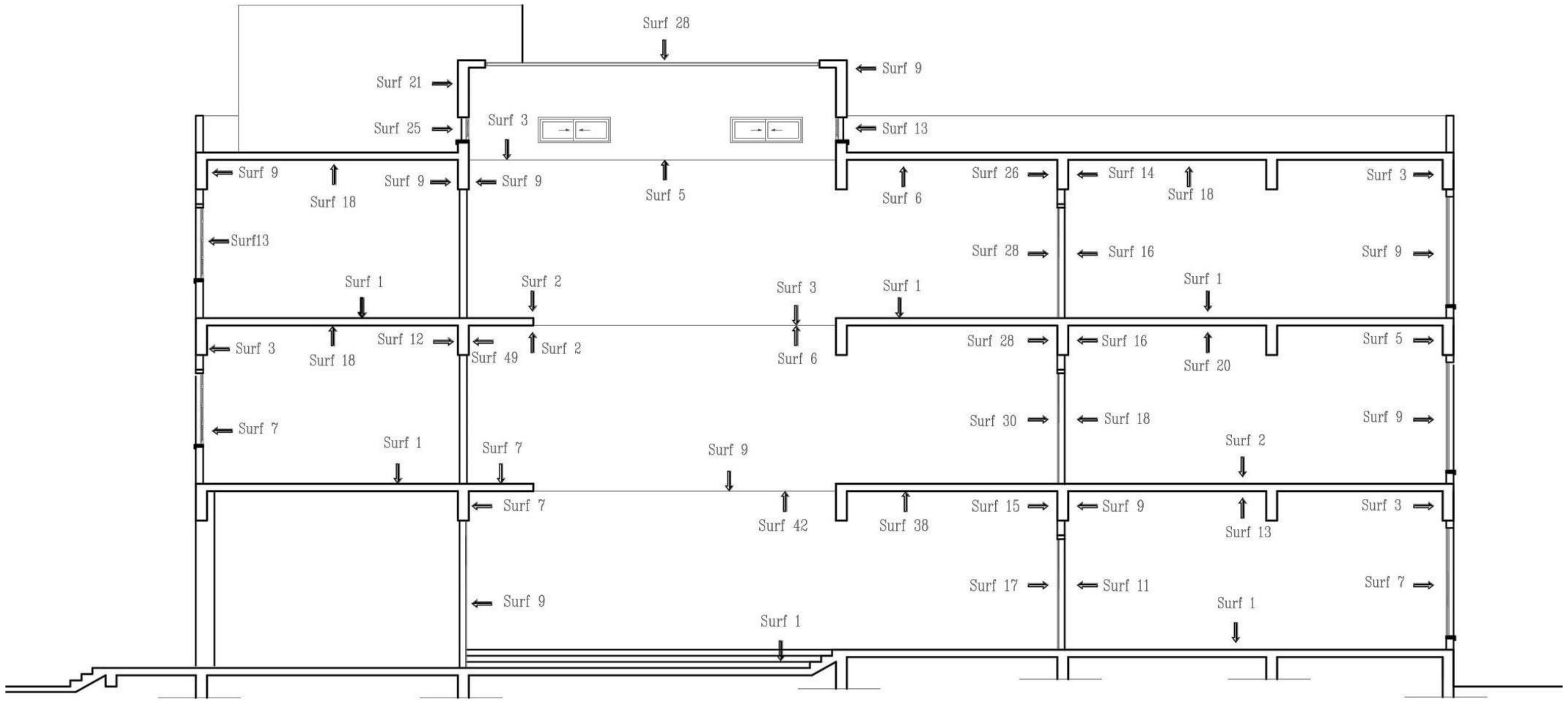

Figure 59: The Coloured Building with the Glass Roof

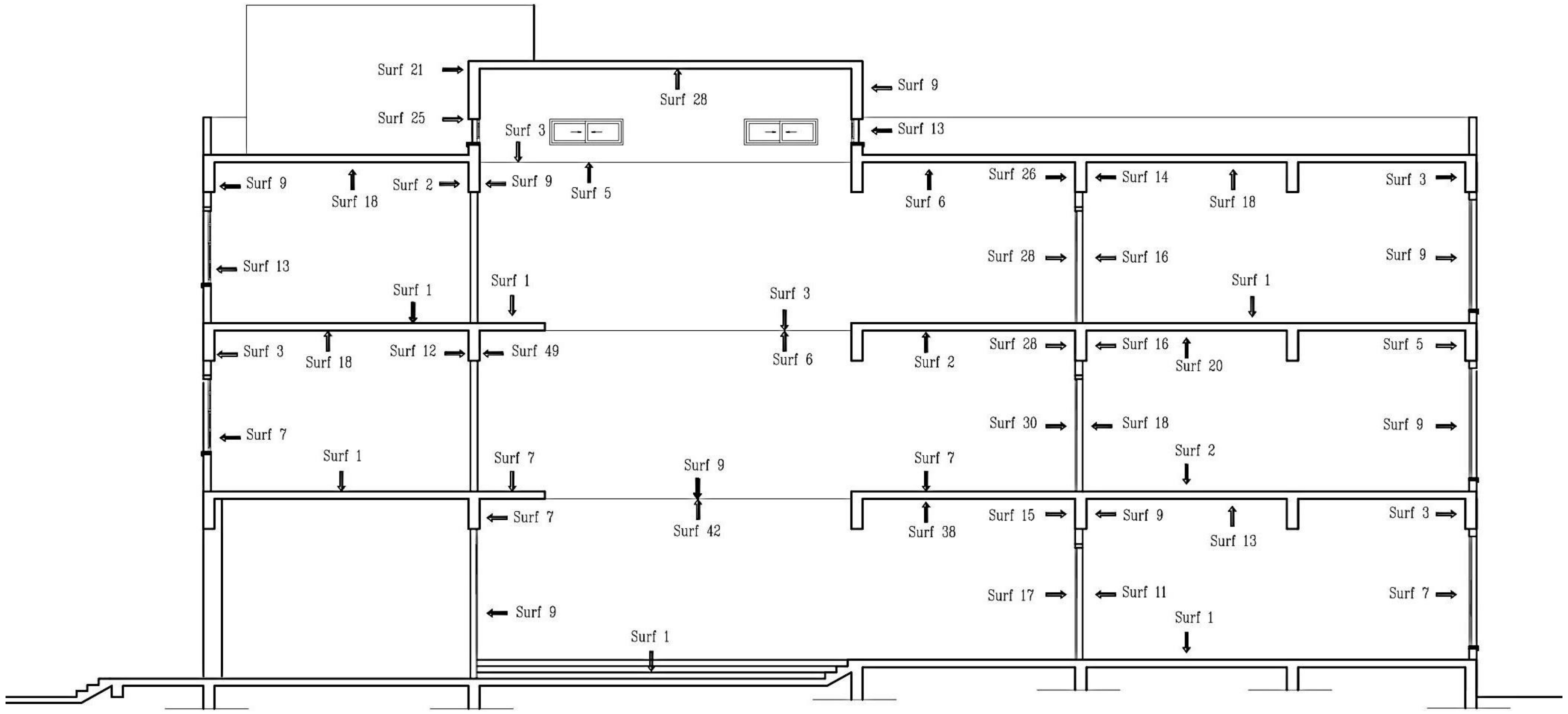

Figure 60: The Coloured Building with the Solid Roof

Appendix E: Sample of Bioclimatic Charts of Each Simulation

The notable point is that positions of zone 1 and 36 to comfort zone were shown in the following bioclimatic charts. It means the lowest and highest part of atrium space, zone 1 and zone 36 respectably, in Coloured Building.

- **Simulation 1**

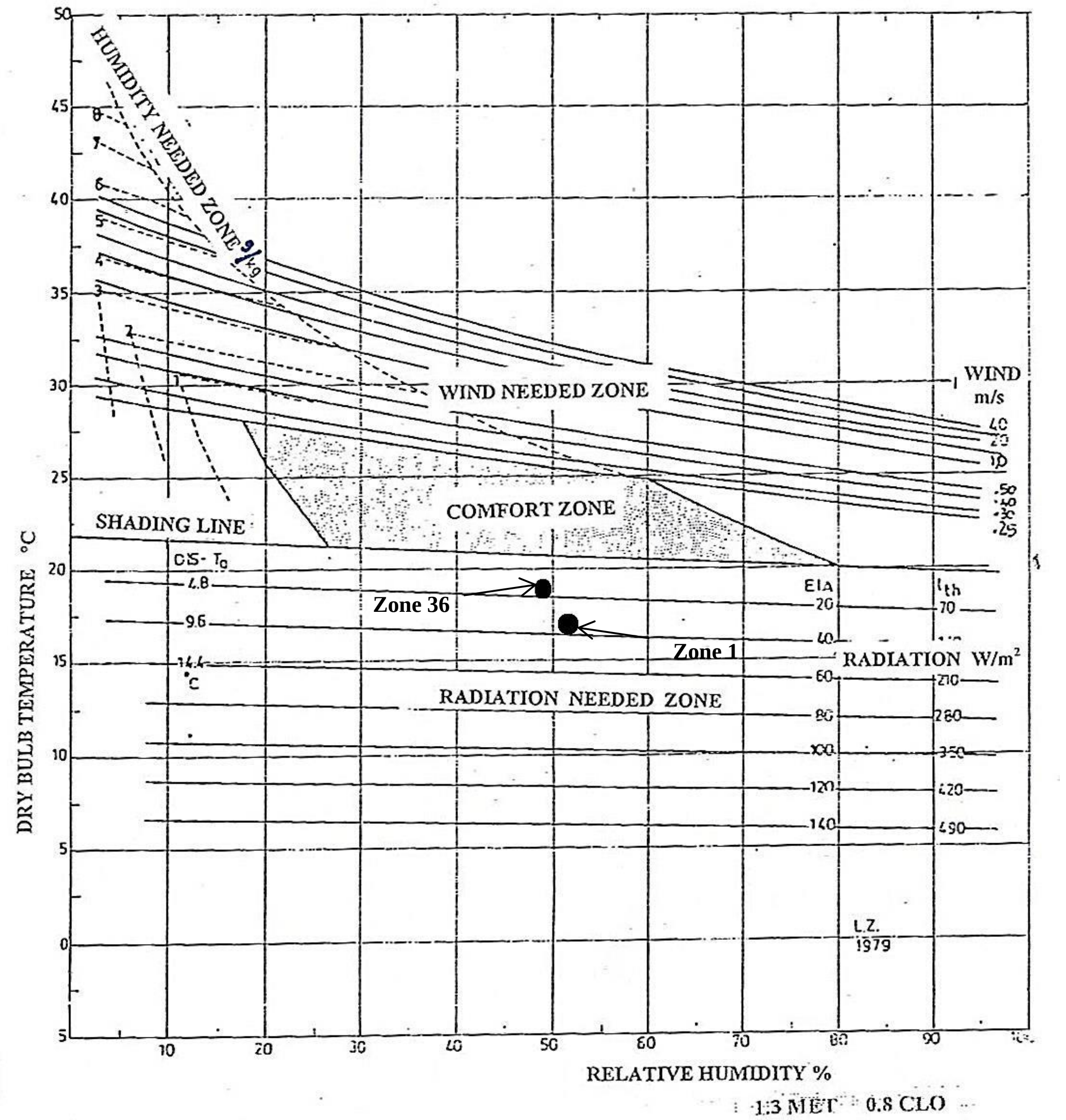

Figure 61: 21th March, At Noon Time (12:00 pm) in Simulation 1

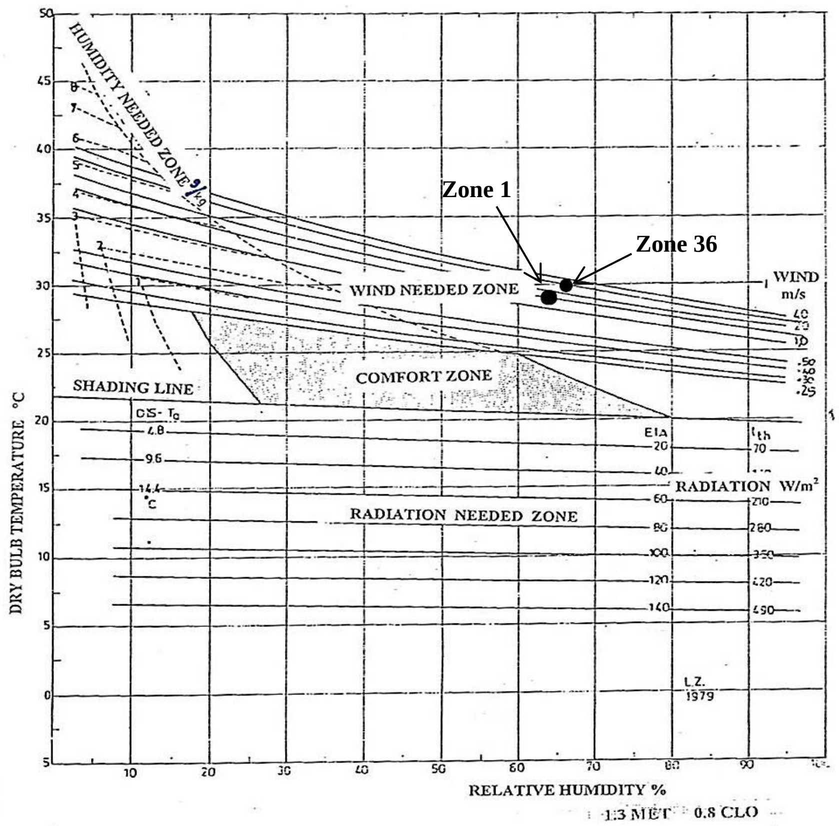

Figure 62: 21th June, At Noon Time (12:00 pm) in Simulation 1

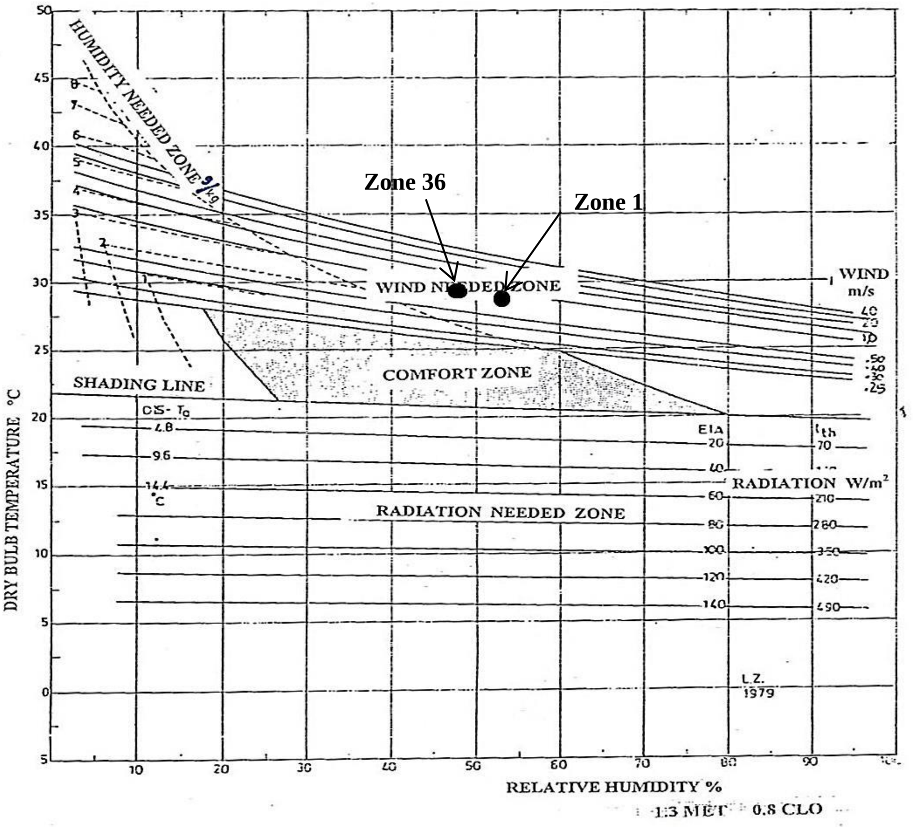

Figure 63: 21th September, At Noon Time (12:00 pm) in Simulation 1

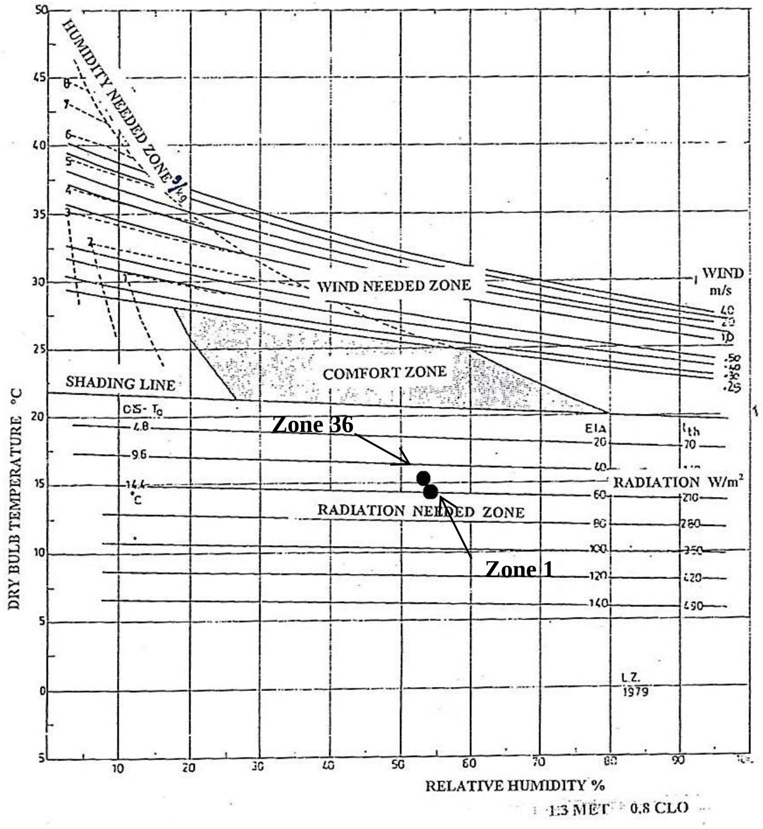

Figure 64: 21th December, At Noon Time (12:00 pm) in Simulation 1

- **Simulation 2**

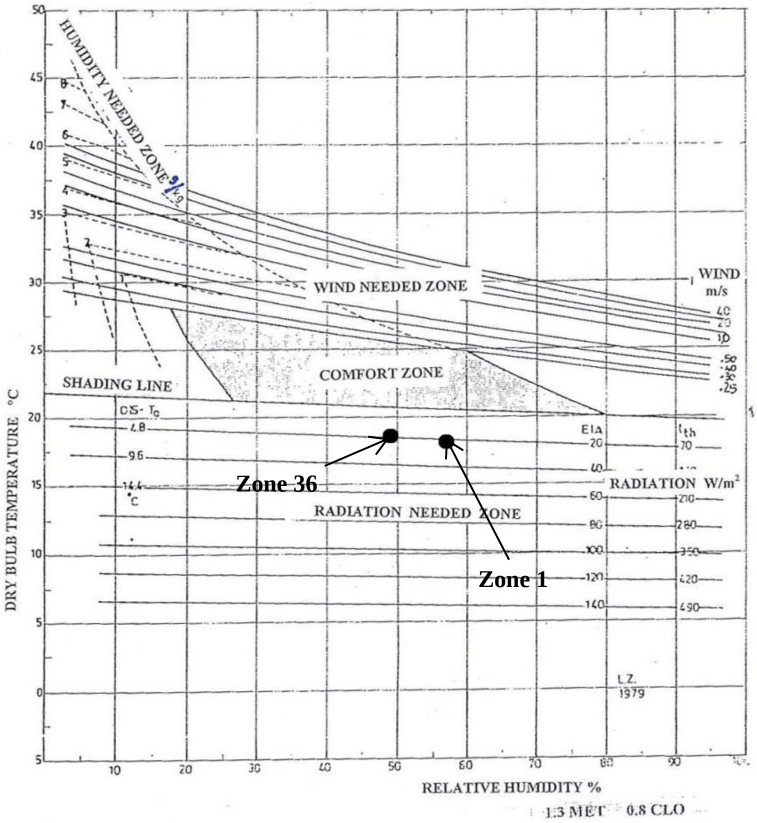

Figure 65: 21th March, At Noon Time (12:00 pm) in Simulation 2

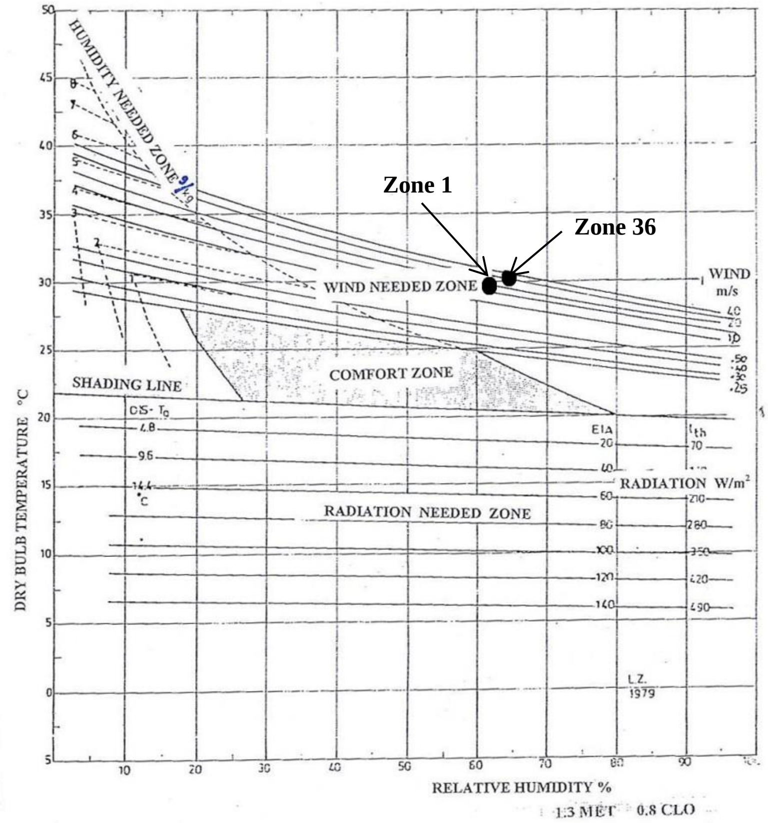

Figure 66: 21th June, At Noon Time (12:00 pm) in Simulation 2

- **Simulation 3**

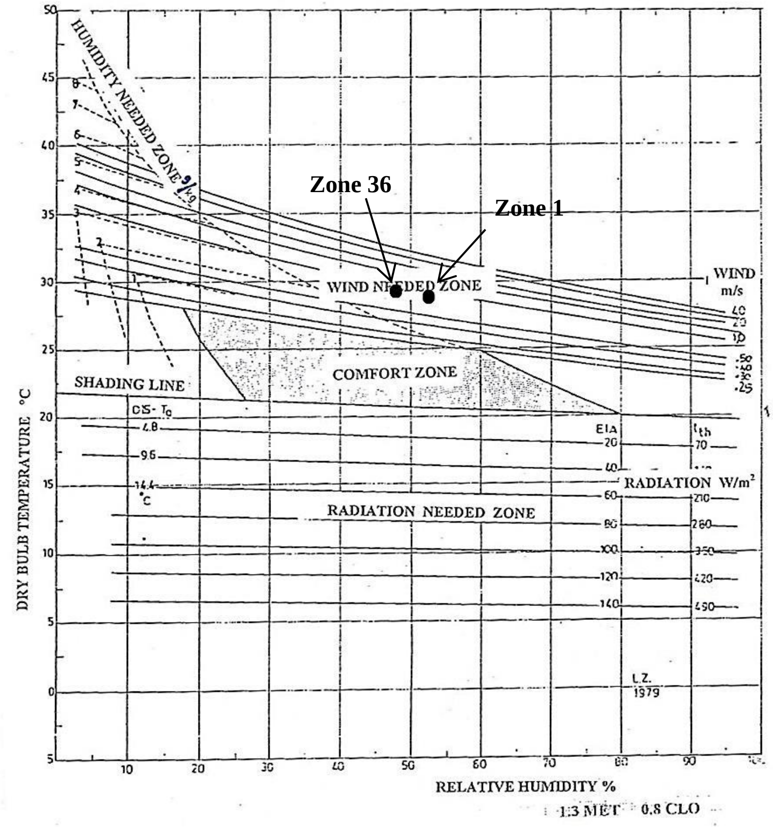

Figure 67: 21th September, At Noon Time (12:00pm) in Simulation 3

- **Simulation 4**

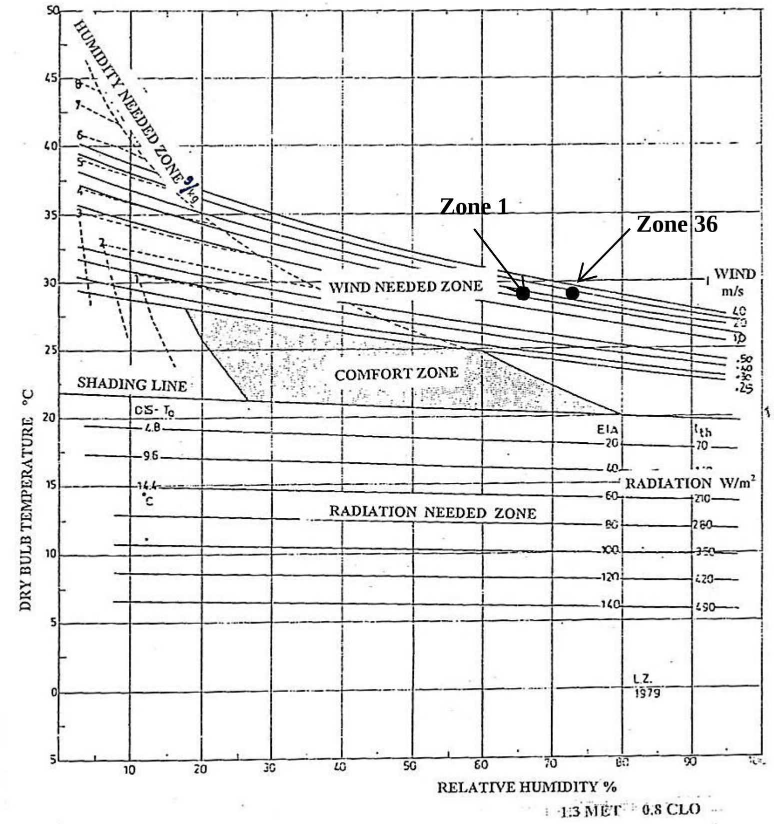

Figure 69: 21th June, At Noon Time (12:00pm) in Simulation 4

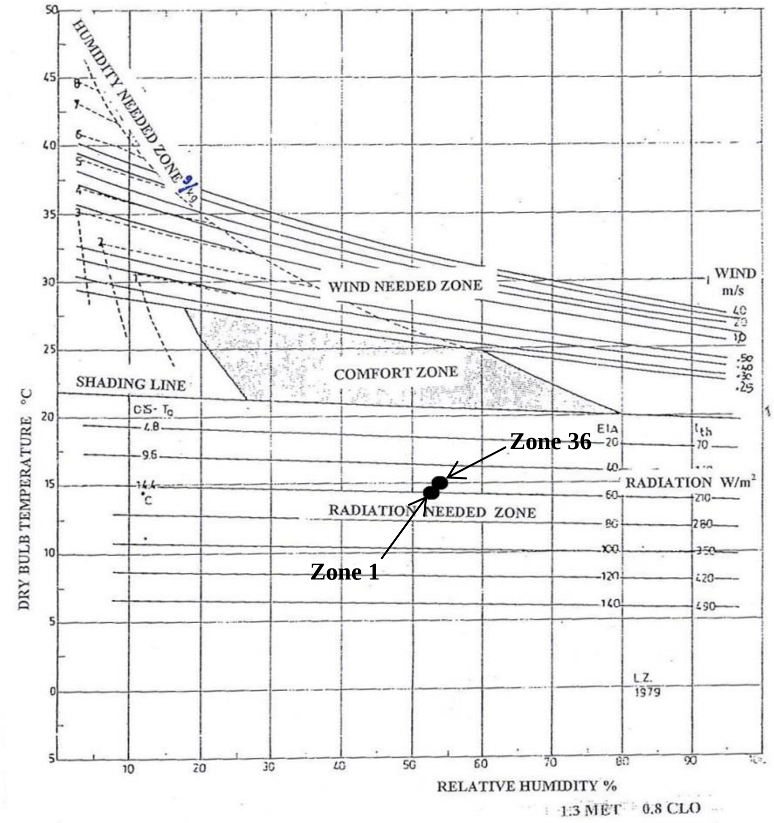

Figure 68: 21th December, At Noon Time (12:00pm) in Simulation 4

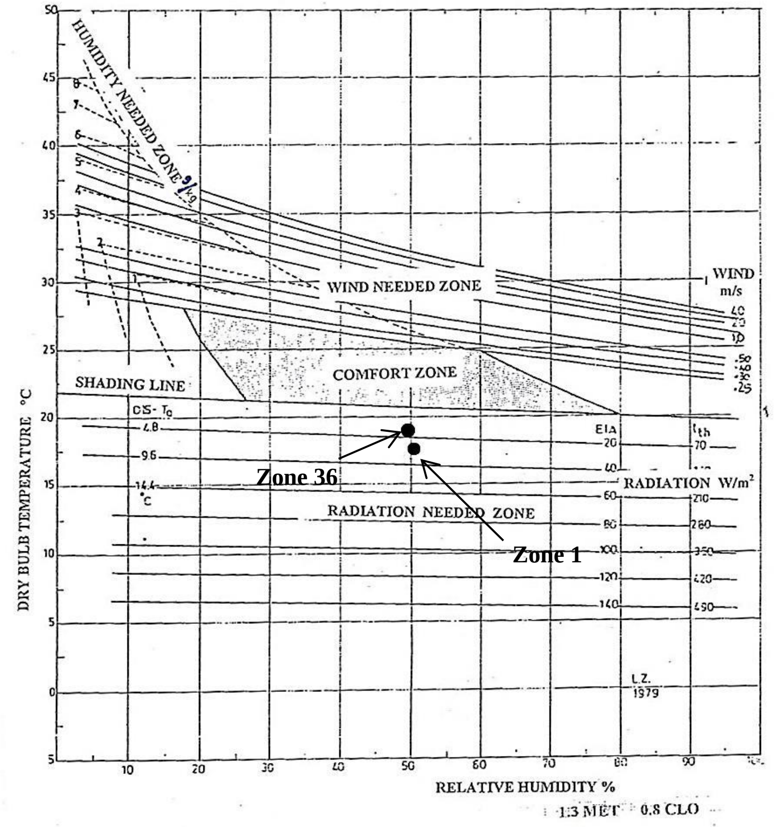

Figure 70: 21th March, At Noon (12:00pm) in Simulation 4

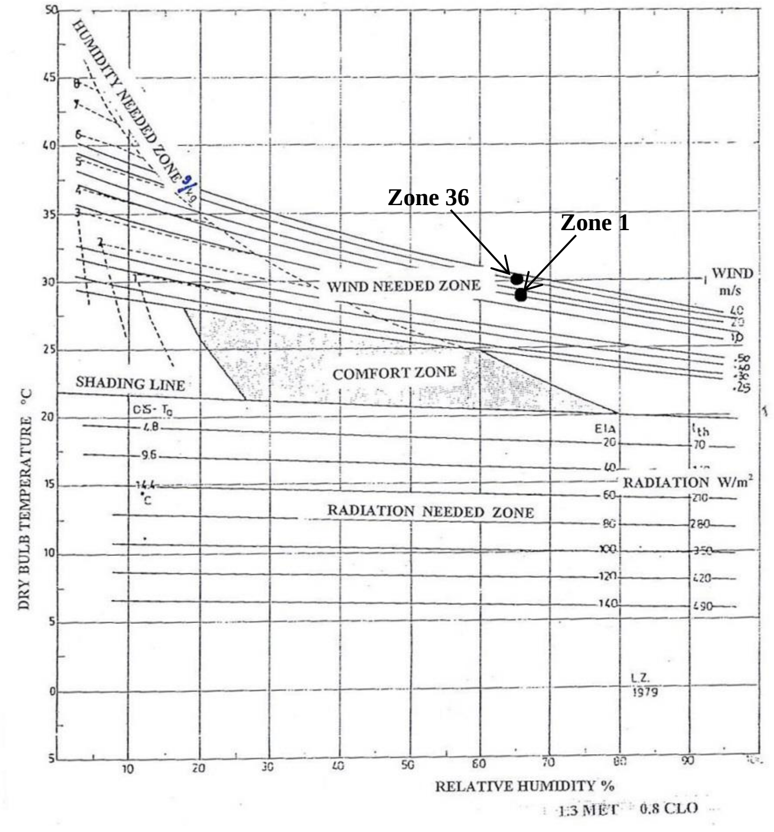

Figure 71: 21th June, At Noon (12:00pm) in Simulation 4

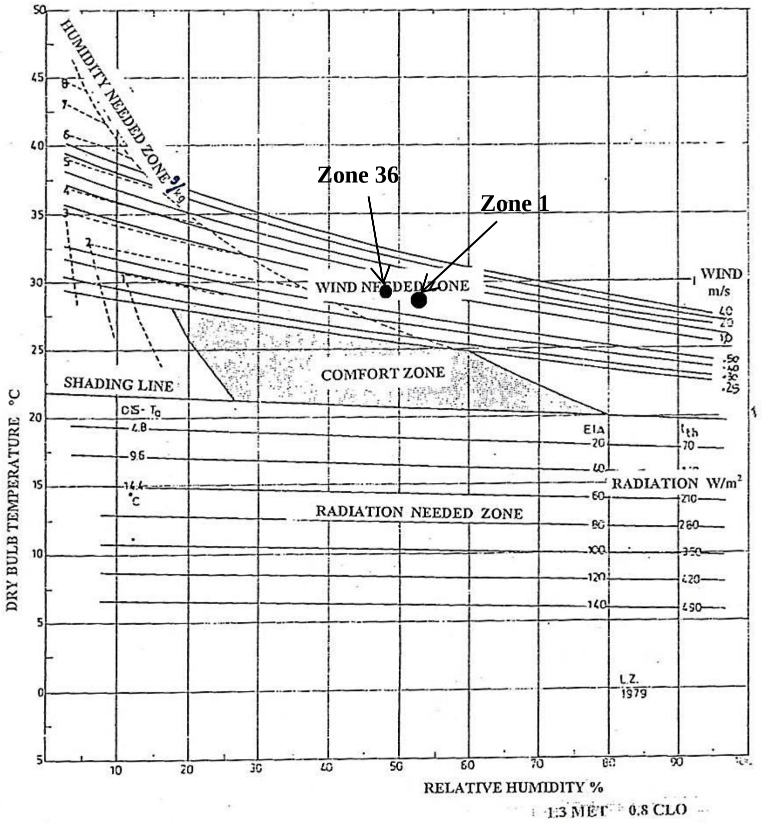

Figure 72: 21th September, At Noon (12:00pm) in Simulation 4

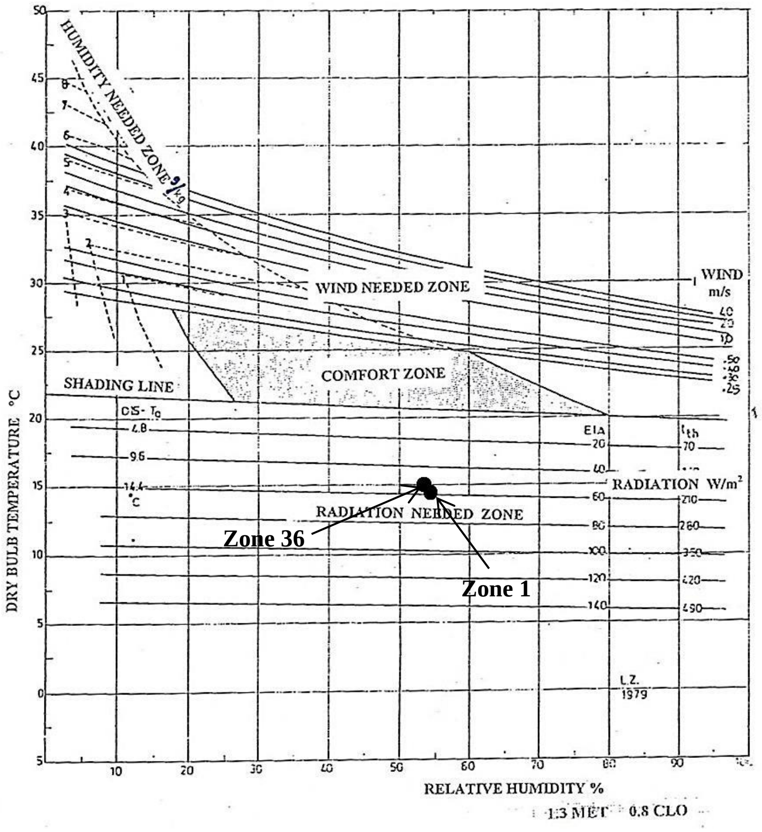

Figure 73: 21th December, At Noon (12:00pm) in Simulation 4