DAYLIGHT PENETRATION IN ATRIUM SPACES

A THESIS
SUBMITTED TO THE DEPARTMENT OF
INTERIOR ARCHITECTURE AND ENVIRONMENTAL DESIGN
AND THE INSTITUTE OF FINE ARTS
OF BİLKENT UNIVERSITY
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF FINE ARTS

By

Murat Özdamar

May, 1998

I certify that I have read this thesis and that in my opinion it is fully adequate, in scope and in quality as a thesis for the degree of Master of Fine Arts.

Assoc. Prof. Dr. Cengiz Yener

I certify that I have read this thesis and that in my opinion it is fully adequate, in scope and in quality as a thesis for the degree of Master of Fine Arts.

Dr. Nur Altınyıldız

I certify that I have read this thesis and that in my opinion it is fully adequate, in scope and in quality as a thesis for the degree of Master of Fine Arts.

Assist. Prof. Dr. Markus Wilsing

Approved by the Institute of Fine Arts

Prof. Dr. Bülent Özgüç

ABSTRACT

DAYLIGHT PENETRATION IN ATRIUM SPACES

Murat Özdamar

M.F.A. in Interior Architecture and Environmental Design

Supervisor: Assoc. Prof. Dr. Cengiz Yener

May, 1998

In today's world, one of the most important factors is energy saving. The proper use of daylight is one of the most important ways of it. The aim of this thesis is to study the effects of daylight in the atrium well and in the spaces adjacent to the atrium. The relative contributions on the illumination levels in the side spaces due to changes in the reflectivity of the floor materials and the glazing material, or both for enhancing the illumination will be determined. For the study, a square type of atrium (four sided atrium) has been chosen, and during the study, a physical scale model has been used, for the analysis of the light distribution within the atrium.

Keywords: Daylight, atrium buildings, atria, daylighting in atrium buildings, daylighting in atria.

Özet

Atrium Mekanlarında Gün Işığı

Murat Özdamar

İç Mimarlık ve Çevre Tasarımı Bölümü Yüksek Lisans Çalışması

Danışman: Doç. Dr. Cengiz Yener

Mayıs, 1998

Günümüzün en önemli sorunlarından bir tanesi, enerji tasarrufudur; diğer bir deyişle enerji politikaları, ve gün ışığını en verimli şekilde kullanmaktır. Bu tezin amacı atrium binası içerisine ve yan mekanlara düşen ışık miktarlarını, yansıma oranlarına ve cam geçirgenliğine göre incelemektir. Bu çalışma için bir kare atrium binası tasarlanmış, ve ölçekli maket üzerinde çalışmalar yapılmıştır.

Anahtar Kelimeler: Gün Işığı, atrium, atriumlarda gün ışığı

ACKNOWLEDGEMENTS

I would like to thank Assoc. Prof. Dr. Cengiz Yener for his invaluable supervision and encouragement throughout the preperation of this thesis.

I am greatful to my parents, Serpil and Ertuğrul Özdamar for their invaluable support, encouragement and patience.

Finally, I would like to thank Ece Çalgüner, for all her invaluable, continual support, patience and encouragement.

I would like to dedicate this work to my parents, Serpil and Ertuğrul Özdamar.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1- Introduction

Daylight is a free light source with full spectrum, and excellent color rendering. If it is introduced with care, it provides both vertical and horizontal illuminance, pleasant modeling effects, and enhances task contrast.

Many new buildings have glazed atrium spaces that provide a variety of amenities in addition to daylight illuminance. Atrium is a traditional form that influenced buildings in Europe throughout the nineteenth century. Its universal presence in today's offices and retail complexes is connected to energy issues.

Many atria use more energy than a simpler, less appealing, unglazed interior space but their importance to building owners is based upon the need to provide appropriate corporate imagery and to offer relevant amenities in the competitive real estate market. The importance of these issues is obvious when these needs conflict with increased energy used, they will almost always take priority. This suggests that the effort of future studies might be to minimize unnecessary energy use, in conjunction with meeting the aesthetic and functional goals for atria (lighting of the right quality and quantity), rather than viewing atria in a narrower sense, primarily as energy-saving features.

Boubekri and Annimos (89) state that, in non- residential buildings, a high proportion of delivered energy goes to provide electric light. For the past few decades since the introduction of the fluorescent light, buildings have been designed to rely heavily on electric rather than natural light, and the desire for daylight planning has been lost. The atrium is a form of large light well that allows the core area of a building to be naturally lit. In the past few decades, the atrium has become a common design feature of many buildings. An atrium not only provides daylight to spaces adjacent to it, but also acts as transitory environmental zone between the interior and exterior.

There are many factors influencing the behavior of daylight inside the atrium space. The most important factors are its proportions, the light transmittance of the glazing systems, the reflectance of the surfaces.

As the depth of an atrium increases, the illumination decreases. This is because at each floor, light is drawn into the adjacent spaces (Raniga 198). As a result, the reflectivity of surface materials is important as higher reflectance of the materials increase the amount of light within the atrium well.

Taking into consideration this aspect, the thesis concentrates on the effects of daylight in the adjacent spaces: the relative contributions of daylight on the illumination levels in the adjacent spaces due to changes in the reflectivity of the floor materials of the adjacent spaces.

According to these themes, the thesis covers the following chapters:

Chapter one deals with the introduction of the subject, the demand on the atrium buildings and effects of daylighting within the atrium space. The scope of the subject and the aim of the study are also stated in the first chapter. In the second chapter the importance of daylight and the reasons for the demand on daylighting are investigated. The definition and historical development of the atria throughout history are examined in the third chapter, with investigations on the three development periods of atria. The fourth chapter introduces the basic forms of the atrium buildings. The factors influencing the performance of daylight inside the atrium spaces, geometry, and relative proportions, the kinds of glazing materials and the light transmittance of the glazing system, the reflectance of atrium walls and floor, and the reflectance of the surfaces of the adjacent spaces are examined in the fifth chapter. The sixth chapter comprises the case study. The scale model is introduced, the measurements are explained, and the results are interpreted. The seventh chapter, the conclusion, includes where the comments and design proposals for atrium buildings.

2- Daylight

Daylight has always been one of the most influential forces upon the form of architecture throughout history. In recent years, for the large majority of buildings, daylight has played a significant role on the utilitarian as well as aesthetic qualities of the designed environment. Consequently, proper design for the use of daylight, whether for primary visual tasks or for general aesthetic emphasis, requires the highest skills of the architect and lighting designer and the most careful planning.

"Daylight has been important through the entire history of buildings. It was the primary light source for thousands of years, and always had a special symbolic meaning. For example daylight is still used today to light special places like church altars, just as Greeks, and older civilizations used the sun in their temples. Architectural form, from ancient history to modern times, has responded to daylight" (Gowth: Lawrance Berkeley National Laboratory).

The sun is the dominant light source in nature. The sun emits a continuous spectrum of energy, and because of the very high source temperature involved, the total spectrum ranges into the longer and shorter wavelengths on both sides of the visible band. Intensity of energy through out the visible range is fairly uniform.

Daylight is constantly changing in intensity and color from dawn to dusk, from day to day, from season to season. Some people consider it as a capricious vehicle of architectural expression, because it moves, changes character, varies with the weather, and as a result, provides buildings a living quality. Bednar (86) points that, the value of daylighting is universal to good architecture. All architecture until the advent of electric lighting addressed this issue as a primary form determinant, leading to many creative solutions. The atrium concept allows the innovative exploitation of daylight by bringing natural light into the centers of buildings, thus eliminating deep, dark spaces. The generated interior facades, in tandem with exterior facades, serve to balance the distribution of daylight within the occupied zones, and Erhardt (46) states that proper use of natural light in buildings must be part of the early design concept. The building's form is extensively influenced by its use of exterior light. The open atrium of history has become the vast glass-covered courtyard in modern shopping centers.

2.1 WHY DAYLIGHT?

"Daylight does more than save energy; people prefer daylit spaces for many reasons. It is the best light source for color rendering, and its variability is pleasurable. This is not surprising since humans evolved in a world lit by sunlight" (Gowth: Lawrance Berkeley Labs). Daylight, skillfully employed, provides the architect with one of his most effective modes of aesthetic expression, and means of energy conservation.

According to most people, good light means only much light. If we do not see well enough, we simply demand more light. Very often, we find that it does not help because the quantity of light is not nearly as important as its quality. The optimal use of natural daylight, especially in buildings used mainly by day, make a significant contribution to energy efficiency, visual comfort, and the well being of occupants by replacing artificial light. Such a strategy should include the potential for heat gain, and conservation, energy savings by replacing artificial light, and the more subjective benefits of natural light, and external views enjoyed by the occupants (Commission of the European Communities 24). Energy conservation policies have encouraged a return to a partial reliance on daylighting techniques, and practices. However, there are many problems to be overcome relating directly to the behavior of diffuse radiation, which can be defined as sunlight, scattered and reflected by the atmosphere and clouds.

By considering the inclusion of daylight in a building, Robbins (56) comes to the point that a designer must have one or more compelling reasons to do so. Most often, daylight is used as either a primary or a secondary interior illuminant; but even if it is used only to provide a particular design effect, the designer must consider the impact of light on all aspects of the building and its occupants. Many reasons can justify daylight as a light source in both residential, and commercial buildings;

- Quality of the light
- Importance of daylight as a design element
- View (Daylight apertures provide visual communication channels to the outside)
- Energy conservation resulting from the use of daylight as a primary or secondary illuminant
- Energy consumption and peak demand cost savings resulting from the use of daylight
- No cost change in construction
- Opportunity to develop integrated structural, and mechanical systems
- Psychological, and physiological benefits that are not obtainable with electric lighting, or windowless buildings

- The genuine desire to have natural light, and sunlight in a space

Beside these according to Button and Pye (82), daylight, and artificial light may need to be integrated for two main reasons:

- Artificial lighting may be needed to supplement an inadequate supply of daylight.
- Daylight is used, as the main form of lighting to achieve a high level of energy efficiency within the building interior.

Concern for the conservation of energy was strong in the early 1970's atrium building, but waned as fuel supplies returned, and cheapened. Now the pressure has redoubled with the realization that all fuel-burning releases CO_2. The potential passive solar performance of atrium buildings is demonstrated but still rarely used. Winter warming, summer shading, and especially natural lighting can all contribute significantly .

3- Definition and Historical Development of Atrium Space

The atrium, that is a particular form of courtyard, was the social center of the ancient Greek and Roman house. Throughout architectural history, the form of courtyard building has been widely used for monasteries, missions, houses, castles, and grand palaces. In the nineteenth century, the development of iron and glass technology created a new possibility for courtyards, creating an interior space protected from the climate but still enjoying the light and view of the open sky. The atrium form was born and began to develop, as a unique building form with a wide range of design possibilities.

An atrium must be an interior space, that is, a space enclosed with a glazed roof structure for maximizing daylight while controlling the indoor climate, and protecting from the weather outside. Otherwise, it would be called a courtyard. Besides, it must be daylit, with some measure of direct natural lighting.

The atrium is a daylit, centroidal, interior space which organizes a building. By being centroidal, it serves as a place of orientation for the rooms which surround it, thereby bringing spatial integrity to the building.

Centroidal is the keyword, as the atrium is in the center of a plan and extends vertically through the building in section, having the potential to spatially organize the building. The atrium need not be in the geometric center to achieve this purpose; it can be centroidal in its spatial role as long as the majority of spaces relate to it.

The concept of shelter is central to atrium buildings. The sheltered central court is a great amenity in itself, creating a type of space not otherwise available in most cities, an all-weather public gathering space.

It is in the interaction between the court and the spaces around it(adjacent spaces), that the more skilful sheltering goes on. The atrium brings light, but keeps wind and rain away from the overlooking space. Atrium is an interior living space of a building that permits the entry of light to other interior spaces linked to it by pass-through components. It provides a decreasing levels of light to adjacent spaces. Its dimensions vary widely depending on the building size. Normally it occupies the total height of the building. The covering may consist of a metal structure supporting the glazing. The interior finishes should have high reflectance to ensure good daylight penetration into the adjacent spaces.

In spirit, the concept was evidenced in many courtyards built before the end of the eighteenth century. The first period of the development of atrium took place in Europe during the first half of the nineteenth century, when iron and glass technology permitted the covering of large courtyard spaces. This development continued during the second period of the atrium during the latter half of the nineteenth and the beginning of the twentieth century in the United States. After another period of relative oblivion, the atrium buildings were rediscovered. This third period, of the new atrium that began in the 1960s, continues to the present day.

3.1 First Period

By the beginning of the nineteenth century in France, England, and America. Metal and glass stated to be increasingly used in buildings. Although cast and wrought iron were available since the 1800s, they were not widely used. But the search for greater spans led to a rapid development of structural technology. Simultaneously, glass manufacturing also advanced, resulting in larger panes, held in place with milled-iron frames.

The fascination with this new technology resulted in buildings made entirely of iron and glass. One of the most important examples to this development is the Crystal Palace in Hyde Park (1851).

Figure 3.1 Crystal Palace
Croix, H. and R.G. Tansey. Art Through the Ages, New York: Harcourt Brace Jovannovich, 1986. 882.

Concurrent with the construction of an all glass and iron building, there were many explorations in combining this new technology with traditional masonry building forms. These explorations resulted in two new functional and spatial types, the arcade and the atrium.

The arcade is a glass covered passageway with shops on both sides, which connects two busy streets. It developed and prospered during the course of the nineteenth century in England, France, Italy, Germany, and America. Its appearance was based on the specific need of society for a public space, protected from traffic and weather, which would enable the marketing of luxury goods being rapidly produced by industry. Perhaps the best known of the arcades is the Galleria Vittorio Emanuelle II in Milan built in 1867.

Figure 3.2 Galleria Vittorio Emanuelle II
Bednar, M.J. The New Atrium. New York: McGraw Hill, 1986. 9.

The development of the arcade is certainly parallel to that of the atrium, and there are many similarities between these two spatial types. The first known atrium was in the Reform Club, by Sir Charles Barry in London (1837-1841), where for the first time the court became an interior room, fully protected from the weather but enjoying the light of an outdoor court (Bednar 9).

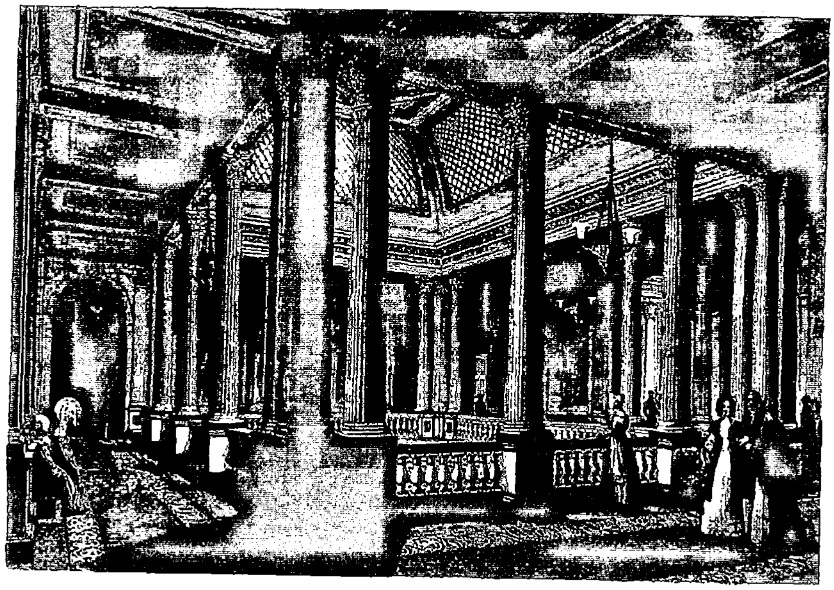


Figure 3.3 Reform Club
Bednar, M.J. The New Atrium. New York: McGraw Hill, 1986. 10.

3.2 Second Period

The second term of the atrium took place in the United States at the turn of the nineteenth century. The construction in this period was based on the earlier European models. The buildings were all masonry on the exterior, with iron, steel, and glass being used only in the atrium spaces.

All of these atrium buildings were either square or rectangular in plan and multi-storied in section. In many, the glazed roof was placed at an intermediate level of the light court, rather than at the top of the building, so that the atrium and the light court occupied the same plan position.

The use of the atrium was very appropriate to monumental civic buildings, such as post offices, court houses, and city halls that had to accommodate large crowds of people requiring a multitude of services.

This period of the atrium buildings came to an uncertain close in the years following World War I. The late nineteenth and early twentieth centuries had witnesses great luxuriance and architectural spirit that saw the atrium plan adapted to many different building types and to various styles. But the atria in the United States, like the ones in Europe, were threatened by fire hazards.

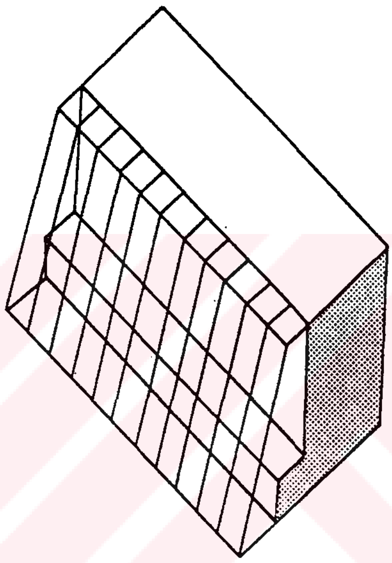
3.3 Third Period

Not only have a peerless number of atrium buildings been built since the 1960's, but the concept has also been adapted to new roles and extended to new kinds of developments. In recent years, atria have been used in hospitals, schools, merchandise exchanges, libraries, etc. New design concepts have evolved. Atria of unprecedented scale and complexity have been used as focal spaces in multi-functional centers.

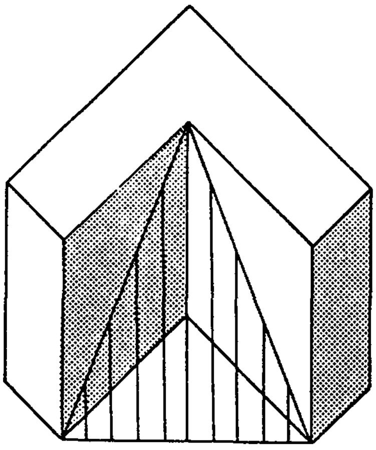
4- Types of Atria

In the built environment, there are five basic forms of atrium buildings. The types of atrium buildings are differentiated according to the sides or planes that are glazed.

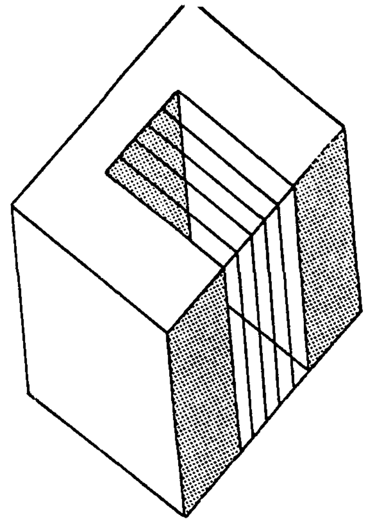
These types are:



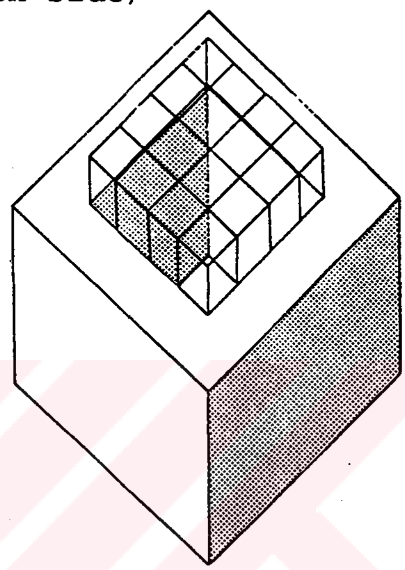
Single-sided or conservatory atrium



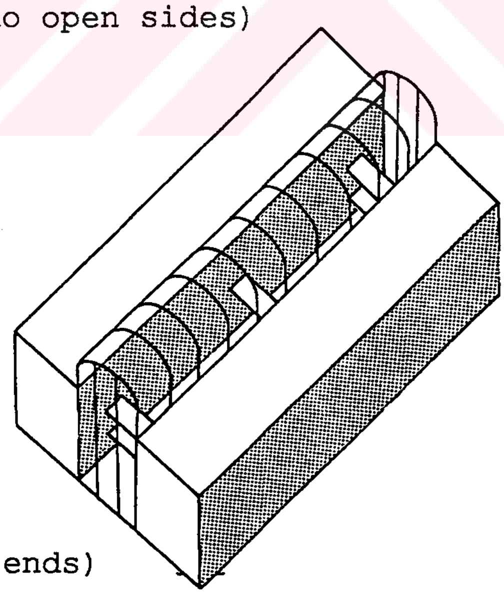
Two-sided atrium (two open sides)



Three-sided atrium (one open side)



Four-sided atrium (no open sides)



Linear atrium (open ends)

Figure 4.1 Basic Forms of Atria
Saxon, R. Atrium Buildings: Development and Design. London: Architectural Press Limited, 1986. 74.

The pure forms, one-, two-, three-, four-sided, and linear atria can be applied to single buildings as well as to large complexes, such as combination of two or more types within a single complex.

5- Daylighting in Atrium Spaces

The value of daylighting is valid for all good architecture. Architecture, until the arrival of electric lighting, addressed this issue as a primary determinant, leading to many creative solutions. The atrium concept allows the innovative use of daylighting by bringing natural light into the centers of buildings, thus eliminating deep, dark spaces. The generated interior facades, in tandem with the exterior facades, serve to balance the distribution of daylight within the occupied zones.

The use of daylighting as a free energy source can offset the cost of electricity, which is the most expensive energy source. This is particularly appropriate in commercial and institutional buildings where high light levels are required during the daytime. Each unit of energy utilized for artificial lighting requires money to be spent on an additional one-half unit of energy for air conditioning to offset the heat generated by the lights. Energy usage increases. Daylighting has a short payback period in all climates, when designed in a coordinated system with artificial lighting.

An atrium's primary value in terms of daylighting optimization is in the generated perimeter of occupied spaces which face it. A courtyard scheme achieves the same purpose but at the cost of exterior walls which must be built to withstand the elements and to directly address the climate (insulation materials, wall thickness). In an atrium scheme, this daylight-absorbing perimeter is achieved with considerable means of economy. The atrium walls can be made of interior materials, with maximum use of clear glazing for daylight. Moreover, the atrium scheme creates a controlled viewing environment, which is often a necessity on restricted urban sites.

5.1 Daylight Requirements in Atria

One of the strongest contributions which atria can make to energy conservation in buildings is in reintroducing the use of daylight. Atria are expected to satisfy three major requirements:

- Light level requirements of users in the atrium
- Light level requirements of adjacent spaces
- Light level requirements for plant growth.

The cost of artificial lighting, directly in terms of power consumption and indirectly in terms of the cost of removing the heat released, may be higher than the cost of daylight, which is one of the main factors that should be considered with the atria. An atrium can make a very significant contribution to energy savings in artificial light, by providing a source of natural light, deep into the building. The energy cost of daylighting lies in the low insulation and shading value of glass, causing heat loss and gain. Moreover good quality lighting and control of glare are expected in atria.

Good daylighting means, lighting of the right quality and quantity, delivered to the greatest plan depth possible. Quality rather than quantity counts, since low glare and contrast are desirable. The quality of light now sought for working spaces presents the greatest challenge: residential or leisure buildings have less critical requirements and are now lit for character rather than performance.

Office spaces are discovering a changing need for light quality under the impacts of energy costs and advance of office electronics. An agreement of opinion is emerging that light can best be delivered as a combination of two components; known as ambient light and task light. Task light provides the right level of acuity at the work place while ambient light provides background illumination. The ratio of background to foreground light must be in balance to provide adequate contrast for the performance of task, while preventing glare as a result of high level of contrast. (Saxon 77)

For electronic offices with staff using visual display units, a separate task-lighting component is not needed; as the task is self-illuminating. The way in which the ambient component is delivered becomes more critical, since reflections of bright sources in the VDU screen are disabling. Ceiling mounted luminaries and bright windows are equally problematic, and indirect light appears to offer greatest comfort.

By comparison with an external wall, the area of glazing within the atrium can be increased to admit more light. Usually, daylit rooms receive direct light from the sky. In the case of the atrium, the sky is now the glazing, and thus its brightness is reduced by the absorption of the glass and the fraction of the fixed shading(if there is any). The reflected light also has to pass through the glazing. Thus, where daylighting of surrounding rooms is required, it is essential to provide as much light from the sky into the atrium and rooms adjacent to it as possible, by the geometry and the use of high transmittance glass, and as much reflected light as possible by the use of highly reflective finishes of the atrium walls.

5.1.1 Glazing System and Its Transmittance

The optical properties of glazing materials influence daylighting quality, quantity, and the potential for energy savings due to reduced artificial lighting.

There are three major types of glazing materials that are either translucent(light transmitting) or transparent (view transmitting). These three basic types of skin materials are; glass, plastic sheeting, and composite materials. Glass and some plastics offer transparency, the composites offer only translucence. The tendency in recent practice is to use glass for vertical vision areas, but to use plastics or composites in roof glazing where light weight, safety, and insulation values gain precedence (Saxon 80).

Transparent materials transmit the most daylight, and provide the most natural view of the sky, but they admit strong direct beams of sunlight into the building, causing glare. Beams of sunlight may be blocked, redirected, scattered or diffused by interior objects.

The lower light transmission of transparent tinted glazing is commonly used to reduce sunlight and sky view. However, the color of the tint affects the perceived color of objects in the space below. Therefore, for daylighting purposes, transparent glazing materials with high transmission properties, like single glazing with no tint, are often preferred.

Translucent materials that diffuse and distribute sunlight do not allow a direct view of the sky. To provide a uniform light quality under direct sunshine, the glazing material has to be highly diffusing. However, highly diffusing materials tend to have lower light transmittance that reduces the light levels under overcast sky conditions.

5.1.1.1 Glass

Security against the effects of breakage is necessary for overhead glass. Ordinary glass is not likely to break, yet it is not without hazard. Wired glass prevents the dropping of loose pieces after breaking, and survives well in case of fire. Tempered glass is thick and strong. Laminated glass, produced by interleaving a plastic sheet between glass layers, is expensive but safe.

Wired and roughcast glasses are not vision glasses like laminated or tempered glass, in other words they are not transparent. Diffused light may be desirable, since these type of glasses give a better distribution for working illumination, and reduces solar radiation discomfort. As all of these glass roof glazing materials are quite heavy, they may have some disadvantages of using.

5.1.1.2 Plastics

The established glazing plastics are polyvinyl chloride (PVC), acrylic, polycarbonate and glass reinforced polyester resin (GRP). All except GRP can be produced in transparent sheets. Acrylic can be shaped, tinted, and colored freely, to give diffused or clear light.

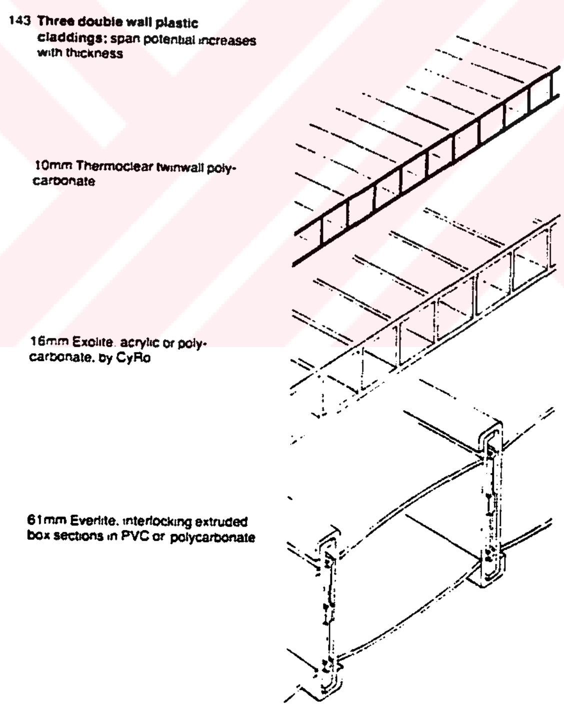


Figure 5.1 Plastic Glazing Materials
Saxon, R. Atrium Buildings: Development and Design. London: Architectural Press Limited, 1986. 120.

5.1.1.3 Composites

Combination of glass, plastics and even metal can produce higher performance skin materials than any of the components alone. Composite glazing materials are made of two separate sheets of glass with a layer of capillary plastic tubing stacked perpendicular to the glass.

It is important that composite glazing materials provide diffuse light that should be distributed deep into the occupied spaces where quantity of light must not be reduced.

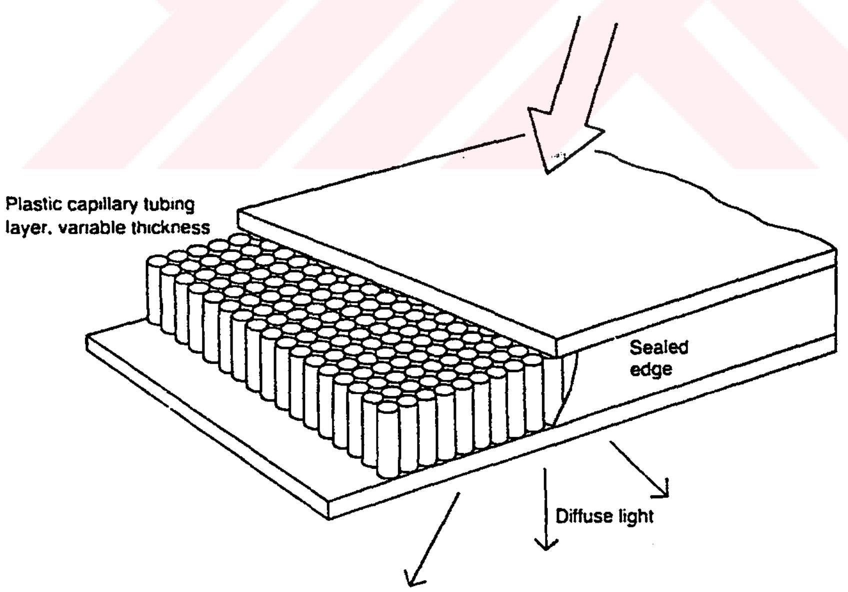


Figure 5.2 Composite Glazing Materials
Saxon, R. Atrium Buildings: Development and Design. London: Architectural Press Limited, 1986. 121.

5.1.2 Structural System for the Glazing

The fenestration system controls the intensity and distribution of daylight entering the atrium. The net transmittance of this system depends on the geometry and structure of glazing systems, the glazing orientation, the type of shading, and the daylight availability (diffuse sky, direct sun).

Besides, the amount of daylight entering the atrium, depends on the structural system for the glazing (transmittance, shading devices, sun controls). The size of the structural system determines the net glazed area.

In atria designed for climates with mainly overcast skies, one should attempt to minimize the area taken up by the primary and the secondary structural members to maximize the area of glazing. This will affect the type of roof construction chosen and the dimensions of structural members.

5.2 Daylight Penetration and Dispersion within the Atrium

The strongest influence on the way light can be admitted into an atrium should be the climatic conditions of site. Different approaches are valid in climates where skies are often cloudy from those that are usually clear;

temperate climates and those with extremes of daily and annual conditions.

For the overcast climate of Britain, rest of Northern Europe, and Russia, daylighting expectations must be based on the cloudy sky. In fact, a standard overcast sky (the CIE sky) has been adopted for calculation and model-testing purposes. It translates a brightness of 5000-10000 lux (Raniga 205) but is brighter at the top of the sky than at the horizon. The ideal atrium in this case would be largely top-lit, with a clear, unobstructed glazed roof to achieve the maximum transmission of light. Diffuse light from all parts of the sky would enter the atrium in this way. When sunny conditions occur, diffusion of light to rooms on the shaded side of the atrium would need to be provided.

In sunny climates, daylighting is difficult to achieve successfully with direct light, since sunlight is too harsh, and shadow is too dark. Sunlight must either be excluded by shades or converted to diffuse light. Where the sky is usually bright, even with clouds, polar roof light will deliver plenty of useful diffuse light.

Where skies are usually cloudless, there is very little light to be collected from the sky-vault, and sunlight must be captured and diffused. Passive or active shading devices can be used. A passive approach is to use solar-facing glazing in a sawtooth roof and fix summer sun rays, to reflect the rays onto the underside of the roof and from there, down into the atrium, while winter sun will enter directly.

In very hot conditions, only a small amount of light transmission is needed to give adequate daylight levels. Most sunlight must be excluded and any admitted must be converted to diffuse light.

The illumination in the atrium can be qualified through two components of the daylight factor:

- The direct light from the sky reaching the floor and the walls of the atrium. Ds(sky component horizontal or vertical).
- The reflected light from the surrounding surfaces, atrium walls and floor, Di(internal reflected component).

The direct light from the sky may also include reflected light from outside of the atrium, which in this case is considered to be sky vault.

The atrium acts as a light duct. Openings into occupied spaces are its outlets, but it is the walls of the duct that determine the amount of light captured and how much light reaches to the lower floors and the lowest storey of the building.

One of the design decision is the proportions of the court itself; its aspect ratio. The ratio between its width, length, and depth will control the rate of decay of light levels in the court: the less bright the sky, the wider will a court need to be in order to deliver a useful level of light to the lowest storey.

However, the reflectivity of the sides is also very important: there can be enormous variation in performance depending on how reflective the walls are. For the adjacent spaces of lower storeys lit from an atrium, their "sky" is the reflective wall opposite them. If the walls are of glass from floor-to-ceiling, or are completely open, very little light will bounce to travel downwards to lower storeys. At the opposite, theoretical, extreme, if there are no openings, and a high reflective surface on the walls, light would jump down the duct as it does inside an optical glass fiber, loosing light intensity. Light should ideally be drawn off for each storey only to the amount necessary, with the rest reflected back for further transmission downwards.

Light enters the adjacent spaces in two ways, according to the level in the atrium:

- The upper atrium predominantly receives direct light from the sky.
- The lower atrium predominantly receives reflected light from the opposite walls and the floor of the atrium.

The logical outcome of this concept is that; fenestration should differ at each floor level. At the top storey, there is need for small windows, reinforced with collecting devices. Lower down, progressively more glass is necessary.

Theoretically, therefore, each floor should have different sizes of windows: small windows on the upper floors, larger windows on the middle and lower floors. Another design option is to alter the ceiling heights of each floor, with the tallest spaces at the bottom of the atrium.

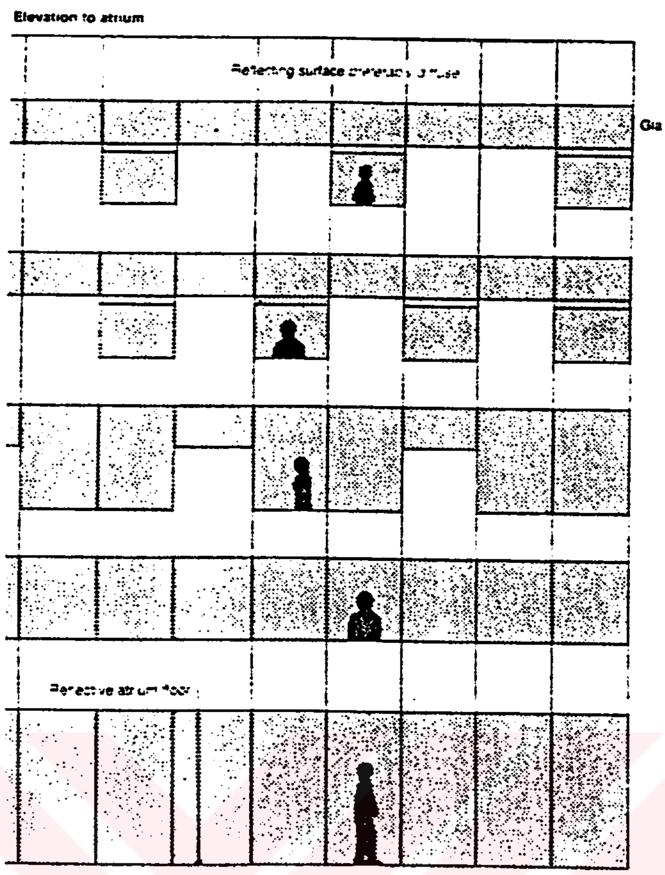


Figure 5.3 Different Sized Windows
Saxon, R. Atrium Buildings: Development and Design. London: Architectural Press Limited, 1986. 81.

As an alternative to varying the glass surface area from floor to floor, types of glass could be varied. Reflective glass of different strengths could be used. This may be less effective as a strategy, as specular reflection is a less efficient way to bounce light down the duct. Diffuse reflection from white tile, metal or laminate surfaces is more effective. Diffusing glasses exist and can be used to transmit part of the light and to reflect part of it. The ratio of diffusing and clear glass would then vary from the top to the bottom of the atrium.

Another point related to this issue is the landscaping within the atrium which can conflict with the daylighting performance of the building. Planting on balcony levels has very low reflectivity. Plants absorb light and affect the illuminance levels of the lower floors. Planting is a welcome feature, but should be located to minimize such losses of light.

5.3 Orientation of the Building (Solar Orientation)

The solar orientation (in conjunction with the glazing system) determines the amount of daylight to reach the atrium interior. It is a relevant daylighting factor, especially for the rectangular plan atria with the east-west axis preferred to maximize the north or south daylight availability.

The southern skies are on average significantly brighter than northern skies, in the northern hemisphere. This applies to all cloudy climates, because the most frequent sky conditions are of broken or periodic cloud, brighter in the direction of the sun (the fully overcast sky has a luminance distribution independent of the position of the sun). Since southern skies are generally brighter, it may be argued that buildings should be oriented towards the south to maximize available daylight.

Orientation of the glazing is in fact often done. The reason is not so much to take advantage of brighter diffuse skies, but to allow the occupants of the building the opportunity to receive direct sunlight when it is available.

If it is argued that the glazing facing the south should be made smaller than those facing the north, it will follow that on dull, fully overcast days, when the sky has no preferred brightness towards the south, the spaces with smaller glazing will suffer more from inadequate daylight. These spaces with smaller glazing will therefore have frequent recourse to artificial lighting. Accordingly the general practice for daylight design is to separate orientation from glazing size on the assumption that the sky will either have uniform luminance, or a symmetrical distribution of luminance about the zenith. But, it will follow that if glazings are designed on the basis of a symmetrical sky luminance distribution, there will be many more occasions during the year when glare will be caused due to excessively bright skies, in spaces facing the south rather than in spaces facing the north. If the glazings in a south-facing space are not made smaller, some means must be found for screening the excessively bright sky. Practices has been to design for dull sky conditions, and to provide suitable screens for use when necessary, in order to counter sky glare. Though the technique of permanent artificial lighting has led to much rethinking of these basic assumptions, it may well become more common for glazings to be designed for visual comfort throughout the year, so that a permanent supplement of suitable artificial lighting can provide much of the illumination on the work surface.

Skylights with clear glazing are optimal under cloudy sky conditions since the greatest quantity of non-directional daylight will be admitted to the atrium from the bright sky dome. Under sunny sky conditions directional skylights or roof monitors should be utilized. When these face south, roof overhangs or horizontal sun shades must be provided to control the high-angled summer sun. This problem is not present with north-facing glazings although the area of glazing needs to be larger than in a south-facing monitor to admit an equal amount of daylight. Many designers advocate having both south and north-facing glazings to balance the quantity and quality of daylight under different sky conditions.

5.4 Geometry of the Atrium

The proportions of the atrium will affect the amount of direct daylight reaching the atrium floor. The wider and more shallow the atrium space, the better generally the contribution of direct daylight from the sky. But the shape of the floor plan affects this condition.

If the atrium is shallow and wide, then the shape of the floor plan is less critical. However, as the building height increases, the distribution of daylight becomes more dependent on internal reflections and a simpler, quadrangular plan shape often performs best.

The impact of the geometry of the atrium becomes evident in the performance of the internally reflected component: due to the fact that, the surrounding surfaces of the square floor plan are minimized compared to the rectangular/triangular floor plan, the number of internal reflections within the atrium is smaller.

Atria that are higher than their width generally result in poor daylight levels for all lower floor levels and thus require atrium walls with high reflectances.

5.5 Plan Aspect Ratio (PAR)

Plan aspect ratio is, the ratio of width to length of the atrium floor.(This is always less than 1.00 except in a square plan when it is 1.00.) (Boubekri, Anninos 76)

$$PAR = \frac{\text{Well Width}}{\text{Well Length}}$$

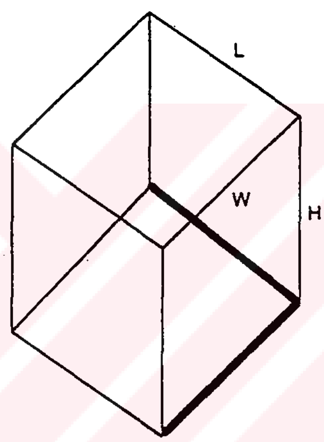


Figure 5.4 Plan Aspect Ratio
Saxon, R. Atrium Buildings: Development and Design. London: Architectural Press Limited, 1986. 80.

5.6 Section Aspect Ratio (SAR)

The section aspect ratio greatly influences the daylighting within an atrium building, and high SAR buildings do not permit solar radiation to reach to the floor of the building or lower portions of the interior facades.

An atrium with a SAR of less than 1.00 can be considered shallow, whereas a SAR above 2.00 yields a tall and/or narrow proportion. The large majority of SAR figures are between 1.00 and 2.00, a reasonable proportion for effective daylight penetration. (Boubekri, Anninos 76)

$$\text{SAR} = \frac{\text{Well Height}}{\text{Well Width}}$$

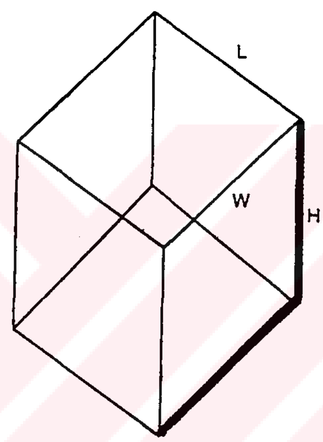


Figure 5.5 Section Aspect Ratio
Saxon, R. Atrium Buildings: Development and Design. London: Architectural Press Limited, 1986. 80.

5.7 Sectional Scheme

The sectional scheme can contribute greatly to daylight distribution. A stepped building section with each floor projecting into the atrium further than the floor above gives a portion of that floor, its own view of the skylight source.

While a stepped building section can be an effective design device, it reduces the atrium floor area while making each adjacent space progressively deeper and therefore more difficult to daylight.

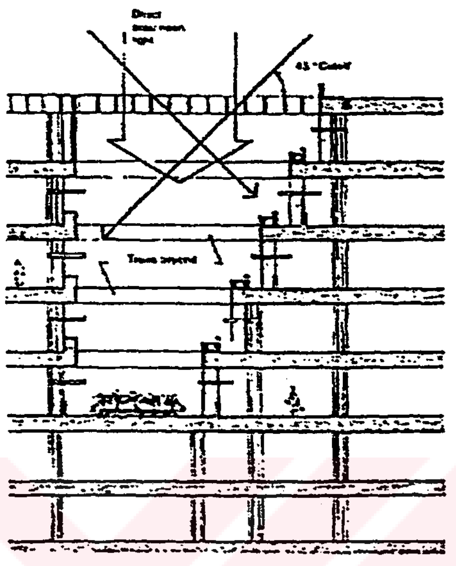


Figure 5.6 Stepped Atrium Building
Commission of European Communities. Energy in Architecture. London: BA Batford Ltd., 1992. 149.

5.8 Well Index

The concept of the well index has been one of the most effective means to analyze natural lighting efficiency in light wells and atria. For daylighting studies using physical scale models, well indexes have been used to standardize the various configurations of atria.

The illumination within the atrium is related with that dimension of the atrium well. The behavior of light in the adjacent space is also expressed as a relation to the light levels in the atrium well, since the light levels in the adjacent spaces depends on the physical dimensions of the atrium. The formula is given as follows:

$$\text{Well index} = \frac{H \times (W + L)}{2 \times W \times L}$$

(Flynn, Kreemers, Segil, Steffy, 82) where, W is the width, L is the length of the atrium well in plan and H is the height of the atrium well. It is just a ratio expressing the relative sizes of the boundaries comprising the atrium.

5.9 Surface Properties of Internal Architectural Elements

The atrium surfaces are responsible for either reflecting or absorbing the daylight that is admitted from the source.

The quantitative improvement of natural illumination is based on the contribution of the reflected light from the surrounding atrium walls and from the atrium floor.

The reflectance of the atrium surfaces should be as high as possible to reflect as much light downwards as possible.

Light reflected into the spaces can contribute to lighting levels or can create unwanted glare. Designers should be cautious about potential reflected light from surfaces in the surrounding area. Surfaces with light-colored, glossy, or highly-reflective oriented so as to reflect the sun into other spaces should be designed in a way that they would not cause any glare in those spaces.

5.9.1 Atrium Walls

The vertical illumination at the atrium walls determines the amount of light that enters the adjacent spaces.

The design of atrium walls affects the distribution of light in the space. The quantity of reflected light is the product of the average reflectance of the walls and the type of reflection. Diffuse reflecting materials reduce the quantity of daylight reaching the lower parts of the atrium walls and the floor; specular reflecting materials perform better but tend to increase glare for occupants, especially when sunlight strikes the atrium facades.

For tall atria, the total illumination decreases rapidly because both daylight components are decreased with height. The design of the facades will influence the illumination due to the reduced overall reflectance.

5.9.1.1 Reflectance of the Surfaces

The design of the atrium walls affects the distribution of light within the space. The amount of reflected light depends on the average reflectance of the walls and the type of the reflection.

Walls covered with a light color, and highly reflective finish would direct most light into the building. But the need for internal glazing to light adjacent spaces of necessity diminishes the amount of reflected light, and although the reflective materials perform better, they tend to increase glare for the occupants especially when sunlight strikes the walls.

The way light enters the occupied spaces varies at different levels of the atrium, the upper part receives predominantly direct light from the sky and the lower part receives predominantly reflected light from the opposite walls and the floor. As a consequence, as much light as possible should be reflected to the lower floor, since glazing does not reflect as much light as white walls, the amount of glazing in the upper storeys should be reduced to the minimum sufficient to provide good daylight for the occupants. Each floor will therefore have different window sizes, being largest at the lowest floor and smallest at the top. Another design option is to alter the ceiling heights for each floor having the highest spaces at the bottom of the atrium.

Under general cloudy sky conditions, clear-glazed, non-directional skylights will bring in the most daylight, to the atrium space. On the other hand, if and when clouds disappear, problems begin to occur and the interior atrium facades need daylight control. Although the sun might be preferred in the winter to provide direct heat gain, there is no way to keep it out in the summer.

5.9.2 Atrium Floor

The designer must deal with the surfaces, which describe the atrium related to their daylight significance. Opaque surfaces which are light colored, smooth, and reflective are the most advantageous ones for distributing daylight. A ground floor with the same characteristics is useful for projecting daylight into spaces that surround it. Off-white paving tiles and pools of water in the atrium are effective in this regard. Dense planting, heavily shaded trees, and brick pavers make the floor space a light absorbing area.

The presence of plants on the atrium floor affects the contribution of reflected light. Landscaping in the atrium, using dark-colored materials and plants will reduce the reflectance of the atrium floor. "The natural illumination of most adjacent spaces facing the atrium, except the top floors, depends particularly on reflected light from the atrium floor" (Baker, Fanchiotti, Steemers 5.36).

5.9.2.1 Reflectance of the Surfaces

The reflectance of the floor of the atrium influences the light levels of the lower storeys. The greatest benefit would be provided by a glossy floor material. Light colored materials provide the greatest amount of reflected light. However, plants and greenery reduce the reflection of the floor. Trees can also shade the lower floors if they are planted too close to the walls. To maximize the contribution of light reflected from the floor of the atrium, plants should be positioned in the center of the space, with a band of highly reflective floor near the atrium walls.

5.9.3 Maintenance

Routine maintenance and cleaning both of the glazings and the internal surfaces is required when daylighting is the case. With the help of artificial lighting, the illumination level can be changed according to the pollution (artificial lighting elements can be increased), but when the daylighting is the point, it is impossible to increase the glazing areas, as it would be a structural problem, and certainly would cause an unwanted increase in the loss of internal heat in winter and possibly in the penetration of solar heat at other times of the year. Thus, the simple procedure of increasing the glazing area, to make allowance for reduction can not be followed easily in daylighting design.

Daylighting of deep side-lit adjacent spaces is particularly dependent on good reflected light. Over a large part of such spaces, the internally reflected component may exceed the direct sky component by a considerable margin. The use of surfaces with high reflectance makes the most efficient use of daylight admitted by the glazings, but it is certain that the reflecting properties of these surfaces should be maintained in their original condition.

There are two main factors that affect the reduction of daylighting in the buildings. The first one is, as dirt is deposited both on the glazings of skylight and adjacent spaces, the whole of the daylight, both direct and indirect components, is reduced in quantity. The second one is, as dirt is deposited on the interior surfaces, it would cause a reduction in the internally reflected component. As the values of the direct and reflected daylight vary at different positions in a space, the relative effect of dirtying of internal surfaces will also vary. In single side lit spaces, (adjacent spaces) much of the daylighting in positions remote from the glazing depends on the maintenance of the internal surfaces.

Dust and dirt are deposited on all room surfaces and on windows in proportion with the amount of dirt in the atmosphere, both outside the building because of the character of the region in which the building is situated, and inside the building due to these causes and also to the nature of the activity that goes on within the building.

The rate of dirtying of different surfaces depends on the inclination of these surfaces, and their textures. Horizontal surfaces clearly will suffer most from deposit of dirt.

The depreciation of the surfaces of the spaces and the necessary cleaning schedules can be deduced from measurements of deterioration in reflecting properties, similar to those made for the deterioration in the transmission of the glazing due to dirtying. The need to maintain room surfaces is of importance in daylighting design since the internally reflected component is depending upon these values of reflectance.

Indistinguishing change of color or reflectance during the course of redecoration must be avoided, since not only will the appearance of the interior be changed, but the value of the internally reflected component will also be revised.

5.10 Spaces Adjacent to the Atrium

Another major daylighting design consideration concerns the illumination of the occupied zones around the atrium, in other words, the adjacent spaces.

Both the sky component and the internally reflected component (IRC) of the atrium can be considered as light sources for the illumination of an adjacent space.

The amount of daylight reaching the occupied zone (adjacent space) is significantly influenced by its distance from the atrium facade.

The illumination contribution to adjacent spaces can be improved by designing atrium walls in a way that the skylight and sunlight that enter the atrium can also be used for lighting the occupied space.

From a conventional window, or unglazed opening, light levels within a room fall off quite rapidly. Generally useful levels of light are hard to achieve at the back sides of the adjacent spaces, virtually regardless of window brightness. Indeed, sheer window brightness is a negative feature, causing glare and gloom effects. Ideally, a window should allow view generally, but direct much of its light upwards onto the ceiling, to bounce further into the room and reduce contrasts.

This inversion of natural law can only be achieved by reflection. Indeed the light that can be used in an atrium building has already been reflected many times, in the roof, and from upper side walls.

Interior reflectance in the adjacent space should be as high as possible. Because of decreasing light levels in an atrium, the floor plans of adjacent spaces, further down in the atrium, should be less deep than in upper storeys.

Interior reflectances should be as high as possible, depending on the direction of the exterior light sources in the atrium. The parts of the room receiving the most light from the atrium should have the highest reflectance.

Different design strategies can be applied like:

- Setting back of the atrium walls so that each room has a view of a portion of the sky.
- Using guidance systems that direct the light from the atrium to the ceiling of the adjacent space like light-shelves, reflectors, prismatic systems etc.

The idea of light shelf is a good choice for external and atrium use. A light shelf is a horizontal or inclined baffle in the window, placed just above eye level, but as far below ceiling level as possible. Sunlight and diffuse light are kept from passing straight to the floor close to the window, and reflected back onto the ceiling. The more even distribution of light within the room is achieved, and views of bright upper part of the window are cut off, the easier contrast problems can be solved.

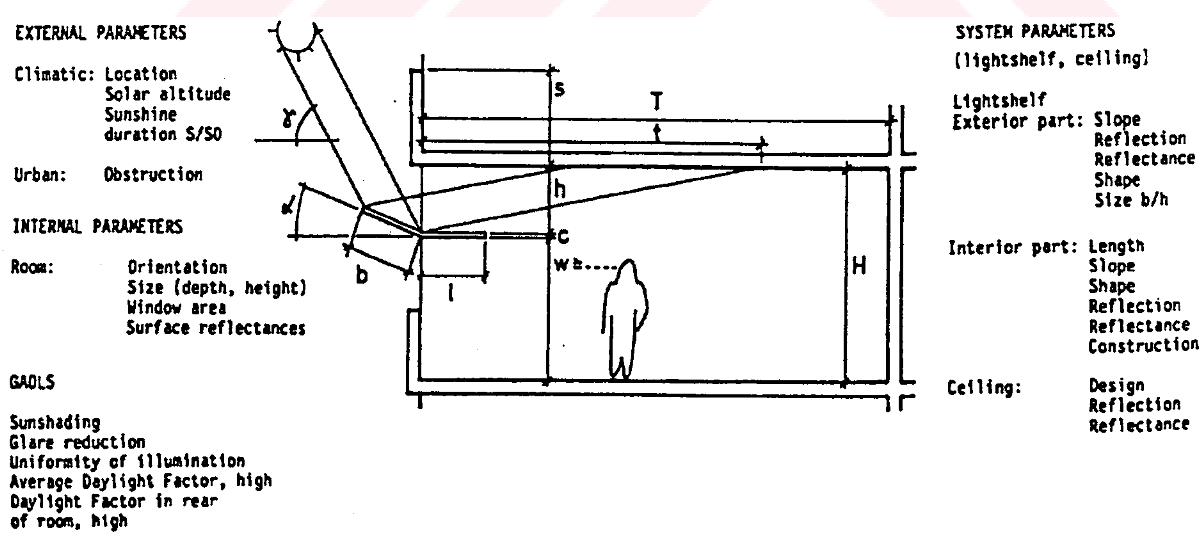


Figure 5.7 Light Shelves
Commission of European Communities. Daylighting in Architecture: A European Reference Book. London: James James, 1993. 5.54.

The shape and finish of light shelves can vary according to the design of the building. The horizontal matt white shelves scatter diffuse light effectively. Angled or curved specular reflectors can throw sunlight even further in the room, but their performance is better than matt white surfaces when dealing with diffuse light.

There is the discussion for allowing each shelf to see the atrium roof, since the brightest light source within the atrium is the skylight of the building. Many atria have stepped sections, with floors moving closer together further down the court. This gives each floor, a window projecting into the light without shading the floor below, where little useful reflection is provided by the walls of the atrium. This is useful, but only increases the brightness at the front of the rooms; with light shelves it is more effective. Stepped sections have disadvantages: floors get deeper towards the base of the building, where least daylight is available to them, and more artificial light should be used.

5.10.1 Dimensions of Adjacent Spaces

As the available daylight in the atrium decreases towards lower levels, the depth of adjacent spaces being daylit from the atrium should also decrease, otherwise some artificial light would be required.

The height and the depth of the room from the side window of the adjacent space are highly significant and their effects are important and interlinked. The level of direct daylight decreases in a predictable manner, as the distance from the window increases.

5.10.2 Orientation of the Adjacent Spaces within the Atrium

The contribution of daylight to the illumination of the adjacent space varies according to the location of the room within the height of the building. A room located at the atrium floor level is mainly illuminated by the light reflected from the floor. A room located near the atrium roof receives most light directly from the sky.

Besides the location of the adjacent space, the orientation of the space within the building has great importance on the illuminance level. As the level of illuminance within the space on the work plane changes according to the direction of the adjacent space, the quantity and quality of the light also changes according to the directional scheme.

5.10.3 Location, Form and Dimensions of Openings

The spacing and the placing of the windows affects the daylighting level within the adjacent space. The same area of glazing will give greater penetration of direct daylight, if most of the glazing is placed high. High glazing has its major effect on the direct daylight, and less effect on the internally reflected component.

A given area of glazing will normally be more efficient as regards penetration of direct daylight if it is used in the form of a tall vertical window, rather than a low horizontal window.

5.10.4 Glazing of the Adjacent Spaces

One of the major daylighting design considerations concerns the illumination of the occupied zones around the atrium. The fenestration design of the facades should acknowledge the differences in daylight levels between the top and the bottom of the space by utilizing different sizes of glass or different kinds of glazing.

The amount of light passing into the adjacent space will be reduced by the framing of the window and the transmittance of the glazing. In order to provide as much daylight in the adjacent space as possible, optimization of the framing and the transmittance properties of the glazing materials is necessary.

For thermal savings, glazing is recommended between the atrium and the adjacent space. For daylighting purposes, the glazing used should have high light transmission properties, single glazing, being generally the best, if building and fire regulations permit.

5.10.5 Interior Walls and Floors of Adjacent Spaces

The amount of reflected light, relative to direct skylight in the total daylight in a room, depends essentially upon the average reflectance of all the internal reflecting surfaces. Since the direct component of light from the sky is reflected first from the floor near the window and from the adjacent walls, the reflectance of these surfaces has a great importance in illuminating the interior.

The effect of reflected light from any one wall is greatest at points close to that wall, but this amount of reflected light depends on the reflectance of the surface. Consequently, the level of daylight at the back of a room remote from the window is influenced by the reflectance of the back wall.

The dark walls and furniture in adjacent spaces remote from a window, reduce the level of daylight within the space and enhance a gloomy impression.

The use of light colors for reveals and surrounds enhances the reflected light. Reveals should usually be arranged to minimize cut-off and to allow maximum penetration of daylight into a room.

6. Previous Studies on Atrium Daylighting

There are other researchers who are interested in daylighting in atrium buildings.

Michael J. Bednar(111-114) has analyzed the five factors as a basis for simulating the daylighting performance of any given atrium design, in his work "An Analysis of Daylighting Design Factors in Atria". They are, solar orientation, plan aspect ratio, section aspect ratio, sectional scheme, and atrium surfaces. According to him these five daylighting design factors should be considered together in any atrium design due to the trade-offs between them and possible mutually enhancing relationships. However, the dynamics and complexity of these interacting factors is impossible to fully grasp through these crude methods. He concludes that, the only realistic way to account for all of the unforeseen relationship is to conduct a model simulation study.

S.J. Treado and G.L. Gillette(360-373) has a work on "*The Daylighting and Energy Performance of Building Atria*". In their work, the influence of fenestration design on building energy performance was evaluated, based on measurements in four atrium buildings and a series of detailed computer simulations using TARP and CEL-1 computer programs. The impact of glazing area and solar-optical properties were examined for linear and central atrium building for different geographical locations. The usefulness of automatic solar shading was also investigated, and some guidelines were presented for effective design of atrium fenestration.

K. Kim and L.L. Boyer(345-359) have worked on "*Development of Daylight Prediction Methods for Atrium Design*". Their study evaluates the daylighting performance in atrium buildings, and also, develops algorithms to predict daylighting levels in different types of atria. According to them, the well index is the primary variable to predict daylighting levels in atria. At the center of the atrium, horizontal illumination levels are linearly related with the well index, and also vertical light levels on walls in square atria are linearly related with the well index.

Raymond J. Cole(37-42) studied on the effect of the surfaces enclosing atria on daylight in adjacent spaces. According to him, the reflective characteristics of the surfaces enclosing an atrium space can significantly influence the distribution of daylight in the adjacent spaces. Large scale model studies were used to evaluate the effects of floor reflectance and the proportions of the openings in the atrium walls during overcast sky conditions.

Usha-Iyer Raniga studied the effects of daylight in spaces adjacent to an atrium in her work *"Daylighting in Atrium Spaces"*. The relative contributions to the daylighting in the adjacent spaces due to variable opening sizes and surface reflectivities on the wall facades of the atrium, and the surface reflectivities of the atrium floor have been studied in her study. Physical scale models were used as they offer accurate detailed analysis may be more than computational methods and graphic techniques. Measurements were taken at different well indexes of the atria under fully overcast skies.

In his work *"The Effect of the Cover and Reflective Properties of a Four-Sided Atrium on the Behavior of Light"* Mohammed Boubekri(3-8) examined the effect of roof configuration and reflective properties of the atrium intermediate boundaries on the behavior of light along the atrium walls. His investigation was limited to a top-lit atrium and the results indicated that the reflective characteristics of the atrium walls can significantly affect the intensity that reaches the lower levels of the atrium. Floor reflectance has been found to have a significant daylighting effect. According to him, the design parameter that had the most significant daylighting effect is the type of roof cover.

Again Boubekri and Wenbo Y. Anninos(75-81) worked on the computer modeling of daylight distribution in the top-lit, four sided atrium, in their work *"Daylight Efficiency of an Atrium: Part 1-The Four Sided Type"*. In their study a systematic evaluation of daylighting efficiency of atrium buildings has been undertaken and the effect of the main design parameters most sensitive to impact the daylighting performance has been examined. These parameters are, the wall reflectance and the geometric proportions of the atrium, described by the plan aspect ratio and the section aspect ratio. The results of their simulations were compiled into tables where daylight efficiency factors are given.

In Boubekri and Anninos's(83-88) following work *"Daylight Efficiency of an Atrium Part 2-The Three-Sided Type"*, they examined the effect of the wall reflectance and geometric proportions on the distribution of daylight, as the lighting benefits of a three-sided atrium involve the collection of daylight not only from the top but also from one of the sides.

In Boubekri and Anninos's(179-186) other work *"Daylighting Efficiency of an Atrium: Part 3-The Four-Sided Type"*, a computer modeling technique using the flux-transfer method was presented focusing on the linear, open-end atrium. An evaluation of the Daylighting

Efficiency was done according to the effects of some dominant design attributes. Daylighting Efficiency Factors were generated for typical atrium sizes. The effects of the geometric proportions of the atrium and the atrium wall reflectance were embedded with in these factors.

Ibrahim Al-Turki and Mark Schiler(241-245) worked on "Predicting Natural Light in Atria and Adjacent Spaces Using Physical Scale Models". Their study was intended to measure the daylight performance in atria and in the spaces adjacent to atria under exclusively clear sky conditions. The quantitative and qualitative available light in all orientations has been illustrated using physical scale models. According to them, most daylighting calculations do not work well for atrium buildings. At present, the most sophisticated method is the physical scale model.

7- Case Study

A daylighting experiment was performed at Bilkent University which lasted for five days, from dawn to sunset. The illuminance measurements were taken in a physical scale model in the natural environment using clear sky.

7.1 Objectives

Adjacent spaces are one of the most important features within an atrium. The people live and work there, so that illumination levels within those spaces have significance.

The natural light falling down through the atrium roof impinges on the floors , so the reflectivity of the floors of the adjacent spaces influences the amount of light on the work surfaces within them.

Another point with the study is the transparency of glass. Does the glazing placed on top of the atrium and in front of the adjacent spaces affect the illuminance of light within the adjacent spaces?

During the study the wall and the ceiling reflectances remain constant.

As a result, the research formed overall the following hypotheses,

Hypothesis 1: The reflectivity of the floor material affects the illuminance within the adjacent spaces.
Hypothesis 2: The presence of glass in front of the adjacent spaces affects the illuminance level within the space.

7.2 Model

The scale model built for the study is in 1/20 scale, made of model card board with a thickness of 0.5 cm. That made it opaque. The dimensions of the model was 105 cm to 105 cm and the height was 72 cm. It was representing a square planned atrium building which is 21 meters to 21 meters, and the room heights within the building was accepted 3.5 meters. Besides, the well indexes for floors, in sequence were 0.5, 1.0, 1.5, and 2.0.

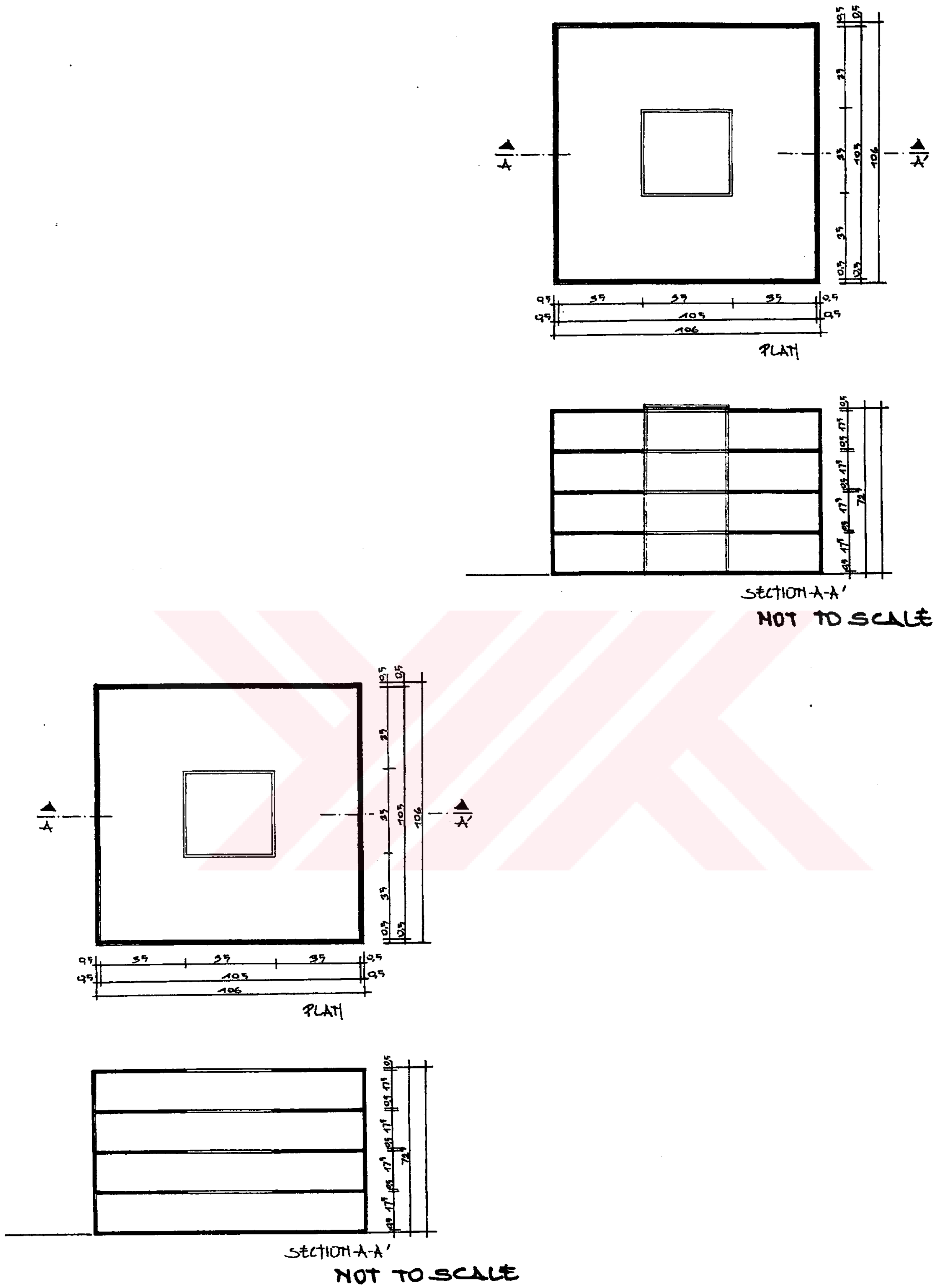


Figure 7.1 The Drawings of Scale Model(with glass and without glass)

Figure 7.2 The Scale Model, General View

The model was placed at an unobstructed site, which is beside the parking area of the Faculty of Art, Design, and Architecture, at Bilkent University, Ankara, Turkey. It is placed at an open area to avoid obstructions due to pedestrians as well as neighboring buildings and other things, so that the light reaching in the scale model would not be affected by these obstructions.

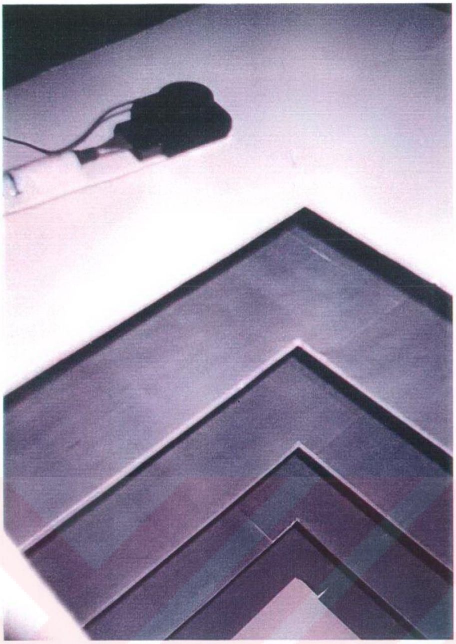


Figure 7.3 The Scale Model, Top View Looking at Towards Atrium Well

To be able to measure different parameters such as illumination "with glazing", and "without glazing", the model was built as a flexible one, so that different measurements were taken easily during the experiment.

The model was placed on the north-south axis so that it was possible to take the illumination measurements at cardinal directions.

7.3 Measurements

Only horizontal illuminance measurements were taken during the study. These illumination measurements were taken at the work plane height of 0.80 m (4 cm. in model) above the floor, in twelve points in each floor of the atrium building.

Illumination levels are measured at three points in each cardinal direction of the scale model, the first point was in the space just near the atrium well, the second one was in the middle of the space and the third one was at the far end of the space.

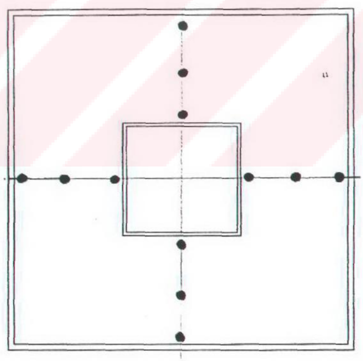


Figure 7.4 The Scale Model, The Measurement Points.

The study was conducted in three sets. In each set of measurement, the reflectance of the floor covering was changed. In the first set, the floor surface of the adjacent spaces were covered with a grey which has 75% reflectance; in the second set, the floor surface of the adjacent spaces with a grey that has 50% reflectance; and in the third set, the floor surface of the adjacent spaces were covered with a grey that has 25% reflectance (these reflectances were all found by using Minolta Luminance Meter LS-110).

Beside this, in each set, measurements were taken twice; with and without glazing. During the measurements taken with glazing, the glazing materials were placed both on the top of the atrium well, and in front of the adjacent spaces.

According to the measurements that have been done with the scale model, the results were taken and are presented below:

4th Floor (without glass)

Hour	West 1	West 2	West 3	MEAN	OUT Lx	WEST %	South 1	South 2	South 3	MEAN	OUT Lx	SOUTH %	East 1	East 2	East 3	MEAN	OUT Lx	EAST %	North 1	North 2	North 3	MEAN	OUT Lx	NORTH %
6:30	334	176	130	213.3	750.0	28.4	187	93	73	117.7	750.0	15.7	256	155	118	175.7	750.0	23.4	376	208	153	245.0	750.0	32.7
7:00	1360	619	515	831.3	5300.0	15.7	1090	550	395	678.3	5300.0	12.8	2220	1290	950	1486.7	5300.0	28.1	1730	790	650	1083.3	5300.0	20.1
8:00	2240	1520	1290	1683.3	23000.0	7.3	4420	2580	1800	2928.7	23000.0	12.7	2480	15900	15200	13193.3	23000.0	57.4	4030	2470	2100	2866.7	23000.0	12.5
9:00	4460	3630	3340	3810.0	45000.0	8.5	6610	4180	3510	4760.0	45000.0	10.6	40800	37800	10900	29866.7	45000.0	66.4	5890	3950	3470	4370.0	45000.0	9.7
10:00	4480	3510	3430	3800.0	59800.0	6.5	9900	5820	4650	6790.0	59800.0	11.4	59800	12100	9190	26963.3	59800.0	45.1	7180	5100	4400	5560.0	59800.0	9.3
11:00	8060	6550	5850	6820.0	80500.0	8.5	67000	7950	5870	26940.0	80500.0	33.5	74800	11000	8550	31383.3	80500.0	39.0	8780	6500	5620	6966.7	80500.0	8.7
12:00	10000	7600	5950	7850.0	90400.0	8.7	88500	10200	7550	35416.7	90400.0	39.2	87500	10100	8340	35313.3	90400.0	39.1	9080	7440	6550	7633.3	90400.0	8.5
13:00	14000	7710	6130	9280.0	93500.0	9.9	91200	11000	7570	36590.0	93500.0	39.1	16700	7250	5830	9926.7	93500.0	10.6	8850	6980	6230	7236.7	93500.0	7.8
14:00	33100	8420	6160	15893.3	95400.0	16.7	83000	11200	8020	34073.3	95400.0	35.7	9400	6610	5680	7230.0	95400.0	7.6	8080	6400	5600	6693.3	95400.0	7.0
15:00	65000	8950	7440	27463.3	73500.0	37.4	68500	10300	7370	28723.3	73500.0	39.1	7170	5200	4450	5606.7	73500.0	7.6	7340	5610	5080	6010.0	73500.0	8.2
16:00	55500	11200	8810	25170.0	63000.0	40.0	51500	8820	6010	22043.3	63000.0	35.0	5120	4200	3740	4353.3	63000.0	6.9	6600	4710	4410	5240.0	63000.0	8.3
17:00	34500	31300	7860	24553.3	42500.0	57.8	8210	4610	3740	5520.0	42500.0	13.0	4060	2580	2130	2926.7	42500.0	6.9	5120	3450	2980	3850.0	42500.0	9.1
18:00	8760	5270	10800	7550.0	16500.0	45.8	4550	2400	1910	2953.3	16500.0	17.9	2610	1710	1490	1936.7	16500.0	11.7	3570	2060	1750	2460.0	16500.0	14.9
19:00	1380	844	570	931.3	3780.0	24.6	1100	606	335	647.0	3780.0	17.1	900	440	330	556.7	3780.0	14.7	1020	495	360	615.0	3780.0	16.3
Mean	17228.7	7057.1	4848.2	9710.7	49495.0	22.5	34697.6	5712.1	4200.2	14870.0	49495.0	23.8	22817.6	8315.4	5492.8	12208.6	49495.0	26.0	5515.1	4009.4	3325.2	4350.2	49495.0	12.3
Max	65000	31500	10800	35700.0	95400	57.8	91200	11200	8020	38806.7	95400	39.2	87500	37900	15200	35313.3	95400	66.4	9080	7440	6550	7633.3	95400	32.7
Min	334	178	130	213.3	750	6.5	187	93	73	117.7	750	10.8	256	155	118	175.7	750	6.9	376	208	153	245.0	750	7.0

4th Floor (with glass)

Hour	West 1	West 2	West 3	MEAN	OUT Lx	WEST %	South 1	South 2	South 3	MEAN	OUT Lx	SOUTH %	East 1	East 2	East 3	MEAN	OUT Lx	EAST %	North 1	North 2	North 3	MEAN	OUT Lx	NORTH %
6:30	100	49	35	61.3	250.0	24.5	38	19	13	23.3	250.0	9.3	78	38	25	47.0	250.0	18.8	95	55	34	61.3	250.0	24.5
7:00	790	420	320	510.0	3200.0	15.9	445	225	187	285.7	3200.0	8.9	880	440	360	560.0	3200.0	17.5	665	390	324	466.3	3200.0	14.6
8:00	2090	1200	1000	1430.0	20000.0	7.2	3290	1700	1360	2116.7	20000.0	10.6	6730	9780	10200	8903.3	20000.0	44.5	3290	1920	1650	2286.7	20000.0	11.4
9:00	3710	3120	2750	3193.3	42000.0	7.6	4620	3120	2460	3400.0	42000.0	8.1	29900	22700	8010	20203.3	42000.0	48.1	4880	3270	2890	3680.0	42000.0	8.7
10:00	5290	4470	4190	4650.0	59500.0	7.8	7930	4790	3560	5426.7	59500.0	9.1	45600	12400	7400	21800.0	59500.0	36.6	6450	4590	4070	5036.7	59500.0	8.5
11:00	6620	5420	4500	5513.3	68000.0	8.1	35900	6100	4360	15453.3	68000.0	22.7	55700	9640	7390	24243.3	68000.0	35.7	7320	5510	4870	5900.0	68000.0	8.7
12:00	8210	5510	4640	6120.0	91000.0	6.7	58200	7960	5960	24040.0	91000.0	26.4	52300	8000	7350	22550.0	91000.0	24.8	8030	6560	5840	6818.7	91000.0	7.5
13:00	9700	5810	4950	6820.0	95000.0	7.2	67300	9630	6540	27823.3	95000.0	29.3	12800	6330	5320	8150.0	95000.0	8.6	7840	6400	6710	6850.0	95000.0	7.0
14:00	13000	6240	5870	8370.0	92800.0	9.0	66500	9310	6440	27416.7	92800.0	29.5	8820	5840	5010	6556.7	92800.0	7.1	7130	5600	5030	5936.7	92800.0	6.4
15:00	42600	7400	6330	18776.7	79300.0	23.7	56500	9160	5990	23883.3	79300.0	30.1	6380	4700	4160	5080.0	79300.0	6.4	6200	4780	4300	5093.3	79300.0	6.4
16:00	42900	9700	6780	19793.3	67000.0	29.5	43100	7240	5050	18463.3	67000.0	27.6	5340	4110	3740	4396.7	67000.0	6.6	5600	4260	3650	4503.3	67000.0	6.7
17:00	26400	23400	8020	19273.3	45100.0	42.7	8460	4460	3080	5333.3	45100.0	11.8	3470	2610	2250	2776.7	45100.0	6.2	4580	3100	2750	3476.7	45100.0	7.7
18:00	5720	6200	5850	5923.3	26900.0	22.0	3850	2290	1680	2606.7	26900.0	9.7	2290	1380	1260	1650.0	26900.0	6.1	3220	1860	1450	2110.0	26900.0	7.8
19:00	1390	762	510	887.3	4400.0	20.2	1050	500	335	628.3	4400.0	14.3	850	440	343	544.3	4400.0	12.4	1050	520	362	644.0	4400.0	14.6
Mean	12180.0	5692.8	3838.9	7237.3	49603.6	18.6	25514.5	4750.3	3356.8	11207.2	49603.6	17.7	16509.1	6314.9	4489.1	9104.4	49603.6	19.9	4743.6	3472.5	3064.3	3760.1	49603.6	10.0
Max	42800	23400	6780	24300.0	95000	42.7	67300	9630	6540	27823.3	95000	30.1	55700	22700	10200	29533.3	95000	48.1	8030	6560	5840	6818.7	95000	24.5
Min	100	49	35	61.3	250	6.7	38	19	13	23.3	250	8.1	78	38	25	47.0	250	6.1	95	55	34	61.3	250	6.4

Table 6.1: Illuminance values of the 4th floor, for grey with 75% reflectance.

3rd Floor (without glass)

Hour	West 1	West 2	West 3	MEAN	OUT Lx	WEST %	South 1	South 2	South 3	MEAN	OUT Lx	SOUTH %	East 1	East 2	East 3	MEAN	OUT Lx	EAST %	North 1	North 2	North 3	MEAN	OUT Lx	NORTH %
6.30	156	67	45	89.3	750.0	11.9	93	38	25	51.3	750.0	6.8	120	45	30	65.0	750.0	8.7	166	55	41	87.3	750.0	11.6
7.00	710	270	202	394.0	5300.0	7.4	565	260	196	340.3	5300.0	6.4	840	350	196	462.0	5300.0	8.7	830	236	192	419.3	5300.0	7.9
8.00	1250	753	633	878.7	23000.0	3.8	2050	850	754	1218.0	23000.0	5.3	2520	1180	723	1474.3	23000.0	6.4	1580	780	670	1013.3	23000.0	4.4
9.00	2000	1340	1100	1480.0	45000.0	3.3	3370	1410	1150	1976.7	45000.0	4.4	4750	1960	1190	2633.3	45000.0	5.9	2550	1370	1080	1666.7	45000.0	3.7
10.00	3000	1630	1430	2020.0	59800.0	3.4	4980	2350	1870	3066.7	59800.0	5.1	40000	3890	3290	15726.7	59800.0	26.3	3500	1600	1480	2193.3	59800.0	3.7
11.00	4440	2200	1860	2833.3	80500.0	3.5	7480	3230	2500	4403.3	80500.0	5.5	63500	4740	3750	23996.7	80500.0	29.8	4260	2290	2000	2850.0	80500.0	3.5
12.00	5520	2650	2240	3470.0	90400.0	3.8	80000	5020	3780	29600.0	90400.0	32.7	8770	4410	3220	5466.7	90400.0	6.0	4750	2530	2180	3153.3	90400.0	3.5
13.00	6850	3260	2460	4190.0	93500.0	4.5	84400	6440	5000	31946.7	93500.0	34.2	6980	3220	2520	4240.0	93500.0	4.5	4800	2610	2240	3216.7	93500.0	3.4
14.00	8190	3530	2730	4816.7	95400.0	5.0	74800	6400	4840	28680.0	95400.0	30.1	5810	2710	2210	3576.7	95400.0	3.7	4600	2480	2220	3100.0	95400.0	3.2
15.00	8400	3830	2840	5023.3	73500.0	6.8	10000	4620	3510	6043.3	73500.0	8.2	3960	2100	1860	2640.0	73500.0	3.6	4050	2250	1980	2780.0	73500.0	3.8
16.00	6780	3540	2630	4316.7	63000.0	6.9	6390	2890	2130	3803.3	63000.0	6.0	3410	1960	1670	2346.7	63000.0	3.7	3400	1690	1860	2316.7	63000.0	3.7
17.00	3860	1580	1040	2160.0	42500.0	5.1	3440	1370	1010	1940.0	42500.0	4.6	2350	1230	990	1523.3	42500.0	3.6	2520	1260	1100	1626.7	42500.0	3.8
18.00	2230	882	453	1188.3	16500.0	7.2	1750	694	569	1004.3	16500.0	6.1	1360	676	537	857.7	16500.0	5.2	1570	614	499	894.3	16500.0	5.4
19.00	508	191	104	267.7	3780.0	7.1	467	185	115	255.7	3780.0	6.8	384	146	108	212.0	3780.0	5.6	417	140	103	220.0	3780.0	5.8
Mean	3848.1	1638.5	1411.9	2365.3	49495.0	6.7	19984.6	2563.9	1960.6	6168.4	49495.0	11.6	10339.6	2044.1	1592.3	4658.6	49495.0	8.7	2771.6	1450.4	1246.1	1622.7	49495.0	4.6
Max	8400	3830	2840	5023.3	95400	11.9	84400	6440	5000	31946.7	95400	34.2	63500	4740	3750	23996.7	95400	29.8	4800	2610	2240	3216.7	95400	11.6
Min	156	67	45	89.3	750	3.3	93	38	25	51.3	750	4.4	120	45	30	65.0	750	3.6	166	55	41	87.3	750	3.2

3rd Floor (with glass)

Hour	West 1	West 2	West 3	MEAN	OUT Lx	WEST %	South 1	South 2	South 3	MEAN	OUT Lx	SOUTH %	East 1	East 2	East 3	MEAN	OUT Lx	EAST %	North 1	North 2	North 3	MEAN	OUT Lx	NORTH %
6.30	54	20	14	29.3	250.0	11.7	22	10	7	13.0	250.0	5.2	38	15	9	20.7	250.0	8.3	52	17	11	26.7	250.0	10.7
7.00	395	130	110	211.7	3200.0	6.6	250	120	92	154.0	3200.0	4.8	390	123	103	205.3	3200.0	6.4	380	175	160	238.3	3200.0	7.4
8.00	1110	675	550	778.3	20000.0	3.9	1750	783	645	1059.3	20000.0	5.3	2410	1110	659	1393.0	20000.0	7.0	1500	763	600	954.3	20000.0	4.8
9.00	3220	1960	1450	2210.0	42000.0	5.3	2450	1200	1020	1556.7	42000.0	3.7	3950	1850	1020	2273.3	42000.0	5.4	2290	1190	980	1436.7	42000.0	3.5
10.00	3550	2200	1810	2520.0	59500.0	4.2	4730	2010	1630	2790.0	59500.0	4.7	9740	4610	3210	5853.3	59500.0	9.8	3250	1580	1490	2106.7	59500.0	3.5
11.00	3870	2530	1760	2720.0	68000.0	4.0	9210	2900	2160	4756.7	68000.0	7.0	44500	4620	3460	17526.7	68000.0	25.8	3810	1850	1680	2430.0	68000.0	3.6
12.00	4350	2620	2070	3013.3	91000.0	3.3	55500	4080	3130	20903.3	91000.0	23.0	27600	3820	2750	11390.0	91000.0	12.5	4020	2290	1940	2750.0	91000.0	3.0
13.00	5150	2760	2080	3330.0	95000.0	3.5	61400	5450	3800	23553.3	95000.0	24.8	5900	2810	2120	3610.0	95000.0	3.8	4050	2410	2150	2870.0	95000.0	3.0
14.00	6890	2910	2200	4000.0	92800.0	4.3	61000	6070	4170	23746.7	92800.0	25.6	4690	2330	1850	2956.7	92800.0	3.2	3890	2250	1990	2710.0	92800.0	2.9
15.00	10800	3100	2450	5450.0	79300.0	6.9	40000	4400	3180	15860.0	79300.0	20.0	3740	2020	1740	2500.0	79300.0	3.2	3420	2050	1900	2456.7	79300.0	3.1
16.00	11800	3170	2590	5853.3	67000.0	8.7	10500	3130	2360	5330.0	67000.0	8.0	3030	1760	1570	2120.0	67000.0	3.2	3120	1850	1680	2216.7	67000.0	3.3
17.00	3990	1910	1150	2350.0	45100.0	5.2	3420	1430	1150	2000.0	45100.0	4.4	2530	1340	1110	1660.0	45100.0	3.7	2320	1230	1110	1553.3	45100.0	3.4
18.00	2140	986	572	1232.7	26900.0	4.6	1850	895	684	1143.0	26900.0	4.2	1310	615	895	940.0	26900.0	3.5	1540	675	586	933.7	26900.0	3.5
19.00	562	222	126	303.3	4400.0	6.9	538	204	130	290.7	4400.0	6.6	415	172	123	236.7	4400.0	5.4	465	175	119	253.0	4400.0	5.8
Mean	4120.1	1798.5	1366.5	2428.7	49803.6	5.7	18044.3	2334.4	1732.7	7370.5	49803.6	10.5	7874.5	1956.8	1458.5	3763.3	49803.6	7.2	2435.2	1328.9	1171.1	1645.4	49803.6	4.4
Max	11800	3170	2590	5853.3	95000	11.7	61400	6070	4170	23820.0	95000	25.6	44500	4620	3480	17526.7	95000	25.8	4050	2410	2150	2870.0	95000	10.7
Min	54	20	14	29.3	250	3.3	22	10	7	13.0	250	3.7	38	15	9	20.7	250	3.2	52	17	11	26.7	250	2.9

Table 6.2: Illuminance values of the 3rd floor, for grey with 75% reflectance.

2nd Floor (without glass)

Hour	West 1	West 2	West 3	MEAN	OUT Lx	WEST %	South 1	South 2	South 3	MEAN	OUT Lx	SOUTH %	East 1	East 2	East 3	MEAN	OUT Lx	EAST %	North 1	North 2	North 3	MEAN	OUT Lx	NORTH %
6.30	85	35	31	50.3	750.0	6.7	56	21	19	32.0	750.0	4.3	70	26	21	39.0	750.0	5.2	83	28	26	45.7	750.0	6.1
7.00	405	160	145	236.7	5300.0	4.5	340	150	140	210.0	5300.0	4.0	375	141	131	215.7	5300.0	4.1	411	159	151	240.3	5300.0	4.5
8.00	939	650	618	736.0	23000.0	3.2	1190	588	570	782.7	23000.0	3.4	1110	485	458	684.3	23000.0	3.0	1030	570	528	709.3	23000.0	3.1
9.00	1760	1020	979	1253.0	45000.0	2.8	1780	880	835	1165.0	45000.0	2.6	2070	810	751	1210.3	45000.0	2.7	1550	858	792	1066.7	45000.0	2.4
10.00	2480	1400	1260	1713.3	59800.0	2.9	2780	1070	960	1603.3	59800.0	2.7	3480	1400	1120	2000.0	59800.0	3.3	2050	1100	1030	1393.3	59800.0	2.3
11.00	3280	1750	1640	2223.3	80500.0	2.8	4310	1570	1400	2426.7	80500.0	3.0	5190	2440	2200	3276.7	80500.0	4.1	2680	1540	1370	1863.3	80500.0	2.3
12.00	3860	1970	1800	2543.3	90400.0	2.8	8000	3230	2630	4620.0	90400.0	5.1	5150	2310	2090	3183.3	90400.0	3.5	3230	1930	1790	2316.7	90400.0	2.6
13.00	4620	2160	1900	2893.3	93500.0	3.1	80900	5860	4420	30393.3	93500.0	32.5	4680	2100	1800	2860.0	93500.0	3.1	3510	2100	1930	2513.3	93500.0	2.7
14.00	4800	2190	1880	2956.7	95400.0	3.1	69800	4150	3440	25796.7	95400.0	27.0	3770	1800	1520	2363.3	95400.0	2.5	3350	1910	1750	2336.7	95400.0	2.4
15.00	4330	1510	1320	2386.7	73500.0	3.2	6600	1780	1550	3310.0	73500.0	4.5	2890	1440	1290	1873.3	73500.0	2.5	2830	1550	1460	1946.7	73500.0	2.6
16.00	2770	1010	932	1570.7	63000.0	2.5	3060	1050	953	1687.7	63000.0	2.7	2240	1090	935	1421.7	63000.0	2.3	2360	1240	1180	1593.3	63000.0	2.5
17.00	2020	750	693	1154.3	42500.0	2.7	1850	819	746	1138.3	42500.0	2.7	1500	740	630	956.7	42500.0	2.3	1610	880	750	1080.0	42500.0	2.5
18.00	1020	274	249	514.3	16500.0	3.1	1080	448	416	648.0	16500.0	3.9	772	356	303	477.0	16500.0	2.9	828	326	299	484.3	16500.0	2.9
19.00	259	73	64	132.0	3780.0	3.5	275	84	75	144.7	3750.0	3.8	230	79	71	126.7	3780.0	3.4	215	74	67	118.7	3780.0	3.1
Mean	2330.6	1058.0	965.1	1454.6	49495.0	3.3	13000.1	1550.0	1298.1	5282.7	49495.0	7.2	2384.8	1088.9	951.4	1477.7	49495.0	3.2	1838.4	1018.9	937.4	1264.9	49495.0	3.0
Max	4800	2190	1900	2963.3	95400	6.7	80900	5860	4420	30393.3	95400	32.5	5160	2440	2200	3276.7	95400	5.2	3510	2100	1930	2513.3	95400	6.1
Min	85	35	31	50.3	750	2.5	56	21	19	32.0	750	2.6	70	26	21	39.0	750	2.3	83	26	26	45.7	750	2.3

2nd Floor (with glass)

Hour	West 1	West 2	West 3	MEAN	OUT Lx	WEST %	South 1	South 2	South 3	MEAN	OUT Lx	SOUTH %	East 1	East 2	East 3	MEAN	OUT Lx	EAST %	North 1	North 2	North 3	MEAN	OUT Lx	NORTH %
6.30	30	12	11	17.7	250.0	7.1	14	6	5	8.3	250.0	3.3	20	7	6	11.0	250.0	4.4	27	9	8	14.7	250.0	5.9
7.00	188	56	64	122.7	3200.0	3.8	170	75	70	105.0	3200.0	3.3	202	82	74	119.3	3200.0	3.7	220	135	121	162.0	3200.0	5.1
8.00	882	560	515	652.3	20000.0	3.3	1080	525	495	700.0	20000.0	3.5	1220	483	450	717.7	20000.0	3.6	970	521	490	660.3	20000.0	3.3
9.00	1580	1080	980	1213.3	42000.0	2.9	1900	520	775	1065.0	42000.0	2.5	2030	807	692	1176.3	42000.0	2.8	1470	795	770	1011.7	42000.0	2.4
10.00	2200	1680	1410	1763.3	59500.0	3.0	2510	1050	1000	1520.0	59500.0	2.6	3410	1540	1350	2100.0	59500.0	3.5	2120	1130	990	1413.3	59500.0	2.4
11.00	2880	1860	1840	2193.3	68000.0	3.2	7470	1500	1310	3426.7	68000.0	5.0	5420	2410	2040	3290.0	68000.0	4.8	2730	1500	1340	1856.7	68000.0	2.7
12.00	3560	2000	1680	2413.3	91000.0	2.7	18800	2910	2280	7996.7	91000.0	8.8	12800	2200	1910	5636.7	91000.0	6.2	3280	1860	1750	2296.7	91000.0	2.5
13.00	4300	2040	1740	2693.3	95000.0	2.8	59200	4910	3650	22586.7	95000.0	23.8	4440	1910	1620	2656.7	95000.0	2.8	3550	2130	1990	2556.7	95000.0	2.7
14.00	5000	2080	1780	2953.3	92800.0	3.2	58000	4500	3520	22006.7	92800.0	23.7	3470	1800	1550	2273.3	92800.0	2.4	3430	2010	1730	2390.0	92800.0	2.6
15.00	7750	1850	1520	3706.7	79300.0	4.7	13600	2160	1860	5873.3	79300.0	7.4	2730	1440	1370	1846.7	79300.0	2.3	2760	1620	1500	1960.0	79300.0	2.5
16.00	2890	1030	930	1616.7	67000.0	2.4	3470	1240	1120	1943.3	67000.0	2.9	1900	1270	1060	1410.0	67000.0	2.1	2300	1310	1220	1610.0	67000.0	2.4
17.00	2000	780	696	1158.7	45100.0	2.6	1880	797	744	1140.3	45100.0	2.5	1460	1050	682	1064.0	45100.0	2.4	1560	935	903	1132.7	45100.0	2.5
18.00	1110	420	386	638.7	26900.0	2.4	1240	570	536	782.0	26900.0	2.9	892	487	406	595.0	26900.0	2.2	980	523	513	672.0	26900.0	2.5
19.00	291	92	81	154.7	4400.0	3.5	316	103	91	170.7	4400.0	3.9	246	98	83	142.3	4400.0	3.2	270	97	87	151.3	4400.0	3.4
Mean	2477.1	1119.4	980.9	1519.1	49603.6	3.4	12096.8	1511.9	1246.9	4951.8	49603.6	6.8	2874.3	1113.1	949.5	1645.6	49603.6	3.3	1834.1	1041.1	958.0	1277.7	49603.6	3.1
Max	7750	2080	1780	3870.0	95000	7.1	59200	4910	3650	22586.7	95000	23.8	12800	2410	2040	5750.0	95000	6.2	3550	2130	1990	2556.7	95000	5.9
Min	30	12	11	17.7	250	2.4	14	6	5	8.3	250	2.5	20	7	6	11.0	250	2.1	27	9	8	14.7	250	2.4

Table 6.3: Illuminance values of the 2nd floor, for grey with 75% reflectance.

1st Floor (without glass)

Hour	West 1	West 2	West 3	MEAN	OUT Lx	WEST %	South 1	South 2	South 3	MEAN	OUT Lx	SOUTH %	East 1	East 2	East 3	MEAN	OUT Lx	EAST %	North 1	North 2	North 3	MEAN	OUT Lx	NORTH %
6.30	59	23	20	34.0	750.0	4.5	27	14	12	17.7	750.0	2.4	50	18	15	27.7	750.0	3.7	59	21	18	32.7	750.0	4.4
7.00	264	109	85	152.7	5300.0	2.9	210	92	85	129.0	5300.0	2.4	338	102	88	175.3	5300.0	3.3	275	115	102	164.0	5300.0	3.1
8.00	835	314	289	412.7	23000.0	1.8	843	339	327	436.3	23000.0	1.9	820	343	321	428.0	23000.0	1.9	891	358	358	478.3	23000.0	2.1
9.00	1100	620	537	752.3	45000.0	1.7	1080	550	497	709.0	45000.0	1.6	1110	550	509	723.0	45000.0	1.6	1130	602	537	756.3	45000.0	1.7
10.00	1500	820	670	996.7	59800.0	1.7	1500	684	595	919.7	59800.0	1.5	1640	632	550	1007.3	59800.0	1.7	1490	740	680	970.0	59800.0	1.6
11.00	1980	840	880	1266.7	80300.0	1.6	2270	834	747	1283.7	80500.0	1.6	2350	876	788	1330.7	80500.0	1.7	2190	870	840	1333.3	80500.0	1.7
12.00	2350	1000	900	1416.7	90400.0	1.6	3390	1410	1210	2003.3	90400.0	2.2	2620	1120	940	1560.0	90400.0	1.7	2680	1240	1020	1840.0	90400.0	1.8
13.00	2650	1050	950	1550.0	93500.0	1.7	3360	1220	1080	1850.0	93500.0	2.0	3080	1230	1050	1786.7	93500.0	1.9	2700	1220	1030	1650.0	93500.0	1.5
14.00	2890	1110	960	1660.0	95400.0	1.7	2950	960	865	1598.3	95400.0	1.7	2770	1040	883	1564.3	95400.0	1.6	2480	1110	975	1515.0	95400.0	1.6
15.00	2070	880	800	1283.3	73500.0	1.7	2220	800	712	1244.0	73500.0	1.7	1880	864	730	1151.3	73500.0	1.6	1960	820	845	1241.7	73500.0	1.7
16.00	1820	670	600	963.3	63000.0	1.5	1650	730	647	1009.0	63000.0	1.6	1470	676	568	904.7	63000.0	1.4	1590	770	700	1020.0	63000.0	1.6
17.00	1190	510	463	721.0	42500.0	1.7	1110	521	485	705.3	42500.0	1.7	1000	415	397	604.0	42500.0	1.4	1050	650	518	706.0	42500.0	1.7
18.00	530	181	154	288.3	16500.0	1.7	607	264	233	368.0	16500.0	2.2	482	199	174	285.0	16500.0	1.7	524	193	172	298.3	16500.0	1.8
19.00	135	48	42	75.0	3780.0	2.0	161	56	48	88.3	3780.0	2.3	139	51	45	78.3	3780.0	2.1	145	51	45	80.3	3780.0	2.1
Mean	1354.5	598.2	527.1	826.6	49495.0	2.0	1512.7	605.3	537.4	885.1	49495.0	1.9	1409.1	579.7	502.8	830.5	49495.0	2.0	1351.7	634.9	560.0	########	49495.0	2.0
Max	2890	1110	980	1660.0	95400	4.5	3390	1410	1210	2003.3	95400	2.4	3080	1230	1050	1786.7	95400	3.7	2700	1240	1030	1656.7	95400	4.4
Min	59	23	20	34.0	750	1.5	27	14	12	17.7	750	1.5	50	18	15	27.7	750	1.4	59	21	18	32.7	750	1.6

1st Floor (with glass)

Hour	West 1	West 2	West 3	MEAN	OUT Lx	WEST %	South 1	South 2	South 3	MEAN	OUT Lx	SOUTH %	East 1	East 2	East 3	MEAN	OUT Lx	EAST %	North 1	North 2	North 3	MEAN	OUT Lx	NORTH %
6.30	24	10	8	14.0	250.0	5.6	9	4.5	4	5.8	250.0	2.3	13	6	5	8.0	250.0	3.2	19	8	7	11.3	250.0	4.5
7.00	141	79	71	97.0	3200.0	3.0	130	60	50	80.0	3200.0	2.5	145	63	56	88.0	3200.0	2.8	175	88	82	114.3	3200.0	3.6
8.00	602	320	305	409.0	20000.0	2.0	727	365	331	474.3	20000.0	2.4	765	352	324	480.3	20000.0	2.4	665	373	346	461.3	20000.0	2.3
9.00	1010	546	495	683.7	42000.0	1.6	1130	547	496	724.3	42000.0	1.7	1220	521	478	739.7	42000.0	1.8	1110	587	573	756.7	42000.0	1.8
10.00	1740	876	756	1124.0	59500.0	1.9	1640	717	650	1002.3	59500.0	1.7	1600	787	701	1029.3	59500.0	1.7	1710	838	751	1099.7	59500.0	1.8
11.00	2360	1180	1040	1526.7	68000.0	2.2	3040	980	853	1624.3	68000.0	2.4	2680	937	817	1478.0	68000.0	2.2	2060	1010	882	1317.3	68000.0	1.9
12.00	2670	1370	1200	1746.7	91000.0	1.9	14900	1670	1390	5988.7	91000.0	6.6	10400	1700	1430	4510.0	91000.0	5.0	2770	1540	1300	1870.0	91000.0	2.1
13.00	3190	1480	1230	1966.7	95000.0	2.1	4140	1740	1420	2433.3	95000.0	2.6	3510	1550	1340	2133.3	95000.0	2.2	8950	2110	1800	4286.7	95000.0	4.5
14.00	3340	1490	1260	2030.0	92800.0	2.2	3000	1300	1080	1793.3	92800.0	1.9	2570	1290	1090	1650.0	92800.0	1.8	7320	1910	1520	3583.3	92800.0	3.9
15.00	3230	970	818	1672.0	79300.0	2.1	2390	920	815	1375.0	79300.0	1.7	1910	910	788	1202.7	79300.0	1.5	2390	1090	955	1488.3	79300.0	1.9
16.00	1930	703	647	1093.3	67000.0	1.6	1780	800	674	1084.7	67000.0	1.6	1520	712	635	955.7	67000.0	1.4	1500	810	750	1020.0	67000.0	1.5
17.00	1210	524	475	736.3	45100.0	1.8	1160	540	514	738.0	45100.0	1.6	1030	490	434	651.3	45100.0	1.4	1040	610	575	741.7	45100.0	1.6
18.00	665	289	260	404.7	26900.0	1.5	784	383	350	505.7	26900.0	1.9	554	281	248	360.3	26900.0	1.3	617	317	288	407.3	26900.0	1.5
19.00	169	69	60	99.3	4400.0	2.3	197	73	66	112.0	4400.0	2.5	165	70	61	98.7	4400.0	2.2	176	73	63	104.0	4400.0	2.4
Mean	1591.5	707.6	615.8	971.7	49603.6	2.3	2501.9	721.4	620.9	1281.4	49603.6	2.4	2005.9	690.6	600.4	1099.0	49603.6	2.2	2179.6	811.8	706.6	1231.6	49603.6	2.5
Max	3340	1490	1260	2030.0	95000	5.6	14900	1740	1420	6020.0	95000	6.6	10400	1700	1430	4510.0	95000	5.0	8950	2110	1800	4286.7	95000	4.5
Min	24	10	8	14.0	250	1.5	9	4.5	4	5.8	250	1.6	13	6	5	8.0	250	1.3	19	8	7	11.3	250	1.5

Table 6.4: Illuminance values of the 1st floor, for grey with 75% reflectance.

4th Floor (without glass)

Hour	West 1	West 2	West 3	MEAN	OUT Lx	WEST %	South 1	South 2	South 3	MEAN	OUT Lx	SOUTH %	East 1	East 2	East 3	MEAN	OUT Lx	EAST %	North 1	North 2	North 3	MEAN	OUT Lx	NORTH %
6.30	380	162	98	206.7	1250.0	18.5	281	100	65	148.7	1250.0	11.9	451	242	183	285.3	1250.0	22.8	388	156	110	211.3	1250.0	16.9
7.00	1170	730	615	838.3	6500.0	12.9	1220	650	501	790.3	6500.0	12.2	2760	2130	2620	2500.0	6500.0	38.5	1530	830	685	1015.0	6500.0	15.6
8.00	2390	1790	1640	1940.0	23500.0	8.2	3310	2080	1680	2356.7	23500.0	10.0	6920	25200	25000	19040.0	23500.0	81.0	2800	2150	1790	2246.7	23500.0	9.6
9.00	3270	2590	2230	2696.7	48500.0	5.6	6400	3380	2830	4803.3	48500.0	9.9	52300	48900	7200	36466.7	48500.0	75.2	3800	2870	2420	3030.0	48500.0	6.2
10.00	4160	3000	2540	3233.3	70000.0	4.6	65500	5180	3870	24850.0	70000.0	35.5	69000	7900	6460	27786.7	70000.0	39.7	4600	3540	3230	3790.0	70000.0	5.4
11.00	5370	3530	2740	3880.0	87000.0	4.5	85700	5710	3900	31770.0	87000.0	36.5	82000	6890	5460	31450.0	87000.0	36.1	5300	4290	3930	4506.7	87000.0	5.2
12.00	6110	4320	3210	4546.7	95000.0	4.8	93500	8580	6520	36233.3	95000.0	38.1	62600	6720	5100	24806.7	95000.0	26.1	5960	5230	4720	5303.3	95000.0	5.6
13.00	6630	4550	3220	4800.0	99600.0	4.8	95900	8520	6720	37050.0	99600.0	37.2	15700	5900	4940	8846.7	99600.0	8.9	6100	5510	5060	5556.7	99600.0	5.6
14.00	9250	5070	3500	5940.0	92300.0	6.4	88000	8230	6210	34146.7	92300.0	37.0	6350	4970	4390	5236.7	92300.0	5.7	5640	4890	4400	4976.7	92300.0	5.4
15.00	72700	5850	3980	27510.0	84000.0	32.8	75800	6370	4910	28960.0	84000.0	34.5	4880	3820	3060	3920.0	84000.0	4.7	4740	3750	3300	3930.0	84000.0	4.7
16.00	59300	5960	4350	23203.3	69700.0	33.3	13500	4720	3370	7196.7	69700.0	10.3	4070	3410	2990	3490.0	69700.0	5.0	4060	2850	2670	3193.3	69700.0	4.6
17.00	40200	35600	4920	26906.7	37500.0	71.8	4300	2400	1520	2740.0	37500.0	7.3	1980	1180	890	1350.0	37500.0	3.6	3430	2310	1930	2556.7	37500.0	6.8
18.00	6130	9800	12900	9610.0	15900.0	60.4	3840	1450	860	2050.0	15900.0	12.9	2350	1230	925	1501.7	15900.0	9.4	2400	1270	890	1520.0	15900.0	9.6
19.00	738	300	165	401.0	3050.0	13.1	874	345	203	474.0	3050.0	15.5	831	352	213	468.7	3050.0	15.4	752	325	186	421.0	3050.0	13.8
Mean	15555.6	5946.6	3293.4	8265.2	52414.3	20.0	31544.6	4151.1	3069.2	15255.0	52414.3	22.1	22298.7	5581.0	4957.9	11939.2	52414.3	26.6	3877.1	2855.1	2522.9	3018.4	52414.3	8.2
Max	72700	35600	12900	27510	99600	71.8	95900	8520	6720	37050	99600	38.1	82000	48900	25000	36466.7	99600	81.0	6100	5510	5060	5556.7	99600	16.9
Min	380	162	95	206.7	1250	4.5	281	100	65	148.7	1250	7.3	451	242	183	285.3	1250	3.6	388	156	110	211.3	1250	4.8

4th Floor (with glass)

Hour	West 1	West 2	West 3	MEAN	OUT Lx	WEST %	South 1	South 2	South 3	MEAN	OUT Lx	SOUTH %	East 1	East 2	East 3	MEAN	OUT Lx	EAST %	North 1	North 2	North 3	MEAN	OUT Lx	NORTH %
6.30	138	50	35	74.3	400.0	18.6	100	40	26	55.3	400.0	13.8	154	70	50	91.3	400.0	22.8	150	60	40	83.3	400.0	20.8
7.00	878	336	214	409.3	4350.0	9.4	790	310	210	436.7	4350.0	10.0	1460	745	580	901.7	4350.0	20.7	940	402	315	552.3	4350.0	12.7
8.00	1830	1390	1140	1453.3	22500.0	6.5	2450	1570	1280	1773.3	22500.0	7.9	5270	13800	13200	10756.7	22500.0	47.8	2530	1640	1290	1820.0	22500.0	8.1
9.00	2780	2130	1850	2246.7	44500.0	5.0	4600	2360	1950	3070.0	44500.0	6.9	36100	33100	5880	25060.0	44500.0	56.3	3360	2280	1990	2550.0	44500.0	5.7
10.00	3760	2950	2410	3040.0	64000.0	4.8	30500	3310	2460	12190.0	64000.0	19.0	52200	25300	5700	27733.3	64000.0	43.3	4000	3100	2550	3216.7	64000.0	5.0
11.00	4350	3170	2480	3333.3	82500.0	4.0	50000	5560	4400	19986.7	82500.0	24.2	61500	5930	4620	24016.7	82500.0	29.1	4570	3720	3080	3790.0	82500.0	4.6
12.00	5500	3820	2800	4040.0	92000.0	4.4	65100	16500	4700	28766.7	92000.0	31.3	47200	5350	4460	19003.3	92000.0	20.7	5110	4490	3830	4476.7	92000.0	4.9
13.00	5830	3800	2850	4193.3	94600.0	4.4	75500	56800	5880	46060.0	94600.0	48.7	11300	5320	4260	6960.0	94600.0	7.4	5220	5000	4280	4833.3	94600.0	5.1
14.00	10800	4260	2920	5993.3	96300.0	6.2	70400	16500	5800	30900.0	96300.0	32.1	5640	4800	4220	4886.7	96300.0	5.1	5120	4650	4310	4693.3	96300.0	4.9
15.00	47300	4550	2990	18280.0	83000.0	22.0	57800	6850	4250	22966.7	83000.0	27.7	3850	3150	2600	3200.0	83000.0	3.9	4570	3520	2940	3676.7	83000.0	4.4
16.00	49000	5430	3530	19320.0	73000.0	26.5	43400	4400	3170	16990.0	73000.0	23.3	3240	3050	2510	2933.3	73000.0	4.0	3830	2520	2170	2840.0	73000.0	3.9
17.00	25000	17700	2960	15220.0	43000.0	35.4	5550	2370	1850	3256.7	43000.0	7.6	2140	1600	1350	1763.3	43000.0	4.1	2900	1920	1590	2136.7	43000.0	5.0
18.00	4810	3570	2260	3546.7	20000.0	17.7	3820	1380	1130	2276.7	20000.0	11.4	2370	1070	740	1393.3	20000.0	7.0	2260	981	698	1313.0	20000.0	6.6
19.00	982	418	168	522.7	4880.0	10.7	1240	480	274	664.7	4880.0	13.6	933	398	254	528.3	4880.0	10.8	914	406	230	516.7	4880.0	10.6
Mean	11622.7	3833.8	2044.8	5833.8	51787.9	12.5	25375.7	8559.3	2670.7	13535.2	51787.9	19.5	16664.1	7441.6	3580.0	9230.6	51787.9	20.2	3248.6	2477.5	2093.8	2607.0	51787.9	7.3
Max	49000	17700	3530	19320	96300	35.4	75500	56800	5880	46060	96300	48.7	61500	33100	13200	27733.3	96300	56.3	5220	5000	4310	4833.3	96300	20.8
Min	138	50	35	74.3	400	4.0	100	40	26	55.3	400	6.9	154	70	50	91.3	400	3.9	150	60	40	83.3	400	3.9

Table 6.5: Illuminance values of the 4th floor, for grey with 50% reflectance.

3rd Floor (without glass)

Hour	West 1	West 2	West 3	MEAN	OUT Lx	WEST %	South 1	South 2	South 3	MEAN	OUT Lx	SOUTH %	East 1	East 2	East 3	MEAN	OUT Lx	EAST %	North 1	North 2	North 3	MEAN	OUT Lx	NORTH %
6.30	132	44	28	68.0	1250.0	5.4	87	28	20	44.3	1250.0	3.5	180	47	23	83.3	1250.0	6.7	134	46	25	68.3	1250.0	5.5
7.00	582	338	325	415.0	6500.0	6.4	510	188	182	293.3	6500.0	4.5	986	315	187	496.0	6500.0	7.6	625	245	208	359.3	6500.0	5.5
8.00	1240	780	600	873.3	23500.0	3.7	1130	560	454	714.7	23500.0	3.0	1960	880	502	1114.0	23500.0	4.7	1350	625	525	833.3	23500.0	3.5
9.00	1600	1070	860	1176.7	48500.0	2.4	2120	650	868	1212.7	48500.0	2.5	3250	1830	1020	2036.7	48500.0	4.2	1880	950	710	1173.3	48500.0	2.4
10.00	2020	1200	1100	1440.0	70000.0	2.1	3020	1320	1090	1810.0	70000.0	2.6	60400	2910	2380	21896.7	70000.0	31.3	2280	1160	900	1440.0	70000.0	2.1
11.00	2360	1280	1120	1589.0	87000.0	1.8	4790	2030	1550	2790.0	87000.0	3.2	39000	2440	1730	14390.0	87000.0	16.5	2470	1350	1110	1643.3	87000.0	1.9
12.00	2860	1460	1160	1826.7	95000.0	1.9	89100	2960	2070	31376.7	95000.0	33.0	4380	2050	1430	2620.0	95000.0	2.8	2770	1490	1290	1850.0	95000.0	1.9
13.00	3310	1570	1200	2026.7	99600.0	2.0	90600	3320	2430	32116.7	99600.0	32.2	3900	1650	1210	2253.3	99600.0	2.3	2830	1520	1300	1883.3	99600.0	1.9
14.00	3620	1790	1290	2333.3	92300.0	2.5	82000	3070	2150	29073.3	92300.0	31.5	2660	1370	1020	1683.3	92300.0	1.8	2680	1470	1160	1770.0	92300.0	1.9
15.00	5370	2210	1600	3060.0	84000.0	3.6	5550	1800	1480	2943.3	84000.0	3.5	2980	1180	1000	1623.3	84000.0	1.9	2380	1310	1070	1586.7	84000.0	1.9
16.00	3980	1860	1420	2413.3	69700.0	3.5	2950	1230	920	1700.0	69700.0	2.4	2040	1070	766	1292.0	69700.0	1.9	1990	1010	813	1271.0	69700.0	1.8
17.00	2980	1400	900	1760.0	37500.0	4.7	1530	550	450	843.3	37500.0	2.2	1300	846	715	953.7	37500.0	2.5	1600	730	600	976.7	37500.0	2.6
18.00	2060	860	351	1090.3	15900.0	6.9	1360	314	216	630.0	15900.0	4.0	1280	420	260	660.0	15900.0	4.2	1130	326	251	569.0	15900.0	3.6
19.00	329	90	36	151.7	3050.0	5.0	317	70	45	144.0	3050.0	4.7	354	111	47	170.7	3050.0	5.6	337	94	40	157.0	3050.0	5.1
Mean	2335.9	1139.4	856.4	1443.9	52414.3	3.7	20259.8	1308.3	980.4	7548.7	52414.3	9.5	8884.3	1222.8	880.0	3662.4	52414.3	6.7	1744.0	880.4	714.4	1113.0	52414.3	3.0
Max	5370	2210	1600	3060	99600	6.9	90600	3320	2430	32116.7	99600	33.0	60400	2910	2380	21896.7	99600	31.3	2830	1520	1300	1883.3	99600	5.5
Min	132	44	28	68	1250	1.8	87	28	20	44.3	1250	2.2	180	47	23	83.3	1250	1.8	134	46	25	68.3	1250	1.8

3rd Floor (with glass)

Hour	West 1	West 2	West 3	MEAN	OUT Lx	WEST %	South 1	South 2	South 3	MEAN	OUT Lx	SOUTH %	East 1	East 2	East 3	MEAN	OUT Lx	EAST %	North 1	North 2	North 3	MEAN	OUT Lx	NORTH %
6.30	66	21	15	34.0	400.0	8.5	45	12	9	22.0	400.0	5.5	66	23	10	33.0	400.0	8.3	77	24	12	37.7	400.0	9.4
7.00	348	164	146	219.3	4350.0	5.0	356	126	104	195.3	4350.0	4.5	585	280	114	319.7	4350.0	7.3	480	183	126	259.7	4350.0	6.0
8.00	1060	845	614	839.7	22500.0	3.7	1060	486	438	661.3	22500.0	2.9	1560	760	440	926.7	22500.0	4.1	1190	580	455	741.7	22500.0	3.3
9.00	1730	1000	820	1183.3	44500.0	2.7	1820	767	605	1064.0	44500.0	2.4	2940	1770	780	1830.0	44500.0	4.1	1690	770	630	1030.0	44500.0	2.3
10.00	2000	1280	890	1390.0	64000.0	2.2	4370	1220	940	2176.7	64000.0	3.4	38700	3400	2150	14083.3	64000.0	22.0	2070	1110	860	1346.7	64000.0	2.1
11.00	2200	1380	940	1506.7	82500.0	1.8	10800	1300	1320	4573.3	82500.0	5.5	54000	2510	1730	19413.3	82500.0	23.5	2270	1230	1000	1500.0	82500.0	1.8
12.00	2700	1420	1010	1710.0	92000.0	1.9	53800	2220	1440	19153.3	92000.0	20.8	8750	1640	1160	3850.0	92000.0	4.2	2540	1400	1200	1713.3	92000.0	1.9
13.00	2920	1530	1090	1846.7	94600.0	2.0	66700	3230	2040	23990.0	94600.0	25.4	3050	1400	1020	1823.3	94600.0	1.9	2450	1410	1240	1700.0	94600.0	1.8
14.00	5060	1620	1120	2600.0	96300.0	2.7	64400	2910	2000	23103.3	96300.0	24.0	2600	1330	1000	1643.3	96300.0	1.7	2350	1300	1200	1616.7	96300.0	1.7
15.00	11100	1800	1240	4713.3	83000.0	5.7	7110	1970	1390	3490.0	83000.0	4.2	2080	1180	980	1413.3	83000.0	1.7	2110	1110	980	1400.0	83000.0	1.7
16.00	13800	2030	1470	5766.7	73000.0	7.9	3200	1390	1020	1870.0	73000.0	2.6	1850	1080	910	1280.0	73000.0	1.8	1740	830	740	1103.3	73000.0	1.5
17.00	2400	1390	533	1441.0	43000.0	3.4	1950	602	485	1012.3	43000.0	2.4	1570	950	600	1040.0	43000.0	2.4	1270	640	545	818.3	43000.0	1.9
18.00	1830	566	243	879.7	20000.0	4.4	1510	507	296	771.0	20000.0	3.9	1230	412	305	649.0	20000.0	3.2	977	372	257	535.3	20000.0	2.7
19.00	416	124	53	197.7	4880.0	4.1	542	100	64	235.3	4880.0	4.8	483	104	87	221.3	4880.0	4.5	481	105	56	214.0	4880.0	4.4
Mean	3402.0	1063.6	727.6	1737.7	51787.9	4.0	18533.1	1238.6	867.9	5879.9	51787.9	8.0	8393.1	1202.1	803.3	3466.2	51787.9	6.5	1548.2	791.0	664.4	1001.2	51787.9	3.0
Max	13800	2030	1470	5766.7	96300	8.5	66700	3230	2040	23990	96300	25.4	54000	3400	2150	19413.33	96300	23.5	2540	1410	1240	1713.3	96300	9.416667
Min	66	21	15	34	400	1.8	45	12	9	22	400	2.4	66	23	10	33	400	1.7	77	24	12	37.7	400	1.511416

Table 6.6: Illuminance values of the 3rd floor, for grey with 50% reflectance.

2nd Floor (without glass)

Hour	West 1	West 2	West 3	MEAN	OUT Lx	WEST %	South 1	South 2	South 3	MEAN	OUT Lx	SOUTH %	East 1	East 2	East 3	MEAN	OUT Lx	EAST %	North 1	North 2	North 3	MEAN	OUT Lx	NORTH %
6.30	95	25	22	47.3	1250.0	3.8	57	17	16	30.0	1250.0	2.4	97	20	18	45.0	1250.0	3.6	78	20	19	38.3	1250.0	3.1
7.00	340	290	250	293.3	6500.0	4.5	304	155	154	204.3	6500.0	3.1	452	134	158	258.0	6500.0	4.0	400	174	173	249.0	6500.0	3.8
8.00	845	660	610	705.0	23500.0	3.0	736	410	395	513.7	23500.0	2.2	1000	400	300	566.7	23500.0	2.4	828	370	300	499.3	23500.0	2.1
9.00	1170	675	651	832.0	48500.0	1.7	1150	460	431	680.3	48500.0	1.4	1680	640	450	923.3	48500.0	1.9	1100	510	500	703.3	48500.0	1.5
10.00	1460	790	700	983.3	70000.0	1.4	1570	520	484	858.0	70000.0	1.2	2440	870	740	1350.0	70000.0	1.9	1550	700	820	956.7	70000.0	1.4
11.00	1700	900	770	1123.3	87000.0	1.3	2700	1030	880	1536.7	87000.0	1.8	2800	1160	980	1646.7	87000.0	1.9	1940	850	745	1178.3	87000.0	1.4
12.00	1900	980	860	1246.7	95000.0	1.3	85000	2040	1570	29536.7	95000.0	31.1	2810	1230	1020	1686.7	95000.0	1.8	1990	1020	890	1300.0	95000.0	1.4
13.00	2200	1060	920	1393.3	99600.0	1.4	89600	3170	2360	31710.0	99600.0	31.8	2540	1170	980	1563.3	99600.0	1.6	1850	956	840	1215.3	99600.0	1.2
14.00	2880	1120	930	1570.0	92300.0	1.7	80300	2180	1670	28050.0	92300.0	30.4	2110	820	694	1208.0	92300.0	1.3	1690	890	768	1116.0	92300.0	1.2
15.00	2250	730	680	1213.3	84000.0	1.4	2620	836	710	1455.3	84000.0	1.7	1630	620	450	919.7	84000.0	1.1	1480	800	665	981.7	84000.0	1.2
16.00	1730	455	435	873.3	69700.0	1.3	1450	480	420	783.3	69700.0	1.1	1290	430	300	690.0	69700.0	1.0	1200	640	526	788.7	69700.0	1.1
17.00	1370	385	362	705.7	37500.0	1.9	910	320	290	506.7	37500.0	1.4	950	330	200	493.3	37500.0	1.3	950	460	418	609.3	37500.0	1.6
18.00	925	215	199	446.3	15900.0	2.8	675	165	142	327.3	15900.0	2.1	670	168	80	306.0	15900.0	1.9	570	195	186	317.0	15900.0	2.0
19.00	159	24	21	68.0	3050.0	2.2	175	34	29	79.3	3050.0	2.6	184	32	29	75.0	3050.0	2.5	147	29	25	67.0	3050.0	2.2
Mean	1343.1	593.5	527.9	821.5	52414.3	2.1	19103.4	844.1	682.2	6876.5	52414.3	6.2	1477.4	578.9	457.1	837.8	52414.3	2.0	1126.5	543.9	476.8	715.7	52414.3	1.5
Max	2880	1120	930	1570	99600	4.5	89600	3170	2360	31710	99600	31.8	2810	1230	1020	1686.7	99600	4.0	1990	1020	890	1300	99600	3.8
Min	95	24	21	47.3	1250	1.3	57	17	16	30	1250	1.1	97	20	18	45	1250	1.0	78	20	19	38.3	1250	1.1

2nd Floor (with glass)

Hour	West 1	West 2	West 3	MEAN	OUT Lx	WEST %	South 1	South 2	South 3	MEAN	OUT Lx	SOUTH %	East 1	East 2	East 3	MEAN	OUT Lx	EAST %	North 1	North 2	North 3	MEAN	OUT Lx	NORTH %
6.30	38	13	12	21.0	400.0	5.3	28	8	7	14.7	400.0	3.7	38	10	9	18.3	400.0	4.6	43	11	10	21.3	400.0	5.3
7.00	227	115	110	150.7	4350.0	3.5	230	100	98	142.7	4350.0	3.3	311	106	104	173.7	4350.0	4.0	298	116	112	174.7	4350.0	4.0
8.00	705	590	496	597.0	22500.0	2.7	734	403	402	513.0	22500.0	2.3	873	397	395	555.0	22500.0	2.5	771	410	395	525.3	22500.0	2.3
9.00	1070	800	750	873.3	44500.0	2.0	1040	430	410	626.7	44500.0	1.4	1450	545	450	815.0	44500.0	1.8	1000	550	446	665.3	44500.0	1.5
10.00	1360	930	825	1038.3	64000.0	1.6	1900	540	505	981.7	64000.0	1.5	4600	575	527	1900.7	64000.0	3.0	1320	710	570	866.7	64000.0	1.4
11.00	1730	980	860	1183.3	82500.0	1.4	9120	1010	820	3650.0	82500.0	4.4	16000	1280	1050	6110.0	82500.0	7.4	1620	900	750	1090.0	82500.0	1.3
12.00	2030	980	900	1303.3	92000.0	1.4	45000	1350	1380	16076.7	92000.0	17.5	10600	1100	850	4183.3	92000.0	4.5	1910	1110	960	1326.7	92000.0	1.4
13.00	3330	1120	910	1786.7	94600.0	1.9	66300	3000	2100	23800.0	94600.0	25.2	2580	1030	910	1506.7	94600.0	1.6	2110	1190	980	1426.7	94600.0	1.5
14.00	9200	1130	863	3731.0	98300.0	3.8	62400	2500	1820	22240.0	98300.0	23.1	1960	980	880	1273.3	98300.0	1.3	1960	1000	923	1301.0	98300.0	1.4
15.00	3490	910	695	1698.3	83000.0	2.0	11700	1200	920	4606.7	83000.0	5.6	1520	708	634	954.0	83000.0	1.1	1580	806	750	1038.7	83000.0	1.3
16.00	1660	501	463	874.7	73000.0	1.2	5260	586	517	2121.0	73000.0	2.9	1300	700	560	853.3	73000.0	1.2	1130	643	617	796.7	73000.0	1.1
17.00	1080	375	330	595.0	43000.0	1.4	1040	340	311	563.7	43000.0	1.3	753	376	283	464.0	43000.0	1.1	750	344	330	474.7	43000.0	1.1
18.00	750	190	157	365.7	20000.0	1.8	657	225	190	424.0	20000.0	2.1	706	222	181	369.7	20000.0	1.8	551	211	192	318.0	20000.0	1.6
19.00	215	47	37	99.7	4880.0	2.0	329	68	51	149.3	4880.0	3.1	295	64	47	135.3	4880.0	2.8	257	48	39	114.0	4880.0	2.3
Mean	1920.4	618.6	526.1	1021.7	51787.9	2.2	13709.9	875.6	690.8	5422.1	51787.9	6.9	3063.1	578.1	497.1	1379.5	51787.9	2.8	1062.7	574.8	505.3	724.3	51787.9	2.0
Max	9200	1130	910	3731	98300	5.3	66300	3000	2100	23800	98300	25.2	16000	1280	1050	6110	98300	7.4	2110	1190	980	1426.7	98300	5.3
Min	38	13	12	21	400	1.2	28	8	7	14.7	400	1.3	38	10	9	18.3	400	1.1	43	11	10	21.3	400	1.1

Table 6.7: Illuminance values of the 2nd floor, for grey with 50% reflectance.

1st Floor (without glass)

Hour	West 1	West 2	West 3	MEAN	OUT Lx	WEST %	South 1	South 2	South 3	MEAN	OUT Lx	SOUTH %	East 1	East 2	East 3	MEAN	OUT Lx	EAST %	North 1	North 2	North 3	MEAN	OUT Lx	NORTH %
6.30	50	17	15	27.3	1250.0	2.2	35	14	12	20.3	1250.0	1.6	32	16	13	20.3	1250.0	1.6	41	17	15	24.3	1250.0	1.9
7.00	213	120	110	147.7	6500.0	2.3	175	110	108	131.0	6500.0	2.0	264	120	113	165.7	6500.0	2.5	250	120	116	162.7	6500.0	2.5
8.00	475	245	240	320.0	23500.0	1.4	511	293	272	358.7	23500.0	1.5	510	312	301	374.3	23500.0	1.6	500	306	301	369.0	23500.0	1.6
9.00	710	395	320	475.0	48500.0	1.0	731	390	355	492.0	48500.0	1.0	770	330	350	500.0	48500.0	1.0	690	390	360	480.0	48500.0	1.0
10.00	985	490	400	618.3	70000.0	0.9	1030	620	415	655.0	70000.0	0.9	1000	430	405	618.3	70000.0	0.9	940	450	435	608.3	70000.0	0.9
11.00	1230	580	460	756.7	87000.0	0.9	1240	660	510	803.3	87000.0	0.9	1290	570	490	783.3	87000.0	0.8	1280	570	485	771.7	87000.0	0.9
12.00	1410	610	500	840.0	95000.0	0.9	1520	780	660	986.7	95000.0	1.0	1530	660	580	923.3	95000.0	1.0	1490	700	572	920.7	95000.0	1.0
13.00	1540	580	460	860.0	99600.0	0.9	1660	680	550	958.7	99600.0	1.0	1610	535	530	908.3	99600.0	0.9	1500	740	610	950.0	99600.0	1.0
14.00	1420	500	425	781.7	92300.0	0.8	1580	560	460	866.7	92300.0	0.9	1510	530	480	840.0	92300.0	0.9	1400	650	540	863.3	92300.0	0.9
15.00	1260	437	390	695.7	84000.0	0.8	1280	468	412	723.3	84000.0	0.9	1280	434	380	698.0	84000.0	0.8	1150	513	450	704.3	84000.0	0.8
16.00	857	345	315	539.0	69700.0	0.8	805	341	321	489.0	69700.0	0.7	800	360	335	498.3	69700.0	0.7	781	400	338	506.3	69700.0	0.7
17.00	770	310	280	453.3	37500.0	1.2	516	251	220	328.7	37500.0	0.9	504	240	223	322.3	37500.0	0.9	615	290	200	368.3	37500.0	1.0
18.00	475	153	135	254.3	15900.0	1.6	358	139	118	204.3	15900.0	1.3	320	125	112	185.7	15900.0	1.2	350	160	100	203.3	15900.0	1.3
19.00	82	20	17	39.7	3050.0	1.3	67	28	23	39.3	3050.0	1.3	93	25	21	46.3	3050.0	1.5	77	22	18	39.0	3050.0	1.3
Mean	825.5	343.0	290.5	486.3	52414.3	1.2	823.2	371.7	316.9	503.9	52414.3	1.1	822.4	343.4	309.5	491.7	52414.3	1.2	788.9	380.6	324.4	498.0	52414.3	1.2
Max	1540	610	500	860	99600	2.3	1660	780	660	986.7	99600	2.0	1610	660	580	923.3	99600	2.5	1500	740	610	950	99600	2.5
Min	50	17	15	27.3	1250	0.8	35	14	12	20.3	1250	0.7	32	16	13	20.3	1250	0.7	41	17	15	24.3	1250	0.7

1st Floor (with glass)

Hour	West 1	West 2	West 3	MEAN	OUT Lx	WEST %	South 1	South 2	South 3	MEAN	OUT Lx	SOUTH %	East 1	East 2	East 3	MEAN	OUT Lx	EAST %	North 1	North 2	North 3	MEAN	OUT Lx	NORTH %
6.30	27	11	9	15.7	400.0	3.9	20	8	6	11.3	400.0	2.8	25	8	7	13.3	400.0	3.3	31	10	8	16.3	400.0	4.1
7.00	159	78	71	102.7	4350.0	2.4	155	78	74	102.3	4350.0	2.4	184	81	77	114.0	4350.0	2.6	198	86	81	121.7	4350.0	2.8
8.00	410	256	225	297.0	22500.0	1.3	505	298	285	362.0	22500.0	1.6	555	295	271	373.7	22500.0	1.7	522	284	283	363.0	22500.0	1.6
9.00	730	405	401	512.0	44500.0	1.2	735	382	359	492.0	44500.0	1.1	826	400	345	524.3	44500.0	1.2	737	370	350	485.7	44500.0	1.1
10.00	1120	580	525	741.7	64000.0	1.2	1330	490	452	757.3	64000.0	1.2	1080	510	455	681.7	64000.0	1.1	980	450	430	620.0	64000.0	1.0
11.00	1440	700	585	908.3	82500.0	1.1	4060	650	546	1752.0	82500.0	2.1	1800	580	510	963.3	82500.0	1.2	1320	630	530	826.7	82500.0	1.0
12.00	1710	790	710	1070.0	92000.0	1.2	5920	943	754	2539.0	92000.0	2.8	5950	1180	955	2695.0	92000.0	2.9	2630	1120	860	1536.7	92000.0	1.7
13.00	2290	970	800	1353.3	94600.0	1.4	4000	1110	860	1990.0	94600.0	2.1	2340	1230	980	1510.0	94600.0	1.6	8620	1550	1160	3776.7	94600.0	4.0
14.00	3710	1010	765	1828.3	98300.0	1.9	2300	770	615	1228.3	98300.0	1.3	1490	1000	661	1050.3	98300.0	1.1	8470	1250	944	3554.7	98300.0	3.7
15.00	1990	620	400	1003.3	83000.0	1.2	1430	501	440	790.3	83000.0	1.0	1280	630	412	790.7	83000.0	1.0	1720	820	455	998.3	83000.0	1.2
16.00	1100	360	240	566.7	73000.0	0.8	898	404	355	552.3	73000.0	0.8	1040	515	305	620.0	73000.0	0.8	878	425	402	568.3	73000.0	0.8
17.00	845	250	234	376.3	43000.0	0.9	625	281	244	383.3	43000.0	0.9	680	231	230	380.3	43000.0	0.9	435	252	230	305.7	43000.0	0.7
18.00	520	182	149	283.7	20000.0	1.4	500	201	168	289.7	20000.0	1.4	499	185	165	283.0	20000.0	1.4	310	189	161	220.0	20000.0	1.1
19.00	143	42	35	73.3	4880.0	1.5	210	59	48	105.7	4880.0	2.2	196	53	43	97.3	4880.0	2.0	175	47	38	86.7	4880.0	1.8
Mean	1142.4	446.7	367.6	652.3	51787.9	1.5	1620.6	440.9	371.9	811.1	51787.9	1.7	1281.8	498.4	385.4	721.9	51787.6	1.6	1930.4	534.5	423.7	962.9	51787.9	1.9
Max	3710	1010	800	1828.3	98300	3.9	5920	1110	860	2539	98300	2.8	5950	1230	980	2695	98300	3.3	8620	1550	1160	3776.7	98300	4.1
Min	27	11	9	15.7	400	0.8	20	8	6	11.3	400	0.8	25	8	7	13.3	400	0.8	31	10	8	16.3	400	0.7

Table 6.8: Illuminance values of the 1st floor, for grey with 50% reflectance.

4th Floor (without glass)

Hour	West 1	West 2	West 3	MEAN	OUT Lx	WEST %	South 1	South 2	South 3	MEAN	OUT Lx	SOUTH %	East 1	East 2	East 3	MEAN	OUT Lx	EAST %	North 1	North 2	North 3	MEAN	OUT Lx	NORTH %
6.30	130	60	36	75.3	330.0	22.8	74	30	19	41.0	330.0	12.4	142	80	53	91.7	330.0	27.8	120	57	37	71.3	330.0	21.6
7.00	864	525	465	618.0	5000.0	12.4	815	410	285	503.3	5000.0	10.1	1750	1500	1810	1686.7	5000.0	33.7	1100	600	420	706.7	5000.0	14.1
8.00	2330	1730	1620	1893.3	25500.0	7.4	2590	1450	1170	1736.7	25500.0	6.8	7270	24700	24000	18656.7	25500.0	73.2	2600	1750	1210	1853.3	25500.0	7.3
9.00	3160	2500	2310	2656.7	45000.0	5.9	7500	2350	1640	3830.0	45000.0	8.5	44100	42800	8600	31833.3	45000.0	70.7	3480	2420	1890	2596.7	45000.0	5.8
10.00	3930	3270	2930	3376.7	70000.0	4.8	26900	3200	2140	10746.7	70000.0	15.4	63000	10800	4850	25216.7	70000.0	37.5	4480	2860	2500	3280.0	70000.0	4.7
11.00	4520	3610	3070	3733.3	84000.0	4.4	68500	4190	2750	25146.7	84000.0	29.9	72500	5070	4290	27620.0	84000.0	32.9	5600	3450	2990	4013.3	84000.0	4.8
12.00	5980	4570	3230	4593.3	96000.0	4.8	86200	5660	3010	31623.3	96000.0	32.9	66500	5380	4310	25396.7	96000.0	26.5	7200	4040	3400	4880.0	96000.0	5.1
13.00	9230	5010	3640	5960.0	85800.0	6.9	84800	5930	3230	31320.0	85800.0	36.5	22000	5110	3890	10333.3	85800.0	12.0	8700	4530	3720	5670.0	85800.0	6.6
14.00	16000	5230	3910	8380.0	93000.0	9.0	74300	6660	3510	28156.7	93000.0	30.3	9800	4070	3270	5713.3	93000.0	6.1	7200	4200	3420	4960.0	93000.0	5.3
15.00	71200	6950	4330	27493.3	79500.0	34.6	50500	5580	3200	19760.0	79500.0	24.9	6000	3710	3030	4246.7	79500.0	5.3	5920	3840	2960	4240.0	79500.0	5.3
16.00	58400	10300	4400	24366.7	74000.0	32.9	16000	4620	2760	7793.3	74000.0	10.5	5100	3020	2010	3376.7	74000.0	4.6	4800	3250	2600	3550.0	74000.0	4.8
17.00	30500	23600	4000	19366.7	33500.0	57.8	5760	2300	1420	3160.0	33500.0	9.4	3400	2000	1600	2333.3	33500.0	7.0	3880	2150	1670	2566.7	33500.0	7.7
18.00	5590	2590	1090	3090.0	16000.0	19.3	3640	1500	700	1946.7	16000.0	12.2	3040	1070	730	1613.3	16000.0	10.1	2850	1290	800	1646.7	16000.0	10.3
19.00	1040	569	355	654.7	3700.0	17.7	908	313	165	462.0	3700.0	12.5	677	295	190	454.0	3700.0	12.3	1010	371	220	533.7	3700.0	14.4
Mean	15205.3	5036.7	2527.6	7589.9	50809.3	17.2	30606.2	3158.6	1857.1	11872.3	50809.3	13.0	21519.9	7900.4	4473.8	11398.0	50809.3	25.7	4216.6	2486.3	1988.4	2897.7	50809.3	8.4
Max	71200	23600	4400	27493.3	96000	57.8	86200	6660	3510	31623.3	96000	36.5	72500	42800	24000	31833.3	96000	73.2	8760	4530	3720	5670	96000	21.61618
Min	130	60	36	75.3	330	4.4	74	30	19	41	330	6.8	142	80	53	91.7	330	4.6	120	57	37	71.3	330	4.685714

4th Floor (with glass)

Hour	West 1	West 2	West 3	MEAN	OUT Lx	WEST %	South 1	South 2	South 3	MEAN	OUT Lx	SOUTH %	East 1	East 2	East 3	MEAN	OUT Lx	EAST %	North 1	North 2	North 3	MEAN	OUT Lx	NORTH %
6.30	36	13	10	19.7	85.0	22.1	15	7	3	8.3	85.0	9.8	32	16	9	19.0	85.0	22.4	36	14	9	19.7	85.0	23.1
7.00	495	315	244	351.3	2900.0	12.1	485	196	130	270.3	2900.0	9.3	914	611	385	636.7	2900.0	22.0	621	318	205	381.3	2900.0	13.1
8.00	1910	1260	1160	1443.3	19000.0	7.6	1980	1010	780	1256.7	19000.0	6.6	4860	11400	8850	8370.0	19000.0	44.1	2230	1150	980	1453.3	19000.0	7.6
9.00	2540	2060	1910	2170.0	45000.0	4.8	3380	1740	1280	2133.3	45000.0	4.7	31400	28500	5230	21710.0	45000.0	48.2	3260	2250	1710	2406.7	45000.0	5.3
10.00	3210	2150	1600	2320.0	66000.0	3.5	11400	2520	1750	5223.3	66000.0	7.9	60500	11300	4100	25300.0	66000.0	38.3	3770	2880	2600	3083.3	66000.0	4.7
11.00	3710	2880	2520	3036.7	82000.0	3.7	34800	3750	2340	13630.0	82000.0	16.6	48800	6000	3960	19586.7	52000.0	23.9	4440	3280	2900	3573.3	82000.0	4.4
12.00	5100	3020	3010	3710.0	93600.0	4.0	56500	4410	2800	21236.7	93600.0	22.7	35400	4750	3800	14650.0	93600.0	15.7	5280	3700	3090	4016.7	93600.0	4.3
13.00	6000	3920	3440	4453.3	99500.0	4.5	69400	6340	3390	26376.7	99500.0	26.5	13200	4730	3680	7203.3	99500.0	7.2	6980	3860	3060	4633.3	99500.0	4.7
14.00	11300	4100	3700	6366.7	96300.0	6.6	64600	5490	2920	24336.7	96300.0	25.3	7660	3570	2210	4480.0	96300.0	4.7	5440	3560	2950	3983.3	96300.0	4.1
15.00	47400	4900	3810	18703.3	84000.0	22.3	50000	4600	2870	19156.7	84000.0	22.8	6380	3380	2150	3970.0	84000.0	4.7	4410	3440	2840	3563.3	84000.0	4.2
16.00	47500	7540	3960	19666.7	78000.0	25.2	31600	4130	2500	12743.3	78000.0	16.3	5060	3280	2020	3453.3	78000.0	4.4	3930	2940	2350	3073.3	78000.0	3.9
17.00	25400	18700	2740	15613.3	45000.0	34.7	7410	2350	1450	3736.7	45000.0	8.3	3310	1900	1380	2196.7	45000.0	4.9	3250	2180	1740	2390.0	45000.0	5.3
18.00	5500	3620	2200	3776.7	18000.0	21.0	3160	1030	575	1588.3	18000.0	8.8	2490	1030	770	1430.0	18000.0	7.9	2480	1230	800	1503.3	18000.0	8.4
19.00	1030	504	319	617.7	5100.0	12.1	990	390	176	518.7	5100.0	10.2	986	355	220	513.7	5100.0	10.1	1070	405	235	570.0	5100.0	11.2
Mean	11509.4	3928.0	2187.4	5874.9	52463.2	13.2	23980.0	2711.6	1640.3	9444.0	52463.2	14.0	15783.7	5773.0	2768.9	8108.5	52463.2	18.5	3369.8	2236.2	1819.2	2475.1	52463.2	7.5
Max	47500	18700	3960	19666.7	99500	34.7	69400	6340	3390	26376.7	99500	26.5	60500	28500	8850	25300	99500	48.2	6980	3860	3090	4633.3	99500	23.13725
Min	36	13	10	19.7	85	3.5	15	7	3	8.3	85	4.7	32	16	9	19	85	4.4	36	14	9	19.7	85	3.940171

Table 6.9: Illuminance values of the 4th floor, for grey with 25% reflectance.

3rd Floor (without glass)

Hour	West 1	West 2	West 3	MEAN	OUT Lx	WEST %	South 1	South 2	South 3	MEAN	OUT Lx	SOUTH %	East 1	East 2	East 3	MEAN	OUT Lx	EAST %	North 1	North 2	North 3	MEAN	OUT Lx	NORTH %
6.30	57	14	7	26.0	330.0	7.9	36	10	4	16.7	330.0	5.1	49	14	5	22.7	330.0	6.9	42	10	5	19.0	330.0	5.8
7.00	410	180	125	238.3	5000.0	4.8	355	122	80	185.7	5000.0	3.7	530	210	75	271.7	5000.0	5.4	350	95	71	172.0	5000.0	3.4
8.00	1140	540	440	706.7	25500.0	2.8	1150	370	280	600.0	25500.0	2.4	1610	745	290	881.7	25500.0	3.5	950	375	250	525.0	25500.0	2.1
9.00	1480	739	613	944.0	45000.0	2.1	1890	690	426	1002.0	45000.0	2.2	8900	2040	454	3798.0	45000.0	8.4	1430	630	420	826.7	45000.0	1.8
10.00	1800	835	621	1085.3	70000.0	1.6	2710	968	620	1432.7	70000.0	2.0	58000	1740	1150	20296.7	70000.0	29.0	1750	770	485	1001.7	70000.0	1.4
11.00	2430	875	643	1316.0	84000.0	1.6	5420	1140	811	2457.0	84000.0	2.9	60200	1170	907	20759.0	84000.0	24.7	2150	866	604	1206.7	84000.0	1.4
12.00	3240	900	650	1596.7	96000.0	1.7	78000	1230	1090	26773.3	96000.0	27.9	12000	1130	760	4630.0	96000.0	4.8	2700	950	700	1450.0	96000.0	1.5
13.00	4520	1050	683	2084.3	85800.0	2.4	68600	1930	1170	23900.0	85800.0	27.9	4080	1060	696	1945.3	65800.0	2.3	3520	1010	800	1776.7	85800.0	2.1
14.00	5550	1330	700	2526.7	93000.0	2.7	36700	1570	965	13078.3	93000.0	14.1	4010	1000	640	1883.3	93000.0	2.0	2790	945	765	1500.0	93000.0	1.6
15.00	6750	1580	815	3048.3	79500.0	3.8	10000	1360	860	4073.3	79500.0	5.1	3120	870	619	1536.3	79500.0	1.9	2340	860	680	1293.3	79500.0	1.6
16.00	5490	1440	755	2561.7	74000.0	3.5	3420	900	599	1639.7	74000.0	2.2	2130	845	583	1186.0	74000.0	1.6	1970	760	614	1114.7	74000.0	1.5
17.00	3520	1060	333	1637.7	33500.0	4.9	1880	527	284	897.0	33500.0	2.7	1420	545	383	782.7	33500.0	2.3	1500	414	360	758.0	33500.0	2.3
18.00	2290	481	135	968.7	16000.0	6.1	1180	375	138	564.3	16000.0	3.5	1360	235	146	587.0	16000.0	3.7	1140	260	134	511.3	16000.0	3.2
19.00	419	76	32	175.7	3700.0	4.7	254	89	38	160.3	3700.0	4.3	374	53	35	154.0	3700.0	4.2	420	75	34	176.3	3700.0	4.8
Mean	2792.6	792.9	468.0	1351.1	50809.3	3.6	15121.1	805.8	526.1	5484.3	50809.3	7.6	11271.6	832.6	431.6	4195.3	50809.3	7.2	1646.6	572.9	423.0	880.8	50809.3	2.5
Max	6750	1580	815	3048.3	96000	7.9	78000	1930	1170	26773.3	96000	27.9	60200	2040	1150	20759	96000	29.0	3520	1010	800	1776.7	96000	5.8
Min	57	14	7	26	330	1.6	36	10	4	16.7	330	2.0	49	14	5	22.7	330	1.6	42	10	5	19.0	330	1.4

3rd Floor (with glass)

Hour	West 1	West 2	West 3	MEAN	OUT Lx	WEST %	South 1	South 2	South 3	MEAN	OUT Lx	SOUTH %	East 1	East 2	East 3	MEAN	OUT Lx	EAST %	North 1	North 2	North 3	MEAN	OUT Lx	NORTH %
6.30	18	5	2	8.3	85.0	9.8	8	3	1.6	4.2	85.0	4.9	12	4	1.4	5.8	85.0	6.8	16	4	2	7.3	85.0	8.6
7.00	231	98	61	130.0	2900.0	4.5	231	82	46	119.7	2900.0	4.1	306	116	45	155.7	2900.0	5.4	265	80	46	130.7	2900.0	4.5
8.00	850	600	500	650.0	19000.0	3.4	900	365	260	508.3	19000.0	2.7	1320	660	280	753.3	19000.0	4.0	720	364	230	438.0	19000.0	2.3
9.00	3060	2060	661	1927.0	45000.0	4.3	1460	500	395	785.0	45000.0	1.7	5600	1380	400	2460.0	45000.0	5.5	1100	570	343	671.0	45000.0	1.5
10.00	1650	690	465	935.0	66000.0	1.4	3700	900	540	1713.3	66000.0	2.6	34000	1710	1080	12263.3	66000.0	18.6	1570	713	460	914.3	66000.0	1.4
11.00	1810	980	280	1023.3	82000.0	1.2	8990	1190	745	3641.7	82000.0	4.4	50400	1370	921	17563.7	82000.0	21.4	1960	905	545	1136.7	82000.0	1.4
12.00	2180	1080	280	1180.0	93600.0	1.3	59900	1510	910	20773.3	93600.0	22.2	14200	1230	708	5379.3	93600.0	5.7	2600	1080	633	1437.7	93600.0	1.5
13.00	3760	1200	510	1823.3	99500.0	1.8	64300	2400	1250	22650.0	99500.0	22.8	7300	1070	600	2990.0	99500.0	3.0	3700	1210	824	1911.3	99500.0	1.9
14.00	6050	1370	664	2694.7	96300.0	2.8	52000	2050	1110	18386.7	96300.0	19.1	3870	940	614	1808.0	96300.0	1.9	3260	1030	800	1696.7	96300.0	1.8
15.00	12900	1650	768	5106.0	84000.0	6.1	9000	1490	864	3784.7	84000.0	4.5	3010	852	610	1490.7	84000.0	1.8	2350	900	684	1311.3	84000.0	1.6
16.00	11700	1400	780	4626.7	78000.0	5.9	4000	995	670	1888.3	78000.0	2.4	2180	814	605	1199.7	78000.0	1.5	1600	790	500	1030.0	78000.0	1.3
17.00	3530	1080	570	1726.7	45000.0	3.6	2430	468	350	1082.7	45000.0	2.4	1650	670	511	943.7	45000.0	2.1	1490	560	260	770.0	45000.0	1.7
18.00	1650	614	154	806.0	18000.0	4.5	1230	315	150	565.0	18000.0	3.1	1190	345	202	579.0	18000.0	3.2	1080	258	167	501.7	18000.0	2.8
19.00	499	81	39	206.3	5100.0	4.0	503	95	49	215.7	5100.0	4.2	464	107	47	206.0	5100.0	4.0	520	75	45	213.3	5100.0	4.2
Mean	3563.4	922.0	409.5	1631.7	52463.2	3.9	14902.7	683.1	524.3	5437.0	52463.2	7.2	8964.4	804.9	473.2	3414.2	52463.2	6.1	1602.3	609.9	395.6	869.3	52463.2	2.6
Max	12900	2060	780	5106	99500	9.8	64300	2400	1250	22650	99500	22.8	50400	1710	1080	17563.67	99500	21.4	3700	1210	824	1911.3	99500	8.6
Min	18	5	2	5.3	85	1.2	8	3	1.6	4.2	85	1.7	12	4	1.4	5.8	85	1.5	16	4	2	7.3	85	1.3

Table 6.10: Illuminance values of the 3rd floor, for grey with 25% reflectance.

2nd Floor (without glass)

Hour	West 1	West 2	West 3	MEAN	OUT Lx	WEST %	South 1	South 2	South 3	MEAN	OUT Lx	SOUTH %	East 1	East 2	East 3	MEAN	OUT Lx	EAST %	North 1	North 2	North 3	MEAN	OUT Lx	NORTH %
6.30	28	6	5	13.0	330.0	3.9	16	5	4	8.3	330.0	2.5	23	5	4	10.7	330.0	3.2	23	5	4	10.7	330.0	3.2
7.00	203	75	67	115.0	5000.0	2.3	192	62	59	104.3	5000.0	2.1	255	70	66	130.3	5000.0	2.6	220	74	71	121.7	5000.0	2.4
8.00	650	390	290	443.3	25500.0	1.7	585	255	248	362.7	25500.0	1.4	805	265	255	441.7	25500.0	1.7	520	260	240	340.0	25500.0	1.3
9.00	935	510	500	648.3	45000.0	1.4	1000	353	349	567.3	45000.0	1.3	1290	361	320	657.0	45000.0	1.5	800	350	335	495.0	45000.0	1.1
10.00	1190	595	548	777.7	70000.0	1.1	1280	410	402	697.3	70000.0	1.0	2110	560	450	1040.0	70000.0	1.5	1060	465	420	648.3	70000.0	0.9
11.00	1360	627	580	855.7	84000.0	1.0	6000	656	568	2408.7	84000.0	2.9	3200	740	633	1524.3	84000.0	1.8	1500	543	481	841.3	84000.0	1.0
12.00	1710	656	595	987.7	96000.0	1.0	78900	1000	803	26901.0	96000.0	28.0	2940	737	613	1430.0	96000.0	1.5	1950	655	520	1041.7	96000.0	1.1
13.00	2450	740	600	1263.3	85800.0	1.5	65100	1150	925	22391.7	85800.0	26.1	2500	660	549	1236.3	85800.0	1.4	2530	713	618	1287.0	85800.0	1.5
14.00	3420	808	553	1593.7	93000.0	1.7	27300	1090	920	9770.0	93000.0	10.5	2260	590	530	1126.7	93000.0	1.2	1950	677	634	1087.0	93000.0	1.2
15.00	2670	579	520	1256.3	79500.0	1.6	6000	590	531	2373.7	79500.0	3.0	1920	550	504	991.3	79500.0	1.2	1500	653	624	925.7	79500.0	1.2
16.00	1960	441	380	933.7	74000.0	1.3	1960	468	410	946.0	74000.0	1.3	1400	424	361	728.3	74000.0	1.0	1160	563	520	754.3	74000.0	1.0
17.00	1340	265	200	601.7	33500.0	1.8	1010	252	235	499.0	33500.0	1.5	950	330	242	507.3	33500.0	1.5	864	286	210	453.3	33500.0	1.4
18.00	900	117	102	373.0	16000.0	2.3	603	130	112	281.7	16000.0	1.8	520	125	115	253.3	16000.0	1.6	600	119	109	276.0	16000.0	1.7
19.00	197	29	25	83.7	3700.0	2.3	242	33	29	101.3	3700.0	2.7	247	33	30	103.3	3700.0	2.8	184	30	28	80.7	3700.0	2.2
Mean	1359.5	417.1	354.6	710.4	50809.3	1.8	13584.9	461.1	399.6	4815.2	50809.3	6.1	1458.6	389.3	333.7	727.2	50809.3	1.8	1061.5	386.8	343.9	597.3	50809.3	1.5
Max	3420	808	600	1593.7	96000	3.9	78900	1150	925	26901	96000	28.0	3200	740	633	1524.3	96000	3.2	2530	713	634	1287	96000	3.2
Min	28	6	5	13	330	1.0	16	5	4	8.3	330	1.0	23	5	4	10.7	330	1.0	23	5	4	10.7	330	0.9

2nd Floor (with glass)

Hour	West 1	West 2	West 3	MEAN	OUT Lx	WEST %	South 1	South 2	South 3	MEAN	OUT Lx	SOUTH %	East 1	East 2	East 3	MEAN	OUT Lx	EAST %	North 1	North 2	North 3	MEAN	OUT Lx	NORTH %
6.30	10	3	2.13	5.0	85.0	5.9	5	1.19	1.08	2.4	85.0	2.9	7	1.4	1.2	3.2	85.0	3.8	10	2	1.57	4.5	85.0	5.3
7.00	132	54	50	78.7	2900.0	2.7	137	44	41	74.0	2900.0	2.6	157	45	43	81.7	2900.0	2.8	164	52	49	88.3	2900.0	3.0
8.00	510	280	250	346.7	19000.0	1.8	545	230	225	333.3	19000.0	1.8	690	245	236	390.3	19000.0	2.1	585	243	230	352.7	19000.0	1.9
9.00	940	480	565	661.7	45000.0	1.5	895	345	335	525.0	45000.0	1.2	1290	430	347	689.0	45000.0	1.5	1200	355	344	633.0	45000.0	1.4
10.00	1120	700	401	740.3	66000.0	1.1	1710	440	420	856.7	66000.0	1.3	4800	460	411	1890.3	66000.0	2.9	3890	621	455	1655.3	66000.0	2.5
11.00	1490	715	698	967.7	82000.0	1.2	8010	645	549	3068.0	82000.0	3.7	16200	857	674	5910.3	82000.0	7.2	1340	730	529	866.3	82000.0	1.1
12.00	1700	730	617	1015.7	93600.0	1.1	17700	992	750	6480.7	93600.0	6.9	12200	833	650	4561.0	93600.0	4.9	1640	770	616	1008.7	93600.0	1.1
13.00	2880	885	475	1413.3	99500.0	1.4	60700	1730	1200	21210.0	99500.0	21.3	4300	732	613	1881.7	99500.0	1.9	2810	965	718	1497.7	99500.0	1.5
14.00	8800	1010	644	3484.7	96300.0	3.6	50900	1490	1060	17816.7	96300.0	18.5	2810	716	571	1365.7	96300.0	1.4	2630	815	645	1363.3	96300.0	1.4
15.00	4120	670	560	1783.3	84000.0	2.1	11200	776	612	4196.0	84000.0	5.0	2300	671	490	1153.7	84000.0	1.4	2100	700	620	1140.0	84000.0	1.4
16.00	2760	514	370	1214.7	78000.0	1.6	5210	530	475	2071.7	78000.0	2.7	1480	596	450	842.0	78000.0	1.1	1440	565	520	841.7	78000.0	1.1
17.00	1600	275	254	709.7	45000.0	1.6	1260	324	289	624.3	45000.0	1.4	1000	586	400	662.0	45000.0	1.5	973	370	359	567.3	45000.0	1.3
18.00	1030	157	136	441.0	18000.0	2.5	690	162	133	328.3	18000.0	1.8	790	206	155	383.7	18000.0	2.1	700	172	146	339.3	18000.0	1.9
19.00	260	44	35	113.0	5100.0	2.2	296	53	42	130.3	5100.0	2.6	287	50	40	125.7	5100.0	2.5	315	48	39	134.0	5100.0	2.6
Mean	1953.7	465.5	361.2	926.8	52463.2	2.2	11375.6	554.4	438.0	4122.7	52463.2	5.3	3450.8	459.2	362.9	1424.3	52463.2	2.6	1414.1	457.7	376.5	749.4	52463.2	2.0
Max	8800	1010	698	3484.7	99500	5.9	60700	1730	1200	21210	99500	21.3	16200	857	674	5910.3	99500	7.2	3890	965	718	1655.3	99500	5.3
Min	10	3	2.13	5.0	85	1.1	5	1.19	1.08	2.4	85	1.2	7	1.4	1.2	3.2	85	1.1	10	2	1.57	4.5	85	1.1

Table 6.11: Illuminance values of the 2nd floor, for grey with 25% reflectance.

1st Floor (without glass)

Hour	West 1	West 2	West 3	MEAN	OUT Lx	WEST %	South 1	South 2	South 3	MEAN	OUT Lx	SOUTH %	East 1	East 2	East 3	MEAN	OUT Lx	EAST %	North 1	North 2	North 3	MEAN	OUT Lx	NORTH %
6.30	18	5	4	9.0	330.0	2.7	10	4	3	5.7	330.0	1.7	13	4	3	6.7	330.0	2.0	15	5	4	8.0	330.0	2.4
7.00	143	53	50	82.0	5000.0	1.6	105	55	51	70.3	5000.0	1.4	151	65	82	92.7	5000.0	1.9	150	58	56	88.0	5000.0	1.8
8.00	365	200	190	251.7	25500.0	1.0	373	205	200	260.3	25500.0	1.0	370	235	230	278.3	25500.0	1.1	370	210	205	261.7	25500.0	1.0
9.00	613	254	235	367.3	45000.0	0.8	660	300	295	418.3	45000.0	0.9	600	310	295	401.7	45000.0	0.9	590	304	295	396.3	45000.0	0.9
10.00	794	321	300	471.7	70000.0	0.7	946	372	342	553.3	70000.0	0.8	930	355	332	539.0	70000.0	0.8	795	338	310	481.0	70000.0	0.7
11.00	1080	404	362	615.3	84000.0	0.7	1210	402	357	656.3	84000.0	0.8	1210	395	358	654.3	84000.0	0.8	1040	410	328	592.0	84000.0	0.7
12.00	1470	463	392	775.0	96000.0	0.8	2310	588	478	1125.3	96000.0	1.2	1520	516	418	816.0	96000.0	0.9	1290	490	378	719.3	96000.0	0.7
13.00	2470	609	483	1187.3	85800.0	1.4	4910	662	532	2034.7	85800.0	2.4	2150	583	466	1066.3	85800.0	1.2	1820	565	454	946.3	85800.0	1.1
14.00	1610	416	374	800.0	93000.0	0.9	2960	554	465	1326.3	93000.0	1.4	1500	580	464	841.3	93000.0	0.9	1480	570	430	826.7	93000.0	0.9
15.00	1330	372	332	678.0	79500.0	0.9	1250	390	349	663.0	79500.0	0.8	1140	450	350	646.7	79500.0	0.8	1120	480	380	660.0	79500.0	0.8
16.00	1090	342	311	581.0	74000.0	0.8	870	378	342	530.0	74000.0	0.7	790	340	281	470.3	74000.0	0.6	850	393	300	514.3	74000.0	0.7
17.00	780	226	205	403.7	33500.0	1.2	455	193	182	276.7	33500.0	0.8	400	197	178	258.3	33500.0	0.8	554	225	190	323.0	33500.0	1.0
18.00	477	114	99	230.0	16000.0	1.4	288	119	102	169.7	16000.0	1.1	240	112	100	150.7	16000.0	0.9	410	117	110	212.3	16000.0	1.3
19.00	150	28	24	67.3	3700.0	1.8	72	29	25	42.0	3700.0	1.1	102	30	25	52.3	3700.0	1.4	251	30	26	103.3	3700.0	2.8
Mean	885.0	271.9	240.1	465.7	50809.3	1.2	1172.8	303.9	265.9	580.9	50809.3	1.2	794.0	296.6	254.4	448.3	50809.3	1.1	767.0	299.6	247.4	438.0	50809.3	1.2
Max	2470	609	483	1187.3	96000	2.7	4910	662	532	2034.7	96000	2.4	2150	583	466	1066.3	96000	2.0	1820	570	454	946.3	96000	2.8
Min	18	5	4	9	330	0.7	10	4	3	5.7	330	0.7	13	4	3	6.7	330	0.6	15	5	4	8	330	0.7

1st Floor (with glass)

Hour	West 1	West 2	West 3	MEAN	OUT Lx	WEST %	South 1	South 2	South 3	MEAN	OUT Lx	SOUTH %	East 1	East 2	East 3	MEAN	OUT Lx	EAST %	North 1	North 2	North 3	MEAN	OUT Lx	NORTH %
6.30	7	2	1.8	3.6	85.0	4.2	4	1.1	1.01	2.0	85.0	2.4	4	1.5	1.3	2.3	85.0	2.7	7	1.9	1.5	3.5	85.0	4.1
7.00	91	50	46	62.3	2900.0	2.1	97	38	36	57.0	2900.0	2.0	104	45	41	63.3	2900.0	2.2	113	47	41	67.0	2900.0	2.3
8.00	335	175	152	220.7	19000.0	1.2	400	195	186	260.3	19000.0	1.4	456	220	210	295.3	19000.0	1.6	424	215	199	279.3	19000.0	1.5
9.00	630	355	240	408.3	45000.0	0.9	643	290	278	403.7	45000.0	0.9	745	330	298	457.7	45000.0	1.0	650	310	290	416.7	45000.0	0.9
10.00	1060	430	323	604.3	66000.0	0.9	1270	415	365	683.3	66000.0	1.0	1150	423	365	646.0	66000.0	1.0	1000	450	400	616.7	66000.0	0.9
11.00	1690	565	439	898.0	82000.0	1.1	5690	540	490	2240.0	82000.0	2.7	1700	480	414	864.7	82000.0	1.1	1400	660	405	828.3	82000.0	1.0
12.00	2160	760	560	1160.0	93600.0	1.2	16100	1180	943	6074.3	93600.0	6.5	11600	1000	723	4441.0	93600.0	4.7	2170	920	595	1228.3	93600.0	1.3
13.00	3150	959	734	1614.3	99500.0	1.6	6800	863	720	2801.0	99500.0	2.8	2210	875	682	1255.7	99500.0	1.3	6830	1150	916	2965.3	99500.0	3.0
14.00	2140	680	530	1116.7	96300.0	1.2	4430	820	658	1969.3	96300.0	2.0	2150	713	577	1146.7	96300.0	1.2	5750	1030	721	2500.3	96300.0	2.6
15.00	1610	520	418	916.0	84000.0	1.1	1800	457	415	890.7	84000.0	1.1	1360	445	3365	1730.0	84000.0	2.1	2420	710	520	1216.7	84000.0	1.4
16.00	1340	430	340	703.3	78000.0	0.9	1790	442	381	871.0	78000.0	1.1	1290	420	344	684.7	78000.0	0.9	1420	460	364	748.0	78000.0	1.0
17.00	690	270	214	391.3	45000.0	0.9	721	256	240	405.7	45000.0	0.9	590	220	203	337.7	45000.0	0.6	665	260	225	390.3	45000.0	0.9
18.00	390	158	140	229.3	18000.0	1.3	524	164	133	273.7	18000.0	1.5	546	150	127	274.3	18000.0	1.5	575	159	142	292.0	18000.0	1.6
19.00	191	45	38	91.3	5100.0	1.6	193	52	43	96.0	5100.0	1.9	210	50	41	100.3	5100.0	2.0	207	48	41	98.7	5100.0	1.9
Mean	1120.3	385.6	298.3	601.4	52463.2	1.5	2890.1	409.5	349.2	1216.3	52463.2	2.0	1723.9	383.8	528.0	878.5	52463.2	1.7	1684.0	481.5	347.2	832.2	52463.2	1.7
Max	3150	959	734	1614.3	99500	4.2	16100	1180	943	6074.3	99500	6.5	11600	1000	3365	5321.7	99500	4.7	6830	1150	916	2965.3	99500	4.1
Min	7	2	1.8	3.6	85	0.9	4	1.1	1.01	2.0	85	0.9	4	1.5	1.3	2.3	85	0.8	7	1.9	1.5	3.5	85	0.9

Table 6.12: Illuminance values of the 1st floor, for grey with 25% reflectance.

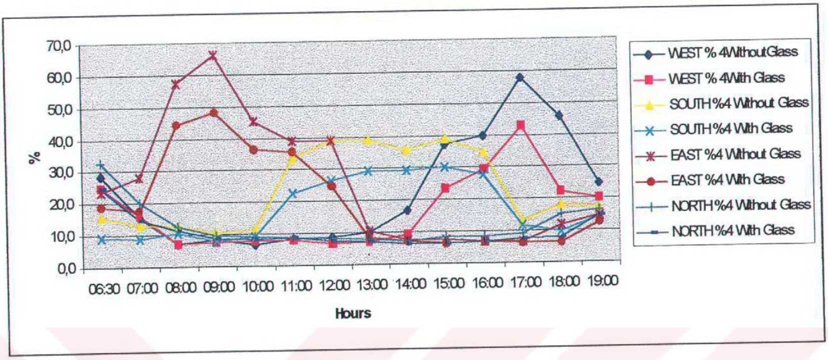


Figure 7.5: Illuminance values of 4th floor, in all directions, for grey with 75% reflectance. (With and Without glass)

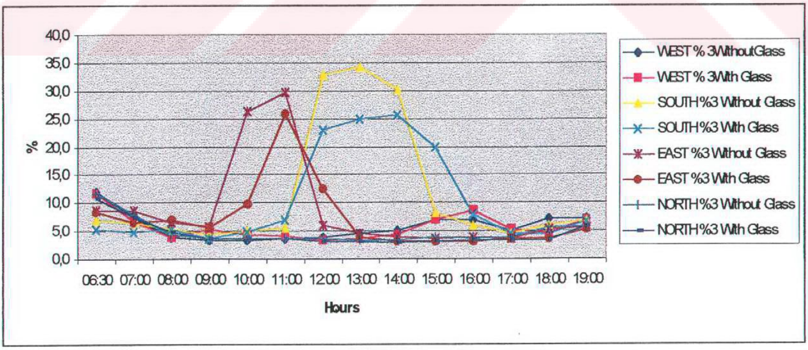


Figure 7.6: Illuminance values of 3rd floor, in all directions, for grey with 75% reflectance. (With and Without glass)

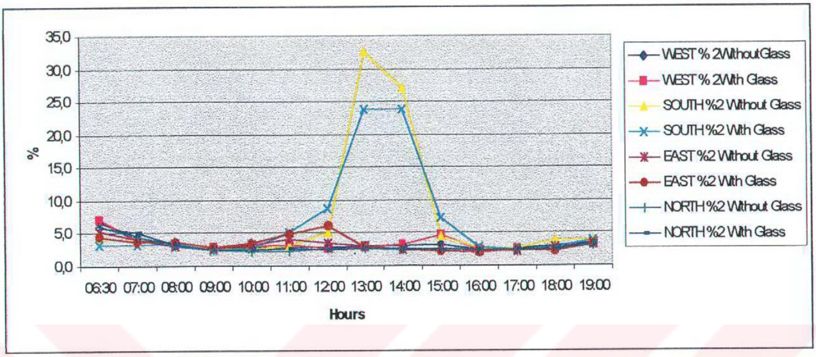


Figure 7.7: Illuminance values of 2nd floor, in all directions, for grey with 75% reflectance. (With and Without glass)

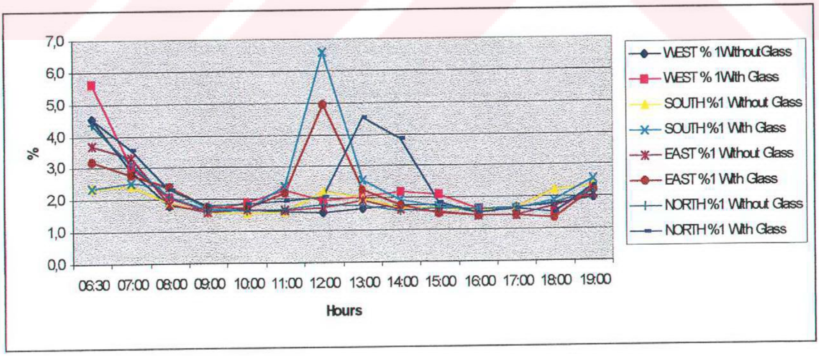


Figure 7.8: Illuminance values of 1st floor, in all directions, for grey with 75% reflectance. (With and Without glass)

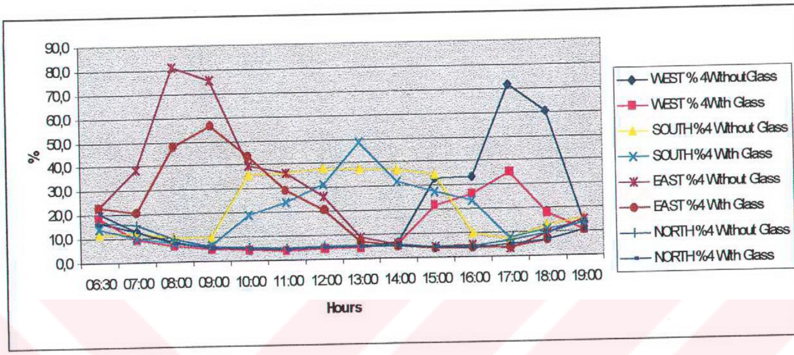


Figure 7.9: Illuminance values of 4th floor, in all directions, for grey with 50% reflectance. (With and Without glass)

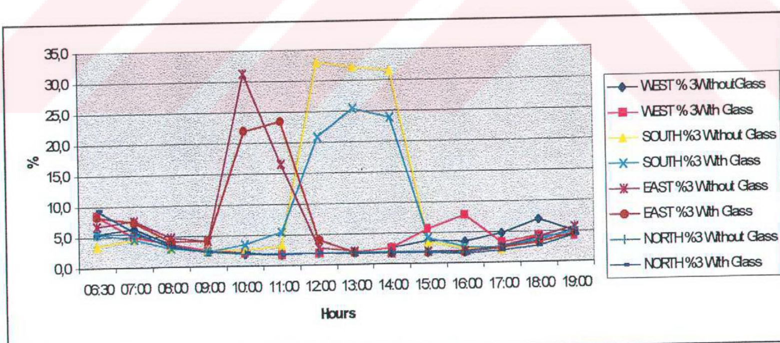


Figure 7.10: Illuminance values of 3rd floor, in all directions for grey with 50% reflectance. (With and Without glass)

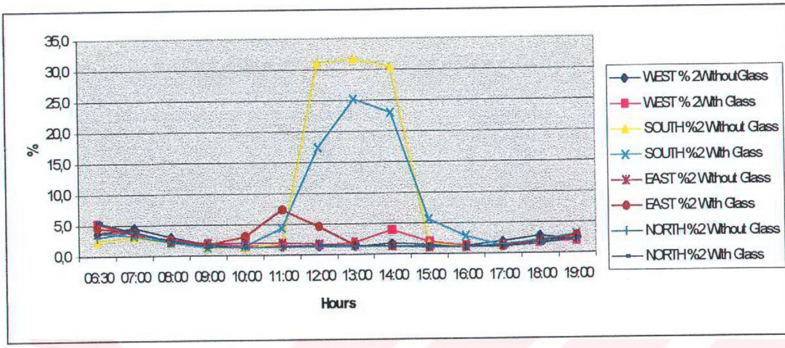


Figure 7.11: Illuminance values of 2nd floor, in all directions, for grey with 50% reflectance. (With and Without glass)

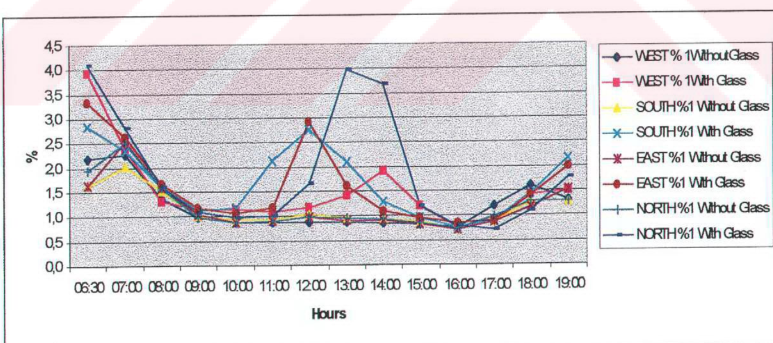


Figure 7.12: Illuminance values of 1st floor, in all directions, for grey with 50% reflectance. (With and Without glass)

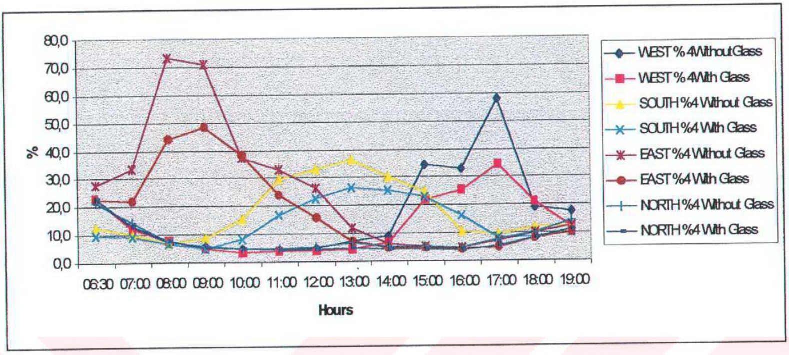


Figure 7.13: Illuminance values of 4th floor, in all directions, for grey with 25% reflectance. (With and Without glass)

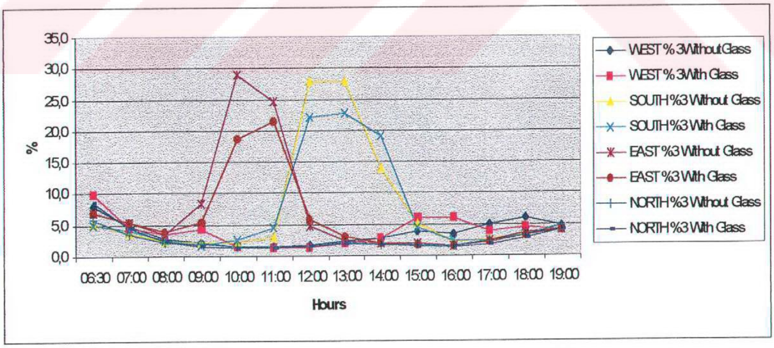


Figure 7.14: Illuminance values of 3rd floor, in all directions, for grey with 25% reflectance. (With and Without glass)

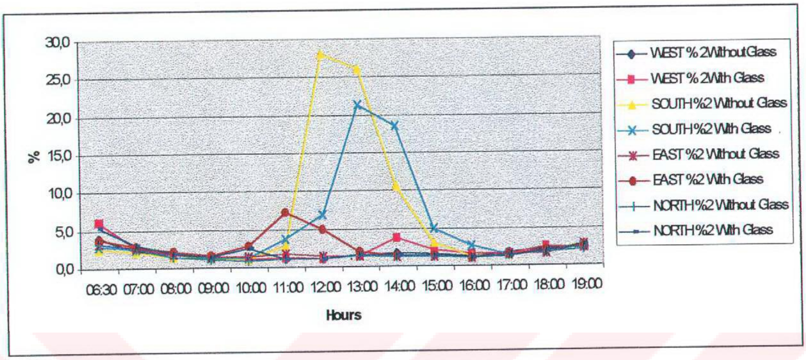


Figure 7.15: Illuminance values of 2nd floor, in all directions, for grey with 25% reflectance. (With and Without glass)

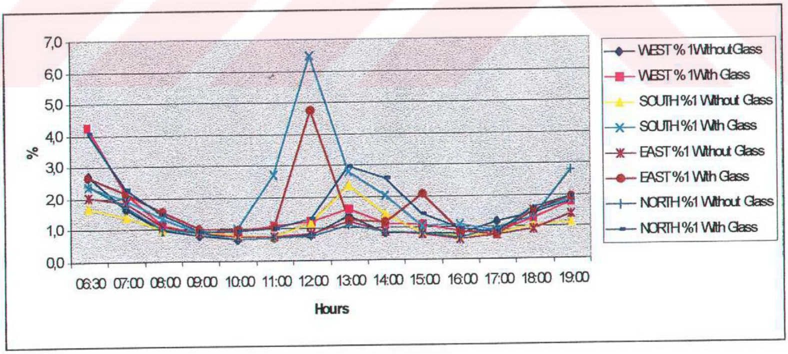


Figure 7.16: Illuminance values of 1st floor, in all directions, for grey with 25% reflectance. (With and Without glass)

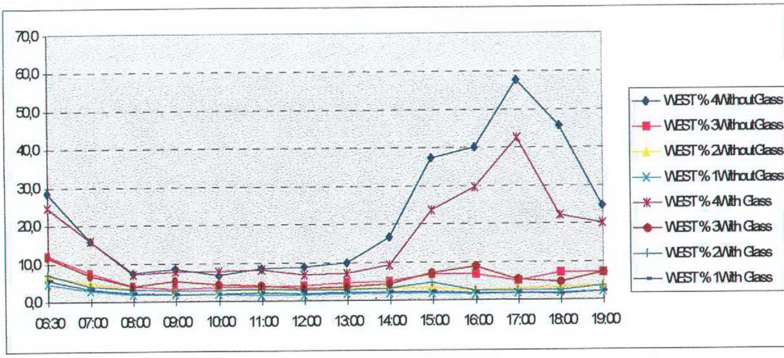


Figure 7.17: Illuminance values of all floors, in West, for grey with 75% reflectance. (With and Without glass)

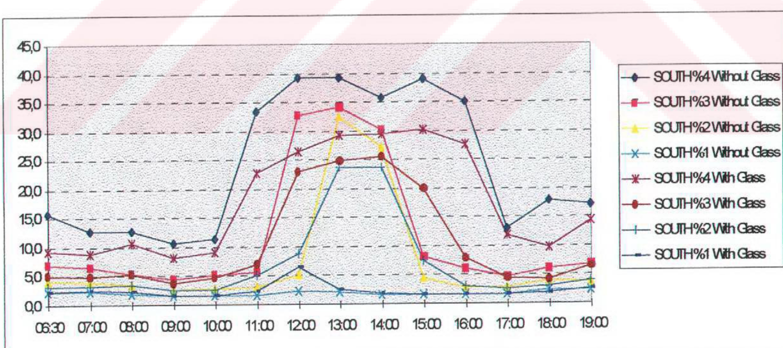


Figure 7.18: Illuminance values of all floors, in South, for grey with 75% reflectance. (With and Without glass)

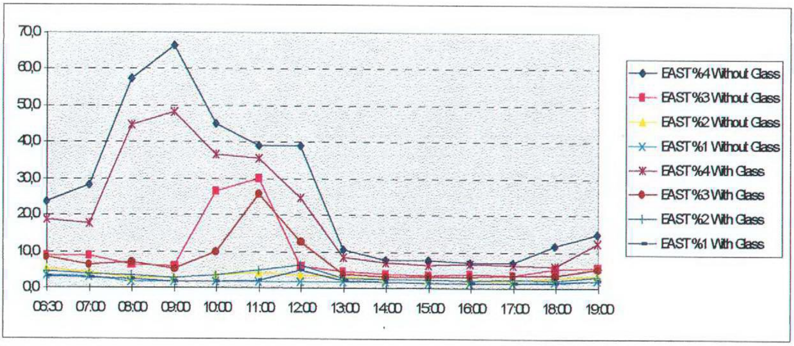


Figure 7.19: Illuminance values of all floors, in East, for grey with 75% reflectance. (With and Without glass)

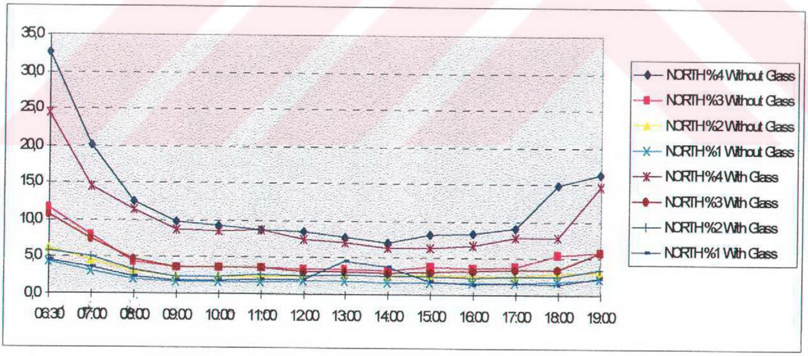


Figure 7.20: Illuminance values of all floors, in North, for grey with 75% reflectance. (With and Without glass)

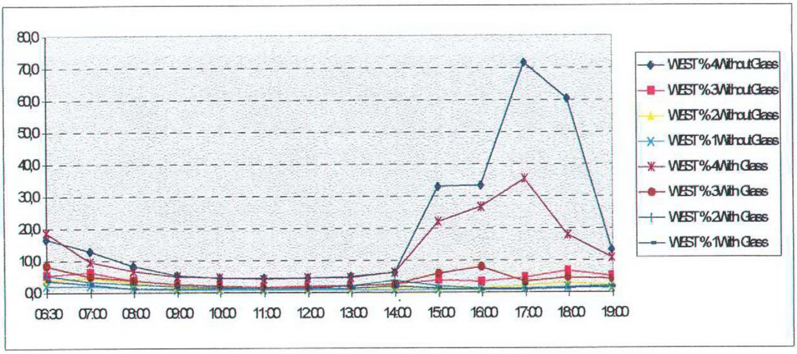


Figure 7.21: Illuminance values of all floors, in West, for grey with 50% reflectance. (With and Without glass)

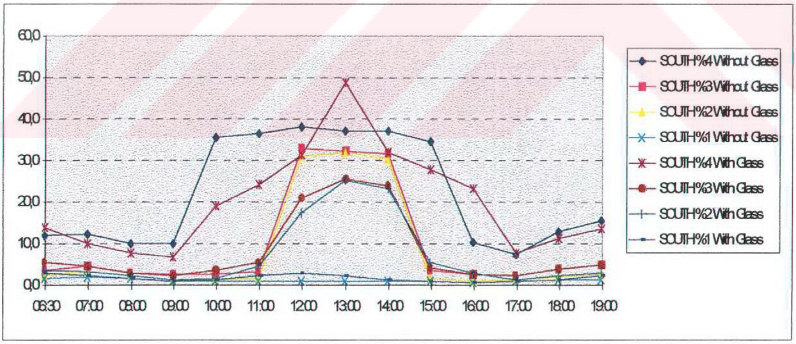


Figure 7.22: Illuminance values of all floors, in South, for grey with 50% reflectance. (With and Without glass)

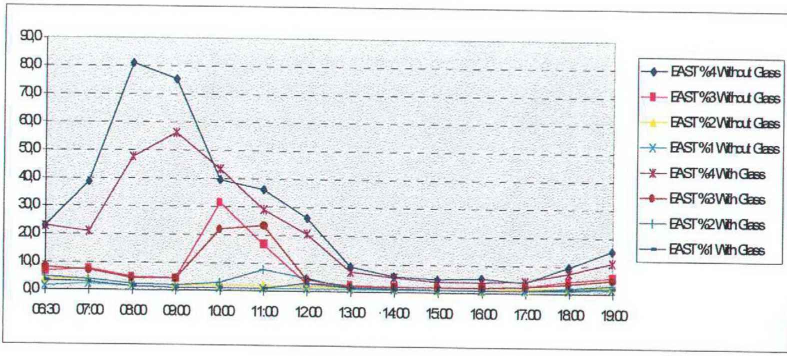


Figure 7.23: Illuminance values of all floors, in East, for grey with 50% reflectance. (With and Without glass)

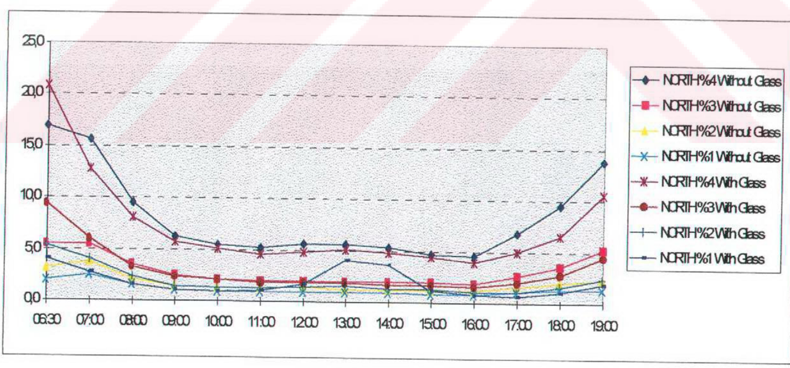


Figure 7.24: Illuminance values of all floors, in North, for grey with 50% reflectance. (With and Without glass)

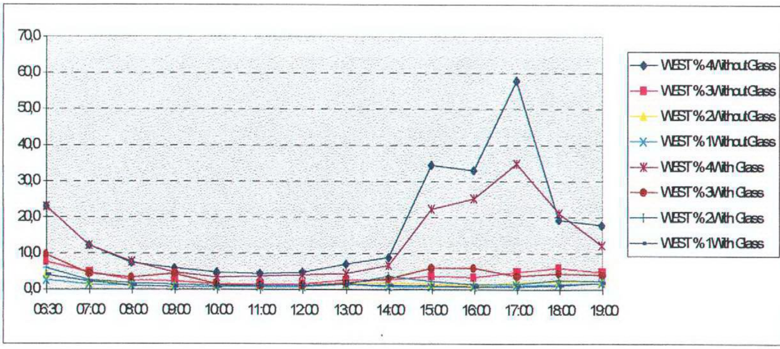


Figure 7.25: Illuminance values of all floors, in West, for grey with 25% reflectance. (With and Without glass)

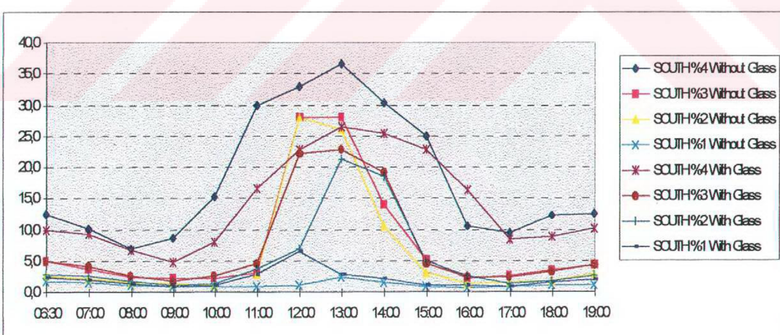


Figure 7.26: Illuminance values of all floors, in South, for grey with 25% reflectance. (With and Without glass)

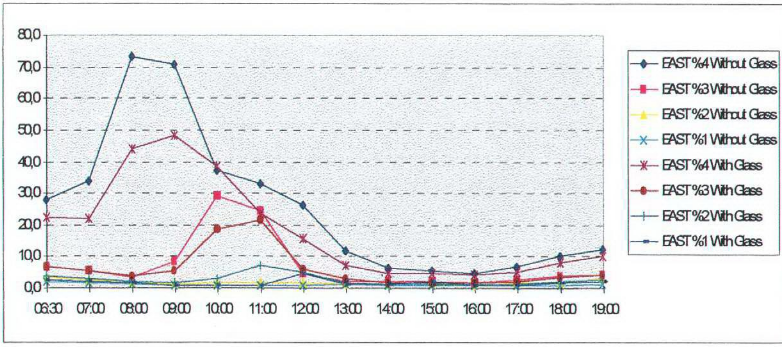


Figure 7.27: Illuminance values of all floors, in East, for grey with 25% reflectance. (With and Without glass)

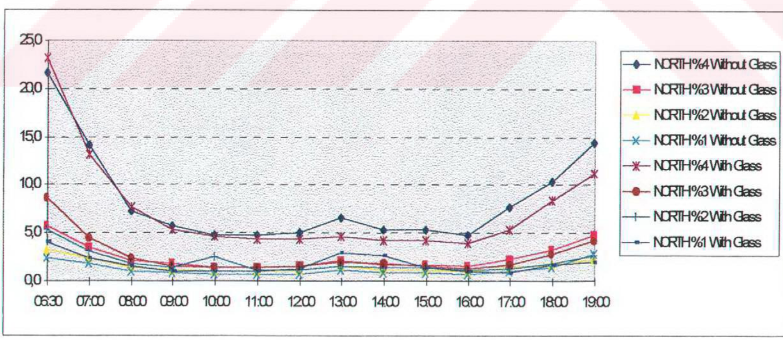


Figure 7.28: Illuminance values of all floors, in North, for grey with 25% reflectance. (With and Without glass)

7.3.1 Adjacent Spaces

The adjacent spaces were essentially single volumes on the sides, facing the atrium well. The surfaces of walls and ceilings were all white and have the reflectance of 90% relying on MgO tablet, and remained constant during the study. The floors of the adjacent spaces were changed during the study. They were changed according to the reflectance values of (greys) 25%, 50%, 75%, and the measurements were all taken for all these reflectance values.

7.3.2 Illuminance Meter

The size of the model was chosen so that the photocell could be moved easily within the scale model. The model was constructed in the scale of 1/20, and the illuminance meter's photocell were at the work plane height, that is approximately 80 cm above the floor level.

A Minolta illuminance meter T-1 was used for the study. It has the range of 0 to 99.900 lux, which is appropriate for a study that is done in clear sky conditions. Beside the illuminance meter itself, a one meter adapter cord was used in order to be able to move the photocell of the illuminance meter within the model.

7.4 Results

According to the measurements and the evaluation, which has been done, the results below were found:

Especially on the fourth floor; before noon, the west side of the atrium (see figures 7.5, 7.9, 7.13), in the afternoon, the east side of the atrium (see figures 7.5, 7.9, 7.13), had high illuminance values (both with glass and without glass), because during these periods these spaces received direct sunlight because of this fact the illuminance values are high.

It has been seen that the spaces have not been affected by the reflectance of the floor material (within the adjacent spaces) when they receive direct sunlight on the work surface(see figures 7.6, 7.10, 7.14).

The measurements showed that the illuminance level changes considerably on the top floors, in east (see figure 7.19)and west (see figure 7.17) directions of the building, beside this, in the directions of east, west and north, on the third, second and first floors, the illuminance level had a homogeneous distribution.

With higher floor surface reflectance, the illuminance values were also higher. When the surface reflectance increased, the floor bounces more light off within the adjacent space. By this way the first hypothesis is supported.

Besides this, there are other results that should be taken into account. At short distances from the well, the illumination levels in the adjacent spaces decrease significantly between two consecutive points. This is more at the lower well index (see tables 7.1-7.12). But as the distance from the atrium well increases, the difference becomes less significant. At points near the atrium well, the illuminance values are higher, since the light is projected directly from the sky and partly due to the inter-reflections within the atrium well. At lower levels contribution from the sky component is less, most of the illuminance is inter-reflection from the sides and the floor of the atrium. At the back of the adjacent spaces, the illumination totally depends on the internally reflected component.

Using the floor reflectance 75%, the changes in the illumination levels in the different floors of the atrium are significant. This shows that, as the distance from the atrium well in the adjacent space increases, supplementary lighting required.

During the evaluation, the outputs showed that there is a reduction in the illuminance values between the measurements taken with glass and without glass. In general, the values were higher in the experiments done without glass, but when we evaluate figures 7.26 and 7.28 it is seen that, the difference between the values are significant. This shows that, depending on the existence of glass, the internal reflections had occurred and these reflections caused an increase in the illuminance values. So the second hypothesis is supported according to the measurements and the evaluation.

8. Conclusion

Although the architects may understand the significance of the size and shape of atria in daylighting of adjacent spaces as reported by Cole (37), the effects of surface treatment are less well understood. The study presented in this thesis is the investigation of the effects of the use of glazing within the atrium and the effects of floor reflectance of the adjacent spaces on the daylight in adjacent spaces.

Atria may be used effectively to serve environmental benefits. Within the scope of daylighting itself, further studies can be done to understand how lighting in the adjacent spaces especially in the lower storeys of atria, are affected.

Certain guidelines can be drawn from this study:

The illumination levels in the atrium well and occupied spaces vary greatly with increase in the distance from the light source in top-lit atria. As Raniga (206) has also reported that, the lower the well index, the greater the illumination at that level, either in the atrium well or in the spaces adjacent to it.

A design solution for the adjacent spaces, which receive direct sunlight, would be to use reflective elements, such as fins and light shelves, that would reflect light to the adjacent spaces. This would eventually increase the uniformity of light distribution at the atrium.

The floor materials have great importance on the illumination of the adjacent spaces of an atrium building. To obtain equal illumination at all floors, in the adjacent spaces of the upper floors of atria, less reflective floor materials can be used, and below that floor relatively higher reflective floor materials can be used at each floor of the atrium.

The transparency of the glazing materials used on top of atrium well and on the adjacent space front as well has a great importance on the daylighting of atrium space and the adjacent spaces. So, the choice of the glazing material has a great effect on the daylighting of atria. For the glazings of adjacent spaces, different kinds of glazing materials (10%, 20%,……… and etc. transparent or reflective) can be used in each floor, as the illuminance differs according to the material chosen.

The illumination levels in the spaces adjacent to the atrium are higher at points close to the atrium well, and decrease towards the back of the adjacent spaces. If the intensity of light in the lower level is required to be high, the reflectivity of the atrium and adjacent spaces' floors should be high.

The floor and the glazing materials has a great importance on the illumination of the adjacent spaces of an atrium building.

9. Bibliography

Al-Turki, I., M. Schiler. "Predicting Natural Light in Atria and Adjacent Spaces Using Physical Models". *Solar Energy.* 59: 241-245, 1997.

Annimos, W.Y., M. Boubekri. "Daylighting Efficiency of an Atrium: Part 1- The Four-Sided Type." *Architectural Science Review.* 39: 75-81, 1996.

---. "Daylight Efficiency of an Atrium: Part 2- The Three-Sided Type." *Architectural Science Review.* 39: 83-88, 1996.

---. "Daylighting Efficiency of an Atrium: Part 3- The Four-Sided Type." *Architectural Science Review.* 39: 179-186, 1996.

Atif, M.R., L.L. Boyer, L.O. Degelman. "Development of Atrium Daylighting Prediction: From an Algorithm to a Design Tool". *Journal of Illuminating Engineering Society.* Winter: 3-12. 1995.

---. "Top Glazed Public Spaces: Amenities, Energy costs and Indoor Environment" 1994. Available: http://www.nrc.ca/irc/practice/gen3_E.html

Bednar, Michael J. *The New Atrium.* 1986. (McGraw-Hill building types series). New York: McGraw-Hill, Inc.

---. "An Analysis of Daylighting Design Factors in Atria". *Proceedings of Tenth National Passive Solar Conference.* Illuminating Engineering Society of North America. 111-114, 1986.

Boubekri, M. "The Effect of the Cover, and the Reflective Properties of a Four Sided Atrium on the Behavior of Light." *Architectural Science Review.* 38: 3-8. 1995.

Button, David, Brian, Pye. 1993. *Glass in Building: Guide to Modern Architectural Glass Performance.* Oxford: Butterworth-Heinemann Ltd.

Cole, R.J. "The Effect of the Surfaces Enclosing Atria on the Daylight in Adjacent Spaces", *Building and Environment.* 25: 37-42. 1990.

Commission of the European Communities. 1993. *Daylighting in Architecture: a European Reference Book.* London: James and James.

---. *Energy in Architecture, The European Passive Solar Handbook.* 1992. London: The Bath Press.

---. *Energy Conscious Design, A Primer For Architects.* 1992. London: B. T. Batsford Ltd.

Degelman, L.O., M.R. Atif, L.L. Boyer. "Development of Atrium Daylighting Prediction: From an Algorithm to a Design Tool." *Journal of Illuminating Engineering Society*. 1995. New York: IESNA.

Erhardt, Louis. 1985. *Views on the Visual Environment.* New York: Illuminating Engineering Society of North America.

Flynn, John F. *Architectural Interior Systems: Lighting, Acoustics, Air Conditioning.* 3rd ed. 1992. New York: Van Nostrand Reinhold.

Gotwh: Lawrence Berkeley National Laboratory. "Introduction to Daylighting Basic Concepts." 1995. Available: http://solstice.crest.org/environment/gotwh/general/lbl-daylight/html/basics.html

"Introduction to Daylight Comfort." 1995. Available: http://solstice.crest.org/environment/gotwh/general/lbl-daylight/html/comfort.html

"Footnote-6", 1996. Available: http://www.nrc.ca/irc/practice.

Fontoynont, M.R., B.A. Fluery. "Daylighting of Large Enclosures" *Proceedings of 1986 International Daylighting Conference*. American Society of Heating, Refrigerating, and Air Conditioning Engineers. 333-343. 1986.

Henderson,S.T. 1970. *Daylight and Its Spectrum.* New York: American Elseiver Publishing Company.

Hopkinson, R.G., P. Petherbridge, J. Longmore. 1966. *Daylighting.* London: Heinemann.

Illuminating Engineering Society of North America. 1984. *IES Lighting Handbook 1984 Reference Volume.* Illuminating Society of North America: New York.

---. *IESNA Recommended Practice of Daylighting.* 1979. Illuminating Society of North America: New York.

Kim, K., L.L. Boyer. "Development of Daylight Prediction Methods for Atrium Design". *Proceedings of 1986 International Daylighting Conference.* 345-359. 1986. American Society of Heating, Refrigerating, and Air Conditioning Engineers.

Lam, William M. C. 1986. *Sunlight as Formgiver for Architecture.* New York: Van Nostrand Reinhold Company.

Law, S. K. "Sinyan K. Law's Research." Available: http://www.mit.edu/people/sylaw/research.html

Lynes, J.A. 1986. *Developments in Lighting.* London: Applied Science Publishers Ltd.

---. *Principles of Natural Lighting.* 1968. Essex: Elsevier Publishing Company.

Moore, Fuller. 1985. *Concepts and Practice of Architectural Daylighting.* New York: Van Nostrand Reinhold Company.

Raniga, Usha Iyer. "Daylight in Atrium Spaces", *Architectural Science Review.* 37: 195-208. 1994.

Rassmussen. S. 1964. *Experiencing Architecture.* London: Chapman and Hall.

Robbins, Claude L. 1986. *Daylighting: Design and Analysis.* New York: Van Nostrand Reinhold Company Inc.

Rodgers, Nancy C., John A. Ballinger, Christopher Dunkerley. "An Analysis of Innovative Methods in Natural Lighting", *Architectural Science Review.* 22: 44-48. 1979.

Ruck, Nancy C. "Skylight Availability in Different Climatic Zones Using Regression Procedures", *Architectural Science Review.* 29: 31-39. 1986.

---. "The Passive Daylighting of Building Interiors". *Architectural Science Review.* 31: 87-98. 1988.

Saxon, Richard. 1986. *Atrium Buildings: Development and Design. ed. 2* Hampshire: BAS Printers Limited.

---. *The Atrium Comes of Age.* 1993. Hong Kong: Longman Group Ltd.

Schiler, M. 1992. *Simplified Design of Building Lighting.* New York: John Wiley and Sons Ltd.

Selkowitz, Stephen E., James W. Griffith "Effective Daylighting in Buildings-Revisited" *Lighting Design and Application.* 3: 34-47. 1986

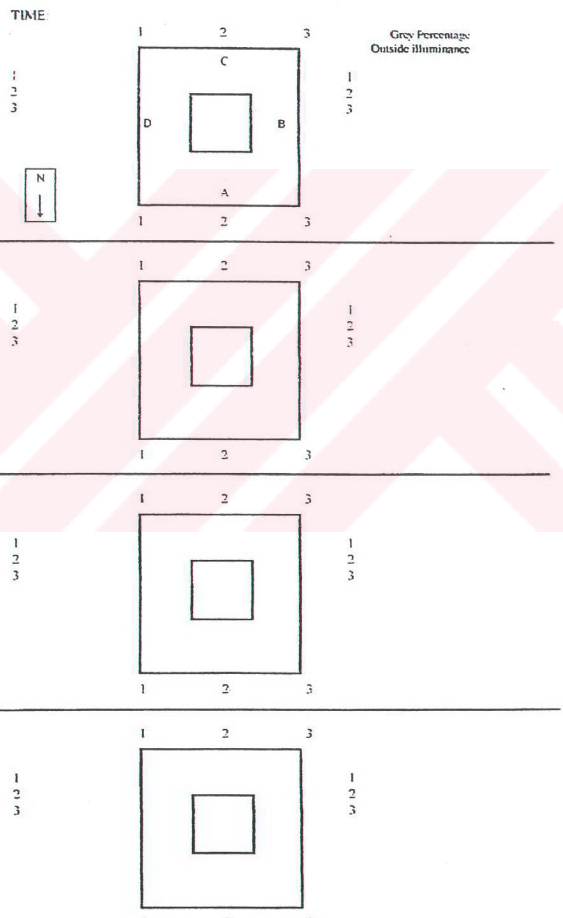
Sorcar, Prafulla C. 1987 *Architectural Lighting for Commercial Interiors.* New York: John Wiley and Sons.

Serefhanoglu, M. 1992. *Yapilarin Iç Aydinlatmasinda Gün Isigi ile Lamba Isiginin Temel Özellikleri ve Ayrimlari*. Istanbul: Y.Ü. Mimarlik Fakültesi Baski Isligi.

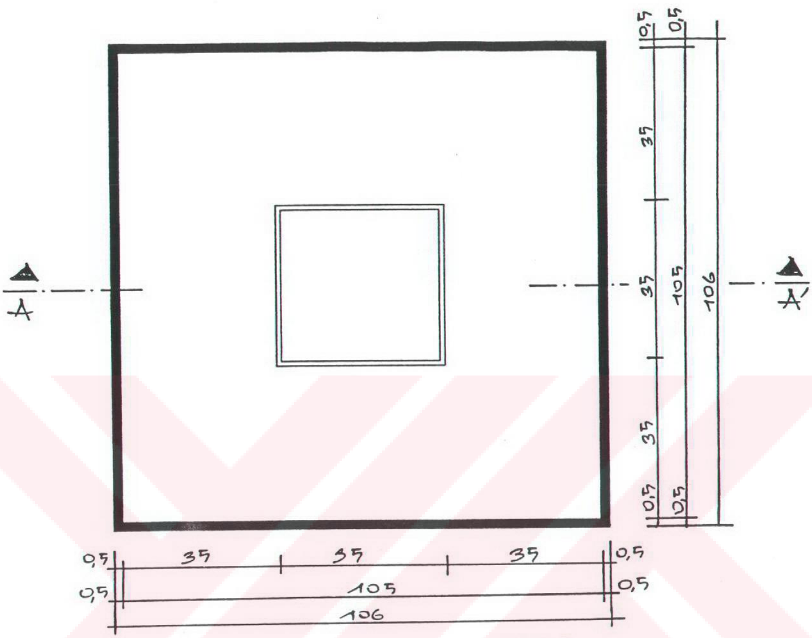
Treado, S.J., Gillette, G.L. "The Daylighting and Energy Performance of Building Atria" *Proceedings of 1986 International Daylighting Conference*. New York: American Society of Heating, Refrigerating, and Air Conditioning Engineers. 360-373. 1986.

10. Appendices

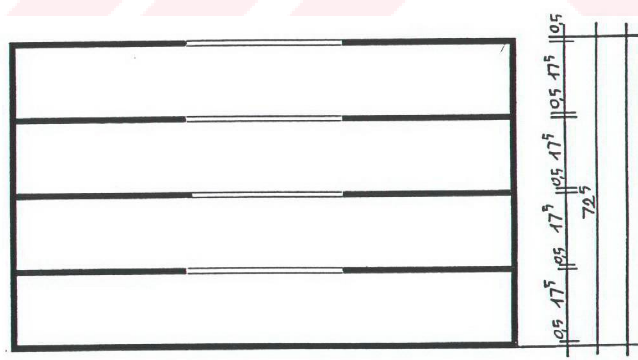
Appendix A Measurement Record Sheet



Appendix B



PLAN



SECTION A-A'
NOT TO SCALE.