SHADING DEVICE DESIGN ALTERNATIVE DECISION MAKING

by

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REPORT ABSTRACT

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This report considers some effects of Sun Shading Devices on building envelope performance including thermal control, noise control, air flow and Ventilation; with particular emphasis on daylight illumination and admission of solar radiant heat energy. Quantity of daylight admitted through three forms of shading devices were assessed and evaluated through model study relative to external daylight illuminance reference, and to daylight illumination levels inside the model. Solar radiant heat admission was evaluated on a relative basis, under direct and diffuse radiation exposures.

The influence of shading devices on alternative design decision making process is evaluated through assessment of costs associated with each alternative. Results and discussion indicates the usefulness of shading devices to control direct solar radiation along with their abilities to admit useable daylight to efficient room depths. Reduction in cooling loads and associated maintenance costs data is used as a basis for alternative comparison using Life Cycle Costing.

CHAPTER 1

INTRODUCTION

BACKGROUND KNOWLEDGE

Built environment is a mean for providing a suitable shelter for people, needed for fulfilling the requirements of comfort, both physically and psychologically. This was a real motivation for mankind to seek out the most suitable indoor environmental conditions that meet his needs satisfactorily. Having achieved that, people experimented different themes trying to pursue further development in their environment through acceptable improved environmental conditions. [1]

Human beings have always had the motivation and eagerness to improve their environment and make it more suitable for living, and that was the reason behind the success of early human beings to control the surrounding with which they were in direct contact. In recent years, air conditioning systems had been efficient solution for providing and maintaining desirable temperature by cooling indoor air to remove heat gained during summer seasons. Air conditioning systems have become capable of controlling temperature, moisture content, cleanliness, air quality as well as air circulation indoors as required by the occupants along with type of activities in the building.

Air conditioning in its wider terminology that relates to various air qualities in building raised an important controversy regarding its contribution to the conservation of natural resources. In other words, people, and scientists in particular, became aware of the fact that air conditioning systems require large amounts of energy to operate, and demand high rate of power to be delivered by power stations, which has been a major concern to energy conservation enthusiasts. Air conditioning in this context awakened specialists and energy conservation enthusiasts to the energy consumption in the cooling process. They have noticed that besides its consumption to energy in a direct way, these systems cause pollution to the environment indirectly by continuous energy demand supplied by power plants which considered to be unfriendly to the environment.

The awareness of energy conservation did in fact alert the specialists in building HVAC systems to the waste of energy in form of high energy-demanding cooling systems operating continuously to achieve an acceptable thermal comfort indoors. From economical point of view, HVAC professionals considered the factors affecting the thermal inconvenience indoors, such as the temperature build-up. As a clue, they have considered the factors and the means by which heat is gained through the building envelope toward interiors as a start for their demanding solution. Logically that was the key solution as to consider the factors causing temperature build-up indoors and excessive heat gain. Generally speaking, engineers and scientists noticed throughout their research that the

factors causing excessive heat gain indoors were external ones, in spite of the fact that internal factors could be a major contribution to overall cooling load, depending upon the type of activities undertaken in such a building. When talking about external factors we usually refer to the heat gain generated by 'Sun', which is the source of most of energy used by humans on earth. More accurately, the sun is a source of solar radiation -a short-wave high temperature energy in form of electromagnetic waves that contain visible light as a component in its spectrum. These short-wave radiation falls upon objects, whether human or building, and raise their temperature. As a consequence, these objects re-radiate the energy they have just absorbed as a long-wave radiation which raise the ambient temperature of the surrounding. [3]

In order to understand solar effects on the indoors environment, we have to consider the ways in which solar heat penetrates through our building's envelope and to give it its proper weight. On the other hand, this subject is discussed in more details in chapter 2, part of which is dedicated to the various aspect of solar radiation and heat transfer modes in relation to heat gain in buildings. Briefly, heat transfers in three different modes which are: *conduction*, *convection*, and *radiation*. Each mode describes the mechanism of transformation between two different media. The rate at which energy is transferred to or generated within a space is referred to as 'Heat Gain', which is an important terminology when talking about cooling of indoor environment. As a result, it becomes essential to

remove this heat gain at a specific rate, referred to as '*Cooling Load',* to achieve the required thermal comfort,. [4]

'Cooling Load' is an important quantity since it represents the amount of energy to be removed in order to maintain the preferred level of temperature and humidity. As this value gets larger, the amount of energy needed to cool a specific space increases, and on the other extreme, as this value becomes smaller, we will be relieved to know that a reduction in energy consumption and money saving is achieved, and that's our goal.

Up to this point we have determined our goals for minimizing energy consumption in cooling indoors to be the reduction of the 'cooling load' quantity, which is -as have been defined- a measure of heat gain characterizing the indoor environment. Heat gain is dependent upon the solar radiation received indoors, which in turn, is dependent upon other factors, such as the thermal properties of materials constituting the building structural and architectural envelope, solar angle and altitude, geometry, colors and finishing. In accordance with this fact and that we are trying to reduce the solar heat gain, the most suitable solution to accomplish this would be to search for the building elements that are responsible for the admission of solar heat. The elements we are talking about are usually fenestration elements that are in direct contact with the exterior. Walls, floors, ceiling, and glass windows are those fenestration elements of interest to us. Nevertheless, glass windows represent the weakest element of all in accordance

with the fact that typical glass is transparent to the short-wave radiation emitted by sun. [3]

For further assessment in finding out the most suitable ways to control solar radiation we have gathered the following facts which would lead us to the appropriate solution :

- Heat gains occur in such forms as solar radiation through openings, heat conduction through boundaries and radiation from inner surfaces, ventilation and infiltration, latent heat gains generated within the space, and finally, sensible heat: convection and radiation from internal objects.

- Roofs and Windows represent the major components of solar heat gains.

- Glass is a transparent material and when subjected to short-wave radiation, it transmits much of the radiation from the sun falling on its surface. Thus, it represents the weakest interface element when heat gain is concerned.

- According to the third edition of *'HVAC analysis and design'* text book, external shading of a window is effective in reducing solar heat gain to a space, and may produce reductions of up to 80 percent. [5]

Based on these facts, we may initiate our research for minimizing heat transfer into our prospected enclosed environment. Clearly straightforward, windows

comprise the main source of excessive heat gain, and for that reason we should consider the means by which we can externally shade windows. A shadow cast by trees, other buildings, or even by any structural or architectural element of the building itself may be sufficient. Conversely, these accidental and uncontrolled situations do not provide adequate shading to the windows, or at least, reject the whole solar radiation throughout the daytime. Besides, cooling loads calculations can not be based on such a variable circumstances. A mature decision to make is to study the shading requirement of a building and to design the suitable shading device that can control the solar radiation admitted by the window, along with other building performance characteristics as we will see later.

Such a thing mentioned up could be achieved by using *Shading Devices* [Fig. 1.2, 1.3, 1.4] which work as a screen eliminating direct solar radiation. In more precise words, these devices prevent direct sun rays - direct solar radiation - from being transmitted through the transparent material of the window.

STATEMENT OF THE PROBLEM

Shading devices exclude the direct component of solar radiation and filter it out so that no energy transfer, due to direct solar radiation, is taking place. They eliminate the major factor contributing to the excessive heat gain indoors. Their placement would be most probably outside glass windows in order to provide

shadow over these glazed areas, and that would be good issue for inspection in this report.

Windows are intended to provide occupants with daylight, as well as exterior views and cheerful breeze whenever the situation permits. Therefore, shading devices should be designed in accordance with certain guidelines for them not to be interfering with the building functional characteristics.

Consider for instance the natural ventilation in such a building where we intending to apply the shading devices. Windows – as openings – represent the inlet and, mostly, the outlet of air flow. With the existence of an obstruction – shading devices – the air flow inside that building would be altered and of course will influence the ventilation system. Other building characteristics that might be also influenced by the existence of shading devices is the daylight. The illumination levels received indoors is a function of openings of the building. Shading devices in their role reduce solar radiation and , consequently, daylight. Privacy, and acoustical behavior of the buildings and other building characteristics will be also discussed as they might influence by shading devices.

The decision to choose among alternative designs of a building element is very complicated and crucial to the success of project, whether investment of service is intended. This report will focus on design decision scenarios, in which two alternatives will be presented for investigation, with relative to pre-set criteria and

guidelines analysis. The case study example should be able to open a new era for solar engineering application in building, with great attention drawn to cost engineering using life cycle costing.

GOALS AND OBJECTIVES

OBJECTIVE 1 : HUMAN'S COMFORT

Buildings are intended to provide shelters for different creatures, and particularly for humans. Their role in any community might be social, symbolic, artistic, or functional. To be functionally substantial and satisfactory, the building has to be evaluated in term of indoor climatic conditions when thermal comfort, both physiologically and psychologically, is considered. Indoor thermal comfort is a measure of several factors that constitute a performance characteristic of an indoor environment. As a fact that we have discussed several factors governing the external-heat gain through building envelope and the thermal comfort indoors, you might guess that indoor thermal comfort is affected mainly by solar radiation incident upon the glazed area of a building envelope.

Nevertheless, unsolved questions, such as what makes indoors climate affected by external climatic conditions, and how is human's comfort related to climatic conditions, remain with no answers until we have this subject brought up for an insight analysis and comprehensive discussion. Along with the elements of climate and its contribution to human's comfort, the first goal to be achieved is to

address issues and principles related to the thermal environment that illustrate the interactive relation between human beings, their comfort and the climate, whether external or internal.

OBJECTIVE 2 : CONSIDERATION OF SHADING DEVICES

Our next objective will be the consideration of shading devices from functional point of view. We will clarify the way shading devices react to reduce heat gain generated by solar radiation. Further explanation to the subject of shading devices is to be given through a brief introduction of their principles and design methodology. Their impact, on the other hand, will be of a major concern as it relates to the various performance characteristics of building envelope. We will consider how shading devices influence the thermal, acoustical behavior, air flow, privacy, and daylight admission as will as glare phenomena in buildings. From a different prospective, the subject of materials, colors, and geometry development of shading devices will be discussed to draw attentions to such factors that might affect the performance of shading devices considerably, as well as improving their qualities as a building elements that must be of a great effectiveness in serving their roles.

OBJECTIVE 3 : SOLAR RADIATION ADMISSION

Sun provides daylight in form of visible electromagnetic radiation, that is sufficient to provide illumination levels required in order to carry out various visual tasks

during daytime. Shading devices, on the other hand, reduce the amount of direct and diffuse daylight admitted indoors since they obstruct sun rays and some of the sky vault that is considered to be the source of diffuse daylight. How much of daylight is exterminated because of shading devices, and to which extents the amount of daylight admitted inside relative to what is available outdoor is dependent upon the geometry and color of the shading device. For this reason, we will evaluate daylight and quantify it by taking illumination measurements indoors when shading devices of various geometry and colors are used. Moreover, the evaluation of shading devices for their contribution to thermal comfort has to be considered along with the daylight admission evaluation. Basically, this is essential in the view of the fact that daylight -sunlight- is a form of electromagnetic radiation (energy) that is a major contribute to solar radiant heat gains. We will aim to access a way to evaluate shading devices ability to reject solar radiation incident upon them, and we will try to correlate between shading device geometry and color with the amount of solar radiation admitted indoors.

OBJECTIVE 4 : DESIGN ALTERNATIVES DECISION MAKING

This objective will focus on assessing two design alternatives for an office building, in which the first alternative involves utilizing shading devices to reduce heat gain through building envelope. The second alternative will investigate cycle

costs associated with extra head load when building envelope is subject to direct solar radiation, including windows and wall section.

OBJECTIVE 5 : DRAW CONCLUSION

The final objective will be concerned with coming up with conclusions and recommendations regarding the usage of shading devices, and other facts about their behavior and performance characteristics. Attentions will be drawn to selecting the most suitable colors, along with some consideration to the geometry and materials to be used.

METHOD OF ACHIEVEMENT

LITERATURE REVIEW

The general information to be presented in this report will be the digestion of a comprehensive study and conceptual analysis of principles, concepts, and historical literature obtained from several references such as textbooks, periodicals, and technical themes and papers, along with a mature personal experience of the supervisor of this report.

THEORETICAL CONCEPTS

We mean by theoretical concepts the innovative ideas developed in form of drawings and diagrams describing some of the possible application of shading

device as to be one of the building envelop integrated elements to enhance some of the basic functions of this interface between external and internal environments.

DESIGN AND SETUP OF THE EXPERIMENT

This stage will be concerned with the models and the experiment setup for taking illumination measurements to quantify the daylight and solar radiation admitted through shading devices. This will be a fundamental step for the success of the experiment, and for which we will start with the models needed for daylight measurement. This consists of making the room prototype model, shading devices models - of various geometry and color-, and finally, making other accessories for assisting in measurement readings. The setup of this experiment, however, will be a carefully designed timetable and readings arrangement schedule since the data collecting process will take several days, during which the measurements will be taken at different times on a daily basis.

EXPERIMENTS

This is referred to as experiment implementation. The daylight and solar radiation measurement and data collecting will, as expected, take several days. We will be collecting data of daylight illuminance levels inside the model-room on both horizontal and vertical planes and under various sky conditions, and with different variables as an input such as the color of shading devices, floor color, and

moreover, through different geometry of shading devices. These readings will be taken using the photoelectric cell, a light measuring device. Daylight illuminance readings on horizontal plane will be used and converted to daylight factors, with which we will evaluate the admission of daylight through different shading devices, while illuminance readings on a vertical plane will be compared among different shading devices to evaluate solar radiation admission through different geometry of shading devices.

DATA ANALYSIS

Data analysis will be the final assignment where we will study the data collected and analyze them in accordance with the standards and recommended data published in different references. Conclusion drawn out from the model studies results will be considered with various applications, and for that we might be able to add some overall guidelines regarding the design of fenestration of buildings. This analysis is very important and considered to be the output of the whole report since it gives us a comprehensive evaluation of the shading devices from daylight and solar radiant energy heat admission point of view, along with other characteristics and facts about them.

SUMMARY CONCLUSION

The data analysis of the model studies, along with the technical consideration of shading devices in chapter 2 will be the subject of the last issue brought up in

this report. As a conclusion, we will present a set of inferential points extracted from the analysis of the data collected regarding the overall characteristics of shading devices, both from daylight and solar radiation admission point of view. Based on these facts withdrawn from our conclusion, we will try to recommend some points to take care of when using shading devices, such as their colors, geometry, and other facts about their orientation consequences, and behavior when designed as a penetration elements.

SCOPE AND LIMITATIONS

While it's essential to define the scope of this report, it is difficult to pinpoint to every task or objective to be achieved due to unexpected conditions and limitation especially in the experiment part. Nevertheless, bringing up the limitation counteracting upon our interests might be helpful in realizing the scope to which we will attenuate our elaboration. Of main concern, the time factor and the availability of measuring devices are the major limiting factors for achieving the desirable goals. Unfortunately, the time factor is a predominant element in any academic research, especially if it was experimental. However, we could coop with this fact, and limit ourselves to some pre-established limited objectives. Briefly, here are some of the limitations the are expected to tie up our objectives throughout the report:

SHADING DEVICES IMPACTS ON BUILDINGS

Some facts and new concepts developed under this topic might not have any experimental confirmation. Otherwise, some will be rationalized by evidence from literature to prove our points, while other will be justified on a logical basis. Generally speaking, most of these impact are to be considered as a theoretical models.

DAYLIGHT ILLUMINANCE READINGS:

All daylight illuminance measurements would be taken under actual sky condition, which is known to be instantaneously changing both qualitatively and quantitatively. Therefore, we expect to have some variation and inadequacy in daylight illuminance readings among different sets of collected data. A more consistence results and data would have been achieved if we could have had the opportunity to make this daylight model study under artificial sky illuminance. [Fig. 1.5, 1.6]

In accordance with the fact that we have taken the daylight illuminance readings during September, we were not able to take the internal daylight illuminance measurements for a north facing shading device under the direct solar radiation condition, as long as we know that no direct solar radiation falls upon north facing facades during September for 24° latitude on the northern hemisphere.

SOLAR RADIATION MEASUREMENT :

Actual measurements of solar radiation would be denied because of the unavailability of devices for such measurements. Accordingly, we will measure the illumination intensities and correlate these values to the solar radiation, as to be explained in appendix A.

COOLING LOAD CALCULATION

The case study presented in chapter 4 will illustrate the guidelines followed to workout the required chiller size for our building, when shading devices are used to exclude direct solar radiation from striking windows and penetrating the building envelope. However, we have used and assumed average solar intensity values for our calculation, due to lack of actual data radiation for Dhahran.

SIGNIFICANCE OF THE STUDY

Significance of the study underlies in the experimental results and obtained daylight illuminance data. These are clearly valued when we come to the experimental part in chapter 3. Generally speaking, the daylight illuminance readings can be used as a direct daylight design reference under specific conditions as to be explained in appendix A. The whole issue of investigating shading devices on the other hand, would draw attention to buildings envelope

and the way its elements react together to enhance the building envelope performance.

Data presented in chapter 4 should be a great potential for further investigations, by incorporating data outcomes in other sets of variable in order to assess actual real-life situations. Generally speaking, these calculation can assist in making decision in selecting the most economical building envelope's element, using life cycle costing with these data as input.

CHAPTER 2

SHADING DEVICES PRINCIPLES AND CONSIDERATION

CLIMATE CONTRIBUTION TO HUMAN'S COMFORT

Although the purpose of building as a shelter is to provide a safe and secured enclosed environment, having its own controlled elements of climate to achieve an internal isolated environment, nevertheless, the external climate is considered as a medium which surrounds and penetrates - by heat transfer, fenestration - through this enclosed environment. Thus, external climate is continuos with the internal one found indoors. As a matter of fact, human beings can not survive in a totally isolated artificial -man controlled- environment, and moreover, whenever we leave an artificial and overly conditioned climate and walk outside into ambient conditions that are much different we will experience the metabolic shock that cause us a lot of struggling to adopt our bodies to the current conditions, and that may lead to illness. [4,6]

The issue, therefore, is to provide and maintain balances of internal body functions which operate efficiently at certain climatic conditions, and to control external climatic factors and manipulate them to meet the acceptable comfortable environmental conditions. Before we do so, however, we have to

study the interactive relation between humans and their environment, and the way they response to climatic changes. [6]

HUMAN'S RESPONSE TO CLIMATE

The way in which human beings interact with their environment is rather complex and instantaneous at the same time. That is because humans body maintains a constant internal temperature needed to energize all reactions and processes taking place in various human systems. A continuous exchange of heat between human bodies and their surrounding take place in four physical different ways that are :

- Conduction
- Convection
- Radiation
- Evaporation Fig. 2.1

This heat exchange is dependent upon the environmental factors. In other words, human beings are strongly influenced by the climatic conditions by which they are surrounded. Their thermal comfort along with other critical processes needed for their survival is also affected by various climatic and environmental factors. Which means that human's psychological and physical comfort is associated with their surrounding climatic conditions. [6]

To measure the climatic effects on humans beings in general, however, we have to analyze the :

- Negative effects on human beings.
- Conditions in which productivity are at its highest.

and by which we can decide upon the extent to which various climatic factors can affect human comfort. In actual fact, recent studies indicated that temperature and climatic factors have a major impact on health, and some from day to day climatic changes stimulate our activities while other depress us. [1]

As far as we have talked about climate and human's response to climatic factors and conditions, we did not give decent definition of the climate itself. Thereof, next section will deal with the climatic terminology along with the elements of climate and their relation with each other and the impact they have on the thermal performance of buildings.

ELEMENTS OF THERMAL CLIMATE

Through the previous lines we have realized the direct impact the climate has on human beings, and the interaction that exists between climatic changes and human comfort. In the forthcoming paragraphs we will give a brief introduction to the factors that determine the status of climate.

When talking about elements of climate that contribute to the overall thermal comfort of an environment we might consider those elements as two categories according to their influential scale point of view. That is, we can regard the elements or factors that affect the 'Global climate' on one hand, and consider the factors which affect some local environmental condition that we call 'Microclimate' on the other hand. Sun movement, solar radiation, temperature, wind and humidity are those climatic factors affecting the global condition. On the microclimatic scale, however, sun and shade along with the temperature, wind and humidity are the only factors determining the climatic conditions in any local environment. [7]

In general, the climatic elements that are of interest when human comfort and building design are concerned, are *solar radiation*, *temperature, humidity, wind, precipitation* and *special characteristics*, such as lightning, dusts, etc. The ones of major concern of these elements is the *Solar Radiation* and *Temperature* factors which have a direct impact on human's comfort and contribute to the thermal performance of building in the first place.

SOLAR RADIATION

Our planet 'Earth' is one of the nine planets orbiting the sun. Our nearest star -the sun- is a power plant providing energy by a nuclear fusion reaction. Solar energy is the source of energy and life on earth in form of coal, wood,

gas, wind and other forms of energy utilized by human beings. The amount of energy received on earth from sun is enormous, and it's estimated that the amount of energy sun is bathing over earth each hour equals the amount of energy contained in over 21 billion tons of bituminous coal. The energy received at the outer space of earth, which is called the 'extraterrestrial' radiation, is 429 BTU/hr/sq.ft. However, what reaches the surface of the earth is around 330 BTU/hr./sq.ft. though to the reflection and absorption by air particles. This value, on the other hand, varies with the geographic location, altitude, and weather. [4]

The intensity of the solar radiation received at earth is dependent upon two factors; the atmospheric conditions (amount of dust particles, water vapor, ozone content, and atmospheric pressure), and the solar altitude. [8]

What happens actually to the solar radiation as it enters the earth atmosphere - Fig. 2.2 - could be categorized into three components of solar radiation. Portion of incoming solar radiation inside earth sphere is reflected by the surface of the clouds, and part of which is absorbed by atmospheric ingredients, such as water vapor and ozone, which constitute the first component. A certain amount of the remaining radiation is scattered by molecules in the atmosphere, but some of this is re-gained as diffuse radiation. This second component of solar radiation is altered in direction due to the reflection and scattering by water vapor molecules, dust particles,

and other air molecules. The portion of solar radiation that have been unaltered in direction is the third component of the solar radiation. [1,8]

At the earth level part of the radiation received at ground is reflected by the earth's surface, leaving the larger portion absorbed by different objects. That absorbed energy changes to heat as the objects which absorbed it re-radiate that energy as a long-wave radiation in form of heat that raises the temperature of the air, ground, and surrounding objects whether humans, vegetation, or buildings. [4]

"Heat energy cannot be lost". That was a well known principle in physics which states also that energy can be converted to another form of energy, such as electrical, chemical, or mechanical, or remains as heat. It can be converted, stored, absorbed, moved, gained, and son on. Heat flows from one place to another due to the temperature difference between two points, and its direction, according to the second law of thermodynamics, is to the cooler point or object. In other words, heat flows from hot point or objects towards the cooler one until the two objects reaches the state of equilibrium at which they would have the same temperature. [4,8]

Solar radiation is a form of energy, and thus it transforms from one state to another, move, be gained or absorbed. Its transformation from one place to

another is of interest to us. 'Heat' transfer occurs basically through three different modes:

- Conduction
- Convection
- Radiation Fig. 2.3

Conduction heat transfer occurs through direct contact between two different objects. While in *Convection* the heat transfers between two discrete places via a fluid, such as gas or liquid. *Radiation* heat transfer is somewhat similar to the convection mode except that there is no medium through which heat transfers, such as electromagnetic waves, until being absorbed or reflected. [4]

In general, heat transfer via radiation represents a major mode of heat transfer that affects our buildings. Of radiation, the Solar Radiation is the major source of heat acting upon our environment. There are four channels of radiant heat transfer affecting buildings which are:

- Direct short-wave radiation from the sun.
- Diffused short-wave radiation from the sky vault.
- Short-wave radiation reflected from surroundings.
- Long-wave radiation from heated ground. [6]

The mechanism by which heat get indoors is simply illustrated by having insight view of what happens to the short-wave high temperature energy in form of solar radiation emitted from the sun. This energy affects buildings in two ways. First, this energy enters through windows and it is absorbed by internal objects and surfaces, such as furniture, people and walls, and in turn, these objects emit long-wave or infrared, low temperature radiation to the surrounding. Second, this energy may be absorbed by outside surface of the building creating heat input, a large portion of which is conducted through the structure, and emitted to the interior. In either ways, the short-wave emission from sun enters through the glass window -which is transparent to short wave radiation- and when absorbed and re-radiated by interior objects as a long-wave radiation is trapped inside since it can not escape through glass windows toward outside. By these two effects together, we have a heat input toward inside environment which yield a high temperature build up that cause the thermal inconvenience. [6]

The fact that glass windows are opaque to long-wave radiation, and they don't allow for transmission of long-wave radiation creates the phenomena of greenhouse effect, which was a good applied physical principle that allowed agriculturists to raise their crops even in cold climates .

The thermal forces acting on the outside of a structure are combinations of radiation and convection impacts. The radiation component consists of

incident solar radiation and of radiant heat exchange with outdoor surrounding and air temperature, and may be accelerated by air motion which will be discussed in a while.

AIR TEMPERATURE AND THERMAL COMFORT

Air temperature is a climatic element that varies according to location, time and other climatic factors. The description of comfort temperature is subjectively relative and people usually can not agree upon the extent to which their environment is hot or cold. A lot of other people also argue about how cold or hot their surrounding is when talking about thermal comfort, while others do not realize the importance of temperature for human survivals. One fact is that air temperature is one of the climatic elements that have an instantaneous effect on human beings and their productivity. They can experience temperature effect instantaneously as they walkout from one place to another having different temperature reading. Air temperature influence can be observed through human's :

- Survival

- Comfort

- Performance

- Health

- Psychological , social and economic factors. [7]

By now we realize that Thermal comfort can not be measured in terms of psychological factors. Therefore, the most suitable methodology to be adopted in order to provide a thermally comfortable environment is to maintain the thermal balance between human body and the surrounding. Maintaining such balance implies keeping internal human temperature within a certain range, at which it can function efficiently and with minimum efforts and energy wasted. That can be achieved by controlling the surrounding temperature (Operative Temperature), which is a measure of both *Median Radiant Temperature* and *Ambient Air Temperature*. Human bodies experience the heat produced by the *Radiant* and *Ambient* temperature to produce what is called Sol-Air temperature, which is influenced by the outdoor air temperature, solar radiation absorbed by the body, and the long-wave radiation heat exchange with environment. [6]

Having reached the forth mentioned state of balance, we will be in a thermal comfort or what we call the Comfort Zone. In other words, arriving at conditions at which minimum expenditure of energy is needed to adjust with environment whereas most of energy is freed for productivity, we will be in a comfort zone. [1]

SHADING DEVICES IN BUILDINGS

It's obvious from our previous discussion that heat gain from solar radiation is the most important factor affecting the indoor temperature build up. This is caused by direct sunlight falling upon the glazed area of a building, which might also create a glare problem. A fact is that heat gain and glare from direct solar radiation can be controlled by preventing direct sunlight from falling upon the glazed areas of the building facade. At this stage we can say that a shading device is the tool to eliminate the incident solar radiation to provide a thermally comfortable environment while reducing the cooling load significantly. That is, shading devices reject the direct radiation and allow the diffuse component only to be admitted through in. [8]

From functional point of view, shading devices are intended to provide an adequate thermally comfortable climate, with enough lighting levels to perform various anticipated tasks while managing the utilization of daylight illumination, as well as their contribution to glare and solar heat gain control when well designed. Based on their geometry, color, and materials, shading devices reduce contrast between glazed areas and bright sky, pass breezes, filter light, allow controlled views, and cast interest playful shadow patterns that change continuously. Of these characteristics, control of solar heat gain (thermal control) constitutes the principal role of shading devices, since their effectiveness could be appreciated from thermal comfort, efficiency and economic point of view.

A good point extracted from our introduction to the solar radiation climatic element could be that solar radiation from sunlight accounts for the solar heat gain indoors. We have talked about the heat transfer from outdoor toward building interiors, and that the primer cause to such a transfer was the temperature difference between the indoors and the local environment outdoors. Nevertheless, the solar radiation is not the only factor causing the temperature buildup indoors, outside air temperature as well as the internal heat gain (light sources, human beings, and process work) also have a role in the play. Other factors could be the rate of ventilation and the relative humidity of air, but to some extent. [8]

To these facts we add that the building envelope represent the interface boundary between the interior and the external climate, and it stands for the heat gained through the roof, windows, and walls elements. Of these, windows and walls elements contribute to the major heat gain, and they must receive our focus and attention to provide them with the suitable defense against solar heat gain since they are the weakest fenestration elements. How this can be achieved is the subject of the next section.

CONTROL OF SOLAR RADIATION

So far we have talked about shading devices, their functions, the thermal comfort, and we have introduced the solar radiation and its impact on building thermal performance. Besides, we noticed that the sun is the factor determining

our thermal environment, and that the amount of solar radiation received indoor by direct penetration of sunlight through windows is usually the greatest source of solar heat gain. [8]

To overcome this problem we usually cool the indoor by using one of our sophisticated air conditioning systems available on the market nowadays. Not to mention the fact that these air conditioning system are capable not only of providing the desired air temperature, but also they provide the desirable climatic condition with the a whole set of climatic elements fully controllable. Air conditioning systems are efficient solution although it's an expensive and costly for operating. On the other hand, these air conditioning systems actually remove heat that has been gained and trapped indoors and do not reduce heat gain in the first place, in addition to the waste of energy and the pollution pumped out to the environment that they cause. [9]

In order to provide satisfaction for a building's occupants through the provision of thermally comfortable climate, we have to seek the ways in which we can reduce the impact of solar radiation that causes heat gain. To start with, we have to search for the building elements that are responsible for the admission of heat. These are usually fenestration elements which are in direct contact with the exterior. Walls, floors, ceiling and glass are the elements constituting the point through which heat transfers. Orientation of the building itself also contributes to the amount of solar heat gained. Nevertheless, the window represents the

weakest element of all since it's transparent to the short-wave radiation emitted by sun. In recent decades a lot of studies and researches were made to investigate the ways in which we can reduce the solar impact on windows, and one of these studies, reference [8], came up with the following actions to reduce the solar impact:

- Orienting the building in such a way that the facades with large openings face towards the directions which receive less sunlight.
- Using special glasses which act as heat filters.
- Using shading devices such as screens, overhangs, louver systems, blinds, etc., in front of the windows.

Another research, reference [4], came up with some guidelines which are not applicable in all situations, one of which was that the first line of action to reach a very thermally comfortable indoor climate is to shade the external, internal, and the surrounding of the structure. Doing this, we will be able to reduce the temperature build up due to ambient air and solar radiation incidence. However, this is rather an impractical solution since we can not isolate our buildings completely and shade them from the exterior and interior.

For housing and residential buildings, glass windows represents a small portion of the wall area if they were well designed and oriented to avoid excessive heat gain. In commercial and office buildings where glazing component is responsible

for 50% of the cooling load, the situation however is different. These glazed elements represent a major admission of solar radiation, and additional cooling load is acquired. In that case, the shading strategies are quiet important to the reduction of these cooling loads. [10]

Shading devices take over in this scene and play their role impressively to reduce the excessive cooling loads. As mentioned before, shading devices reject the direct solar radiation and filter it out so that no energy transfer due to direct solar radiation is taking place. In other words, shading devices, are intended to exclude the direct radiation component of the solar radiation which contributes to the major heat gain. Based on this point, it seems logical to place the shading device at the external part of the building envelope. [1]

One fact states that external arrangement of shading devices is more effective than internal arrangement, although efficiency depends also on orientation. That is because on the inner side of the building envelope, the shading device intercepts solar energy that have just passed though glass surface. It eliminates only that portion of radiant energy which can be reflected through the glass again. That is, energy is absorbed, convected and radiated into the room for an interior shading devices. And as we know about the green house effect, this solution would still yield a temperature build up indoors since the admitted energy would be trapped inside.

A second situation represents a shading device placed at the surface of the glass. At this instance, part of the energy will be reflected back at the entry layer. Part of it will be transmitted, while other part will be absorbed. This last portion which is absorbed will be convected and radiated both to the outside and into the interior of the building.

A final situation is where the shading devices are exterior ones that act as a protecting shading devices that dispose the convected and radiated portion of energy to the outdoor air since no incident energy reaches the surface of the glass. This solution seems to be the most suitable one, because having the shading device in front of the glass window will prevent any direct radiation from being transmitted through in. [1]

PRINCIPLES AND DESIGN

Although beyond the scope of this thesis, we will try to guide the reader to the principles that govern the design of shading devices along with the basic principles and considerations that should be taken into account in design to get the optimal result. The designer of a shading device should be familiar with the solar geometry, which is an essential background knowledge needed for the design. Geometry of solar movement includes the knowledge of the terrestrial latitude and longitude, the celestial sphere, zenith, nadir and horizon, celestial poles, the coordinate systems, relation between horizontal and equatorial systems, sun's apparent motion, time, equation of time local and standard time,

and most important the calculation of solar altitude and azimuth. The foregoing knowledge will qualify the designer to establish the basic geometry of the shading device based on the data values of solar altitude and azimuth. [8] Some monographs have been devoted for this particular subject concerned with the design of shading devices. Basically, ones start by obtaining the horizontal and vertical shadow angles for a specific orientation and particular month of year from a solar chart with the help of a protractor. These angles constitute the first step toward the completion of design of a shading device by projecting these angles from plane and section elevation for a window where we are interested to use shading device. The rest will be a matter of obtaining the intersection of these projected lines to form the basic geometry of the shading device.

SAMPLE DESIGN

This section includes two different shading devices that are going to be used in the daylight study conducted in chapter three. First shading device is for a north facing window, that designed to exclude all direct solar radiation throughout the year. The other shading device is for a south facing window that exclude direct solar radiation from February through to October.

North Facing Shading Device. For a north oriented shading device, figure 2.4 shows the basic geometry obtained by projecting solar

vertical and horizontal shadow angle obtained from the solar chart and protractor, Fig. 2.5. The figure also indicates the horizontal and vertical shadow angles at different times during the day. This shading device guarantees that no direct solar radiation would be admitted all around the year. The geometry is simple, and it provides a great deal of daylight since it obstructs a little portion of the sky vault.

South Facing Shading Device. The other figure. 2.6 shows a south facing shading device along with the horizontal and vertical shadow angles at different time during the day. This type of shading device excludes the solar radiation from February through to October. Based on the geometry, it's obvious that this shading device will admit less daylight compared with the shading device designed for the north facing window.

SHADING DEVICES EFFECTS ON BUILDING PERFORMANCE

The foregoing sections were mainly concerned with the shading devices from functional point of view. At that time it was not suitable to present the shading devices impact on buildings and the way they influence various characteristics of buildings envelope. Meanwhile, it's time to deal with five major impacts that shading devices have on buildings envelope performance. Thermal comfort, daylight and glare are those impacts of importance to the occupants who sense their effects instantaneously. How quiet the building is and its ability to provide

the acceptable level of privacy is also of great concern to occupants. Other characteristics affected by having an exterior obstruction outside the window - such as a shading device- is the ventilation and air flow around and inside the building itself. Each of these impact will be dealt with separately in this section.

THERMAL CONTROL

Today's technology has taken a lot of forms in which it has been displayed, and promoted for eager customers who are looking always for all new technical developments. Windows' technology has received its dole of attention in a form of larger and larger glazed areas in building facades, which have an impressive image that nobody can deny. On the other extreme, the design of very large windows are now being tempered by the realization of the environmental problems created by such large areas of glazing. The first of these environmental problems to be recognized is the excessive solar heat gain experienced by buildings having such large areas of glass with no mean of protection or shading. The problem of solar heat gain was discussed before in earlier sections, however, we want to stress that even when heat absorbing glass or any other special type of glass are used to reduce the impact of solar radiation, the result is still unsatisfactory and the efficiency is limited to some extents. [11]

In the situation using reflective glass we will encounter another type of problem, which is that these types of glass will reflect the incident sunlight away to nearby buildings and traffics, Fig. 2.7. This in turn will cause heat gain concentration on

other buildings, not to mention the glare caused by these large glazing reflecting sunlight toward pedestrian and traffic. Shading devices by their role protect typical clear glass from direct solar radiation, and hence, they eliminate the major factor causing the excessive solar heat gain in buildings. Moreover, by selecting the suitable material for shading devices to be made of, we can further reduce the impact of convected heat from air in contact with the glass windows, and by providing a mean of ventilation so that the hot air flows away. To further illustrate the impact of shading devices in providing a more thermally comfortable climate indoors, we will consider two situation in which the first represents a glass window having no external sun-protection such as a shading device, while in the other situation we will recognize what effects does shading device fixed at the exterior side of a glass window has, see Fig. 2.8.

NOISE CONTROL

The fore mentioned fact that the development in windows' technology lead to larger and larger areas of glazed facade did in fact alert us to other environmental problems as a result of using such a large glazing in buildings. As excessive solar heat gain was one of the problems of these glazed areas, the increasing traffic noise that contributes to discomfort experienced by the occupants is another problem. Typical and average cost glass used for glazing is not a good insulator for noise especially for high frequency noises. For this

reason, it becomes essential for seeking out some solutions to the noise penetration problem. [12]

Before we try establishing a solution, we have to identify the nature of noise, and the physical principles that govern its transmission. Generally speaking, noise is unwanted sound caused by a vibrating medium acting on the ear. The source of vibration could be natural or man-made. Natural vibration causing noise could be wind, water, rain, etc., while, on the other hand, man-made vibrating sources include machines, motors, traffic, etc. Physically, noise is a form of a series of compression and contraction of air particles that set the air in motion. It travels in a spherical wavefront and is usually forced to reflect, diffract, diffuse, or absorbed depending on the surface, and size of objects it is striking. One of the facts known about noise impact on human beings is that it produces both psychological and physiological effects. Working efficiency is dropped when people are exposed for sustained period to a noise level of 80 dB (dB: unit for measuring the noise level). [12]

The first solution to be thought of in order to reduce the noise transmission to the interiors would be to reduce the areas of glazing. That is based on the fact that windows component of the building skin admit most of the noise because their surface weight is much bellow that of the exterior walls that known to be opaque surfaces and good reflectors to the exterior noise. However, this solution is not desired since the purpose of having such a large glazed areas is to provide a

wide vision angle to the occupants, and admitting most of available daylight. Having shading devices fixed outside the glazed areas to control the solar heat gain, we can utilize them as an obstructing elements in the building envelope that are capable of reflecting, absorbing, and reducing the noise effect on the interior. [12]

In this prospective we have to consider the ways in which we can manipulate shading devices and develop them to accomplish our acoustical requirements. Geometry, materials, and orientation of shading devices must be considered in order to be able to control the penetration of sound waves of various frequencies. Take the orientation of shading devices for instance, the direction they are facing contributes to the solution of the problem. Fig. 2.9 shows different orientations of the same shading device. Consider the three situation and notice that the first situation represents the correct direction of the shading devices in which they act as a shelter, and protect the window from the noise waves either by reflecting the noise waves or absorbing them, if it were taken into account when selecting the shading device material. While in the other two situations the direction of shading devices magnify the penetration of noise as they act like a collectors of noise. The other three figures, 2.10, 2.11, 2.12 illustrate a practical application that utilizes shading devices as an acoustical elements in the building envelope. These figures shows noise transmission and its behavior when it meets the building envelope. In each figure there are graphical interpretation of different

noise frequency that may exist in any noise source, such a combination of low, medium, and high frequencies that can exist in the noisy sound of an air jet.

AIR MOVEMENT - VENTILATION CONTROL

Prior to the invention of air conditioning systems, people had the intuition to utilize the desirable air movement -especially in hot seasons- to cool and ventilate their homes. For that they knew how and when air movement should be activated, Fig. 2.13. They knew that in hot seasons they had to create an air flow inside their homes in order to reduce the impact of high temperature and humid air, and that they had to avoid any air movement indoors in cold seasons. From my point of view, I think that at those days people wondered what forces acted to produce the natural ventilation system they utilized. At the time being the answer is clear and simply there are two types of forces that produce natural ventilation in buildings, and can be categorized as :

- Air movement produced by pressure difference, or simply wind forces.
- Air change caused by difference in temperature. [1]

What have shading devices to do with all of this anyway!. In actual fact, shading devices produce type of forces similar to the first category. Shading devices are regarded as an obstructing elements around the windows, which produce pressure concentrations around the window and cause air to flow in an altered patterns. On the other hand, shading devices are not the only factor affecting the

air flow patterns around windows openings. Orientation as well as placement of windows are another factors by which air flow pattern is influenced. For instance, the air will flow at higher level than that of the normal level when seeping through a window on the tenth floor, while the air will flow at lower levels when it passes a window on the first floor. The two factors mentioned above do not contribute much to the air flow patterns in low buildings with respect to the shading device influence on air movement whenever they are used. For high rise buildings, however, this effect is remarkable in determining what flow pattern air will have around as well as inside the building, depending on the geometry and scale of shading devices used. [1]

Inlet attachment, such as a shading device, is an influential element as far as air movement is concerned, Fig. 2.14. Different configuration of opening along with shading devices in different locations are presented in Fig. 2.15, 2.16, 2.17. Different case is encountered in Fig. 2.18 which illustrates two situations in which we are trying to control the air flow patterns indoor to bring it down to the desirable levels.

PRIVACY

At the time when we were talking about shading devices impact on the thermal performance of buildings, we have mentioned types of glass used to provide a mean to control solar heat gain. The reflected glass type in particular is widely used to reject a percentage of incident solar radiation. During daytime, reflected

glass acts as mirrors, so no one can see through in, and thus it provides privacy for the building occupants. That is true as far as it is daytime. However, this type of glass act in the opposite way at night, where the larger amount of light will be inside the building itself. A lot of us have experienced the black hole effect in office and commercial buildings glazed with reflected type of glass during night time. We see our images on these reflected glass type instead of the exterior scene. For an observer standing outside the building, this glass would be transparent and he can see beyond the glassed facade at night whenever the light is on. Fig. 2.19

It is obvious that any type of glass can not stand by itself to provide the privacy acquired by the occupants. The privacy issue is relative and subjected to various factors such as the culture, purpose, utility and tasks performed in the building along with the time these activities take place. In our culture, the privacy is one of the main characteristics that must be one of the building's if it is to be satisfactory, especially for residence buildings. Shading devices reduce solar radiation admitted indoors in because they obstruct some of the sky vault the window exposed to. Therefore, one should expect that shading devices also reduce the view, or in other words, control it and allow for controlled vision in and out through them, Fig. 2.20. To make the subject more familiar, we might correlate between nowadays shading devices and the "Mashrabiyah" used by Islamic architects to provide a mean for privacy, reducing temperature build up, ventilation, and to add an interesting element to the facade. Shading devices

might be thought of as a developed and more sophisticated version of "Mashrabiyah", for which we might consider the addition and modification of finishing to keep the traditional characteristic of old "Mashrabiyah", along with its superior provision of privacy.

DAYLIGHT, GLARE, AND VISUAL COMFORT

Light is important for human communication since it represents the basic element in the visual sense which human beings depend upon as a mean for interaction with the surrounding environment. Sun provides visible light as a part of its electromagnetic radiation. The amount of these radiation which lies in the visible spectrum is indeed large and sufficient for all tasks and activities needed to be done indoors and outdoors.

The need for sunlight in buildings depend on climatic regions and tasks undertaken in different places. Living areas in houses need to receive a lot of sunlight to be psychologically comfortable relative to bedrooms and relaxation areas. In hot climate the sunlight is welcomed but to some extents and in certain periods. Nevertheless, it's always welcomed in cold regions and all around the year. [8]

We know that shading devices eliminate the direct solar radiation although they influence the amount of light getting inside, which is sometimes desirable in case of glare. Shading devices may reduce the illumination excessively, and that what

usually happens. However, they compensate for the daylight loss by providing a more visually and thermally comfortable environment. Well designed shading devices can provide most of the daylight incident upon them by reflecting the sunlight toward the interior, and by which they make up for lost sunlight that would have been admitted indoors. That can be achieved by providing the shading devices with louvered tops or roofs, using light colored finishing, and furthermore, developing the geometry of the shading devices as to chop off any unneeded volumes -redundancies- to eliminate any additional blockage of sunlight, as indicated in Fig. 2.21. [13]

Being visible through a window, sun's disc can cause excessive glare, and that can even happen when it produces huge contrasts upon falling on a work bench or chalkboard. There are two types of glare namely, Discomfort glare and Disability glare. The discomfort glare can be uncomfortable, and sometimes painful, however, it does not reduce ability to perform visual tasks significantly. What affect the discomfort glare is the brightness conditions within the entire field of vision. Disability glare reduces the ability to perceive visual information needed for task performance. It is influenced by object brightness. Glare problem becomes apparent in office building and very disturbing in correlation with the fact that large glazed areas permit the scene of a great deal of the bright sky from most parts of the room. This acquires human's eye a considerable effort to adjust from the brightness of the room to the higher brightness of the sky. [11,14]

The solution to all of this lies in the considerable and conceptual understanding of the variables which control the problem. Orientation of windows should be considered in relation to the times of day when sunshine is required. The effect of the direction of sunlight shall also be under consideration. Blinds or curtains behind the glass windows may be effective in reducing glare, although they may block the whole view, and still admitting solar radiant heat. Shading devices having the right material and color would increase the amount of daylight that could be reflected off them. [11]

Those was some of the impact shading devices have on the performance of buildings from different prospective. Fig. 2.22 gives a comprehensive summary of the role and impact of shading devices on building envelope performance.

CONSIDERATION OF SHADING DEVICES

We have noticed throughout the previous pages how shading devices affect the performance of building envelope though the alteration of daylight admission, besides the noise transmission and other functional characteristics of building envelope.

GEOMETRY DEVELOPMENT

The principle of thermal-solar sun control is to let sun's energy into the building during winter, and intercept it during summer when additional heat gain is

undesirable. For this reason, while designing a shading device, we have to consider that principle and give careful consideration to the shading device in relation with the fact that we need to:

- Minimize the heat gain during summer.

- Allow winter sun to come in.

- Interfere as little as possible with windows views. [15]

To illustrate how simple consideration in design of a shading device can be effective in improving some of its performance characteristics, consider for instance the south facing shading device presented in the previous section, Fig. 2.5. We might consider further development in the basic geometry to increase the daylight admission for instance. If we eliminate the roof, which is small enough to be functionally disturbing when removed, we would expect that the daylight admission will increase -as we will see in the daylight study in chapter 3, Fig. 2.23.

Another justification for eliminating the roof could be based on the fact that surface temperature of sunlit materials will be higher than that of air. Therefore, air movements over these exposed surfaces will reduce the external heat impact. In our case, this can be achieved be providing an air channel through the shading devices, such that hot air will flow up and cool the hot surfaces, windows and walls. Eliminating the roof element of the shading device would achieve this

result, and air channel could be a mean for ventilating the enclosed volumes inside the shading devices, whenever the geometry of the shading device permits. Fig. 2.24 [1]

MATERIALS AND FINISHES

The subject of selecting the suitable materials for shading devices is beyond the scope of this thesis since it's subjected to so many factors governing the structural, architectural, thermal, and visual performance of the shading devices and the building envelope itself. In this section we were intending to draw attention to the impact of materials used for making shading devices on their performance, and the contributions those materials have on the building envelope itself as we will see in a while.

Consideration of materials can be regarded from two points of view, in which the first takes into account what impact does the selected material have on shading devices with respect to their performance. In other words, material selection might affect the shading devices ability to function well, last longer, look better, cost less to maintain, and so on. In this sense, we are looking for materials that can stand for different forces acting on them such as the wind forces, and those materials which resist deterioration and last longer, and any other suitable materials that might be considered in making such an industrial piece. On the other hand, the second point is concerned with the impact that materials might have on the building itself. Based on the fact that shading devices are placed

outside glass windows at a close distance to the building surface, we shall consider the interaction between these shading devices and the building envelope especially the windows.

Nowadays technology have reached beyond many expectations, and the industrial field have received its dole of this technology. It became no more a problem to come up with new designs of any mechanical, structural, or even architectural element that could be readily converted into industrial piece. For this reason, the first point we have mentioned above represents a solved issue for which there are many experts who could help and assist in the decision making of selecting the most suitable materials. However, the designer of shading devices is the one who should decide upon the material to be selected in accordance with the second point of view. For this, an expert in building engineering should consider the selection of materials. As a matter of fact, poor choice of material might lead to excessive heat gain through building envelope. Fig. 2.25, 2.28

When impact of materials on thermal performance is concerned, we have to select the preferred absorption and emissivity of materials. What is preferred are the materials which reflect rather than absorb radiation, and readily release the absorbed quantity as thermal radiation will cause lower temperatures within the structure. Generally speaking, material and finishes for shading devices has to be considered for its emissivity, surface conductance, reflection, texture - in the

way it affects the surface conductance-, durability, easiness of maintenance and many other factors that determine the performance quality of these shading devices. Fig. 2.26 [1]

Take for instance the type of material used for finishing the surface of a shading device, whether it was a paint or a rough finishing or the structural material of the shading device. If we were to use a polished surface as a finishing, we have to consider the consequences in view with the fact that polished surfaces are glossy and cause a specular reflection of light. That might cause glare to both occupants of the building - if the inner surface of the shading device has the same finishing- and viewer outside the building. Whereas rough finishing provide diffuse reflection that is more desirable for viewer outdoors and might increase the daylight admitted through shading devices indoors if were designed to get benefit of that. Fig. 2.27

COLORS

Colors of the shading devices is very important factor affecting the daylight admission indoors as well as the quantity of solar radiation gained. It's well-known that light colors reflect incident light and dark ones absorbs them. In other words, light colored shading devices of the same geometry are expected to provide more daylight indoors, along with an increased admission of solar radiation, while dark colored shading devices will reduce the amount of daylight admitted through in and maintain a good balance of solar radiation admitted

indoors. For this reason, we have considered the color of shading devices to be one of our variable in evaluating the daylight and solar radiation admission through shading devices indoors, as we will see in chapters 3 and 4. Fig. 2.28 [1]

CHAPTER 3

PERFORMANCE EVALUATION OF SHADING DEVICES

This chapter investigates the impact of shading devices on solar radiation admitted indoors with accordance to the fact presented in chapter two that shading devices actually reduce and control solar radiant heat admitted indoors. In order to assist in determining this impact and to get a practical understanding of thermal control as an element in building design, we have designed an experiment in which heat gain will be measured when using shading devices.

CHARACTERISTICS OF SUNLIGHT

Radiant energy emitted from sun is a whole range of electromagnetic waves having different frequencies that contains light as a very small part of this spectrum. Exclusively, light has an action on the eye that result in vision, and the variation in wavelengths of this radiant energy is what gives rise to the sensation of different colors that we see. This light what our eyes detect within the visible range of the radiant energy spectrum is what we call the 'Daylight'. [11]

Daylight is different from artificial lighting in that it is dependent upon outdoor climatic conditions. In fact, daylight is variable in quantity and in color

continuously throughout the day though to the earth revolution about the sun and the sky conditions. And this is one of the things that makes daylighting design difficult and unreliable, although, on cloudy days, daylight quantity and color would remains constant. Nevertheless, "*daylight has predictable daily and seasonal variations and unpredictable patterns from cloud cover, atmospheric pollution, and other climatic variations.*" Sky condition is the most climatic factor influencing the quantity and quality of daylight received at a certain point. As the figures show, there are three basic sky conditions which are:

- Clear Sky : which produces intense, direct light from sun and diffuse light from sky.
- Partly Cloudy Sky : produces constantly changing, intense, diffuse light.
- Overcast Sky : produces diffuse light. [14], Fig. 3.1

EXPERIMENTAL ASSESSMENT SOLAR RADIATION

The purpose of this chapter - as was mentioned before- is to evaluate the daylight and solar radiation admitted through shading devices as one of their performance characteristics. To launch far beyond theoretical discussion, we designed this chapter to be a practical application that employs an experiment to participate in our assessment. We designed this experiment to study the daylight quantity and quality admitted through different shading devices with considerations to various variables in the experiment. Such imposed variables

are the shading device geometry, orientation, and color, for both shading devices and the interior floor.

TERMS AND DEFINITIONS

Since we are concerned with daylight measurements, whether we have shading devices mounted on the windows or not, we have to consider some basic terms and definitions of daylight. Some of the very important photometric concepts and units are presented in table 3.1. Of these units, lumen and lx are of great importance to us.

LUMINOUS FLUX 'F' - LUMEN

The light -previously discussed- is a from of electromagnetic radiation, and the rate of emission of any radiation of any kind including light from a source, may be measured in watts. Likewise the rate of reception of radiation on a surface may be measured in watts or in watts per square meter of area of the surface. Therefore, the lumen may be looked upon as a unit which is of the same kind as the watt. The difference between them is in their magnitudes. This is because in measuring light, as distinct from other kinds of radiation, it is necessary to take account of the way in which the human eye responds to the various colors of light. To put it in another way, the lumen can be considered as a unit of light-producing power of a light source. The rate at which light falls on one square foot of surface area

one foot from a source of one candlepower can be defined as a one lumen. [16], Fig. 3.4 (a)

ILLUMINANCE   'E' - LUX

The other very important unit in light measurement is the 'lux', which is a unit for measuring the illuminance. This concept is derived from the lumen, that is, a 'lux' is the quantity of light -or illumination level- on one square meter of surface area one meter away from the light source. In other words, the illumination of a surface is the luminance received on that surface over the area of that surface lumen/m^2. [16], Fig. 3.4 (b)

DAYLIGHT COMPONENTS

The daylight reaching a point indoors can be thought of as a sum of light beams coming from different sources. Sources are either self-illuminated, 'sun', or light-reflecting surfaces, such as the surfaces of internal and external objects which reflect back the light incident upon them. This is an important attribute of light that should be taken into the account since we are going to measure the daylight illuminance indoors at certain locations along the depth of the room. Generally, components of daylight reaching a certain point indoors are:

- direct light from the sky. (SC)

- light reflected from external surfaces. (ERC)

- light reflected and inter-reflected from internal surfaces. (IRC)

Direct light from the sky -sky component (SC)- contributes for the major part of total daylight admitted inside, especially in an unobstructed field. Externally reflected component (ERC) represents the light reflected from external surfaces, and of significance when the area under consideration is heavily built-up, or in the situation where we have sort of obstruction outside windows, as the case with shading devices. The internally reflected component (IRC) includes all the light which reaches the reference point indoors after multiple internal reflections, that is, light from sky being reflected from the floor and then from walls and ceiling. [11]. Fig. 3.5

DAYLIGHT FACTROR 'DF'

The daylight available indoors is not measured in absolute values of lux, as we might think, but as a ratio '*daylight factor*' of the total daylight available outdoors. That is, the Daylight Factor expresses the total interior illumination - the light which reaches the interior directly from the sky, by reflection from outside obstruction, and by inter-reflection from the surfaces within the room- as a percentage of that available outdoors.

The concept of daylight factor is valuable for two reasons, first of which is that human's eyes adapt readily to changes in the luminance of the sky and

hence to changes of daylight illuminance in a room, thus, the illumination indoors measured as a ratio -daylight factor- remains constant as the sky luminance changes. That is, this ratio of the interior to the exterior light is a measure which to some extent takes into account the eye adaptation effect. While the second reason is that "*daylight factor is an arithmetic convenience because it is not only a measure of the lighting which accords well enough with the visual effect on the eye, but it is also a quantity which can be expressed in terms of the size and position of the windows relative to the reference point, the reflectance of the internal and exterior surfaces, and angular obstructions of these exterior surfaces, all of which are measurable physical quantities which can be fed into an appropriate computing formula to enable the daylight factor to be calculated with the design of the building.*" [11]

EXPERIMENT SETUP

LIGHT METER (PHOTOELECTRIC CELL)

Light-meter -Fig. 3.6- is a device used for measuring both indoors and outdoors lighting illuminance. It could be used to measure brightness, reflectance, transmittance, and approximate candlepower distribution, as well as illumination levels. Most light meters are cosine-corrected and a lot of them are also color-corrected. light meters -or the photoelectric cells- are

part of a group of devices which are more commonly known as the radiation detectors. The name photoelectric implies that the electrical characteristics of the cell material are changed when radiation is incident upon its surface, and that the range of wavelengths which produce this change is in the visible spectrum. The cell is provided with suitable contacts by means of which it is connected to an external electric circuit. Radiation incident upon the cell causes a direct current to flow in that circuit and measurement of this current forms the basis of the system to measure the incident radiation. Readings measured using light meter are expressed in 'Lux'.

MODELS

The objective of this experiment is to evaluate and measure daylight admitted indoors through windows openings having shading devices fixed over them. Actually, we will not take illuminance measurements inside an actual, full-size room. That is because we can not afford building full-scale shading devices of different geometry and colors to be fixed over windows. As an alternative, we will make a prototype model of a room with opening to a scale to represent a typical room with a window. In addition, we will construct a shading device models to represent different geometry that we are intending to analyze. Scale, dimension, and various aspects of each model is listed below.

Arch. Fig. 3.7 shows an arch-shaped cardboard model. This arch was made to cast shadow over the photoelectric cell when taking measurements of diffused daylight illuminance, as well as direct daylight illuminance to make sure that no ground-reflected daylight would greatly affect our readings. It has no specific dimensions, nevertheless, you should consider the height of the arch as to be at a distance above the photoelectric cell such that reflection from the surface of the arch would not affect the readings.

Room Protoype. Model room is simply a box-shaped cardboard with one opening at its front to represent the window. Another opening was provided at the other end to be able to access the photoelectric cell inside the model. Model scale and dimensions are shown on Fig. 3.8 (a) and (b). Regarding the color of the inner surfaces of the model, all should be white corresponding to the actual color to be used in reality. Depth of the room, in model-scale, should be marked on the floor for every meter as to guide us when taking measurements of daylight illuminance at each meter-interval depth. Fig. 3.9

Shading Devices. Three sets of shading devices will be made resembling the three different types of shading devices to be used in the experiment. Each of these three sets will have the same shading device but of different color -white, gray, black. First set contains north-facing shading devices. Second set, has south-facing 'version a'

shading devices. Last set has also south-facing shading devices but 'version b'. See Fig. 2.4, 2.5, 3.10, 3.11, 3.12

Accessories. As the name implies, these are supplementary parts to the main components of the model. These include a vertical and horizontal stands for the photoelectric cell for taking daylight illuminance on vertical and horizontal plans, respectively. A small circular cardboard mounted on a wooden rod to cast shadow over the cell when taking the diffuse illuminance readings. And most important, three colored sheets -white, gray, brown- of the same size of the model floor, and marked with 1 meter intervals to be used as a model interior floor when taking the daylight illuminance inside. Fig. 3.13 shows also a black piece of clothe and a black cardboard used as a base for our model for a purpose discussed later.

READINGS ARRANGEMENT

The manner in which data will be taken is the most important element in the experiment setup that should receive careful attention whether in analysis, planing or scheduling. As far as it will be the subject of Procedure section to deal up with the methodology of obtaining illumination measurements, we will outline here the groups of data readings as considered from objective point of view, regardless of chronological order.

Global Sky Illuminance on a Horizontal Plane. Set of data taken through measurement of daylight illuminance outdoors with no obstructions. This data contains two subsets of measurements, in which the first has measurements of outdoor total -Direct and diffuse- daylight illuminance, and second subset that contains measurements of outdoor daylight illuminance with direct component being eliminated. These readings will be used as a reference for internal illuminance readings as to obtain the Daylight Factor.

Daylight Illumination Inside the Model. These sets of data are concerned with the measurements of daylight illuminance inside the model with either situations that we have shading devices mounted over the 'window opening', or with bare window. That includes illuminance readings on horizontal plan -at height of 80 cm of model- scale to represent the working task level- within the model at every meter of room depth. The set of measurements will be taken under two sky conditions, in which the first sun is facing the window elevation, where Direct and diffuse daylight is admitted into the model. While the other set is taken when sun is somewhere on the other hemisphere, where only diffuse component of daylight is reaching the window.

Daylight Illumination Behind Shading Devices (vertical plane) - Solar Radiation. In an attempt to evaluate the solar radiation admitted

through shading devices we will take vertical illuminance readings at both sides of the shading devices such that we can estimate the percentage illuminance admitted through various shading devices.

Ground-Reflected Daylight Component. Since we were involved in daylight measuring experiment, we noticed some of the facts about daylight illuminance distribution throughout different angles, along with some other characteristics of light behavior. As a result, we intended to take several measurements that give an indication to levels of light under different circumstances where light is reflected from nearby bright-colored buildings and objects. This direct to reflected illuminance ratio represents a measure through which we will consider some of those characteristics in designing building daylighting.

PROCEDURE

Procedure is as follows, taking into consideration the data arrangement outlined in the Setup section, with minor changes as to sort them by chronological order.

GLOBAL SKY ILLUMINANCE ON A HORIZONTAL PLANE

▪ Readings will begin at 9:00 am and terminate at 5:00 pm, with 15 minutes intervals.

- Take horizontal illuminance outdoors, both <u>Unshaded</u> and shaded readings, using the arch, every 15 minutes. Fig. 3.7

<u>MODEL STUDIES OF DAYLIGHT AND SOLAR RADIATION ADMISSION</u>

For simplicity, we will categorize the measurements into two main groups regardless of the chronological order of actual data measurement. Within each group there will be a number of data sets corresponding to certain shading device type or, in some instances, where there is no shading device is used. For each of the following groups, a detailed execution procedure for obtaining different measurements and data will be outlined as necessary.

- For all readings, make sure that you use a large black cardboard base for your model as to avoid excessive light reflection from ground or other lower light-colored nearby surfaces.
- In addition, use black cloth to cover the model up when taking the internal illuminance readings.
- Make sure that no sunlight get through the boundaries of the shading device. For that use any type of sealant to seal out the glued edges of the model shading device. Fig. 3.14

  <u>South Orientation</u>
  - Orient the model such that the window elevation is facing toward south. You can make use of a compass to get the right direction.

- Again, use black cloth to cover the model tightly before taking each reading.

- Follow up the points outlined under measurements.

- The sets of measurements will be taken twice, one when the sun is facing window's elevation, and the other sets will be taken when no sun is facing that elevation, where only the diffuse component of daylight is acting upon the window. see Fig. 3.15

- Notice the parentheses (Un-shaded / shaded) in some points under measurements which means that readings of illuminance will be always taken 'Un-shading' the cell, and that illuminance readings when the photoelectric cell is 'shaded' will be taken only in situation when sun is facing window's elevation.

- The measurements will be taken for each of the following situations, with regard to the type of shading device mounted over the opening :

1. <u>No</u> shading device

   Take measurements for an unobstruced windows openening. Fig. 3.16

2. shading device 'South a'

   Take measurement using south-facing shading dievice type 'a'. Fig. 3.17

3. shading device 'South b'

   Take measurement using south-facing shading dievice type 'b'. Fig. 3.18

<u>measurements:</u>

- record date and time of each measurement on the data sheet.

- take horinzontal illuminance outdoors. (<u>Unshaded</u> / shaded)

- take horizontal illuminance inside model at each 'model-scale' meter across the depth of the room.

- repeat these two setps for each floor color. (white, gray, brown)

- repeat setps 1 through 3 for each color of shading device. (white, gray, black)

- measure the vertical illuminance outdoors. (<u>Unshaded</u> / shaded)

- measure the vertical illuminance across the center of window behind shading device.

Note : measurement in step 5 is not required for readings of case '1', where there is No shading device.

<u>North Orientation</u>

- Orient the model such that the window elevation is facing toward north. You can make use of a compass to get the right direction.

- Again, use black cloth to cover the model tightly before taking each reading.

- Follow up the points outlined under measurements.

- The sets of measurements will be taken once this time according to the fact that sun will not face the window elevation on September, the time when the measurements were taken, which implies that only the diffuse component of daylight will be measured this time. see Fig. 3.15

- The measurements will be taken for each of the following situations, with regard to the type of shading device mounted over the opening :

  1. No shading device

     Take measurements for an unobstruced windows openening. Fig. 3.16

  2. shading device 'North'

     Take measurement using north-facing shading dievice. Fig. 3.19

<u>measurements:</u>

- record date and time of each measurement on the data sheet.

- take horizontal illuminance outdoors. (shaded only)

- take horizontal illuminance inside model at each 'model-scale' meter across the depth of the room.

- repeat these two steps for each floor color. (white, gray, brown)

- repeat steps 1 through 3 for each color of shading device. (white, gray, black)

- measure the vertical illuminance outdoors. (shaded only)

- measure the vertical illuminance across the center of window behind shading device.

Note : measurement in step 5 is not required for readings of case '1', where there is No shading device.

EVALUATION OF GROUND-REFLECTED DAYLIGHT

Readings of the model - Fig. 3.20 diagram A

- Lay down the black cardboard, used previously in daylight measurements, and put the model above it.

- Take horizontal and vertical daylight illuminance readings in front of the model.

- Take two horizontal readings, one with the photoelectric cell upwards facing the sky, and other reading with the cell downwards facing the ground.

- Take one vertical reading with cell facing away from the model.

- Remove the black cardboard and repeat the measurement.

- Record down your data on a sketch showing the results.

Readings of a high-rise building - Fig. 3.20 diagram b

- Chose high rise building - we have chosen building # 5 on the campus for convenience- for taking some horizontal daylight illuminance.

- Draw a sketch plan of the building to record the obtained data near each location on the drawing.

- At the building roof, and for each of the four sides take daylight illuminance readings beyond the parapet height, as in the following steps.

- Take two horizontal readings, one with the photoelectric cell upwards facing the sky, and other reading with the cell downwards facing the ground.

- Take one vertical reading with cell facing away from the building.

EXPERIMENT OUTPUT - Raw Data

This section contains the data obtained by measuring daylight illuminance as was illustrated in the previous section. The data obtained, as categorized in 3.2, as follows:

GLOBAL SKY ILLUMINANCE ON A HORIZONTAL PLANE

Table 3.2 shows external reference daylight illuminance readings for both diffuse and global (D+d) sky condition, along with the time at which measurements were

taken. These illuminance readings is discussed in chapter 4, where the importance of these readings are clearly stated.

MODELS STUDIES OF DAYLIGHT AND SOLAR RADIATION ADMISSION

Tables 3.3 through 3.5 show the resultant data of the model study readings. Each table contains some daylight illuminance data regarding specific types of shading devices, and contains the actual daylight illuminance readings measured in the model along with the external reference daylight illuminance, external reference solar radiation on the vertical plane, the total solar radiation admitted by shading devices onto the vertical plane outside windows glass, and the time at which the measurements were taken. These three tables are considered to be the raw data for our analysis in the next chapter were these three tables are developed further into a number of tables and charts containing useful information to be our subject of analysis and discussion.

EVALUATION OF GROUND-REFLECTED DAYLIGHT

Table 3.6 contains two tabulation data of daylight illuminance readings on a horizontal and vertical plane as illustrated in the Fig. 3.20. These readings are very important for our discussion of the subject of daylight being reflected from the ground by comparing the ratio reflected - direct daylight admitted indoors. That and more discussion of daylight reflection and components will be dealt with in chapter 4.

CHAPTER 4

SHADING DEVICES IMPACT ON DESIGN ALTERNATIVE DECISION

Case Study: Office Building

This chapter illustrates how shading devices can influence the design decision of different subsystem of the building, including mechanical and lighting system. We will present a case study involving the design of mechanical system – HVAC of an office building. The calculation of cooling load will illustrate the impact of shading device on chiller size and ducts. Furthermore, using Life Cycle Costing design will be able to make a decision on whether to incorporate shading devices in his building or not.

The object of our study is a typical office building that represents a great potential improvement in investment decision. Such office building usually take a simple form of architectural design, one characteristic which will make our analysis straight forward.

Typical floor of this building is shown in Figure 4-1 Building Plan. The floor is divided into number of zones to reflect the various heat loads acting on each area of the floor. Our case study involves two design alternatives concerning the

building envelop, which affect the performance of building interior accordingly. The basic design alternatives are using Sun Shading devises, which are designed in accordance with the guidelines presented in chapter 2, or not. Figure 4-2 and figure 4-3 are typical building elevations showing the modular shading devices, shown in figure 4-4, figure 4-5, figure 4-6, figure 4-7, which shows more detailed drawings of basic geometry of these shading devices.

Input Data

Now we are going to calculate and represent some useful characteristics and properties of materials forming the building envelop presented in previous section. The main output of this section is to come up with composite section thermal values needed for our calculation. Namely, 'U' values will be calculated for composite sections, and other will be obtained from material reference tables. The values used hereby are obtained from "*Solar Radiation Control in Building*".

$$\text{"U"} = \frac{1}{\text{Total Resistance} (R)}$$

Total Resistance (R_{total}) = $R_{internal\,f.}$ + $R_{material\,1}$ + $R_{material\,2}$ + ……. + $R_{external\,f.}$

$$R = d \times \frac{1}{k}$$

Refer to the drawings of building section to follow up with the calculations of 'U' values for different materials, and refer to appendix C for detailed calculations.

DESIGN ALTERNATIVE EVALUATION

This section will utilize the obtained 'U' values in previous section to calculate cooling load on different zones of the office building in both cases, when shading devices are used and when building facade is exposed to direct sun light. In order to develop realistic assessment of the actual situation, we have to include different internal heat generating source and heat transfer through building envelop. Generally speaking, cooling loads are considered *Internal* and *External*, as explained next.

INTERNAL COOLING LOADS

The internal cooling load represents the internal heat build up due to different internally generating heat object. These included:

- People.
- Lights.
- Equipment.
- External hot air coming inside as a mean for ventilation.

PEOPLE COOLING LOAD

The heat load contributed to the people occupying the building is estimated to be: 110 watts/person.

Cooling Load due to people : $Q_p = 110 \ \frac{watts}{persons} \ x \ A_z \ m2 \ x \ \frac{1 \, person}{10 \, m^2}$

where, Q_p : cooling load in watts per zone area.

A_z : Area of the zone under consideration.

LIGHT COOLING LOAD

Lights load is calculated based on a factor multiplied by the area under consideration. This factor is usually taken as :

$f = 20 \dfrac{watts}{m^2}$ thus,

$Q_L = 20 \dfrac{watts}{m^2} \times A_z \, m^2$

EQUIPMENT COOLING LOAD

The heat gain due to the different equipment used are estimated
to be around 3.7 Kw/floor , that is :
average value = 3.7 Kw/floor.

VENTILATION COOLING LOAD

As it is necessary to allow for fresh, clean air to get inside buildings, extra cooling load is required as a result of the heat gain acquired by the outdoor air admitted inside as a mean of ventilation. It's estimated that 10% volume of fresh air should be let inside of the total volume to be ventilated. It is calculated in the following manner:

$m_i = q + m_a \, i_2 + m_w \, i_{wc}$

$m_a \, w_1 = m_w + m_a \, w_2$

$q = m_a \, (i_1 - i_2) - m_a \, (w_1 - w_2) \, i_w$

For the following temperatures and humidity, the values of i's and w's are obtained form psychrometric charts

$T_o = 104°F$	H = 54%
$T_i = 58°$ F	H = 65%

$i_1 = 54$	$w_1 = 0.0255$
$i_2 = 26.5$	$w_2 = 0.0085$

$$m_a = \frac{0.1V_z}{14.8}$$

$$q = m_a[\ (i_1 - i_2) - (w_1 - w^2)\ i^w\ ]$$

usually, the second term inside the bracket is insignificant.

$$q = m_a[\ (54 - 26.5) - (0.0255 - 0.0085)\ 28.08\ ]$$

$$q = m_a\ (27.5)\ \frac{Btu}{hr}\ = 8.06\ m_a\ \frac{watts}{hr}$$

Refer to Appendix D for Internal Cooling Loads Calculation for our case study.

EXTERNAL COOLING LOADS

The external heat load represents the heat penetrating into the building as a result of solar radiation. In general, we consider the heat coming through two main components of the building facade:

- WINDOWS

- WALLS

- ROOF

  (not applicable for a typical floor)

WINDOWS

These elements of any building are responsible for the major heat gains compared to other elements, because the glass material allow for both heat transmission and conductance. Instantaneous heat gain through glass may be divided into two principal components:

- Conducted Heat

- Instantaneously Transmitted Heat

CONDUCTED HEAT

This conducted heat is due to the difference in temperature between the outside air and the inside air. It is to be calculated as follows:

q_c = "U" x Area x Δt

= "U" x Area x (T_O - T_i)

;where   'U' = air-to-air thermal transmittance of the glass surface.

Area = total area of glass surface

T_O = outside air temperature

T_i = inside air temperature = 23°C

We usually calculate the conducted heat for one module, and then multiply this quantity by the length of the area under consideration. A common module is 1.2m since it represents the width of one window.

q_c = *some quantity* watts /module.

INSTANTANEOUSLY TRANSMITTED HEAT

This component of heat is due to the incidence of direct and diffuse solar radiation. To calculate the transmitted heat, simply plug in the numbers in the following formula:

$q_t = (I_D A_s \tau_1 + I_d A \tau_2)$

where I_D = intensity of direct solar radiation normal to the glass surface.

I_d = intensity of diffuse solar radiation on the glass surface.

A_S = area of glass under direct sunlight.

A = total area of glass.

τ_1 = transmissivitty of glass for direct solar radiation.

τ_2 = transmissivitty of glass for diffuse solar radiation.(the value of τ_2 is usually taken as equal to the value of τ_1 at 58°. that is equal to 0.70)

These values can be obtained from any textbook or reference having tables of thermal properties of materials. The values used in this report will be obtained from the "Solar Radiation Control in Building" textbook.

Since we are using sunscreens for shading windows, we will assume that no direct radiation will fall on the glass surface. As a result, transmitted heat equation becomes:

$$q_t = I_d A \tau_2$$

Total solar heat gains through glass area will eventually become the sum of its two components, that is :

Total Solar Heat Gains Through Glass Window= q_c +q_t

WALLS

In general, the heat gain through opaque sunlit surfaces, such as walls, can't be determined simply by multiplying the air-to-air temperature by the transmittance of the element. If we do so, we will be ignoring the amount of solar radiation absorbed by the element. To account for this fact, we use the sol-air temperature, which is higher temperature used to account for solar radiation being absorbed by the structure.

$$T_{s\text{-}a} = T_o + \frac{Ia}{f_o}$$

T_o = outside air temperature.

$T_{s\text{-}a}$ = sol-air temperature.

I = intensity of solar radiation (direct + diffuse) normal to the surface.

a = absorptivity of the surface.

f_o = outer surface conductance.

This $T_{s\text{-}a}$ is then substituted for T_o 'outside temperature' in the following equation:

q_c = "U" x Area x (T_{s-a} - T_i)

;where   'U' = air-to-air thermal transmittance of the glass surface.

Area = area of element

T_{s-a} = sol-air temperature

T_i = inside air temperature = 23°C

Refer to Appendix E for External Cooling Load Calculations.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

SUMMARY

Throughout this report we were mainly concerned with shading devices as one of the building envelope components enrolled in enhancing some basic functional characteristics of building envelope. As a start we reviewed monographs of solar geometry, design for climate, and daylight illumination and browsed several journals concerned with building and environment. Based on information and data gathered throughout our literature review we have established a methodology in which we were able to evaluate some effects of shading devices on building envelope performance, starting by investigating shading devices impact on thermal comfort indoors by applying different mathematical models. Fortunately, most of these models did not work probably because no specific model had the flexibility for considering various geometry of shading devices, and therefore, we had to study shading devices effects experimentally, which came to be a remarkable event at a later stage. Before then, we investigated other impacts of shading devices theoretically.

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At that stage we went forward to theoretical consideration of shading devices in form of new concepts and ideas developed to utilize shading devices in certain ways. We have considered noise transmission through glass windows, and based on our background knowledge though literature review, we proposed some solution to noise control through drawings and diagrams that illustrate the ways in which shading devices could be utilized to provide noise control. We came across the ventilation and privacy issues in buildings in conjunction with shading device utilization to achieve more desirable air flow patterns and maintain privacy as a characteristic of building. Of a major concern, daylight and solar radiation admission through shading devices were considered in more details and were evaluated through experimental assessment considering different geometry and colors, and under various sky conditions. The data collected were considered to be a direct reference for daylight design in Dhahran and under certain conditions.

CONCLUSIONS

As an output to our literature review, along with the developed theoretical concepts and the experimental model studies, the following have been proven in accordance with the conditions described throughout this thesis :

- Buildings are intended for providing shelters for human beings, animals, plants, and other creatures. Building envelopes represent the interface between the external and internal environments, and this interface should control heat gain, daylight, view, noise transmission and ventilation.

- Shading devices are considered to be one of the building envelope components that should protect occupants from direct solar radiation and enable admitted daylight to be used by controlling glare, in addition to their contribution to cooling loads minimization.

- Shading devices affect building envelope performance, and particularly daylight and solar radiation admission.

- For certain types of buildings that depends on natural ventilation, shading devices have some solution to undesirable air flow patterns for which shading devices of different configurations could be used to alter the air flow patterns to bring it to the desirable levels.

- Having its basic form, shading devices provide privacy for occupants with no need to use internal blinds or curtains that might block the whole view. Further development in shading device form and material can offer us prototypes of our Islamic styled "Mashrabiyah".

- Selecting the most suitable colors and material of shading devices will give us the opportunity to control glare over large glazed areas of an office building for instance. In other words, shading devices when correctly utilized will provide the acquired visual comfort by building occupants.

- The optimum orientation for windows is north where; maximum daylight illumination through shading devices can be achieved, and shading devices can be designed to exclude all direct solar radiation from windows for the entire year.

- A combination of shading devices and clear type of glass provides admission of daylight through the clear glass more than any other special type of glass, and protection for the window glass from any direct solar radiation that might cause excessive solar heat gain.

- Removing redundancy from shading devices achieves more admission of daylight and increased admission of solar radiation, thus value judgment should be made with regard to this fact.

- Shading devices provide better thermal control over some special types of glass by providing lower shading coefficients that have been found to be more efficient than ones achievable using any special type of glass. And daylight

admitted through clear glass used with shading devices is much more than the quantity of daylight admitted through special type of glass.

- Shading devices of bright colors such as white admit more daylight than dark colored shading device. While bright colored shading devices admit more solar radiation than gray or black shading devices.

- Gray shading devices have lower contrast to the sky within an occupant's cone of vision, and they reflect less glaring light than a white shading device. Black shading devices, on the other hand, have high contrast between its black color and the sky. Therefore, gray shading device were found to give better glare control over either the white or black shading device.

- Floor color has no effect on daylight admission in the perimeter zone near the window, while shading device color control the amount of daylight admission near the window.

RECOMMENDATIONS

As a final statement, I would like to recommend come points and give some guidelines for researchers who might be interested in further investigation in this topic. Here are some recommendation for future researches :

- Daylight studies should be conducted under artificial sky illuminance, which will provide constant illumination conditions throughout the experiment, and will save you big climatic difficulties that would most probably face you.

- Solar radiation readings should be taken using a 'radiometer' instead of the photometer that we have used, as discussed before.

- In our daylight studies, we have considered only limited number of variables such as shading device geometry, color, and floor color. While in practical life these represents few variables of the factors that contribute to the performance of these shading devices. Ones might consider the following variables when investigating shading devices :

  - Other geometry for certain orientations.
  - Different colors and finished of the shading devices.
  - Different area of grid of windows, and that would probably affect the quantity of daylight admitted indoors.
  - Using more than one row of shading devices at the same time, in order to investigate the effect of reflected daylight from other shading devices.

APPENDIX A

TABLES

APPENDIX B

FIGURES

APPENDIX C

CASE STUDY 'U' VALUE CALCULATION

SECTION A-A (Section through main beam; north and south elevations)

A-PORTION (slab)

1.Portion Components

1. 100mm Pre-Cast Concrete Panel
2. 50mm Air Cavity
3. xx mm Concrete Slab

   where xx represent a large number such that the effect of solar radiation is neglected.

2.Calculation of 'U' value

Since this portion of the section contains the floor slab with xx length, the 'U' value for this portion is taken to be zero.

$U_A = 0$

B-PORTION (main beam)

1.Portion Components

1. 100mm Pre-Cast Concrete Panel
2. 50mm Air Cavity
3. 400 mm Concrete Beam

2.Calculation of 'U' value:

a. north elevation:

$R_{total} = R_{internal\ f.} + R_{conc.\ beam} + R_{air\ cavity} + R_{precast\ panel} + R_{external\ f.}$

$$= \frac{1}{8.4} + \frac{0.4}{1.4} + \frac{1}{5.5} + \frac{0.1}{1.4} + \frac{1}{13.5} = 0.732 \text{ m}^2 \text{ °C/W}$$

$U_{B\ North} = \dfrac{1}{0.732} = 1.366 \text{ W/m}^2 \text{ °C}$

b. south elevation:

$R_{total} = R_{internal\ f.} + R_{conc.\ beam} + R_{air\ cavity} + R_{precast\ panel} + R_{external\ f.}$

$$= \frac{1}{8.4} + \frac{0.4}{1.4} + \frac{1}{5.5} + \frac{0.1}{1.4} + \frac{1}{10} = 0.758 \text{ m}^2 \text{ °C/W}$$

$U_{B\ South} = \dfrac{1}{0.758} = 1.319 \text{ W/m}^2 \text{ °C}$

3.Lag Time:

lag time for this portion is 15.5 hours.

C-PORTION (above window)

1.Portion Components:

1. 100mm Pre-Cast Concrete Panel
2. 50mm Air Cavity
3. 100 mm Bulk Insulation

2.Calculation of 'U' value:

a. north elevation:

$R_{total} = R_{internal\ f.} + R_{insulation} + R_{air\ cavity} + R_{precast\ panel} + R_{external\ f.}$

$$= \frac{1}{8.4} + \frac{0.1}{0.056} + \frac{1}{5.5} + \frac{0.1}{1.4} + \frac{1}{13.5} = 2.232\ m^2\ ^{\circ}C/W$$

$U_{C\ North} = \dfrac{1}{2.232} = 0.448\ W/m^2\ ^{\circ}C$

b. south elevation:

$R_{total} = R_{internal\ f.} + R_{insulation} + R_{air\ cavity} + R_{precast\ panel} + R_{external\ f.}$

$$= \frac{1}{8.4} + \frac{0.1}{0.056} + \frac{1}{5.5} + \frac{0.1}{1.4} + \frac{1}{10} = 2.258\ m^2\ ^{\circ}C/W$$

$U_{C\ South} = \dfrac{1}{2.258} = 0.443\ W/m^2\ ^{\circ}C$

3.Lag Time:

lag time for this portion is 3 hours.

W-PORTION (glass window)

1.Portion Components:

1. Single Glazing Clear Glass

2. 'U' value:

'U' = 6 W/m2 $^{\circ}$C
3.Lag Time:

lag time for this portion is 0. instantaneously transmitted heat

D-PORTION (below window)

1.Portion Components:

1. 100mm Pre-Cast Concrete Panel
2. 50mm Air Cavity
3. 100 mm Bulk Insulation
4. 200 mm Concrete Blocks

2.Calculation of 'U' value:

a. north elevation:

$R_{total} = R_{internal\,f.} + R_{blockwall} + R_{insulation} + R_{air\,cavity} + R_{precast\,panel} + R_{external\,f.}$

$$= \frac{1}{8.4} + \frac{0.2}{1.4} + \frac{0.1}{0.056} + \frac{1}{5.5} + \frac{0.1}{1.4} + \frac{1}{13.5} = 2.374 \text{ m}^2 \,{}^\circ\text{C/W}$$

$U_{D\,North} = \dfrac{1}{2.374} = 0.421 \text{ W/m}^2 \,{}^\circ\text{C}$

b. south elevation:

$R_{total} = R_{internal\,f.} + R_{blockwall} + R_{insulation} + R_{air\,cavity} + R_{precast\,panel} + R_{external\,f.}$

$$= \frac{1}{8.4} + \frac{0.2}{1.4} + \frac{0.1}{0.056} + \frac{1}{5.5} + \frac{0.1}{1.4} + \frac{1}{10} = 2.400 \text{ m}^2 \,{}^\circ\text{C/W}$$

$U_{D\,South} = \dfrac{1}{2.400} = 0.417 \text{ W/m2} \,{}^\circ\text{C}$

3.Lag Time:

lag time for this portion is 10 hours.

I. SECTION B-B (Section through secondary beam; east and west elevations)

By the examination of the section through one of these elevations, one find out that the only portion that makes a difference in the calculation is the width of the secondary beam, that's, we have to calculate the 'U' value for the secondary beam section. Otherwise, use the previously obtained values for 'U', for South Elevation, since the conductance of the external surface is the same for this particular elevation.

B-PORTION (secondary beam)

1.Portion Components:

1. 100mm Pre-Cast Concrete Panel
2. 50mm Air Cavity
3. 300 mm Concrete Beam

2.Calculation of 'U' value:

$R_{total} = R_{internal\,f.} + R_{conc.\,beam} + R_{air\,cavity} + R_{precast\,panel} + R_{external\,f.}$

$$= \frac{1}{8.4} + \frac{0.3}{1.4} + \frac{1}{5.5} + \frac{0.1}{1.4} + \frac{1}{10} = 0.687 \text{ m}^2 \,{}^\circ\text{C/W}$$

$U_{B\,North} = \dfrac{1}{0.687} = 1.456 \text{ W/m}^2 \,{}^\circ\text{C}$

3.Lag Time:

lag time for this portion is 14 hours.

APPENDIX D

INTERNAL COOLING LOAD CALCULATIONS

INTERNAL ZONES (5-6-7-8)

AREA OF EACH ZONE IS : 340.2 M2

People Load

$$Q_p = 110 \frac{watts}{persons} \times 340.2 \text{ m}^2 \times \frac{1 \text{ person}}{10 \text{ m2}} = 3.742 \text{ kw/h}$$

Light Cooling Load

$$QL = 20 \frac{watts}{m^2} \times 340.2 \text{ m2} = 6.804 \text{ kw/h}$$

Equipment Cooling Load

average = 3.7 kw/floor

$$\text{ratio of zone to floor area} = \frac{340.2}{(3175.2)_{total}} = 0.1071$$

QE = 3.7 kw x 0.1071 = 0.3963 kw/h

Ventilation cooling load

$$ma = \frac{\frac{0.1V_z}{14.8}}{}$$

$$ma = \frac{0.1 \times 340.2 \times 2.4 \times 35.32}{14.8} = 194.85$$

$$q = 194.85 \times 27.5 = 5358.38 \frac{Btu}{hr} = 1571.37 \frac{watts}{hr}$$

q = 1.571 kw/h

TOTAL INTERNAL COOLING LOAD = $\sum q$

$\sum q$ = 3.742 +6.804 +0.396 +1.571

Q_{total} = 12.513 kw/h

EXTERNAL ZONES-A (3,4)

AREA OF EACH ZONE IS : 272.16 m^2

People Load

$$Q_p = 110 \frac{watts}{persons} \times 272.16 \text{ m}^2 \times \frac{1 person}{10 m2} = 2.994 \text{ kw/h}$$

Light Cooling Load

$$Q_L = 20 \frac{watts}{m^2} \times 272.16 \text{ m2} = 5.443 \text{ kw/h}$$

Equipment Cooling Load

average = 3.7 kw/floor

ratio of zone to floor area = $\dfrac{272.16}{(3175.2)_{total}} = 0.0857$

Q_E = 3.7 kw x 0.0857 = 0.317 kw/h

Ventilation cooling load

$$m_a = \frac{0.1 V_z}{14.8}$$

$$m_a = \frac{0.1 \times 272.16 \times 2.4 \times 35.32}{14.8} = 155.86$$

q = 155.86 x 27.5 = 4286.15 $\dfrac{\text{Btu}}{\text{hr}}$ = 1256.94 $\dfrac{\text{watts}}{\text{hr}}$

q = 1.257 kw/h

TOTAL INTERNAL COOLING LOAD = Σq

Σq = 2.994 +5.443 +0.317 +1.257

Q$_{total}$ = 10.011 kw/h

External Zones–B (1A,2A,1B,2B)

AREA OF EACH ZONE IS : 226.8 m^2

People Load

$$Q_p = 110 \frac{watts}{persons} \times 226.8 \ m^2 \times \frac{1 \, person}{10 \, m2} = 2.495 \ kw/h$$

Light Cooling Load

$$Q_L = 20 \frac{watts}{m^2} \times 226.8 \ m2 = 4.536 \ kw/h$$

Equipment Cooling Load

average = 3.7 kw/floor

ratio of zone to floor area = $\dfrac{226.8}{(3175.2)_{total}} = 0.0714$

$Q_E = 3.7 \ kw \times 0.0714 = 0.264 \ kw/h$

Ventilation cooling load

$$m_a = \frac{0.1 V_z}{14.8}$$

$$m_a = \frac{0.1 \times 226.8 \times 2.4 \times 35.32}{14.8} = 129.88$$

$q = 129.88 \times 27.5 = 3571.7 \dfrac{Btu}{hr} = 1047.42 \dfrac{watts}{hr}$

$q = 1.047 \ kw/h$

TOTAL INTERNAL COOLING LOAD = Σq

$\Sigma q = 2.495 + 4.536 + 0.264 + 1.047$

$Q_{total} = 8.342 \ kw/h$

APPENDIX E

EXTERNAL COOLING LOAD CALCULATIONS

North Elevation

WINDOWS

Area = 1.2 x 1.5 = 1.8 m^2

'U' = 6.0 $\dfrac{W}{m^2.^oC}$

Conducted Heat

Q_c = "U" x Area x Δt

= 6 x 1.8 x (40°c - 23°c)

q_c = 183.6 watts /hour per module.

Instantaneously Transmitted Heat

q_t = $I_d A \tau_2$

I_d = 0.415 x $\dfrac{150}{2}$ = 31.125 watts\m^2

q_t = 31.125 x 1.8 x 0.7 = 39.218 watts /hour per module.

Total Solar Heat Gains Through Glass Window = q_c + q_t

q_g = 183.6 + 39.218 = 222.818 watts /hour per module.

WALLS

Slab Portion

Area = 1.2 x .14 = 0.168 m^2

'U' = 0

lag time = ∞.

Q $\approx$ 0.0

Main Beam Portion

Area = 1.2 x .78 = 0.936 m^2

'U' = 1.366 $\dfrac{W}{m^2.°C}$

lag time = 15.5 hours.

3:00 pm - 15.5 hours = 11:30 pm

at 11:30 pm,

T_{s-a}= T_o = 34.5°C

q_c = "U" x Area x (T_{s-a} - T_i)

   = 1.366 x 0.936 x (34.5°C - 23°C)

q_c = 14.704 watts /hour per module.

Portion above window

Area = 1.2 x 0.6 = 0.72 m^2

'U' = 0.448 $\dfrac{W}{m^2.°C}$

lag time = 3 hours.

3:00 pm - 3 hours = 12:00 pm

$I_{d.12:00pm}$= 0.415 x $\dfrac{225}{2}$= 46.69 watts\m^2

T_{s-a} = T_o + $\dfrac{Ia}{f_o}$

T_{s-a} = 37.5°c + $\dfrac{46.69 \times 0.65}{13.6}$ = 39.73°c

q_c = "U" x Area x (T_{s-a} - T_i)

   = 0.448 x 0.72 x (39.73°C - 23°C)

q_c = 5.396 watts /hour per module.

Portion below window

Area = 1.2 x 0.9 = 1.08 m^2

'U' = 0.421 $\dfrac{W}{m^2.°C}$

lag time = 10 hours.

3:00 pm - 10 hours = 5:00 am

$I_D = I_d = 0$

$T_{s-a} = T_o = 30°C$

q_c = "U" x Area x (T_{s-a} - T_i)

   = 0.421 x 1.08 x (30°C - 23°C)

q_c = 3.183 watts /hour per module.

<u>Total Solar Heat Gains Through Walls</u> = Σq_c

q_w = 0 + 14.704 + 5.396 + 3.183 = 23.283 watts /hour per module.

EXTERNAL COOLING LOAD FOR NORTH ELEVATION:

$Q_{per\ module}$ = q_g + q_w = 222.818 + 23.283 = 246.101 watts /hour per module.

East Elevation

WINDOWS

Area = 1.2 x 1.5 = 1.8 m^2

'U' = 6.0 $\dfrac{W}{m^2.°C}$

Conducted Heat

Q_c = "U" x Area x Δt

   = 6 x 1.8 x (40°c - 23°c)

q_c = 183.6 watts /hour per module.

Instantaneously Transmitted Heat

$q_t = I_d A \tau_2$

$I_d = 0.105 \times \dfrac{150}{2} = 7.88$ watts\m^2

$q_t = 7.88 \times 1.8 \times 0.7 = 9.93$ watts /hour per module.

Total Solar Heat Gains Through Glass Window = $q_c + q_t$

$q_g = 183.6 + 9.93 = 193.53$ watts /hour per module.

WALLS

Slab Portion

Area = 1.2 x .14 = 0.168 m^2

'U' = 0

lag time = $\propto$.

$Q \approx 0.0$

Main Beam Portion

Area = 1.2 x .78 = 0.936 m^2

'U' = 1.366 $\dfrac{W}{m^2.{}^{o}C}$

lag time = 15.5 hours.

3:00 pm - 15.5 hours = 11:30 pm

at 11:30 pm,

$T_{s-a} = T_O = 34.5°C$

q_c = "U" x Area x (T_{s-a} - T_i)

   = 1.366 x 0.936 x (34.5°C - 23°C)

q_c = 14.704 watts /hour per module.

Portion above window

Area = 1.2 x 0.6 = 0.72 m^2

'U' = 0.448 $\dfrac{W}{m^2.{}^{o}C}$

lag time = 3 hours.

3:00 pm - 3 hours = 12:00 pm

$I_{d.12:00pm}$= 0.415 x $\dfrac{225}{2}$ = 46.69 watts\m^2

$T_{s-a} = T_0 + \dfrac{Ia}{f_o}$

T_{s-a} = 37.5°c + $\dfrac{46.69 \times 0.65}{13.6}$ = 39.73°c

q_c = "U" x Area x (T_{s-a} - T_i)

   = 0.448 x 0.72 x (39.73°C - 23°C)

q_c = 5.396 watts /hour per module.

Portion below window

Area = 1.2 x 0.9 = 1.08 m^2

'U' = 0.421 $\dfrac{W}{m^2.°C}$

lag time = 10 hours.

3:00 pm - 10 hours = 5:00 am

I_D = I_d = 0

$T_{s-a} = T_0$ = 30°C

q_c = "U" x Area x (T_{s-a} - T_i)

   = 0.421 x 1.08 x (30°C - 23°C)

q_c = 3.183 watts /hour per module.

Total Solar Heat Gains Through Walls = Σq_c

q_W = 0 + 14.704 + 5.396 + 3.183 = 23.283 watts /hour per module.

EXTERNAL COOLING LOAD FOR NORTH ELEVATION:

$Q_{per\ module} = q_g + q_W$ = 222.818 + 23.283 = 246.101 watts /hour per module.

West Elevation

WINDOWS

Area = 1.2 x 1.5 = 1.8 m^2

'U' = 6.0 $\dfrac{W}{m^2.°C}$

Conducted Heat

Q_c = "U" x Area x Δt

 = 6 x 1.8 x (40°c - 23°c)

q_c = 183.6 watts /hour per module.

Instantaneously Transmitted Heat

$q_t = I_d A \tau_2$

I_d = 0.415 x $\dfrac{150}{2}$ = 13.125 watts\m^2

q_t = 13.125 x 1.8 = 39.218 watts /hour per module.

Total Solar Heat Gains Through Glass Window = q_c + q_t

q_g = 183.6 + 39.218 = 222.818 watts /hour per module.

WALLS

Slab Portion

Area = 1.2 x .14 = 0.168 m^2

'U' = 0

lag time = ∞.

$Q \approx 0.0$

Main Beam Portion

Area = 1.2 x .78 = 0.936 m^2

$'U' = 1.366 \ \dfrac{W}{m^2.^{\circ}C}$

lag time = 15.5 hours.

3:00 pm - 15.5 hours = 11:30 pm

at 11:30 pm,

$T_{s-a} = T_o = 34.5°C$

$q_c =$ "U" x Area x ($T_{s-a} - T_i$)

= 1.366 x 0.936 x (34.5°C - 23°C)

$q_c =$ 14.704 watts /hour per module.

Portion above window

Area = 1.2 x 0.6 = 0.72 m^2

$'U' = 0.448 \ \dfrac{W}{m^2.^{\circ}C}$

lag time = 3 hours.

3:00 pm - 3 hours = 12:00 pm

$I_{d.12:00pm} = 0.415 \ x \ \dfrac{225}{2} = 46.69$ watts\m^2

$T_{s-a} = T_o + \dfrac{Ia}{f_o}$

$T_{s-a} = 37.5°c + \dfrac{46.69 \times 0.65}{13.6} = 39.73°c$

$q_c =$ "U" x Area x ($T_{s-a} - T_i$)

= 0.448 x 0.72 x (39.73°C - 23°C)

$q_c =$ 5.396 watts /hour per module.

Portion below window

Area = 1.2 x 0.9 = 1.08 m^2

$'U' = 0.421 \ \dfrac{W}{m^2.^{\circ}C}$

lag time = 10 hours.

3:00 pm - 10 hours = 5:00 am

$I_D = I_d = 0$

$T_{s-a} = T_o = 30°C$

$q_c = $ "U" x Area x $(T_{s-a} - T_i)$

   $= 0.421$ x 1.08 x $(30°C - 23°C)$

$q_c = 3.183$ watts /hour per module.

<u>Total Solar Heat Gains Through Walls</u> $= \Sigma q_c$

$q_w = 0 + 14.704 + 5.396 + 3.183 = 23.283$ watts /hour per module.

EXTERNAL COOLING LOAD FOR NORTH ELEVATION:

$Q_{per\ module} = q_g + q_w = 222.818 + 23.283 = 246.101$ **watts /hour per module.**

South Elevation

WINDOWS

Area = 1.2 x 1.5 = 1.8 m^2

'U' = 6.0 $\dfrac{W}{m^2.°C}$

Conducted Heat

$Q_c = $ "U" x Area x Δt

   $= 6$ x 1.8 x $(40°c - 23°c)$

$q_c = 183.6$ watts /hour per module.

Instantaneously Transmitted Heat

$q_t = I_d A \tau_2$

$I_d = 0.415$ x $\dfrac{150}{2} = 13.125$ watts\m^2

$q_t = 13.125$ x $1.8 = 39.218$ watts /hour per module.

Total Solar Heat Gains Through Glass Window = q_c +q_t

q_g = 183.6 + 39.218 = 222.818   watts /hour per module.

WALLS

Slab Portion

Area = 1.2 x .14 = 0.168 m^2

'U' = 0

lag time = $\propto$.

$Q \approx 0.0$

Main Beam Portion

Area = 1.2 x .78 = 0.936 m^2

'U' = 1.366 $\dfrac{W}{m^2.{}^\circ C}$

lag time = 15.5 hours.

3:00 pm - 15.5 hours = 11:30 pm

at 11:30 pm,

T_{s-a}= T_o = 34.5°C

q_c = "U" x Area x (T_{s-a} - T_i)

   = 1.366 x 0.936 x (34.5°C - 23°C)

q_c = 14.704 watts /hour per module.

Portion above window

Area = 1.2 x 0.6 = 0.72 m^2

'U' = 0.448 $\dfrac{W}{m^2.{}^\circ C}$

lag time = 3 hours.

3:00 pm - 3 hours = 12:00 pm

$I_{d.12:00pm}$= 0.415 x $\dfrac{225}{2}$= 46.69 watts\m^2

$$T_{S\text{-}a} = T_O + \frac{Ia}{f_o}$$

$$T_{S\text{-}a} = 37.5°c + \frac{46.69 \times 0.65}{13.6} = 39.73°c$$

$$q_C = \text{"U"} \times \text{Area} \times (T_{S\text{-}a} - T_i)$$

$$= 0.448 \times 0.72 \times (39.73°C - 23°C)$$

$q_c = 5.396$ watts /hour per module.

Portion below window

Area $= 1.2 \times 0.9 = 1.08$ m^2

$$\text{'U'} = 0.421 \ \frac{W}{m^2.°C}$$

lag time $= 10$ hours.

3:00 pm - 10 hours $= 5:00$ am

$$I_D = I_d = 0$$

$$T_{S\text{-}a} = T_O = 30°C$$

$$q_c = \text{"U"} \times \text{Area} \times (T_{S\text{-}a} - T_i)$$

$$= 0.421 \times 1.08 \times (30°C - 23°C)$$

$q_c = 3.183$ watts /hour per module.

Total Solar Heat Gains Through Walls $= \Sigma q_c$

$q_w = 0 + 14.704 + 5.396 + 3.183 = 23.283$ watts /hour per module.

EXTERNAL COOLING LOAD FOR NORTH ELEVATION:

$Q_{\text{per module}} = q_g + q_w = 222.818 + 23.283 = 246.101$ watts /hour per module.

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