DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

A PARAMETRIC STUDY ABOUT MINIMIZING OF AIR CONDITIONING AND LIGHTING ENERGY LOADS FOR A BUILDING IN İZMİR

by
Burcu ÇİFTÇİ

September 2008
İZMİR

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M.Sc. THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **“A PARAMETRIC STUDY ABOUT MINIMIZING OF AIR CONDITIONING AND LIGHTING ENERGY LOADS FOR A BUILDING IN İZMİR”** completed by **BURCU ÇİFTÇİ** under supervision of **ASSIST. PROF. DR. TAHSİN BAŞARAN** and we certify that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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ABSTRACT

In this thesis, the effect of lighting and air-conditioning energy loads was evaluated on total electric consumption in office buildings. This evaluation taked account of calculated values combined the lighting and the thermal condition effects. It was in terms of saved energy by using a daylight responsive different glazing system in comparison with an artificial lighting system by obtaining the numerical and experimental results during eight-month. Experimental result and data were classified as hourly, monthly, and seasonal terms. Furthermore the weather conditions were considered by classifying the days as clear, mixed or overcast. Energy savings obtained by daylight responsivity was investigated by evaluating the differences of glazing units according to the months and seasons. According to the results of this experimental study, up to 30% energy saving on total electric consumption could be obtained for suitable glazing units.

Keywords: Daylighting; Daylight factor, Office buildings, Energy saving, Solar heating

İZMİRDEKİ BİR BİNA İÇİN İKLİMLENDİRME VE AYDINLATMA ENERJİ YÜKLERİNİ AZALTMA ÜZERİNE PAREMETRİK ÇALIŞMA

ÖZ

Bu tezde, ofis binalarındaki aydınlatma ve iklimlendirme enerji yüklerinin toplam elektrik tüketimi üzerindeki etkileri değerlendirilmiştir. Değerlendirme aydınlatma ve ısıl durum etkileri birlikte göz önüne alınarak gerçekleştirilmiştir. Kullanılan yapay aydınlatma sistemleri ile gün ışığı tepkiselliğini farklı camlama sistemleri için sekiz aylık süre boyunca elde edilen sayısal ve deneysel sonuçların karşılaştırılmasıyla enerji kazanımı bağlamında incelenmiştir. Deneysel sonuçlar ve veriler mevsimlik, aylık ve saatlik olarak sınıflandırılmıştır. Ayrıca günlerin açık, karışık ve çok bulutlu olarak sınıflandırılması ile hava şartları da değerlendirilmeye alınmıştır. Gün ışığı tepkiselliği ile bulunan enerji kazançları; cam ünitelerin aylık ve mevsimsel olarak farklılıkları göz önüne alınarak değerlendirilmiştir. Bu deneysel çalışmaların sonuçlarına bağlı olarak, uygun cam ünite kullanımı ile, toplam elektrik tüketiminde %30’a varan kazanç sağlanmasının mümkün olabileceği vurgulanmıştır.

Anahtar sözcükler: Gün ışığı, Gün ışığı faktörü, Ofis binaları, Enerji kazanımı, Güneşle ısıtma.

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CHAPTER ONE
INTRODUCTION

Energy consumption in the office buildings is one of the highest parts compared to the consumption of the other building types. The annual energy consumption in the office buildings varies, depending on geographic location; usage and type of office equipments, operational schedules, and the usage of air-condition systems, type of lighting, number of persons, the description of the work, etc. Energy in office buildings is mainly consumed for heating, cooling and lighting purposes.

Office buildings in Turkey consume over one-third of the nation’s primary energy. Artificial lighting is estimated to account for 25%–40% of this energy consumption. Over the last three decades, several measurements have been considered to reduce electricity use associated with artificial lighting. The use of compact fluorescent lamps, installation of occupancy sensors, and better design strategies to minimize the number of fixtures are commonly utilized energy efficiency measures.

In the office building, most of the electricity is used for creating a thermally and visually comfortable built-environment by using air-conditioning system and artificial lighting. Solar heat gain via fenestration, contributes to a significant proportion of the building envelope for cooling load. More solar radiation means more solar heat gain and, according to this, a greater cooling load and larger air-conditioning plant capacity. In hot climate regions, the principal objectives of fenestration designs include eliminating direct beam of sunlight radiation and reducing cooling energy. Besides, daylighting has long been recognized as an important and useful strategy for energy conservation and visual comfort in buildings. Energy savings resulting from daylighting mean not only low electric lighting and reduced peak electrical demands, but also reduced cooling loads and the potential for the smaller size of heating, ventilating and air-conditioning equipments. The initial, running and maintenance costs of a building due to a smaller air-condition plant capacity and peak electrical demand can be lowered. On the other hand daylighting makes an interior space look more attractive. People mostly expect good natural lighting in their working spaces. The amount of daylighting entering to a building is mainly through window openings that provide the dual function not only of admitting light into the indoor environment, but also in connecting the outside world to the inside of a building.

There are so many studies related to the evaluation of lighting and air-conditing systems in the literature. An experimental study was realized in a laboratory (Figure 1.1) to compare the measured value of daylight illuminance level on the working plane and the value estimated by software named LIGHT by Franzetti, Fraisse & Achard (2004). The laboratory is located in the Research Centre of EDF (Les Renardières, France). In the laboratory, illuminance meters control the illuminance level on the working plane and on other characteristic points.

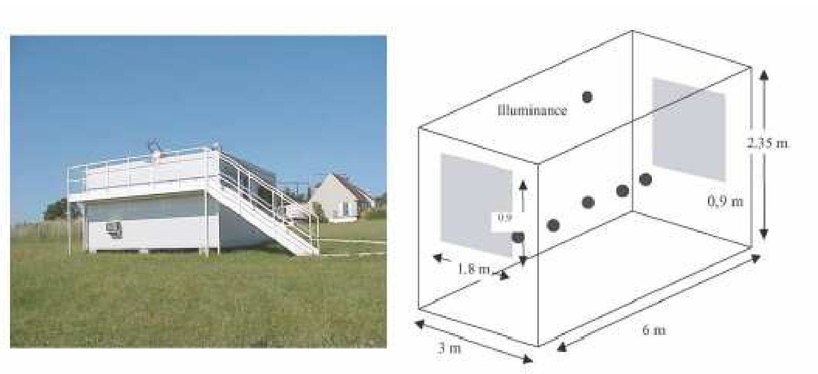


Figure 1.1 Laboratory and inside points of illuminance measures (Franzetti, Fraisse & Achard, 2004)

On the other hand, a reference building was also defined as a square-shaped four floors office building in their study. The total area of the five floors is 2800m2. All the offices are allocated on the periphery of each floor and the common services are in the centre of the building. People are working in the building 5 days per week from 8:00 am to 7:00 pm. Thermal consigns are able of the occupation. The interactions between natural and artificial lighting and HVAC process were evaluated by relationships linking energy needs and the most efficient parameters which were defined in the reference of (Franzetti at al, 2004). They showed that without valorization of the natural light, the cooling needs were more important than the heating needs in their study. Cooling was used to evacuate the internal loads which were mainly due to lighting in the hot period. This implied a large reduction of all energy needs (except heating needs) when daylight was valorized even by a basic light control device. This work (Franzetti at al, 2004) illustrates the importance of taking into account the interaction between lighting and HVAC system. This notion was useful to understand and foresee the energy needs of office buildings.

A series of measurements of illuminance was carried out within an office room located in Boulder, Colorado (US), (Ihm, Nemri & Krarti, 2008). The measurements were obtained for over four-month period during the year of 2004. The office room has a rectangular shape layout with a width of 2.9m and a length of 5.5m with a floor to ceiling height of 2.4m. Two windows with double-pane low-e glazing were placed in the west facade of the office. Continuous indoor measurements were performed over a period of four months. For each day, hourly measurements were monitored from 8:00 am to 6:00 pm. All the measurements were performed at desk height. To assess the daylighting availability inside the office space, the door was shut and the electrical lighting was turned off to ensure that measured illuminance levels within the office space were only caused by natural light transmitted from the windows. It was found during sunny days that the interior illuminance levels in the office room at the desk level reached over 500 lux if natural light was utilized. As expected, measurements show that the illuminance level was higher close to the windows than at the back of the room. Figure 1.2(a) and (b) showed the lines for equal illuminance level (at desk height) on March 9 (sunny day) at 10:00 am and 4:00 pm, respectively. As depicted in Figure 1.2, the 500 lx illuminance level was achieved only near the two windows. Away from the windows, electrical lighting was required to complement daylighting to accomplish the required 500 lux-illuminance level at the work plane.

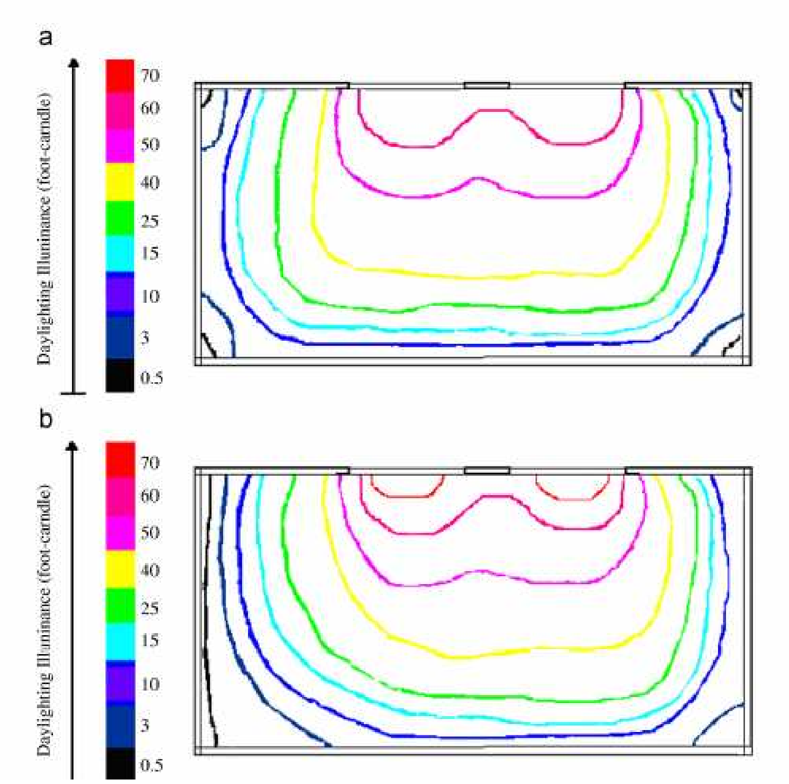


Figure 1.2 (a) Iso illuminance distribution in the tested office room at 10:00 am of March 9 (sunny day). (b) Iso illuminance distribution in the tested office room at 4:00 am of March 9 (sunny day) (Ihm at al. 2008).

A simplified analysis method which was obtained by Ihm at al. (2008) was developed and validated to estimate the potential reduction in annual electrical lighting energy use for office buildings. The simplified method accounted for the building geometry, window size, and type of glazing. For the office space considered in the validation analysis, an annual energy use savings of up to 60% associated with lighting could achieved using dimming control strategy.

Krarti, Erickson & Hillman (2005) were studied to provided a simplified analysis method to evaluate the potential of daylighting to save energy associated with electric lighting use. Specifically, impacts on daylighting performance were investigated for several combinations of building geometry, window opening size, and glazing type for four geographical locations in the United States. Four building geometries with various window-to-floor areas, along with different glazing types were analyzed. In their study, the daylighting aperture defined as the product of window visible transmittance and window to perimeter floor area ratio was found to have a significant impact on energy savings from daylighting. Increasing daylighting aperture (either by increasing glazing transmittance or window area) leads to greater daylighting benefits. It had shown that a daylighting aperture greater than 0.30 will yield diminishing returns on energy savings. It had also found that geographical location had relatively low impact on daylighting savings potential.

The literature showed that it was very difficult to evaluate the energy savings coming from the artificial lighting dimming as a function of the daylighting availability. For office buildings, with classical windows (no specific daylighting system), Szerman (1993), gave the following values (calculated by simulations): 77% of lighting energy savings and 14% of total energy savings. Zeguers (1993), also gave about 20% of lighting energy saving. Embrechts & Van Bellegem (1997), measured that an individual lighting dimming system offered 20% of lighting consumption savings. Opdal & Brekke (1993), compared measurements and calculation results and obtained 40% of lighting savings in simulations and 30% of lighting energy saving in measurements. Zonneveldt & Rutten (1993), expect a reduction of the lighting consumption up to 30%. They speak about 46% of lighting savings coming from the artificial lighting management as a function of daylighting for a building.

The literature gave very different values. These values could be explained by the fact that many parameters play a rule mainly on the results. The presented values here were difficult to compare because they were related to a particular climate, building and daylighting systems. However, all the authors agreed that the artificial lighting management according to daylighting availabilities could save much lighting energy but that this management could not be done without taking into account the visual comfort. An important think that also had to be considered was that the management system had to be accepted by the employees. If it was not the case, the energy savings could be decreased to zero (Embrechts & Bellegem, 1997).

Besides the issue of cooling energy in small glazed-envelope buildings, there were two problems deteriorating the comfort level. One was solar heat gains from a glazed envelope, and the other was intense sunlight. Intense daylight of working areas affects the attention and visual performance of the occupant (Sanders & McCormic, 1992; Luckiesh & Moss, 1927–1932), while thermal discomfort in overheated or cold office rooms could lead to physical stresses, which were commonly responsible for illness and poor performance (Kaynakli & Kilic, 2005). These problems, caused by insufficient consideration of the negative influences of glazing on the comfort level during the design process, affect how occupants use their buildings and interfere with architects' intended expressions (Kang, 1990). According to the study of Lomonaco & Miller (1997), productivity was increased by 15% when office workers were satisfied with their environments.

CHAPTER TWO

DEFINITION OF SOLAR ENERGY

2.1 Definition of Solar Energy

The sun is an average planet of diameter 1.39 × 10^9m and is, 1.5 ×10^{11}m from the earth and has a mass of about 2×10^{30}kg. It radiates energy from an effective surface temperature of about 5777^oK. From the central interior regions of the sun, energy is transmitted radial, outward as electromagnetic radiation called "solar energy". This electromagnetic spectrum, which contain all the energy radiated by the sun, extends from gamma rays (of wavelength 10^{-6} μm and lower) to radio waves (of wavelength 10^{-3} μm and longer). The quantity of energy radiated by the sun can be estimated from knowledge of the sun's radius and its surface temperature and this amount to a rate of about 3.8×10^{23}kW (Duffie & Beckman, 1991).

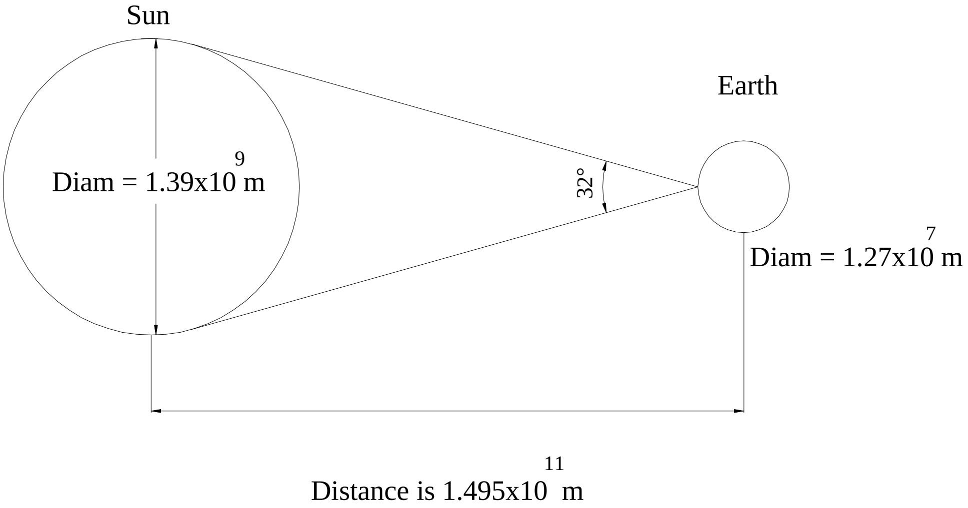


Figure 2.1 Sun- earth relationship

The earth is at 149.5 million km from the sun and has a radius of about 6360km. The total surface area of the earth is about 510 million km^2. Figure 2.1 shows schematically the geometry of the sun-earth relationships. This tilted position together with its daily rotation and yearly revolution accounts for the distribution of solar radiation over the earth's surface and the change in day length.

The intensity of solar radiation is measured by a pyranometer. The instruments have a sensor to cover in a transparent hemisphere. It records the total quantity of short-wave solar radiation. Pyranometers measure “global” or “total” radiation: the sum of direct solar and diffuse radiation.

2.2 Sun - Earth Angles

The solar radiation taken to the earth's surface is not constant. This common information could be explained by an understanding of the sun earth angle concepts. There are earth's surface varies in our daily life at the solar radiation;

- Hourly variations during the day
- Daily variations, because of the clouds.
- Monthly variations, location and the sun's position.
- Location variations.
- The surface of depending on the orientation.

The radiation emitted by the sun and its spatial relationship to the outside of the earth's atmosphere. The solar constant, G_{sc}, is the energy from the sun, per unit time, received on a unit area of surface perpendicular to the direction of propagation of the radiation, at the outside of the atmosphere. The value of 1367W/m^2 is used in this thesis.

The earth moves around the sun on an elliptical orbit. The variation of the earth-sun distance due to earth’s orbit causes variable extraterrestrial radiation. The dependence of extraterrestrial radiation on time of year is defined by Equation 2.1 and is shown in (Duffie & Beckman, 1991).

$$G_{0n} = G_{sc}\left(1 + 0.033 \cos\frac{360\, n}{365}\right) \tag{2.1}$$

where G_{0n}, the extraterrestrial radiation, (measured on the plane normal to the radiation on the n^{th} day of the year.)

The location on the earth's surface is described by the coordinates latitude and longitude. The sun's position in the sky is described by the hour angle and the declination. The relative position is described by the altitude and the azimuth angles (Figure 2.2).

Latitude (φ) is defined as the angular distance of a point from the equator on the surface of the earth. The angular location could be north or south of the equator. North latitudes are taken to be positive, while south latitudes are taken as negative.

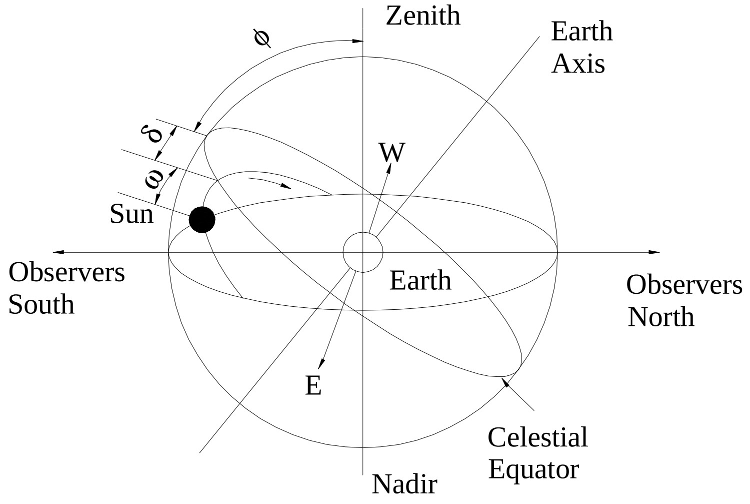


Figure 2.2 Solar angles, $(\omega, \delta, \varphi)$

Longitudes or Meridians are semi great circles passing through the poles of the earth. The zero (0) meridian passing through Greenwich near London is called the prime meridian by international agreement.

Hour angle (ω) is defined as the number of minutes between the Local Standard Time and solar noon, when the sun is straight overhead. The hour angle, thus, is zero at local solar noon, where afternoon hours are designated as positive. As the outcome of 360 degrees per 24 hours, each hour is equivalent to 15° of longitude. The hour angle in degrees is,

$$\omega = (\text{Local solar time} - \text{noon time})\, 15^{\circ} \qquad (2.2)$$

where local solar time and noon times are in hours(noon time is 12:00)

Declination (δ) is the angular distance north (or south) of the equator of the point, when the sun is at its zenith with respect to the plane of the equator, north positive; $-23.45° < \delta < 23.45°$. It can also be defined as the angle formed by the line extending from the centre of the sun to the centre of the earth and the projection of this line upon the earth's equatorial plane. When the sun is directly overhead at any location during solar noon, the latitude of that location gives the declination. This is shown clearly in Figure 2.3.

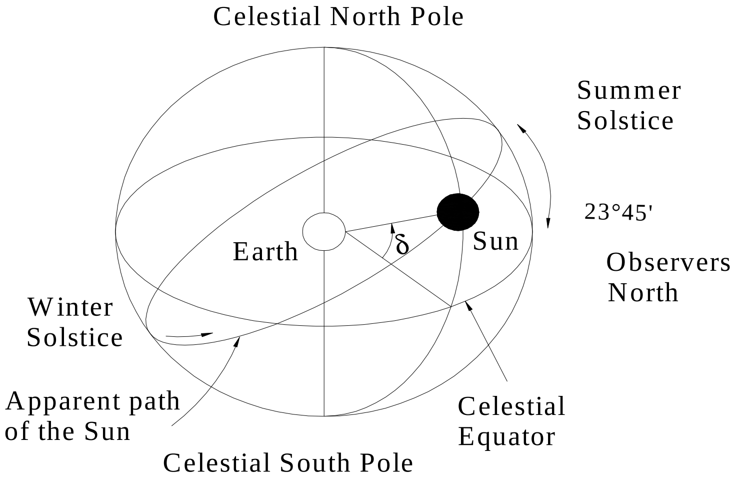


Figure 2.3 Sun path, Equinox and Solstices

The declination can be found from the equation of Cooper (1969):

$$\delta = 23.45 \sin\left(360 \frac{284 + n}{365}\right) \tag{2.3}$$

where, *n* is the day number of the year (Table 2.1) (Duffie & Beckman, 1991)

Table 2.1 *n^{th}* Day of a year

Month	Date	n Day of year
January	17	17
February	16	47
March	17	76
April	16	106
May	16	136
June	12	163
July	18	199
August	17	229

Additional angles are defined that describe the position of the sun in the sky:

Angle of incidence (θ), the angle between the beam radiation (I_b) on a surface and the normal to that surface.

Zenith angle (θ_z), the angle of incidence of beam radiation on a horizontal surface. It is the angle between I_b and X line as shown in Figure 2.4.

Solar altitude angle (α), the angle between the horizontal and the line to the sun, i.e., the complement of the zenith angle (Figure 2.4).

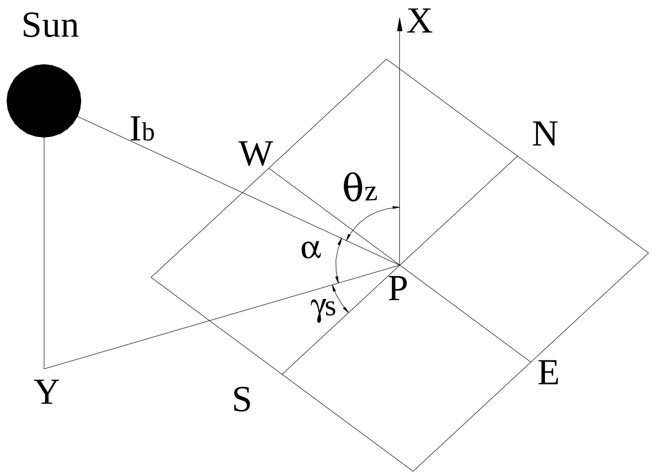


Figure 2.4 The Zenith Angle, Altitude Angle and the Solar Azimuth.

Solar azimuth angle (γ_s), the angular displacement from south of the projection of beam radiation on the horizontal plane, shown in Figure 2.4. Displacements east of south are negative and west of south are positive.

The Slope or Tilt Angle (β), is the angle the surface makes with the horizontal plane (Figure 2.5). $0 < \beta < 180°$ ($\beta > 90°$ means that the surface has a downward facing component.)

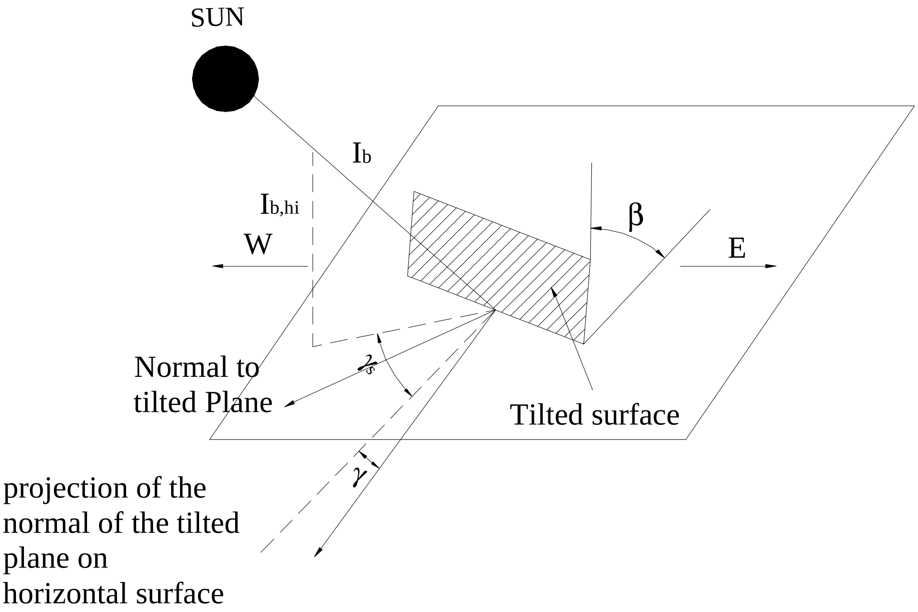


Figure 2.5 Tilt angle and azimuth angle for a non south facing tilted surface.

The Surface Azimuth Angle (γ) is the angle measured on the horizontal plane from due south to the horizontal projection of the normal to the surface (Figure 2.5). It is also given as the angle between the local meridian and the horizontal projection of the normal to the surface.

2.3 Solar Incident Angle (θ)

Sunlight reaching the earth surface is termed beam or direct radiation. It is the type of sunlight that casts a sharp shadow, and on a sunny day it can be as much as

80% of the total sunlight striking a surface. Hence, beam or direct radiation is the most important type of radiation for solar processes.

The second type of solar radiation is diffuse or scattered sunlight. This is such sunlight that comes from all directions in the sky dome other than the direction of the sun. It is the sunlight scattered by atmospheric components such as particles, water vapor, and aerosols. On a cloudy day, the sunlight is 100% diffuse. The amount of direct radiation on a horizontal surface can be calculated by multiplying the direct normal irradiance times the cosine of the zenith angle. Solar incident angle is;

$$\begin{aligned}\cos\theta &= \sin\delta\sin\varphi\cos\beta - \sin\delta\cos\varphi\sin\beta\cos\gamma + \cos\delta\cos\varphi\cos\beta\cos\omega \\ &\quad + \cos\delta\sin\varphi\sin\beta\cos\gamma\cos\omega + \cos\delta\sin\beta\sin\gamma\sin\omega\end{aligned} \tag{2.4}$$

There are several commonly occurring cases for Equation 2.4 simplified. For different direction of surface calculate with a surface azimuth angle γ must be between 0° and 180°. For vertical surfaces, β=90° and Equation 2.4 becomes;

$$\begin{aligned}\cos\theta &= -\sin\delta\cos\varphi\sin\beta\cos\gamma + \cos\delta\sin\varphi\cos\gamma\cos\omega \\ &\quad + \cos\delta\sin\gamma\sin\omega\end{aligned} \tag{2.5}$$

Useful relationships for the angle of incidence of surfaces sloped due north or due south can be derived from the fact that surfaces with slope β to the north or south have the same angular relationship to beam radiation as a horizontal surface at an artificial latitude of (φ-β). The relationship is shown in Figure 2.6 for the northern hemisphere. (Duffie and Beckman 1991)

$$\cos\theta = \cos(\varphi-\beta)\cos\delta\cos\omega + \sin(\varphi-\beta)\sin\delta \tag{2.6a}$$

For the southern hemisphere modify the equation by replacing (φ-β) by (φ+β), consistent with the sign conventions on φ and δ:

$$\cos\theta = \cos(\varphi+\beta)\cos\delta\ \cos\omega + \sin(\varphi+\beta)\sin\delta \tag{2.6b}$$

It also follows that the number of daylight hours is given by

$$N = \frac{2}{15}\cos^{-1}\left(-\tan\varphi\ \tan\delta\right) \tag{2.7}$$

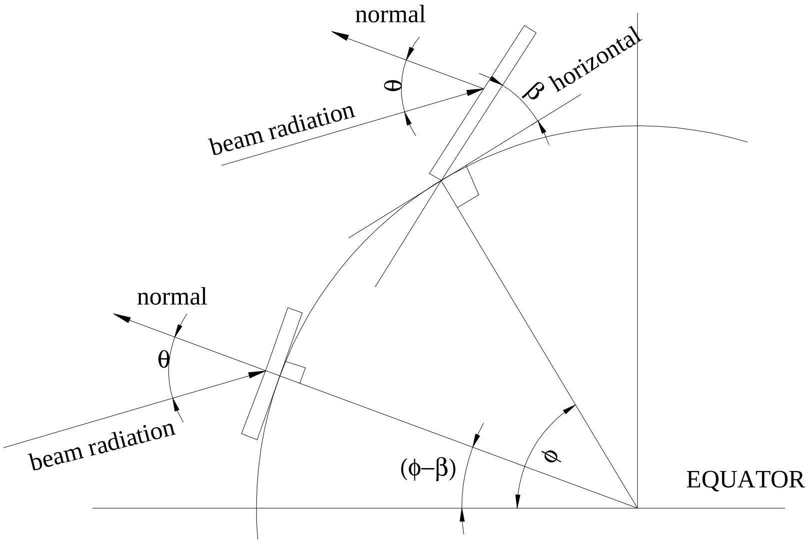


Figure 2.6 Section of Earth showing *β*, *φ*, *θ*, and (*φ-β*) for a south-facing surface.

2.4 Extraterrestrial Radiation on a Horizontal Surface

The extraterrestrial radiation on a surface at any time is;

$$G_0 = G_{0n}\cos\theta \tag{2.8}$$

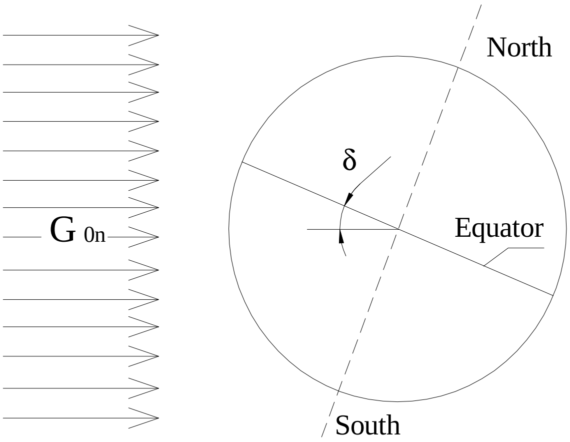


Figure 2.7 Schematic of the sun rays coming to earth’s atmosphere

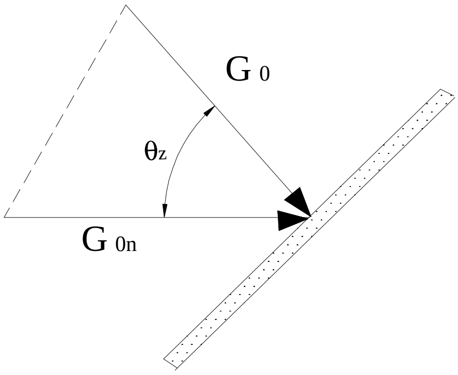


Figure 2.8 Extraterrestrial radiation on a horizontal surface outside of the atmosphere

If Equation 2.7 for G_{0n} and Equation 2.3 for $cos\theta$ are substituted in this equation, below equation is obtained for the extraterrestrial radiation on a surface.

$$G_0 = G_{sc}\left(1 \ + \ 0.033 \ \cos\frac{360n}{365}\right)\cos\theta_z \tag{2.9}$$

where

G_{sc} : solar constant

n : day of the year.

Combining Equation 2.8 for $cos\theta_z$ with Equation 2.4 gives G_0 for a horizontal surface at any time between sunrise and sunset.

$$G_0 = G_{sc}\left(1 + 0.033\cos\frac{360n}{365}\right)(\cos\varphi\cos\delta\cos\omega + \sin\varphi\sin\delta) \tag{2.10}$$

Integration of this equation over the period from sunrise to sunset, gives daily extraterrestrial radiation on a horizontal surface.

$$H_0 = \frac{24 \times 3600 G_{SC}}{\pi} \left(1 + 0.033\ \cos\frac{360n}{365}\right)\left(\cos\varphi\cos\delta\cos\omega_S + \frac{\pi\omega_S}{180}\sin\varphi\sin\delta\right) \tag{2.11}$$

where ω_S is the sunset hour angle, in degrees. ω_S is:

$$\cos\omega_S = -\frac{\sin\varphi\sin\delta}{\cos\varphi\cos\delta} = -\tan\delta\tan\varphi \tag{2.12}$$

It is also of interest to calculate the extraterrestrial radiation on a horizontal surface for an hour period. Integration Equation 2.11 for a period between hour angel ω_1 and ω_2 which define an hour (where ω_2 is the larger),

$$I_0 = \frac{3600\ G_{SC} 12}{\pi}\left(1 + 0.033\cos\frac{360n}{365}\right)\left(\left(\cos\varphi\cos\delta\sin(\omega_2 - \omega_1)\right) + \frac{\pi(\omega_2 - \omega_1)}{180}\sin\varphi\sin\delta\right) \tag{2.13}$$

(The limits ω_1 and ω_2 may define a time other than an hour.)

CHAPTER THREE

GLAZING, FENESTRATION AND FENESTRATION COMPONENTS

Fenestration components consist of glazing material, framing and shading devices. Fenestration can attend as a physical and visual connection to the outdoors with solar radiation. Natural lighting and heat gain are provided by the solar radiation. Fenestration units can allow natural ventilation, building energy use thermal heat transfer, solar heat gain, air leakage, and daylighting (ASHRAE, 1999).

3.1 Fenestration Components

Fenestration is made up of framing, glazing, and some times shading devices. The glazing unit consists of two type of glazing system such as single glazing or multiple glazing. The most common glazing material is glass, but occasionally plastic is used. The glass or plastic may be clear, tinted, obscured, or coated (ASHRAE, 1999).

Clear glass provides a high transmission of daylight with typical visible transmittance (*VT*) of 0.75 but it also allows a large amount of solar heat (high shading coefficient) to pass through into a building.

Tinted glass absorbs a great amount of infrared with some reduction of visible light. The *VT* ranges from 0.23 to 0.51 and manufacture in many colors.

Coatings on glass affect the transmission of solar radiation, and visible light may affect the absorptance of room temperature radiation. Some coatings are highly reflective (such as mirrors), while others are designed to have a very low reflectance. Some coatings result in a visible light transmittance that is as much as 1.4 times higher than the solar heat gain coefficient (desirable for good daylighting while minimizing cooling loads).

3.2 Insulating Glass Units

Insulating glazing units (IGUs) are a put under seal assembly with a minimum of two panes of clear or coated glass (Figure 3.1). The insulating glazing unites consist of three type of property category such as heat control glazing, solar control glazing and heat and solar control glazing. The most common type of glass is clear. However, low-emittance glazing has become common, because of the good thermal performance. Reflective glass absorbs more heat than tinted glass and offers good reflecting characteristic in the infrared region with a certain reduction of *VT*. There are two types of low-e coating: high-solar-gain and low-solar-gain. The first type reduces heat conduction through the glazing system and is used for cold climates. The second type reduces solar heat gain by blocking the infrared range of the solar spectrum, is used for hot climates. There are two ways of providing low solar- gain low-e performance. The first is with a special multilayer solar infrared reflecting coating. The second is with a solar infrared absorbing outer glass. To protect the inner glazing and the building interior from the absorbed heat from this outer glass, a cold-climate type low-e coating is also used to reduce conduction of heat from the outer pane to the inner one. In addition, argon and krypton gas are used to reduce energy transfer instead of air in the gap between the panes and low-emittance (low-e) glazing (ASHRAE, 1999).

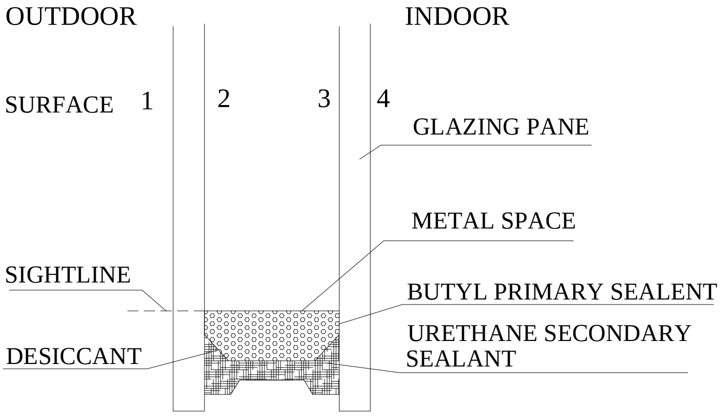


Figure 3.1 Insulating glass unit construction detail

The chosen glazing units, in this thesis, are: Classic Glazing, Heat Control Glazing, Solar Control Glazing, Heat and Solar Control Glazing; which are given below and defined by Trakya Cam, (2008).

3.2.1 Classic Glazing

Classic glazing is produced from glass unit, assembled with two or more panes of glass separated by a dehydrated air or gas filled intermediary space. Classic glazing comprising two panes of clear float glass decreases heat loss by 50% when compared with single glazing and contributes to energy saving.

3.2.2 Heat Control Glazing

Glass when used as single glazing in windows benefiting from the light and heat of the sun is possible, but high amount of heat loss occurs in winter. Increasing the thickness of glass does not fully contribute to heat insulation. Insulating glass units contribute to energy saving by decreasing the loss of heat through windows and provide a comfortable environment.

Heat control glazing has a neutral appearance closer to clear float glass. It provides high light transmittance. Its effective thermal insulation provides heating expense reduction. In winter, cold spaces by windows are eliminated. The heat inside the office is radiated equally.

3.2.3 Solar Control

Solar control glasses provide a comfortable environment by limiting the solar heat gains to interior spaces and enables controlling sun's excessive glare. It also provides the reduction in cooling energy consumption and expenses in air-conditioned environments. Solar control glass offers various alternatives to users in terms of solar control performance, such as; color, reflection, and benefit from sunlight.

Solar control performance of glass is determined by the total amount of solar radiant energy entering to the room through the glass, and is expressed as solar factor. Solar factor varies according to the quantity of energy transmitted directly and the quantity of energy absorbed. Solar control glasses are related to thermal breakage risks.

3.2.4 Heat and Solar Control

In geographical regions, where summers and winters are both experienced throughout the year, it is important for glass to provide heat insulation and solar control as well. Heat and solar control glasses have to be used for decreasing heat loss during the cold days and for limiting solar heat gains during the hot days of the year. Heat and solar control properties can be provided by applying a coating on the surface of the glass or by incorporating a solar control glass and a heat control glass within an insulating glass unit separately.
Heat and Solar Control Glass reduces heating and cooling expenses by;

- decreasing heat loss through the glass (from the interior to exterior)
- decreasing solar heat gains.

3.3 Framing

The three main used to window framing materials are wood, aluminum, and polymers. Wood is known as a good structural and insulating material, but it is affected from weather, humidity and organic corruption. Metal is strong but it has very poor thermal performance. The metal of choice in windows is aluminum, because of manufactures ease, low cost, and light weight, but the other side aluminum has a thermal conductivity more than wood or polymers. Polymer frames are made of extruded vinyl. They have similar thermal and structural performance of wood, but vinyl frames are not strong for large windows (ASHRAE, 1999).

3.4 Shading

Shading devices shade the window from direct sun penetration but allow diffuse of daylight to be admitted. Shading devices include interior and exterior blinds, integral blinds, interior and exterior screens, shutters, draperies, and roller shades. Shading devices on the exterior of the glazing reduce solar heat gain more effectively than interior devices. However, interior devices are easier to operate, adjust and service. (ASHRAE, 1999)

For exterior window shading; upper horizontal projecting which is made of concrete wall is supposed to be used for increasing summer sunlight coming with a wide surface azimuth angle and keeping still the winter sunlight with a narrow surface azimuth angle. By this way; heat gain in winter will be saved and in summer will be reduced (Figure 3.2.).

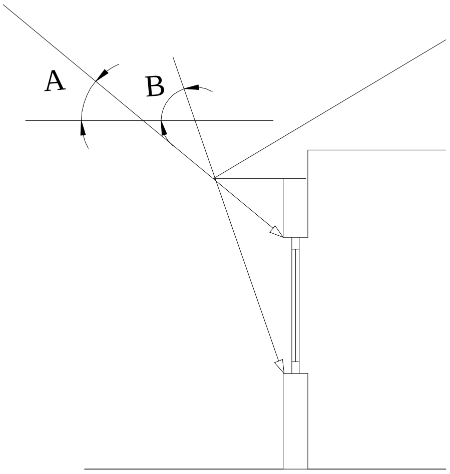


Figure 3.2 Overhang
(A) represents summer angle of the sun,
(B) represent winter angle of the sun (Wachberger, 1998)

3.5 Determining Fenestration Energy Flow

Energy flows occur three ways. First reason is the temperature difference between outdoor and indoor air through fenestration by way of conductive and convective heat transfer. Second reason is net long-wave (above 2500µm) radiative exchange between the fenestration and its surrounding and between glazing layers. Finally is short-wave (below 2500µm) solar radiation (either directly from the sun or reflected from the ground or adjacent objects) incident on the fenestration product. (ASHRAE, 1999)

Calculations are based on the observation that the temperatures of the sky, ground, and surrounding objects (and hence their radiant emission) correlate with the exterior air temperature. The radiative interchanges are then approximated by assuming that all the radiating surfaces (including the sky) are at the same temperature as the outdoor air. With this assumption, the basic equation for the instantaneous energy flow Q through a fenestration is (ASHRAE, 1999)

$$Q = UA_{pf}(t_{out} - t_{in}) + (SHGC)A_{pf}E_t \tag{3.1}$$

where is

Q : instantaneous energy flow, W

U : overall coefficient of heat transfer (U-factor), W/(m^2·K)

t_{in} : interior air temperature, °C

t_{out} : exterior air temperature, °C

A_{pf} : total projected area of fenestration, m^2

$SHGC$: solar heat gain coefficient, non dimensional

E_t : incident total irradiance, W/m^2

The quantities U and $SHGC$ are instantaneous performance values. Q is divided into two parts:

$$Q = Q_{th} + Q_{sol} \tag{3.2}$$

where

Q_{th} : instantaneous energy flow due to indoor-outdoor temperature difference (thermal energy flow)

Q_{sol} : instantaneous energy flow due to solar radiation (solar energy flow)

U – Factor (Heat Transmittance) touches on Q_{th}, while Solar Heat Gain and Visible Transmittance takes up θ_{sol}.

$$Q_{th} = A_f Q_f + A_g Q_g \tag{3.3}$$

where the subscript *f* refers to the frame, and *g* refers to the glazing.

Solar radiation will have a different effect on the frame and the glazed area of a fenestration, so that;

$$Q_{sol} = A_{op} Q_{op} + A_s Q_s \tag{3.4}$$

where the subscript *op* refers to the (opaque) frame (for solar energy flow), and *s* refers to the (solar-transmitting) glazing.

3.6 U-Factor (Heat Transmittance)

The glazing unit’s heat transfer paths include a one-dimensional center of-glass contribution and a two-dimensional edge contribution. The frame contribution is primarily two-dimensional. Consequently, the total rate of heat transfer through a fenestration system can be calculated knowing the separate heat transfer contributions of the center glass, edge glass, and frame. The overall U-factor is estimated using area-weighted U-factors for each contribution by (ASHRAE, 1999);

$$U_0 = \frac{U_{cg} A_{cg} + U_{eg} A_{eg} + U_f A_f}{A_{pf}} \tag{3.5}$$

where the subscripts *cg*, *eg*, and *f* refer to the center-of-glass, edge of- glass, and frame, respectively. A_{pf} is the area of the fenestration product's rough opening in the wall or roof less installation clearances.

3.6.1 Determining Fenestration U-Factors

3.6.1.1 Center-of-Glass U-Factor

Heat flow across the central glazed must think about both convective and radiative transfer. Convective heat transfer is based on high-aspect-ratio and natural convection correlations for vertical. The U-factor for single glass can be calculated as, (ASHRAE, 1999)

$$U = \frac{1}{1/h_o + 1/h_i + L/1000k} \tag{3.6}$$

where,

h_o, h_i : outdoor and indoor respective glass surface heat transfer coefficients, W/(m^2 K)

L : glass thickness, mm

k : thermal conductivity, W/ (m·K)

3.6.1.2 Edge-of-Glass U-Factor

Edge-of-glass heat transfer is two-dimensional and requires detailed modeling for accurate determination. Based on detailed two-dimensional modeling, developed the following correlation to calculate the edge-of-glass U-factor as a function of spacer type and center-of-glass U-factor (ASHRAE, 1999).

$$U_{eg} = A + BU_{cg} + CU_{cg}^2 \qquad (3.7)$$

where *A*, *B*, and *C* are correlation coefficients, which are listed in Table 3.1 for metal, insulating (including wood) and fused-glass spacers, and a combination of insulating and metal spacers.

Table 3.1 Coefficients for edge of glass U-factor

Material	A	B	C
Metal	1.266	0.842	-0.027
Insulating	0.681	0.682	0.043
Glass	0.897	0.774	0.01
Metal and insulation	0.769	0.706	0.033

Note: A, B and C have units of $(W/(m^2 K))^n$, where n=1,0 and -1 respectively

3.6.1.3 Frame U-Factor

Fenestration frame elements consist of all structural members exclusive of the glazing units and include sash, jamb, head, and sill members; meeting rails and stiles; mullions; and other glazing dividers. Estimating the rate of heat transfer through the frame is complicated by the variety of fenestration products and frame configurations, the different combinations of materials used for frames, the different sizes available, and to a lesser extent, the glazing unit width and spacer type. Table A4 lists frame U-factors for a variety of frame and spacer materials and glazing unit thicknesses (ASHRAE, 1999).

3.7 Indoor and Outdoor Surface Heat Transfer Coefficients

Fenestration system is exposed surfaces and the environment due to the convective and radiative heat transfer. Surface heat transfer coefficients outer glazing surfaces h_o and inner glazing surfaces h_i provides of radiation and convection. Outer glazing surfaces h_o change the wind speed and orientation of the building (Table 3.2). Convective heat transfer coefficients are usually decided at standard temperature and air velocity conditions on each side. Wind speed can use from less than 0.2m/s for calm weather to over 29m/s for storm conditions. A standard value of 29W/(m^2 K) for 6.7m/s wind is often used to winter design conditions. For natural convection at the inner surface coefficient h_i depends on the indoor air and glass surface temperatures and on the emissivity of the glass inner surface. Table A.5 shows the variation of h_i values for winter conditions, summer conditions, glazing high and types. Designers often use h_i =8.3W/(m^2 K), which corresponds to t_i =21°C, glass temperature of –9°C. For summer conditions, the same value [h_i =8.3W/(m^2 K)] is normally used, and it corresponds approximately to glass temperature of 35°C, t_i =24°C. If the room surface of the glass has a low-e coating, *hi* values are about halved at both winter and summer conditions (ASHRAE, 1999).

Table 3.2 Glazing – factor for various wind speeds (ASHRAE, 1999).

Wind speed, km/h		
24	12	0
U-Factor, W/(m^2 K)		
0.5	0.46	0.42
1.0	0.92	0.85
1.5	1.33	1.27
2.0	1.74	1.69
2.5	2.15	2.12
3.0	2.56	2.54
3.5	2.98	2.96
4.0	3.39	3.38
4.5	3.80	3.81
5.0	4.21	4.23
5.5	4.62	4.65
6.0	5.03	5.08
6.5	5.95	5.50

Estimate a representative *U-factor* for an aluminum-framed, double-glazing is clean glass and solar turquoise coating on a second surface and heat gray coating on a third surface. Total dimension is 1500mm by 4000mm and it occur four of 1350mm by 1350mm panes (true divided panels), each consisting of double-glazing with a 6-12-6mm air space and a metal spacer.

Tepekule office building information, assume that the dividers have the same *U-factor* as the frame, and that the divider edge has the same *U-factor* as the edge-of-glass. Calculate the center-of-glass (cg), edge-of-glass (eg), and frame areas (f), respectively.

$$A_{cg} = \left[4\left(94-13\right)\left(135-13\right)\right]/10^4 = 3.95\text{m}^2$$

$$A_{eg} = \left[4\left(94 \times 135\right)\right]/10^4 - 3.95 = 1.126\text{m}^2$$

$$A_f = \left[400 \times 145\right]/10^4 - 4 \times (94 \times 135)/10^4 = 0.724\text{m}^2$$

U_{cg}= 1.78 W/m^2 K (Table A.1)

U_{eg} = 3.40 W/m^2 K (Table A.7 center of glass 6. topic 2. column)

U_f = 5.2 W/m^2 K (Table A.4 aluminum frame double-glazing insulated)

$$U_0 = (U_{cg}A_{cg} + U_{eg}A_{eg} + U_f A_f)A_{pf}$$

$$U_0 = \left[(1.78 \times 3.95) + (3.40 \times 1.126) + (5.2 \times 0.724)\right]/4 \times 1.45$$

$$U_0 = 2.52 \text{ W/m}^2\text{K}$$

If our glass type was classic double and clear glasses; than we should take the heat transfer coefficient at the center of the glass as 2.78 W/m^2 K due to the Table.A.6 Topic 6 Column 1. Calculating is done below.

$$U_0 = (U_{cg} A_{cg} + U_{eg} A_{eg} + U_f A_f \ ) \ A_{pf}$$

$$U_0 = \left[(2.78 \times 3.95) + (3.40 \times 1.126) + (5.2 \times 0.724)\right] / \, 4 \times 1.45$$

$$U_0 = 3.20 \mathrm{W/m^2K}$$

If there is no certain knowledge about the total heat transfer coefficient of the glass; than we may use the numbers given at the standarts part of ASHRAE, 1999. From Table A7 it was used the heat transfer coefficient value of 3.21W/m^2 K.

It was released that; there was an acceptable difference between the ASHRAE standards and our calculated value. According to this; the value of the heat transfer coefficient for the fenestration was supposed to be acceptable.

CHAPTER FOUR
LIGHTING, TYPES AND PROPERTIES

4.1 Lighting

Lighting as a term; has been mostly used literally to get vision and to establish perceptual relationship between human and physical environment. Light is not just a physical quantity that provided sufficient illumination; it is a certain factor in human perception.

Daylighting; is bringing the daylight rays into a space via various means, that is available during the day. When sunlight reaches a certain low level, addition natural daylight with artificial light becomes necessary. Because lighting has a motivating factor in human life. Lighting is performed in various spaces such as; offices, schools, hospitals, traffic, security and almost all issues to establish comfortable visual conditions. In this work it was aimed to study the glazing properties to establish these conditions. Quality and quantity of light was examined firstly, then basic rules valid for general lighting issue formed in the specific area; workspaces (Ozturk, 2006).

4.2 Types of Lighting

A successful lighting scheme is made up of several layers: natural, general and public light. People would not notice the bad lighting but would know the symptoms: headaches and sore eyes, frustration in the places at not being able to see what are there and what they are doing (Ozturk, 2006).

4.2.1 Natural / Daylight

Daylight factor is the percentage of sunlight coming down to a reference point in a room, and is related with dimensions of window, its transmission, area of room, surface from which light is reflected. Daylight is an important part of natural light. Sun’s kinetically movement in an area is the show passing time and ray of light come the different angels (Ozturk, 2006).

Illumination’s additive effect to working occupier and its effect in creating the suitable effect for correct comprehension are absolutely accepted. High levels of daylight have an extremely positive effect on occupiers’ working performance and behavior. There are several ways to maximize natural light. Releasing light to come through windows without obstructions, removing secondary glazing which absorbs light, and choosing light and bright paint colors will affect how light a room is. To make the most of the natural light available in a space, firstly it is needed to know how to use it, and secondly remember that daylight changes throughout the year (Ozturk, 2006).

4.2.2 Artificial Lighting

Daylight had always been the defining agent. With the development of more efficient artificial light source, the knowledge that has been gained of daylight technology was joined to artificial light. Natural indoor lighting describes by windows and skylights, artificial indoor lighting means by lamps; electric lights. Lighting refers to the devices or techniques used for illumination comprising artificial light sources; lamps (Ozturk, 2006).

Long-term experiments on preferred levels of lighting in office have shown that even with daylight levels in the middle range of 500lux, people will switch on artificial light as well. From this it can be understood that the need for light is stronger in artificially lighted rooms than the value required by the standards.

The beneficial effects of light are undisputed. From an economic point of view, however, opinions differ:

- Daylight helps to save energy. If a lighting level of 500lux can be achieved through the incidence of daylight, artificial light can be switched off reduced this one view
- Daylight intensifies feelings of comfort. Being able to experience daylight changing with the time of day and to have a view outside are positive components of daylight.

4.2.3 Lighting Design

Lighting design as it applies to the built environment, also known as lighting design and is both a science and an art. Proper comprehensive lighting design requires consideration of the amount of functional light provided, the energy consumed, as well as the imaginary effect provided by the lighting system. Office buildings are worried about saving money through the lowering of energy consumption used by the lighting system (Ozturk, 2006).

These artificial lighting systems should also think the impacts of, and ideally be integrated with, daylighting systems. Lighting design requires the consideration of several design factors:

- Tasks occurring in the environment
- Occupants of the environment
- Initial and continued operational costs
- Aesthetic designer impact
- Physical size of the environment
- Surface characteristics (reflectance, specularity)
- Maintenance capabilities
- Operating schedule of the building

Table 4.1 Illuminance level (E_m), for office (Manav, 2005)

Building Type :OFFICE	**E_m(lux)**
Circulation area, photocopy	300
Writing, Reading, data input etc.	500
Drawing	750
Computer Room	500
Meeting/Lecture Room	500
Information	300
Archive	200

4.3 Office Lighting Systems

4.3.1 Lighting Effects

Lighting effects, rather than just equipment, enables us to describe the intended results of the lighting system, not just the means. For instance some effects are Direct Lighting, Indirect Lighting, Direct/Indirect Lighting, Diffuse Lighting etc. In office lighting, the desk represents the most common work plane for measuring light levels (Ozturk, 2006).

4.3.2 Ideal Office Lighting Criterion

Before putting in order the basic rules for “ideal office lighting”, we must assign its meaning or what we are trying to explain. The term “ideal office lighting” includes conditions such as; employee’s visual comfort, interior ambience and energy consumption of the lighting systems. “Ideal office lighting” has to satisfy employee, employers in both physical and psychological ways.

- As “subjective brightness” evaluation, is not a measurable quantity but perceived quality, it is concerned with issues taking place in visual area such as; surface and objects' reflectance factors, colors, location and illuminance level dispersion of light source (natural-artificial) etc.

- Lighting system must integrate with designer. The lighting system must be arranged suitable for office building's structure, interior office types, chosen furniture and properties.
- Workplace plane and adjacent environment every part in visual area must not have the same illuminance level; there must be hierarchy among focal points. Thus; we can interfere with monotonousness.
- With automation systems, it is possible for us to adjust both daylight and artificial light at a level; also they offer more comfortable and effective workplaces (Carlson, Sylvia & Verne, 1991).

4.3.3 Office Performance

Suspended indirect lighting can cause excessive ceiling brightness which reflects on computer screens, reducing user comfort and productivity. A furniture mounted unit can spread light smoothly across the ceiling to eliminate these hot spots. They balance the brightness of the ceiling with the workstation and provide comfortable illumination to surrounding spaces (Ozturk, 2006).

When workstation surfaces are brighter than their surrounds, occupants are drawn to their work and distractions are reduced. This helps to direct office speech into sound absorbing partitions, and no recessed lighting means more acoustical ceiling tiles.

4.3.4 Ideal Luminance at Workplace

Luminance means the amount of light that strikes an object or surface. The IES (Illuminating Engineering Society of North America) recommends luminance levels in a range depending on the task. The office environment includes different visual activities. Office work requires various luminance levels over a wide range;

too much light should not wash out the screen and make nearby papers brighter and uncomfortable for vision. On the other hand, graphic design and other visual performances require much more.

In general, luminance over 500lux is most effectively obtained by a combination of local and general lighting systems. Office and furniture surfaces should be of light color and high reflectance avoiding high contrast with visual tasks and also reducing the output required of the lighting system, making it more economical and energy efficient. Providing visual interest through selective use of highlights and accent colors makes a space more appealing and enhances workers' sense of well-being. Luminance should be relatively uniform to prevent distracting bright and dark patches. Uniformity is the ratio between the minimum and average levels of luminance (Ozturk, 2006).

Figure 4.1 An office with indirectly lighted ceiling

4.4 Daylight Factor Measurement

The effect of glazing type on electric lighting demand was studied in this section. There were a lot of variable for performed to investigate the effect of window area, window transmittance, orientation, wideness of office. When the electric lights are controlled, electricity consumption is further reduced; the impact of automatic control of dimmable lighting on cooling load was also investigated. The selection of window size for each orientation was an important criterion. Window size is expressed as window- to-wall ratio (WWR). Firs of all, three factors were examined for daylight availability:

(i) the ability to provide adequate daylight into the space;
(ii) the reduction in electricity demand for lighting and
(iii) the impact on peak heating and cooling demand and energy consumption.

Although, there are many other parameters which should be taken into account when selecting window size, such as glare, thermal comfort, or even aesthetics, those should be evaluated at a second step.

The lighting system has been adjusted for maintaining a constant illumination level of 500lux on the working desk for this study. When the daylight level at the work desk exceeds 500lux, the artificial lighting is switched off manual. Furthermore the values measured by light meter on the working desk have been checked at each measured point every 30min., if the illumination level drops below the limit of 500lux the artificial lighting is switched on. An experiment has been conducted for 500lux illumination level on the working desk with daylight, and 5kWh energy consumption has been recorded in a day which is read of electricity meter every experimental days (Ozturk, 2006)..

4.5 The Parameters Influencing the Artificial Lighting Consumption

4.5.1 Effect of the Window Orientation on the Lighting Energy Consumption

The north oriented room consumption is always higher than from other orientations. Then, coming in this order, the orientation is east, west and south. When there is a large amount of available daylighting in the room, coming from a large window are or/and a high glazing transmittance, the orientation influence can be minor or even non-existent. During high clear hours, the daylighting availability is so important that the diffuse and the external reflected lighting portions, added to the internal reflected lighting are sufficient to reach the lighting demand (Bodart & Herde, 2001).

4.5.2 Effect of the Office Width, Depth on the Lighting Energy Consumption

When the room width increase, the electric lighting consumption per floor in square meter decreases. But the office depth effect is not high value according to the width of the window. This evaluation is true for every facade configuration. Effect of the room depth is shown in Figure 4.2 (Bodart & Herde, 2001).

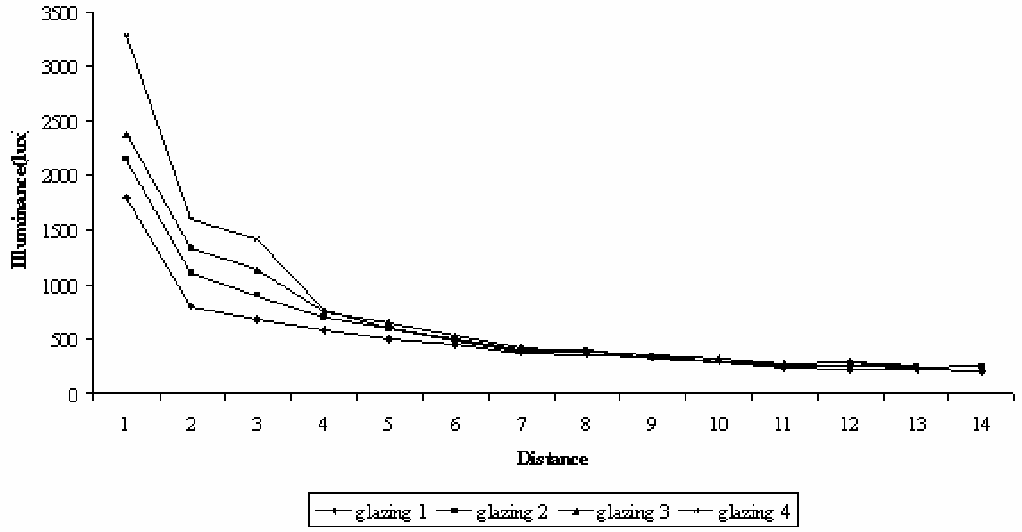


Figure 4.2 Illuminance distributions on the work plane distance from façade (18.07.2008).

4.5.3 Effect of the Room Wall Reflection Coefficients on the Lighting nergy Consumption

Light colored internal surface are always helpful for the lighting consumption. The lighting consumption difference between facade configuration and room size is higher for dark rooms. The light color has high reflection coefficient and this provide that lighting energy consumption decreases (Bodart & Herde, 2001).

4.5.4 Influence of the Glazing Transmission Factor on Lighting Consumption

The transmission of the windows has a significant impact on daylighting induced, the energy saving. The artificial lighting consumption increases when the lighting transmission factor decreases however, this consumption variation is not linear and the lighting calculation is based on a necessary lighting level (500lux). Figure 4.3 shows the lighting artificial consumption for the four orientations (Bodart & Herde, 2001).

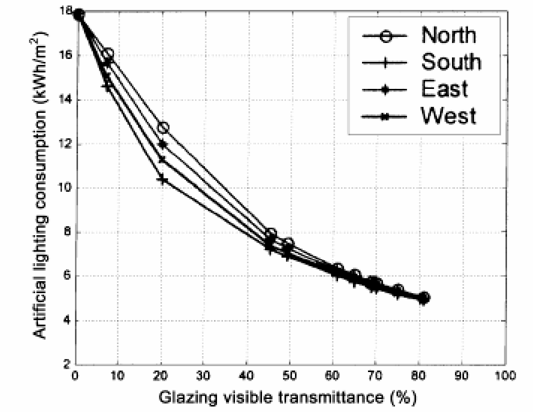


Figure 4.3 Evolution of artificial lighting consumption of the glazing visible transmittance (Bodart & Herde, 2001).

4.5.5 Parametric Analysis

This thesis study contains various types of glazing for offices. The perimeter and floor areas ratio of office is defined the geometric characterization of the office. The intent was to obtain a wide range of transmittance values to get broad representation of available numerical data. The Table 4.2 lists the window areas and four different types of glazing used in the experimental study (Ihm, 2008).

Table 4.2 Window transmittance and range of A_w/A_p and A_p/A_f ratios used in the experimental study

Glazing	**Label**	**Visible Transmittance**	**Window to Perimeter Floor area ratio (A_w/A_p)**	**Perimeter to Total Floor Area Ratio (A_p/A_f)**
Clear	C	0.78	0.4	0.3
Heat Control	H	0.77	0.4	0.3
Solar Control	S	0.16	0.4	0.3
Heat and Solar Control	H&C	0.69	0.4	0.3

A_w/A_p: Window to perimeter floor area: This parameter provides a good indicator of the window size relative to the daylight floor area.

A_p/A_f: Perimeter to the floor area: This parameter indicates the extent of the daylight area relative to the total office floor area. Thus when $A_p/A_f = 1$, the whole building can benefit from daylighting (Ihm, 2008).

These measurements were carried out for over eight months period during the year of the 2008. For each experimental day was hourly measurement from 8:00 am to 6:00 pm. All the measurements were performed at desk height (working plane) of 0.762m. Measurement shows that the illuminance level is higher different to the windows than at the back of the room (Ihm, 2008).

To determine the percent savings, f_d, in annual use of artificial lighting due to daylighting; implementation of using daylighting controls in office buildings, (Krarti et al, 2008) found that the following equation can be used:

$$f_d = b\left[1 - \exp\left(-a\ \tau_w A_w / A_p\right)\right] A_p / A_f \tag{4.1}$$

where is:

τ_w : the visible transmittance of the window glazing

A_w/A_p : the window to perimeter floor area.

A_p/A_f :the perimeter to total floor area.

Thus, when $A_p/A_f = 1$, the whole building can benefit from daylighting; a and b are coefficients that depend only on building location and control strategy. The coefficient b represents the percent of time in a year that daylighting illuminance level can provide the required design illuminance set point, 500lux. In other terms, the coefficient b measures the daylighting availability during building operating hours in a given geographical location (Pyonchan, Abderrezek & Moncef).

CHAPTER FIVE
EXPERIMENTAL SET-UP

5.1 Office Description

Tepekule is one of the businesses building in İzmir (38^o 27’ 02.48’’N latitude and 27^o 10’ 13.37’’E longitude) (Figure 5.1). One of offices was arranged for an experimental study from Tepekule. Building was selected for study and measurements because of the three reasons: It is relatively big-size building with a glazed envelope on four sides. Secondly, the designer was intended to express a high-tech appearance and feeling of expansiveness by applying glazing to this building envelope design as the Chamber of Mechanical Engineers in İzmir. Finally even though it has been designed with high quality, its occupants have suffered from the poor illuminance at indoor environment.

Tepekule has twenty floors and height of 69.70m. The seven floors over the ground floor are belonged to the Chamber of Mechanical Engineers. These are used for business, exhibition and conference purposes. The first of two floors under the ground floors are used to garage. All of the ten floors over the Chamber of Mechanical Engineers are employed for offices. The top of the floor is used for local service (Figure 5.2).

Figure 5.1 View of Tepekule

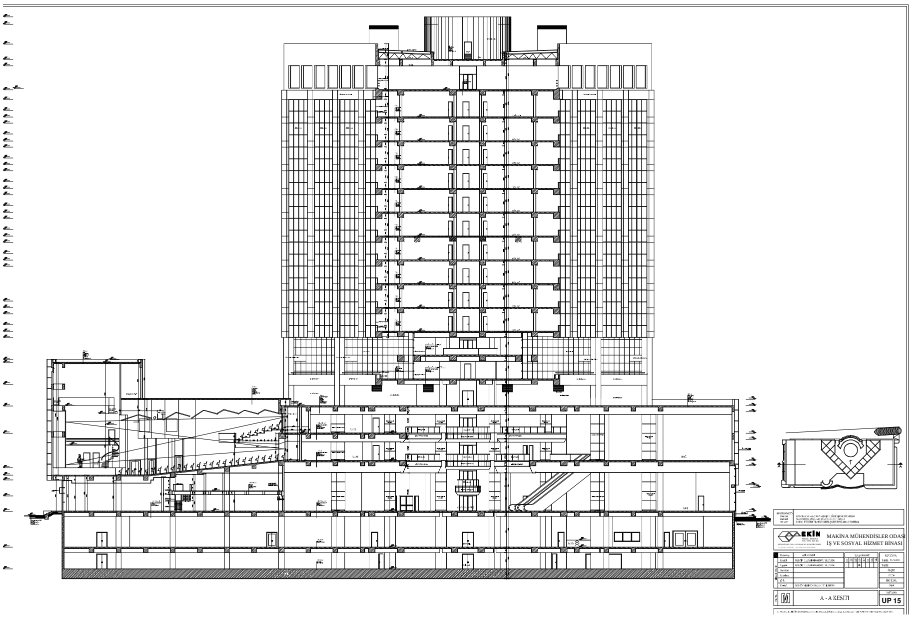


Figure 5.2 Section of Tepekule

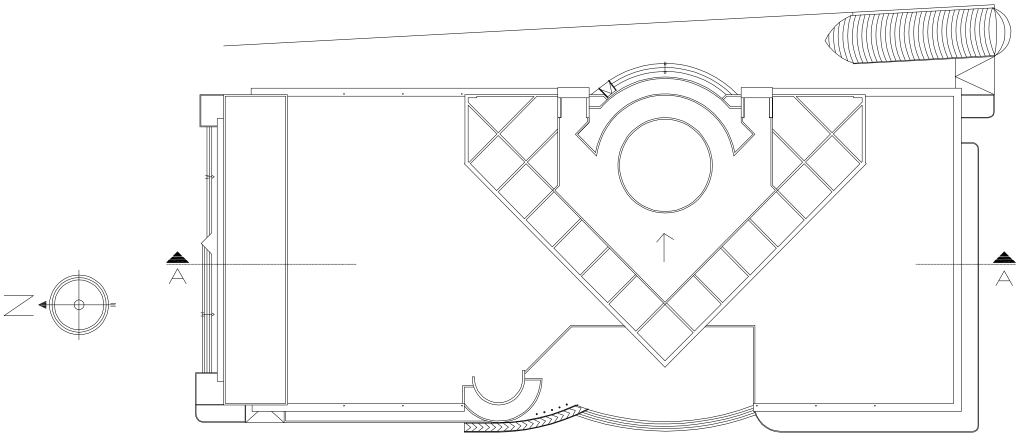


Figure 5.3 Tepekule settlement plan

The office floors have two different types of settlement which are 50m^2 and 100m^2. The offices at the corner side are 100m^2 and the offices at other sides are 50m^2 (Figure 5.3). First type of the office has an area of 50m^2 with a width of 5m, the length of 10m, and height of 3.15m. The offices with the area of 100m^2 have width of 10m, length of 10m, and height of 3.15m (Figure 5.4). Small offices are oriented to southwest and southeast side and windows are totally 6m^2. Big offices are oriented both southwest and southeast and windows are two different directions to totally 12m^2.

The office, number 407 at the tenth floor of Tepekule was selected for the experimental study (Figure 5.5). Office was provided for this experiment by the Chamber of Mechanical Engineers. There has not been any occupier in the office during the experinetal study. Office is at the direction of the sea side. Windows with double-pane off-line coated reflective solar control glazing are placed in the southwest facade, 1m ×1.5m dimension four pieces at the office. The glazing is middle degree of dirty. The flame of the window is aluminum and non-opened.

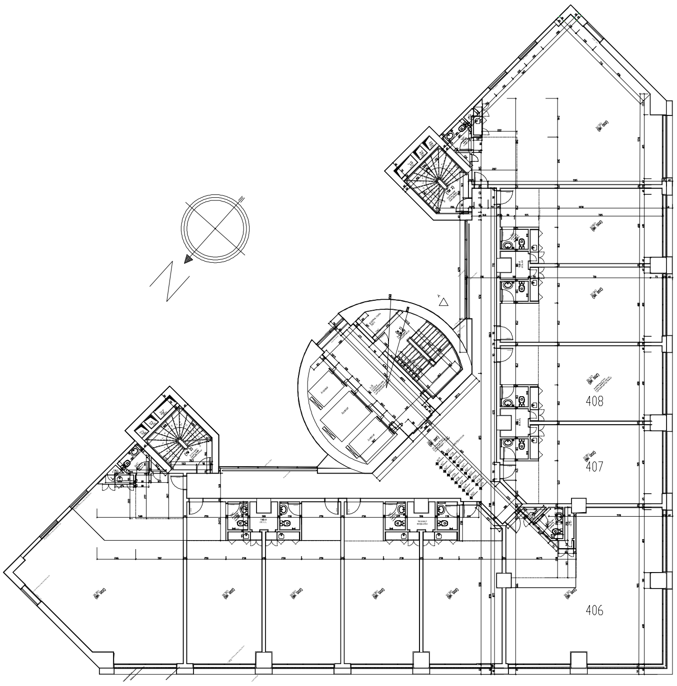


Figure 5.4 Section of office floor

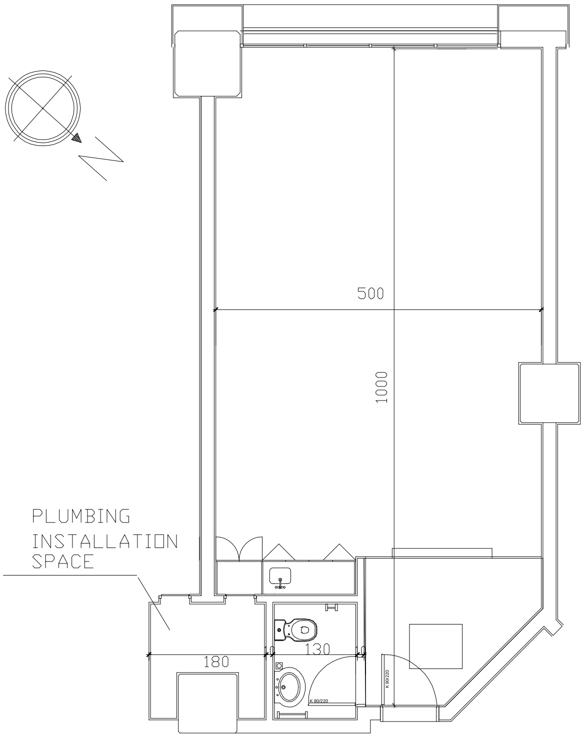


Figure 5.5 Office plan (in mm)

Table 5.1 Geometrical and optical properties of the office envelope

Envelope element	**Total area**	**Reflectance**
Ceiling	$50m^2$	0.9
Opaque walls	$95m^2$	0.7
Floor	$50m^2$	0.2

The ceiling color of the office is white, walls are light pink and floor is concrete (reflection coefficient of envelope $\rho_c = 0.9$, $\rho_w = 0.7$, $\rho_f = 0.2$ respectively) (Table 5.1). Since the office has not been used for occupiers already; there have not been any furnitures and equipments during the experiments. When the experiment was done, it was behaved as there were occupiers in the office, while the air-condition system and artificial lighting used. The illumination system consists of six luminaries with incandescent lamps, each has 100W, which is marked as plus in Figure 5.6, Figure A.7 and Figure A.8. Luminaries are positioned in two rows: The first row is parallel to the windows and the second one is suspended under the ceiling with the length of 0.6m. All of the lamps have turned on during the working hours. The electric consumption is counted with an electric meter which has owned by each office.

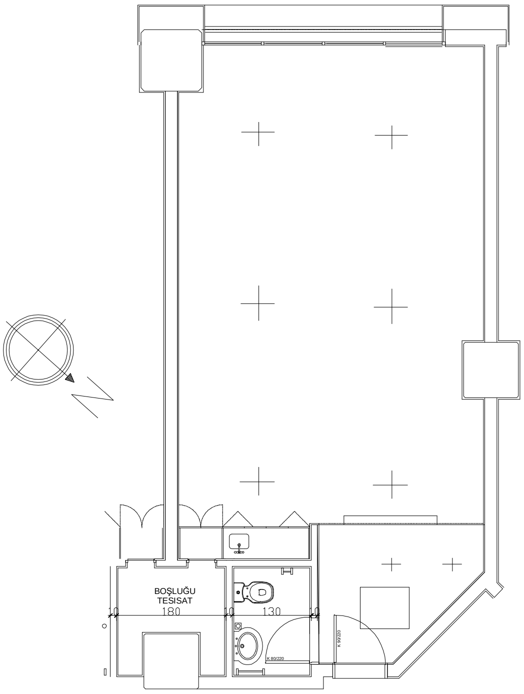


Figure 5.6 Incandescent bulbs plan of the office

For temperature measurement, T-type thermocouples were installed at each measurement point of the office as shown in Figure 5.7, Figure A.7 and Figure A.8. The thermocouples were set up nine points of the indoor office which were numbered from one to nine. The thermocouple numbered nine was settled in interior surface of the glass. Six of the thermocouples, which were hanged up the incandescent lamps with the distance of 60cm from the ceiling, were set up inside of the office. Thermocouples numbered one and two were set up to exhaust vent and intake vent of air-condition system. A data logger was used to measure the temperature at each measurement point at every 30min. Each one of the measurements was taken twenty four values in four minutes. After each measurement, the average value was calculated and this average value was used in the next step of calculations. Outdoor temperature was taken from Ege University Institute of Solar Energy.

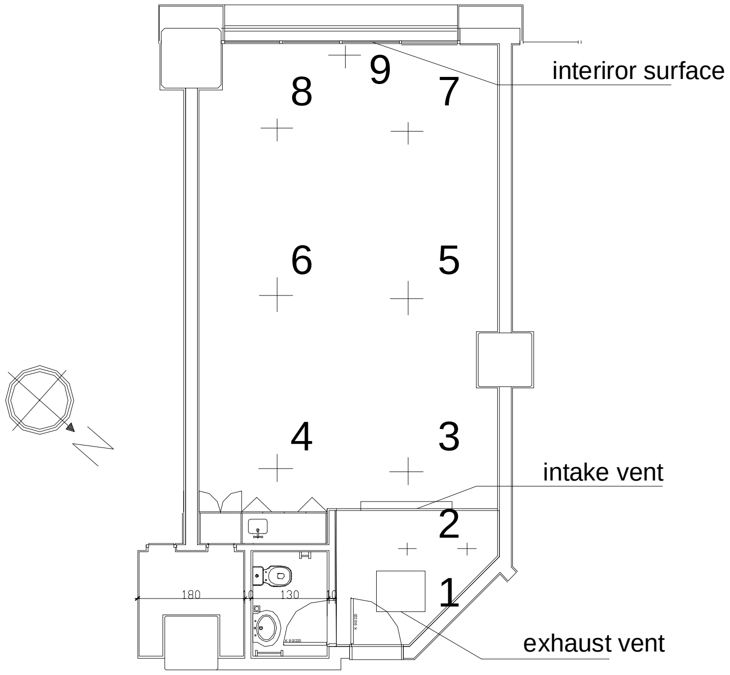


Figure5.7 Thermocouples' plan of the office

Illumination values (daylight + artificial light) were measured by light meter from the desk height (working plane). Measured points of the office are as shown in Figure 5.8. Vertical lines were installed at center of each window. The intersection points of vertical lines and five horizontal lines which are installed in front of the window region distance of 75cm and the other lines were distance 150cm. The intersections of the lines were measurement points for the lighting values. These values were recorded continuously and stored at every 30min.

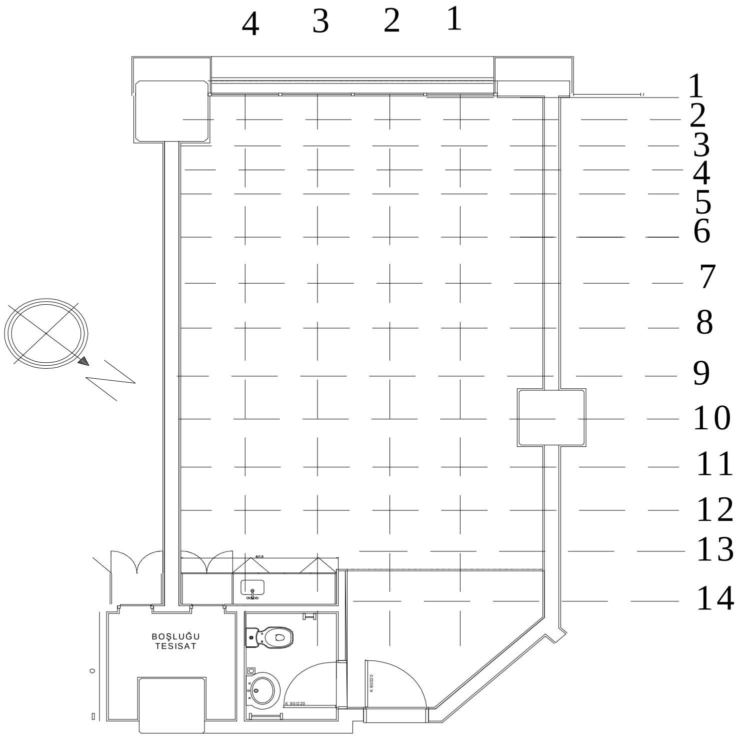


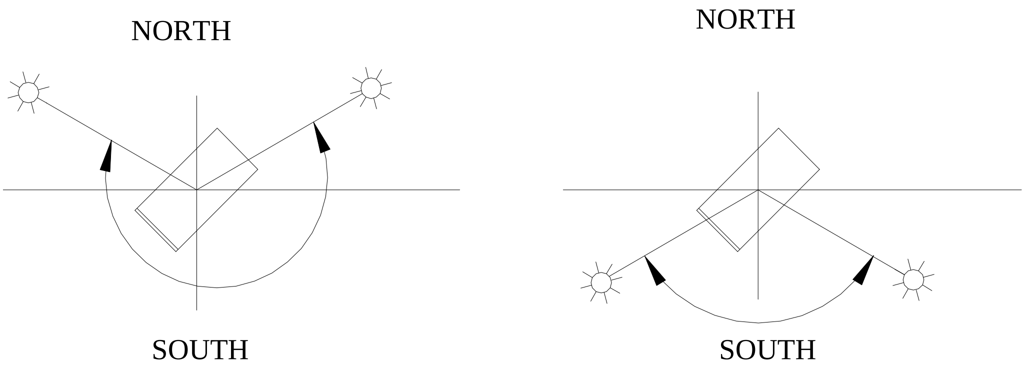
Figure 5.8 Measurement of illuminance plan of the office

Table 5.2 Technical property of air condition interior unite

Cooling capacity	5.6 kW	19,000 btu/h
Heating capacity	6.3 kW	21,500 btu/h

The indoor unit of air-condition system is dropped ceiling type. Interior unit's absorbing and intake vents are set up through the hidden ceiling which is done entry of the office. The intake vent is providing the flow of conditioned air to the office space from the front side of the hidden ceiling. The exhaust vent is 60cm x 60cm dimension and set up at the bottom surface of the hidden ceiling. By this way, a circulation of air inside the office is provided.

The office was selected according to the solar gain and daylight design criteria from glazing. It has been designed to be rectangle shape and elongated along northeast and southwest axis. During winter period, the building needs maximum energy of solar. The lighting requirement of the office has been based on the glazing unit of the building. The site is suitable for the location of the building since there are not high buildings which can overshadow it. The site views the sea. These are advantageous conditions for the office. Figure 5.9 shows the paths of the sun for İzmir. For summer, considering in the time of sunrise and sunset, the sun has the azimuth angle of about 120^o, and for winter the sun has the azimuth angle of 60^o. These are the critical angles to be considered in a building design in terms of thermal condition (Karadağ, 2006).



Summer sun path
Office azimuth angle

Winter sun path
Office azimuth angle

Figure 5.9 The path of the sun of summer and winter from office

5. 2 Building Components

5. 2. 1 Wall Components

Heat transfers to/from the office through two walls: The first one is the outdoor wall and the second one is wall along the entrance. The neighbor offices, are using the air-condition system and that’s why there is not any heat loss/gain from them. The following criteria have been taken into consideration while determining the wall material. Heat conductivity coefficient of 15m^2 outdoor wall (Figure 5.10) is 0.488W/mK, and 20m 2 indoor walls (Figure 5.11), 0.806W/mK (TS 825).

Aerated concrete has been chosen as the wall material. Technical properties are given of the wall below;

The density (when it is dry)	: 500kg/m^3
Heat conductivity coefficient	: 0.22W/mK
Thickness	: 20cm

For wall insulation, curtain wall facades have been used. The reasons for utilizing curtain wall facades are to perform better light transparency, appearances, ventilation, heat and noise.

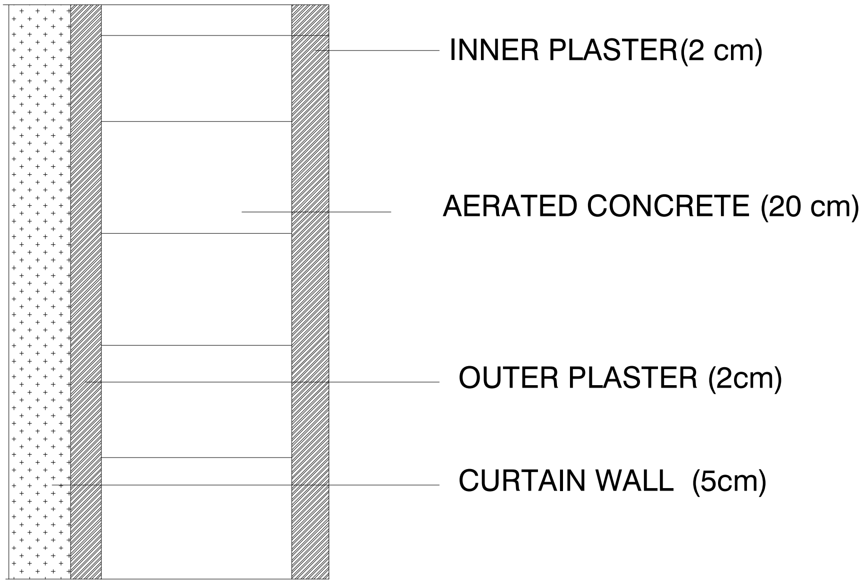


Figure 5.10 Section of outdoor wall

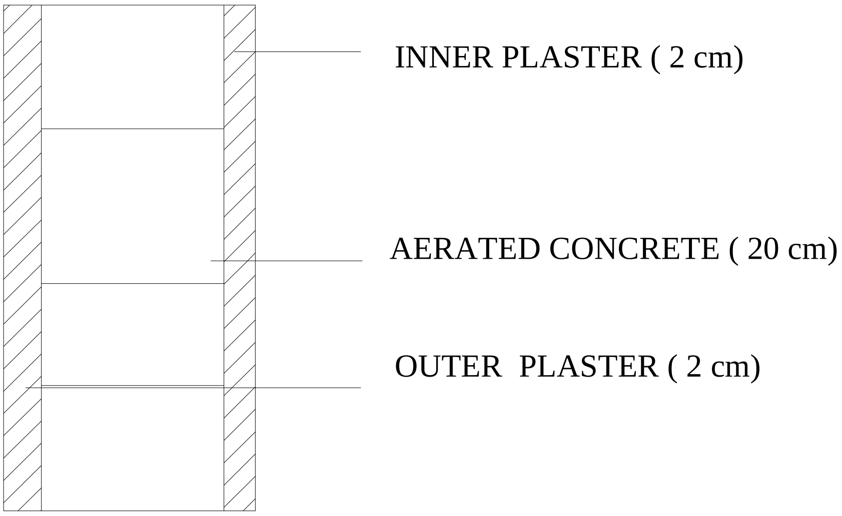


Figure 5.11 Section of indoor wall

5. 2. 2 Window Components

The energy efficiency of windows is usually represented with their *U-Factor*. There are some factors that affect the U-value of a window.

- The type of the glazing material
- The number of layers of glass (double glazing)
- The size of the air space between the layers of the glazing
- The thermal resistance or conductance of the frame and spacer materials
- The air tightness of the installation.

In the experiment, double glazed window with 12mm gap glazing, which was coded ITR120 and gave the heating and lighting properties in Table A2, has been used Heat transfer coefficient of glazing is 2.52W/m^{2o}C which was calculated at the chapter third (ASHRAE,2001).

5. 3 Air-Condition System

Cooling and heating of the office is made with an air-condition system. Ventilation is the preferred to spring season because it is not necessary any cooling and heating in this office. Solar gain of the glazing function of the building added excessive heat gains in summer, because of the glazing solar transmittance property.

For air-condition system design;

- Wind speed and its direction in the building site,
- Other buildings and plants surrounding the building (if exists),
- Type of windows utilized,
- Calculation of solar heat gain
- Calculation of cooling and heating load

Natural ventilation is not possible because windows are non-opened. Infiltration or overload under worst conditions is not entered the indoor of the office. Because of that mechanical ventilation is obligatory. Size of the vents is a function of a number of factors, the aim of the place and the area of the office, the number of the occupier. The intake vents should be high and the exhaust vents low. The intake vent is turned towards to the office space and the exhaust vent is placed to the entry of the office.

CHAPTER SIX

CALCULATION METHODS

In this chapter, the required calculations for our project will be done so as to gather qualified information about the effectiveness of the glazing system on heating, cooling and ventilation. These calculations are done according to three seasonal periods, winter, summer and spring. As the office is set up dynamic calculation principles and this chapter will be devoted to solar calculations (Karadağ, 2006).

6.1 Solar Calculation

The basis heating resource of the office is the solar energy from the glazing so solar radiation is the base interest in solar calculations. Beam radiation is the solar radiation received from the sun without having been dispersed by the atmospheric processes such as clouds. It is defined direct solar radiation. Diffuse radiation is the solar radiation received from the sun after its direction has been changed by dispersing by atmospheric elements such as particles, dust, smoke and water vapor. Absorption of radiation in the atmosphere in the solar energy spectrum is due largely to ozone in the ultraviolet and to water vapor and carbon dioxide in bands in the infrared (Duffie & Beckman, 1991).

Reflected radiation is either diffusing or beam radiation reflected from the foreground onto the solar aperture as shown in Figure 6.1. Calculation of these three types of solar radiation is very important in determining the efficiency of solar resource for heating and cooling. Radiation incident on a surface that does not have a direct view of the sun consists of diffuse and reflected radiation. Solar calculations are quite complex and have different variable to consider. Therefore, in order to examine them in detail, they are studied under separate sections (Duffie & Beckman, 1991).

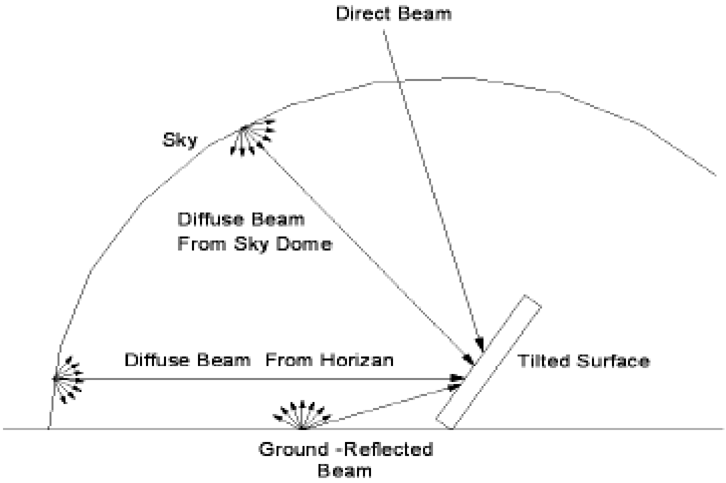


Figure 6.1 Direct, diffuce and ground-reflected radiation on a tilted surface (Duffie and Beckman, 1991)

6.1.1 Calculation of Beam and Diffuse Components of the Total Radiation Measured on a Horizontal Surface

Clearness of the sky has an important role in determination of beam and diffuses components of the total radiation, and it is expressed by a ratio named as “clearness index (K_T)”. The ratio of monthly average daily radiation on a horizontal surface to the monthly average daily extraterrestrial radiation is defined as monthly average clearness index (Karadağ, 2006).

The data H, H_0 and I_0 are from measurements of total solar radiation on a horizontal surface, that is, the commonly available pyranometer measurements. Values H, H_0 and I_0 can be calculated by the methods of Section 2.4.

6.1.2 Beam Radiation Acting on a Tilted Surface

Solar radiation at a time, a place inside the atmosphere depends on the geometrical relationship and orientation of the surface. Maximum solar gain is obtained on surfaces where solar radiation comes with right position of the sun. In some cases, investigation of the sun on a right axis (North-south, west-east, horizontal, vertical, tilted, polar etc.) may provide obtaining more solar energy from the system (Karadağ, 2006).

To find of the solar radiation values of vertical and solar azimuth angle surfaces and the other solar and surface angles for offices’ position. Generally it is easy to find out the data for measured and estimated radiation on normal direction or for horizontal surfaces. These radiation data must be formulated for tilted surfaces to vertical surface (Karadağ, 2006).

It formulates beam radiation data for vertical surfaces. For horizontal surfaces,

$$\cos\theta_Z = \frac{H_b}{H_{bt}} \tag{6.1}$$

For tilted surfaces,

$$\cos\theta = \frac{H_{bt}}{H_{bn}} \tag{6.2}$$

Where

H_{bn} :Beam radiation at normal incidence (W/m^2)
H_b :Beam radiation on horizontal surface (W/m^2)
H_{bt} :Beam radiation on tilted surface (W/m^2)

From these two equations, the geometric factor R_b, the ratio of beam radiation on the tilted surface to that on the horizontal surface at any time, can be calculated.

$$R_b = \frac{H_{bt}}{H_b} = \frac{\cos\theta}{\cos\theta_z} \tag{6.3}$$

If R_b factor is known, then beam radiation on the surface can be calculated with the following formula;

$$H_{bt} = H_b \times R_b \tag{6.4}$$

If the surface faces the south, then R_b factor at any time is,

$$R_b = \frac{\cos\theta_T}{\cos\theta_Z} = \frac{\cos(\varphi-\beta)\cos\delta\cos\omega + \sin(\varphi-\beta)\sin\delta}{\cos\varphi\cos\delta\cos\omega + \sin\varphi\sin\delta} \tag{6.5}$$

The equation for diffuse radiation from the sky dome for surfaces with β slope is, $H_d\left(\frac{1+\cos\beta}{2}\right)$ where H_d is the diffuse radiation on horizontal surface (Duffie and Beckman, 1991).

Tilted surfaces also receive reflected radiation from the ground and other substances. If reflection coefficient for reflected radiation that tilted surfaces receive isρ, then the ratio of ground-reflected radiation to surfaces with slope β is, $\rho\left(\frac{1-\cos\beta}{2}\right)$ and ground-reflected radiation is, $(H_b + H_d)\rho\left(\frac{1-\cos\beta}{2}\right)$.

The sum of beam, diffuse and reflected radiation gives total solar incidence radiation on a tilted surface;

$$H_T = H_b\, R_b + H_d\left(\frac{1+\cos\beta}{2}\right) + (H_b + H_d)\rho\left(\frac{1-\cos\beta}{2}\right) \tag{6.6}$$

where $H = H_b + H_d$ gives the sum of beam and diffuse radiation on horizontal surfaces coming from the sky dome.

Liu and Jordan systems are developed to predict monthly average daily total radiation on tilted surfaces. This method monthly average clearness index K_T

depending on the ratio of diffuse radiation to total solar radiation (Duffie & Beckman, 1991).

For $\omega_S \leq 81.4^{o}$ and $0.3 \leq \bar{K}_T \leq 0.8$

$$\frac{\bar{H}_d}{\bar{H}} = 1.391 - 3.560\bar{K}_T + 4.189\,\bar{K}_T^2 - 2.137\,\bar{K}_T^3 \qquad (6.7.a)$$

For $\omega_S \geq 81.4^{o}$ and $0.3 \leq \bar{K}_T \leq 0.8$

$$\frac{\bar{H}_d}{\bar{H}} = 1.311 - 3.022\,\bar{K}_T + 3.427\,\bar{K}_T^2 - 1.821\,\bar{K}_T^3 \qquad (6.7.b)$$

$\bar{H}_d$ is the monthly average diffuse radiation on horizontal surfaces.

Klein extpanded the equation of Liu and Jordan to calculate monthly average daily radiation on tilted surfaces to be used in solar process design procedures (Özbalta et al. 2004). If the diffuse and ground-reflected radiation is assumed to be isotropic, then the monthly mean solar radiation on a tilted surface can be calculated with the following equation (Karadağ, 2006).

$$\bar{H}_T = \bar{H}\left(1 - \frac{\bar{H}_d}{\bar{H}}\right)\bar{R}_b + \bar{H}_d\left(\frac{1+\cos\beta}{2}\right) + \bar{H}\rho\left(\frac{1-\cos\beta}{2}\right) \qquad (6.8)$$

Table 6.1 Property of wall

Azimuth *γ*	**Tilt *β***	**Orientation**
45^{o}	90^{o}	south-west fasing wall

Therefore, monthly average absorbed radiation, *S* can be found by multiplying monthly average solar heat gain factor, *SHGF*, and monthly average incident radiation on tilted surface ($\bar{H}_T$).The tilted surface is defined in Table 6.1.

$$\bar{S} = SHGF(\bar{H}_T) \qquad (6.9)$$

The *SHGF* is needed to determine the solar radiant heat gain through a window’s glazing system. The coefficient should be included with the *U-Factor* and other instantaneous performance properties in any manufacturer’s description of a window’s energy performance. Because the optical properties as and τ_S vary with angle of incidence. Because the optical properties as and τ_S vary with angle of incidence θ (defined as the angle between the rays incident on the glazing and the normal (perpendicular) to the glazing), the solar heat gain coefficient is also a function of angle of incidence. Once the incident irradiance and *SHGF* are known for the angle of incidence, the solar gain can be computed with Equation (6.9). The direct beam solar heat gain coefficient *SHGF* is a characteristic of each type of fenestration and varies with the incident angle, because transmittance and absorptance of the glazing material depend on the angle of incidence θ (Karadağ, 2006).

$$SHGF = \tau + U\alpha / h_0 \tag{6.10}$$

For double glazing

$$SHGF = \tau + U\alpha / h_0 + \left[(U / h_0) + (U / h_s) \right] \alpha_i \tag{6.11}$$

For shaded glazing materials and other more complex fenestration, *SHGF* could be calculated for standard conditions and the result of these calculations were given at the product catalogues. The angle of incidencele’s change values were found with the help of diagrams which were given in Solar Engineering of Thermal Processes. The diagrams could also be seen in Appendix, Figure A.1, and Figure A.2. To prove the truth of these calculated values; an extra experiment was made. This experiment was defined at Chapter 8.

6.2 Heat Loss and Heat Gain Calculations

Thermal system of a building is formed by the combination of various factors as Figure 6.2. Quantities of main heat flow are listed below (Carroll, 1982):

- Q_i : Internal heat gain from electric lights, people, power equipment and appliances.
- Q_s : Solar heat gain through fenestration areas and, conduction heat gain through roofs and external walls.
- Q_c : Conduction heat gain or heat loss through the enclosing elements, caused by a temperature difference between outside and inside.
- Q_v : Ventilation heat gain or heat loss due to or mechanical ventilation and infiltration.
- Q_m : Mechanical heating or cooling produced by some energy-based installation.

The mathematical description the monthly required auxiliary heat by calculating the heat lost and heat gained through various component of the building is expressed by ;

$$Q_t = Q_i + Q_s \pm Q_c \pm Q_v \pm Q_m \tag{6.12}$$

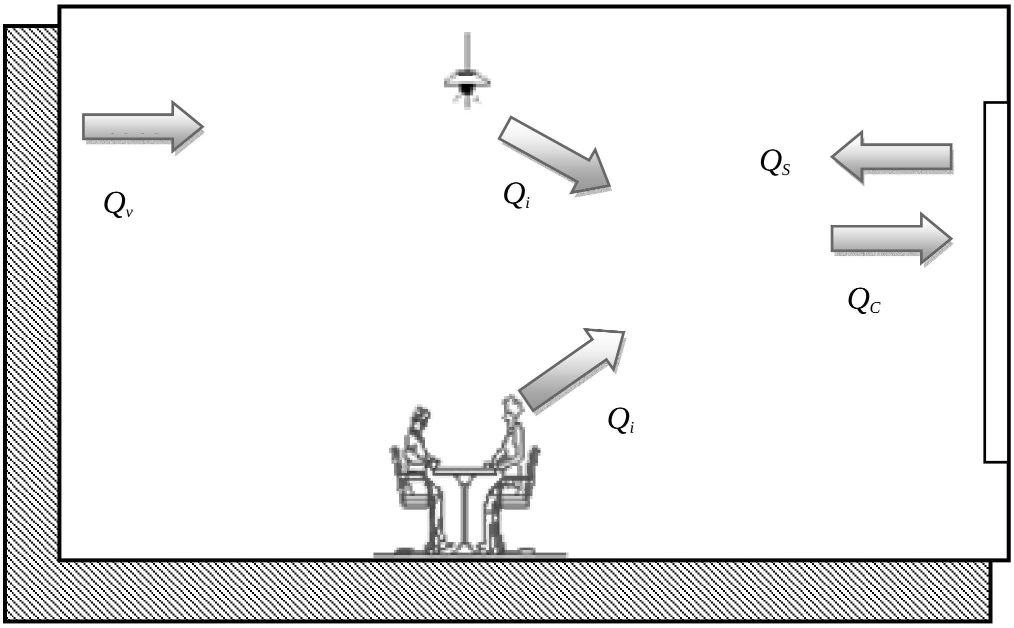


Figure 6.2 Termal system of the office

6.2.1 Conduction Heat Gain or Loss (Q_c)

The heat loss by conduction and convection heat transfer through any surface is given by:

$$Q = UA\left[T_i - T_o\right] \tag{6.13}$$

where;

Q: Heat transfer through walls, roof, glass, floor, etc (W)

A: Surface areas (m^2)

U: Heat transfer coefficient (W/m^2°C)

T_i: Indoor air temperature (°C)

T_o: Outdoor air temperature (°C)

Heat transfer through external walls, indoor wall the different heat, windows to the external wall depends on:

- Difference between room air temperature and ground temperature/outdoor air temperature,
- Materials of walls, windows,
- Conductivity of the surrounding earth.

6.2.2 Infiltration and Ventilation Heat Loss

The total heat loss due to indoor- outdoor air exchange, Q_v can be calculated by:

$$Q_v = Q_{\inf} + Q_c \tag{6.14}$$

where;

Q_{inf} : Infiltration heat loss (W)

Q_c : Ventilation heat loss (W)

Natural ventilation was not used and infiltration has been ignored (come from door) only mechanical air ventilation was considered for total calculations which are given by;

$$Q_c = V \rho c_{pa} (T_i - T_o) \tag{6.15}$$

where;

V : Volumetric air flow rate (m^3)

c_{pa} : Specific heat capacity of air at constant pressure, (J/kg^{o}C)

ρ : Air density (kg/m^3)

6.2.3 Internal Heat Gain

The internal heat gain is divided into three main groups; occupants, lights and equipments which is given by;

$$Q_i = Q_p + Q_{light} + Q_e \tag{6.16}$$

where;

Q_i : Internal heat gain

Q_p : Heat gain from people

Q_{light} : Heat gain from lightening

Q_e : Heat gain from equipment

6.2.4 Passive Solar Gains

Total solar gain (Q_s) equations for all orientations were mentioned in the previous section. Passive solar gains per square meter was calculated parallel to glazing areas exposed to solar radiation for three cases – north-facing, south-facing of the office.

6.3 Lighting Demand

The lighting of the office was used during the whole work time. Daily usage of lighting was calculated as 5 kW. The monthly usage value of lighting was accepted as certain and 100 kW.

CHAPTER SEVEN
RESULTS AND ANALYSIS

7.1 Results

Steps that were followed in calculations of the project were;

- Calculation of useful solar gains over heating season and calculation of increase in cooling load due to solar gains,
- Calculation of internal gains
- Calculation of total heating demand over heating season and cooling demand over cooling season,
- Calculation of total demand of additional lighting demand
- Calculation of overall energy savings.

Office consists of one zone and calculated living space (Figure 7.1). Wall of offices are used two different types, which are named indoor and outdoor, for heat gain and heat loss calculations. Offices outdoor is facing the south-west side.

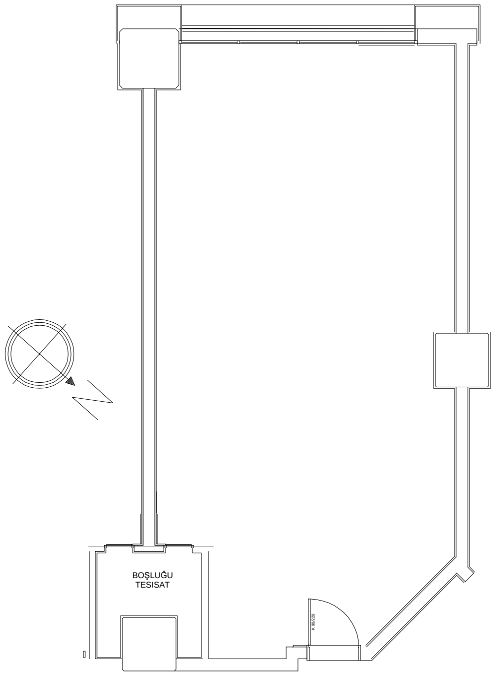


Figure 7.1 Elevations of the office

Three climates effect were investigated experimently,

- **Winter Climate**: The winter period is defined as from 1st of January to 30th of February. In winter period, the aim is to gain solar energy as much as possible and subjected to direct solar radiation through heating control glazing. At the same time lighting is wanted as enough as to study surface.

- **Summer Climate**: The summer period is defined from 1st of June to 30th of August. In summer period, the aim of the project is to provide direct sunlight as much as possible inside the office. The lighting value is wanted as over the minimum level.

- **Spring Climate:** The spring period is defined from 1st of March to 30th of May. In winter period, the aim is to provide better conditions for solar radiation and lighting.

In this chapter, calculations were done under five main headings;

1. Calculation of hourly useful solar energy,
2. Calculation of monthly useful solar energy
3. Hourly heat gain and heat loss calculations
4. Monthly heat gain and heat loss calculations.
5. Monthly lighting load calculation

7.1.1 Calculation of Hourly and Monthly Useful Solar Energy

The calculation steps are:

- Determining solar radiation, I_0, I_b, I_d and ω_s
- Determining I_T ,
- Determining solar radiation, H_0, H_b, H_d and ω_s
- The Monthly Average Clearness Index, K_T
- Determining H_T , S

7.1.1.1 Calculation of Sunset Hour Angles

Calculation of the sunset hour angle (ω_s) is given by expression:

$$\cos\omega_S = -\tan\varphi\tan\delta \tag{7.1}$$

In Table 7.1, the sunset or sunrise hour angle is given for horizontal surface and $\beta = 90^o$

where

ϕ :latitude of the location (38^o 27’ N for Izmir Bayraklı)

δ :solar declination

δ changes with mean day of the month and it is given by expression:

$$\delta = 23.45\sin\left[360\left(284+n\right)/365\right] \tag{7.2}$$

Where n mean day of the month

Table 7.1 Monthly values of n, δ, ω_S

Month	Jan.	Feb.	Mar	April	May.	Jun.	July.	Aug.
n	17	47	75	105	135	162	198	228
δ	-20.917	-12.95	-2.417	9.41	18.79	23.08	21	13.45
ω_s	72.47	79.55	88.09	97.50	105.55	109.62	107.78	100.86

7.1.1.2 Solar Radiation

Table 7.2 shows $\bar{H}$ and $\bar{H}_0$ values for İzmir (Latitude: 38° 27’ N). These values were calculated. And the graphics of the values show Figure 7.2.

Table 7.2 Monthly Average $\bar{H}$, $\bar{H}_0$, $\bar{H}_d$, $\bar{H}_b$ values for İzmir (MJ/m^2).

Month	Jan.	Feb.	Mar	April	May.	Jun.	July.	Aug.
$\bar{H}$	6.6	9.4	13.2	17.6	22.4	24	24.6	23
$\bar{H}_0$	16.1	21.3	27.9	34.7	39.4	41.3	40.3	36.5
$\bar{H}_d$	3.22	4.25	6.01	7.43	8.29	8.52	8.09	7.17
$\bar{H}_b$	3.38	5.15	7.19	10.17	14.2	15.48	16.51	15.83

$\bar{H}$: Monthly average daily radiation on a horizontal surface (MJ/m^2)

$\bar{H}_0$: Monthly average extraterrestrial radiation for the location (MJ/m^2)

$\bar{H}_d$: Monthly average diffuse radiation for the location (MJ/m^2)

$\bar{H}_b$: Monthly average beam radiation for the location (MJ/m^2)

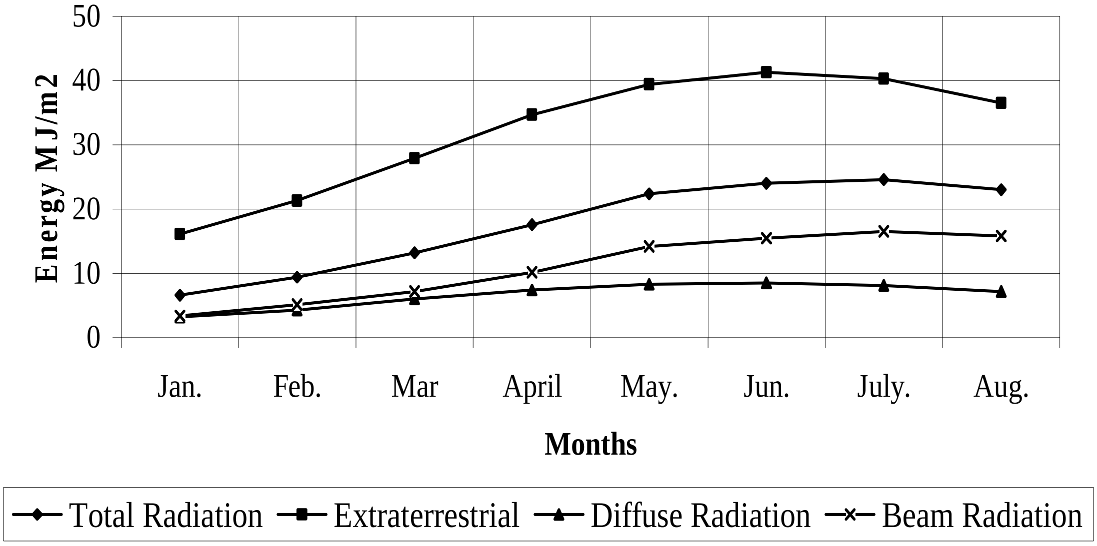


Figure 7.2 Solar Radiation Value for experimental month.

Hourly averaged global solar radiation on a horizontal surface for six month (kJ/m^2) was given in Table 7.3 and Figure 7.3. These values were calculated in the chapter sixth. The monthly average hourly global and diffuse solar radiation data which was included measurement for 5 years were given in Table A6, while they were shown graphically in Figures A3–A6 (Ulgen & Hepbasli, 2002)

Table 7.3 Hourly averaged global solar radiation on a horizontal surface (kJ/m^2)

Hour	**Jan.**	**Feb.**	**Mar**	**April**	**May.**	**Jun.**	**July.**	**Aug.**
7-18	0	0	377.2	987	1425	1606.4	1520.3	1170
8-17	298.11	770.6	1356.7	1937.9	2323.9	2472.4	2397.3	2092.9
9-16	1137.4	1638.8	2234.8	2790.6	3129.9	3248.9	3183.6	2920.2
10-15	1822.7	2347.6	2951.8	3486.7	3787.9	3882.8	3825.6	3595.7
11-14	2307.3	2848.9	3458.8	3978.9	4253.3	4331	4279.6	4073.3
12.-13	2558.1	3108.4	3721.2	4233.8	4494.1	4563.1	4514.5	4320.6

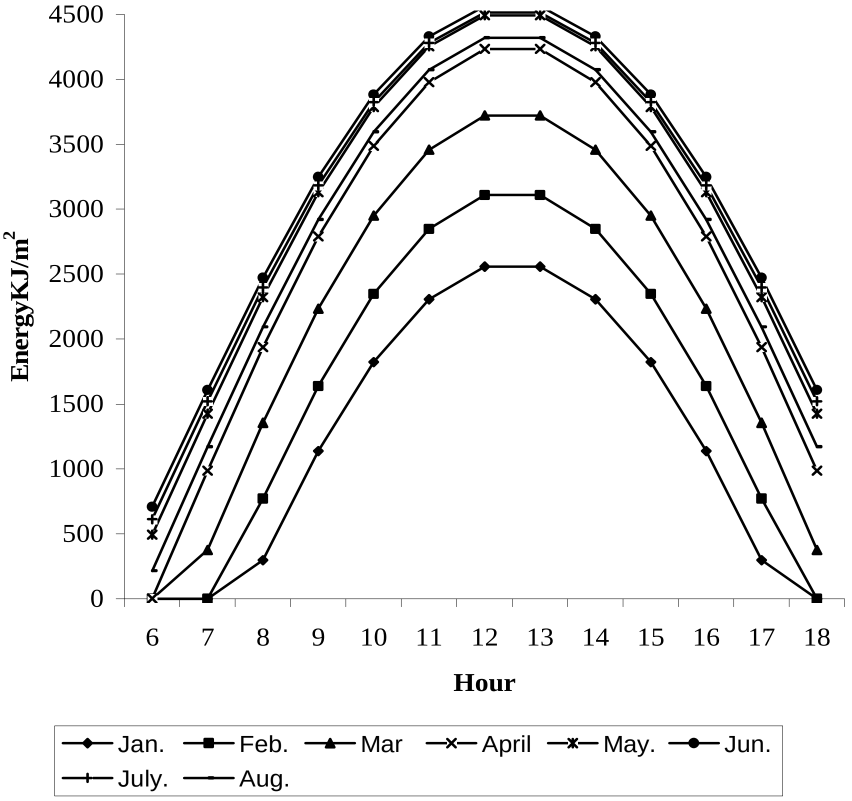


Figure 7.3 Hourly averaged global solar radiation for eight month.

7.1.1.3 Monthly Average Clearness Index

Monthly average clearness index calculations are given below

$$\bar{K}_T = \frac{\bar{H}}{\bar{H}_0} \tag{7.3}$$

On the basis of monthly average clearness index prediction of monthly average daily horizontal diffuse radiation to monthly average daily extraterrestrial radiation conclusions were given in Table 7.4 and Figure 7.4.

Table 7.4 Monthly average clearness index and monthly average horizontal diffuse radiation from monthly average horizontal radiation ratio.

Mouth	**Jan.**	**Feb.**	**Mar**	**April**	**May.**	**Jun.**	**July.**	**Aug.**
$\bar{K}_T$	0.41	0.44	0.43	0.51	0.57	0.58	0.61	0.63

7.1.1 4 Monthly Average Beam Radiation Factor

Beam radiation factor was calculated for different orientation and vertical surface. The values were showed in Table 7.5.

For south facing vertical; γ= 0 and β = 90,

For east and west sides**;** γ= ±90

7.1.1.5 Monthly Solar Radiation on a Tilted Surface

In the calculation of monthly solar radiation on a tilted surface the ground reflectance, ρ is assumed at value of 0.5 for all months (ASHREA, 2001).

Table 7.5 Monthly average beam radiation factor and monthly solar radiation values.

Month	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May.**	**Jun.**	**Jul.**	**Aug.**
R_b (South-west)	1.46	1.11	0.77	0.52	0.23	039	0.37	0.46
$\bar{H}_T$ (South-west)	16.15	13.27	11.99	13.52	14.38	14.50	16.61	17.17

7.1.1.6 Monthly Average Absorbed Radiation Solar Heat Gain Coefficient

Monthly absorbed radiation calculations have been done for all sides of the building by using equation 5.21. The results are shown in the following table.

$$\bar{S} = SHGF(\bar{H}_T) \tag{7.4}$$

The monthly average, *SHGF* and $(\bar{S})$

Table 7.6 Monthly average *SHGF* and $(\bar{S})$ for South-west directions

Month	**Jan.**	**Feb.**	**Mar**	**April**	**May.**	**Jun.**	**July.**	**Aug.**
SHGF	0.71	0.69	0.63	0.51	0.38	0.26	0.27	0.44
$(\bar{S})$	11.63	9.16	7.55	6.90	5.46	3.37	4.488	7.55

7.1.2 Heating and Cooling Load Calculations

Heat gain and heat loss calculation steps are;

- Suitable design parameters
- Calculating overall heat transfer coefficient
- Calculating heat loss of the office
- Calculating heat gain of the office

7.1.2.1 Design Parameters

Location property of the office, climatic values and indoor design parameters influenced heat gain and heat loss calculations. The heating and cooling loads were calculated according to dynamic principle of the indoor design conditions according to the experiment results. In this project, outdoor design temperature was determined by using hourly average outdoor temperature recorded by Ege University of Solar Energy Institute in İzmir.

- The hourly average outdoor temperature values were obtained to average the recorded temperature values which were recorded by Ege University of Solar Energy Institute in İzmir every fifteen minutes**.**

- The hourly average indoor temperature values, which were recorded every half an hour from nine different points of office, were obtained to calculate the average thermocouple value. The average value of the six temperatures was used for indoor temperature.

The indoor environmental property of the office is determined occupier request. The occupier is using the air-conditioning system for its own design temperature parameters.

7.1.2.2 Heat Loss Calculations

Properties of building materials were mentioned in chapter five. Details about the materials and where they were used could be seen in related figures in the chapter. Features of these materials were taken from ASHRAE and TSE 825. The office is at fourth floor and its neighbors, upstairs and downstairs of the offices have the air-condition system so that the thermal effect of ceiling, floor and indoor of the neighbor offices were neglected for the heat transfer calculations. The heat loss/gain occurred from/to outdoor, indoors which were neighbor of the entrance and space of the plumbing and showed A, B and C respectively in the Figure 7.5.

The heat transfer calculations were made up to the dynamic principle. The measured indoor and outdoor temperatures were used at the calculations. The heat loads calculation was defined by the difference of temperature of indoor and outdoor (Table 7.8).

To find out the specific heat loss value; it was multipled the area of the walls which had heat loss and the heat transfer coefficient (U) (Table 7.5) so the daily heat transfer gain was calculated by using the specific heat valve with the multiplication of temperature difference in Table 7.8.

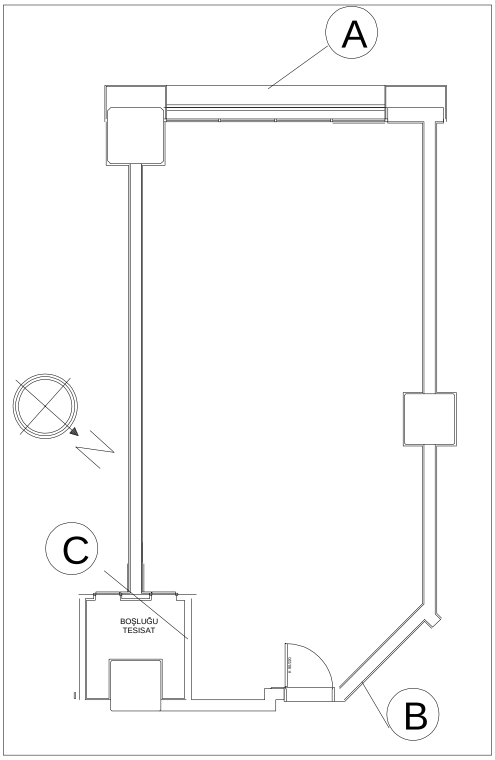


Figure 7.5 Heat loss/gain parts of the office

Table 7.8 Total specific heat loss of the office

Construction Components	**U- Heat Transfer coeff. (W/m^{2}K)**	**Area (m^2)**	**UxA (W/K)**
Outdoor Wall	0.488	9	4.39
Window (double glazzing Low-e)	2.52	6	15.12
Indoor Wall	0.806	15	12.09

7.1.2.3 Heat Loss Calculations

Total Heat Gain;

$$\sum Q = Q_c + Q_v + Q_i + Q_s \tag{7.5}$$

Total Heat Loss;

$$\sum Q = Q_c + Q_v - (\ Q_i + Q_s) \tag{7.6}$$

7.1.2.3.1 Heat Transmission Loss.

$$Q_c = UA(T_i - T_o) \tag{7.7}$$

The Q_c value was calculated by using the experimantal results which were daily dynamically measured. Values of outdoor temperature were taken from the Ege University, Solar Institute. Average indoor temperature (T_i) value was found by using six thermocouples numbered three to eight in Figure 5.7. The example calculation for the mentioned day was given below in Table 7.9. The monthly heat loss value was calculated with these results in Table 7.10. These results for the monthly heat loss value had an acceptable difference with the results which had been repaired by the MMO (The Chamber of Mechanical Engineers).

Table 7.9 Daily heat transmission gain in working hours for 17.01.2008

17.01.2008					
Time	T_o	T_i	ΔT	***UA*** **(W/°C)**	**Heat Loss (W)**
08:00	12.46	20.8	8.34	31.60	853.35
09:00	13.28	21.2	7.92		839.29
10:00	13.86	21.35	7.49		824.89
11:00	16.24	21.4	5.16		749.93
12:00	16.39	24.5	8.11		845.65
13:00	14.96	26.88	11.92		973.18
14:00	14.95	27.33	12.38		988.58
15:00	16.35	23.84	7.49		824.89
16:00	17.63	24.94	7.31		818.87
17:00	16.97	25	8.03		841.97
18:00	14.19	23.96	9.77		901.21
				Total	9461.81 Wh

Table 7.10 Monthly heat transmission loss of office

Heat Loss/Gain		
Month	**UA(W/C)**	**Total Monthly Loss(KWh)**
Junuary	31.60	215.96
February		225.4
March		160
April		176
May		180
June		350.24
July		350.8
August		357.8

7.1.2.3.2 Internal Heat Gains

$$Q_i = Q_p + Q_{light} + Q_e \tag{7.8}$$

Q_p **:** Heat gain from people:

$$Q_p = S\left(SHG\right)\left(CLF\right) + S\left(LHG\right) \tag{7.9}$$

SHG: Sensible heat gain

LHG: Latent heat gain

S: Number of people. The office is assumed to be two people worked so;

S =2

CLF = 0.93

$$Q_p = 2 \text{ x}70\text{x}0.93 + 2\text{x}45 = 220.2\text{W}$$

Q_{light}**:** Heat gain from lightening

$$Q_{light} = \ Lighting\ \ Load \times A \times CLF$$

Lighting Load = 12 W/m^2

Lighting period is ten hours a day so,

CLF = 0.93

A = 50 m^2

$$Q_{light} = 12 \text{ x } 50 \text{ x } 0.93 = 588\text{W}$$

Q_e: Heat gain from equipment:

$$Q_e = P \times CLF$$

Equipments in the office;

Computer: 0.30 kW × 2 = 600W

Printer: 0.20 kW × 2 = 400 W

P = 600+400 = 1000W

CLF = 0.93

$$Q_e = 1000 \times 0.93 = \ 930\text{W}$$

Q_i : Internal heat gain

$$Q_i = 220.2 + 588 + 930 = 1738.2\text{W} = 6.23 \text{ MJ/day}$$

7.1.2.3.3 Ventilation Loss. In the thesis, the heat load of mechanical ventilation was presented. Infiltration is ignored because the windows were not opened and the infiltration from door was neglected. The mechanical ventilation increased the heat loss in winter and it also rose to heat gain in summer. Q_c value was added in total load calculation with mutplied by difference of temperature (Karadağ, 2006).

$$Q_c = V \rho c_{pa} (T_i - T_o) n$$

$V = 50m^2 x 3.15m = 157.5m^3$

$c_{pa} = 1.007 \ Kj/kg^oC = 0.279 \ W/kg^oC$

$\rho = 1.194 \ kg/m^3$

n = *Air change factor (20%)*

$Qc = 10.5 \ W/^oC$

Also the ventilation was provided with air-condition system in the spring season. Air ventilation was provided by the fan as mechanically. There was no heating or cooling action with the air ventilation in the sipring season. The only electric requirement is occurred while the fan is at work. The fan was working while applicating the experiments. The monthly energy requirement of the fan is taken from the administrator of entire building of Tepekule as 75kWh.

7.1.2.3.4 Passive Solar Gain. The following tables showed calculation results of;

- Total hourly solar heat gain for southwest facing position of the office
- Total monthly solar heat gain for southwest-facing position of the office,
- Total heating and cooling load of the office for southwest-facing,
- Total heating,cooling and lighting demand for the office

7.1.3 Lighting Demand

The lighting of the office was used during the whole work time. Daily usage of lighting was calculated as 5kW. The monthly usage value of lighting was accepted as 100kW.

7.1.4 Calculation of Total Heating Cooling and Lighting Demand

The hourly heat gain from sunlight radiation has been calculated and given in Table 7.11. The monthly heat gain from sunlight radiation was also calculated by using the values on this table. The monthly change of the heat transmission coefficient of glasses was given in Table 7.6. The monthly average absorbed radiation for south west of the office was given in Table 7.7.

Table 7.11. Hourly passive solar gain for the office

January			
Hour	***S* (kJ/m$^{2)}$**	***A*(m^2)**	**Total Solar Gain(kJ)**
7:00-8:00	5.832	6	34.99
8:00-9:00	75.66	6	453.96
9:00-10:00	151.80	6	910.80
10:00-11:00	462.22	6	2773.32
11:00-12:00	560.04	6	3360.24
12:00-13:00	860.4	6	5162.40
13:00-14:00	791.3	6	4747.80
14:00-15:00	643.88	6	3863.28
15:00-16:00	502.53	6	3015.18
16:00-17:00	150.92	6	905.52
17:00-18:00	3.86	6	23.16

Table 7.12 Monthly passive solar gain for the office

South-West Facing			
Month	***S* (MJ/m^2)**	***A* (m^2)**	**Total Solar Gain (MJ)**
January	11.63	6	69.78
February	9.16	6	54.96
March	7.55	6	45.30
April	6.90	6	41.40
May	5.46	6	32.76
June	3.77	6	22.62
July	4.48	6	26.88
August	7.55	6	45.30

The total loads were given in Table 7.12. The effect of the heat gain from the sunlight radiation to the total load could be seen in this table.

Table7.13 Monthly heat gain for the office.

Total Heating and Cooling Load					
Month	Q	Q_S	Q_i	Q_v	**Total Load**
	Total (MJ)	**Total (MJ)**	**Total (MJ)**	**Total (MJ)**	**Total (MJ)**
Junuary	842.5	-69.78	-6.23	7.5	774
February	770	-54.96	-6.23	11.5	720
March	270	0	-0	0	270
April	270	0	0	0	270
May	270	0	0	0	270
June	1298	22.62	6.23	7.5	1335
July	1305	26.88	6.23	11.5	1350
August	1306	45.30	6.23	11.5	1369

Table 7.14 Monthly heat transfer loss of the office

	Heating and cooling load	**Lighting demand**
Month	**Total Monthly Load(KWh)**	**Total Monthly Lighting Load(KWh)**
Junuary	215.96	100
February	225.4	100
March	75	100
April	75	100
May	75	100
June	350.24	100
July	350.8	100
Augost	357.8	100

The first graphic curve at the Figure 7.6 was about the heating and cooling loads which were shown at the Table 7.14. The second graphic curve in Figure 7.6 was about total load due to the lighting demand which was also shown in Table 7.14.

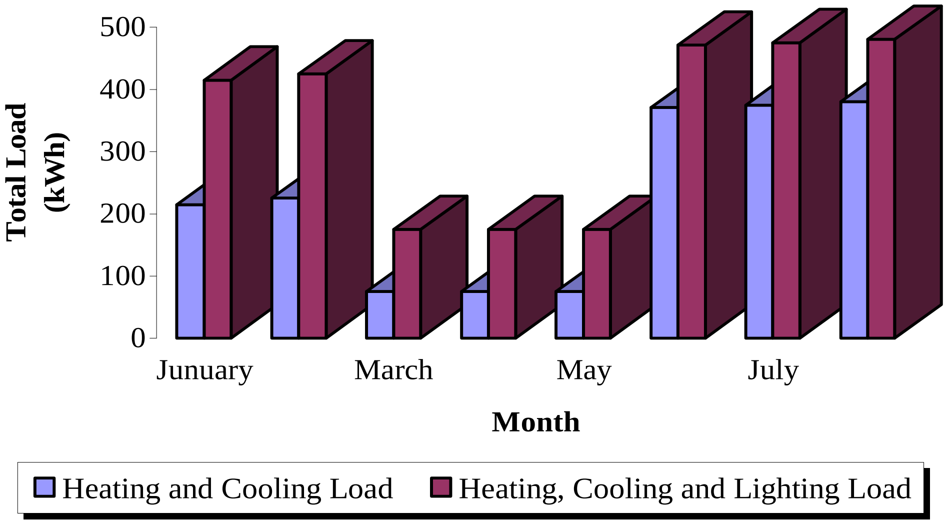


Figure 7.6 Monthly heating, cooling and lighting demand of the office

The electric requirement was accepted as certain as 100kWh per month. But the electric requirement values were taken from the administrator of the Tepekule showed that it was double in winter time. Because of this, the total electric requirement increased as much as shown below in Figure 7.7.

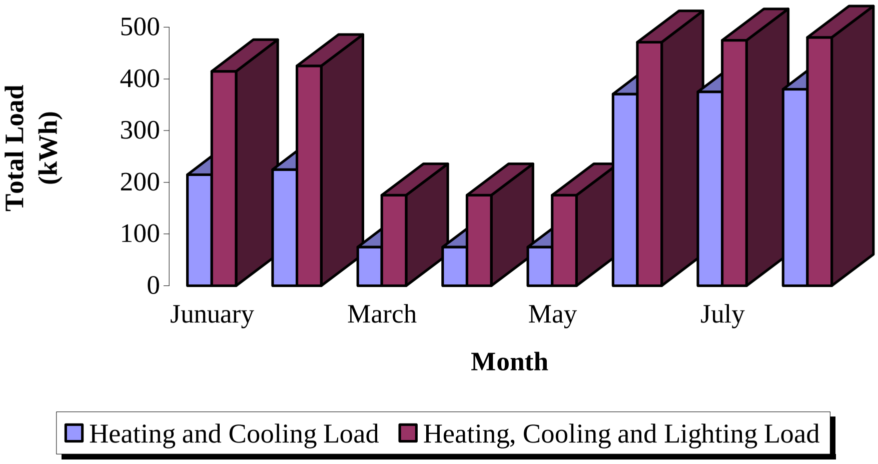


Figure 7.7 Monthly heating, cooling and lighting demand of the office

The annual total electric requirement of artifical lighting was the 31% of the annual total electric requirement. The heating and cooling load was the 69% of the annual total electric requirement.

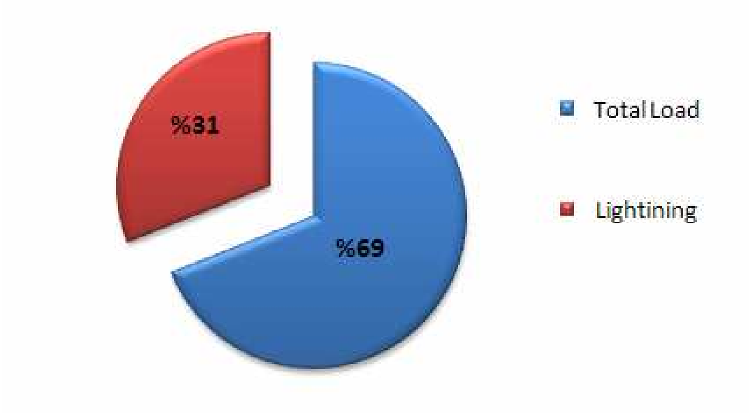


Figure 7.8 Lighting demand and total heating and cooling load ratio of the annual calculation total demand of the office

The 40% of the annual electric requirement was seen the artifical lightening due to the values taken from the administrator of the Tepekule building.

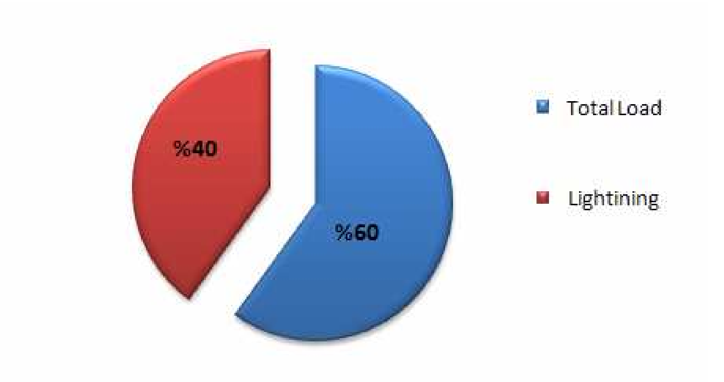


Figure 7.9 Lighting demand and total heating and cooling load ratio of the using annual total demand of the office

The increase of electric requirement in winter could be explained as the insufficient lighting value.

For the other glazing types' SHGF which was given in Table 7.15, the monthly heating and cooling loads were calculated in Figure 7.10.

Table 7.15 Monthly solar heat gain factor for deferent glazing types of office

Glazing Type	**Label**	***SHGF***
Clasic	*C*	0.92
Solar	*S*	0.72
Heating	*H*	0.68
Heating&Solar	*H&S*	0.62

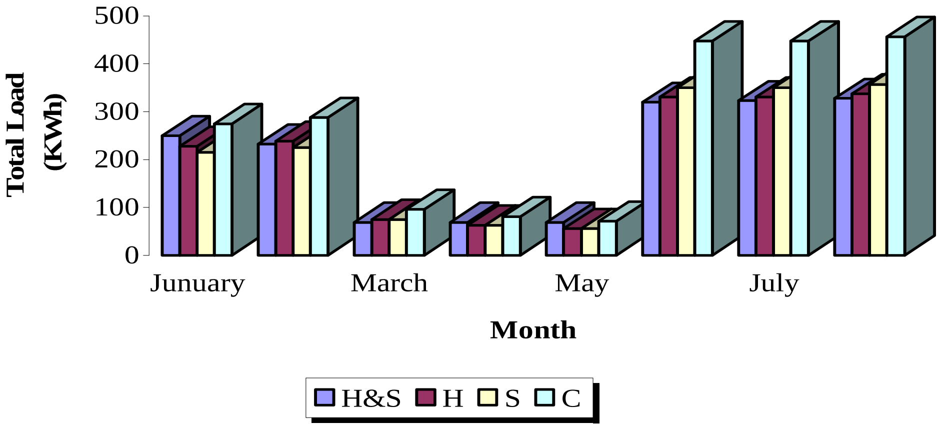


Figure 7.10 Monthly total heating and cooling load demand for different glazing

The most energy requirement occured at the classic glass compared at the other coated glasses as shown in Figure 7.10. The Solar control glass had the minimum energy requirement in summer. But in winter time, it had more energy requirement than the other coated glasses. The Solar control glass which was calculated at this experimental study, had the minimum energy requirement in winter and had more energy requirement at the summer, because of the high absorbtion value of glass. High *SHGF* made a positive effect for winter but in summer time, it increased the energy requirement with the heat gain from the sunlight radiation.

There were acceptable differences between *SHGF* of Solar, Heating, and Heating&Solar control glasses. But the values of the classic glass had a great difference from the coated glasses.

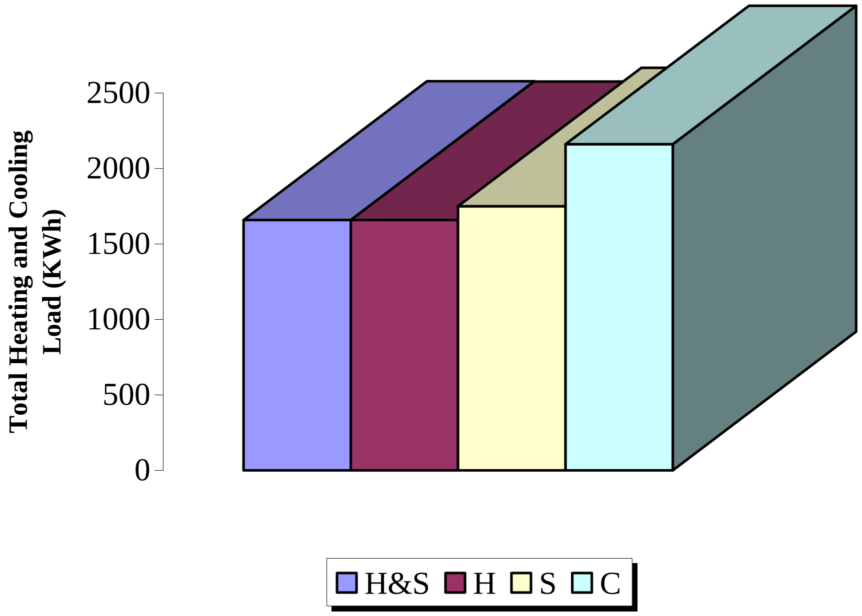


Figure 7.11 Annual heating and cooling load demand for different glazing

To observe the effect of other glasses to the lighting requirement, it could make a comparison with the visible transmittance value (*VT*). The *VT* values of the glass types were given at the Table 7.16.

Table 7.16.Geometrical and optical properties of the glass and the office

Glazing	**Label**	**Visible Transmittance**	**Window to Perimeter Floor area ratio (A_w/A_p)**	**Perimeter to Total Floor Area Ratio (A_p/A_f)**	**f_d Daylight Availability Ratio**
Classic	*C*	0.78	0.4	0.3	21.95
Heat Control	*H*	0.77	0.4	0.3	21.94
Solar Control	*S*	0.16	0.4	0.3	14.18
Heat and solar Control	*H&C*	0.69	0.4	0.3	21.95

f_d is daylight availability ratio and it was defined as how to calculate in Chapter 4. When it was accepted a certain lighting electric demand for 100kW per month; the monthly energy requirement according to the f_d value of the other glasses were calculated and given in Table 7.17.

Table 7.17 Monthly lighting demands for different glazing

Glazing	**Monthly Lighting Load (KWh)**
C	63.78
H	63.81
S	100
H&S	64

Heating, cooling and lighting loads were given in Table 7.18. The first value of the table was the total of monthly heating and cooling values for each glass. And the second value was the total load with the lighting. The last value was the reference one: It showed the profits and the losses. Also the percentage of difference between the reference and the real values were shown. The negative values represented the losses and the positive values represented the profits.

Table 7.18 Monthly total demand for different glazing

Mounth	***C*(Heating and Cooling Load)**	***C* (Heating, Cooling and Lighting Load)**	***H* (Heating and Cooling Load)**	***H* Heating, Cooling and Lighting Load**	***S* (Heating and Cooling Load)**	***S* Heating, Cooling and Lighting Load**	***H&S* Heating and Cooling Load)**	***H&S* Heating, Cooling and Lighting Load**
January	275	339	228	291	215	315	250	314
February	288	351	238	302	200	325	232	296
March	96	160	75	139	75	175	75	133
April	81	144	75	127	75	213	75	133
May	72	135	75	120	75	156	75	133
June	447	511	331	394	371	450	319	383
July	447	511	331	394	375	450	323	387
August	456	520	337	401	380	457	328	392
Total	2161	2671	1658	2169	1750	2541	1659	2171
Different	19%	5%	-5%	-15%	0	0	-5%	-15%

The total annual energy requirement value of four different glazing was shown at Figure 7.12 and Figure 7.13. Annual heating and cooling load demand for different glazing; the calculation of heating and cooling load, without lighting, occured an acceptable difference between the three different types of glazing and coating. When the lighting load added to total load; the lighting load of the solar control glazing increased due to the low f_d coefficient value. As a result of this; the total load increased. The total load increasing of classic glazing did not happen as much as the solar control glazing due to the effects of followings: The low *SHGF* (the solar heat gain factor) value increased the heating and cooling loads and the lighting load was decreased with the high f_d coefficient value. By this way; total load was balanced. The high lighting load of solar control glazing causes the closing of the total annual energy requirement to the value of classic glazing.

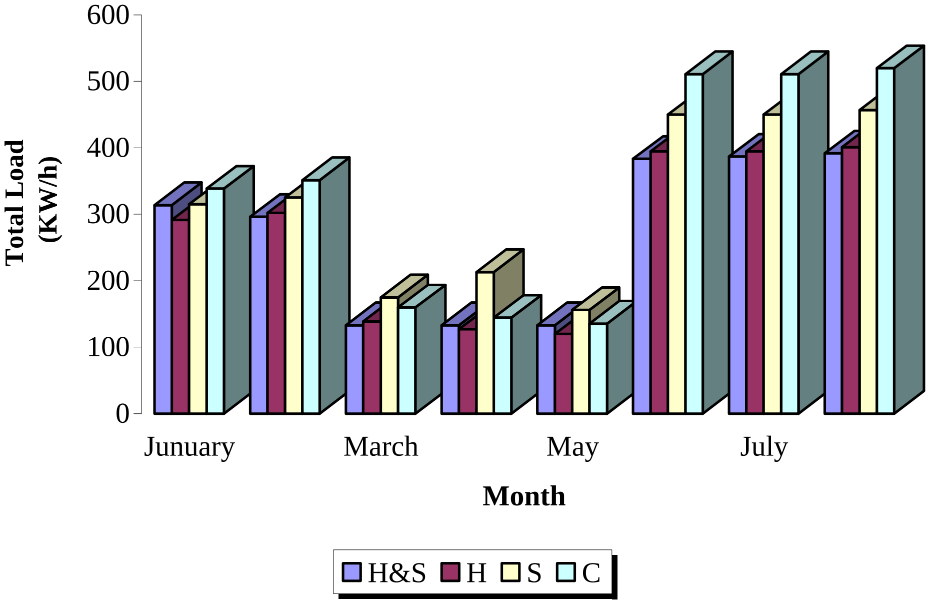


Figure 7.12 Monthly total demand for different glazing

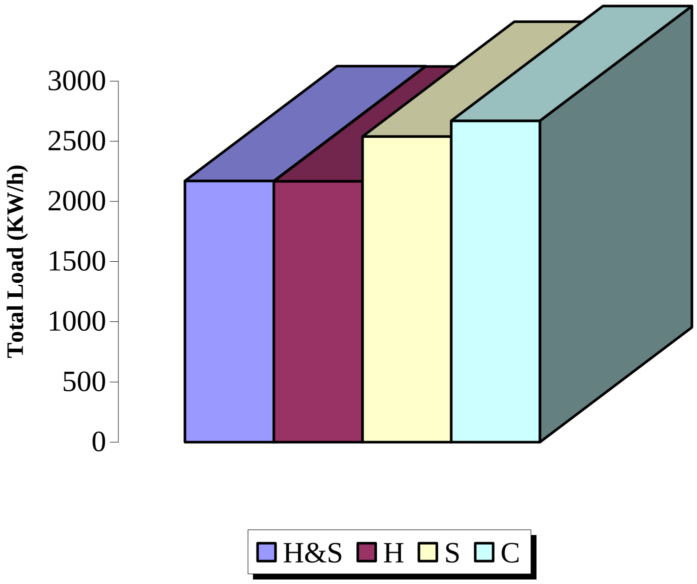


Figure 7.13 Annual total demands for different glazing

7.2 Analysis

7.2.1 Temperature Analysis

Offices are usually occupied 10 hours per day (from 8:00 am to 6:00 pm for week days). So, the data were taken between 8:00 am and 6:00 pm. The temperature values of the interior surfaces, indoor, intake vent and outdoor were taken for all measurement days. The indicated values of the temperatures were considered for every hour.

The weather conditions were considered in this study by classifying the days according to the personal observations as clear, mixed or overcast. Clear day was the conditions of absence of clouds, overcast day was rainy and cloudy and mixed day had the conditions of both. The office was placed along southwest to northeast. The glazings were placed at the southwest side of the office. As a result of this; the sunlight radiation effect increased at afternoon specially.

The measured temperature values were showed with the distributing shape in the room on the isothermal curves.The isothermal curves were drawn by the programme of SigmaPlot (sigma plot, web cites). The curves gave us a point of view for the homogen distrubition of the temperature values. During the experiment days; the suitable hour for observation had been choosen according to the consideration of the distiribution of the temperature values.

7.2.1.1 Experimental Study in January (17-01-2008)

The weather was overcast and the average outdoor temperature measured as 15.2°C. The required values of the office were measured among ten hours, from 8:00 am to 6:00 pm. The air-conditioning system had operated intermittently because the indoor temperature value was approximately 21°C. The increases of the indoor temperature observed in spite of the non-operated air- conditioning system. Occupier of the office had operated the air-conditioning system intermittently during 12:00 am to 6:00 pm.

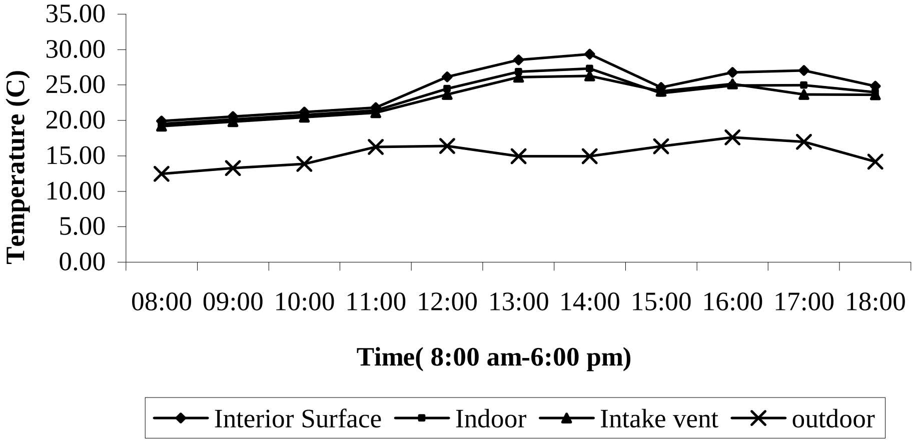


Figure 7.14 Hourly temperature values of the office

The indoor temperature of the office was about 20°C during the whole morning time in spite of the non-operated air-conditioning system and the low outdoor temperature value. The solar heat gain profit from glazing and low heat loss had a much more effect than internal heat gains on the office especially at the afternoon. The air-condition system had opened at 12:00 am. It has been set to 27°C between

12:00 am – 2:00 pm. It has been set to 24°C between 2:00 pm – 6:00 pm. When the remote control was set to 27°C; the temperature of the office reached to 30°C and the remote control was set to 24°C; the temperature of the office reached to 25°C.

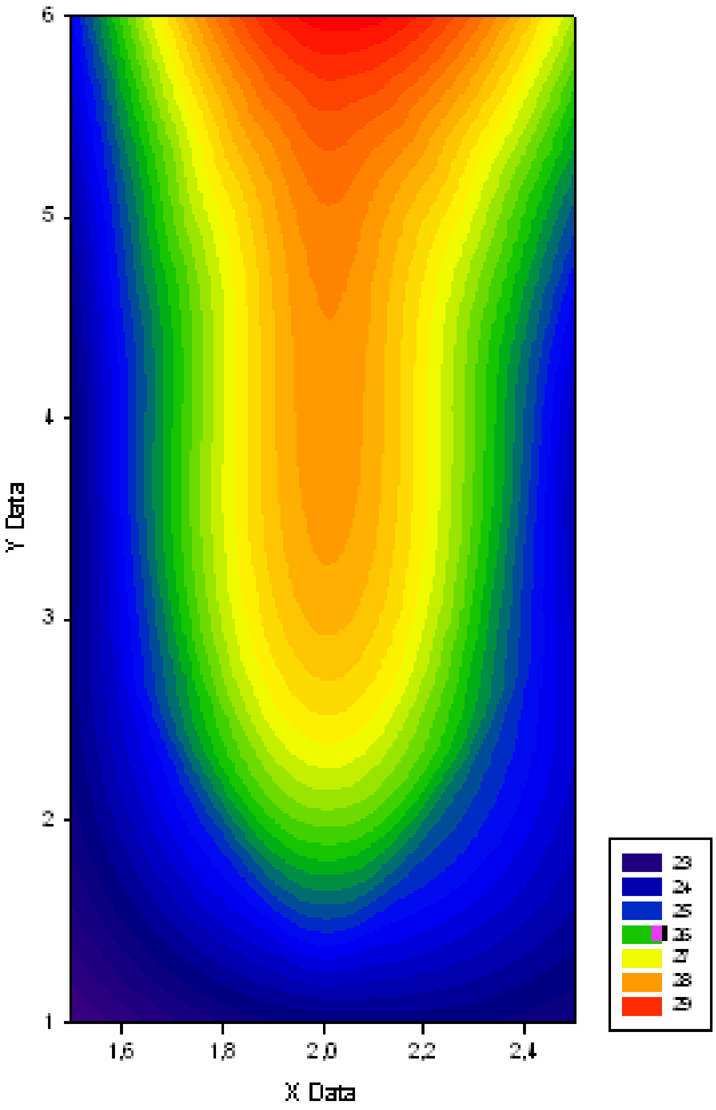


Figure 7.15 Distribution of heat when the air condition worked at 2:00 pm (17-01-2008)

The isothermal curve of the Figure 7.15 has been prepaired by using the values which was taken at 2:00 pm when the air condition remote control was set to 24°C. The observation results of that time show us the interior surface temperature of the glazing unit was 29 °C. The difference between the working set limit of the air condition and the interior surface temperature of the glazing unit showed us the effectivity of the high solar transmission coefficient value and the solar thermal radiation passes through the glazing unit. The red line at the isothermal curves showed the temperature level of 29 ^{o}C. This effective area of the red curved could be seen on the figure as a diffisioning field towards inside the office. The occupiers working on this area can get discomfort because of high temperature value.

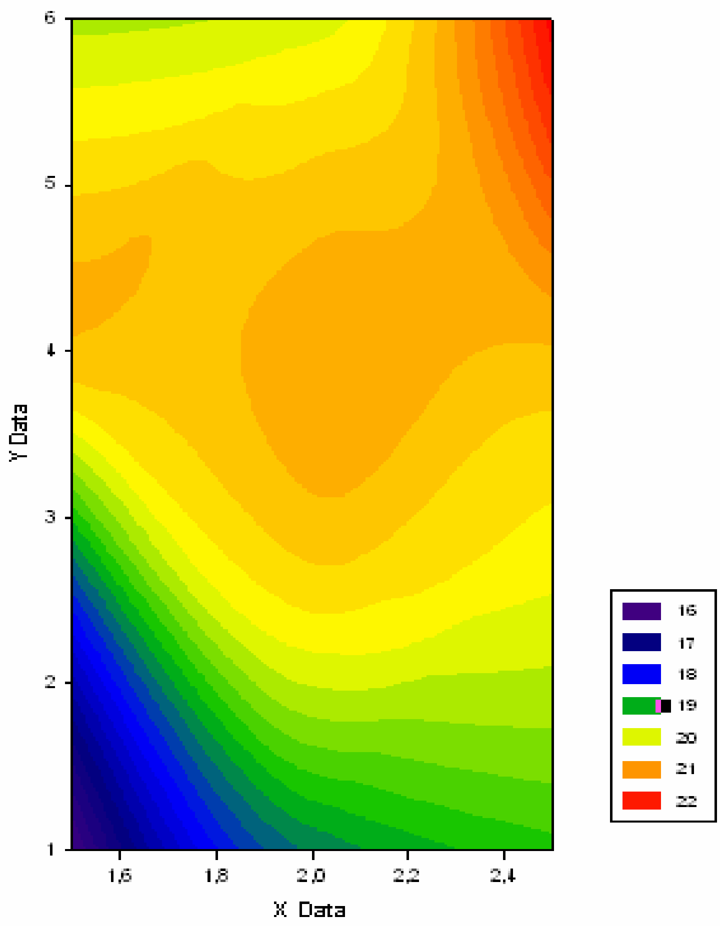


Figure 7.16 Distribution of heat when the air condition non worked at 11:00 am (17-01-2008)

The isothermal curves of the Figure 7.16 had prepaired by using the values which was taken at 11:00 am when the air condition remote control was closed. The reason to select a morning time period for observation was to consider the direction effect of sunlight. Due to this, the temperature value changed on the interior surface of the glazing unit could be seen as 21 ^{o}C and the interior surface of northwest wall which was perpendicular to the glazing unit was 22 ^{o}C because of the direct sunlight effect. The inner side of the office had lower temperature values due to the non-operating air-condition and ventilation.

7.2.1.2 Exeperiment Study in February (16-02-2008)

The weather was partly cloudy and the average outdoor temperature was 10°C. The air-conditioning system was operated at 27°C because of the low outdoor temperature. The indoor average temperature was 24°C due to air-condition.

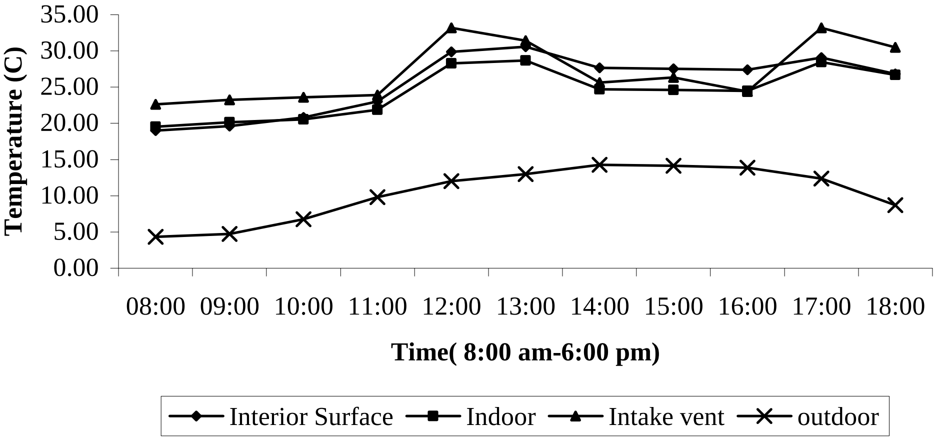


Figure 7.17 Hourly temperature values of office

The intake vent average temperature was 28°C. The indoor temperature and the interior surface temperature values were the same of the intake vent temperature although outdoor temperature was lower (Figure 7.17). Occupier of the office had operated the air-condition system at 27 °C during 12:00 am to 2:00 pm. The air-condition system was operated at 27 °C from 4:00 pm to 6:00 pm. The interior surface temperature which has been measured during morning had a closed value with the indoor temperature value. But at the afternoon, especially between 2:00 pm to 4:00 pm, the interior surface temperature observed as more than the indoor temperature value. The interior surface temperature value has reached to 30°C at 1:00 pm due to the air-conditioning system.

7.2.1.3 Experimental Study in March (17-03-2008)

The weather was partly cloudy and the average outdoor temperature was 20°C. The ventilation was operated because the indoor temperature was enough for the occupier.

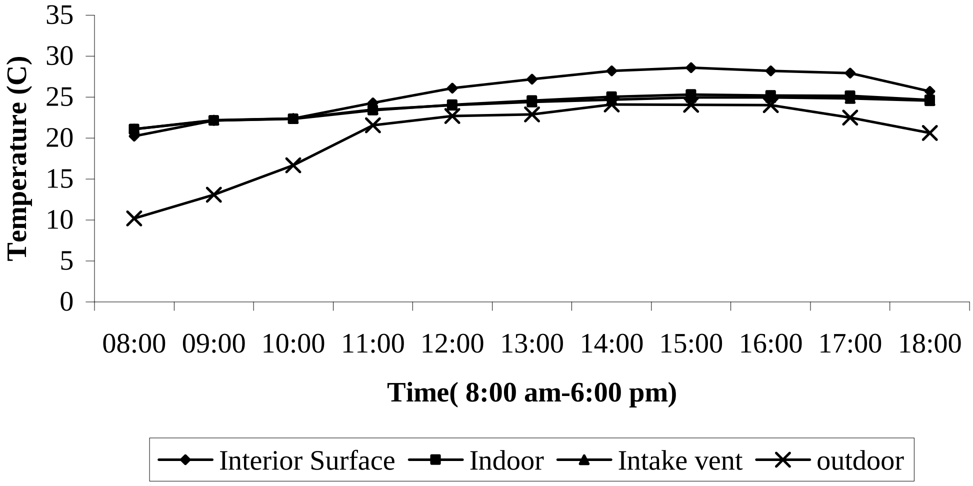


Figure 7.18 Hourly temperature values of the office

The indoor temperature, the interior surface and the intake vent’s temperature values were the same in the morning period from 8:00 am till 11:00 am although outdoor temperature was lower. When the sun was at the top at noon, the interior surface temperature of west side of the office was increased according to the indoor temperature. The interior surface temperature was higher then the indoor temperature by 3.0°C. The interior surface temperature value was obtained as 30°C in afternoon inspite of the 25°C indoor temperature value.

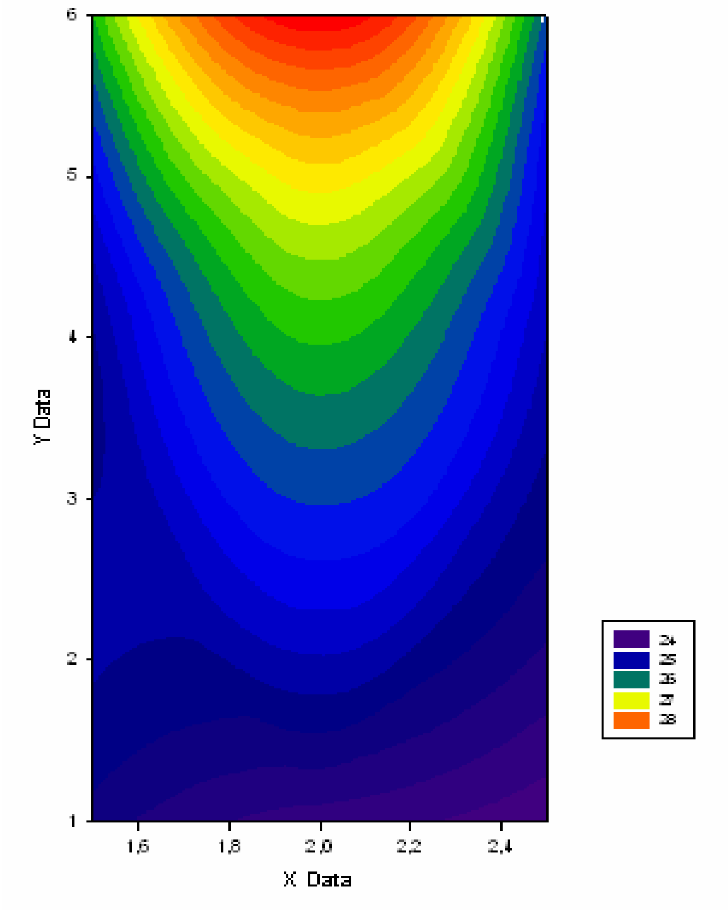


Figure 7.19 Distribution of heat when the air condition non worked at 3:00 pm (17-03-2008).

Figure 7.19 shows the isothermal curves at 3:00 pm when the air condition was closed. The interior surface temperature value of the glazing unit was measured 29°C. The average of both inside and outside temperature values were calculated as 25°C. The distribugtion of the temperature values of the office was shown at the figure. The interior surface temperature value of the glazing unit obtained higher than the outdoor temperature value because of the coating of the glazing unit.

7.2.1.4 Experimental Study in April (16-04-2008)

The weather was partly sunny and the average outdoor temperature was 24°C. The ventilation has been operated. But the air-conditioning system has been operated at the set point of 24°C cooling situation for two hours in the afternoon because of the high outdoor temperature.

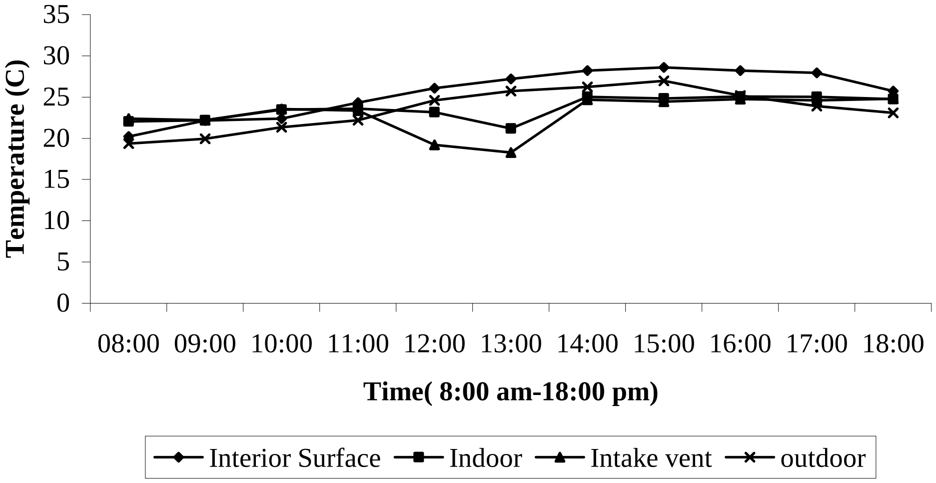


Figure 7.20 Hourly temperature values of the office

As it is seen in the Figure 7.20; the morning time values of the interior surface of the glazing unit temperature, the indoor temperature, the intake vent temperature and the outdoor tempareture were closed to eachother and average value of them was calculated as 23 °C. The air-condition unit- has been worked at 24°C cooling situation from 12:00 am till 1:00 pm and the indoor and intake vent temperature value decreased very fastly. The occupier closed the air-condition unit because of the cold flow air. After than, the outdoor temperature and interior surface temperature were reached 27°C and 28°C, respectively. The indoor temperature value was maintaining about 25°C in spite of the cooling load.

The indoor temperature, the interior surface, the intake vent’s temperature and the outdoor temperature values were about 23 °C at the morning period; from 8:00 am till 11:00 am. When the sun was on the top at noon, the interior surface temperature was increased according to the indoor temperature. The air-condition system was operated at 24 °C of cooling situation from 12:00 am to 2:00 pm. As a result of this, the indoor temperature decreased immediately. So that the occupier felt uncomfortable and stoped the air- condition. The interior surface temperature was higher then the outdoor temperature by 2.0^{o}C due to the non-operating air-condition and the structural property of the glazing unit.

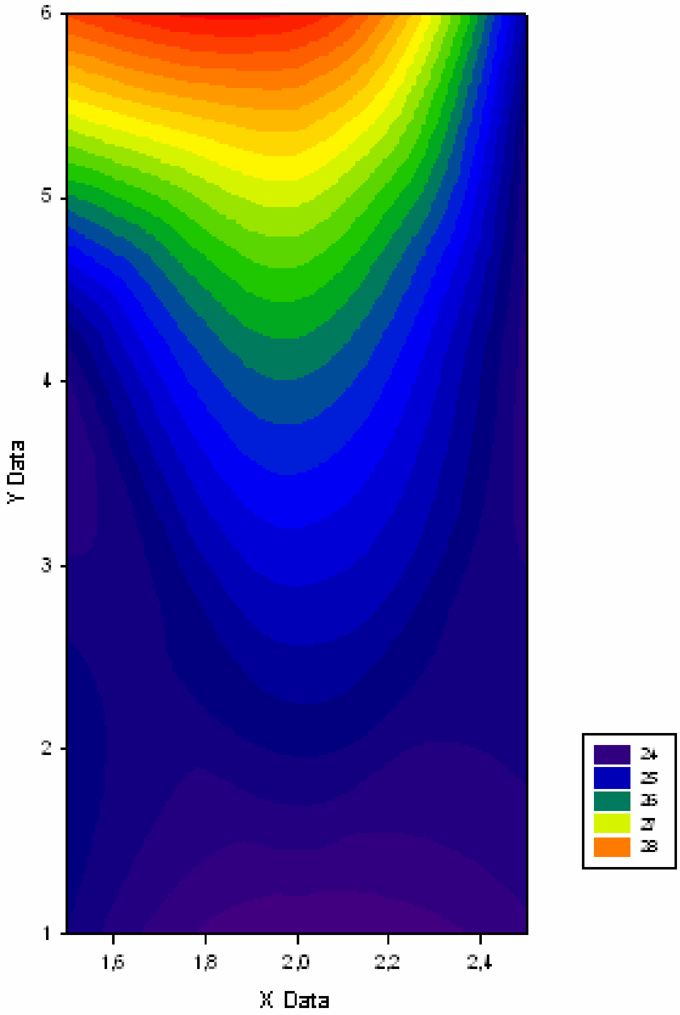


Figure 7.21 Distribution of heat when the air condition nonworked at 3:00 pm (16-04-2008).

The Figure 7.21 showed the isothermal curves of the measured temperature values of the office at 3:00 pm when the air condition unit was non-operated. The interior surface temperature of the glazing unit was obtained as 29^{o}C. The average value of both the indoor and the outdoor temperature was 24^{o}C. When we compared the values with the month of March, the difference was mostly seen on thye southeast wall by directed isothermal curves due to the incidence angle of the sunlight.

7.2.1.5 Experimental Study in May (16-05-2008)

The weather was partly sunny and the average outdoor temperature was 25°C. The ventilation was operated

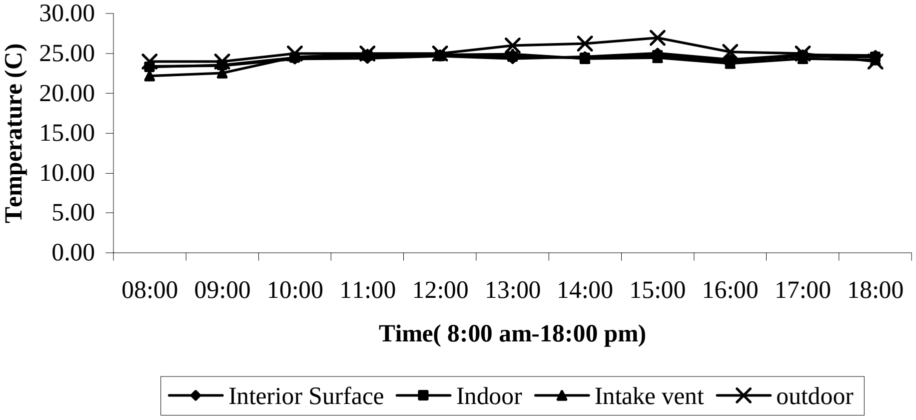


Figure 7.22 Hourly temperature values of the office

The interior surface temperature value was closed to the indoor temperature value because of the ventilation operation through the entire working hours. When the sun was on the west side of the office (12:00 noon-18:00 pm.); the indoor temperature was increased and reached to 25°C and as a result of this, the environment was comfortable for occupier’s worked space.

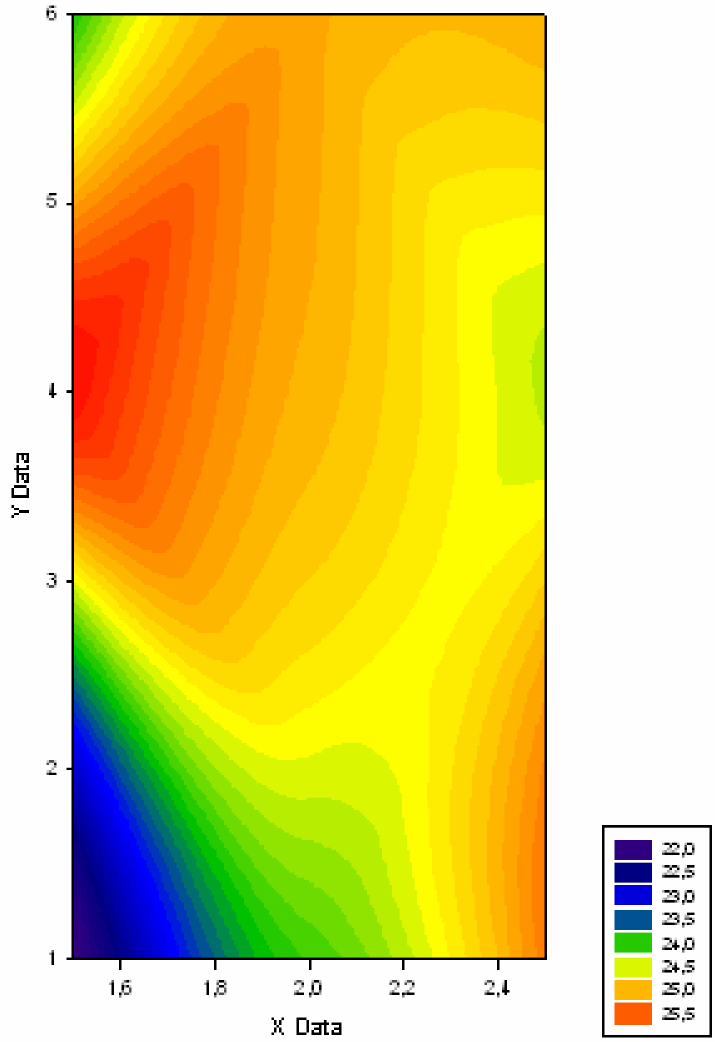


Figure 7.23 Distribution of heat when the ventilation worked at 3:00 pm (16-05-2008)

The Figure 7.23 showed the measured temperature values of the office at 3:00 pm. when the ventilation was operated. The interior surface temperature value of the glazing unit was 25°C. The average value of both the indoor and the outdoor temperature was 24°C. The distirubition of the temperature values of the office observed as a directional line from the interior surface of the glazing unit to southeast side of the office.

7.2.1.6 Experimental Study in June (12-06-2008)

The weather was sunny and the average outdoor temperature was 30^{o}C. The ventilation was operated from 10:00 am till 4:00 pm. The indoor temperature was reached 27^{o}C at 4.00 pm. For this reason the air-conditioning system was operated to the set point of 24^{o}C at cooling situation. As a result of this, the indoor temperature decreased immediately.

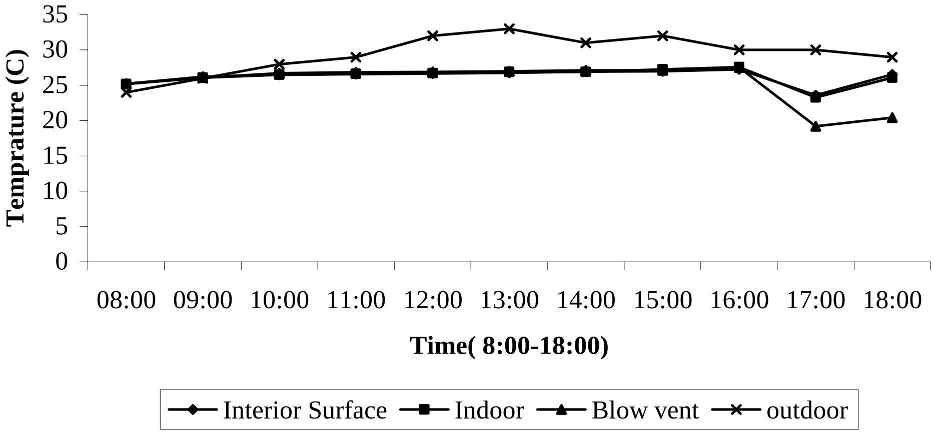


Figure 7.24 Hourly temprature value of the office

The interior surface temperature value was closed to the indoor temperature value because of the ventilation operation from 10:00 am till 4:00 pm. When the sun was on the west side of the office (12:00 noon-18:00 pm.); the indoor temperature has increased and reached to 27^{o}C and as a result of this, the environment was uncomfortable for occupier's worked space.

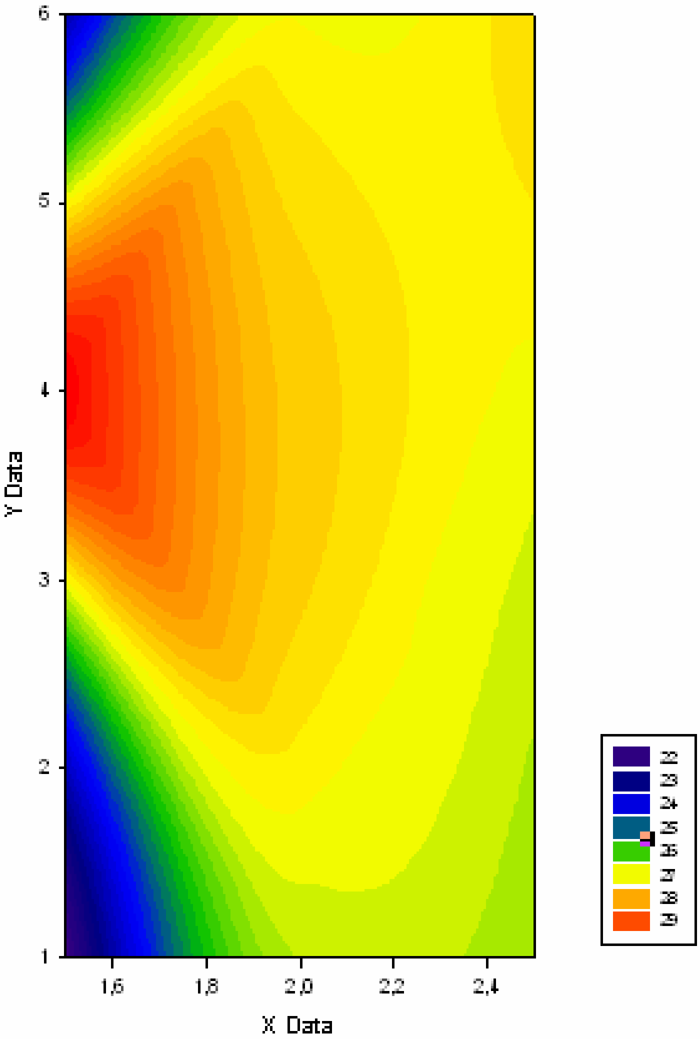


Figure 7.25 Distribution of heat when the ventilation worked at 3:00 pm (12-06-2008).

The Figure 7.25 showed us the measured temperature values of the office at 3:00 pm when the ventilation was operated. The interior surface temperature value of the glazing unit was 27°C. The average of the indoor temperature was 26°C. The average of the outdoor temperature was 28°C. The distirubition of the temperature values of the office observed as a directional line from the interior surface of the glazing unit to southeast side of the office.

7.2.1.7 Experimental Study in July (18-07-2008)

The weather was partly sunny and the average outdoor temperature was 30^{o}C. The air-conditioning system was at cooling position and operated during the entire working hours but from 15:00 pm untill 16:00pm.

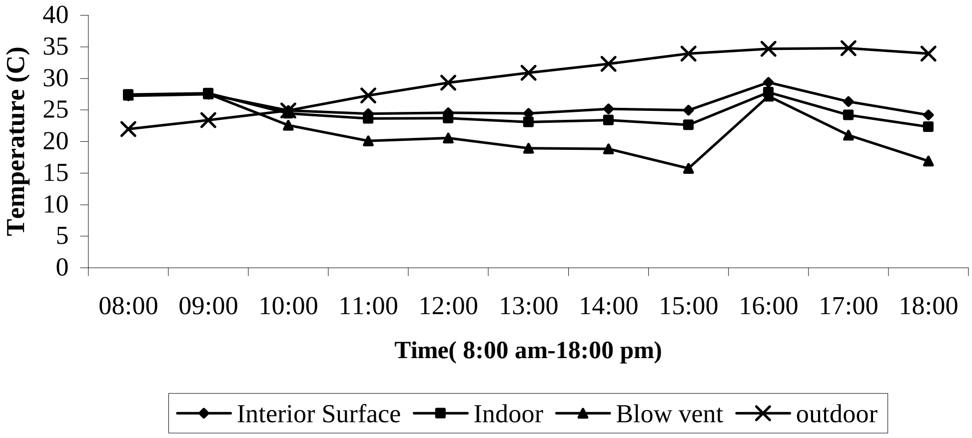


Figure 7.26 Hourly temperature value of office

Indoor temperature value was below 25^{o}C when air-condition was worked of 24^{o}C. The outdoor temperature was higher than the indoor temperature by average value of 10^{o}C. The indoor temperature increased 27^{o}C immediately when the air-condition system was stopped.

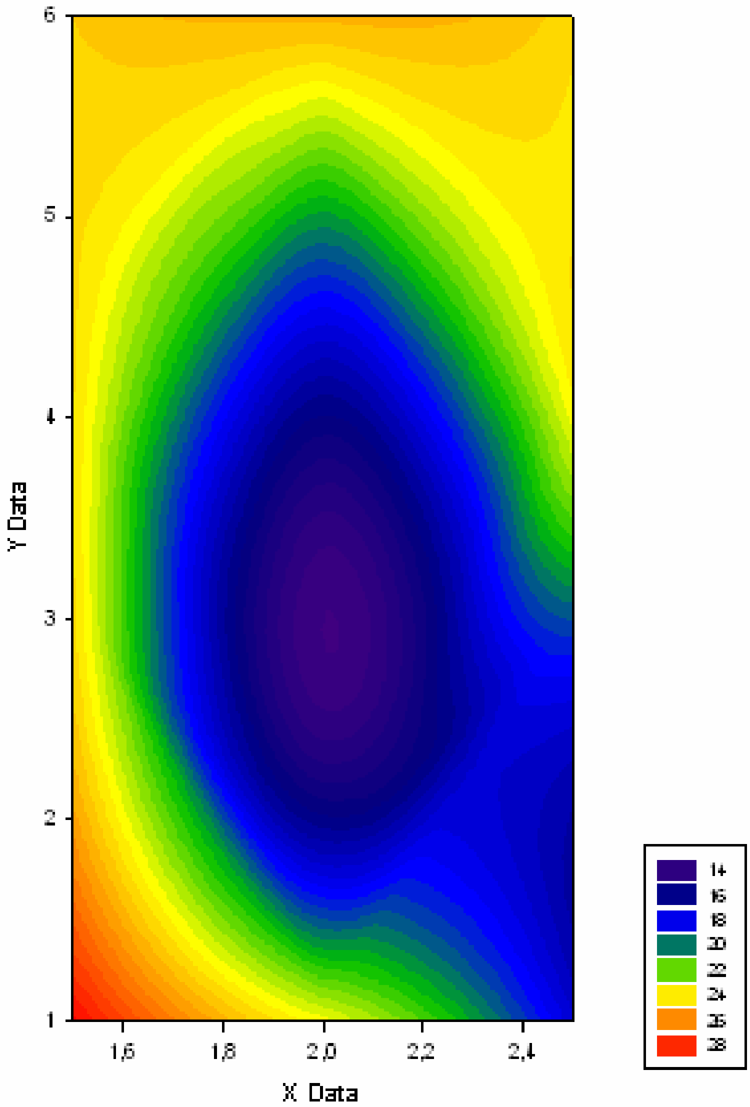


Figure 7.27 Distribution of heat when the air condition cooling position at 3:00 pm (18-07-2008).

The Figure 7.27 showed the temperature value of the office at 3:00 pm. when the air condition was operationed at the cooling situation of 24^{o}C. The interior temperature value of the glazing unit was 25^{o}C. Altough the outdoor temperature value reached to the value of 30^{o}C, the inside temperature value of the office was 25^{o}C. At the figure, the isothermal curves showed that the air flow did not provide a homogeneous temperature distirubition.

7.2.1.8 Experimental Study in August (17-08-2008)

The weather was sunny and the average outdoor temperature was 35^{o}C. The air-conditioning system was at cooling position and operated during the entire working hours.

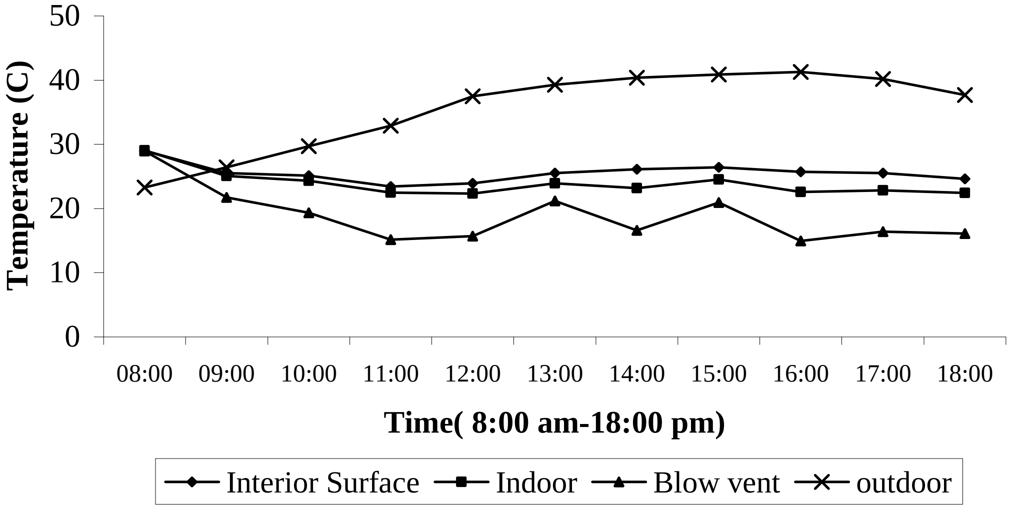


Figure 7.28 Hourly temperature value of office

The indoor average temperature was below 24^{o}C and air-condition was worked at the set of 24^{o}C. The outdoor temperature reached to 41^{o}C and it was higher than the indoor temperature by average value of 10^{o}C.

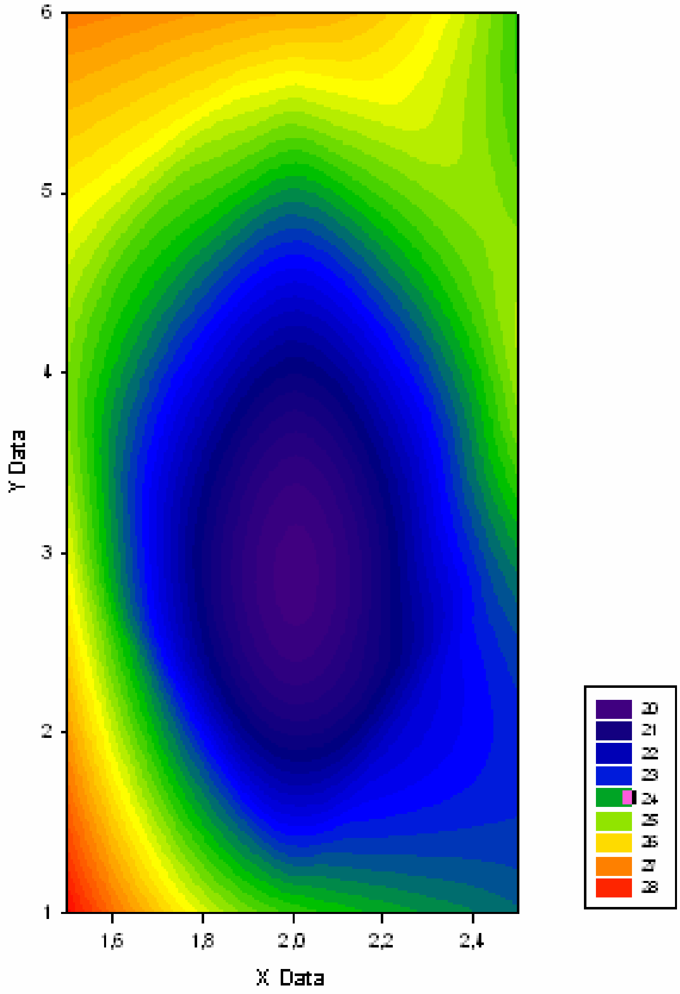


Figure 7.29 Distribution of heat when the air condition cooling position at 3:00 pm (17-07-2008).

The Figure 7.29 showed that there was an acceptable difference between August and July in 2008. The only difference occurs at the isothermal curves which showed that the interior surface temperature of the glazing unit was a bit higher because of the outdoor temperature rising.

7.2.2 Daylighting Analysis

The lighting values of the graphics were measured from 30 cm distance to glazing. The values showed that the visible glazing ratios which were changeable under from the effect of the direct sunlight. These values were very high because of the interior surface lighting. Figure 7.30-7.37 showed all of the measurement days.

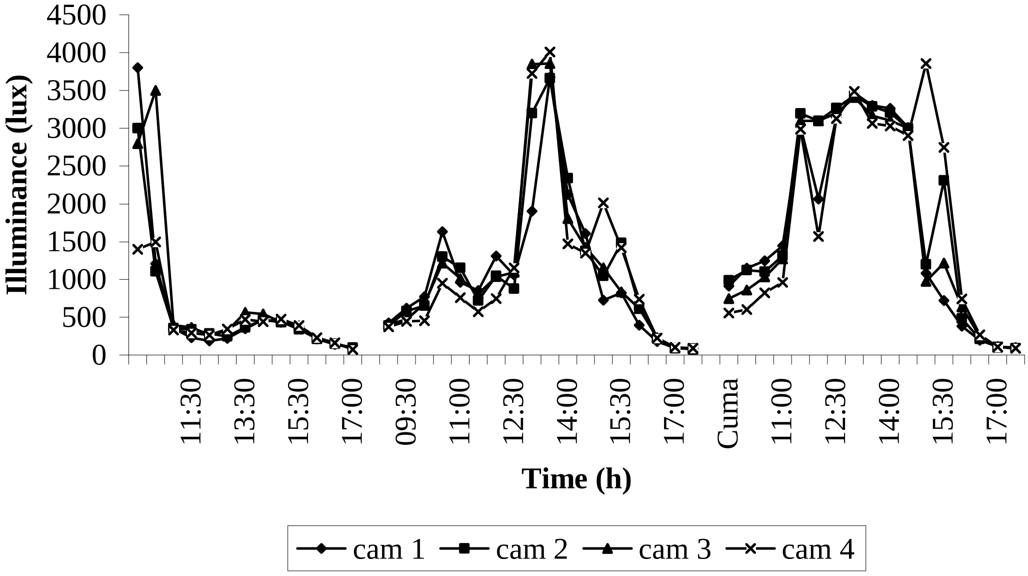


Figure 7.30 Distribution of illuminace values from glazing of 16-17-18 January

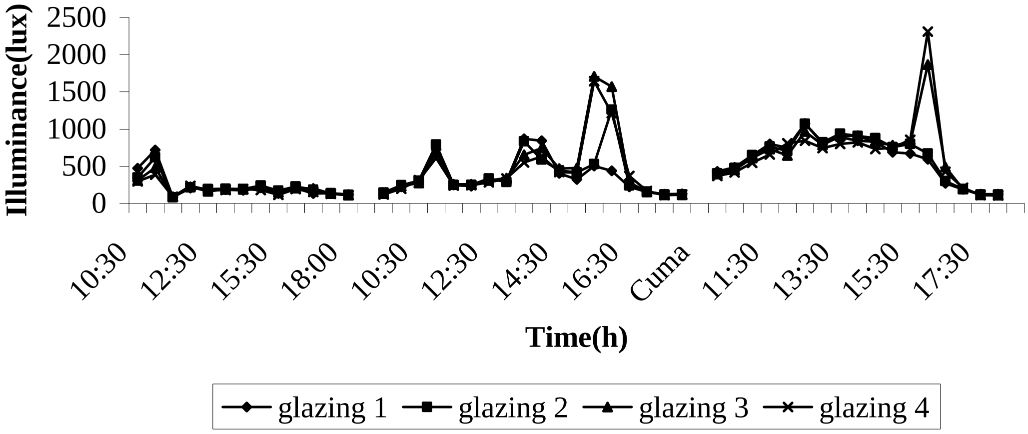


Figure 7.31 Distribution of illuminace values from glazing of 15-16-17 February

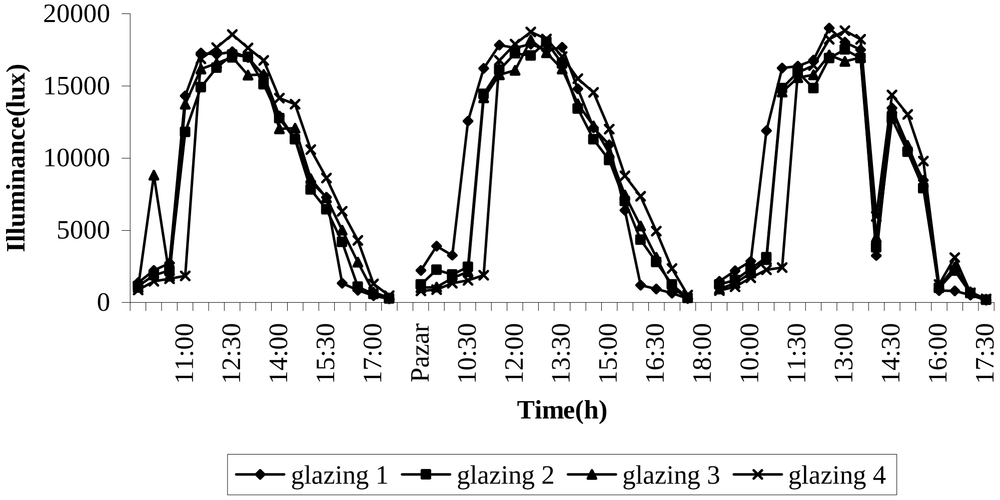


Figure 7.32 Distribution of illuminace values from glazing of 16-17-18 March

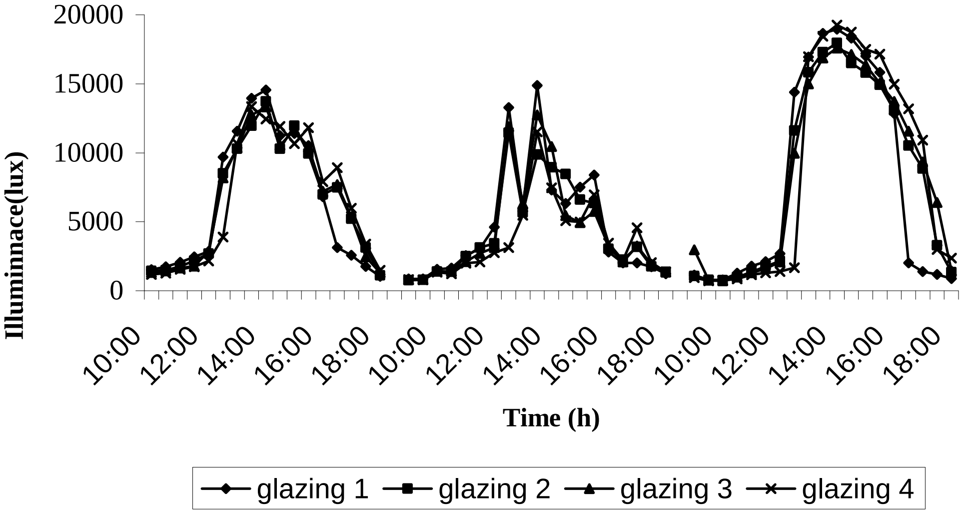


Figure 7.33 Distribution of illuminace values from glazing of 15-16-17 April

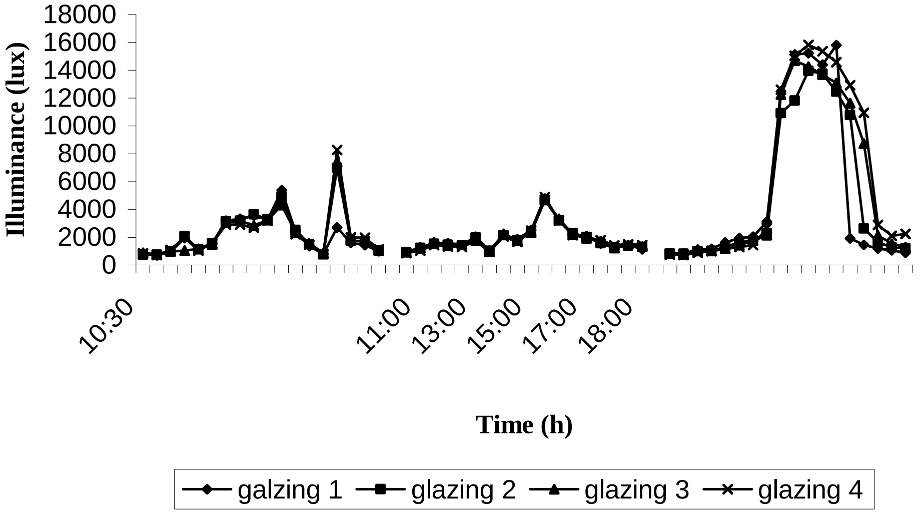


Figure 7.34 Distribution of illuminace values from glazing of 15-16-17 May

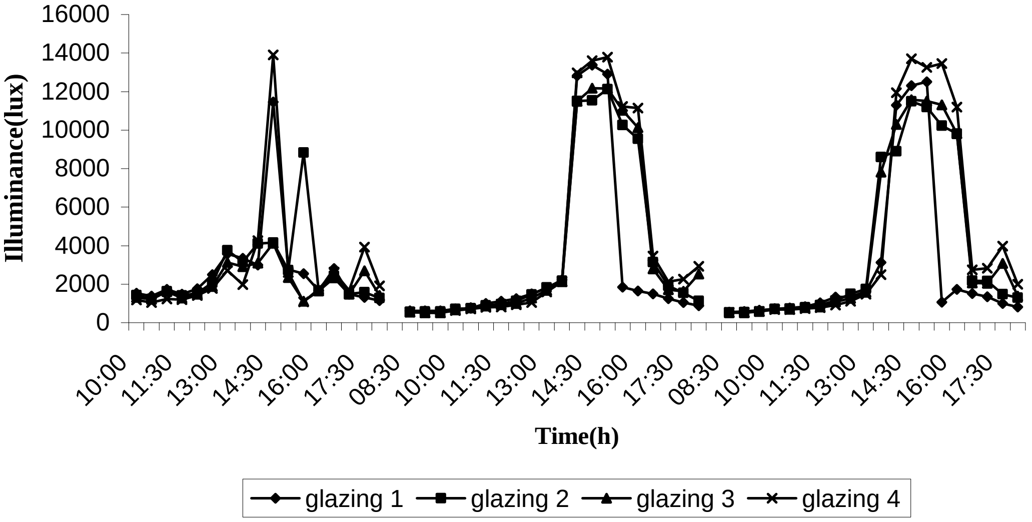


Figure 7.35 Distribution of illuminace values from glazing of 11-12-13 June

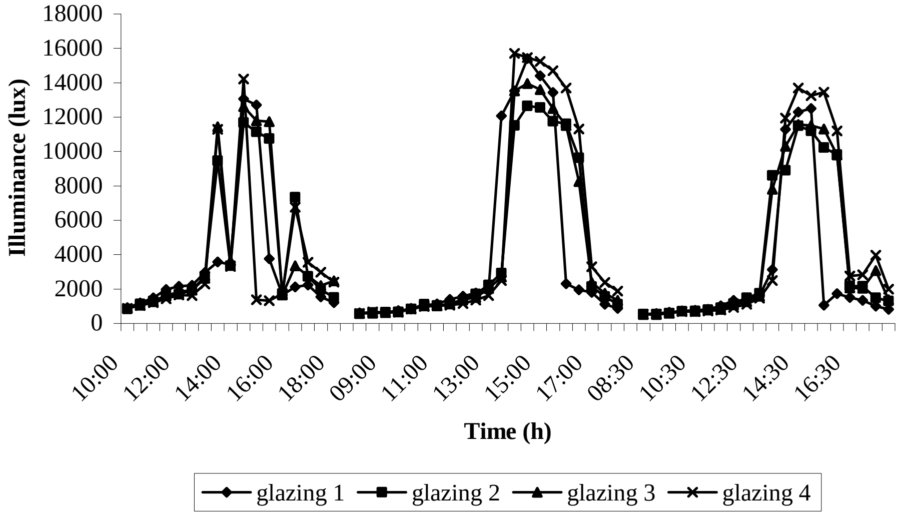


Figure 7.36 Distribution of illuminace values from glazing of 17-18-19 July

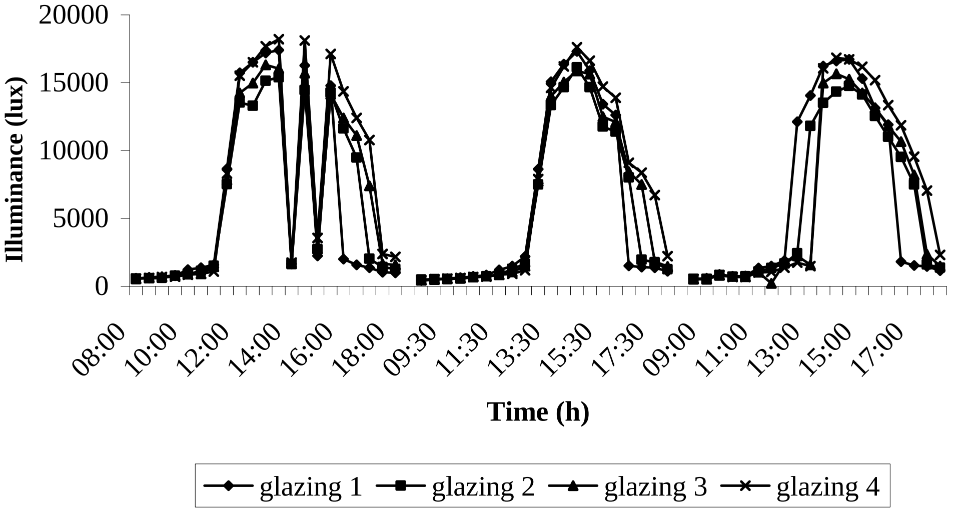


Figure 7.37 Distribution of illuminace values from glazing of 17-18-19 August

7.3 Experimental Study about Glazing

The solar transmission coefficient and the absorbsion coefficient values of the glazing which was used at the experiments of the thesis which were taken from catalogues of the firms. But these values belong to the situation when the solar rays came to the glazing with a perpendicular angle. By the movement of the sun and the orientation effect of the surfaces; the changes of angles of incoming sunlight rays occurred.The value of this change was calculated and mantioned how it was done at the earlier chapters. An extra experiment has been done to determinate the truth of this calculation. The experiment was done during a daytime at the flat roof of The Solar Energy Institute of Aegean University. The experiment was made after the office experiments of June (13-June-2008). By this way, the time period between the calculations and the experiment results were closed to each other.

At the experimental set up, 1m x 1.5m glazing used and iron profile blocks preferred for stabilization. The phronemeter and lightmeter were placed at both sides of glazing for comparing the measuring results. The inner side of the glazing which was prepared for the closed area measurement was covered with the black cloth (Figure 7.39). The results were taken from the Phronometer and Lightmeter at each fifteen minute. The graphic is prepared with the results taken from the measurements. (Figure 7.38)

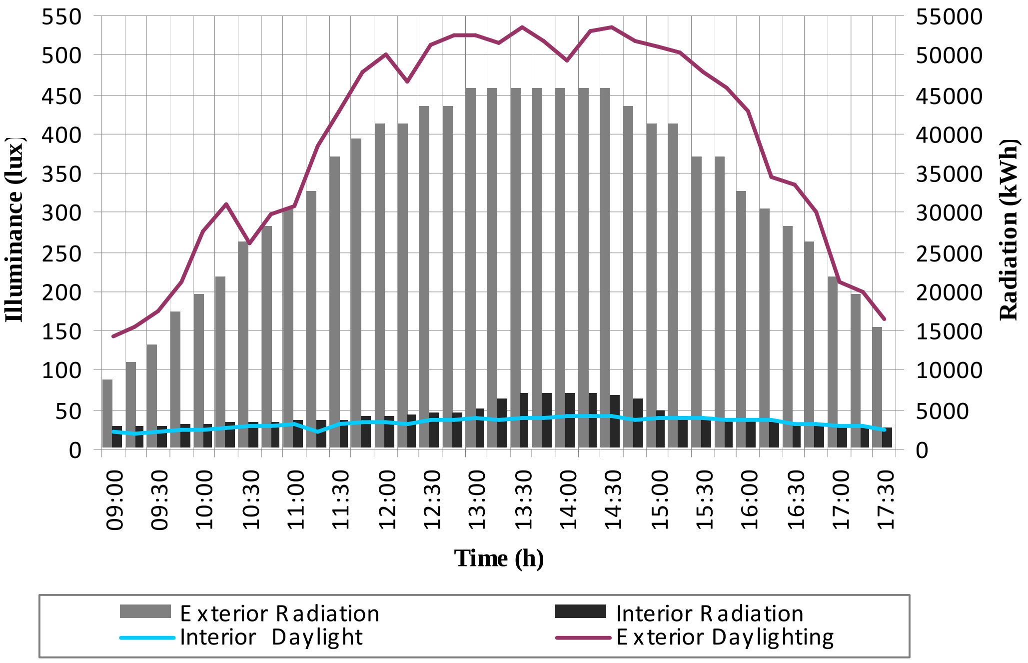


Figure 7.38 Distribution of illuminace and radiation values from glazing unit of the office (17-July-2008).

The decrease of exterior solar radiation and interior radiation were defined as a degree of solar transmission coefficient. As a result; the calculations which were made at earlier chapters were approximately suitable.

Figure 7.39 Picture of experimental plan of glazing unit of the office

7.4 Calibration of the Thermocouples

The thermocouples which used for thermal measurements were calibrated at the Calibration Center of MMO (also called as KALMEM). The thermocouples were T-Type. And water bath method was used for calibration.

A thermocouple is a couple of two different metals which are welded strongly to each other. It is a simple kind of thermal measuring material. Its welded side is called as hot point and the other side is called as cold point. The cold point is also the reference point. The thermocouple function occurs with the thermal difference between the hot point and the cold point. Whatever the distribution of the thermal energy between the hot point and the cold point; the created tension is related with the thermal difference between the hot point and the cold point.

Figure 7.40 Picture of calibration and equipment

The bath for calibration was prepared with the equipments of hot and cold water reservoir, a measuring prop, thermometer and mixer. The prop had a structural shape of a basket which helps to the thermocouples for taking place regularly. At the temperature of the calibration, the device was settled and waited for the temperature to reach the set value. At least ten different values were supposed to be read after the temperature had reached to the set value. The average value of this measurement was the reference value which was ohm. After the ohm value was found; it was translated to the value of temperature as degrees of Celsius. This temperature value was the reference. These procedures were repeated for the other temperatures such as, mines ten, mines five, zero, twenty, thirty, forty, sixty and eighty degrees of Celsius. The calibrated temperatures were especially selected as the values of the experiment results. The reference temperatures and experimental temperatures were combined in a graphic. The equation of the graphic line was obtained and used for the calculations.

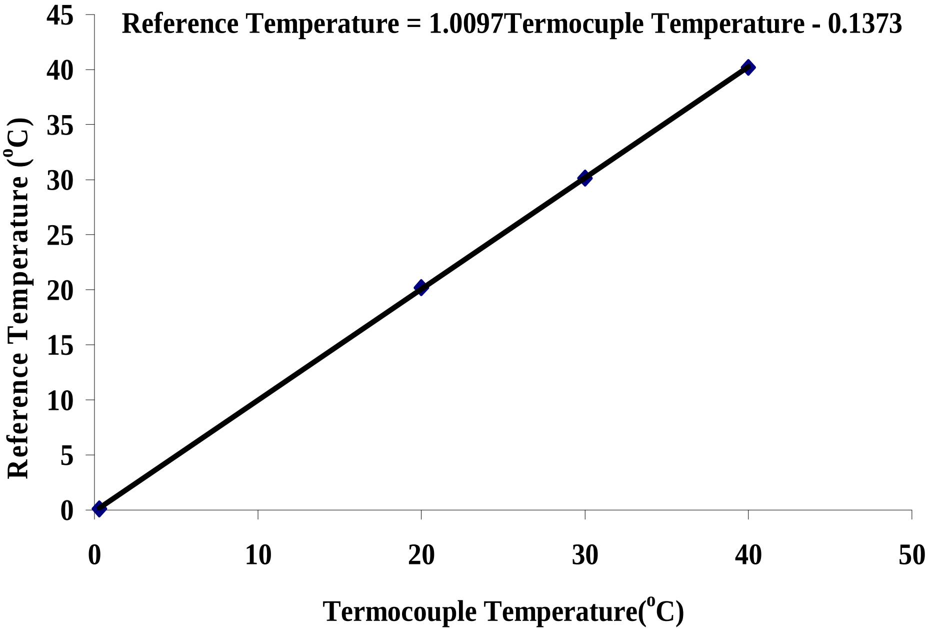


Figure 7.41 Calibration curve of a thermocouple

7.4.1 Uncertainty Analysis

Experimental studies, naturally, cause some uncertainties and unpredictable errors. Such diversions may arise due to human nature reading errors, instrumental manufacturing errors, environmental condition effects or calibration errors and all of which can not be taken into account for evaluating the experimental results. In these researches, computation of the experimental results mainly depends on temperatures, illuminance and radiation of the test section. Latent energy is the dominant one, in comparison with the sensible energy, for calculating the total stored energy and total uncertainty for computing the latent energy can be obtained as ±3.0 %, from the uncertainties of above-mentioned parameters.

Uncertainties arise from,

Thermocouples : ±1.0 %
Reference temperature : ±1.0 %
Data logger system : ±0.3 %
Digital multimeter (luxmeter) : ±5.0 %

7.5 Iso- Illuminance Disturibution

The illuminance values, which were measured at the office, drawn in figure of iso-illuminance curve by the program of Dialux. The office was defined to the program with all details for 3-D design. The following properties of the office were defined with details: the color of the wall, roof and floor colors, glazing unit proporties, the proportions of the used equipment and their replacement. By using the measurement day and hour values; the iso-illuminance values were calculated by the program. The program results were shown on the graphic diagram (Figure 7.42-7.52). The results of the program were similar with the measurement values. By this way; the structural properties of the Heat control glazing, the Classic glazing and the Heat and Solar control glazing were identified to the program. Due to the calculation results of the program by using the identified proporties, the curves on the graphic diagram had been prepaired.

The iso-illuminance curves were prepaired for each glazing unit at the conditions of the same observation day and hour which were shown below. The iso-illuminance value, which was given for the interior side of the glazing unit, decreases through the inner parts of the office. But these values were not shown. The solar transfer coefficient value of the classic glazing unit is the biggest. That's why; the iso-illıminance value of the classic glazing unit was the biggest. The solar transfer coefficient value of the solar control glazing unit was the smallest.

7.5.1 Solar Control Glazing

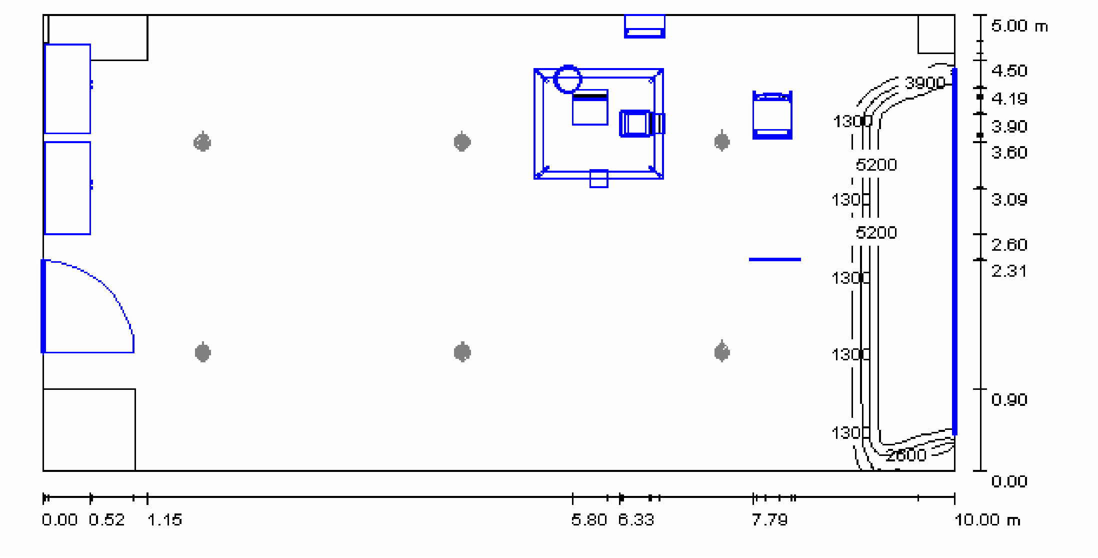


Figure 7.42 Distribution of the iso-illuminnace curve of the office

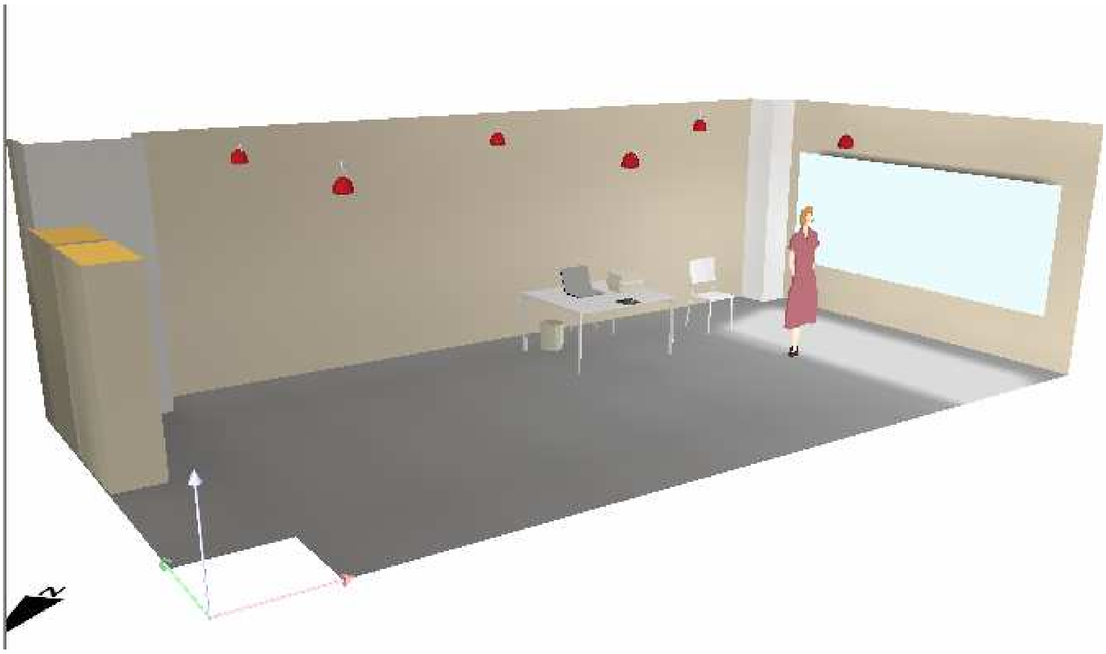


Figure 7.43 3-D design of the office.

7.5.2 Heat and Solar Control Glazing

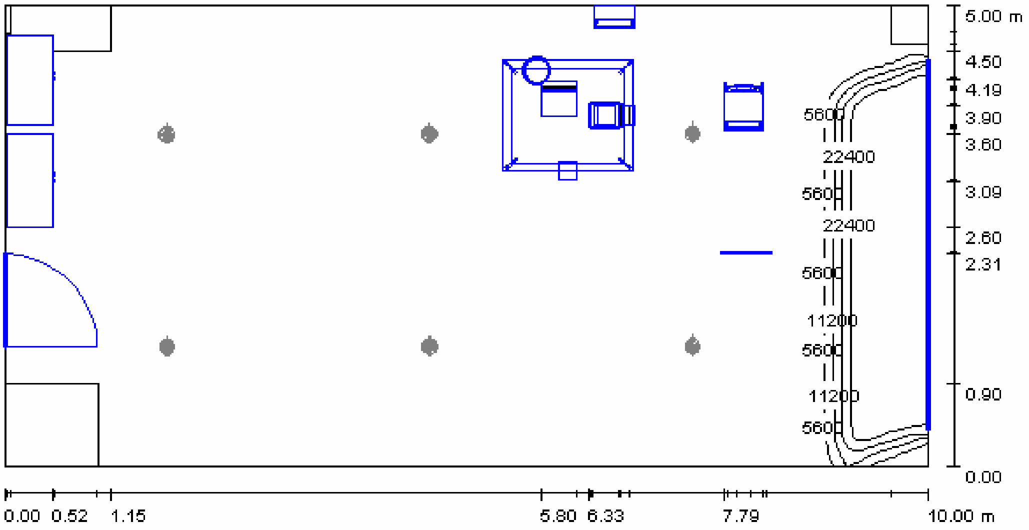


Figure 7.44 Distribution of the iso-illuminnace curve of the office

Figure 7.45 3-D design of the office.

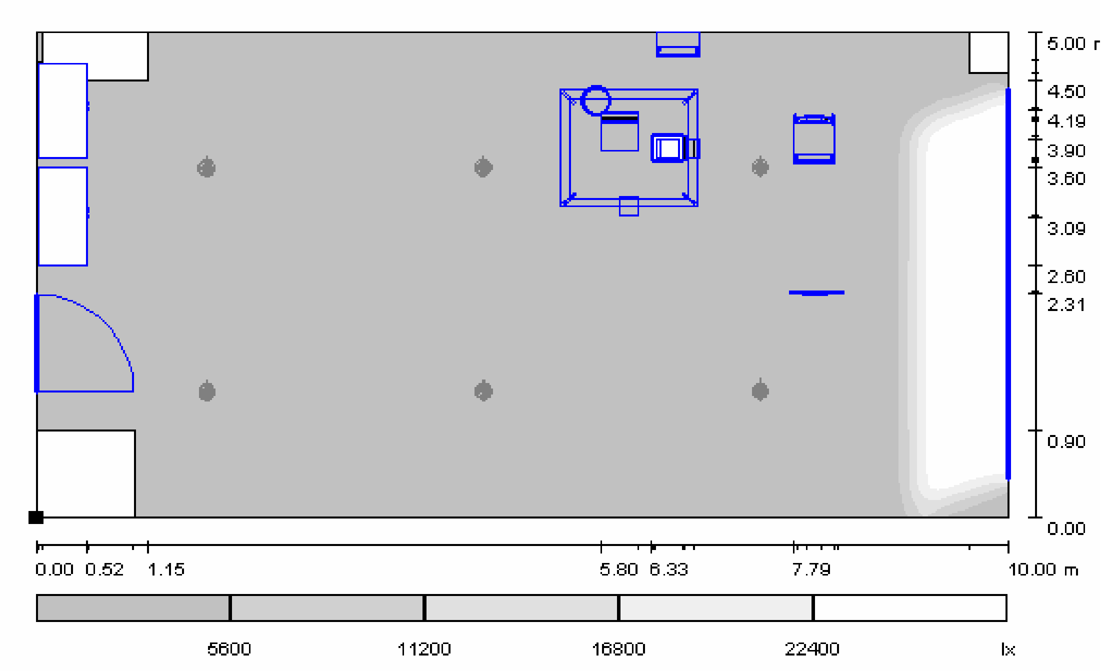


Figure 7.46 Distribution of the iso-illuminnace curve of the office

7.5.3 Heat ControlGlazing

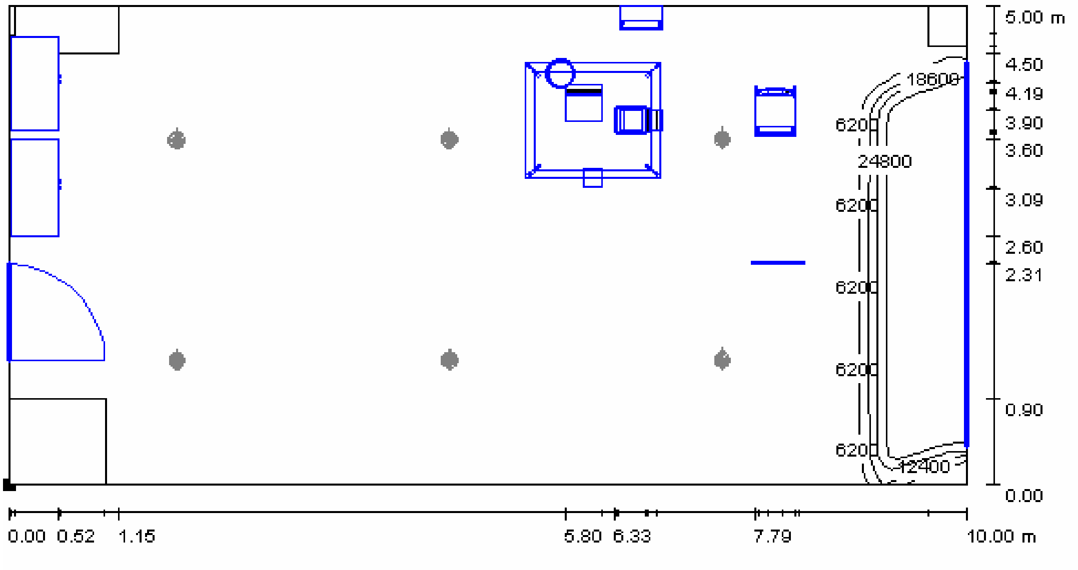


Figure 7.47 Distribution of the iso-illuminnace curve of the office

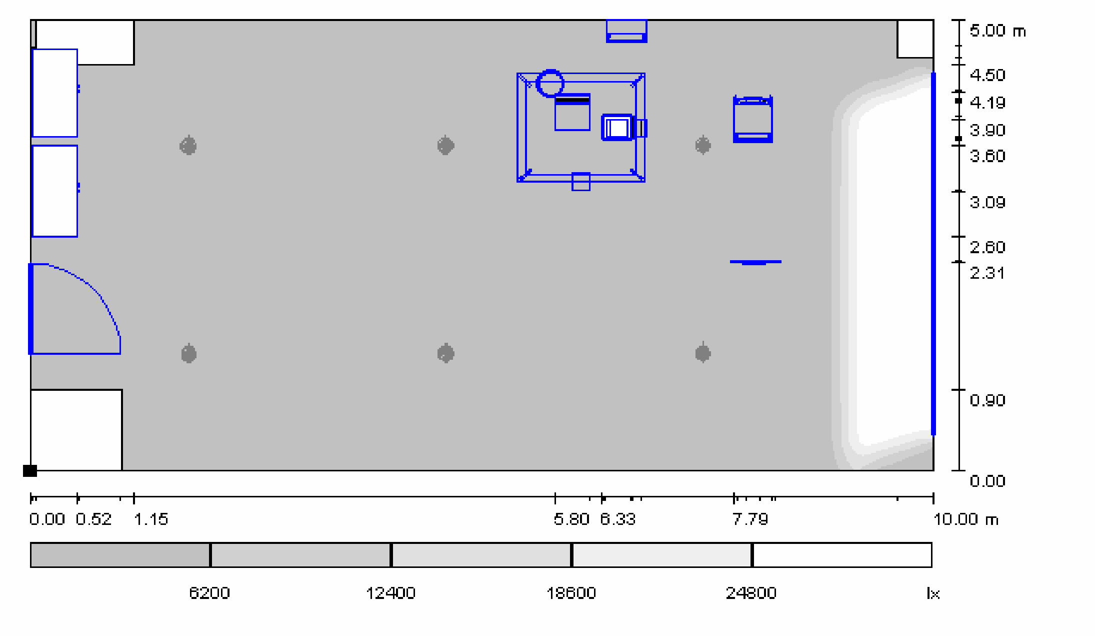


Figure 7.48 Distribution of the iso-illuminnace curve of the office

Figure 7.49 3-D design of the office.

7.5.4 Classic Glazing

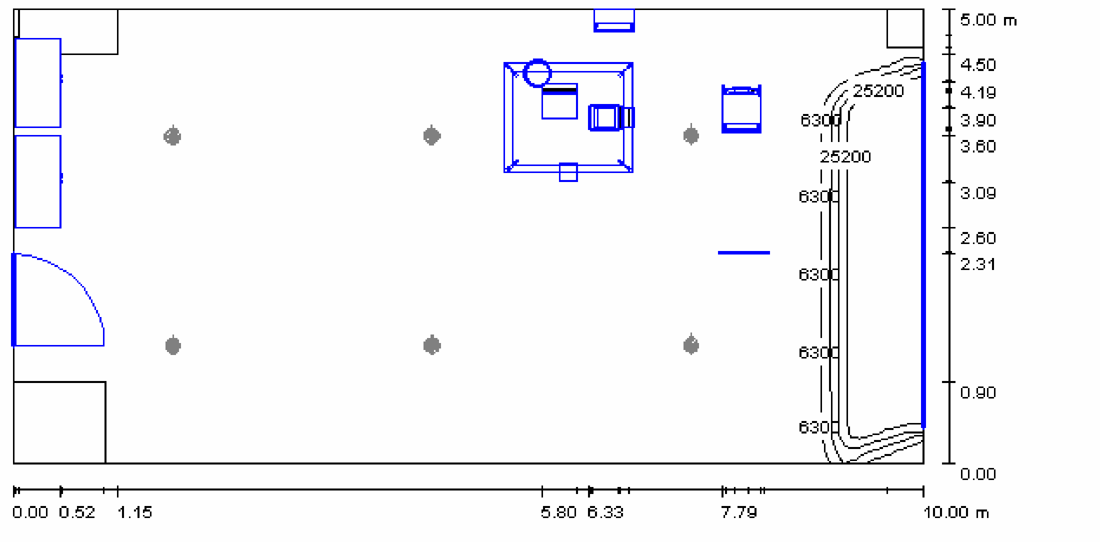


Figure 7.50 Distribution of the iso-illuminnace curve of the office

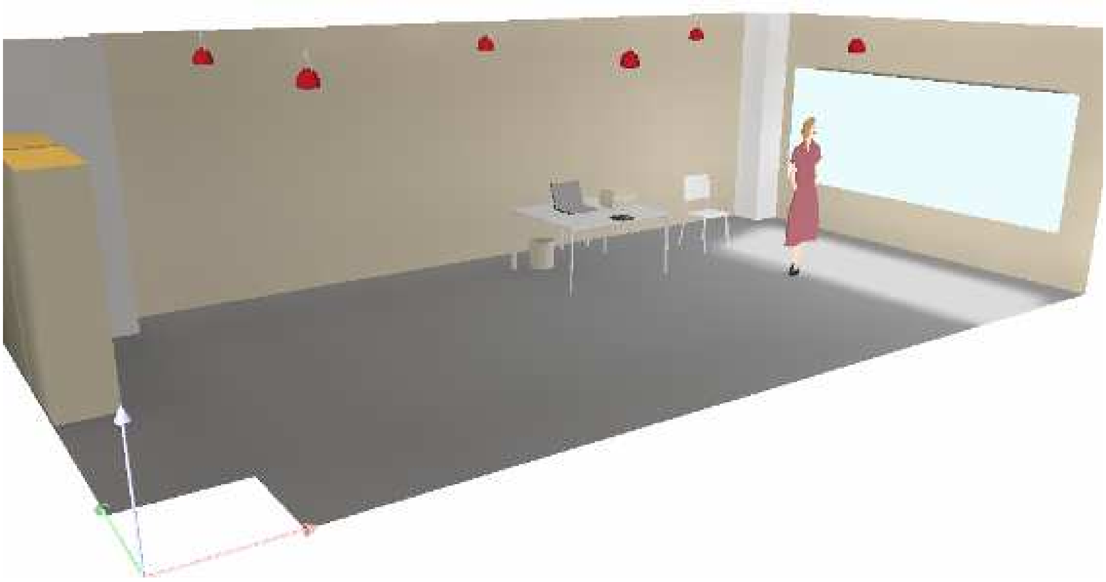


Figure 7.51 3-D design of the office.

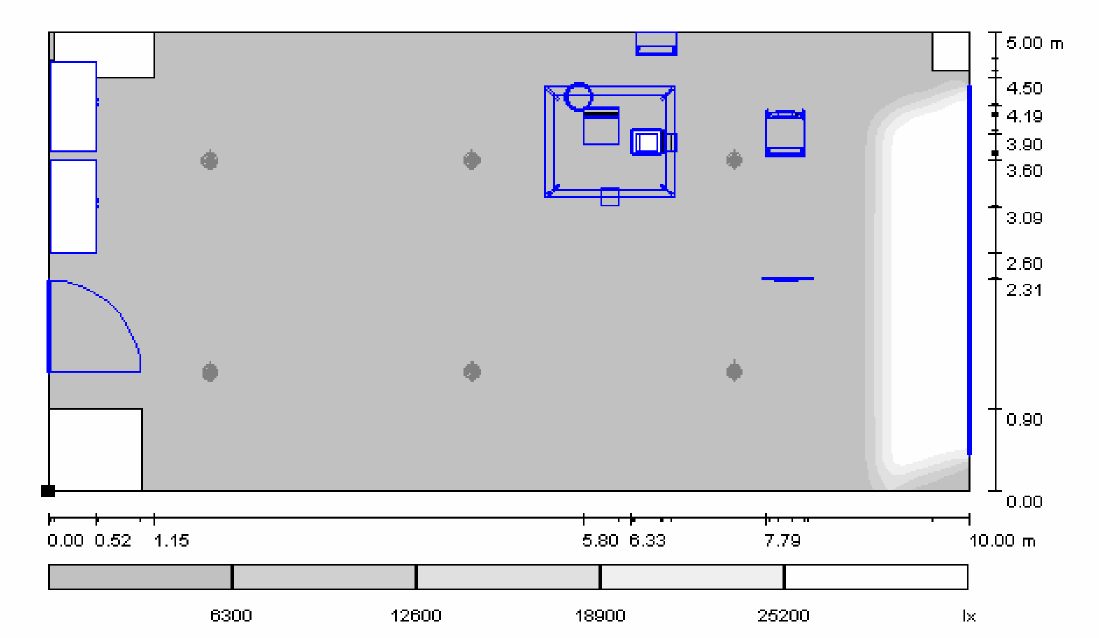


Figure 7.52 Distribution of the iso-illuminnace curve of the office

CHAPTER EIGHT
CONCLUSION

8.1 Performance of the System and Results

In this study, the purpose is to minimize the effect of the heating load, cooling load and the lighting load to due the structural property of the glazing unit. The purpose for planning the glazing unit by using passive solar design principles is increasing the office energy efficiency. Almost all materials and design of the building are based on their thermal properties and passive solar design principles. The motivation of the thesis is to investigate the effectiveness and efficiency of glazing units.

Heating, cooling and lighting demands were determinated as the primary concern (for planning the structural properties of glazing units). The heating and cooling loads of the building were depending on the heat transmission and infiltration values found out and compared with the meteorological data of outdoor temperature which was taken from the Solar Energy Institute of Ege University.

The indoor temperature value was also obtained. As a result of this; the indoor environments were formed on the basis of occupier and heat loss values calculated due to the differences between the indoor and outdoor temperature values. Therefore; the evaluation consists of three periods: The Winter Period, 1st of January- 30th of February; the Spring Period, 1st of March– 30th of May; the Summer Period, 1st of May – 30th of August. The analyses were prepaired in conformity of four different types of glazing units of the office. For each case; the solar heat gain, the artificial lighting consumption, the internal heat gain and the heat losses/gains were considered to find out the total heat gain and losses. Thus; the total heating, cooling and lighting consumption of the office were obtained and the amount of saved energy was compared between each case. The annual heat loss values were the sum of the transmission. The transmission losses were used to determine total heat loss of the office for each case.

For these four cases of the office, there was a heating load in January and February. The heating load decreased gradually due to the solar heat gain factor towards the low value to high value of the glazing. The solar control glazing was taken as the reference glazing and all of the calculations and comparations were made by using the reference glazing. The total heating load was in south-west facing position which was obtained as 440kWh.

- If the glazing type was as the classic glazing unit, then the heating energy requirement of the office would be 721kWh. This means that; more than 64% of the energy was profit. When the artificial lighting was added to this, the total load reached to 640kWh. For the classic glazing, the total load was calculated as 849kWh. The difference between reference and classic showed a decrease of 33%.

- The proportion of the heat control glazing to the total heat load was increased up to 5%. When the artificial lighting load was added; the proportion decreased up to 7% For the heat and solar control glazing; the proportion of the total heat load to the heat load of reference glazing increased up to 16%. With the effect of the artificial lighting; the proportion got closed to one.

- The solar control glazing which was used at the office was different from the other solar control glazing units by the property of higher absorbsion effectivity which caused less heat load in winter and high cooling load in summer.

The cooling load of the office increased gradually from June to August and peak value occured as 380kWh in August. The cooling load increased gradually due to the solar heat gain factor towards the low value to high value of the glazing. The total cooling load occured in south-west facing position which has obtained as 1126kWh.

- If the glazing type was as the classic glazing unit, then the cooling energy requirement of the office would be 1126kWh. This means that; more than the 78% of the energy of heat was profit. When the artificial lighting was added to this, the total load reached to 1426kWh.

- For the classic glazing, the total load was calculated as 2193kWh. The difference between these values showed a decrease of 54%. The proportion of the heat control glazing to the total heat load decreased up to 5%. When the artificial lighting load was added; the proportion decreased up to 12%.

- For the heat and solar control glazing; the proportion of the total heat load to the heat load of reference glazing increased up to 14%. With the effect of the artificial lighting; the proportion decreased up to 19%.

- The solar control glazing which was used at the office was different from the other solar control glazing units by the property of higher absorbsion effectivity which caused less heat load at winter and high cooling load at summer.

The annual total energy consumption of the office, when the lighting was taken into consideration all alone, the solar control glazing obtained the highest increment of the total load of the office. The classic glazing had up to 25% more total annual energy requirement than the reference glazing. On the other hand, the Heat Control glazing had up to 13% more total annual energy requirement than the reference glazing. The heat and solar glazing had up to 14% more total annual energy requirement than the reference glazing.

The experiment was done by using the solar control glazing, enough artifical lighting had not obtained even there was a high value of total lighting demand. Especially in winter season, this disadvantage was obtained more definitely.The total demand of lighting which was taken from the administration of the entire building of Tepekule confirmed the results. The total loads of lighting doubled in winter season.

As a result of the calculations; choose of glazing for the office was definitely wrong. The city of İzmir takes place at where the cooling loads are higher than heating loads. The solar control glazings are designed for places which have higher cooling loads than heating loads. The type of the glazing which was chosen for the office was suitable but the extra coating on the glazing made the structural properties worse such as increasing the absorbsion effectivity and by this way it gained the specialities of heat control glazing. Furthermore these kinds of offices were identified as high artificial lighting requirement owner such as 500lux which was more than the need of a residence. As a result of this; the solar transmission effectivity of the glazing required more than usual. Because of the high reflection effectivity of the glazing which used at the office, the solar transmission coefficient of the glazing decreased and the percentage of utilizing of daylight also decreased. The required lighting was provided by the artificial lighting. Also the lighting load and the cooling load have increased by this way.

There are many factors which effect the change of energy at the offices. If these factors are regularly identified and established, than the total load could be able to decrease. These factors are researched under different topics below.

The glazing type

The visible transmission and the thermal properties of the glazing which was used at the office were supposed to be considered together. The change of the solar heat gain factor and the visible transmission values were better if they were compared together. The choosing was supposed to be done as through to the results of these.

The climate

The region of the applied office must have taken to the consideration. If the heating control glazing was chosen at the region where the cooling loads were incredible, than the cooling loads would be expanded. For the incredible heating loads, the heat control glazing was the best choice. For the incredible cooling loads, the solar control glazing was the best choice. Where the heating and the cooling loads were equal, the heat and solar control glazing is the best choice. The coatings done for solar control or other reasons caused the decrease of the daylight transmission. When the choising the glazing, this situation must be considered.

The usage of the aim

The usage purpose of the office is very important. Due to the purpose of usage; suitable selections must be done. The usage of solar control glazing should be wrong at where a high level of lighting is required.

The dimensional property

The dimensions of the application office and the glazing units are important factors for daylighting. Furthermore the furnitures, the wall mounted stuff, the color of the wall and ceiling and the carpets of the office must be considered.

The illumination equipments

The higher illuminace values are supplied with lesser energy by using the developing technology. If also the lighting plan of the office is prepaired regularly, it should take less afford to provide effective lighting.

NOMENCLATURE

A	Surface area (m^2)
A_{cg}	Center of glazing area (m^2)
A_{eg}	Edge of glazing area (m^2)
A_f	Frame area (m^2)
A_g	Glazing area (m^2)
A_p	Perimeter floor area (m^2)
A_{op}	Opague area of glazing (m^2)
A_{pf}	Fenestration area (m^2)
A_w	Window aera (m^2)
A_s	Solar transmitting area (m^2)
c_{pa}	Specific heat capacity of air at constant pressure (J/kg^{o}C)
E_m	Illuminance level (lux)
E_t	Incident totak irradiance (W/m^2)
f_d	Daylight availability ratio
G_0	Extraterrestrial radiation on a surface (W/m^2)
G_{0n}	Extraterrestrial radiation (W/m^2)
G_{sc}	Solar constant (W/m^2)
h_o	Outdoor glazing surface haet transfer coefficient (W/m^2)
h_i	Indoor glazing surface haet transfer coefficient (W/m^2)
$\overline{H}$	Monthly average radiation (W/m^2)
$\overline{H}_0$	Monthly average extraterrestrial radiation (W/m^2)
$\overline{H}_b$	Monthly average beam radiation (W/m^2)
$\overline{H}_d$	Monthly average diffuse radiation (W/m^2)
$\overline{H}_T$	Monthly average incident radiation on tilted surface (W/m^2)
H_0	Daily extraterrestrial radiation (W/m^2)
H_b	Beam radiation on horizontal surface (W/m^2)

H_{bn}	Beam radiation on a plane normal (W/m^2)
H_{bt}	Beam radiation on a tilted plane (W/m^2)
H_d	Diffuse radiation on surface (W/m^2)
H_T	Total radiation on surface (W/m^2)
I_0	Hourly extraterrestrial radiation (W/m^2)
I_b	Hourly beam radiation (W/m^2)
I_d	Hourly diffuse radiation (W/m^2)
I_T	Hourly total radiation on surface (W/m^2)
k	Termal conductivity (W/m K)
$\overline{K}_T$	Monthly average clearness index
L	Tickness (mm)
LHG	Latent heat gain
n	Mean day of the year
Q	Instantaneous energy (W)
Q_c	Ventilation heat loss (W)
Q_e	Heat gain from equipment (W)
Q_f	Heat gain from fenestration (W)
Q_g	Heat gain from glazing (W)
Q_{op}	Heat gain from opaque frame (W)
Q_s	Heat gain from solar transmitting (W)
Q_i	Internal heat gain (W)
Q_{inf}	Infiltration heat loss (W)
Q_{light}	Heat gain from lighting (W)
Q_p	Heat gain from people (W)
Q_{sol}	Solar energy flow (W)
Q_{th}	Termal energy flow (W)

Q_v	Heat gain from vantilation (W)
Q_m	Heat gain from mechanical (W)
R_b	Geometric factor
S	Absorbed radiation (W/m^2)
$\overline{S}$	Monthly average absorbed radiation (W/m^2)
$SHGF$	Sensible heat gain factor
T_i	Indoor air temperature (C)
T_o	Outdoor air temperature (C)
U	Heat transfer coefficient (W/m^{2}C)
U_{cg}	Heat transfer coefficient of center of glazing (W/m^{2}C)
U_{eg}	Heat transfer coefficient of edge of glazing (W/m^{2}C)
U_f	Heat transfer coefficient of fenestration (W/m^{2}C)
V	Volumetric air flow rate (m^3)
VT	Visible transmittance
WWR	Window to wall ratio

Greek symbols

α	Solar altitude angle (degree)
β	Slope (degree)
γ	Surface azimuth angle (degree)
γ_s	Solar azimuth angle (degree)
δ	Solar declination (degree)
θ	The solar incident angle (degree)
θ_z	Zenith angle (degree)
φ	Latitude (degree)
ρ	Reflection coefficient
ρ_c	Reflection coefficient of celiling
ρ_w	Reflection coefficient of wall
ρ_f	Reflection coefficient of floor
c_{pa}	Specific heat capacity of air at constant pressure (J/kgC)
ρ	Air density (kg/m^3)
ω	Hour angle (degree)
ω_s	Sunset hour angle (degree)
τ_w	Visible transmittance of the window glazing

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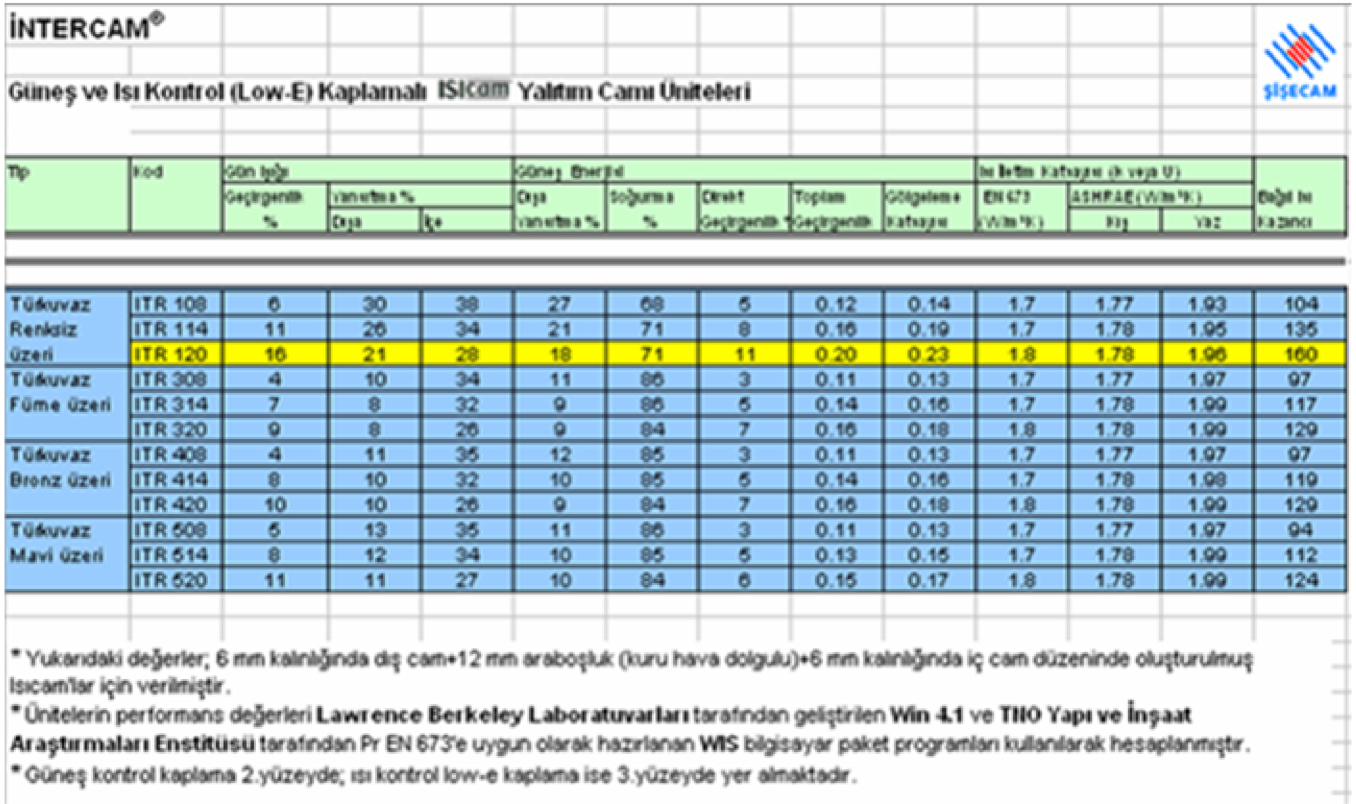
APPENDIX

Table A1 Performance table of glazing units (from Sisecam)

Glazing property	Daylighting		Solar Energy				
Glazing Type	Transmittance	Reflection	Transmittance	Absorption	Direct Transmittance	Total Transmittance	Heat Transmittance Coefficient
Clasic glazing	0.78	0.14	0.12	0.26	0.62	0.71	2.8
Solar Control Glazing	0.16	0.21	0.18	0.71	0.11	0.2	1.78
Heat Control Glazing	0.77	0.12	0.23	0.3	0.48	0.54	1.6
Solar &Control Glazing	0.69	0.1	0.25	0.38	0.37	0.43	1.6

Table A2 Performance table of glazing unit of Office (from Sisecam)



İNTERCAM®

Güneş ve Isı Kontrol (Low-E) Kaplamalı Isıcam Yalıtım Camı Üniteleri

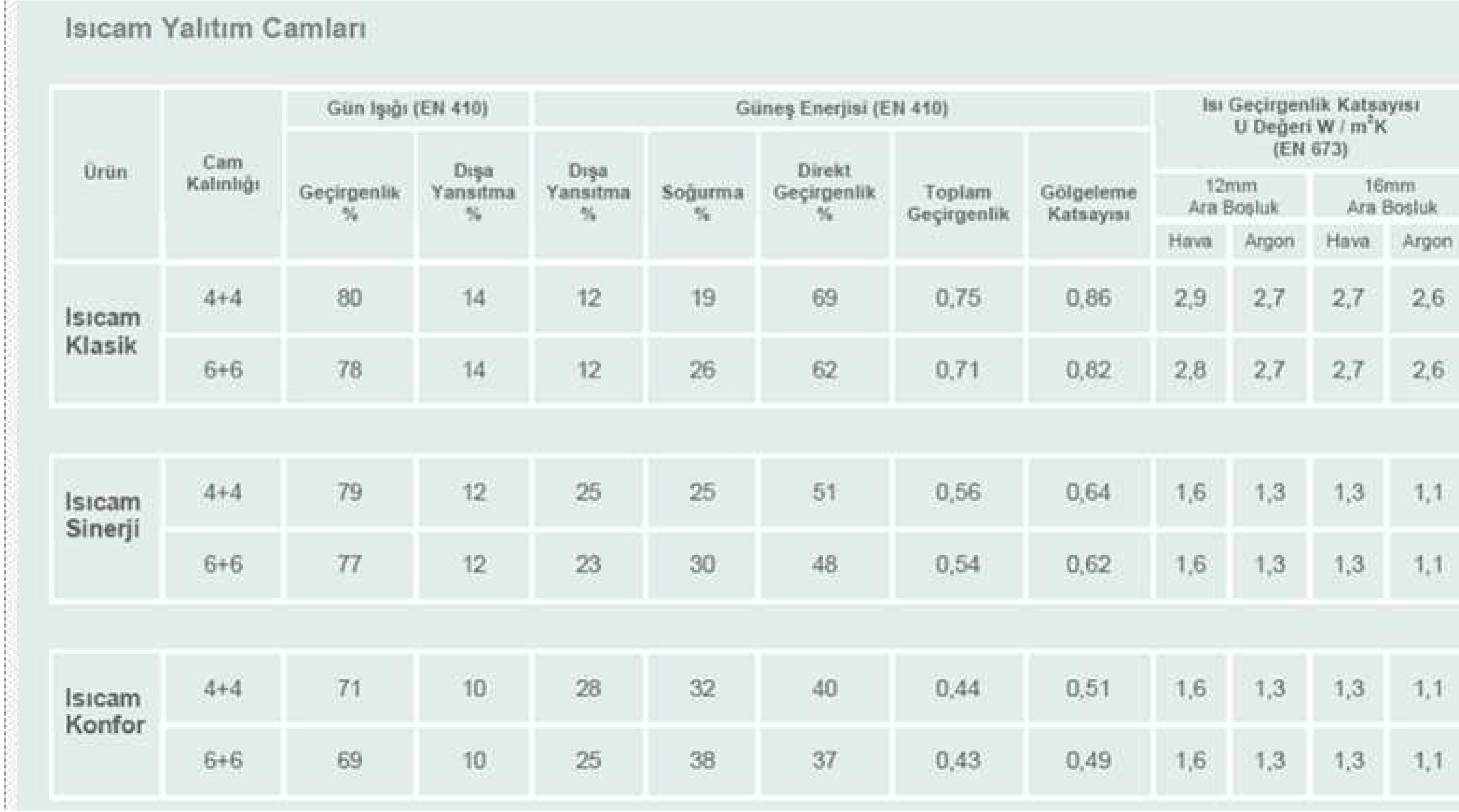
Tip	Kod	Gün Işığı			Güneş Enerjisi					Isı İletim Katsayısı (k veya U)			Bağıl Isı Kazancı
		Geçirgenlik %	Yansıtma %		Dışa Yansıtma %	Soğurma %	Direkt Geçirgenlik	Toplam Geçirgenlik	Gölgeleme Katsayısı	EN 673 (W/m²K)	ASHRAE (W/m²K)		
			Dışa	İçe							Kış	Yaz	
Türkuvaz Renksiz üzeri	ITR 108	6	30	38	27	68	5	0.12	0.14	1.7	1.77	1.93	104
	ITR 114	11	26	34	21	71	8	0.16	0.19	1.7	1.78	1.95	135
	ITR 120	16	21	28	18	71	11	0.20	0.23	1.8	1.78	1.96	160
Türkuvaz Füme üzeri	ITR 308	4	10	34	11	86	3	0.11	0.13	1.7	1.77	1.97	97
	ITR 314	7	8	32	9	86	5	0.14	0.16	1.7	1.78	1.99	117
	ITR 320	9	8	26	9	84	7	0.16	0.18	1.8	1.78	1.99	129
Türkuvaz Bronz üzeri	ITR 408	4	11	35	12	85	3	0.11	0.13	1.7	1.77	1.97	97
	ITR 414	8	10	32	10	85	5	0.14	0.16	1.7	1.78	1.98	119
	ITR 420	10	10	26	9	84	7	0.16	0.18	1.8	1.78	1.99	129
Türkuvaz Mavi üzeri	ITR 508	5	13	35	11	86	3	0.11	0.13	1.7	1.77	1.97	94
	ITR 514	8	12	34	10	85	5	0.13	0.15	1.7	1.78	1.99	112
	ITR 520	11	11	27	10	84	6	0.15	0.17	1.8	1.78	1.99	124

* Yukarıdaki değerler; 6 mm kalınlığında dış cam+12 mm araboşluk (kuru hava dolgulu)+6 mm kalınlığında iç cam düzeninde oluşturulmuş Isıcam'lar için verilmiştir.

* Ünitelerin performans değerleri **Lawrence Berkeley Laboratuvarları** tarafından geliştirilen **Win 4.1** ve **TNO Yapı ve İnşaat Araştırmaları Enstitüsü** tarafından Pr EN 673'e uygun olarak hazırlanan **WIS** bilgisayar paket programları kullanılarak hesaplanmıştır.

* Güneş kontrol kaplama 2.yüzeyde; ısı kontrol low-e kaplama ise 3.yüzeyde yer almaktadır.

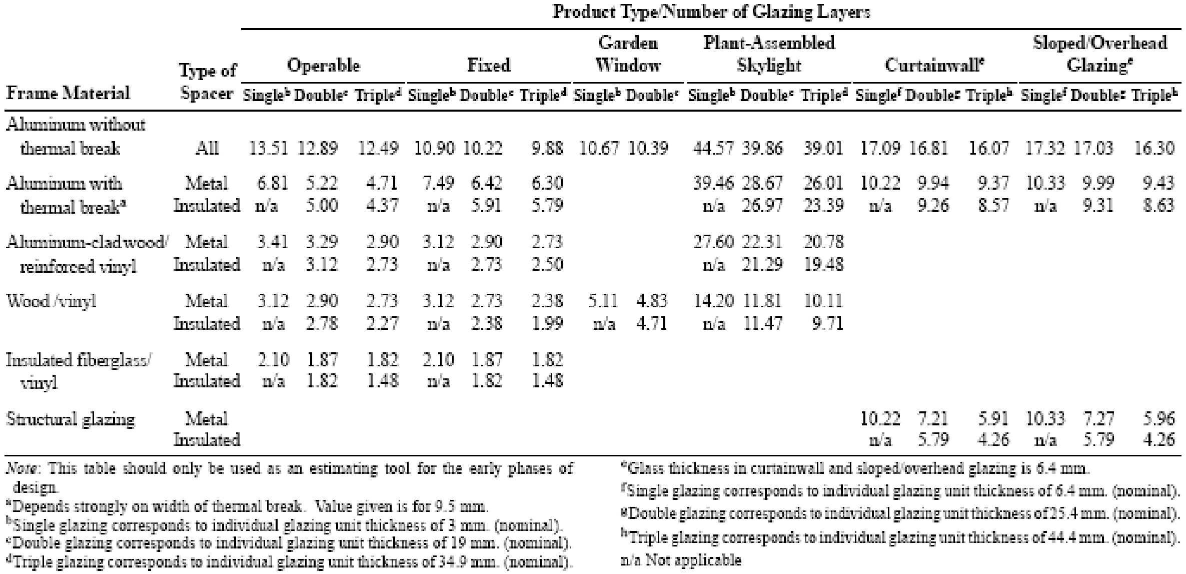
Table A3 Performance table of glazing units (from Sisecam)



Isıcam Yalıtım Camları

Ürün	Cam Kalınlığı	Gün Işığı (EN 410)		Güneş Enerjisi (EN 410)					Isı Geçirgenlik Katsayısı U Değeri W / m²K (EN 673)			
		Geçirgenlik %	Dışa Yansıtma %	Dışa Yansıtma %	Soğurma %	Direkt Geçirgenlik %	Toplam Geçirgenlik	Gölgeleme Katsayısı	12mm Ara Boşluk		16mm Ara Boşluk	
									Hava	Argon	Hava	Argon
Isıcam Klasik	4+4	80	14	12	19	69	0,75	0,86	2,9	2,7	2,7	2,6
	6+6	78	14	12	26	62	0,71	0,82	2,8	2,7	2,7	2,6
Isıcam Sinerji	4+4	79	12	25	25	51	0,56	0,64	1,6	1,3	1,3	1,1
	6+6	77	12	23	30	48	0,54	0,62	1,6	1,3	1,3	1,1
Isıcam Konfor	4+4	71	10	28	32	40	0,44	0,51	1,6	1,3	1,3	1,1
	6+6	69	10	25	38	37	0,43	0,49	1,6	1,3	1,3	1,1

Table A4 Representative Fenestrarion frame *U- factor* in W/m^2 K-vertical orientation



Frame Material	Type of Spacer	Product Type/Number of Glazing Layers																	
		Operable			Fixed			Garden Window		Plant-Assembled Skylight			Curtainwall[e]			Sloped/Overhead Glazing[e]			
		Single[b]	Double[c]	Triple[d]	Single[b]	Double[c]	Triple[d]	Single[b]	Double[c]	Single[b]	Double[c]	Triple[d]	Single[f]	Double[g]	Triple[h]	Single[f]	Double[g]	Triple[h]	
Aluminum without thermal break	All	13.51	12.89	12.49	10.90	10.22	9.88	10.67	10.39	44.57	39.86	39.01	17.09	16.81	16.07	17.32	17.03	16.30	
Aluminum with thermal break[a]	Metal	6.81	5.22	4.71	7.49	6.42	6.30			39.46	28.67	26.01	10.22	9.94	9.37	10.33	9.99	9.43	
	Insulated	n/a	5.00	4.37	n/a	5.91	5.79			n/a	26.97	23.39	n/a	9.26	8.57	n/a	9.31	8.63	
Aluminum-clad wood/ reinforced vinyl	Metal	3.41	3.29	2.90	3.12	2.90	2.73			27.60	22.31	20.78							
	Insulated	n/a	3.12	2.73	n/a	2.73	2.50			n/a	21.29	19.48							
Wood /vinyl	Metal	3.12	2.90	2.73	3.12	2.73	2.38	5.11	4.83	14.20	11.81	10.11							
	Insulated	n/a	2.78	2.27	n/a	2.38	1.99	n/a	4.71	n/a	11.47	9.71							
Insulated fiberglass/ vinyl	Metal	2.10	1.87	1.82	2.10	1.87	1.82												
	Insulated	n/a	1.82	1.48	n/a	1.82	1.48												
Structural glazing	Metal												10.22	7.21	5.91	10.33	7.27	5.96	
	Insulated												n/a	5.79	4.26	n/a	5.79	4.26	

Note: This table should only be used as an estimating tool for the early phases of design.

[a] Depends strongly on width of thermal break. Value given is for 9.5 mm.

[b] Single glazing corresponds to individual glazing unit thickness of 3 mm. (nominal).

[c] Double glazing corresponds to individual glazing unit thickness of 19 mm. (nominal).

[d] Triple glazing corresponds to individual glazing unit thickness of 34.9 mm. (nominal).

[e] Glass thickness in curtainwall and sloped/overhead glazing is 6.4 mm.

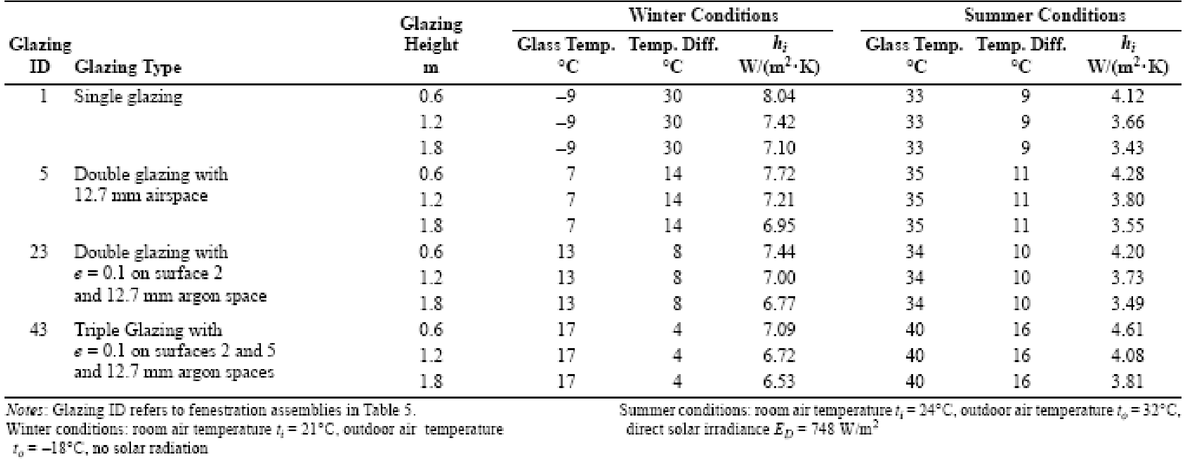
[f] Single glazing corresponds to individual glazing unit thickness of 6.4 mm. (nominal).

[g] Double glazing corresponds to individual glazing unit thickness of 25.4 mm. (nominal).

[h] Triple glazing corresponds to individual glazing unit thickness of 44.4 mm. (nominal).

n/a Not applicable

Table A5 Indoor surface heat transfer coefficient hf in W/m^{2}K)- vertical orientation

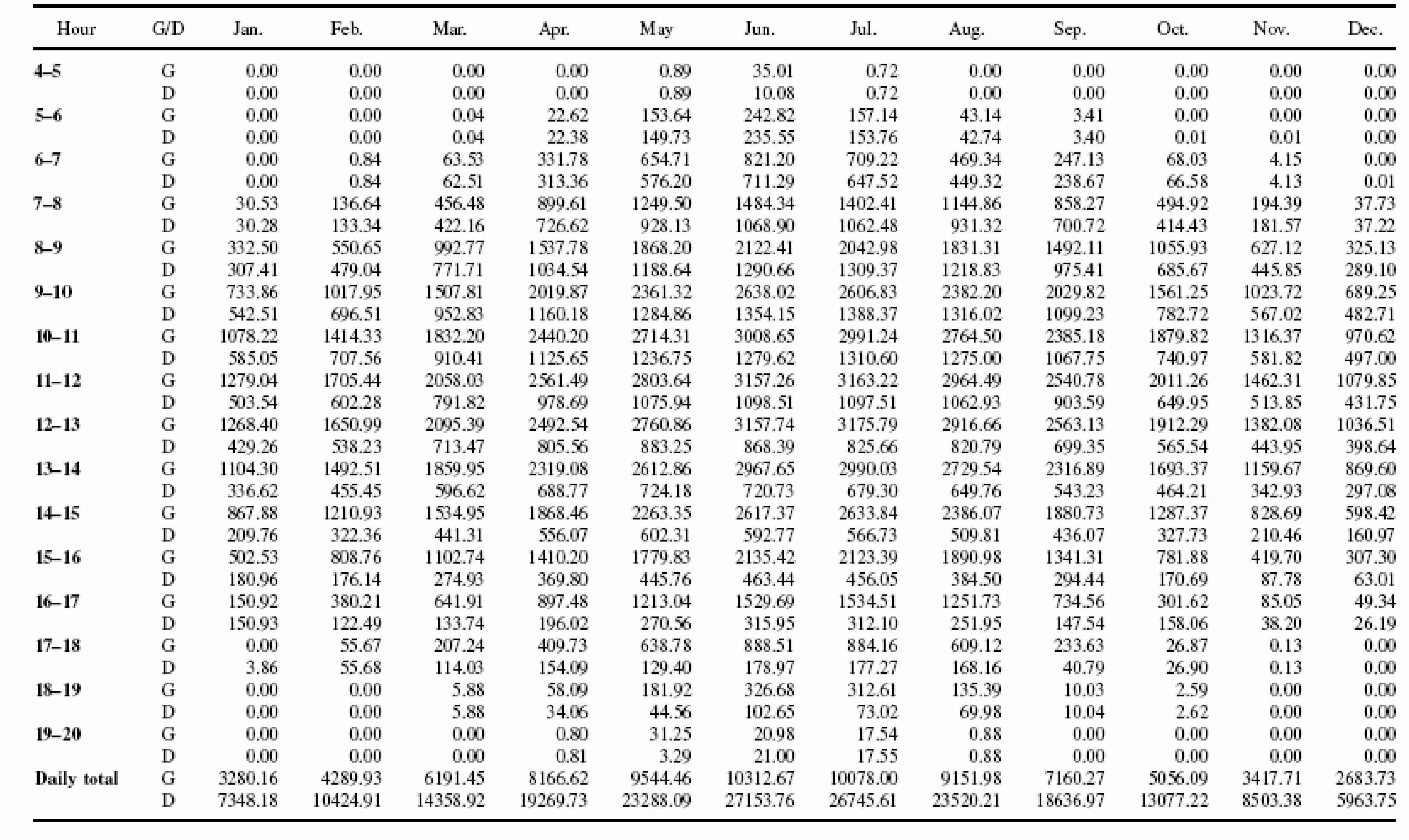


Glazing ID	Glazing Type	Glazing Height m	Winter Conditions: Glass Temp. °C	Winter Conditions: Temp. Diff. °C	Winter Conditions: h_i W/(m^2·K)	Summer Conditions: Glass Temp. °C	Summer Conditions: Temp. Diff. °C	Summer Conditions: h_i W/(m^2·K)
1	Single glazing	0.6	–9	30	8.04	33	9	4.12
		1.2	–9	30	7.42	33	9	3.66
		1.8	–9	30	7.10	33	9	3.43
5	Double glazing with 12.7 mm airspace	0.6	7	14	7.72	35	11	4.28
		1.2	7	14	7.21	35	11	3.80
		1.8	7	14	6.95	35	11	3.55
23	Double glazing with $\varepsilon = 0.1$ on surface 2 and 12.7 mm argon space	0.6	13	8	7.44	34	10	4.20
		1.2	13	8	7.00	34	10	3.73
		1.8	13	8	6.77	34	10	3.49
43	Triple Glazing with $\varepsilon = 0.1$ on surfaces 2 and 5 and 12.7 mm argon spaces	0.6	17	4	7.09	40	16	4.61
		1.2	17	4	6.72	40	16	4.08
		1.8	17	4	6.53	40	16	3.81

Notes: Glazing ID refers to fenestration assemblies in Table 5.
Winter conditions: room air temperature $t_i = 21°C$, outdoor air temperature $t_o = –18°C$, no solar radiation

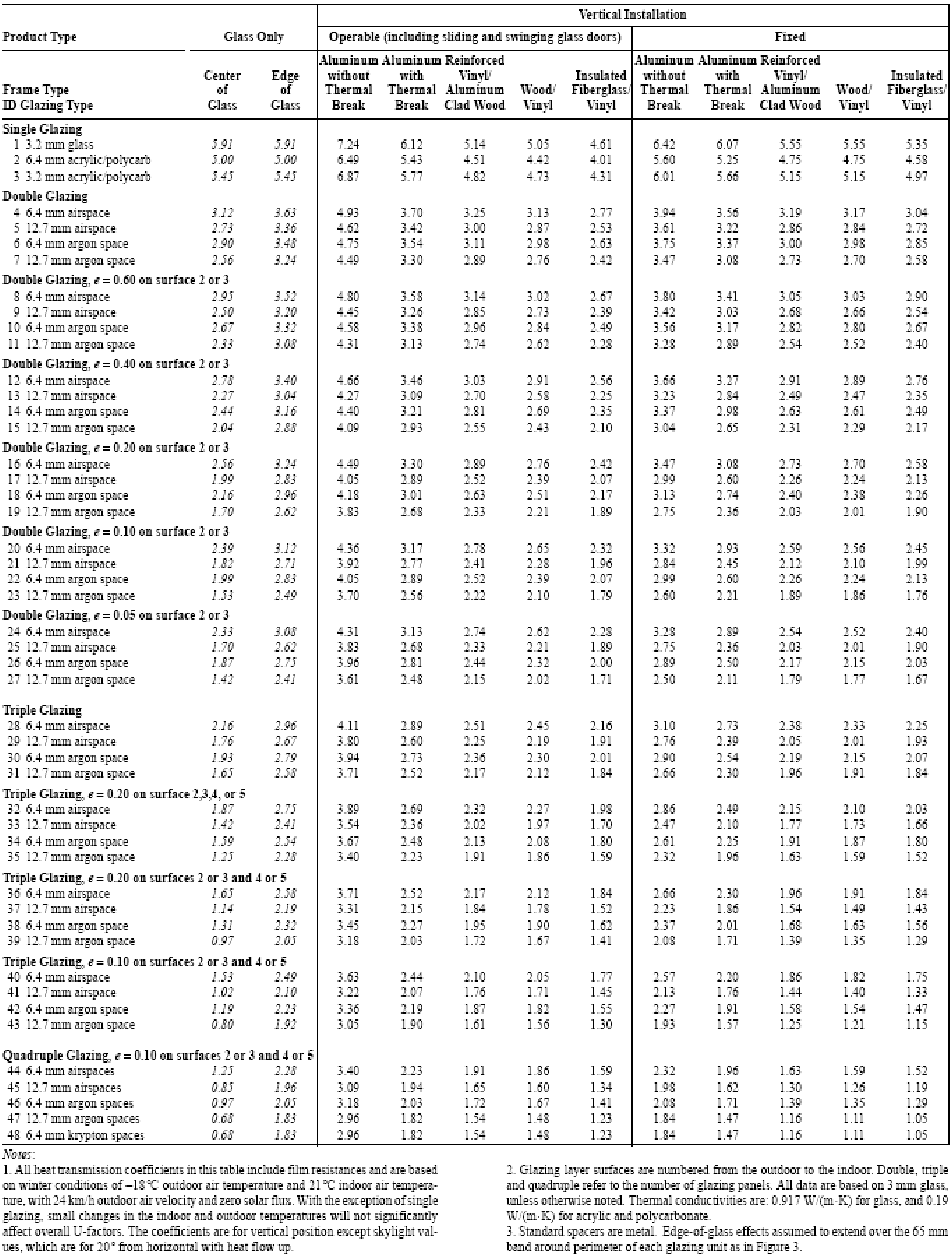
Summer conditions: room air temperature $t_i = 24°C$, outdoor air temperature $t_o = 32°C$, direct solar irradiance $E_D = 748$ W/m^2

Table A6 Horly average global (G) and diffuse (D) solar radiations on horizantal surface (kJ/m^2) (from Ulgen and Hepbasli, 2002)



Hour	G/D	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
4–5	G	0.00	0.00	0.00	0.00	0.89	35.01	0.72	0.00	0.00	0.00	0.00	0.00
	D	0.00	0.00	0.00	0.00	0.89	10.08	0.72	0.00	0.00	0.00	0.00	0.00
5–6	G	0.00	0.00	0.04	22.62	153.64	242.82	157.14	43.14	3.41	0.00	0.00	0.00
	D	0.00	0.00	0.04	22.38	149.73	235.55	153.76	42.74	3.40	0.01	0.01	0.00
6–7	G	0.00	0.84	63.53	331.78	654.71	821.20	709.22	469.34	247.13	68.03	4.15	0.00
	D	0.00	0.84	62.51	313.36	576.20	711.29	647.52	449.32	238.67	66.58	4.13	0.01
7–8	G	30.53	136.64	456.48	899.61	1249.50	1484.34	1402.41	1144.86	858.27	494.92	194.39	37.73
	D	30.28	133.34	422.16	726.62	928.13	1068.90	1062.48	931.32	700.72	414.43	181.57	37.22
8–9	G	332.50	550.65	992.77	1537.78	1868.20	2122.41	2042.98	1831.31	1492.11	1055.93	627.12	325.13
	D	307.41	479.04	771.71	1034.54	1188.64	1290.66	1309.37	1218.83	975.41	685.67	445.85	289.10
9–10	G	733.86	1017.95	1507.81	2019.87	2361.32	2638.02	2606.83	2382.20	2029.82	1561.25	1023.72	689.25
	D	542.51	696.51	952.83	1160.18	1284.86	1354.15	1388.37	1316.02	1099.23	782.72	567.02	482.71
10–11	G	1078.22	1414.33	1832.20	2440.20	2714.31	3008.65	2991.24	2764.50	2385.18	1879.82	1316.37	970.62
	D	585.05	707.56	910.41	1125.65	1236.75	1279.62	1310.60	1275.00	1067.75	740.97	581.82	497.00
11–12	G	1279.04	1705.44	2058.03	2561.49	2803.64	3157.26	3163.22	2964.49	2540.78	2011.26	1462.31	1079.85
	D	503.54	602.28	791.82	978.69	1075.94	1098.51	1097.51	1062.93	903.59	649.95	513.85	431.75
12–13	G	1268.40	1650.99	2095.39	2492.54	2760.86	3157.74	3175.79	2916.66	2563.13	1912.29	1382.08	1036.51
	D	429.26	538.23	713.47	805.56	883.25	868.39	825.66	820.79	699.35	565.54	443.95	398.64
13–14	G	1104.30	1492.51	1859.95	2319.08	2612.86	2967.65	2990.03	2729.54	2316.89	1693.37	1159.67	869.60
	D	336.62	455.45	596.62	688.77	724.18	720.73	679.30	649.76	543.23	464.21	342.93	297.08
14–15	G	867.88	1210.93	1534.95	1868.46	2263.35	2617.37	2633.84	2386.07	1880.73	1287.37	828.69	598.42
	D	209.76	322.36	441.31	556.07	602.31	592.77	566.73	509.81	436.07	327.73	210.46	160.97
15–16	G	502.53	808.76	1102.74	1410.20	1779.83	2135.42	2123.39	1890.98	1341.31	781.88	419.70	307.30
	D	180.96	176.14	274.93	369.80	445.76	463.44	456.05	384.50	294.44	170.69	87.78	63.01
16–17	G	150.92	380.21	641.91	897.48	1213.04	1529.69	1534.51	1251.73	734.56	301.62	85.05	49.34
	D	150.93	122.49	133.74	196.02	270.56	315.95	312.10	251.95	147.54	158.06	38.20	26.19
17–18	G	0.00	55.67	207.24	409.73	638.78	888.51	884.16	609.12	233.63	26.87	0.13	0.00
	D	3.86	55.68	114.03	154.09	129.40	178.97	177.27	168.16	40.79	26.90	0.13	0.00
18–19	G	0.00	0.00	5.88	58.09	181.92	326.68	312.61	135.39	10.03	2.59	0.00	0.00
	D	0.00	0.00	5.88	34.06	44.56	102.65	73.02	69.98	10.04	2.62	0.00	0.00
19–20	G	0.00	0.00	0.00	0.80	31.25	20.98	17.54	0.88	0.00	0.00	0.00	0.00
	D	0.00	0.00	0.00	0.81	3.29	21.00	17.55	0.88	0.00	0.00	0.00	0.00
Daily total	G	3280.16	4289.93	6191.45	8166.62	9544.46	10312.67	10078.00	9151.98	7160.27	5056.09	3417.71	2683.73
	D	7348.18	10424.91	14358.92	19269.73	23288.09	27153.76	26745.61	23520.21	18636.97	13077.22	8503.38	5963.75

Table A7 *U Factor* for various fenestration products in W/m^2 K



Product Type	Glass Only		Vertical Installation									
			Operable (including sliding and swinging glass doors)					Fixed				
Frame Type ID Glazing Type	Center of Glass	Edge of Glass	Aluminum without Thermal Break	Aluminum with Thermal Break	Reinforced Vinyl/ Aluminum Clad Wood	Wood/ Vinyl	Insulated Fiberglass/ Vinyl	Aluminum without Thermal Break	Aluminum with Thermal Break	Reinforced Vinyl/ Aluminum Clad Wood	Wood/ Vinyl	Insulated Fiberglass/ Vinyl
Single Glazing												
1 3.2 mm glass	*5.91*	*5.91*	7.24	6.12	5.14	5.05	4.61	6.42	6.07	5.55	5.55	5.35
2 6.4 mm acrylic/polycarb	*5.00*	*5.00*	6.49	5.43	4.51	4.42	4.01	5.60	5.25	4.75	4.75	4.58
3 3.2 mm acrylic/polycarb	*5.45*	*5.45*	6.87	5.77	4.82	4.73	4.31	6.01	5.66	5.15	5.15	4.97
Double Glazing												
4 6.4 mm airspace	*3.12*	*3.63*	4.93	3.70	3.25	3.13	2.77	3.94	3.56	3.19	3.17	3.04
5 12.7 mm airspace	*2.73*	*3.36*	4.62	3.42	3.00	2.87	2.53	3.61	3.22	2.86	2.84	2.72
6 6.4 mm argon space	*2.90*	*3.48*	4.75	3.54	3.11	2.98	2.63	3.75	3.37	3.00	2.98	2.85
7 12.7 mm argon space	*2.56*	*3.24*	4.49	3.30	2.89	2.76	2.42	3.47	3.08	2.73	2.70	2.58
Double Glazing, $\varepsilon = 0.60$ on surface 2 or 3												
8 6.4 mm airspace	*2.95*	*3.52*	4.80	3.58	3.14	3.02	2.67	3.80	3.41	3.05	3.03	2.90
9 12.7 mm airspace	*2.50*	*3.20*	4.45	3.26	2.85	2.73	2.39	3.42	3.03	2.68	2.66	2.54
10 6.4 mm argon space	*2.67*	*3.32*	4.58	3.38	2.96	2.84	2.49	3.56	3.17	2.82	2.80	2.67
11 12.7 mm argon space	*2.33*	*3.08*	4.31	3.13	2.74	2.62	2.28	3.28	2.89	2.54	2.52	2.40
Double Glazing, $\varepsilon = 0.40$ on surface 2 or 3												
12 6.4 mm airspace	*2.78*	*3.40*	4.66	3.46	3.03	2.91	2.56	3.66	3.27	2.91	2.89	2.76
13 12.7 mm airspace	*2.27*	*3.04*	4.27	3.09	2.70	2.58	2.25	3.23	2.84	2.49	2.47	2.35
14 6.4 mm argon space	*2.44*	*3.16*	4.40	3.21	2.81	2.69	2.35	3.37	2.98	2.63	2.61	2.49
15 12.7 mm argon space	*2.04*	*2.88*	4.09	2.93	2.55	2.43	2.10	3.04	2.65	2.31	2.29	2.17
Double Glazing, $\varepsilon = 0.20$ on surface 2 or 3												
16 6.4 mm airspace	*2.56*	*3.24*	4.49	3.30	2.89	2.76	2.42	3.47	3.08	2.73	2.70	2.58
17 12.7 mm airspace	*1.99*	*2.83*	4.05	2.89	2.52	2.39	2.07	2.99	2.60	2.26	2.24	2.13
18 6.4 mm argon space	*2.16*	*2.96*	4.18	3.01	2.63	2.51	2.17	3.13	2.74	2.40	2.38	2.26
19 12.7 mm argon space	*1.70*	*2.62*	3.83	2.68	2.33	2.21	1.89	2.75	2.36	2.03	2.01	1.90
Double Glazing, $\varepsilon = 0.10$ on surface 2 or 3												
20 6.4 mm airspace	*2.39*	*3.12*	4.36	3.17	2.78	2.65	2.32	3.32	2.93	2.59	2.56	2.45
21 12.7 mm airspace	*1.82*	*2.71*	3.92	2.77	2.41	2.28	1.96	2.84	2.45	2.12	2.10	1.99
22 6.4 mm argon space	*1.99*	*2.83*	4.05	2.89	2.52	2.39	2.07	2.99	2.60	2.26	2.24	2.13
23 12.7 mm argon space	*1.53*	*2.49*	3.70	2.56	2.22	2.10	1.79	2.60	2.21	1.89	1.86	1.76
Double Glazing, $\varepsilon = 0.05$ on surface 2 or 3												
24 6.4 mm airspace	*2.33*	*3.08*	4.31	3.13	2.74	2.62	2.28	3.28	2.89	2.54	2.52	2.40
25 12.7 mm airspace	*1.70*	*2.62*	3.83	2.68	2.33	2.21	1.89	2.75	2.36	2.03	2.01	1.90
26 6.4 mm argon space	*1.87*	*2.75*	3.96	2.81	2.44	2.32	2.00	2.89	2.50	2.17	2.15	2.03
27 12.7 mm argon space	*1.42*	*2.41*	3.61	2.48	2.15	2.02	1.71	2.50	2.11	1.79	1.77	1.67
Triple Glazing												
28 6.4 mm airspace	*2.16*	*2.96*	4.11	2.89	2.51	2.45	2.16	3.10	2.73	2.38	2.33	2.25
29 12.7 mm airspace	*1.76*	*2.67*	3.80	2.60	2.25	2.19	1.91	2.76	2.39	2.05	2.01	1.93
30 6.4 mm argon space	*1.93*	*2.79*	3.94	2.73	2.36	2.30	2.01	2.90	2.54	2.19	2.15	2.07
31 12.7 mm argon space	*1.65*	*2.58*	3.71	2.52	2.17	2.12	1.84	2.66	2.30	1.96	1.91	1.84
Triple Glazing, $\varepsilon = 0.20$ on surface 2,3,4, or 5												
32 6.4 mm airspace	*1.87*	*2.75*	3.89	2.69	2.32	2.27	1.98	2.86	2.49	2.15	2.10	2.03
33 12.7 mm airspace	*1.42*	*2.41*	3.54	2.36	2.02	1.97	1.70	2.47	2.10	1.77	1.73	1.66
34 6.4 mm argon space	*1.59*	*2.54*	3.67	2.48	2.13	2.08	1.80	2.61	2.25	1.91	1.87	1.80
35 12.7 mm argon space	*1.25*	*2.28*	3.40	2.23	1.91	1.86	1.59	2.32	1.96	1.63	1.59	1.52
Triple Glazing, $\varepsilon = 0.20$ on surfaces 2 or 3 and 4 or 5												
36 6.4 mm airspace	*1.65*	*2.58*	3.71	2.52	2.17	2.12	1.84	2.66	2.30	1.96	1.91	1.84
37 12.7 mm airspace	*1.14*	*2.19*	3.31	2.15	1.84	1.78	1.52	2.23	1.86	1.54	1.49	1.43
38 6.4 mm argon space	*1.31*	*2.32*	3.45	2.27	1.95	1.90	1.62	2.37	2.01	1.68	1.63	1.56
39 12.7 mm argon space	*0.97*	*2.05*	3.18	2.03	1.72	1.67	1.41	2.08	1.71	1.39	1.35	1.29
Triple Glazing, $\varepsilon = 0.10$ on surfaces 2 or 3 and 4 or 5												
40 6.4 mm airspace	*1.53*	*2.49*	3.63	2.44	2.10	2.05	1.77	2.57	2.20	1.86	1.82	1.75
41 12.7 mm airspace	*1.02*	*2.10*	3.22	2.07	1.76	1.71	1.45	2.13	1.76	1.44	1.40	1.33
42 6.4 mm argon space	*1.19*	*2.23*	3.36	2.19	1.87	1.82	1.55	2.27	1.91	1.58	1.54	1.47
43 12.7 mm argon space	*0.80*	*1.92*	3.05	1.90	1.61	1.56	1.30	1.93	1.57	1.25	1.21	1.15
Quadruple Glazing, $\varepsilon = 0.10$ on surfaces 2 or 3 and 4 or 5												
44 6.4 mm airspaces	*1.25*	*2.28*	3.40	2.23	1.91	1.86	1.59	2.32	1.96	1.63	1.59	1.52
45 12.7 mm airspaces	*0.85*	*1.96*	3.09	1.94	1.65	1.60	1.34	1.98	1.62	1.30	1.26	1.19
46 6.4 mm argon spaces	*0.97*	*2.05*	3.18	2.03	1.72	1.67	1.41	2.08	1.71	1.39	1.35	1.29
47 12.7 mm argon spaces	*0.68*	*1.83*	2.96	1.82	1.54	1.48	1.23	1.84	1.47	1.16	1.11	1.05
48 6.4 mm krypton spaces	*0.68*	*1.83*	2.96	1.82	1.54	1.48	1.23	1.84	1.47	1.16	1.11	1.05

Notes:

1. All heat transmission coefficients in this table include film resistances and are based on winter conditions of –18 °C outdoor air temperature and 21 °C indoor air temperature, with 24 km/h outdoor air velocity and zero solar flux. With the exception of single glazing, small changes in the indoor and outdoor temperatures will not significantly affect overall U-factors. The coefficients are for vertical position except skylight values, which are for 20° from horizontal with heat flow up.

2. Glazing layer surfaces are numbered from the outdoor to the indoor. Double, triple and quadruple refer to the number of glazing panels. All data are based on 3 mm glass, unless otherwise noted. Thermal conductivities are: 0.917 W/(m·K) for glass, and 0.19 W/(m·K) for acrylic and polycarbonate.

3. Standard spacers are metal. Edge-of-glass effects assumed to extend over the 65 mm band around perimeter of each glazing unit as in Figure 3.

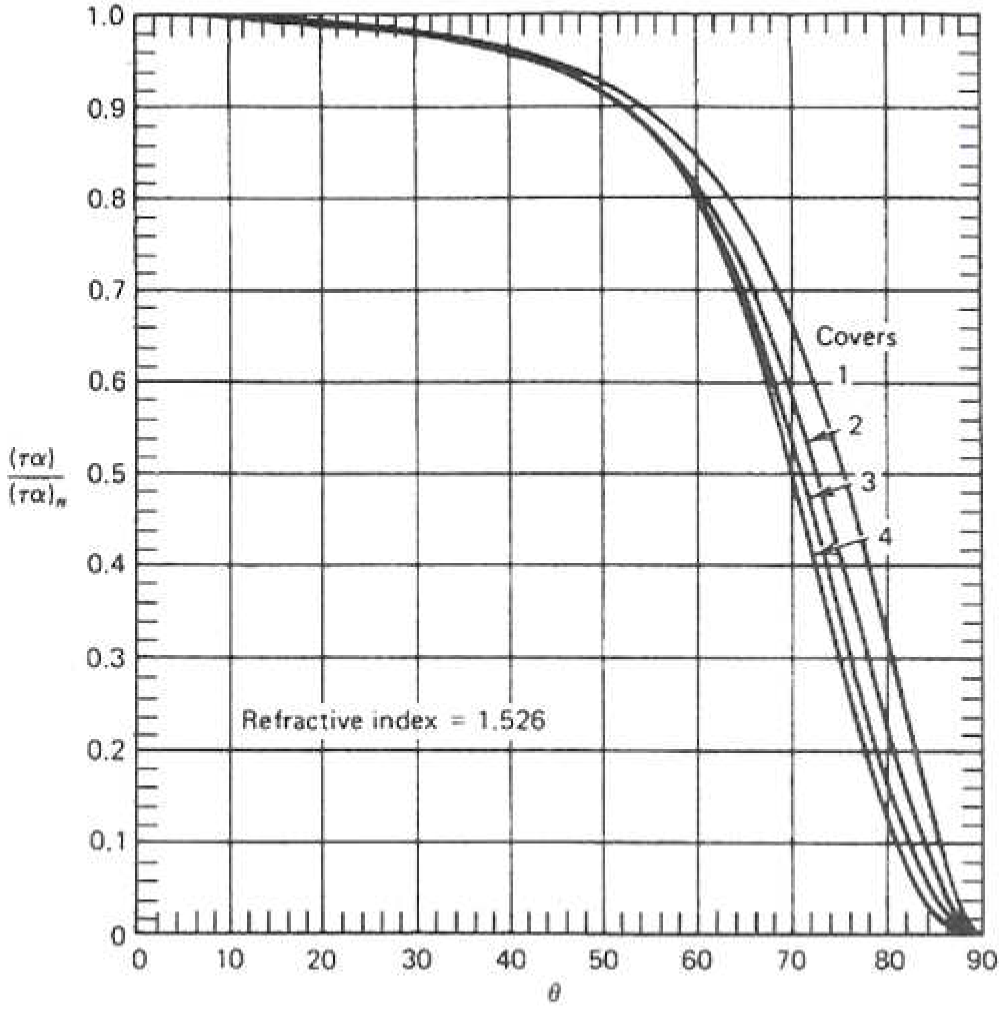
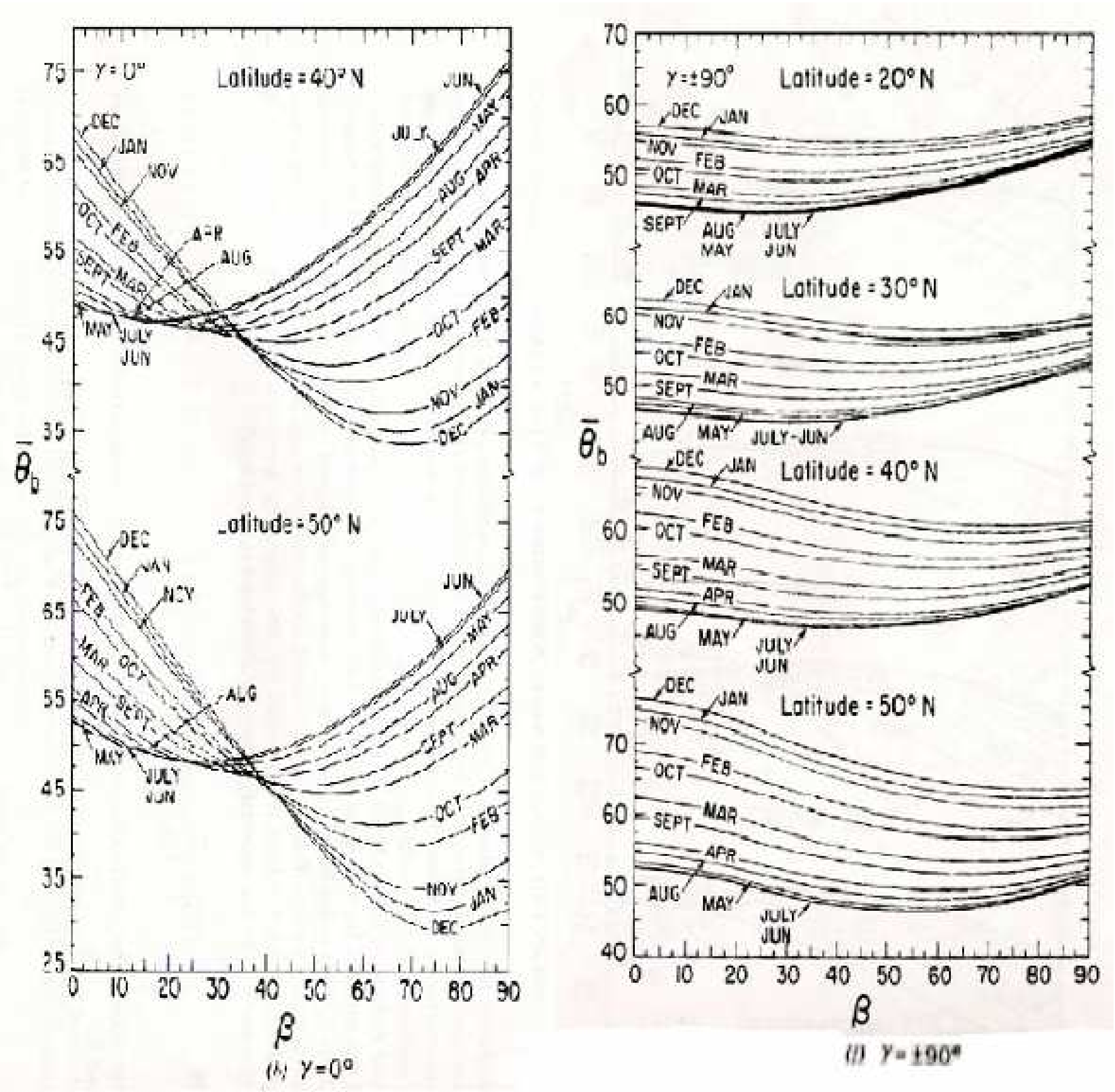


Figure A1 Typical (τα) curves for 1 to covers (Duffie & Backman, 1991)



(h) $\gamma = 0°$

(i) $\gamma = \pm 90°$

Figure A2 Monthly average beam incidence angle for various surface location and orientations (Duffie & Backman, 1991)

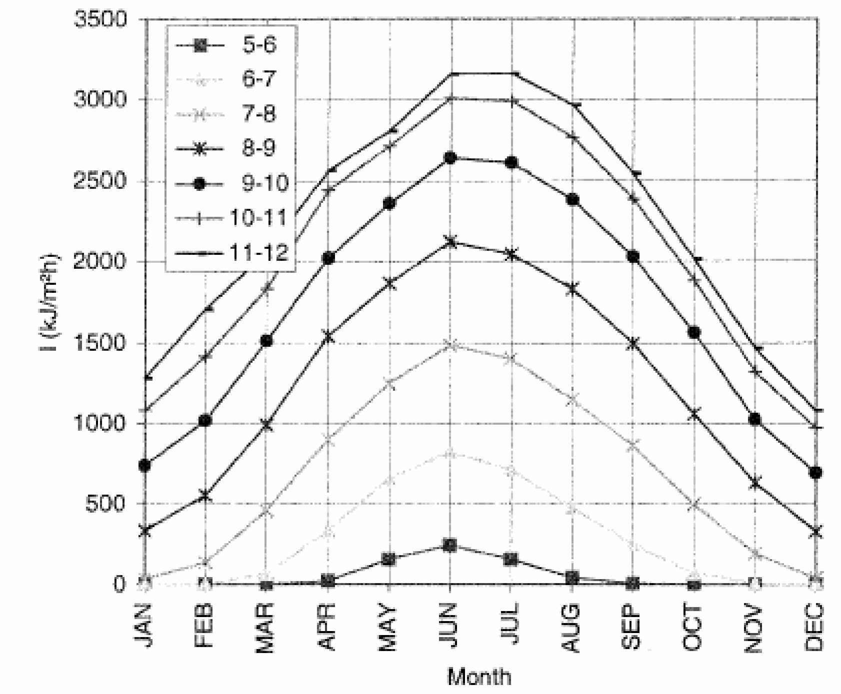


Figure A3 Monthly average hourly global solar radiation between 5:00 and 12:00 (Ulgen & Hepbasli, 2002)

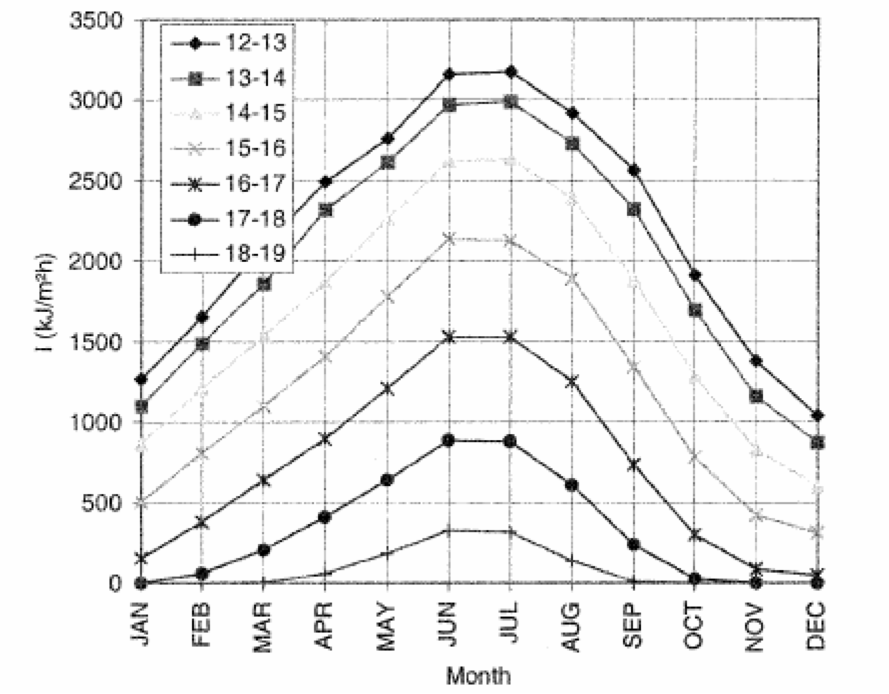
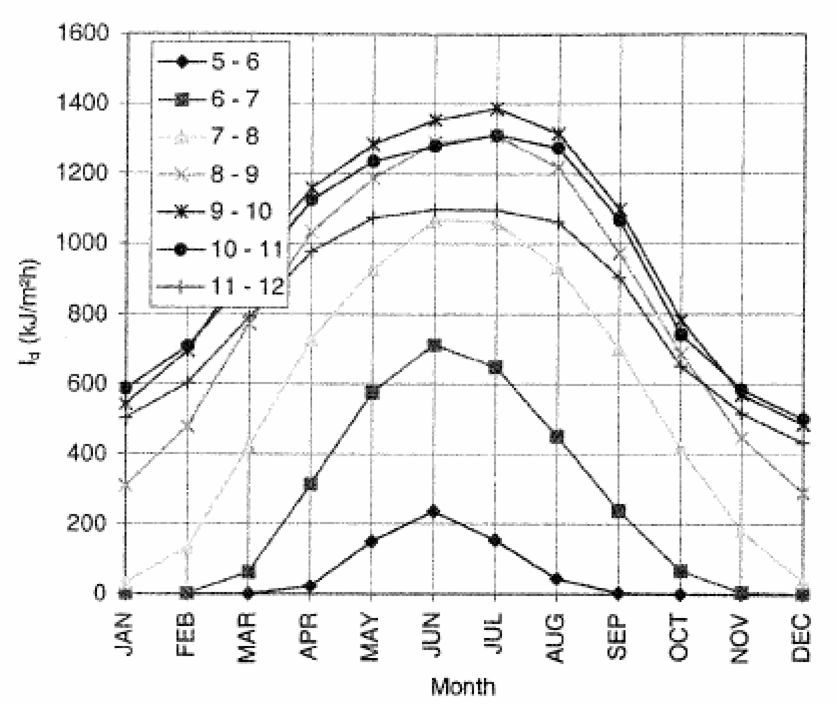


Figure A4 Monthly average hourly global solar radiation between 12:00 and 19:00 (Ulgen & Hepbasli, 2002)



Figgure A5 Monthly average hourly diffuse solar radiation between 5:00 and 12:00 (Ulgen & Hepbasli, 2002)

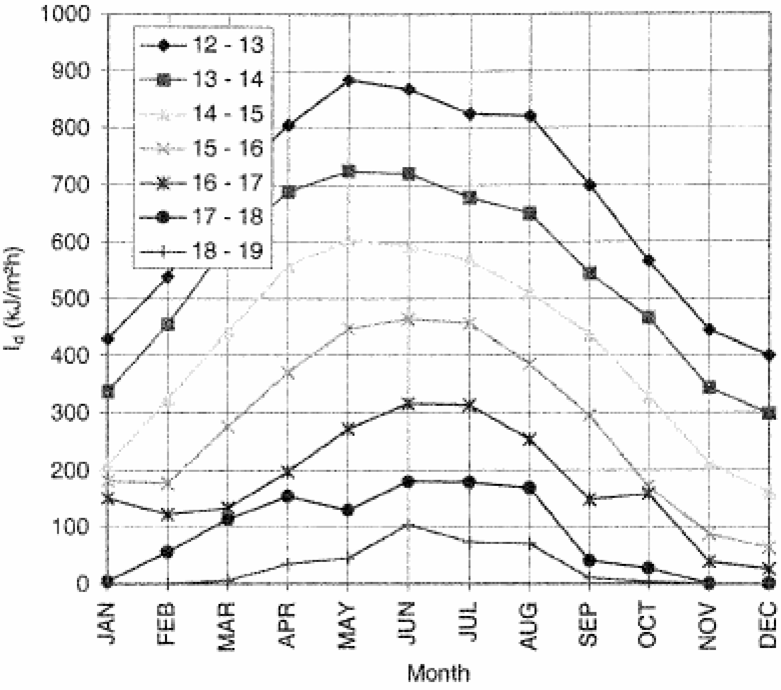


Figure A6 Monthly average hourly diffusel solar radiation between 12:00 and 19:00 (Ulgen & Hepbasli, 2002)

Figure A7 Experimental set up in the office

Figure A8 Experimental set up in the office