The effect of shading and other factors on a novel and analytically estimated cooling load

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Abstract

In this study, a simplified equation to estimate the space cooling load was developed as a function of solar time by taking into account the properties and the plan of the building on the base of the basic equations of heat transfer, thermodynamics and solar engineering. Therefore, tedious look-up tables were eliminated. This method enables to find out the effect of the thermal capacity of a building, the shades, thermal and optical properties, orientations and dimensions of the building on the cooling loads, besides the peak cooling load with the exact time. The shaded areas on the four walls are calculated as a function of solar time. The effect of three types of prevalent shading on the peak cooling load and the daily cooling energy demand are calculated and demonstrated for all orientations of the building. The height of neighboring buildings, the width of the roads around the building, the extension of roof overhang and the open double roof are also taken into consideration.

Keywords: Cooling load, Solar radiation, Glazing, Shading, Orientation and absorbance.

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1. Introduction

The peak cooling load of a space is estimated mainly to determine the required capacity of air conditioning system to keep the indoor air conditions in a certain range according to the quality of air conditioning needed for that space. Cooling load model as a function of time provides a fast calculation of the energy required for the air conditioning season, the peak load, the time at which the peak load occurs and the effects of the parameters on the load.

The heat gains to the space are presented in two main groups. A) The first group is due to highly varying external weather conditions: solar radiation, outdoor temperature, outdoor relative humidity and speed and direction of wind, which are computed in two components 1) the heat gain through walls, roofs and fenestrations, 2) ventilation and infiltration through doors and windows. B) The second group of internal heat gains are the occupants, equipment and lightings which are approximately constant or negligible loads, especially in the residences and where the led lighting is progressing with negligible energy consumption.

The external weather component is common and the method developed in this study can be applied to all buildings. Whilst the internal component is widely different in the type and capacity for the different buildings, it has a minor effect for the residences and can simply be added to the weather component. On the other hand the external weather component is affected by the shadings, but the internal one has no relation with the shading.

It is clear that the most important gains are the highly variable weather components and it will be taken into consideration in this study.

The required data for calculating the cooling load are presented in two groups:
A) The weather parameters recorded for the location:

- Solar radiation: It is of two components; beam and diffuse radiation.
- Outdoor temperature: : $T_{0.4\%}$, $T_{1\%}$ or $T_{2\%}$ are selected according to the quality level of air conditioning.
- Outdoor relative humidity or wet bulb temperature.
- Speed and direction of the wind, which determine the outdoor convection coefficient.

B) The second group of data is the dimension, the orientation and the thermal and optical properties of the external walls, roofs, fenestration and shading devices. Where some of the properties of the building component may be considered as constant because of the small change of the temperatures during cooling season or weakly correlated to cooling load like the convection coefficients.

In this study thermodynamics, heat transfer and solar engineering principles are used to establish a simple equation for calculating and demonstrating easily the cooling loads of the building, the peak load, the time at which the peak load occurs, the daily energy demand during cooling season and the effect of the shadings and the parameters of the building on the cooling load.

Many studies proposed different methods for estimating cooling load with certain accuracy under certain conditions, but a few researches in the literature discussed the effect of shading on the load in limited variables and condition.

1.1. Cooling load studies

ASHRAE [1] Fundamental handbook demonstrates the following three widely used methods for cooling load calculations, where the heat balance approach is a fundamental concept in calculating the loads by using a lot of tables.

1. Transfer function method (TFM): It is computer based procedure, hour by hour, calculated in two steps, the first is heat gain establishing, the second is determining the conversion of such heat gain into cooling load.

2. A simplified version of (TFM): It is in one-step procedure that uses cooling load temperature difference CLTD, solar cooling load SCL and cooling load factor CLF to calculate approximate cooling load by hand for certain buildings.

3. An alternative simplification of TFM technique uses total equivalent temperature differential values and a system time-averaging TETD/TA to calculate cooling load. This method gives valid road-range result to experienced users.

In the study of Sen, et al. [2] Elite CHVAC software is taken for the comparison of results by using the ASHRAE CLTD method and CHVAC method.

Zhang, et al. [3] analyzed the effect of eight input variables combinations on cooling load prediction accuracy. The training and testing data were obtained from an office building by field measurement. It is concluded that the prediction models with an optimized combination perform better than those without optimization and historical cooling capacity data is proving to be the most essential prediction inputs.

In the study of Ding [4] an improved cooling load prediction method for buildings with the estimation of prediction intervals had proposed to reduce the prediction errors and describe the uncertainties of short-term predicted cooling load quantitatively. Therefore, a virtual office building simulated by Energy Plus is employed. The simulated building is rectangular with an area of 46320 m^2 and 12 stories. It is cooled by two water-cooled chillers, VAV with reheat and plenum zones. Results show that the outdoor temperature is strongly correlated with cooling load while the wind direction and speed are weakly correlated with cooling load. The cooling load prediction profiles show that there are valuable differences between the real load and the load predicted by the proposed method.

An, et al. [5] developed a novel stochastic modeling method consisting of (1) six-prototype house models, (2) occupant behavior models of residential building, (3) a stochastic sampling process is used to represent all apartments and occupants in the district. In the study, they aimed to simulate the cooling load of a residential district of Wuhan, China. The simulation result agreed well with the measured data based on five performance metrics representing the aggregated cooling consumption, the peak loads, the spatial load distribution, the temporal load distribution and the load profile. The results showed that over simplified assumption about occupant behavior could lead to significant overestimation of the peak cooling load and the total cooling loads in the district.

The survey of references indicates that the cooling load estimation methods are prepared under certain different conditions with different correlations and correction techniques, consequently they cannot be generalized. According to ASHRAE Handbook [1], the variables affecting cooling load are numerous and often difficult to define precisely, while the designer uses reasonable procedures to account for these variables, the calculation can never be more than a good estimate of the actual cooling load.

1.2 Shading effect studies

Shading on the external walls is performed by many types of interior and exterior devices and they are controllable or fix architectural devices. These devices are available in a wide range of products that differ greatly in their appearance and energy performance [1].

Literature in connection with solar shading of buildings are classified into three main domains 1) physical properties of shading devices 2) effect of solar shading devices on energy use and day lighting and, 3) calculation methods to assess the energy performance of buildings equipped with shading devices. The most of studies investigate and develop the types of shading devices. The studies concerning the performance of shading devices and their effects on the cooling load are rare and limited variables were considered.

Rabczak[6] indicate that in order to minimize the demand of cooling, the effect of shading elements installed on the outside of the windows and its effect on cooling capacity of air conditioning system for the building has been estimated for three different windows shading.

Macia, et al. [7] explores the implications of shading the roof of a residence on the cooling and heating load by simulating a thermal model for a house with half of the roof shaded by PV panels and without PV panels. It is shown that the shading produced by PV arrays has a net effect of reducing the yearly electric bill by approximately 11%.

Shaik, et al. [8] presents thermal performance of various single glazing window glasses, covered with window overhang shading with five glass types such as clear, bronze, green, gray and blue-green. The results of the study help in selecting the best window glass type and also help in selecting the appropriate dimensions for overhang shading devices for reducing cooling loads in buildings.

According to Tzempetikos, et al. [9], shading devices can control solar gains and simultaneously allow adequate daylight to the interior. The simultaneous effects of shading devices properties and control building cooling demand are evaluated. The interactions between cooling and lighting energy use in perimeter spaces are analyzed as a function of window-to-wall ratio and shading parameters. An integrated approach for dynamic operation of fenestration systems in conjunction with controllable electric lighting systems could lead to a minimization of energy consumption for cooling in perimeter spaces, depending on climatic conditions and orientation.

According to Kim et al. [10] a few of studies have investigated the effect of shading installation on cooling load. They confirmed that horizontal shading saved a maximum of 13% energy consumption.

Carrier [11] discussed the effect of closed-weave drapes and venetian blinds as internal shades on the solar component of the cooling load. This study shows graphically that the dark blind results in a higher peak cooling load and shift the peak to an earlier time versus the window without blind due to the higher absorbance of the dark blond.

In the current method the developed equations are used to estimate the time function load instead of the tedious tables for a certain weather conditions and building conditions. Where the time function load enables to calculate the peak load of the air conditioning system, the energy demand and to indicate the influence of the variable factors affecting the load.

2. The Independent Variables

The physical independent variables affecting the instantaneous cooling load of the space are in three groups as follows:

a. Indoor Conditions:

- Dry bulb temperature of the space, T_i
- Relative humidity of the space, φ_i (or wet bulb temperature)
- Change the air volume of the space per hour, $\dot{N}$
- The natural convection coefficient in the space neglecting the differences in the wall temperature, λ_i
- Mean absorbance of the space, α_{rm}
- Reflectance of the closed areas in the blinds, ρ_{bl}
- Enthalpy of air, h_i
- Specific heat of air, C_{pa}
- Density of air, ρ_{ai}

b. Outdoor Condition:

- Latitude angle of the location, $\emptyset$
- Dry bulb temperature of the outdoor air, $T_o$is calculated according to the method of Bulut [12].
- Relative humidity of the outdoor air,φ_o(or wet bulb temperature)
- Convection coefficient due to wind and temperature difference, λ_o
- Monthly average daily solar radiation per square horizontal meter for the location of the building in summer, $\overline{H}_{4-9}$is found from Bulut [13].
- Solar reflectance of the surroundings of the building, ρ_{gr}.
- Enthalpy of air, h_o.

c. Properties of the Building:

The building is a multifamily apartment with rectangular floor of A_b base area and $H_b$height as shown in Figure 1.

- Number of stairs, n
- The ratio of glazing area to wall area, R
- Overall heat transfer coefficient of window glass,U_{wn}
- The transmittance of the glass, τ_{gl}
- Mean conduction coefficient of the wall or roof, $\overline{k}$
- Mean wall or roof thickness, $\bar{\delta}$

- The mean specific heat of the wall or roof, $\bar{C}_p$
- The mean density of the wall or roof, $\bar{\rho}$
- Mean absorbance of the external surface of wall or roof for beam and diffuse radiation, α_b, α_d
- The azimuth angle(orientation) of the face wall is γ_f and for the other walls are rightγ_r, leftγ_l and backγ_k. Where

$$\gamma_r = \gamma_f - 90°, \gamma_l = \gamma_f + 90° \text{ and } \gamma_k = \gamma_f + 180° \quad (1)$$

- The width of adjacent ways around the building:W
- The height of the neighboring buildings:H_n, and here

$$H_n \leq H_b. \quad (2)$$

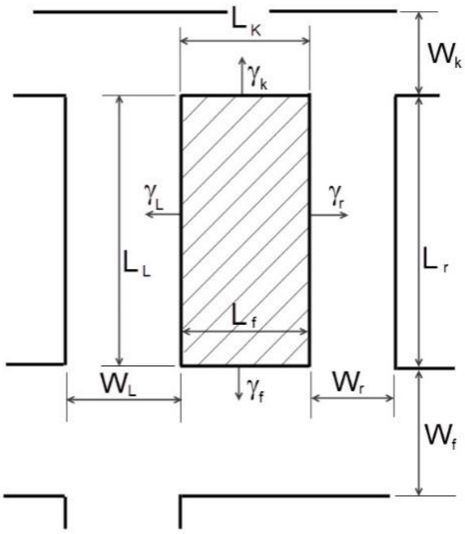

Figure 1. Layout plan of the building.

3. Nomenclature

T_{so}: The temperature of the outside surface of wall or roof, ℃

T_{si}: The temperature of the inside surface of wall or roof,℃

$\dot{S}$: Absorbed solar radiation by a wall or roof, W/m^2 is calculated according to Duffie [14]

t: Time, second

Δt: Time interval, second

$\dot{q}$: Heat transferred, W/m^2

MC: Thermal capacity per square meter of wall or roof, J/m^2℃

G: Global solar radiation, W/m^2as mentioned elsewhere [14]

G_b: Beam solar radiation, W/m^2

G_d: Diffuse solar radiation,W/m^2as mentioned elsewhere [14]

α_b: Absorbance of beam radiation by wall or roof,

α_b: Absorbance of diffuse radiation by wall or roof,

R_b: Ratio of beam radiation on the tilt surface of that on the horizontal, as mentioned elsewhere [14]

R_s: The ratio of shading area to wall area,

θ: Incidence angle of beam solar radiation on the wall or roof, deg., is calculated according to Kalogeria[15]

θ_z: Solar zenith angle, deg.as mentioned elsewhere [14, 15]

A: Surface area of wall, roof or shade, m^2

L: Length of wall, shade or insolation, m

H: Height of building or shade, m

α_p: Projection angle, deg., as mentioned elsewhere [14, 15]

α_s: Solar altitude angle, deg., as mentioned elsewhere [14, 15]

γ_s: Solar azimuth angle, deg., as mentioned elsewhere [14, 15]

γ_w: Azimuth angle (orientation) of the wall, including the windows, deg.

H_r: Permanent shading width of roof overhang,m

B_{ins}: Insolated length in the roof overhang, m

$Q_{pk,b}$: Peak cooling load of the building,W/m^3

$Q_{pk,iv}$: Peak cooling load of the building, including the infiltration and ventilation load,W/m^3

R_{opn}: Percentage of open areas in the blind (drapery) area of A_{wn}, where

$R_{cls} = 1 - R_{opn}$ is the percentage of the close areas in the blind (drapery)

Subscripts

wl: Wall,

wn: Window,

w: Wall including windows

rf: Roof,

iv: Infiltration and ventilation

sen, lat, tot: Sensible latent and total heat

s: Solar or shade

rs: Shading by roof overhang

b: Building

pk: Peak load

4. Methodology

Here, the heat balance approach is applied in estimating the cooling load as a function of the solar time stincluding the thermal capacity for an air conditioned multifamily building at constant indoor condition during cooling season. Where the solar time is 12 at noon and 1 $st\ hour = 15^{\circ}$of longitude.

4.1. Cooling load estimations

4.1.1 External walls

In Figure 2, the heat gains to space due to solar radiation, temperature difference between outdoor and indoor and air convections through the wall is calculated by using the basic relations of McQuiston, Wylen and Holman [16-18]as follows:

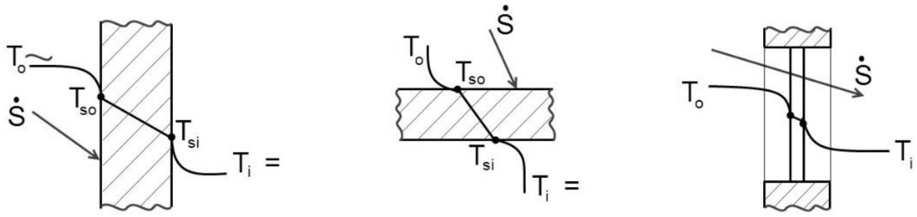

Figure 2 Heat transfers through sections of wall, roof and window.

$$\lambda_o(T_o - T_{so}) + \dot{S} = MC\frac{dT_{so}+dT_{si}}{2dt} + \lambda_i(T_{si} - T_i), \quad (3)$$

$$MC = \delta\rho C_p, \quad (4)$$

$$(\bar{k}/\delta)(T_{so} - T_{si}) = \lambda_i(T_{si} - T_i), \quad (5)$$

$$T_{si} = \frac{\lambda_i T_i + (\bar{k}/\delta)T_{so}}{\lambda_i + (\bar{k}/\delta)},\ dT_{si} = \frac{\bar{k}/\delta}{\lambda_i + (\bar{k}/\delta)}dT_{so}. \quad (6)$$

$$\int_{T_{so1}}^{T_{so2}} \frac{dT_{so}}{AT_{so}+B} = \int_{t_1}^{t_2} Cdt, \quad (7)$$

During ($\Delta t = t_2 - t_1$) time interval: T_o, A, B, C and $\dot{S}$ are constants.

$$A = -(\lambda_o + \frac{\lambda_i(\bar{k}/\delta)}{\lambda_i+(\bar{k}/\delta)}),$$

$$B = \dot{S} + \lambda_o T_o + \lambda_i T_i(1 - \frac{\lambda_i}{\lambda_i+(\bar{k}/\delta)}), \quad (8)$$

$$C = [0.5MC(1 + \frac{\bar{k}/\delta}{\lambda_i+(\bar{k}/\delta)})]^{-1}.$$

$$T_{so2} = (T_{so1} + B/A)\,[Exp(AC\,\Delta t_{12})] - (B/A). \quad (9)$$

$$\dot{q}_{wl} = \lambda_i(T_{si} - T_i). \quad (10)$$

$$\dot{S}_{wl} = \alpha_b G_b R_b + 0.5\alpha_d(G_d + \rho_{gr} G), \quad (11)$$

$$G_b = G - G_d, \quad (12)$$

$$R_b = cos\theta/cos\theta_z. \quad (13)$$

G and$G_d$are calculated using $\overline{H}$according to the methods indicated in Duffie [14].

4.1.2 Roof

The heat gain through the roof is calculated similarly to that through the wall. Therefore, the same equations can be applied by taking into account the properties of the roof and the incidence angle of radiation on the horizontal plane as mentioned elsewhere [14, 18]. Where

$$\dot{S}_{rf} = \alpha_b G_b + \alpha_d G_d. \tag{14}$$

$$\dot{q}_{rf} = [\lambda_i (T_{si} - T_i)]_{rf}. \tag{15}$$

4.1.3 Window

In this study the frame of the window is included and calculated as a part of the wall. Whereas the heat is transferred only through the glass to the space by two components, the first is the solar radiation incident on the glass and the second is the heat convection between the outdoor and indoor as indicated in Figure 2. The heat gain through the window is as mentioned elsewhere [14, 18],

$$\dot{q}_{wn} = \dot{s}_{wn} + U_{wn}(T_{si} - T_i), \tag{16}$$

$$\dot{s}_{wn} = \tau_{gl}\alpha_{rm}(G_b R_b + 0.5G_d + 0.5\rho_{gr}G), \tag{17}$$

4.1.4 Effect of window`s area

$$R = A_{wn}/A_w, \tag{18}$$

$$\dot{q}_w = \dot{q}_{wl} + R(\dot{q}_{wn} - \dot{q}_{wl}). \tag{19}$$

4.1.5 Infiltration and ventilation

Cooling load due to infiltration and ventilation are both calculated totally through$\dot{N}$ the number of air space changed per hour and it is estimated in sensible and latent components as follows using the relations of Farwati [19]:

$$\dot{q}_{iv,sen} = \dot{N}\rho_a C_{pa}(T_o - T_i), \tag{20}$$

$$\dot{q}_{iv,tot} = \dot{N}\rho_a(h_o - h_i), \tag{21}$$

$$\dot{q}_{iv,lat} = \dot{q}_{iv,tot} - \dot{q}_{iv,sen}. \tag{22}$$

4.1.6. Effect of shading

4.1.6.1 Shading from neighbor buildings

In Figure 3 when a shade from neighbor building over the considered wall of a certain γ_w orientation occurs, only direct radiation will be zero ($G_b = 0$) in the shaded area A_s, Meanwhile the diffuse radiation from the sky and surrounding is continuing to incident over the shade. In this partially shaded wall of A_w area, the ratio of shading is:

$$R_s = A_s/A_w, \text{ where} \tag{23}$$

$$A_s = H_s L_s. \tag{24}$$

H_s, L_s: Height and length of the shading for a certain wall orientation.

The shading will affect the value of radiation absorbed by the wall, roof and windows without blinds as follows:

$$\dot{S}_{wl} = \alpha_b G_b R_b (1 - R_{s,w}) + 0.5\alpha_d (G_d + \rho_g G), \quad (25)$$

$$\dot{S}_{rf} = \alpha_b G_b (1 - R_{s,rf}) + \alpha_d G_d, \quad (26)$$

$$\dot{S}_{wn} = \tau_{gl} \alpha_{rm} (G_b R_b (1 - R_{s,w}) + 0.5 G_d + 0.5 \rho_g G). \quad (27)$$

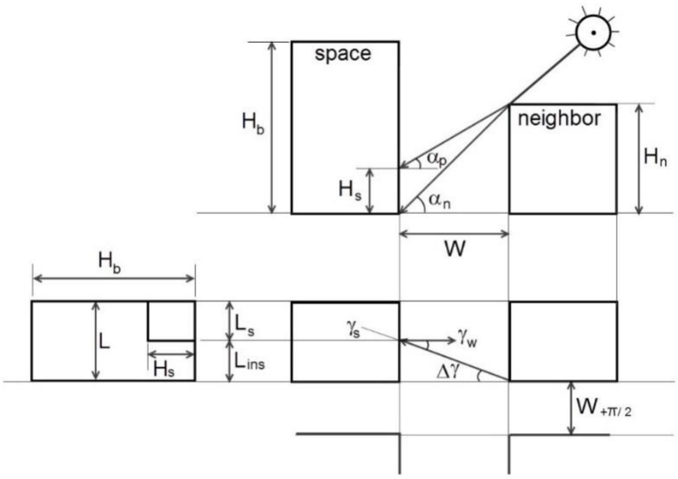

Figure 3. Formation of shading on a wall of the building by a neighbor building.

In Figure 3 the projection angle of the neighbor building $\alpha_n$and the solar projection angle $\alpha_p$for a certain wall are:

$$tan\alpha_n = H_n/W, \quad (28)$$

$$tan\alpha_p = \frac{tan\alpha_s}{\cos(\gamma_s - \gamma_w)}. \quad (29)$$

If $\alpha_p \geq \alpha_n$, then no shade occurs, $H_s = 0$. (30)

If $\alpha_p < \alpha_n$, then, $H_s = H_n - W\ tan\alpha_p$. (31)

In Figure 3 the insolation through the perpendicular street to the considered wall will decrease the shaded wall length L_w by $L_{ins,w}$ and

$L_s = L_{wl} - L_{ins,w}$, where (32)

$L_{ins,wl} = W\ |tan\Delta\gamma_w|$ and (33)

$\Delta\gamma_w = \gamma_s - \gamma_w$. (34)

If $L_{ins,w} \geq L_w$, then $L_s = 0$.

4.1.6.2 Shading by roof overhangs

They are horizontal roof overhang along each story of the building with a width of W_R as it is shown in Figure 4. Where the height of the shadeH_{rs}, the length of insolationB_{ins} and the total shade areaA_{rs} on the considered wall are:

$$H_{rs} = W_R tan\alpha_p, \quad (35)$$

$$B_{ins} = W_R|tan\Delta\gamma|, \quad (36)$$

$$A_{rs} = n[H_{rs}(L_{wl} - 0.5B_{ins}) + H_r L_{wl}]. \quad (37)$$

The horizontal overhangs give generally a greater shading area at noon where the solar radiation is greater in summer than that in winter. This is because of the greater solar altitude angle α_s at noon in summer. Where α_s at noon for Bursa city in 22 July is 73.35° and in 22 December is 26.45°.Consequently the ratio of shading area for south facing wall in July to that in December is about 6.7.

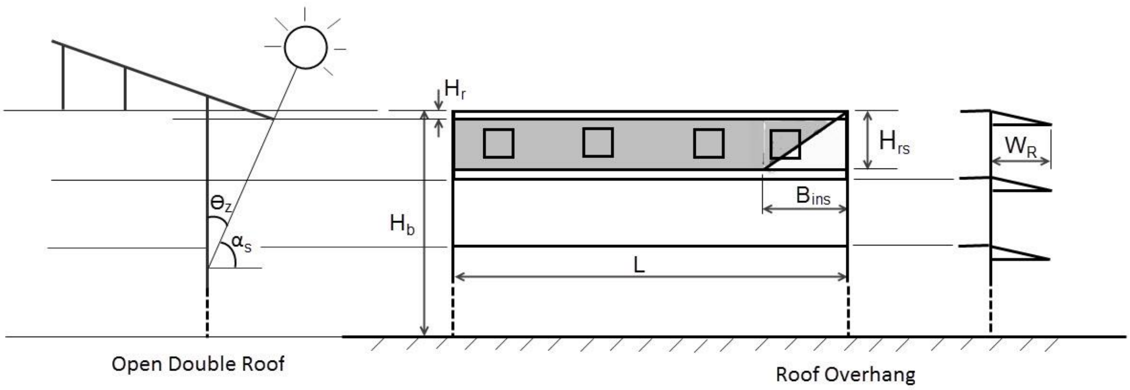

Figure 4 Formation of shading by a roof overhang.

4.1.6.3 Shading by open double roof

As it is shown in Figure 4, the additional open roof has two duties, the shading and supporting the solar hot water and/or photovoltaic panels. In this case the upper roof obstructs the beam radiation and only the diffuse radiation is incident on the base roof as follows:

$$\dot{S}_{rf} = \alpha_d G_d.$$

On the other hand the shade due to$W_R$the extension of the only upper roof is similar to that of overhang but the area is:

$$A_{rs} = H_{rs}(L_{wl} - 0.5B_{ins}) + H_r L_{wl}.$$

4.1.6.4 Shading by Internal Devices

Shading is executed mainly by fabric, draperies or plastic blinds inside of the windows to reflect the solar radiation to the outside through the glass by the reflectance $\rho_{bl}$of yarn or plastic bands. Where, the percentage of the reflecting area of the window's area is R_{cls}.

Most of load calculation methods use many and different types and properties of glasses, blinds and furniture during the design process which lead to use many tables, estimations and approximations. Also, after the design and installation the cooling system, the actual situation of the cooling process may be completely different than the theory. Therefore, in this study the proper optical properties required for calculation of solar radiation through the glass is reduced to τ_{gl} ,R_{cls}, ρ_{bl} and α_{rm} and are estimated by expert designer and using the catalogues of the glasses and the internal blinds. If there are no blinds or the blind is mat black colored and close weave fabric ($R_{cls} = 1$) then $\rho_{bl} = 0$.

The net heat gain transferred through the glass, then absorbed by the space of the building as mentioned elsewhere [14, 16],

$$\dot{S}_{wn} = \tau_{gl}(1 - R_{cls}\rho_{bl}\tau_{gl})\alpha_{rm}(G_b R_b + 0.5G_d + 0.5\rho_{gr}G), \quad (38)$$

$$R_{cls} = 1 - R_{opn}. \quad (39)$$

5. Case Study

The considered data in the study are:

Location: Bursa –Turkey

Time: 17 July

Indoor:

$T_i = 25$°C,$\varphi_i = 50\%$,$\dot{N} = 1\ h^{-1}$,$\lambda_{i,w} = 8.5\,W/m^2$ °C, $\lambda_{i,rf} = 7\,W/m^2$ °C,$\alpha_{rm} = 0.98$, $R_{cls} = 0$.

Outdoor:

$\lambda_{o,w} = 25\,W/m^2$ °C,$\lambda_{o,rf} = 23\,W/m^2$ °C,$\varphi_o = 50\%$,T_o [12], $\bar{H}_{5-9}$ [13],$\rho_{gr} = 0.35$.

Building:

$A_b = 400\ m^2$,$H_b = 15\ m$,$n = 5$, $R = 0.3$, $\tau_{gl} = 0.6$, $U_{wn} = 2.5\ W/m^2$ °C,

$\bar{k} = 1\,W/m$ °C, $\bar{\delta}_w = 0.3\ m$, $\bar{\delta}_{rf} = \bar{\delta}_w + 0.1$, $\bar{C}_p = 1600\ J/kg$,$\bar{\rho} = 900\ kg/m^3$, $\alpha_b, \alpha_d = 0.5$, $\gamma_f = 0°$,

$\gamma_r = \gamma_f - 90°$, $\gamma_l = \gamma_f + 90°\gamma_k = \gamma_f + 180°$, $W = 6\ m$, $H_n = 8\ m$, $H_r = 10\ cm$,

6. Results

6.1 Cooling load due to neighbor buildings shading

6.1.1 The instantaneous ratio of shade area in the four walls

The change of shading ratio $R_s$in the four walls as a function of solar time $st$are shown in Figures 5-8 from sunrise to sunset in the mean day of July under the condition of study case, where the solar azimuth angle at sunset $\gamma_s > 90°$. In E facing wall, Figure 5, it is seen that the shading start at sunrise due to facing neighbor building. Then and because of the increase of the altitude angle of the sunα_s and the projection angle α_p, shading ratio R_s diminishes with time to zero and the whole surface of the wall is insolated until noon. Directly after noon the beam radiation at the back of E wall and all is shaded. The insolation is only by diffuse radiation from the sky and surrounding. Similar discussion can be done to the walls facing S, W and N as indicated in the Figures 5-8.

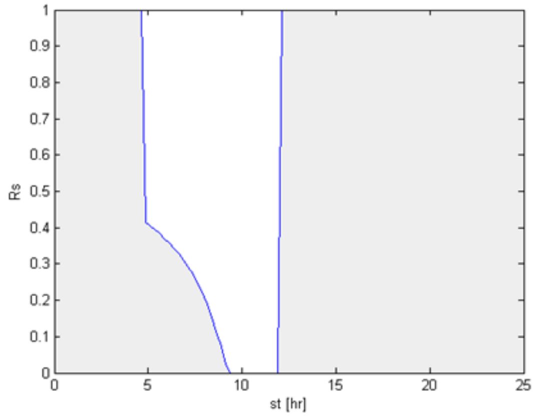

Figure 5. Shading ratio in East facing Wall vs time

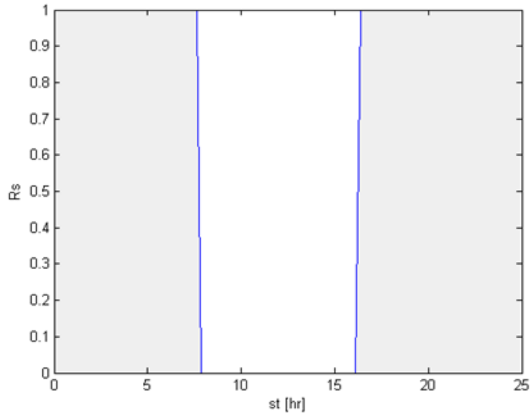

Figure 6. Shading ratio in South facing wall vs time

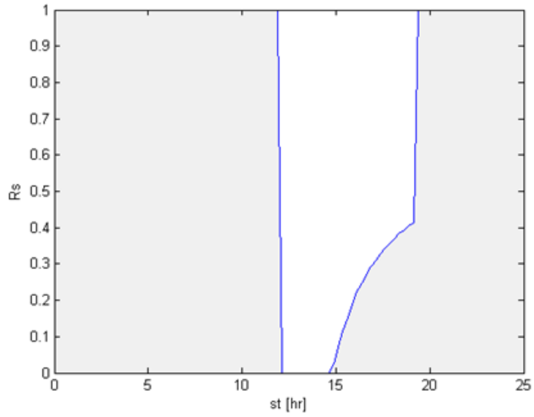

Figure 7. Shading ratio in West facing wall vs time.

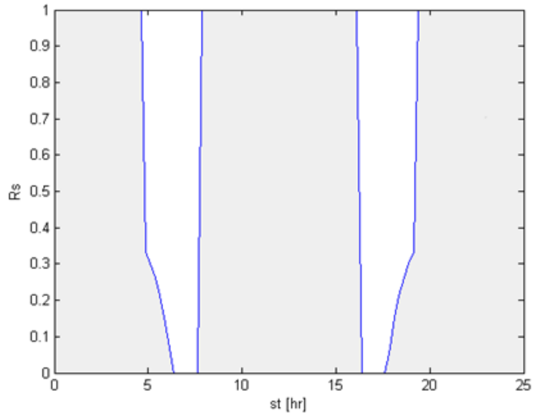

Figure 8. Shading ratio in North facing wall vs time.

6.1.2 Cooling Load Through the Walls under Neighbor Shading:

The cooling loads for the walls, including the windows, are mainly a function of the orientation, the incidence angle and the outdoor temperature as indicated in the Figures 9-12, where the maximum outdoor temperature occurs after noon at 14:22:30 solar time.

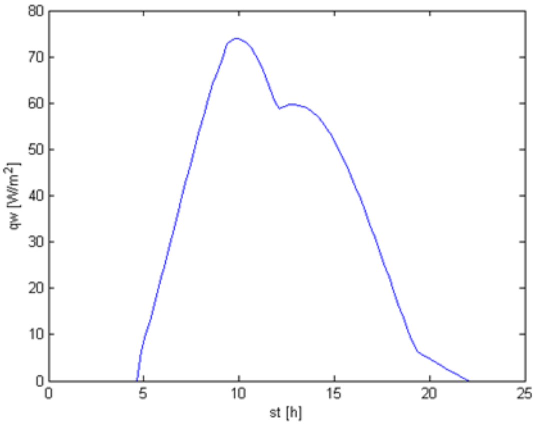

Figure 9. Cooling loads per square meter in East facing wall shaded by neighbor buildings vs time.

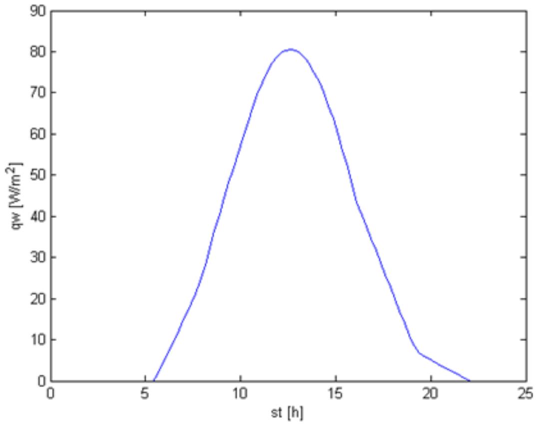

Figure 10. Cooling loads per square meter in South facing wall shaded by neighbor buildings vs time

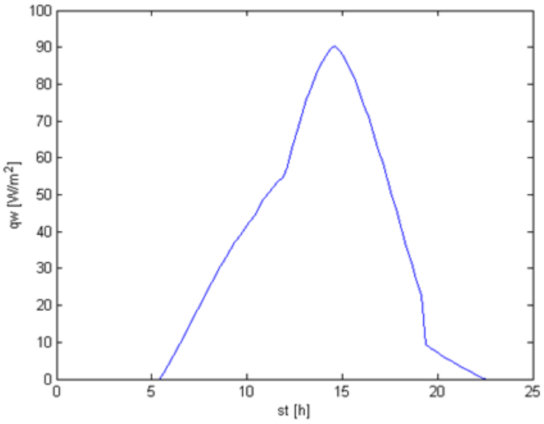

Figure 11. Cooling load per square meter in West facing wall shaded by neighbor buildings vs time.

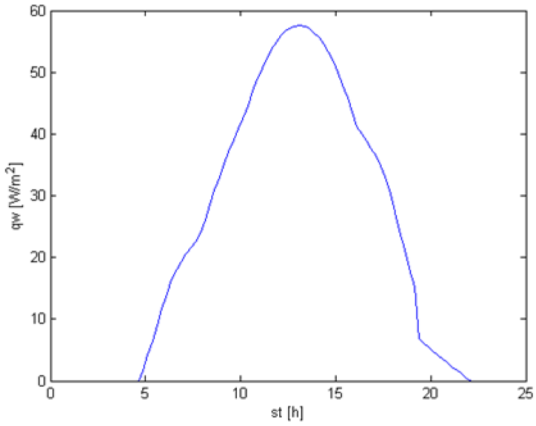

Figure 12. Cooling load per square meter in North facing wall shaded by neighbor buildings vs time.

6.1.3 The effect of wall orientation on the daily cooling energy

Daily cooling energy per square meter through the wall as a function of its orientation (wall azimuth angle) is shown in Figure 13. Where the maximum load at wall azimuth angles >0 is greater than the maximum load at wall azimuth angles <0 because of the increasing outdoor temperature afternoon when the solar azimuth angle at sunset in summer is > 0.

6.1.4 The effect of height of the neighbor buildings on the daily cooling energy demand for the study building

In the case $H_n \leq H_b$ the shading occurs only on the four walls. In Figure 14,it is seen that the decrease in the daily cooling energy is about 9.5% when the height of the neighboring building is equal to the height of the building in the study and the width of roads around is 6 m.The daily cooling energy demand:

$Q_{day} = 508.884\, kJ/day/m^3$for $H_n = 0\, m$.

$Q_{day} = 491.168\, kJ/day/m^3$ for $H_n = 8\, m$,

$Q_{day} = 460.503\, kJ/day/m^3$ for $H_n = 15\, m$.

The difference in daily energy demand for building with full neighbor shading and without any shading is48.381 $kJ/day/m^3$, i.e. the save on cooling energy is 9.5%

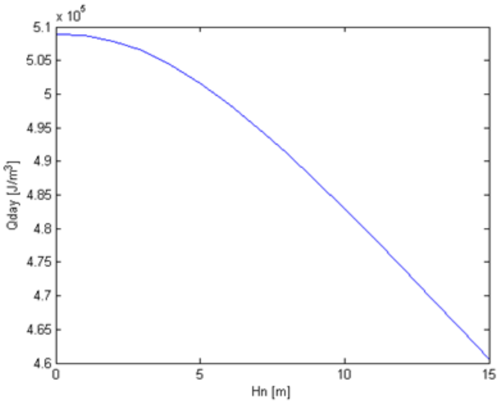

Figure 13 Daily cooling energy per square meter through the wall versus its orientation (wall azimuth angle).

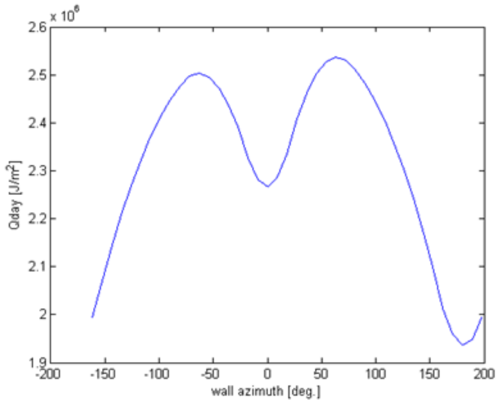

Figure 14 Daily cooling energy per square meter of the building versus height of the neighboring buildings.

6.1.5 The effect of width of the roads around the building on the daily cooling energy

It is seen in Figure 15 that the increase in the daily cooling energy is about 8% if the width of the road extended from 1 m to 14 m for neighbor building height of 8 m.

6.1.6 Cooling loads per cubic meter of the building versus solar time

The investigation of the effect of neighbor shading on the peak load showed that this effect is small as follows:

$Q_{pk,b+iv} = 16.6\ W/m^3$ at 13:52:30 solar time for $H_n = 0\ m$.

$Q_{pk,b+iv} = 16.47\ W/m^3$ at 13:37:30 solar time for $H_n = 15\ m$.

$Q_{pk,b} = 14.78\ W/m^3$at 13:52:30 solar time for $H_n = 0\ m$.

$Q_{pk,b} = 14.68\ W/m^3$ at 13:37:30solar time for $H_n = 15\ m$.

Figure16 shows the various cooling loads of the study building versus solar time, where $H_n = 8\ m$.

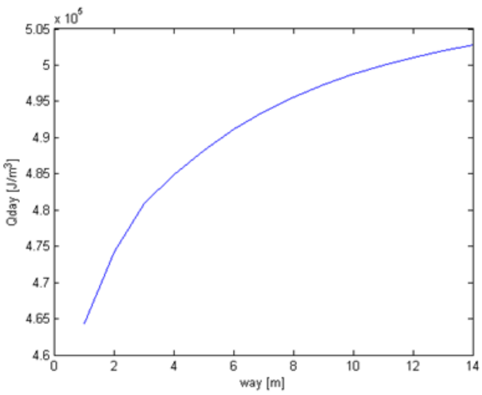

Figure 15 Daily cooling energy per square meter vs width of the ways around the building.

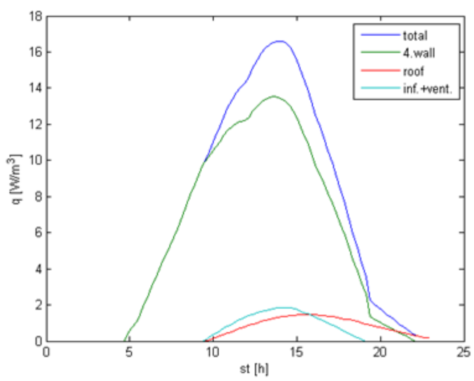

Figure 16 Cooling loads per cubic meter of the study building vs time.

6.1.7 Effect of properties of the building on the peak cooling load

The ratio of glazing, the transmittance of the window's glass, the thermal capacity of the building, the mean conductivity of the wall and the absorbance of the external surfaces of the walls and roof on the peak load of study building are shown in the Figures 17-21. The calculations and the Figures 17 and 18 show that the most effective factors (properties) on the peak load are the area and transmittance of the window's glass, where increasing the glazing ratio from 0.3 to 0.7 leads to elevate the peak load to about twice, meanwhile the second effective property is the glass transmittance, where the peak load increases to more than twice when the transmittance is increased from 0.1 to 0.9. In Figure 19 when the thermal capacity of the external wall of the study building decreases from 700 to 200 kJ/m^2 °C the peak load increases about 0.45. In Figure 20 when the absorbance of the external surface of the study building increases from 0.1 to .9 the peak load increases about 30%. Increasing the mean conductivity of the wall from 0.2 to 2 W/m°C leads to increase the peak load about 24% as indicated in Figure 21.

6.2 The reduction in cooling load due to only roof overhangs shading

6.2.1 Cooling loads of the case study building

In this shading type there is only architectural overhang as a shading devise extended horizontally around the building for each story. The extension of the roof overhang is $W_R = 60\ cm$ as it is shown in Figure 4.

Under this type of shading, the peak cooling load of the building with its infiltration and ventilation, $Q_{pk,b+iv}$, the peak cooling load of the building, $Q_{pk,b}$, and the daily cooling energy demand, Q_{day}, are as follows:

$Q_{pk,b+iv} = 15.54\ W/m^3$ at 14:22:30 solar time,

$Q_{pk,b} = 13.71\ W/m^3$ at 13:52:30 solar time,

$Q_{day} = 477.395\ kJ/day/m^3$.

This type of external shading device saves about 6.2% in cooling energy demand for the case study building.

6.2.2 Effect of the extension of roof overhangs on daily cooling energy

This effect is shown in Figure 22. Where the daily cooling energy decreases about 5% for overhang extension of $W_R = 60\ cm$ and $H_r = 10\ cm$.

6.3 Cooling load due to only open double roof shading

The shading by the type shown in Figure 4 provides the following values:

$Q_{pk,b+iv} = 15.75\ W/m^3$ at 13:52:30 solar time,

$Q_{pk,b} = 13.94\ W/m^3$ at 13:52:30 solar time,

$Q_{day} = 481.912\ kJ/day/m^3$ for $W_R = 60\ cm$ and $H_r = 20\ cm$.

This type of external shading device shown in Figure 4 saves about 5.3% in cooling energy demand for the study building.

6.4 The reduction in cooling loads due to only internal shading

The most effective internal shading in summer is provided by the draperies or blinds with high reflective solar radiation feature. For the case, the optical properties of the beam and the diffuse radiation are considered the same. The practical range of the optical properties as follows;

τ_{gl}: 0.15 → 0.96, R_{cls}: 0.5 → 1,ρ_{bl}: 0 → 0.8, α_{rm}: 0.8 → 1.

The peak cooling loads and the daily cooling energy demand for the study building using woven drapery of semi-openness $R_{opn} = 0.16(R_{cls} = 0.84)$, and medium reflectance of yarn $\rho_{bl} = 0.375$ are:

$Q_{pk,b+iv} = 14.626\, W/m^3$ at 14:07:30 solar time,

$Q_{pk,b} = 12.807\, W/m^3$at 13:52:30 solar time,

$Q_{day} = 434.783\, kJ/day/m^3$.

This type of internal shading device saves about 14.6% in cooling energy demand for the study building.

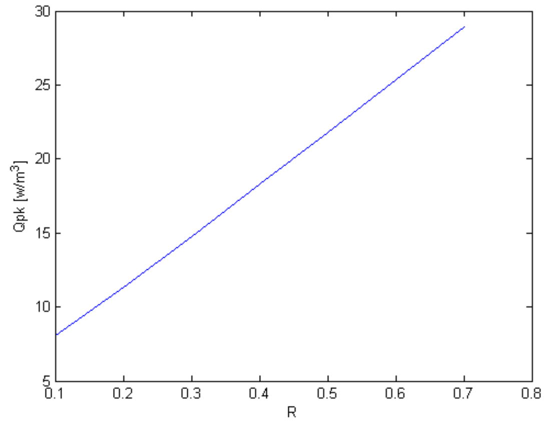

Figure 17. Peak cooling load per cubic meter of the building versus the ratio of glazing.

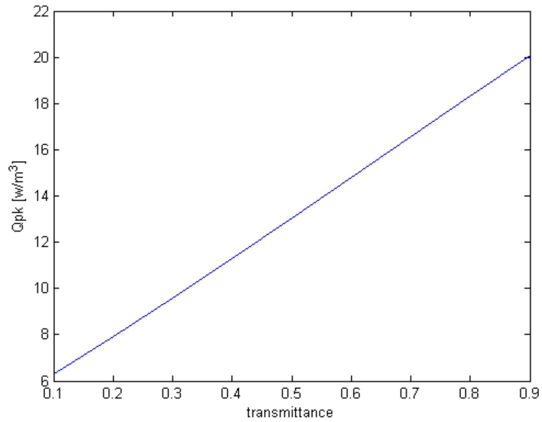

Figure 18. Peak cooling load per cubic meter of the building versus transmittance of the window's glass.

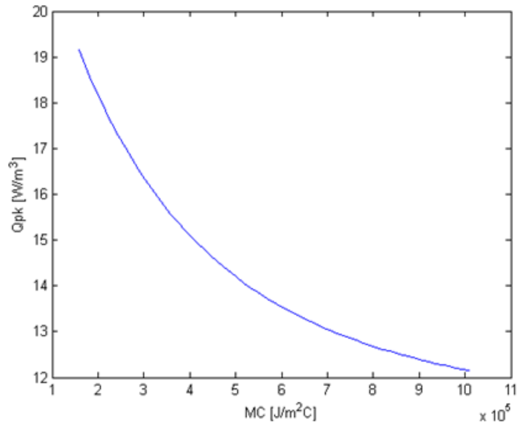

Figure 19. Peak cooling load per cubic meter of the building versus thermal capacity of the wall.

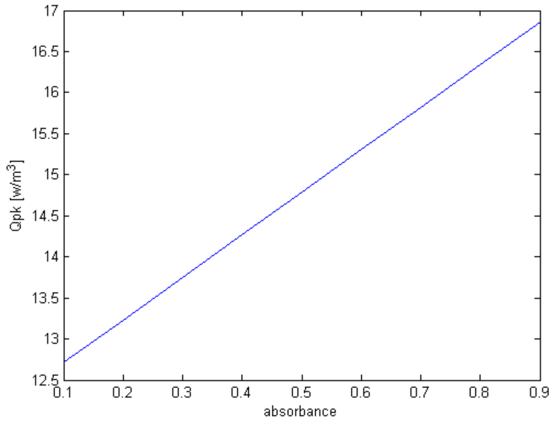

Figure 20. Peak cooling load per cubic meter of the building versus absorbance of the walls and roof.

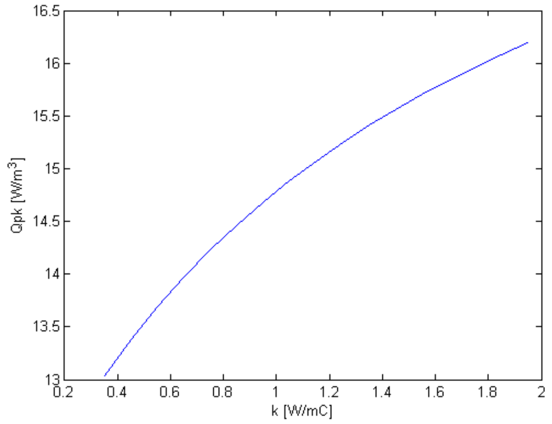

Figure 21. Peak cooling load per cubic meter of the building versus mean conductivity of the walls and roof.

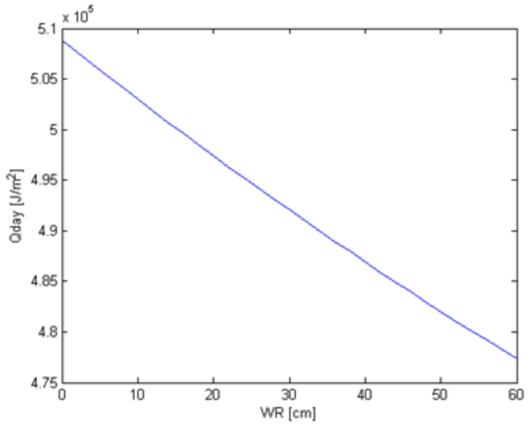

Figure 22. Daily cooling energy through the building versus extension of roof overhang.

7. Conclusion

Investigating the results of the four types of shading devices for the study building shows that the capacity of the cooling system, the time at which the peak load occurs and the save on cooling energy demand are as follows:

A. Neighbor building external shading:

$Q_{pk,b+iv} = 16.47\, W/m^3$ at 13:37:30 solar time,

Save on cooling energy is 9.5%.

B. Roof overhangs external shading:

$Q_{pk,b+iv} = 15.54\ W/m^3$ at 14:22:30 solar time,

Save on cooling energy is 6.2%.

C. Open double roof, external shading:

$Q_{pk,b+iv} = 15.75\ W/m^3$at13:52:30 solar time,

Save on cooling energy is 5.3%.

D. Blind internal shading:

$Q_{pk,b+iv} = 14.626\, W/m^3$ at 14:07:30 solar time,

Save on cooling energy is 14.6%.

As a result, the drapery or the blinds are the most effective shading in reducing the capacity of the cooling system and increasing the save in cooling energy demand.

The characteristics of applied method in this study, can be expressed as follows;

1. Load estimation in this method is based on the following three classic, but precise components: a) the dimensions and thermal and optical properties of the building, b) the weather data of location and c) the developed time function equations. Therefore, this method can be easily applied as a more generalized method, especially with the improved computational techniques instead of the numerous tedious and not precise tables.

2. The peak cooling load and the time at which occurs can be calculated in a very short time with respect to other methods.

3. The daily and season energy demand for the space cooling can be calculated easily.

4. For increasing the accuracy it is possible to minimize the time interval for calculation (in study case $\Delta t = 15$ minute).

5. The effect of the thermal capacity of the building is considered, where the high thermal capacity postpones the time at which the peak load occurs and decreases the cooling energy demand.

6. The influence of change of the properties of the building and the glazing ratio on the required capacity of the cooling system and on the energy demand can be indicated easily.

7. It is the first method has calculated precisely the shading area due to the neighboring buildings and the other shading devises and their effect on the cooling load.

8. This method can help in the studies for finding out the more economic building designs.

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