Effect of using Iraqi insulation position in walls and roofs on cooling load in Iraqi buildings using TFM^{+}

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Abstract

Transfer function method is used to study the effect of local insulation position in walls and roofs on cooling load in Iraqi building. room 4*4*3m with east window on21stJuly located in Baghdad and made of local metals in walls and roofs is used as case study. Many types of walls and roofs (with insulation and without it) are used in different directions to study how the magnitude and the distribution of cooling load are changed. The results show that using local insulation (clay) in walls and roof reduces the cooling load by (23%) and the peak loads reduced (10%), also the study shows that the insulation (any insulation) used in eastern and western wall is more efficient in reducing the cooling load than the southern and northern walls.

The results also show that when using the same amount of insulation in walls and roof at the same time the cooling load distribution changes more than when using this amount of insulation in each one. The study shows that when using north and south window and using efficient (not local) insulation the cooling load is reduced by (32%). This result shows the local insulation is good and active in reducing cooling load.

NOMENCLATURE

A	*Area,* m^2
A_i	*Area of the ith surface,* m^2
C	Specific heat, W/kg.°C
F	*View factor*
$F_{s\text{-}g}$	*View factor from the surface to the ground*
$F_{s\text{-}sky}$	*View factor from the surface to the sky*
g	*Gravity acceleration,* m/s^2
Gt	*Total solar irradiation incident on the surface,* W/m^2
hc	*Convection coefficient,* $W/(m^2\text{-}K)$
i,j,k	*Unit vectors*
k	*Thermal conductivity, W/m. °C*
N	*Number of surfaces in the room*
q	*Heat flux,* W/m^2
$q''_{\text{condition, out, j},\theta}$	*Conduction heat flux,* W/m^2
$q''_{\text{convection, out, j},\theta}$	*Convection heat flux,* W/m^2
$q''_{\text{radiation, out, j},\theta}$	*Thermal radiation heat flux,* W/m^2
$q''_{\text{solar, out, j},\theta}$	*Absorbed solar heat flux* W/m^2
$\dot{q}_{\text{infltration},\theta}$	*Heat gain due to infiltration, W*
$\dot{q}_{\text{system},\theta}$	*Heat gain due to the mechanical system, W*
$\dot{q}_{\text{internal,conv},\theta}$	*Convective portion of internal heat gains due to people, lights. or equipment, W*
t	*Local temperature at point in the slab, C*
t_g	*Ground temperature, K*
$t_{os,j,\theta}$	*The surface temperature, K*
t_{sky}	*Effective sky temperature, K*
U	*Overall heat transfer coefficient,* $W/m^2.K$
V	Wind speed m/s
X	*Exterior CTF coefficient* $W/m^2.K$
Xn	*Exterior CTF coefficient,* $W/(m^2\text{-}K)$
Y	*Cross CTF coefficient* $W/m^2.K$
Yn	*Cross CTF coefficient,* $W/(m^2\text{-}K)$
Z	*Interior CTF coefficient* $W/m^2.K$
Zn	*Interior CTF coefficient,* $W/(m^2\text{-}K)$
α	*Thermal diffusivity,* $k/\rho.C$
ε	*Surface long wavelength emissivity*
σ	*Stefan-Boltzmann constant = 5.67 x 10-8 W/(m2-K4)*
Φn	*Flux coefficient, dimensionless*
ε	Surface long wave emissivity
θ	*Time, s*
ρ	*Density,* kg/m^3
Φ	*Flux coefficient, dimensionless*
б	*Stefan Boltizman constant* 5.6×10^{-8} $W/m^2.K.$
Subscript	
s-g	*ground*
in	*Inside*
os	*Outside surface*
n	*Number*
out	*Outdoor*
j	*jth surface*

Introduction:

As the CLTD method is limited to13 represented flat roofs and only 7 groups of walls and these models are not identical with the walls and roofs used in Iraqi building, in addition this method dose don't allow the engineer to move the layers as he wants TFM is used in this study to estimate the cooling load in building in local materials. This method allows to the designer to use any materials in walls and roofs construction.

DE Bore [1] uses the matrix method to calculate the solar heat gain through roofs and walls tinder assumption that both solar radiation and external temperature go daily through a similar period cycle , and that this cycle is periodic sinusoidal for- both quantities.

The net radiation into the atmosphere is constant, constant inside ambient temperature and finally, the heat transfer. Coefficients on the inner surface of the construction are taken as the sum of the coefficients for the convection and that for the radiation. It was found that this method could be applied to calculate the heat storage effect of the inside layers of building construction, with the possibility to find more accurate values for the heat storage factor This method can be extended to cylindrical and spherical layers. *Sodha et.al* [2]derived an explicit method for the periodic variation in thermal flux through a multi-layered insulated hollow wall , roof ,with one face was exposed to solar radiation and ambient air and the other was in contact with room air at constant. Temperature was seen that for a given total thickness of concert best load leveling was achieved when the thickness of the outer layer was as small as possible. *Kaushik et.al* [3] presents a thermal behavior of a non—air-conditioned building with walls , roof being exposed to a periodic solar radiation and atmospheric air while the inside air temperature was controlled by an isothermal mass windows and door in the walls of the room .

The effects of air ventilation and infiltration on the heat capacities of the isothermal storage mass inside air and walls , roof. heat loss into the ground and the presence , absence of the window / door have been incorporated in the realistic time dependent periodic heat transfer analysis to evaluate the overall heat flux coming into the room and inside temperature. It was found that the heat fluxes through different walls have different magnitudes and phase lags with respect to the corresponding soil-air temperature. The overall heat flux coming into the room as well as the room air temperature is sensitive functions of the number of air changes per hour. *Seems* [5] describes development of CTF coefficient for two and three dimensional surfaces. *Mitalas* [6] uses simple method to calculate the heat gain for each component as a function of the total lighting load by using judgment to estimate heat to space and heat to return percentage. *Maquiston* [7] discusseds the procedure with computer program to calculate specific CTF coefficient for different constructions.

In this study, many kinds of walls, roofs are considered to estimate the effect of their layers arrangement and the position and kind of insulation on the amount and time of peak cooling load on21 July in Baghdad. Therefore, can see the best arrangement of construction in summer to make the peak cooling load of the building as small as possible or to shift it to time where the building is not used. Heat transfer through walls, roofs estimated, so Transfer Function Method with condition transfers function and computer program are used to estimate the cooling load for experimented building in Baghdad for 24 hours with many arrangements of roofs and walls.

Theory

Background:

It is important to differentiate between heat gain, cooling load and heat extraction rate. Heat gain is the rate at which energy is transferred to or generated within the space. It has two components, sensible heat and latent heat, which must be computed separately. Cooling load is the rate at which energy must be removing from the space to maintain the temperature and humidity at the design values. The cooling load will generally differ from the heat gain because the radiation from the inside surface of walls and interior objects as well as the solar radiation coming directly into the space through opening does not heat the air within the space directly. This radiant energy is mostly absorbed by floors, interior walls and furniture, which are cooled primarily by convection as they attain temperatures higher tana that of the room air. Only when then room air receives the energy by convection does this energy become part of the cooling load.

Transfer Function Method [4]

The transfer function method ensures that all energy flow in each zone are balanced and involves the solution of a set of energy balance equations for the zone air and the interior and exterior surfaces of each wall, roof, and floor. These energy balance equations are combined with equations for transient conduction heat transfer through walls and roofs and algorithms or data for weather conditions including outdoor air-dry bulb temperature, wet bulb temperature, solar radiation, and so on.
From Fig (1) it can be seen for zone whicl has solar energy coming through windows, heat is conducted through the exterior walls and roof, and internal heat gains due to lights, equipment, and occupants. The heated balance on the *j*th exterior surface at time θ is represented conceptually by:

$$q''_{\text{condition, out, j},\theta} = q''_{\text{solar, out, j},\theta} + q''_{\text{convection, out, j},\theta} + q''_{\text{radiation, out, j},\theta} \quad \text{--- (1)}$$

And

$$q''_{\text{condition, in, j},\theta} + q''_{\text{solar, in, j},\theta} = q''_{\text{convection, in, j},\theta} + q''_{\text{radiation, in, j},\theta} \quad \text{--- (2)}$$

Finally, with the assumption that the zone air has negligible thermal storage capacity, a heat balance on the zone air may be represent conceptually as:

$$\sum_{j=1}^{N} Ajq_{c}'{}_{onvection,in,j,\theta} + \dot{q}_{\text{infltration},\theta} + \dot{q}_{\text{system},\theta} + \dot{q}_{\text{internal, conv},\theta} = 0 \quad \text{--- (3)}$$

Condition Transfer Function:

While the determination of Conduction Transfer Function Coefficients is relatively complex, their use is relatively straightforward. The CTF coefficients multiply present values of interior and exterior surface temperatures, past values of interior and exterior surface temperatures, and past values of surface heat flux. The heat flux at the *j*th exterior surface for time θ is given by:

$$q'_{conduction,out,j,\theta} = -Y_o t_{is,j,\theta} - \sum_{n=1}^{Ny} Y_n t_{is,j,\theta-n\delta} + X_o t_{os,j,\theta} + \sum_{n=1}^{Nx} X_n t_{os,j,\theta-n\delta} + \sum_{n=1}^{Nq} \Phi_n q'_{conduction,out,j,\theta-n\delta} \quad \text{---(4)}$$

and the heat flux at the jth interior surface for time B is given by

$$q'_{conduction,in,j,\theta} = -Z_o t_{is,j,\theta} - \sum_{n=1}^{Nz} Z_n t_{is,j,\theta-n\delta} + Y_o t_{os,j,\theta} + \sum_{n=1}^{Ny} Y_n t_{os,j,\theta-n\delta} + \sum_{n=1}^{Nq} \Phi_n q'_{conduction,in,j,\theta-n\delta} \quad \text{---- (5)}$$

The CTF constants are estimated using method of [6] , which is put in computer program in [4].

Absorbed Solar Heat Gain

Absorbed solar heat gain is calculated as:

$$q''_{solar,out,j,\theta} = \alpha G_t \quad \text{--- (6)}$$

Exterior Convection

Convection to exterior surfaces may be represented range of models, all of which involve the use of a convection coefficient:

$$q'_{convection,in,j,\theta} = h_c (t_o - t_{os,j,\theta}) \text{------- (7)}$$

Exterior Radiation

Long wavelength (thermal) radiation to and from exterior surfaces is also a very complex phenomenon. The exterior surfaces radiate to and from the surrounding ground, vegetation, parking lots, sidewalks, other buildings, and the sky.

$$q'_{radiation,out,j,\theta} = \varepsilon\sigma[F_{s-g}(t_g^4 - t_{os,j,\theta}^4) + F_{s-sky}(t_{sky}^4 - t_{os,j,\theta}^4)] \text{------(8)}$$

Since it is usually assumed that the building sits on a featureless plain, the view factors are easy to determine.

$$F_{s-g} = \frac{1-\cos\alpha}{2} \qquad \text{......................(9)}$$

$$F_{s-sky} = \frac{1+\cos\alpha}{2}$$

where is the tilt angle of the surface from horizontal. It is often convenient to linearize this equation by introducing radiation heat transfer coefficients:

$$h_{r,g} = \varepsilon\sigma\left[\frac{F_{s-g}(t_g^4 - t_{os,j,\theta}^4)}{t_g - t_{os,j,\theta}}\right]$$

$$h_{r,sky} = \varepsilon\sigma\left[\frac{F_{s-sky}(t_{sky}^4 - t_{os,j,\theta}^4)}{t_{sky} - t_{os,j,\theta}}\right] \qquad \text{..................... (10)}$$

Then Eq.

$$q'_{radiation,out,j,\theta} = h_{r,g}(t_g - t_{os,j,\theta}) + h_{r,sky}(t_{sky} - t_{os,j,\theta}) \qquad \text{........... (11)}$$

Fenestration-transmitted Solar Radiation:

First, it is useful to consider the transmitted direct (beam) and diffused radiation separately, so

$$TSHG_{direct} = (SC)G_D \sum_{j=0}^{5} t_j[\cos\theta]^j$$

$$TSHG_{diffuse} = (SC)2G_d \sum_{j=0}^{5} \frac{t_j}{j+2} \quad \text{- ---(12)}$$

Then after any shading computation has been performed, the total rate of heat transferred into the space in the form of transmitted direct solar radiation is;

$$\dot{q}_{direct} = A_{SL}(SC)G_D \sum_{j=0}^{5} tj[\cos\theta]^j \quad \text{--- (13)}$$

where A_{SL} is the sunlit window area, m^2, and, recalling that both the sunlit and the shaded portion of a window receive diffused radiation, the total rate of heat transferred into the space in the form of transmitted diffused solar radiation is;

$$\dot{q}_{diffuse} = A(SC)2G_d \sum_{j=0}^{5} \frac{t_j}{j+2} \quad \text{--- (14)}$$

If the total transmitted diffused radiation is divided by the total interior surface area of the zone and distributed uniformly, then for all surfaces except the floor,

$$q'_{solar,in,j,\theta} = \frac{\sum \dot{q}_{diffuse}}{\sum_{j=1}^{N} A_j} \quad \text{----(15)}$$

where the numerator is the summation for all windows in the zone. Since we are assuming that all direct radiation is absorbed by the floor, the absorbed solar radiation for the floor is given by;

$$q'_{solar,in,floor,\theta} = \frac{\sum \dot{q}_{diffuse}}{\sum_{j=1}^{N} A_j} + \frac{\dot{q}_{Direct}}{A_{floor}} \quad (16)$$

Interior Surface Heat Balance - Opaque Surfaces

Much like the outside surface heat balance, the inside surface heat balance insures that the heat transfer due to absorbed solar heat gain, convection, and long-wavelength radiation is balanced by the conduction heat transfer.

<u>Convection</u> $q_c'{}_{onvection,in,j,\theta} = h_c(t_{is,j,\theta} - t_i)$ --- (17)

<u>Surface-to-Surface Radiation</u>

Radiation between surfaces in an enclosure is a fairly well-understood process. The area of the fictitious iface that exchanges radiation with the *t*he surface in the room is the sum of the other areas of the other surfaces:

$$A_{f,j} = \sum_{i=1}^{N} A_i(1-\delta_{ij}) \quad \text{---(18)}$$

$$\delta_{ij} = \text{Kronecker delta} = \begin{cases} 1 & if \quad i = j \\ 0 & if \quad i \neq j \end{cases}$$

The emissivity of the fictitious surface is an area-weighted average of the individual surface emissivities, not including the *i*th surface;

$$\varepsilon_{f,j} = \frac{\sum_{i=1}^{N} A_i \varepsilon_i (1-\delta_{ij})}{\sum_{i=1}^{N} A_i (1-\delta_{ij})} \quad \text{---(19)}$$

The temperature is an area-emissivity-weighted temperature

$$t_{f,j} = \frac{\sum_{i=1}^{N} A_i \varepsilon_i t_i (1-\delta_{ij})}{\sum_{i=1}^{N} A_i \varepsilon_i (1-\delta_{ij})} \quad \text{---(20)}$$

The radiation between the interior surface and its corresponding fictitious surface is analyzed based on fundamental principles, although the area, emissivity, temperature, and view factor of the fictitious surface are approximated. A radiation interchange factor is defined as;

$$F_{j,f} = \frac{1}{\frac{1-\varepsilon_j}{\varepsilon_j} + 1 + \left(\frac{A_j}{A_f}\right)\frac{1-\varepsilon_f}{\varepsilon_f}} \quad (21)$$

and a radiation coefficient may be defined as;

$$h_{r,j} = \sigma F_{j,f} \frac{t_i^4 - t_{f,j}^4}{t_i - t_f} \approx 4\sigma F_{j,f}(t_{j,avg})^3 \quad \text{-- (22)}$$

The net radiation leaving each surface for the other room surfaces is then given by;

$$q_r'{}_{adiation-surf,in,j,\theta} = h_{r,j}(t_j - t_{f,j}) \quad \text{--- (23)}$$

The net radiation leaving each surface is then given by;

$$q_r'{}_{adiation-surf,in,j,\theta} = h_{r,j}(t_j - t_{f,j}) - q_b'{}_{alance} \quad \text{--- (24)}$$

Problem Formulation

Figure (2) shows sketch for case study and Table (1) shows the specification of metals used in walls and roofs. Table (2) shows the dimension of room and the outdoor and an indoor conditions of case study and table (3) shows the types of walls and roofs used in this study. Wall No. 1 and roof No. 1 in Table (3) are the standard for Iraqi building.

Results and Discussion

Fig (3) shows the cooling load distribution for the room used in this study, the walls used in this figure are from type (1) (standard Iraqi walls), and the roof is type (1) also (standard Iraqi roof), window is single, this Figure shows that the windows position has great effect on the cooling load distribution and how the eastern and western windows give a larger peak cooling load than the southern and northern windows. Fig (4) shows the room using east window with roof type(1), when using wall type (2), the cooling load reduces only at the beginning and ending hours of the day because at midday the more effected is the roof as the radiation is nearly vertical, this local insulation in the wall (clay) reduces the cooling load by (1.3%) when we use it in eastern wall only and the other walls are of type (1) because most of the area of this wall is window and by (6.5%) when we use wall type (2) in north and south walls the cooling load reduces by (7.7 %) and when all the used walls are from type (2) the cooling load is reduced by (14.7%) and the peak load is reduced by (4.6%). Fig (5) shows the effect of combined using local insulation (clay) in roof and the 4-wall for the same room, the figure shows how the roof with new insulation reduces the load by (7.6%) and when using the insulation in walls and roof , the load reduce by (23%) . This Figure shows that the using of insulation in both walls, and roof change the load distribution (shape) also as the peak load reduce by (10%). Fig (6) shows that the insulation at north and south is affected when the room has eastern window and the effect of insulation on the north and south is obvious because for the eastern wall, most of its area is window. Fig (7) shows that the using of very effective insulation (6 in), (not local) affects is only the magnitude of cooling loads (reduced by 29%) and not its distribution and looks like local insulation, also this Figure shows that the use of local insulation in roof with this insulation reduces the cooling load by (38%). Fig (8) shows how the two windows with insulated walls affected the cooling load distribution. This Figures shows that the case when using eastern and western windows the cooling load is greater than any case and the northern and southern windows give smaller cooling load .

Conclusion

1. The roof in Iraqi building in summer has a great effect at midday and using 150mm of clay with the layer reduces the cooling load by good percentage.
2. Southern and northern windows with local insulation in the walls will decrease the cooling load by good percentage.
3. Local insulation (clay) is a useful material which can be used as insulation in wall and roof composition.

Table 1: Layer information e

LAYER NAME	SPECIFIC HEAT(CP) KJ/KG.	THERMAL CONDUCTIVITY (K)W/M. ^{O}C	THICKNESS (T) MM	DENSITY KG/M^3
Brick	0.84	0.72	240	1920
Gypsum	0.84	0.47	20	1680
Low density concrete	1.67	0.72	20	1857
Clay	1.67	0.33	100	1514
Insulation (6 in)	0.71	0.04	152.4	32.0
High density concrete	0.84	1.73	150	2243
Felt end member	1.8	0.75	20	1120
Sand	1.67	0.33	40	1500
Concrete block	1.00	0.58	40	1920

Table 2: Room specification and outdoor and indoor design conditions

ITY	BAGHDAD
Latitude	33 degrees
Longitude	44
Outdoor dry bulb temperature	45 ^{o}C
Outdoor wet bulb temperature	23.2 ^{o}C
Daily range	18.7
Ground temperature	22.2 ^{o}C
Clearness factor	1
Indoor dry bulb temperature	25 ^{o}C
Month	July
Day	21
Wind direction	315 degrees clockwise from north
Wind speed	3.3 m/s
Room dimension	4*4*3 m
Area of window (located in the eastern wall)	3*3 m

Table 3: Types of walls and roofs used in the study

WALL NO.1	GYPSUM ٠٢ MM	BRICK ٠٤٢MM	LOW DENSITY CONCRETE ٠٢MM			
Wall No.2	gypsum ٠٢ mm	clay ٠٠١mm	brick ٠٤٢mm	clay ٠٠١mm	low density concrete ٠٢mm	
Wall No.3	gypsum ٠٢ mm	insulation ٦ in	brick ٠٤٢mm	low density concrete ٠٢mm		
Roof No. 1	gypsum ٠٢ mm	high density concrete ٠٥١mm	felt and member ٠٢mm	clay ٠٠١mm	sand ٠٤mm	concrete block ٠٤mm
Roof No. 2	gypsum ٠٢ mm	high density concrete ٠٥١mm	felt and member ٠٢mm	clay ٠٥١mm	sand ٠٤mm	concrete block ٠٤mm

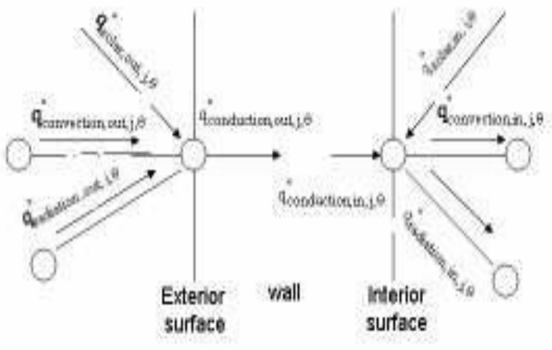
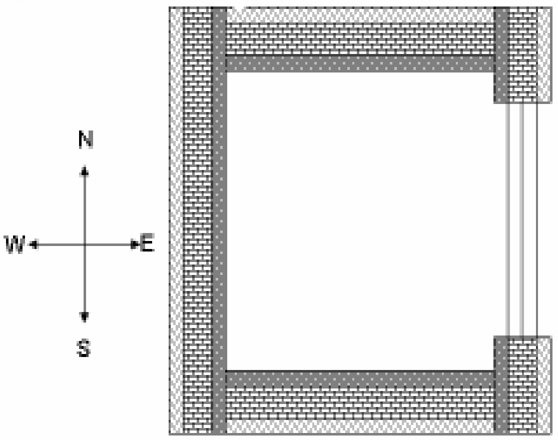


Figure (1) Heat balance



Figure(2) room under study

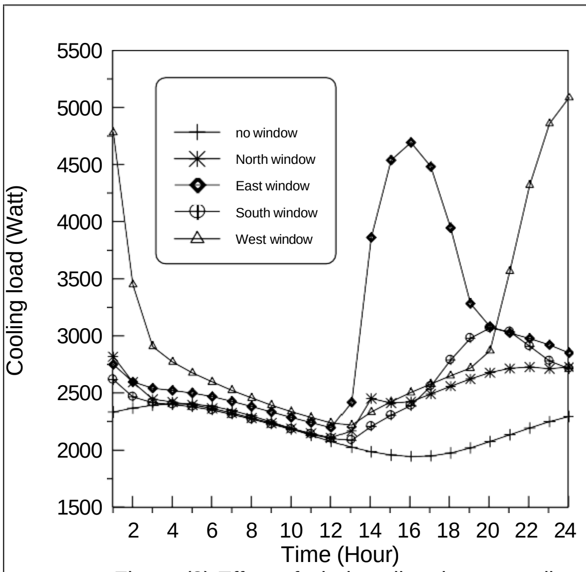
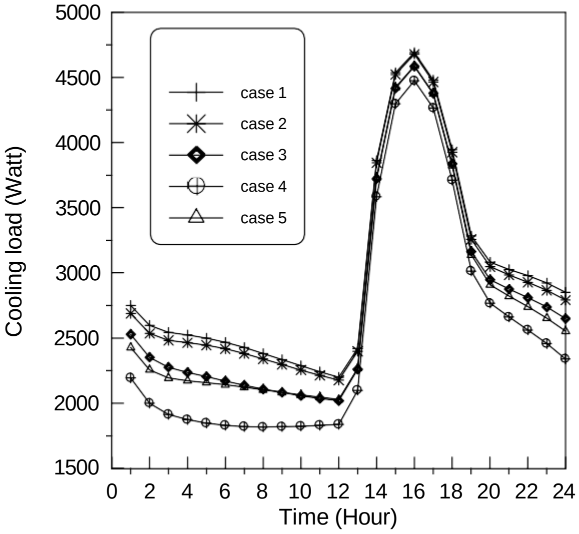


Figure (3) Effect of window direction on cooling load distribution



Figure(4) Effect of walls type on cooling load

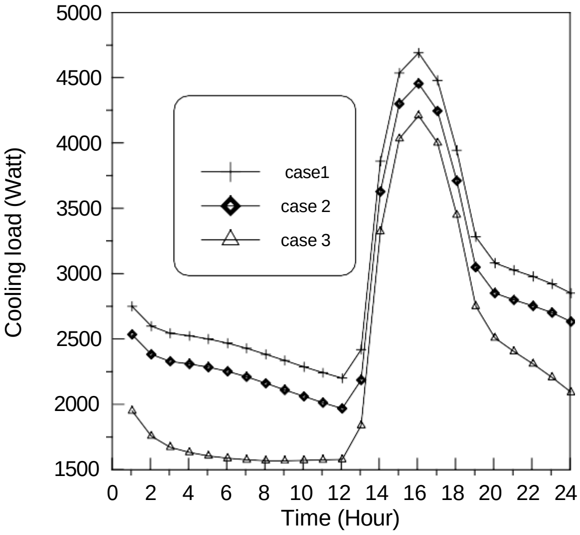


Figure (5) Effect of wall and roof type on cooling load

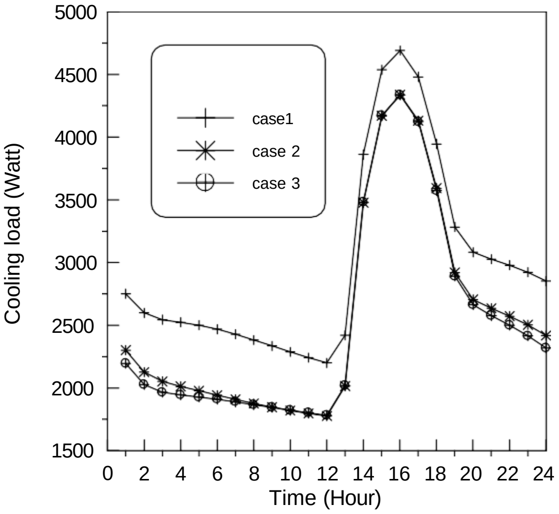


Figure (6) Effect of walls type on cooling load

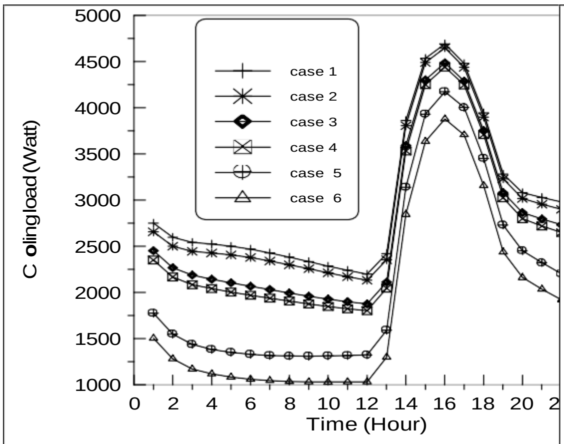


Figure (7) Effect of high insulation wall cooling load

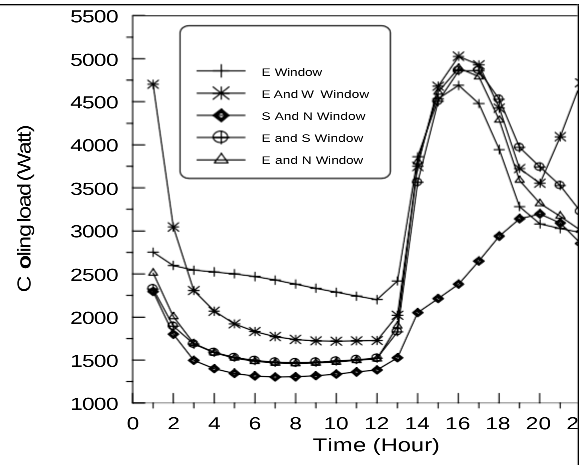


Figure (8) Effect of other window on cooling

NOMENCLATURE

$V0$	cutting velocity [m/s]
k_{sx}	chip thickness coefficient in x-axis direction [N/m]
k_{sy}	chip thickness coefficient in y-axis direction [N/m]
k_v	cutting velocity coefficient [Ns/m]
d_{so}	chip thickness variation [mm]
k_s	chip thickness coefficient [N/m]
dp_x	dynamic cutting force in x-axis direction [N]
dp_y	dynamic cutting force in y-axis direction [N]
k_{1x}	dynamic chip thickness coefficient in x-axis direction [N/m]
k_{1y}	dynamic chip thickness coefficient in y-axis direction [N/m]
k_1	dynamic chip thickness coefficient[N/m]
dt_0	depth of cut variation [mm]
c_x	damping coefficient in x-axis direction [Ns/m]
c_y	damping coefficient in y-axis direction [Ns/m]
v	displacement coefficient
to	depth of cut [mm]
R	feed rate [mm/s]
C_0	feed rate factor
m_y	mass in y-axis direction [Ns^2/m]
m_x	mass in x-axis direction [Ns^2/m]
S_0	nominal feed [mm/rev]
N	number of revolution [rpm]
dr	penetration rate variation [mm/s]
R	radius of workpiece [mm]
s_x	stiffness in x-axis direction [N/m]
s_y	stiffness in y-axis direction [N/m]
T	time lag at each revolution [s]
Ω	angular speed [rad/s]
d_Ω	angular speed variation [rad/s]
k_Ω	angular speed coefficient [Ns]

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