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COOLING LOAD ESTIMATION OF AN OFFICE AREA USING CLTD$_C$ METHOD FOR IMPROVEMENT OF INDOOR AIR QUALITY

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Abstract: In the modern world air conditioning plays a vital role in energy consumption as well as the indoor air quality of an air conditioning space. To improve the air quality and energy consumption reduction many technologies are advancing but proper cooling load estimation is an inevitable part of air conditioning of a building. There are various methods of cooling load estimation, and CLTD$_C$ is one of the such method for efficient determination of quantity of heat inside an air conditioning space. In this work an office area is considered for estimation of heat by using Cooling Load Temperature Differential corrected (CLTD$_C$) method. Here in this work all required parameters for cooling load estimation are taken from ASHRAE guideline. Considering all factors of head addition to the air conditioning space, total cooling load was found to be 12 Tonne of refrigeration.

Key words: **Thermal load estimation, CLTD**

I. INTRODUCTION: To determine the thermal load there are various methods like rule of thumb, CLTD method, Radiant time series method and Heat Balance and Computer Simulation are generally used. This thermal load of a building adopted for cooling in summer and heating in winter is important for accuracy of design and selection of equipment **[5]**. After estimating the total heat inside conditioning space using one of such methods, equipment are selected. Such equipment are like unitary air conditioning system, all water system, air water cooling system all air system, variable refrigerant flow systems etc. All these devices are improvised day by day for low energy consumption ability. Apart from these few other accessories like energy recovery ventilators, heat wheel desiccant dehumidifier etc are widely used to reduce energy consumption. In recent days a major part of electrical energy consumption is done by the air conditioning systems. During the summer the energy consumption is very high **[3]**. The high temperature of the climate increases the condenser pressure and as result power consumption also takes place. To reduce power consumption in large buildings where high power consumption occurs uses Demand Response (DR) method **[2]**. In this method thermal storage, onsite electrical generation and curtailing of power during peak demand is practiced. In large building where chillers are used for conditioning the space contributes a huge amount of pollution by the wet cooling towers **[4]** and also consumes power by the axil and radial fans. Therefore, selection of equipment and type of refrigerant should be done judiciously apart form reduction of power by proper heat load calculations.

II. METHODOLOGY: In this work an office is considered about 4000 sq.ft. containing office room, cafeteria, printing area and toilets of specific dimensions.

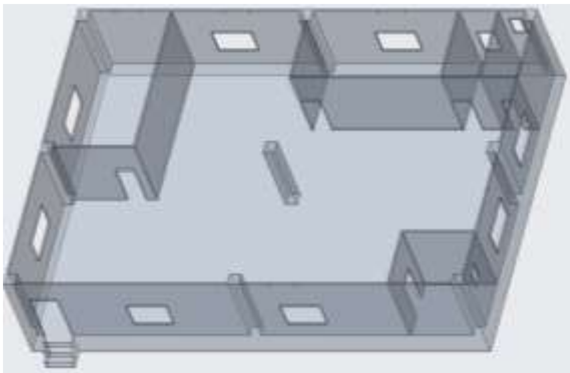


Figure 1: Air conditioning Space of the Office

III. Cooling Load Calculation (CLTDc) method:

a. Wall Load

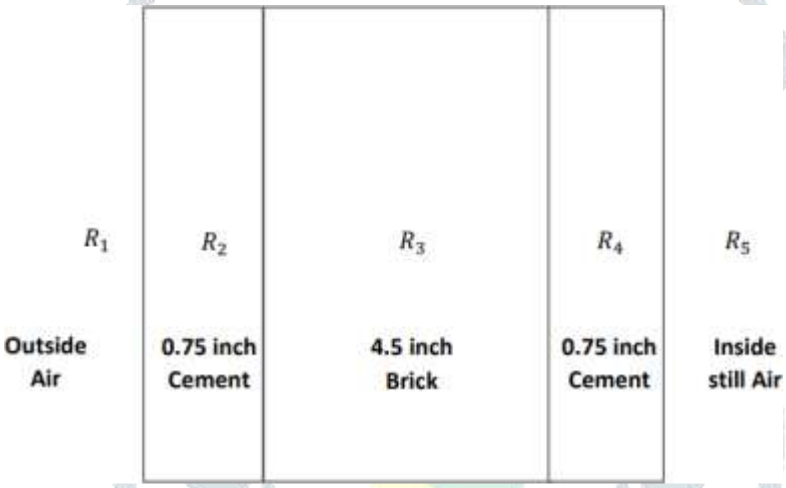
$$Q = U \times A_i \times CLTD_i$$

where, Q = Cooling load,

U = Design Heat Transmission Coefficient,

A_i = Area of walls calculated from Architectural Plans,

$CLTD_i$ = Cooling Load Temperature Difference in the ith wall.



Heat Transmission Coefficient (U) $(\frac{BTU}{ft^2}.h \cdot °F) = \frac{1}{R_t}$

$$R_t = R_1 + R_2 + R_3 + R_4 + \cdots + R_n$$

$R_t = 0.17 + 0.2 \times 0.75 + 4.5 \times 0.2 + 0.2 \times 0.75 + 0.68$

$R_t = 2.05\ ft^2 \cdot h \cdot {}^oF/Btu$

So, $U = \frac{1}{2.05} = 0.48 \frac{BTU}{ft^2}.h.{}^0F$

Wall Surface Area

Table 1: Wall surface area in all direction

Wall Directions	**Area(ft^2)**
East(A_E) West(A_W) North(A_N) South(A_S) Roof(A_R)	960 ft^2 960ft^2 600ft^2 600ft^2 4000ft^2
TOTAL	**7120 ft^2**

Cooling Load Temperature Difference: Peak load inside the room is at 16:00 hours (4PM).

From Table 3.9 (Wall Construction Group Description) of ASHRAE Handbook 2001, Wall Group No. D corresponding to 4-inch face brick +(Brick) + 4- inch Common Brick closely matches our design wall type. Hence, the CLTD values are calculated from Table 3.10 (Cooling Load Temperature Difference for Calculating Cooling Load from Sunlit Walls), ASHRAE Handbook 2001 at the design hour of 16:00 or 4PM.

$CLTD_E = 33$, $CLTD_W = 18$, $CLTD_N = 13$, $CLTD_S = 24$

Adjustments to Table Values

Not that the above values assume a dark colour room with design outdoor temperature of 95°F (35°C); Mean outdoor temperature, T_m = 84.92°F (29.4°C);Inside Design Temperature Tr =77.9°F (25.5°C); a daily range, DR =52.88°F (11.6°C); clear sky on the July 21st & latitude (LM) = 40° North. When conditions are different from above, CLTD values must be corrected before being used. The corrected CLTD value is given by the formula:

$CLTD_{corr} = (CLTD+LM) \times k + ((78 - T_r) + (T_o - 85))$

where,

k = Wall colour correction factor = 0.65 for permanently light coloured (ruralarea).
LM = Latitude Month correction (from Table 3.12, ASHRAE Handbook 2001)
T_r = Inside design temperature = 75°F (or 24°C)
T_o = Average outside temperature on a design day= $T_{max} - \frac{Daily\ range}{2}$
CLTD = is from Table 3.10 (ASHRAE) at the wall orientation From Table 1.3 of ASHRAE Data book 2017, Guwahati, India is located at 26.1158°N Latitude, 91.7086°E Longitude and at an elevation of about 54 metres above sea level. The Month of June has the maximum temperature of 95.9°F with minimum daily range of 14.94°F. Hence, June is selected as the design month.

So $T_0 = T_{max} - \left(\frac{Daily\ Range}{2}\right)$

$T_0 = 95.9 - \left(\frac{14.94}{2}\right) = 88.43\ ^0F$

Therefore, the CLTD Corrected value for each wall orientation is calculated asgiven below.
For 24°N Latitude,

East Wall
LM = 0 (from Table 3.12, ASHRAE Handbook 2001)
CLTDcorr1 = (33 + 0) × 0.65 + ((78 − 75) + (88.43 − 85)) = 27.88 °F

West Wall
LM = 0 (from Table 3.12, ASHRAE Handbook 2001)
CLTDcorr2 = (18 − 0) × 0.65 + ((78 − 75) + (88.43 − 85)) = 18.13 °F

North Wall

LM = 3 (from Table 3.12, ASHRAE Handbook 2001)
CLTDcorr3 = (13 + 3) × 0.65 + ((78 − 75) + (88.43 − 85)) = 16.83 °F

South Wall
LM = -6 (from Table 3.12, ASHRAE Handbook 2001)
CLTDcorr4= (24 − 6) × 0.65 + ((78 − 75) + (88.43 − 85)) = 18.13 °F

Load calculation

$Q = U \times A_i \times CLTD_{corr,i}$

For East Wall,
$Q = U \times A_i \times CLTD_{corr,i}$= 0.48×960×27.88 =12847.104 BTU/hr
For West Wall,
$Q = U \times A_i \times CLTD_{corr,i}$= 0.48×960×18.13 =8354.304 BTU/hr
For North Wall,
$Q = U \times A_i \times CLTD_{corr,i}$= 0.48×600×16.83 =4847.04 BTU/hrFor
South Wall, $Q = U \times A_i \times CLTD_{corr,i}$= 0.48×600×18.13 =5221.44 BTU/hr

Table 2: Cooling load of all the walls

Wall Orientation	Wall Cooling Load, Q (Btu/hr)
East	12847.104 BTU/hr
West	8354.304 BTU/hr
North	4847.04 BTU/hr
South	5221.44 BTU/hr
Total	**31269.888 BTU/hr**

b. Roof Load:

From the Table 3.9 of ASHRAE Handbook 2001, The roof walls of thedesign room fall closely in the category of Wall Group No. B of H.W Concrete + (finish) with the ceiling type being suspended. Hence

Heat Transmission coefficient (U):

U=0.187 $\frac{BTU}{ft^2}$. h. ^{0}F (From ASHRAE table 3.9 2001 handbook)

Area of Roof

Area of the Ceiling, A_R = 4000 ft^2

Cooling Load Temperature Difference (CLTD)

Cooling Load Temperature Difference of Roof, $CLTD_R$ = 30 °F (Table 3.8,ASHRAE Handbook 2001; Roof No.12 and solar time 16hr)

CLTD Corrected

$CLTD_{corr} = (CLTD+LM) \times k + ((78 - T_r) + (T_o - 85))$

For the design month of June & 24°N Latitude;

LM= 1 (From HOZ Column, Table 3.12, ASHRAE Databook 2001)
k = 0.65, T_r = 75°F

$CLTD_{corr} = (30 + 1) \times 0.65 + ((78 - 75) + (88.43 - 85)) = 31.58°F$

Load Calculation

Roof load, Q_R is calculated as follows:

$Q = U\times A_i\times CLTD_{corr,i}$

$Q = 0.187 \times 4000 \times 31.58 = 23621.84$ BTU/hr

c. Door load:

Door Area

Number of doors in the office = 6 (1 main door, 4 general door, 1 storeroom door)Number of flaps in each door = 1
Area of main door flap = 4.92126×8.2021 ft^2 =40.36 ft^2 Area of general door flap = 3.28084×6.56168 ft^2=21.53 ft^{2}Total area of general door flap = 4×21.53 ft^2=85.02 ft^2
Area of storeroom door flap = 6.56168×1.9685 ft^2 =12.29 ft^{2}Thickness of door = 0.125 ft
Total Area of door, A_D = (40.36+85.02+12.29) ft^2= 137.67 ft^2

Transmission Coefficient (U)

Thermal Resistance of Wood, R_W = 1.89 (From Table 3.1A, ASHRAE Handbook2001)
Thermal Resistance of outer air film, $R_{air(o)}$= 0.17 (From Table 3.3, ASHRAE) 24Thermal Resistance of inner air film, $R_{air(i)}$= 0.68 (From Table 3.3, ASHRAE) Therefore, Total thermal Resistance, R_t

$R_t = R_{air(o)}+ R_W+ R_{air(i)}$

$R_t = 0.17 + 1.89 + 0.68 = 2.74$

$$U = \frac{1}{R_t} = \frac{1}{2.74} = 0.36 \frac{BTU}{ft^2} h. {}^0F$$

Cooling Load Temperature Difference (CLTD)

Table 3.9 (Wall Construction Group Description), ASHRAE Handbook 2001, does not specify group type for wooden doors but it is standard practice to take Group G for wooden door calculations. The doors are facing south. The CLTD for solar timing of 16 hrs. is calculated from Table 3.10, ASHRAE Handbook 2001 as

$$CLTD_d = 37°F$$

CLTD Corrected

$$CLTD_{corr} = (CLTD+LM) \times k + ((78 - T_r) + (T_o - 85))$$

For the design month of June & 24°N Latitude

LM = −6 (From Table 3.12, ASHRAE Databook 2001)

k = 0.83 (Permanently dark colour, rural)

T_r = 75°F, T_o = 88.43°F

$$CLTD_{corr} = (37 - 6) \times 0.83 + ((78 - 75) + (88.43 - 85)) = 32.16°F$$

Load Calculation

Door load, Q is calculated as follows:

$Q = U \times A_i \times CLTD_{corr,i}$

$Q = 0.36 \times 137.67 \times 32.16 = 1593.888192$ BTU/hr

d. Window load:

Total number of windows in the office =11

Let us consider, there are all glass windows in the office building.Hence, we have to do the glass load calculation;

CONDUCTION LOAD

Where,

$Q = U \times A_g \times \Delta t$

$\Delta t = T_o - T_r$ = Difference between outside Temperature and insidedesign temperature.

$\Delta t = T_o - T_r$ = 88.43°F − 75 °F = 13.43 °F , A_t = Total Effective glass area.

HEAT TRANSMISSION COEFFICIENT (U)

The glass pane in use is of single glass type with curtains as indoor shade.Hence from Table 13.4A (Overall Coefficients of Heat Transmission (U-factor) for Windows and Skylights, $\frac{BTU}{ft^2} \cdot h \cdot °F$), ASHRAE Handbook 2001, we have

$$U = 0.81 \frac{BTU}{ft^2} \cdot h \cdot °F$$

AREA OF GLASS

Area of type 1 window = 7×4 ft^2 = 28 ft^2Area of type 2 window = 3×2 ft^2 = 6 ft^2 Area of type 3 window = 3×4 ft^2 = 12 ft^2

The Total glass area in each direction is given in tabular form below:

Table 3: Total area of glass window

Orientation	No of type 1 window	No of type 2 window	No of type 3 window	Total window	Total Area (A_t)
East	2	1	0	3	62 ft^2
West	2	0	0	2	56 ft^2

North	2	1	1	4	74 ft^2
South	2	0	0	2	56 ft^2
Total	**8**	**2**	**1**	**11**	**248 ft^2**

Load calculation

$$Q = U \times At \times \Delta t$$

For East Wall, Q = U×At× Δt= 0.81×62×13.43 = 674.4546 BTU/hr For West Wall, Q = U× At× Δt = 0.81×56×13.43 = 609.1848BTU/hrFor North Wall, Q = U× At× Δt = 0.81×74×13.43 =804.9942BTU/hrFor South Wall, Q = U× At× Δt= 0.81×56×13.43 =609.1848 BTU/hr

Table 4: Glass conduction load in all directions

Glass orientation	Glass conduction Load, Q (BTU/hr)
East	674.4546 BTU/hr
West	609.1848 BTU/hr
North	804.9942 BTU/hr
South	609.1848 BTU/hr
Total	**2697.8184 BTU/hr**

SOLAR LOAD

$Q = A_t \times (SC) \times (SHGF)_{max} \times (CLF)$

Where

Q = Cooling load due to solar radiation through glass, BTU/hr.A_t = Net glass area of the fenestration ft^2

SC = Shading Coefficient

$(SHGF)_{max}$= Maximum Solar Heat Gain Factor for the month, latitude andorientation, BTU/hr. ft^2

CLF = Cooling Load Factor

SHADING COEFFICIENT (SC)

It is the ratio of solar gain passing through a glass unit to the solar energy which passes through 3m clear Float Glass. The type of glass used in the construction of windows and glass of the room is a single clear glass with a nominal thickness of ¼inch with roller curtains of red colour as internal shading. Hence from Table 3.18 of ASHRAE Handbook 2001, shading coefficient is taken to be,

SC = 0.59

SOLAR HEAT GAIN FACTOR (SHGF)

The amount of heat the sun can supply to the room. It is dependent on, Window Orientation, Designing location latitude, Design Month

From Table 3.25 of ASHRAE Handbook 2001, for 24°N Latitude, the SHGFfor different glass orientations are given in the table below.

Table 5: SHGF in all directions

Orientation	SHGF
East	212
West	212
North	55
South	43

COOLING LOAD FACTOR (CLF)

The Cooling Load Factor is dependent on three parameters.

- Design Time – This in our case is 16 hours.
- Designing location- 24°N Latitude
- Shading of Window – (from Table 3.28 and Table 3.27, ASHRAE Databook 2001)

From the previous section we have chosen a shading coefficient of 0.59 forroller type curtain as internal shading.

Hence the CLF for each wall orientation is,

Table 6: CLF in all directions

Orientation	**CLF**
East	0.26
West	0.50
North	0.74
South	0.47

Load Calculation

Glass Solar load is given by,

$Q = A_t \times (SC) \times (SHGF)_{max} \times (CLF)$

The total solar heat gain from each orientation is given below,

For East Wall, $Q = A_t \times (SC) \times (SHGF)_{max} \times (CLF)$ =62×0.59×212×0.26=2016.2896 BTU/hrFor West Wall, $Q = A_t \times (SC) \times (SHGF)_{max} \times (CLF)$ =56×0.59×212×0.50=3502.24 BTU/hr For North Wall, $Q = A_t \times (SC) \times (SHGF)_{max} \times (CLF)$ =74×0.59×55×0.74=1776.962 BTU/hrFor South Wall, $Q = A_t \times (SC) \times (SHGF)_{max} \times (CLF)$ =56×0.59×43×0.47=667.7384 BTU/hr

Table 7: Glass solar load in all directions

Direction	Glass solar load, Q (BTU/hr)
East	2016.2896 BTU/hr
West	3502.24 BTU/hr
North	1776.962 BTU/hr
South	667.7384 BTU/hr
Total	7963.23 BTU/hr

Internal Load Factors

e. Lighting load :

$Q = 3.14 \times q_i \times F_a \times F_s \times CLF$

where, Q = Sensible cooling load in BTU/hr

3.41 = Conversion Factor BTU/hrper wattq_i = Total lamp wattage

F_a = Fraction of qi in use

F_s = Special ballast allowance factor for fluorescent fixtures (Table.4.1, ASHRAE) CLF = Cooling load factor (Table 4.4 aided by Table 4.2 and 4.3, ASHRAE 2001)

q_i = Light power density (LPD) × A_R

$q_i = 1.23 \times 4000 = 4920$Watt$F_a = 1$
$F_s = 1.3$

CLF = 0.77

Therefore, Sensible cooling load due to lighting is.

$Q = 3.14 \times 4920 \times 1 \times 1.3 \times 0.77 = 15464.2488$BTU/hr

f. People Load

The maximum occupancy has been taken to be 80 as the peak design capacity.

Sensible Heat (SH) (Btu/hr)

$$Q = \frac{SH}{Person} \text{ X max. number of occupants}$$

$Q = 230 \times 80 = 18400$BTU/hr

Latent Heat (LH)(Btu/hr) $Q = \frac{LH}{Person}$ x Max. number of Occupants $Q = 190 \times 80 = 15200$ BTU/hr

g. Ventilation Load :

Sensible Heat (SH) (Btu/hr)

$Q = 1.1 \times \Delta t \times CFM$

$Q = 230 \times 13.43 \times 250 = 3391.07$BTU/hr

Latent Heat (LH)(Btu/hr)

$Q = 4840 \times \Delta w \times CFM$,

$Q = 4840 \times 0.011 \times 250 = 13310$BTU/hr

h. Infiltration Load

$$Q = 4840 \times \Delta w \times CFM$$

Where

$$CFM = \frac{Volume\ x\ N_a}{60} = 13386.65 \times 0.4860 = 156.17$$

$N_a = 0.48$ (From McQuiston 1985)

So, $Q = 4840 \times 0.01 \times 156.17 = 8314.89$ BTU/hr

i. Miscellaneous Load

Projector and Screen Load

$$Q = 3.14 \times q_i \times F_a \times F_s \times CLF$$

$Q = 3.14 \times 300 \times 1 \times 1 \times 0.5 = 471$ BTU/hr3.2.4 Total

Total Estimated cooling Load

Considering all loads including sensible and latent load total is found to be 141697.87 BTU/hr.

Conversion to Tonnes of Refrigeration (TR)

12000 BTU/hr = 1TR therefore 141697.87 BTU/hr = 11.8 TR ≈ 12 TR

Hence, we require 5 air conditioner devices three of them with 2TR capacity and two of them with 3TR in the designed office building.

Conclusion: Correct cooling load estimation is a crucial part of design and estimation of air conditioning system as it gives the proper thermal requirement of the building. The entire quantity of heat must be removed from the air conditioning space in order to get proper thermal comfort. This assessment takes into account a variety of parameters such as building materials, insulation, occupancy levels, lighting, and office equipment, as well as external climatic conditions such as outdoor temperature. The precision of this calculation highly desirable for efficient design of the HVAC system. The oversizing of such equipment can lead to higher power consumption on the contrary inadequate capacity of the system will be struggling to maintain the required temperature and humidity control of the condition space. Therefore, the rigorous calculation of heat load serves as a foundation for building power efficiency as well as low impact on the environment. In this work 4000 sqft office area is considered for determination of total thermal load and it was found as 12 TR by using $CLTD_C$ method.

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