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Analyzing Temperature Gradient across the Roof of a Building in Baghdad

Asst. Lect. Ma'athe Abdul Wahed
Mechanical Engineering Dept., College of Engineering
Al-Mustansiriya University, Baghdad, Iraq

Abstract

One of the problems that face the designer in the cooling load calculation in Iraq is the usage of CLTD-CF or TETD method. The problem is the difficulty in finding a roof in the tables like the roofs that are used in our buildings in Iraq.

This paper is focused on the problem and analyzing the temperature distribution across the roof. The analysis uses the explicit Finite Difference method to find the temperature gradient and the cooling load for a building in June and July.

To check the validity of the computer program, a measurement of the roof surface temperature has been made which gives very good agreement.

الخلاصـــة

*تعتبر استخدام طريقة الـ **CLTD,TETD** واحدة من المشاكل الرئيسية التي تواجه المصمم أثناء القيام بعمليات حساب حمل التبريد في العراق. سبب ذلك عدم وجود نوع مقارب من السقوف المرفقة في الجداول مشابهة للسقوف المستخدمة في العراق.*

*في هذا البحث تم تحليل توزيع درجات الحرارة خلال السقف بواسطة التحليل العددي **Finite Difference (Explicit)** حيث تم بناء برنامج لإيجاد توزيع درجات الحرارة خلال السقف وبالتالي الحمل الحراري ،تم تطبيق الدراسة للشهرين حزيران و تموز من العام ٢٠٠٣ .*

للتأكد من صحة نتائج البرنامج ومن اجل الحصول على دقة في العمل تم إجراء حسابات عملية للنوعين الشائعين الاستخدام من السقوف وللفترة من ٦ صباحا ولغاية ٦ مساء وقد ظهر وجود تقارب كبير بين النتائج العملية والنظرية.

1. Introduction

Air conditioning system is more expensive than other systems like evaporative air cooler, so it is important to calculate the cooling load for building within the highest accuracy to use the minimal cost device. This work deals with the calculation of the temperature distribution, transmission cooling load and overall heat transfer coefficient for some types of roofs that are used in Iraq. These roofs are non standard which set the designer in a problem when calculating CLTD or TETD and the overall heat transfer coefficient when using standard reference such as ASHRAE.

In this study, the roof is modeled by a numerical explicit finite difference method to calculate the temperature gradient. To check the validity of the computer program, the results are compared with other studies [1] and they give good agreement.

The temperature of the surface is measured and the experimental data are compared with the program results.

2. Analysis

The model of this study deals with tow types of roofs as, shown in **Fig.(1)**, and **Fig.(2)**. Heat transfer through the roof is unsteady and one-dimensional with periodic boundary condition **Fig.(3)**. The exposed roof surface reflects part of incident solar radiation, the absorbed part heats the surface, sky radiation are takes place from the surface to ambient, the remaining heat is conducted through the layers of the roof, and the heat which finally convicts the room manifests itself into the cooling load.

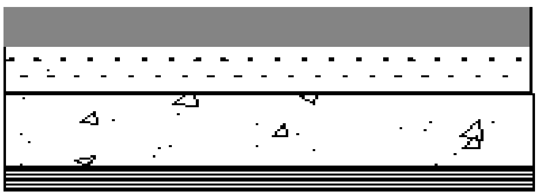

Figure (1) Roof Type (A)

40 mm concrete
40 mm soil
10 mm roll asphalt
140 mm concrete
20 mm plaster

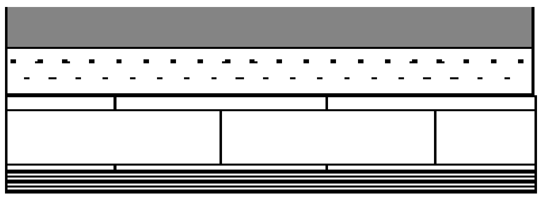

Figure (2) Roof Type (B)

40 mm concrete
40 mm soil
10 mm roll asphalt
60 mm brick
20 mm plaster

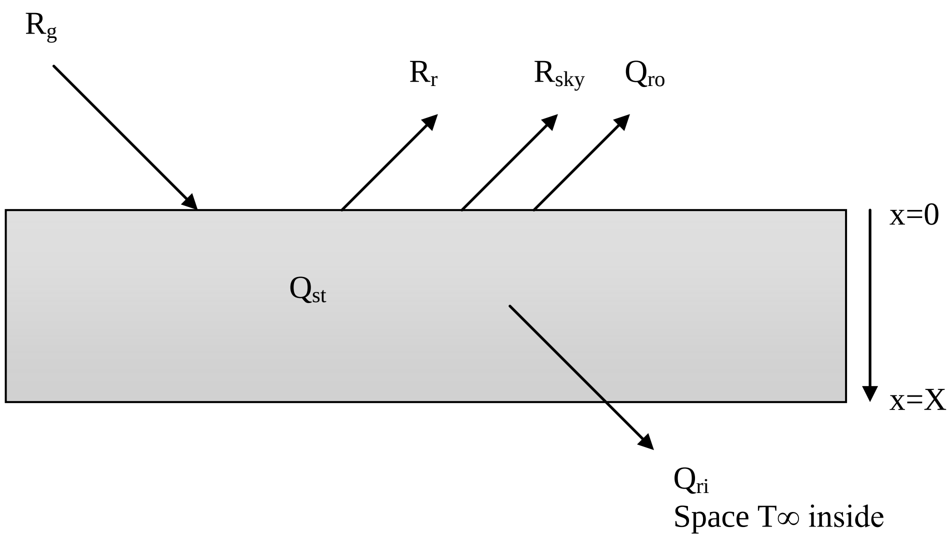

Figure (3) Roof Heat Transfer Model

The governing differential equation for one-dimensional unsteady heat conduction through the roof segment is given by [1]:

$$K\frac{\partial^2 T}{\partial x^2}=\rho cp\frac{\partial t}{\partial \theta} \quad \text{.......... (1)}$$

This equation is differentiated for both x and time, it gives the equation:

$$T_{m,nt1}=\frac{\rho cp}{K}*\frac{1}{(\Delta x)^2}\left[T_{m+1,n}+T_{m-1,n}-2T_{m,n}\right]+T_{m,n} \quad \text{.......... (2)}$$

where m represents the change in x direction, n is change in time direction.

The boundary conditions are:

1. at x=0 , outer surface:

$$R_g+R_r+R_{sky}=K\frac{\partial t}{\partial x} \quad \text{.......... (3)}$$

in numerical form:

$$\frac{T_{m+1,n}-T_{m-1,n}}{2\Delta x}=R_g-R_r-R_{sky} \quad \text{.......... (4)}$$

2. at x= l, inner surface:

$$Q_{rin} = KA\frac{\partial t}{\partial x} \quad \text{.......... (5)}$$

since [2]:

$$Q_{r\,in} = h_{in}A(T_{s\,in} - T_{\infty}) \quad \text{.......... (6)}$$

Solving Eq.(5) and substituting Eq.(6) give:

$$h_{in}A(T_{m,n} - T_{\infty}) = K\frac{T_{m-1,n} - T_{m+1,n}}{2\Delta x} \quad \text{.......... (7)}$$

Both Eq.(7) and (4) are substituted in Eq.(2) to give the temperature profile of the roof for each position of x for any time.

Hence [2]:

$$R_{r} = R_{g}(1-\alpha) \quad \text{.......... (8)}$$

$$R_{sky} = \varepsilon\sigma A({T_{se}}^{4} - {T_{sky}}^{4}) \quad \text{.......... (9)}$$

$$T_{sky} = 0.0552T_{a}^{1.5} \quad \text{.......... (10)}$$

$$h_{co} = 5.7 + 3.8\upsilon \quad \text{.......... (11)}$$

3. Method of Solution

Various operating conditions are assumed, viz. the location (longitude to find local apparent time from standard time considering, latitude to find correction factor in cooling load calculation when checking the program), the roof construction details (K, cp, etc.) are listed in **Table (1)**.

The solution is implemented by starting from initial time say 06:00 o clock solving Eq.(2) with relevant boundary conditions eq.(4 and 7) by explicit F.D. method to find the temperature profile in the slab and hence the inside roof surface temperature(t_{si}) at every interval of time. Then the transmission cooling load through the roof Q_{ri} at every hour and the hourly load is stored from 06:00 a.m to 20:00 p.m.

The study is carried out for a roof at a hot climate in Baghdad, for the months of June and July 2003.

Table (1) Roof Material Properties

Material	K(W/m °C)	ρ Kg/m^3	Cp (kJ/kg °C)
Concrete	0.93	2200	0.653
Soil	0.328	1514	0.800
Roll asphalt	0.666	1120	0.03
Brick	0.6	1540	0.720
Concrete	1.4	2300	0.88
Plaster	0.4	1300	1.08

4. Results and Discussions

The study is carried out for two common types of roof in a hot and dry climate in Baghdad, Iraq n33 deg N, the properties of the roof materials are as shown in **Table (1)**.

The study is carried out for the months of June and July, the variation in global radiation and ambient temperature is shown in **Fig.(4)** and **(5)**.

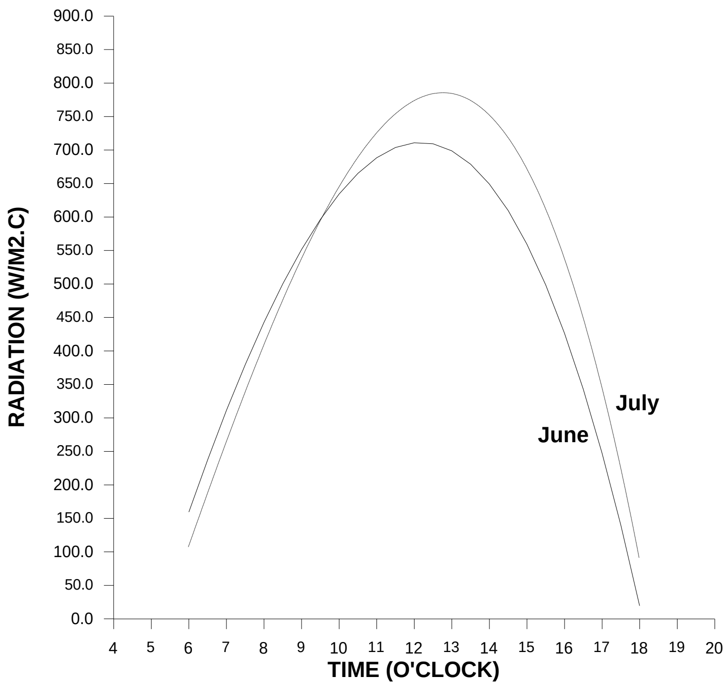

Figure (4) Solar Radiation vs. Time

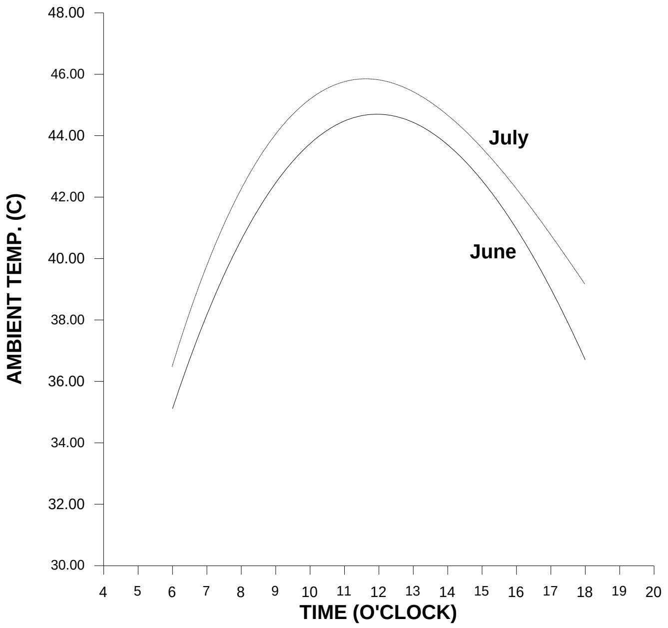

Figure (5) Ambient Temperature vs. Time

Compression between the experimental value (measured value) of the outside surface temperature and the theoretical value is shown in **Fig.(6)** and **(7)**,the small difference between these values because there is difference between the solar radiation [6], materials prosperities outside and inside heat transfer coefficient in the theoretical and experimental calculation. The computer program gives a good agreement with reference to actual value. **Figure (8)** shows the inside surface temperature variation during the day time.

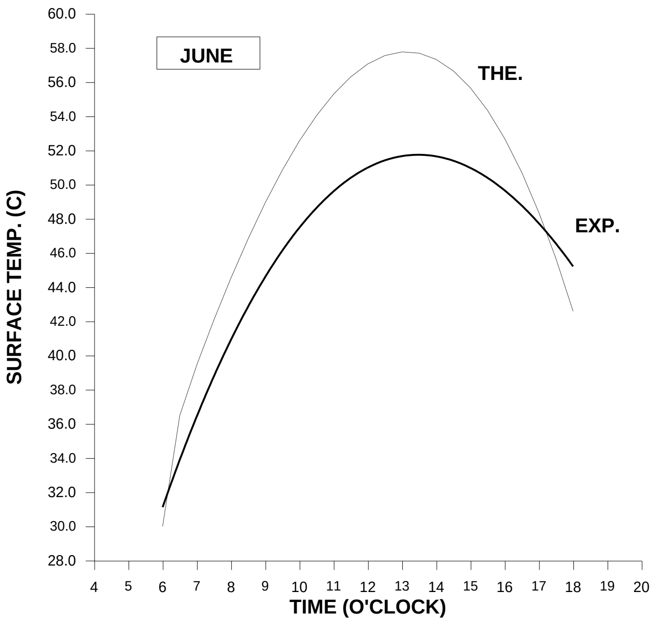

Figure (6) Outside Surface Temperature vs. Time in June

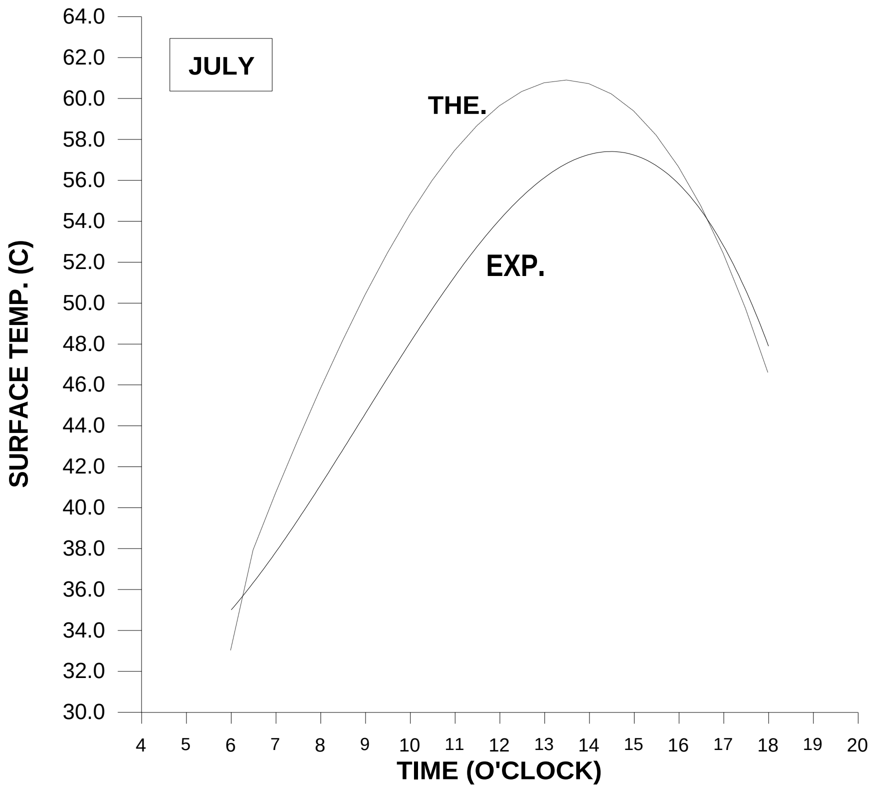

Figure (7) Outside Surface Temperature vs. Time in July

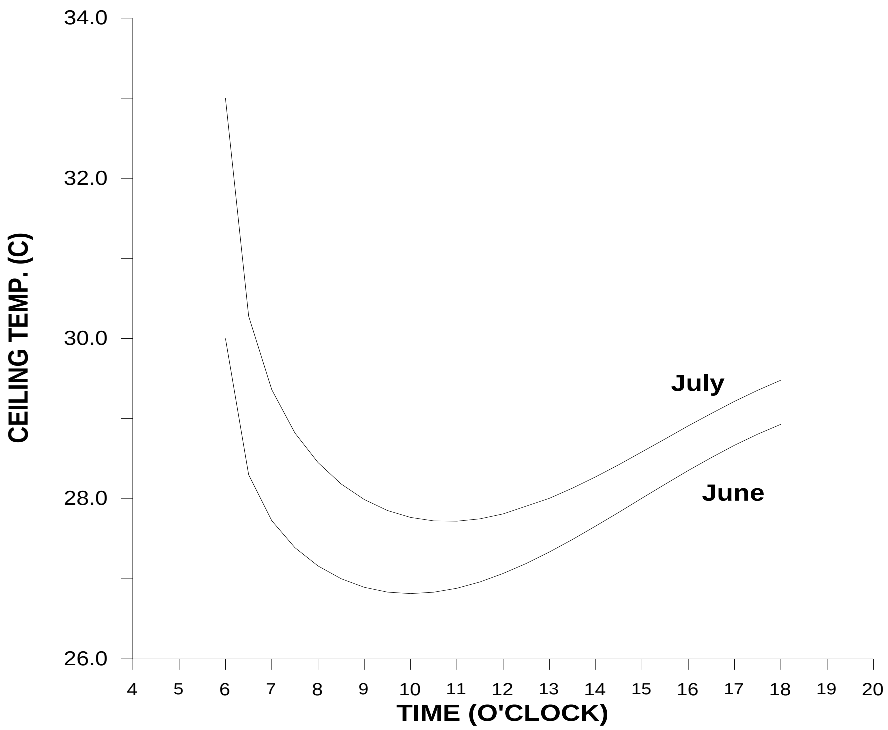

Figure (8) Inside Surface Temperature vs. Time

Finally, **Fig.(9)** and **(10)** illustrate the cooling load transmitted to the inside through the roof per unit area with day time variation for the months June and July for both types of roofs. **Figure (9)** shows the value of cooling load per unit area for the concrete type roof, **Fig.(10)** give the value of the load for brick type roof.

It seems that the solar radiation will be maximum value at the hour (12-14) while the load will be maximum value at the hour (14-16) because the roof will store apart of the heat passing through it.

5. Conclusion

Common roofs which are largely used in Iraq are studied in this paper. It helps the designer when calculating the cooling load through the roof because all the standards of air conditioning do not contain the CLTD value for these types of roofs. **Figure (9)** and **(10)** help the designer (cooling load designer) to get a direct value of load per unit area for the most two types of roofs which used in Iraq and in the worst conditions (June, July).

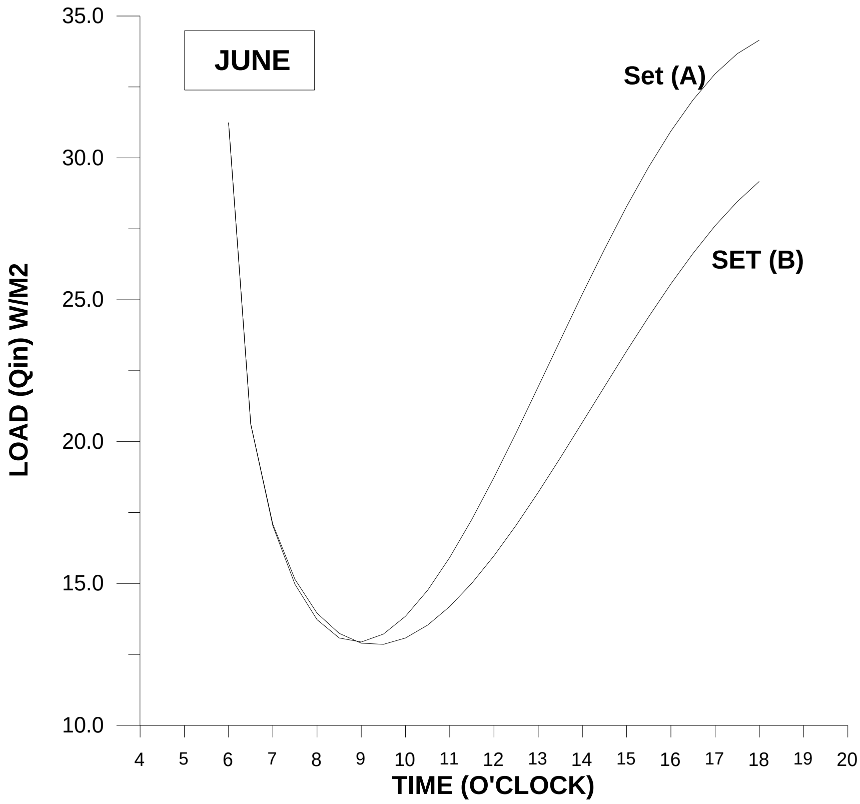

Figure (9) Cooling Load vs. Time (June)

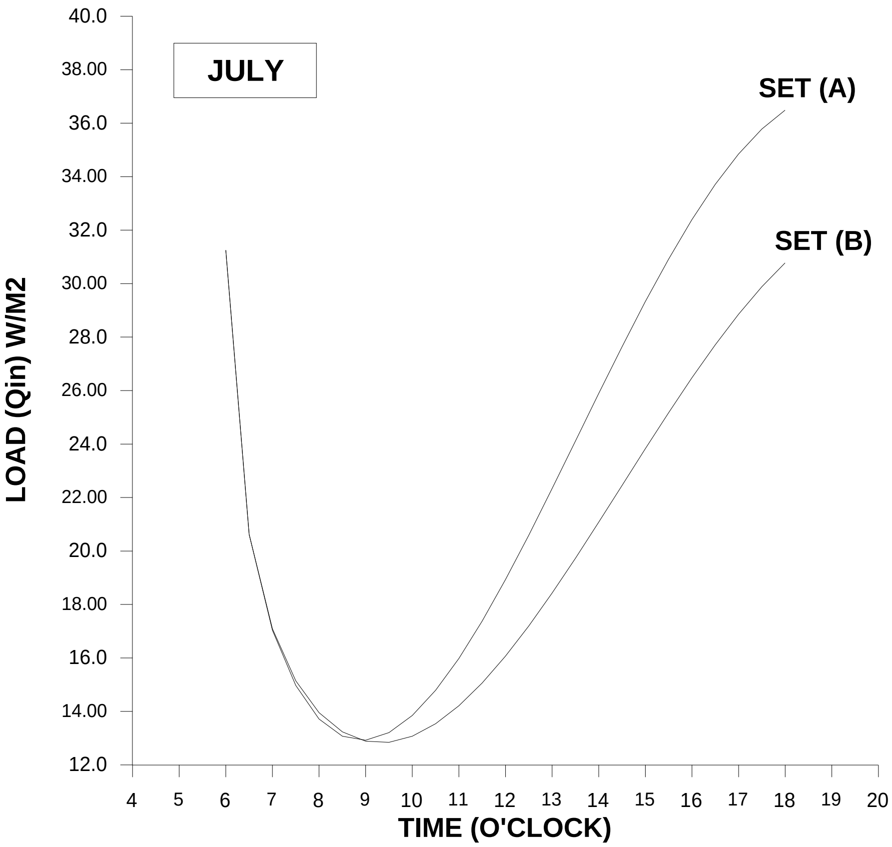

Figure (10) Cooling Load vs. Time (July)

6. References

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6. الأنواء الجوية العراقية.

Nomenclature

h_c = convective heat transfer coefficient W/m^2 ^{o}C.
h_{ci} = roof inside heat transfer coefficient W/m^2 ^{o}C.
h_{co} = roof outside heat transfer coefficient W/m^2 ^{o}C.
K = thermal conductivity W/m ^{o}C.
Q_{ri} = transmission cooling load through the roof W.
Q_{si} = heat stored in the roof per unit time W.
R_g = global radiation W/m2.
R_r = reflected radiation W/m2.
R_{sky} = sky radiation W/m2.
R_g = global radiation W/m2.
t = DBT of air ^{o}C.
t_r = roof temperature ^{o}C.
t_{se},T_{se} = t_r at external surface ^{o}C.
t_{si} = t_r at internal surface ^{o}C.
Tsky = sky temperature C.
X = roof thickness m.
α = absorptivity of roof, dimensionless.
ε = emissivity of the roof, dimensionless.
ρ = density of roof kg/m^3.
σ = Stefan-Boltzmann constant=5.669E-11 Kw/m^{2}K$^{4.}$

Abbreviation

CLTD : cooling load temperature difference.
TETD : total equivalent temperature deference.
ASHRAE : American society of heating refrigeration and air conditioning engineering.