COMPARISON OF COOLING LOAD CALCULATION METHODS BY TFM, CLTD & TETD WITH EXPERIMENTAL MEASUREMENTS

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ABSTRACT

The present work includes cooling load measurement in Iraq. One room located in Baqubah was the object of the study. The measurement was taken for the room in summer months of 2004 (i.e. in May, June, July, August & September). The area of test room was 15 m^2 and 3 m ceiling height with medium weight construction specifications. The test room includes exterior east and west wall facing, un-conditioning adjacent space with an exterior roof, east window and an exterior west door. The air conditioner unit used in this work was a window type with a nominal capacity of 2 T.R. (7 kW). The theoretical cooling load was predicted by three methods of cooling load calculation, which are TFM, CLTD/SCL/CLF & TETD/TA methods. Measurement of cooling load showed that there is a large difference between the measured and predicted cooling load with all theoretical methods. The difference ranged from 33% to 40%. This large difference is appear because of the several season such as the air conditioner type, suffer environmental and the construction specification of the test room where it's represent the Iraqi building and not exactly same as building specification tabulated in ASHRAE tables.

الخلاصة

‘يعنى هذا البحث بإجراء قياسات عملية لحساب حمل التبريد في العراق. غرفة الاختبار الواقعة في مدينة بعقوبة كانت مشروع الدراسة حيث أخذت القياسات خلال اشهر الصيف (أيار، حزيران، تموز، آب و أيلول). و كانت مساحة غرفة الاختبار ١٥م^{٢} مع ارتفاع ٣م للسقف مع مواصفات إنشاء ذات تركيب متوسط. تشمل غرفة الاختبار جداران خارجيان أحدهما مواجه للشرق و الآخر مواجه للغرب مع حيز مجاور غير مكيف مع سقف خارجي

و كذلك شباك مواجه للشرق و باب خارجية مواجه للغرب. و قد كانت منظومة التكييف التي لتبريد هذه الغرفة تم استخدام وحدة تبريد جدارية سعة ٢طن تثليج (٧كيلو واط). أجريت الحسابات النظرية لحمل التبريد بثلاث طرق لحساب حمل التبريد و هي طريقة دالات التحويل TFM وطريقة حمل التبريد من فرق درجات الحرارة (CLTD) بالإضافة إلى طريقة فرق درجات الحرارة الكلي المكافئ (TETD). أظهرت النتائج العملية لحسابات حمل التبريد للغرفة أن هناك فرق في الحمل كبير نسبيا بين النتائج العملية و النتائج النظرية و الفرق يتراوح بين ٣٣% إلى ٤٠%.

Key word: heat gain, cooling load, ambient temperature, sol-air temperature & infiltration

INTRODUCTION

Air-conditioning has been one of the more recent pursuits of man in his quest for a more comfortable existence. The primary purpose of an air-conditioning system, whether heating or cooling, is to maintain conditions that provide thermal comfort for the building occupants and conditions that are required by the products and processes within the space. Central heating systems were being developed in the Nineteenth Century while the development of comfort cooling systems began in the early Twentieth Century. Since then, progress in this direction has taken rapid strides with significant development in various areas of science and technology. Load calculations of the earlier days were based on the elementary steady state energy equation

$$q = U\,A\,\Delta T \qquad \ldots(1)$$

By the mid-1940s ASHRAE developed equivalent temperature differentials for exterior surfaces facing different directions for the worst exposure to sunlight, with values 20 to 40 degrees above the actual temperature difference between the outside and inside, and used them to calculate heat gains (Romine 1991). However, these heat gains were only instantaneous and considered the thermal storage only of these exterior surfaces in delaying the heat passage through them.

In 1967, ASHRAE introduced the Total Equivalent Temperature Difference/Time Averaging (TETD/TA) Method. This method, in addition to estimating the cooling loads due to convective heat gain from all sources, attempted to evaluate the cooling loads due to radiative heat gains (heat gains absorbed by the building's interior and later convected to the inside air) by a mathematical time-averaging of these radiant heat gains. This procedure, however, was only an approximation of the actual phenomenon of thermal lag.

Efforts to explain the phenomenon of thermal lag more accurately and incorporate it into load calculation methodology continued. (Mitalas and Stephenson 1967) developed the thermal response factor method for cooling load calculations. Later on, (Stephenson and Mitalas 1972) further developed their response factor approach by determining and applying the z-transform to problems in transient heat conduction. They obtained the z-transfer functions for various surfaces (roofs and walls) made up of several layers of different materials and subject to arbitrary variations of temperature. The work carried out by (Mitalas 1969) on energy requirements (the thermal response factor and transfer function methods) culminated in the development of the computer-oriented method which is now called the "TRANSFER FUNCTION METHOD". The Transfer Function Method, based on an extension of the response factor methodology, successfully interpreted the phenomenon of thermal lag and delayed cooling loads and first appeared in the ASHRAE Handbook (1972). The equations to calculate the heat gain and cooling load as follows: -

$$\frac{q_\tau}{A} = \sum_{n=0} \left(b_n T_{sol,\tau-n}\right) - \sum_{n=1} \left(d_n \frac{q_{\tau-n}}{A}\right) - T_R \left(\sum_{n=0} c_n\right) \quad \ldots(1)$$

$$Q_\tau = \left[v_o q_\tau + v_1 q_{\tau-1} + \ldots\ldots\right] - \left[\omega_1 Q_{\tau-1} + \omega_2 Q_{\tau-2} + \ldots\ldots\ldots\right] \ldots(2)$$

The mid-70s saw the development of the CLTD/CLF method for load calculation. This method, similar in some respects to the TETD/TA method, but with more extensive data calculated using the TFM. (Sowell and Chiles 1984) found that the CLTD/CLF data presented in the ASHRAE Handbooks of (1977, 1981 &1985) were based on the TFM using the weighting factors developed by (Mitalas 1967). (McQuiston and Harris 1988) performed a study to devise a method to group roofs and walls with similar transient heat transfer characteristics. The CLTD/CLF method is generally employed as a manual method for the calculation of cooling loads. Wall and roof CLTD are obtained by selecting a similar wall or roof type from the list given in the ASHRAE handbooks (1977, 1981 &1985). Advances in the computer industry since the early 80's have led to further changes in load calculation methods.

The objective of this study "Comparison of Cooling Load Calculation Methods by TFM, CLTD & TETD with Experimental Measurements ", have several objectives such as: -

1- Predicting the hourly & peak cooling load for room by TFM, CLTD /SCL /CLF & TETD/TA methods.
2- Measuring the cooling load for a test room conditioned by a window type air conditioner & Comparing the measured and predicted cooling load for test room in summer months of 2004 (i.e. in May, June, July, August & September).
3- Developing a programming model to give an easier method to predicted the cooling load for each of cooling load calculation method.

COOLING LOAD CALCULATION

Space heat gain by radiation is not immediately converted into cooling load. Radiant energy must first be absorbed by the surfaces that enclose the space (walls, floor, and ceiling) and the objects in the space (furniture, etc.). As soon as these surfaces and objects become warmer than the space air, some of their heat is transferred to the air in the space by convection. The composite heat storage capacity of these surfaces and objects determines the rate at which their respective surface temperatures increase for a given radiant input, thus governs the relationship between the radiant portion of heat gain and its corresponding part of the space cooling load. As shown in Fig. (1), the thermal storage effect is critically important in differentiating between instantaneous heat gain for a given space and its cooling load for that moment (Ashrae handbook of fundamentals 1997). Predicting the nature and magnitude of this elusive phenomenon in order to estimate a realistic cooling load for a particular combination of circumstances has long been a subject of major interest to design engineers.

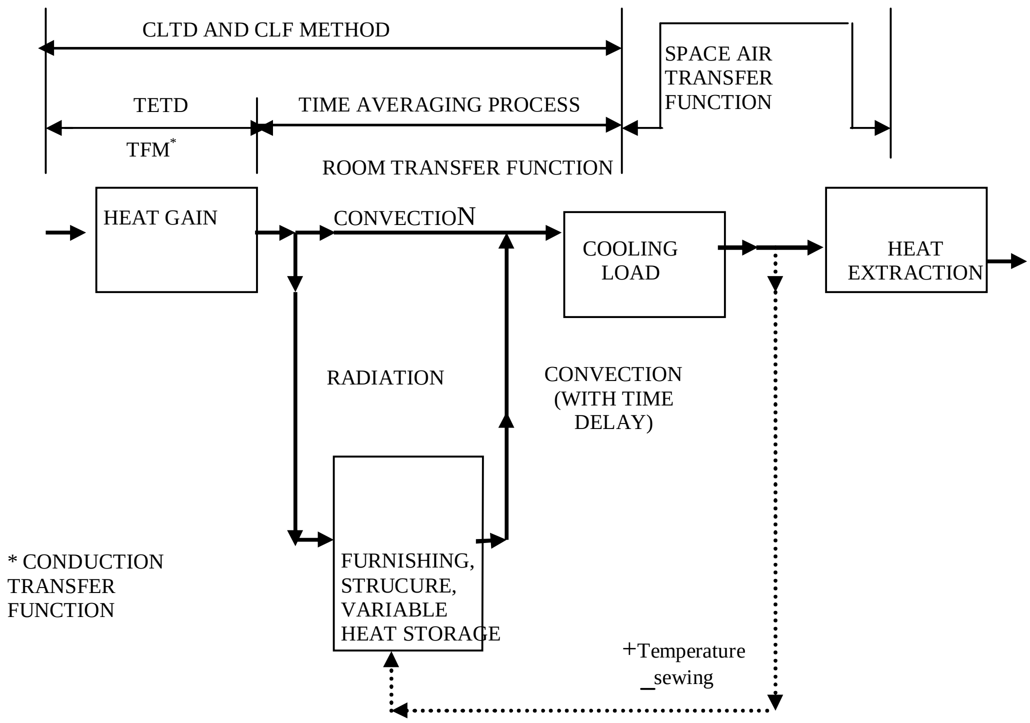


Fig (1) Origin of difference between magnitude of instantaneous heat gain and instantaneous cooling load.

EXPERIMENTAL VERIFICATION OF COOLING LOAD

Construction specification & location of the test room

The test room is of medium weight construction as detailed in table (1) where the medium weight construction is such as 100-mm Concrete exterior wall, 100-mm Concrete floor slab, and approximately 340 kg of material per square meter of floor area. It is of typical Iraqi brick and concrete roof construction. The room is 15 m^2 with a 3 m ceiling height. The room includes tow exterior walls, one exterior door, an east window and exposed roof, as shown in Fig. (2). The room was part of a government building located in Baqubah at 33.3 ^oN latitude and 44.1 ^oE longitude. Baqubah is approximately 60-Km northeast of Baghdad.

Air conditioning unit specification

The test room is equipped with a commercial, air-cooled, direct expansion, window type, 2 T.R. (7.0524 kW) air conditioner. The steady-state performance characteristics, consisting of net cooling capacity and total power input to the system as a function of outdoor dry-bulb temperature, were measured during the experimental days. A short duct was fitted to the discharge out let of the unit to facilitate measurement of airflow.

Steady-state performance

The energy consumption of the system depends on its cooling capacity, percent of time-on, and operation period, The performance characteristics of the air conditioner may be obtained from equation 3.

$$COP = \frac{\text{COIL COOLING LOAD}}{\text{POWER INPUT}} \ldots (3)$$

TABLE (1)

Structural & Energy Consumption Parameters of the test room

Parameter	Specification (from outdoor to indoor)
Roof Type, Color Construction Ceiling height Roof area	 Flat, light (40-mm) high density concrete shtyger. (70 mm) dry sand. (150-mm) high density concrete. (10 mm) juss plaster (3 m) (3*5 = 15 m^2)
Wall Color Construction Wall area	 Light (15 mm) cement plaster (240 mm) common brick (15 mm) juss plaster (north 15 m^2, south 15 m^2, east 7.9 m^2 & west 7.2 m^2)
Glazing Window area Type	 (1.1 m^2) East face (3 mm) clear type

Internal Loads People Lighting	 2 adults (2 Fluorescent + 2 Tungsten)
Appliances	None
Indoor room temperature	26 ^{o}C dB & 50% relative humidity
Air Conditioning system	Air cooled, direct expansion & window-type manufactured by General company.
Nominal cooling capacity	2 T.R (7.0254 kW)
A/C Thermostat	on-off with 2 ^{o}C range
Infiltration air	32 *l*/sec

EXPERIMENTAL PROCEDURE

At the beginning of the experimental program the air conditioner was started up in 6 a:m and the data was recorded directly thereafter. It was noted that the cooling load was specifically high in the morning hours because of the storage effect. After 5 hours the test room reached near steady state condition and the cooling load followed normal variation. This did not depict the actual hourly change of the cooling load. Therefore, the a/c unit was nearly 8 hours ahead of the experimental measurement where by the test room reached approximately steady state condition and lost its stored heat. The time required to eliminate the storage effect from the test room depends on the out door conditions and building characteristics. Normal conditions were reached after 6-10 hours from start up. The averaging indoor temperature was approximately 26 ^{o}C & 55% relative humidity during the experimental tests to maintain comfort conditions in the test room. The fluctuation of the indoor temperature was $\pm$ 1 to $\pm$ 1.5 ^{o}C. The thermal cooling capacity of air conditioner was determined by measuring the velocity & temperature of the air across the evaporator. The following equation was used to calculate the capacity of air conditioning.

$$Q_{coil} = \dot{m}\left(h_2 - h_1\right) \qquad \ldots(4)$$

where the h_1 & h_2 are the inlet and out let of evaporator in A/C and that is by measuring the dry and wet bulb temperature.

To calculate cooling load for test room with on-off control conditioner, we need to measure on-time per hour of the unit, The cooling load for the test room is obtained by the following equation for 1 hour period of operation.

$$Q_{room} = Q_{coil} * \frac{\text{on time}\,(\text{min})}{60\,(\text{min})} \qquad \ldots(5)$$

The hourly experimental measurements of out door and indoor temperatures were required as input data to calculate the cooling load theoretically.

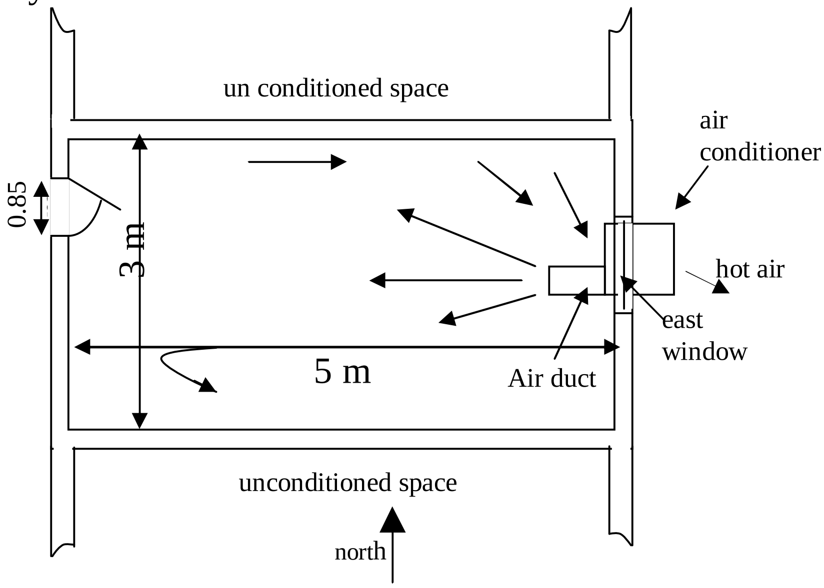


Fig 2 Test room plan with window type air conditioner (a ceiling fan to insure good space air circulation).

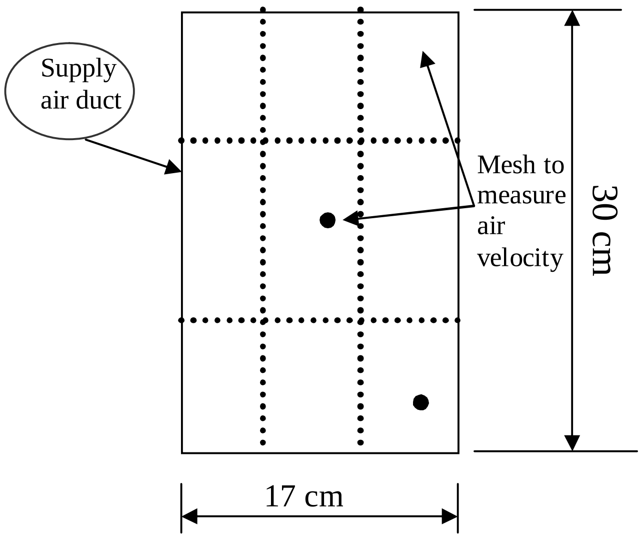


Fig. 3 Mesh at outlet air duct to measure the air velocity (not to scale).

RESULTS AND DISCUSSION

Predicted & Measured Cooling Loads

The prediction of cooling load for the test room was calculated for recommended days of summer months, by each of three methods of cooling load calculation TFM, CLTD/SCL/CLF & TETD/TA methods respectively. Fig. 4 shows the hourly distribution of ambient temperature for recommended days of 21/May, 21/June, 21/ July, 21/August & 21/September of 2004.

Figs. 5 show the effect of orientation on the incident solar radiation for typical days in the summer months. These curves are theoretical values for clear sky conditions. It is evident that the peak values of irradiant of the five orientations occur at different times. East orientation is a mirror image of the west orientation with an 8 hour difference between peak values. It can be seen that the horizontal (roof) orientation has the highest peak value among the other orientations. East and west facing walls has the highest peak value for walls. Therefor, large glazing areas in east and west orientation should be avoided to reduce the cooling load.

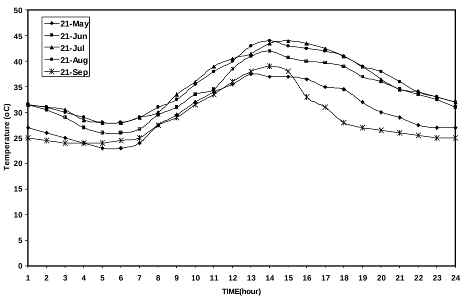
The combined effect of ambient temperature and solar radiation on walls appears in the sol-air temperature as shown in Figs.6 Although, the solar radiation for east and west orientations has equal maximum, the sol-air temperature profile of a west facing wall shows a higher peak than the east and other orientations. The reason for this is the fact that the sol-air temperature depends on the ambient temperature as well as the incident solar.

The measurements for each month were taken as the average of three test runs in that month. At the beginning of experimentation the measured cooling load was taken as soon as the air conditioner was started-up, Such measured values are shown in Fig. 7. The cooling load in this figure represents the current load for test room plus the stored heat from the previous day. This of course does not reflect a true picture of the actual cooling load variation. The storage effect must be eliminated before measured values can be truly said to represent actual cooling load values. Therefor, in the subsequent experiments the a/c was started-up one day ahead of time to eliminate the storage effect. Results thus obtained are shown in Figs. 8. The comparison of the practical results with predicted results show a large difference about 36%, 33% & 40% between measured and predicted cooling load values by CLTD/SCL/CLF, TFM & TETD/TA respectively as shown in Figs. 9. From the calculations of cooling load by different methods we can note that, the difference between CLTD/SCL/CLF & TFM is about 3% .

The results of experimental cooling load measurement for the summer months for the test room are shown in Fig .10. The peak load appears to occur in July and August for the season of 2004.

Measurement of a/c coefficient of performance.

The coefficient of performance of the experimental air conditioner is shown in Fig. 11. The measured COP values for the conditioner was taken at steady state conditions of operation. The results show that the minimum COP occurs about 11:00 am.



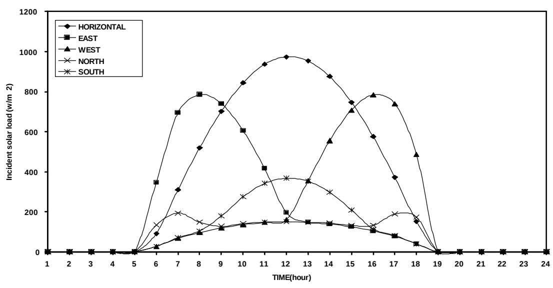
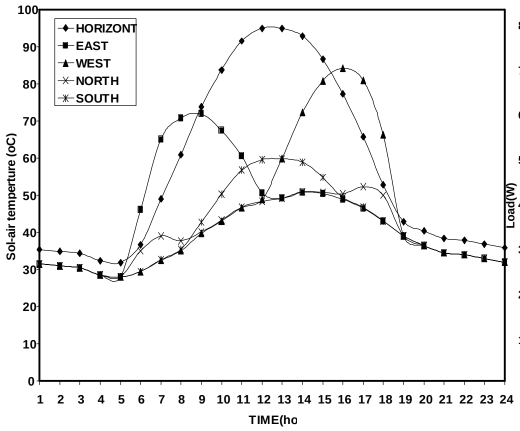


Fig. 4 hourly distribution of ambient temperature in summer season of 2004.

Fig 5 Hourly irradiant distribution for various orientations in 21/July.



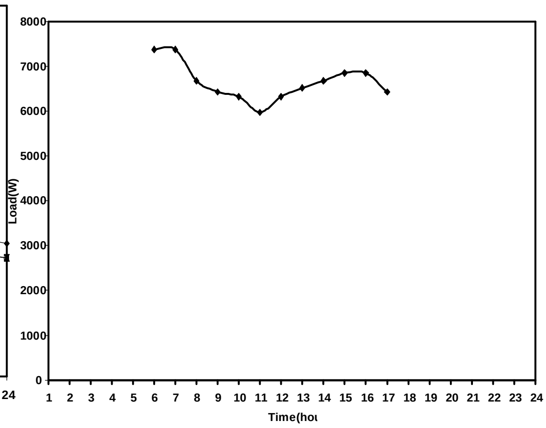
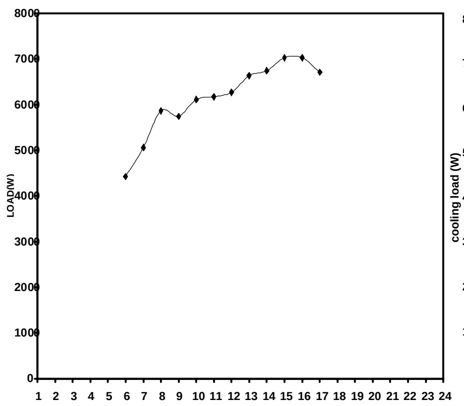


Fig.6 Hourly variation of sol-air temperature of dark colored surfaces for various orientations

Fig 7 Measured cooling load with storage in 21/July effects in18/July/2004.



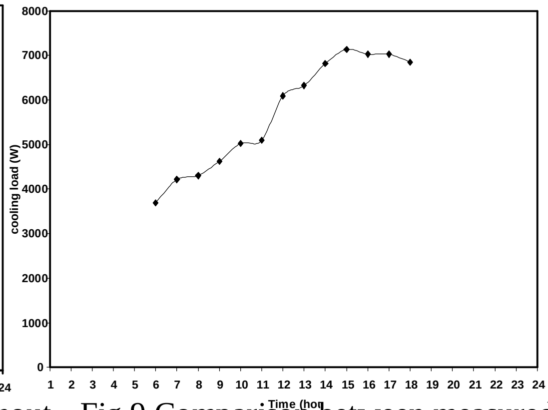
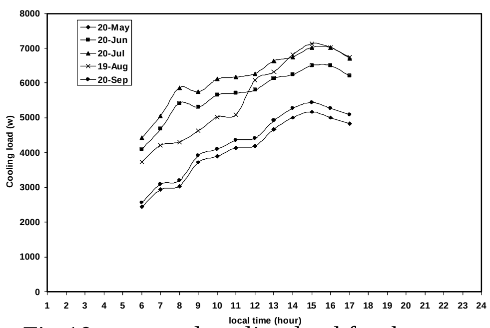


Fig 8 Measured cooling load without storage effect in 20/July/2004.

Fig 9 Comparison between measured and calculated cooling load in 20/July/2004.



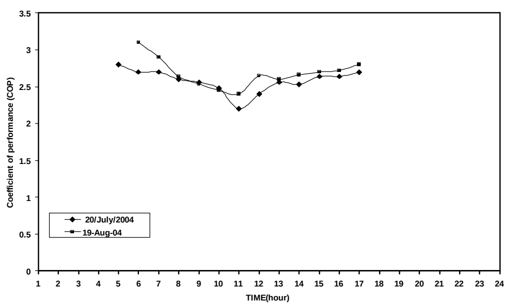


Fig 10 measured cooling load for the test room in 20/May, 20/June, 20/July, 19/August & 20/September of 2004.

Fig. 11 Measurement of COP for the air conditioner in 20/July & 9/August.

CONCLUSIONS

From the results obtained for the experimentally determined cooling load and the predicted load by the TFM, TETD/TA & CLTD/SCL/CLF methods, the following conclusions can be deduced.

1- The difference between theoretical and practical results is partly large and that deduce because the construction specification do not match ASHRAE tabulated specifications.
2- The comparison of the practical results with predicted results are about 36%, 33% & 40% between measured and predicted values of cooling load by CLTD/SCL/CLF, TFM & TETD/TA respectively
3- Peak cooling load doesn’t take place at the maximum ambient temperature because of the transient storage effect and because the peaks of cooling load components occur at different times.
4- The inertia or storage effect of the space structure reduces the instantaneous cooling load and increase the time lag between peak heat gain and peak cooling load.
5- The maximum peak and daily total loads occurred on July & August, and the minimum load is in May

NOMENCLATURE

A	Heat transfer area	m^2
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers.	
$A_o, a_1, \ldots$	Coefficients of the numerator of the z-transfer	
$B_o, b_1, \ldots$	Coefficients of the denominator of the z-transfer	
b_n	Coefficient for the transfer function method	
c_n	Coefficient for the transfer function method	
CLTD	Cooling Load Temperature Difference	
CLF	Cooling Load Factor	
COP	Coefficient Of Performance	
Δ	Sampling interval of the z-transform	

HVAC	Heating Ventilating and Air Conditioning	
h_1,h_2	Enthalpy	KJ/Kg
$\dot{m}$	Mass flow rate	Kg/s
Q_{coil}	Coil cooling load	KW
Q_{room}	Room cooling load	KW
TFM	Transfer Function Method	
TETD	Total Equivalent Temperature Differential	
TA	Time Average	

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