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Hourly Cooling Load Assessment Utilizing Three Different Methods for a Full Day

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Abstract

Human beings are facing an unprecedented rise in temperature rates not recorded for years. HVAC (heating, ventilation, and air conditioning) systems have been created and enhanced to solve this issue.
Cooling load must be estimated with accepted methodologies before designing an efficient and effective air conditioning system. Companies, researchers, institutions, and others advise and develop many cooling load calculation methods. Each one of these methods has its advantages and disadvantages and may give a slightly different result for the same case. For each building, whether it was residential or commercial buildings, gyms, or shopping malls, before making the decision on (HVAC) systems to be used, both heating and cooling loads should be obtained as correctly as possible to minimize expenses as possible. Since the HVAC system consumes the most energy in an air-conditioned building, an accurate method of cooling load estimation is necessary. Consequently, an energy-efficient air conditioning system reduces greenhouse gas emissions into the atmosphere while also saving money on electricity.
Two cases have been compared and studied, one in Dubai UAE, and the other in Baghdad Iraq. Three different methods, HAP, hand calculation method (CLTD/SCL/CLF), and MS-EXCEL E20 form sheet were used to compare the accuracy of the results for cooling load.
Results of E20 and HAP are very close to each other with high accuracy for peak load, the big difference can be found between the CLTD method and the other two methods. The value of the maximum difference percentage was found between CLTD and E20 equals 3.28% and 7.96%, on the other hand, the lowest difference was equals to 0.3% and 1.51% between HAP and E20 results for Baghdad and Dubai respectively. Traditional and local materials came from local factories, used in buildings played a big effect on the results, which may not match those materials stated in the ASHRAE or CARRIER tables, which need to be considered in the results and calculation procedure. However, all methods have a percentage of difference but all results are within the accepted range and are applicable for practical cases. Of course, this percentage is minimal with some methods and maximum with others.

1. Introduction

Cooling of structures such as buildings, gyms, wedding halls, malls, and so on, currently represents an important amount of the world's gross energy usage. In Iraq, the building industry consumes around (38%) of the overall energy generated from electricity [1]. Each space requires a certain degree of conditioning to be comfortable, and obtaining that degree of comfort is entirely contingent on having the appropriate size of air conditioning equipment. Many problems might arise when the heating or cooling system does not meet the needs of your space. Some of these are uncomfortable indoor conditions, reducing the system's life cycle and overloading it, insufficient efficiency, and wasting money on electricity bills.

At present, air conditioning manufacturing is a major business sector. The most important goals are to improve air conditioning system efficiency and building energy performance.

It is known that the more accuracy followed in estimating the cooling load of the construction envelope during the year, the more energy can be conserved. Understanding which strategies provide the optimum cooling impact is critical. Comparing the outcomes of various approaches can help achieve this objective. Over the past several years, numerous techniques have been created and applied for this purpose.

ASHRAE issued five methods for computing building cooling requirements to date: the Total Equivalent Temperature Difference/Time Averaging (TETD/TA) method, the Transfer Function Method (TFM), the Cooling Load Temperature Difference/Solar Cooling Load/Cooling Load Factor (CLTD/SCL/CLF) method, the Heat Balance Method (HBM), and the Radiant Time Series Method (RTSM) [2], [3].

In 2005, Al-Badree and Joudi compared cooling load values from three distinct approaches, which are TFM, CLTD/SCL/CLF and TETD/TA methods and experimental readings. The study case was a single room in Baqubah northeast of Baghdad. The air conditioner employed was a window-mounted unit having a capacity of 2 T.R.

The comparison showed a big difference between calculated and measured values. The difference ranged from 33% to 40%. This large difference appeared due to several reasons but the most important one is that the construction specification of the test room where it's represents the Iraqi building and not the same as the building specification tabulated in ASHRAE tables [4].

An attempt was carried out by Joudi and Hussien in 2015 to create specifications for Iraqi wall and roof structures using ASHRAE's Radiant Time Series (RTS) cooling load estimation technique. Verification has been done experimentally using previously constructed air conditioning space in Baghdad by field measurements. The findings indicated extremely similar values that did not exceed the 9.3% difference [5].

In their study in 2017, Khakre et al. compared the manual calculation results using CLTD with those coming from HAP 4.5 for multistore building in India to find out the availability of replacing high energy air conditioners with an evaporative cooling system. A discrepancy was seen between the two calculation methods since HAP provides a weighted average value, while manual calculations take into account the highest value of the day [6].

A comparison between cooling load results obtained by a written code computer program and HAP was done in 2018 by Zaphar and Sheworke. The present software is based on Visual Basic 6.0 and MS Access. Visual Basic is the programming language and MS Access is the database system. The results of both methods show very close values equal to 98.1% matching [7].

A study by Al Abir in 2019 showed the difference in obtained values from two different calculation methods using hand calculation CLTD with the help of MS-Excel E20 form and HAP to choose the ideal (HVAC) system in a building situated in Bangladesh. The difference in the results between both methods is not more than 1.2 %.

The total cooling load calculated for the Air conditioning system by hand calculation shows 0.99 TR and the total cooling load gained from HAP programs is 1 TR, which satisfies the result [8]. In their research, in 2019, to find the exact value of cooling load, Al Harbi et al. made a study case for Al Fahad Mosque located in K.S.A. to estimate the specification of the air conditioning system. Two different methods, HAP and E20 manual method, have been compared with the market approximation method which gives under or over the actual requirements for comfort conditions.

The results showed a difference between E20 and HAP of about 8.8 % while between E20 and market calculations was 23.5 %. The disparity in findings between the E20 approach and HAP was because HAP used random data, but E20 implemented information from the recommended ASHRAE Handbook that was correct for the location. The HAP data were approximate. While in E20, accurate values were calculated. As a result, HAP may require fewer tons of refrigeration (TR). However, both methods E20 and HAP can be used with an acceptable range of the required cooling load. The market method was not advised because of the big gap in results between the market method, E20, and HAP [9].

Ashiq et al. made use of cooling load temperature difference CLTD for calculating the cooling load required for an auditorium during 2021. The results were legitimized using an hourly analysis program (HAP) and Trace 700 software. The outcomes obtained from CLTD and software are approximately equal, the dissimilarity in results is due to approximation. Differences between the results of the two programs, HAP and TRACE software, are within a 10% range [10].

A study to use both the traditional approach (by Cooling Load Temperature Difference Method) and the hourly analysis program HAP to verify calculated values of cooling load. Saragasan et al. conducted this investigation and published it in 2021. A comparison was made based on the analyzed cooling load using the HAP, the chillers' maximum cooling capacity, the chillers' 80% cooling capacity, and the CLTD technique. Chillers typically operate at 80% of their maximum capacity owing to energy loss.

The Hourly Analysis Program yielded 3,275,100.00 BTU/hr., whereas the chiller produced 4,200,000.00 BTU/hr. The HAP findings showed a 77.9% efficiency; hence the chiller is suitable.

There was a about 5.79% difference between the HAP and CLTD approaches. More cooling load is needed for the CLTD than for the HAP method. Results from the CLTD approach exceeded 80% of the chiller's capacity [11].

Isa and Sies computed the cooling load for Atrium shopping mall in Batu Pahat, Johor. The goal of this study is to calculate the cooling load with the Hourly Analysis Program (HAP) software and the E20 Spreadsheet.

The results reveal that the overall cooling loads for two distinct approaches are identical. The largest variation in total cooling load between E20 and HAP software is 2.3%. The outcomes of manual and HAP calculations are somewhat different. The cooling load variation between the E20 and HAP values was 7.8% [12].

To investigate the accuracy of cooling load computation resulting from three different approaches which are the manual approach (Cooling Load Temperature Difference Method), hourly analysis program (Transfer Function Method), and MS E-20 worksheet.

To discover the pattern of the curve profile of the required cooling load not for a single value but for all the day hours. Finding the differences between the maximum load and its hour for the three different methods for two different cases.

The most important part of this study is that it does not focus on a single value of the result, minimum or maximum, the resulting values of cooling load from three different methods for 24 hours of the day considering all important parameters relative to cooling load values are obtained and all Advantages and disadvantages of each technique are cleared and discussed.

2. Building location

This study has considered two different cases in two different countries and climates. The first room was in Dubai UAE (Lat:25.255N and Long:55.364E) and the other one was in Baghdad Iraq (Lat:33.267N and Long:44.233E). These two countries are famous for high temperature and humidity ratios. Both countries' climate parameters can be found in ASHRAE climatic design conditions [13].

The hottest and most humid day in summer is considered when calculating the cooling load for each case. These values for both countries and cities are summarized in Table 1.

The parameters for indoor design conditions are listed in Table 2.

Table 1. Baghdad and Dubai outdoor conditions.

Baghdad		Dubai	
Dry bulb temperature (°C)	49	Dry bulb temperature (°C)	42
Wet bulb temperature (°C)	25	Wet bulb temperature (°C)	24
Relative humidity	13.7 %	Relative humidity	24 %
Humidity ratio (kg/kg dry air)	0.0101	Humidity ratio (kg/kg dry air)	0.0125

Table 2. indoor conditions.

Dry bulb temperature (°C)	26
Wet bulb temperature (°C)	18.7
Relative humidity %	50
Humidity ratio (kg/kg dry air)	0.0105

For the evaluation of all necessary indoor and outdoor conditional parameters using an Online Interactive Psychrometric Chart [15]. Fig.1 and 2 show the space's floor plan details under the present study with details and dimensions.

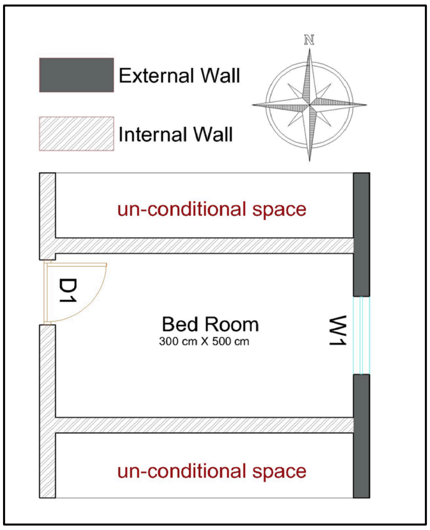

Fig. 1 Baghdad room floor plan.

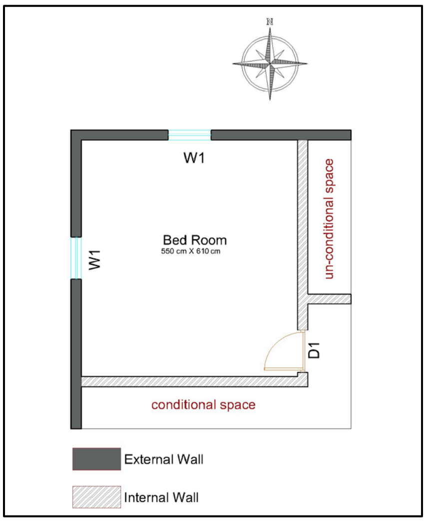

Fig. 2 Dubai room floor plan.

3. Construction specification of the building

In our calculation procedure finding the cooling load to use ASHRAE tables and determining the overall heat transfer coefficient, whether using HAP software or hand calculating method, the materials specifications and construction details of the roof and walls for each building should be known.

The construction specifications and properties for the building space under study are detailed in Tables 3 and 4 for the Baghdad and Dubai cases respectively. The medium weight construction has been considered in the study.

Table 3. Space construction components and materials for Baghdad.

Roof	Flat
	Light
	40 mm High density concreter Shtyger
	70 mm Dry sand
	150 mm High density concrete
	10 mm Juss plaster
Glazing	Type 6 mm thickness clear type no shading
Wall	Medium
	15 mm Cement plaster
	240 mm Common brick
	15 mm Juss plaster
Internal loads	Two adult people
	Lighting 2 Fluorescent and 2 Tungsten

Table 4. Space construction components and materials for Dubai.

Roof	Flat
	Light
	9.525 mm Plywood
	152.4 mm Batt insulation
	12.7 mm Gypsum Plaster
	9.525 mm Built up roofing
Glazing	Type Double glazing glass Shaded
Wall	Medium
	12.7 mm Asphalt sheeting
	203.2 mm Low weight concrete block
	50.8 mm board insulation
	101.6 mm Common brick
Internal loads	Two adult people
	Lighting 2 Fluorescent and 2 Tungsten

Tables 5 and 6 list the resulting values of overall heat transfer coefficients for the Baghdad and Dubai cases, respectively.

Table 5. Overall heat transfer coefficient from HAP program (W/m^2. K) for Baghdad case.

Roof	1.686
Wall	1.834
Floor	2.153
Partitions	1.647
Window	6.975
Door	3.290

Table 6. Overall heat transfer coefficient from HAP program (W/m^2. K) for Dubai case.

Roof	0.255
Wall	0.283
Floor	0.568
Partitions	1.647
Window	1.703

Comparing these values against the approved ones set out by the Republic of Iraq's Ministry of Construction and Housing and Municipalities and Public Works, and Dubai Building Code 2021. The values were within the accepted range [16], [17].

Note that the combination of roof and wall is chosen to match the allowed range of overall heat transfer coefficient for the country governor's allowed values. In all calculation methods used in this research, the same values of conductivity and overall heat transfer coefficient have been considered to be equal.

4. Cooling load calculation methods

Through years of studies and research by companies and individuals, cooling load calculation methods face complexity versus accuracy. This means that as the method's accuracy increased its complexity increased too, according to those three major divisions:

- Manual Methods suited for hand calculation are simple with low accuracy.
- Simplified Computer Methods allow more complexity and give more accurate results but still use simplicity which limits the accuracy of results.
- The first approach for calculating load was the heat balance method, all other methods are a simplification of this method.

The following are the most well-known and commonly utilized methods:

1. Total Equivalent Temperature Difference/Time Average (TETD/TA).
2. Cooling Load Temperature Difference/Cooling Load Factor (CLTD/CLF).
3. Transfer Function Method (TFM).
4. Heat Balance (HB).
5. Radiant Time Series (RTS).

Regardless of the technique employed to ascertain the cooling load of a zone, structure, home, business, etc., the cooling load falls into the following categories, according to their origins:

- Heat emitted by the walls and roof of the building due to the difference in temperature between the outside and inside areas.
- Heat uptake from the sun by means of radiation through transparent materials like glass.
- Heat gains produced internally by people, lights, appliances, and equipment.

Heat gains because of ventilation or outside air penetration.

4.1. E-20 MS sheet

The System Design Manual for Carrier was the source of the E-20 moniker. A fundamental engineering work and the first stage in assessing and choosing HVAC equipment, the Engineering Form E-20 was primarily used to determine peak cooling and heating loads for buildings in the 1960s. [18]

Carrier handbook manuals, load estimating part 1 [19] was used with E-20 to fulfill all required parameters from reference tables.

4.2. CLTD/CLF method

The CLTD/CLF approach is the most practical way to calculate cooling load manually. The heat that Should be withdrawn from the zone to preserve a comfortable environment for occupants is called cooling load. This load consists of two parts external and internal. In the following approach, appliances, motors, and machines were not accounted for.

4.2.1. External loads

The components that comprise external cooling loads consist of:

1. Sensible loads pass across transparent envelope compounds such as walls, floors, and roofs.
2. Sensible loads across translucent envelope assemblies (glazing, windows, skylights, etc.)
3. Sensible loads pass through infiltration and ventilation (leakage of air)
4. Latent loads resulting from infiltration and ventilation.

Each one from the above quantities would be calculated using a different equation and parameter as follows [20]:

A. Roofs, External Walls, partitions, and Conduction through Glass

$$Q = U \times A \times (CLTD)_{\text{cor}} \quad (1)$$

When conditions are different from those in ASHRAE tables, the values of *CLTD* in the table must be rectified before being used in heat transfer equation. To find $CLTD_{cor}$ use the equation below:

$$CLTD_{cor} = CLTD + (78 + T_i) + (T_{om} - 85) \quad (2)$$

$$T_{om} = T_o - \frac{DR}{2} \quad (3)$$

B. Solar Load through Glass

$$Q = A \times SHGC \times SC \times CLF \quad (4)$$

C. Partitions, Ceilings & Floors

$$Q = U \times A \times (T_a - T_i) \quad (5)$$

Lower the outside air temperature to less than 5 °F if there is no air conditioning in the next space.

D. Ventilation and Infiltration Air

$$Q = 4.5 \times CFM \times (h_o - h_i) \quad (6)$$

4.2.2. Internal loads

In the presence study the accounted internal load forms are:

1. Sensible and latent loads from humans.
2. Sensible loads from lights.

The following equations will be used in estimating internal load values [21]:

A. People or occupants

$$Q_{sensible} = N \times Q_s \times CLF \quad (7)$$

$$Q_{latent} = N \times Q_L \quad (8)$$

B. Lights

$$Q = 3.41 \times W \times F_{UT} \times F_{BT} \times CLF \quad (9)$$

While performing the manual calculations, equations (1) to (9) are calculated by utilizing the information presented in the 1997 ASHRAE Handbook of Fundamentals [20]. *U*, *CLF*, Q_s, Q_L, *CLTD*, *CFM*, *SHGC*, and *CLF* were obtained from reference [22].

4.3. Hourly analysis program software HAP 5.1

Beginning in 1987, the first version of HAP was available to engineers and interested people in the HVAC field. Nowadays there are 14 revisions of the program with different methods and strategies to estimate cooling loads, starting with CLTD technique in the first revisions and ending with the energy balance method in the last revisions.

HAP is a computer tool that assists engineers in designing HVAC systems for commercial construction. HAP combines two tools in one.

First and foremost, it is a load estimation and system design tool. Additionally, it may be used to simulate energy usage and expenditures. In this study we used HAP 5.1 international edition, this revision used TFM in calculating cooling loads.

For each heat gain component in a room, the Transfer Function Method determines a general mathematical connection that describes load as a function of heat gain and time. The loads for each hour are then rapidly calculated using this relationship. A room transfer function equation, which looks like this, is how the mathematical connection is expressed [23]:

$$Q_0 = v_0 q_0 + v_1 q_1 + v_2 q_2 + \ldots - w_1 Q_1 - w_2 Q_2 - \ldots \quad (10)$$

In this equation:

1. Q represents a load. The subscripts refer to specific points in time. Subscript 0 is the current hour, 1 is the previous hour and 2 is two hours previous.
2. q represents a heat gain. The subscripts 0, 1 and 2 have the same meaning as for loads.
3. v_0, v_1, v_2, w_1 and w_2 are transfer function coefficients. Values of these coefficients vary for each type of heat gain and room due to the different heat transfer processes involved in converting each kind of heat gain into a load. ASHRAE has published tables of these coefficients for different heat gain components, room types, and building weights.

5. Results and discussion

Understanding and explaining the results would be easier considering the results of Mohamed and Ahmed [24], [25].

Fig. 3 and 4 show the interface of the HAP program for Baghdad and Dubai respectively.

The results are shown in Fig. 5 and 6 for Baghdad and Dubai cases respectively. The difference in drawings of results between Dubai and Baghdad is due to differences in Longitude and latitude, wall and roof construction, direction of orientation, and outdoor conditions.

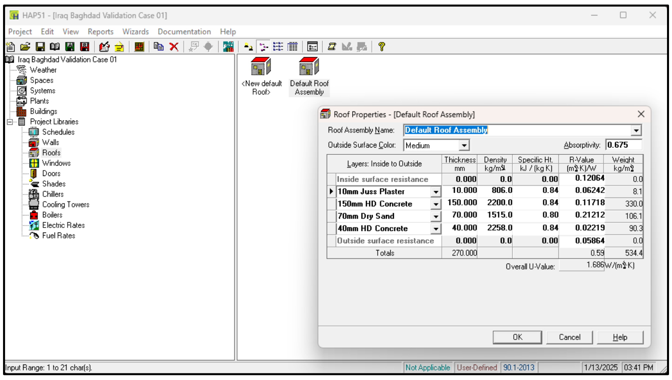

Fig. 3 Baghdad case HAP interface.

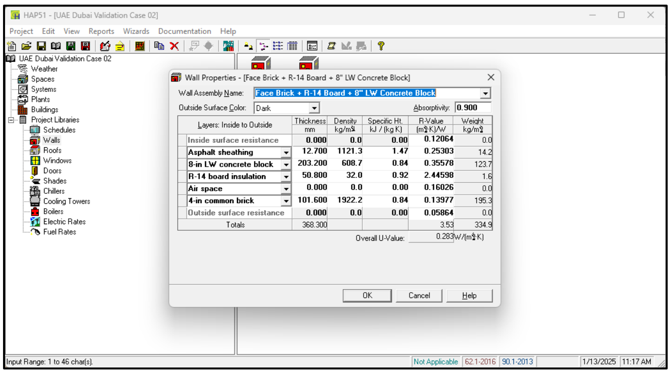

Fig. 4 Dubai case HAP interface.

All methods produced the same profiles for cooling load but with different values at the same day hour. These strategies may provide diverse outputs from similar input data. This is largely due to the manner in which each strategy addresses the solar influence and building dynamics. However, all of the systems discussed above aim to take into account the essential fact that heat flow rates do not occur instantaneously translated to loads, and heat adding or removing incidents on the structure do not instantly result in a temperature difference.

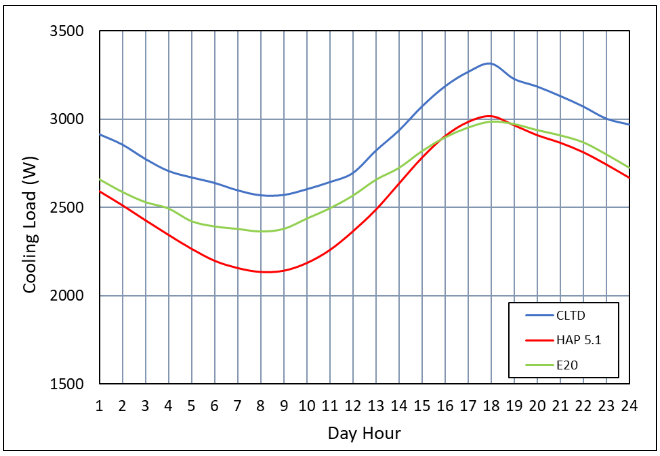

Fig. 5 Baghdad case results.

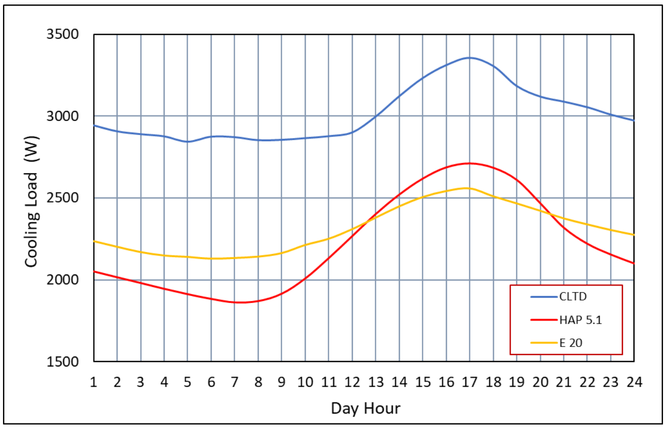

Fig. 6 Dubai case results.

Considering the values of the obtained cooling load for both cases and all three methods at 06:00 PM as the maximum load for Baghdad case and 05:00 PM for Dubai case, the results can be shown in Fig. 7 and 8, while the percentage difference for both Baghdad and Dubai cases is listed in Table 7.

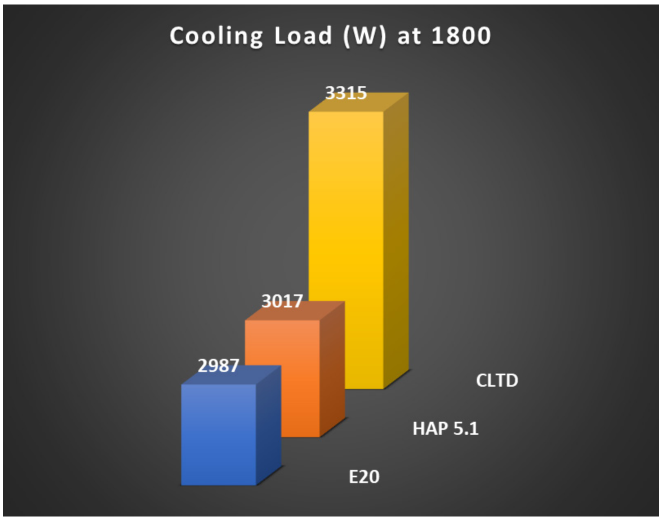

Fig. 7 Baghdad cooling load results at 06:00 PM.

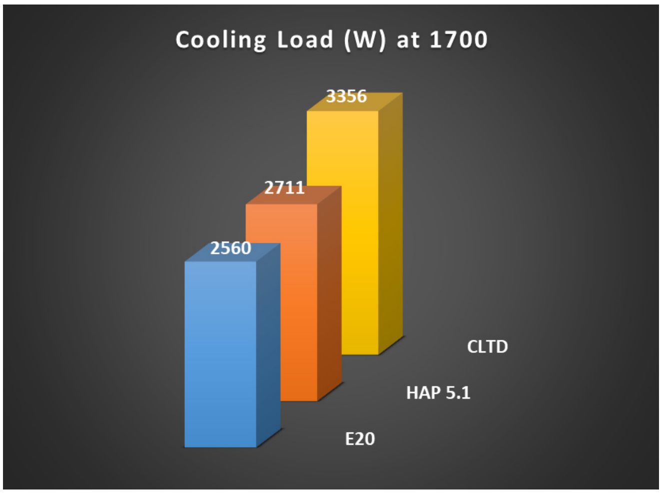

Fig. 8 Dubai cooling load results at 05:00 PM.

In both study cases, the minimum difference in the results is accurse between HAP and E20, while the maximum difference is between E20 and CLTD results.

Table 7. Baghdad and Dubai result percentage difference.

	Baghdad	Dubai
Between HAP and E20	0.30 %	1.51 %
Between HAP and CLTD	2.98 %	6.45 %
Between E20 and CLTD	3.28 %	7.96 %

In general, all methods have a percentage of difference but the lowest values can be seen in both HAP and E20 giving a wide acceptance for these results compared with CLTD manual method. In general, results are within the accepted range for practical cases. The big difference in results between CLTD and other methods, is because of traditional materials used in buildings in Iraq and some of the Middle East countries may not be exactly found in the tables of specifications of ASHRAE or Carrier, which produce a draft in resulting values, add to that the physical properties of materials should be modified to match those of local ones

The E20 method's underlying limiting assumptions make it unsuitable for use in yearly energy simulations, although it is appropriate for peak design load estimates. For peak calculation, E20 and HAP results are the same or approximately equal.

In addition to ASHRAE tables for certain latitudes, a computer application known as CLTDTAB, which has been available since 1993, could be used to build bespoke CLTD/CLF/SCL tables for a given zone type, any latitude, and month. This strategy may be used on any part of the planet without the need for interpolation. If the software CLTDTAB is used, the findings produced with this approach will tend to be fairly similar to the more stringent TFM [26].

6. Conclusions

This research evaluates cooling load calculation methodologies using an E20 Spreadsheet, manual computation, and HAP Software. The findings can be summarized below:

1. The choice of a calculation method depends on the application type to be conditioned, the accuracy of the calculation required, and the error allowed.
2. All methods used for calculation are accepted with minor differences for commercial applications of buildings, shopping malls, sports gyms…etc. and all give the same AC unit using proper safety factor for AC unit size.
3. Each method has a special technique to deal with solar radiation, heat storage, and time delay, giving a different profile for the zone cooling load.
4. New software like HAP considers many details about the building and construction, while other methods do not take them into account, this is reflected in the results.
5. Local construction materials manufactured with different or unequal properties may have thermophysical properties that differ from those mentioned in tables and references.

Nomenclature

Symbol	Description	Unit
A	The surface area of the roof, wall, or glass is computed using construction blueprints.	m^2
CLTD	Cooling Load Temperature Difference for roof, wall, or glass.	°C
CLF	Solar Cooling Load Factor. Cooling Load Factor, by hour of occupancy.	-
CFM	Ventilation airflow rate	ft^3/min
DR	Daily range	°C
F_{UT}	A factor used for lighting, if relevant.	-
F_{BT}	The relevant blast factor allowance.	-
h_o	Outside enthalpy	kJ/kg dry air
h_i	Inside enthalpy of the air	kJ/kg dry air
N	Number of humans in the conditioned area.	-
Q_L, Q_s	Latent and Sensible heat increase due to occupation.	W
Q	Required cooling load	W
SC	Shading coefficient depends on the type of shading	-
SHGC	Solar Heat Gain Coefficient.	W/m^2
T_a	The temperature of the nearby space	°C
T_i	Indoor design dry bulb temperature	°C
T_o	Outdoor design dry bulb temperature	°C
T_{om}	Mean design outdoor dry bulb temperature	°C
U	Overall heat transfer coefficient for a wall, roof, or glass.	W/m^2.°C
W	Wattage of installed lamps as determined by the electrical lighting design or lighting load data.	W

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