Estimation and Analysis of Cooling Load for Indian Subcontinent by CLD/SCL/CLF method at part load conditions

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Abstract: A total equivalent temperature difference (TETD) and cooling load temperature difference (CLTD) methods are developed in the excel spread sheets using Visual Basic Programming for calculating the cooling load for a building. The spread sheets are developed to eradicate the human error and time consuming task of manual calculations. TETD and CLTD methods programmed in spread sheets are easiest and fastest way to estimate the cooling loads as compared to that of the commercially available software’s. The TETD method estimates the peak value of the cooling load and CLTD is used to estimate the cooling load on an hourly basis. Cooling loads estimated using TETD method and CLTD method are validated against CARRIER software HAPv4.9. However, there is a marginal difference in the obtained cooling load values of the spread sheets and HAPv4.9. For selecting the air conditioning equipment for a building, the accurate cooling load calculations are required. For peak cooling load, the solar peak time at a given location is required. The present work deals with the analysis of Solar Peak Time for Indian Sub-Continent, by varying the solar time and geographical directions. The variation patterns as a result of heat gains due to occupants, equipment and lighting in the building are analysed on hourly basis using the CLTD method. Similarly, the variation patterns of cooling load due to variation in outdoor dry bulb temperature and relative humidity are obtained for different cities across India by considering the same room psychometric conditions, internal loads and maximum solar peak time. The TETD method always over predicts the estimated cooling load.

Keywords: CLTD, TETD, HAP v4.9, ASHRAE, Cooling Load, Visual Basic.

1. Introduction

Selecting a suitable air conditioning system for any building requires an accurate estimation of the cooling load. Based on the estimated cooling load, the selection of the system, minimum air supplies (DCFM) for cooling, duct sizing, and energy consumption can be made. Heat gain through walls and roofs depends upon the location, shape and orientation of the building as well as internal surfaces of the conditioned space. The cooling load temperature difference (CLTD)/cooling load factor (CLF)/solar cooling load (SCL) method is one-step hand calculation method developed by ASHRAE [1-6]. Cooling loads result from conduction, convection, and radiation heat transfer processes through the building envelope, in addition to internal sources as well as system components. Building components or contents that may affect cooling loads include the following [7].

1. External: Walls, roofs, windows, skylights, doors, partitions, ceilings, and floors
2. Internal: Lights, people, appliances, and equipment
3. Infiltration: Air leakage and moisture migration
4. System: Outdoor air, duct leakage and heat gain, reheat, fan and pump energy, and energy.
Nomenclature

| Term        | Definition                                                                 |
|-------------|-----------------------------------------------------------------------------|
| CLTD        | Cooling Load Temperature Difference (°F)                                    |
| TETD        | Total Equivalent Temperature Difference (°F)                                |
| VB          | Visual Basic                                                                |
| HAP         | Hourly Analysis Program                                                     |
| RH          | Relative Humidity (%)                                                       |
| DBT         | Dry Bulb Temperature (°F)                                                    |
| WBT         | Wet Bulb Temperature (°F)                                                    |
| DCFM        | Dehumidified Cubic Feet per Minute                                          |
| CLF         | Cooling Load Factor                                                         |
| SCL         | Solar Cooling Load                                                          |
| SC          | Shading Coefficient                                                         |
| N           | North                                                                       |
| TR          | Tonnes of Refrigeration                                                     |
| A           | Area (sq.ft.)                                                               |
| ASHRE       | American Society of Heating Refrigeration and Air-Conditioning Engineers   |
| ISHRAE      | Indian Society of Heating Refrigeration and Air-Conditioning Engineers      |
| W_s         | Outside Specific Humidity (gr/lb)                                           |
| SHG_p       | Sensible Heat Gain per Person (Btu/hr/person)                               |
| LHG_p       | Latent Heat Gain per Person (Btu/hr/person)                                 |
| t_a         | Ambient Temperature (°F)                                                    |
| t_rc        | Room design temperature (°F)                                                |
| W_i         | Inside Specific Humidity (gr/lb)                                            |
| h_o         | Outside Enthalpy (Btu/lb)                                                   |
| N_o         | No of Occupants                                                             |
| F_sa        | Special Allowance Factor                                                    |
| F_al        | Lighting Use Factor                                                         |
| W           | Watt                                                                        |
| E_f         | Efficiency Factor                                                           |
| P           | Horse Power Rating                                                          |
| FR          | Radiation Factor                                                            |
| FU          | Usage Factor                                                                 |
| FL          | Load Factor                                                                 |
| t_o         | Outside temperature (°F)                                                    |
| t_i         | Inside Room Temperature (°F)                                                |
| h_i         | Inside Enthalpy (Btu/lb)                                                    |

TETD method estimates the cooling load by incorporating effective temperature difference for heat gain across the wall and roof due to radiation. The CLTD method uses factors like CLTD, SCL and CLF for estimating heat gains due to external loads, windows and internal loads respectively. The heat gain due to internal loads is directly converted to cooling load in TETD method, whereas in CLTD method the internal loads are partly added to cooling load.

Table 1 reflects cooling load components by taking into consideration sensible and latent heat loads as well as the space and coil load. Space load is used to calculate minimum air supplies to maintain inside psychometric conditions. The addition of space load and coil load is used for sizing of the air conditioning equipment.
The objective of the present work is towards cooling load estimation for a typical Computer Room in an Office. The present work is first of its kind as it deals with development of the TETD and CLTD methods in MS-Excel spreadsheets using Visual Basic programming. Major Cities in Indian subcontinent along with their psychrometric conditions are compiled as database in the spreadsheets. Majority of the inputs required to estimate the cooling load are kept flexible using dropdown list. Accordingly, the spreadsheet developed can be used for industrial, commercial and residential applications. Thereafter, both the methods are compared for the analysis of cooling load estimated.

The following description reveals the geographical, geometrical, constructional and corresponding psychometric details; whereas Fig. 1 depicts architectural drawing of the space under analysis.

| Location:          | Ahmadabad, India               |
|--------------------|--------------------------------|
| Latitude:          | 23.02 N                        |
| Altitude:          | 55 m                           |
| Office Timing:     | 09:00 – 17:00 hrs              |
| Wall material:     | Gypsum Plaster: 1 inch          |
|                    | Brick face: 4 inch              |
|                    | Concrete block: 4 inches        |
|                    | Glass: Double glazing without shading glass |

| Dimension of Computer Room |
|-----------------------------|
| LxBxH: 82 × 23 × 11.5 ft    |
| Occupant No: 24 (light work) |
| Equipment load: 12.5 kW     |

| Outside and Inside Conditions: |
|-------------------------------|
| OUTSIDE | INSIDE |
| DBT(°F) | 110    | 73.4   |
| WBT(°F) | 78     | 65     |
| RH (%)  | 24     | 50     |

![Fig.1. Schematic of office space](image)
2. Method of Solution: - (CLTD/SCL/CLF) [1]

The total cooling load is divided into external cooling load, internal cooling load and loads due to infiltration and ventilation. Table.2 elaborates the procedure for estimating cooling load in detail.

Table.2. Stepwise procedure for estimating cooling load

| A. External Cooling Loads |
|---------------------------|
| *Roofs Walls and Glass* |
| \( Q = UA \times CLTD \) |
| \( Q_{\text{cond}} = UA \times (CLTD) \) |
| *Windows* |
| \( Q_{\text{conv}} = A \times SC \times SCL \) |
| *Partition, Ceilings and Floors* |
| \( Q = UA \times (t_a - t_c) \) |

| B. Internal Cooling Loads |
|---------------------------|
| *People* |
| \( Q_s = No \times SHG_p \times CLF_p \) |
| \( Q_l = No \times LHG_p \) |
| *Lights* |
| \( Q_{el} = W \times F_u \times F_s \times CLF_{el} \) |
| *Power* |
| \( Q_p = P \times CLF \) |
| *Appliances* |
| \( Q_{\text{sensible}} = Q_{\text{input}} \times FU \times FR \times CLF \) |
| \( Q_{\text{sensible}} = Q_{\text{input}} \times FL \times CLF \) |

| C. Ventilation and Infiltration |
|-------------------------------|
| \( Q_{\text{sensible}} = 1.23 \times Q \times (t_o - t_i) \) |
| \( Q_{\text{latent}} = 3010 \times Q \times (W_o - W_i) \) |
| \( Q_{\text{total}} = 1.20 \times Q \times (h_o - h_i) \) |

The lights and equipment’s are considered to be ON during office hours. The Air conditioning is also supposed to be kept ON for 24 hours.

3. Results and Discussions

3.1. Validation of TETD and CLTD with HAP v.4.9

The analysis is carried out by employing the United States customary units and not SI system in accordance with the international standards of ASHRAE.

Table.3. Comparison of Cooling Loads by different methods

| METHOD | TETD | CLTD/CLF/SCL | HAP v4.9 |
|--------|------|--------------|----------|
| Cooling Load (TR) | 13.85 | 12.16 | 11.8 |
Table 3 compares the estimated cooling load by three methods for a given condition. There is a slight deviation in the analytical value than HAP v4.9 because the data is used for calculation of the TETD and CLTD is by considering near the latitude of the location. This deviation is attributed to the slight error in the latitude at 24 degrees NORTH, but actually is 23.1 degrees NORTH. Further, in the calculation of CLTD and TETD, the surface reflection of solar radiation is not considered. The TETD gives higher values as the load due to solar radiation, people, equipment and lighting are directly considered as cooling load. However, this load is not added to the space directly since it gets split into radiation and convection being absorbed by structural element.

3.2. Solar Peak Time for Indian Sub-Continent for different Geographical Directions.

For calculation of cooling load, location, outside conditions and solar peak time are required. The Solar Peak Time is different for different locations. Here, only Indian subcontinent conditions are considered for all geographical orientations as shown in Fig. 1. It can be clearly observed from Fig. 3 that for any geographical orientation, the solar peak time lies between 14:00-16:00 hrs.

3.3. Part Load Analysis:

3.3.1. Part Load due to Lighting in a Space, People and Equipment’s in a Space

During the calculation of cooling load by using TETD method, the lighting, people and equipment are considered as direct cooling load. But these are not directly added to the cooling load in CLTD method. The heat gain from the people and equipment is emitted in the form of radiation. Considerable amount is absorbed by the surrounding structure, e.g. furniture etc. These surrounding structures reradiate after certain time. All these factors are taken care of in the form of CLTD, CLF and SCL values, but are not considered in the TETD method [9].

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**Air System Sizing Summary for Default System**

| Air System Information | Default System | Flow Rate | Location |
|------------------------|----------------|-----------|----------|
| All System Name        | BREEZE         | 1083.6 m³ | Ahmedabad, India |
| All System Type        | HAP v4.9       |           |           |

**Sizing Calculation Information**

| Calculation Months | May to May | Zonal CFM Rating | Steam of space air/operations |
|-------------------|------------|------------------|-------------------------------|
| Sitting Data      | Calculated | Space CFM Sizing | Individual peak load         |

**Central Cooling Coil Sizing Data**

| Total coil load | 11.1 | Local Average May-1509 |
|-----------------|------|------------------------|
| Design Temp | 10.9 | 105/8/77.6°F |
| Cool CFM at May | 4877 | 64/67/63.7°F |
| Cool CFM at ND | 4877 | 64/67/63.7°F |
| Cool CFM at 78% | 4877 | 64/67/63.7°F |
| Cool CFM at 88% | 4877 | 64/67/63.7°F |
| Cool CFM at 95% | 4877 | 64/67/63.7°F |
| Cool CFM at 98% | 4877 | 64/67/63.7°F |
| Cool CFM at 98% | 4877 | 64/67/63.7°F |
| Cool CFM at 98% | 4877 | 64/67/63.7°F |
| Cool CFM at 98% | 4877 | 64/67/63.7°F |
| Cool CFM at 98% | 4877 | 64/67/63.7°F |

**Supply Fan Sizing Data**

| Space CFM | 600 | Fan Motor HP |
|-----------|-----|--------------|
| RPM       | 600 | 4 HP         |
| RPM       | 600 | 4 HP         |
| RPM       | 600 | 4 HP         |
| RPM       | 600 | 4 HP         |

**Outdoor Ventilation Air Data**

| Design air flow CFM | 821 | CFM/person |
|---------------------|-----|------------|
| CFM/m²              | 54.2 | CFM/person |

**Fig.2. Cooling Load Estimated by HAP v4.9**

**Fig.3. Cooling load variation with solar time of the day for different geographical directions.**
Table 4 lists the cooling load values due to variation in lighting, equipment and presence of occupants inside the space, the analysis of the same is given in the figure 4(a) and 4(b).

Fig. 4(a) reflects the part load variation due to lighting. The equipment and people are considered to be working for 8 hours per day as a fixed span. On the other hand, the lighting is considered to be kept ON as a variable over a day. As can be seen from the figure, after every eight hours the equipment load is zero, and there are no occupants inside the space. Accordingly, this load is not to be considered after 8 hours, and gets dropped down.

### Table 4: Part Cooling Load Variation due to Heat Gains from Lighting, People and Equipment.

| Time  | TR vs No of hours after the light turned ON | TR vs People and Equipment hours in space |
|-------|--------------------------------------------|------------------------------------------|
|       | 8 Hours | 10 Hours | 12 Hours | 14 Hours | 16 Hours | 8 hours | 10 hours | 12 hours | 14 hours | 16 hours |
| 1     | 11.62   | 11.62    | 11.63    | 11.64    | 11.65    | 11.62   | 11.62    | 11.63    | 11.64    | 11.66    |
| 2     | 11.72   | 11.73    | 11.73    | 11.75    | 11.75    | 11.72   | 11.73    | 11.74    | 11.74    | 11.75    |
| 3     | 11.79   | 11.79    | 11.8     | 11.81    | 11.82    | 11.79   | 11.79    | 11.79    | 11.8     | 11.81    |
| 4     | 11.83   | 11.83    | 11.84    | 11.85    | 11.86    | 11.83   | 11.84    | 11.85    | 11.85    | 11.86    |
| 5     | 11.87   | 11.87    | 11.88    | 11.88    | 11.89    | 11.87   | 11.87    | 11.87    | 11.88    | 11.88    |
| 6     | 11.89   | 11.9     | 11.91    | 11.92    | 11.92    | 11.89   | 11.89    | 11.9     | 11.9     | 11.91    |
| 7     | 11.92   | 11.92    | 11.93    | 11.93    | 11.94    | 11.92   | 11.92    | 11.92    | 11.92    | 11.93    |
| 8     | 11.94   | 11.94    | 11.94    | 11.95    | 11.96    | 11.94   | 11.94    | 11.94    | 11.94    | 11.94    |
| 9     | 11.11   | 11.56    | 11.56    | 11.57    | 11.57    | 11.11   | 11.51    | 11.51    | 11.51    | 11.52    |
| 10    | 11.02   | 11.52    | 11.53    | 11.53    | 11.54    | 11.02   | 11.47    | 11.47    | 11.47    | 11.48    |
| 11    | 10.96   | 11.05    | 11.5     | 11.5     | 11.5     | 10.96   | 11.06    | 11.45    | 11.45    | 11.46    |
| 12    | 10.93   | 10.97    | 11.48    | 11.48    | 11.48    | 10.93   | 11.44    | 11.44    | 11.44    | 11.44    |
| 13    | 10.9    | 10.93    | 11.01    | 11.46    | 11.46    | 10.9    | 10.96    | 11.05    | 11.44    | 11.44    |
| 14    | 10.87   | 10.9     | 10.94    | 11.44    | 11.45    | 10.87   | 10.92    | 10.99    | 11.44    | 11.45    |
| 15    | 10.86   | 10.87    | 10.9     | 10.99    | 11.44    | 10.86   | 10.9     | 10.96    | 11.05    | 11.45    |
| 16    | 10.85   | 10.86    | 10.89    | 10.93    | 11.43    | 10.85   | 10.87    | 10.92    | 10.99    | 11.44    |
| 17    | 10.83   | 10.85    | 10.86    | 10.89    | 10.97    | 10.83   | 10.85    | 10.89    | 10.95    | 11.04    |
| 18    | 10.82   | 10.83    | 10.85    | 10.87    | 10.92    | 10.82   | 10.84    | 10.87    | 10.92    | 10.99    |
| 19    | 10.81   | 10.82    | 10.83    | 10.85    | 10.88    | 10.81   | 10.83    | 10.86    | 10.9     | 10.95    |
| 20    | 10.81   | 10.82    | 10.83    | 10.85    | 10.87    | 10.81   | 10.82    | 10.84    | 10.87    | 10.92    |
| 21    | 10.8    | 10.81    | 10.82    | 10.83    | 10.85    | 10.8    | 10.81    | 10.83    | 10.85    | 10.89    |
| 22    | 10.79   | 10.8    | 10.81    | 10.82    | 10.84    | 10.79   | 10.8    | 10.81    | 10.83    | 10.87    |
| 23    | 10.79   | 10.79    | 10.81    | 10.82    | 10.83    | 10.79   | 10.8    | 10.81    | 10.83    | 10.85    |
| 24    | 10.79   | 10.79    | 10.8     | 10.81    | 10.83    | 10.79   | 10.8    | 10.81    | 10.83    | 10.83    |

Fig. 4. Cooling load variation for (a) lighting (b) People and equipment.
Fig. 4 (b) depicts the variation of the part load for people and equipment. The lighting is ON for 8 hours. On the other hand, the variables considered are people inside as well as equipments being kept ON. There is a marginal decrease in the cooling load after the people leave the space and equipment is turned OFF, whereas there is steep decrease in the load when lights are also turned OFF.

3.4. Variation in Cooling Load due to Outside Conditions for different Cities in Indian Subcontinent and comparison of part and full load.

The outside DBT, RH and Latitude affect the estimation of cooling load. The DBT affects the sensible heat gain whereas relative humidity affects the latent heat gain. 18 major cities in Indian subcontinent having maximum DBT and RH conditions are analysed. For this, maximum DBT and RH at a given location are traced over the entire day, and such maximum values over the year are investigated using [10]. The results of the same are displayed in Fig. 5 (a). It can be clearly observed that the coastal cities exhibit higher values of cooling load due to higher RH, as expected.

![Fig. 5. Variation of Cooling Load for different cities (b) for part and full load conditions.](image)

Fig 5 (b) portrays the variation of TR at part and full load conditions during regular as well as extended office hours. The cooling load at part load conditions increases gradually, reaches maximum and then decreases. In case of full load, there is steep increase and decrease in the cooling load at the beginning and end of the regular office hours.

4. Concluding Remarks

The present work describes the estimation of cooling load using TETD and CLTD/CLCLF method for a typical Computer Room in an Office. Both the methods are developed in excel spread sheets by using Visual Basic programming. The results of both the methods are validated with the help of CARRIER software HAP v4.9. The cooling load estimated with the help of TETD and CLTD are found to be in reasonable agreement with the values obtained from HAP v4.9. It can be clearly analysed that outdoor DBT and RH have major impact on estimation of cooling load. The coastal cities as well as interior locations have highest cooling loads accordingly. The solar peak time for Indian subcontinent lies between 14:00–16:00 hrs irrespective of the geographical orientation. Therefore, it is used for designing the air-conditioning system.

The CLTD method is also successfully extended for the part load calculations. The effect of lighting, people and equipment are considered for investigating cooling load on hourly basis. While estimating the cooling load at full load conditions, CLFs for internal loads need to be considered as unity. This ultimately results in higher full load calculation than actual cooling load. The heat gain from the light, peoples, and equipment are directly added in the cooling load in case of TETD method, whereas CLTD method deals with partial consideration of internal loads for the cooling load analysis. From the present analysis, it can be clearly concluded that TETD method is relatively faster but yields less accurate predictions, whereas CLTD method consumes more time to offer relatively accurate outcomes.

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