AIR CONDITIONING LOAD CALCULATIONS

By

Chandana Dalugoda

Abstract

This paper describes the load calculation principles and the plant selection with psychrometric analysis. Present day plant managers and maintenance engineers require brief knowledge in air conditioning for selecting equipment particularly in light commercial range A/C systems. Calculating a heat load in air conditioning would be the prim requirement, however elaborate calculations are not required. Magnitude of the air conditioning systems in this nature falls into light commercial range. For those who require simple form of calculating the load and selecting a plant be described towards the end of the article.

This paper gives an actual calculation methods as well as rule of thumbs and first cut analysis which may be particularly important to all mechanical and civil engineers who are not in the air conditioning field.

1.0 Introduction

Scope of this article is firstly to give a brief understanding of the standard practice and secondly giving a simple steps to do a heat load as in the case for first cut analysis or use of rule of thumb check figures. However these methods shall have limited applications such as in-house small air conditioning jobs.

Air conditioning can be classified in to two groups, as Human Comfort A/C and industrial A/C. In this article; our study is limited to Human comfort A/C with cooling and de-humidification only. We shall ignore the heating part of the A/C system for convenience of study.

Air conditioning provides controlling of following factors in a given environment:

1. Dry bulb temperature
2. Relative Humidity
3. Filtration and
4. Air movement

In summer air conditioning, dry bulb and the relative humidity of the room should be lowered to achieve comfort conditions. To accomplish this, total heat generated in the room should be transferred to outdoors by using an air conditioning plant. To select the air conditioning plant we must have a fair idea of the heat load generated in the room.

2.0 Purpose of Heat Load Calculations

Heat load calculations provide the basic data for selecting the AC system and equipment and also provide the basis of sizing the associated ducting and piping.

Usually, heat load is computed for peak load and partial load and then it is compared to achieve any load reductions.

3.0 Building survey

First step for a proper heat load calculation is to obtain an accurate physical data of the building, weather it is a multi-storied complex or a small room.

1. Building plan - civil layout or sketch of the space to be air-conditioned with all the exterior walls adjacent rooms shown. Ceiling height, beam heights etc.
2. Orientation of the building - compass points-North /south direction.
3. Effect of other building structures - shading effects by other buildings, reflective surfaces by parking lots, windows etc.
4. Weather data - Climatic conditions of the area of the building.

Chandana Dalugoda, IEng.(EC), AM CIBSE, AM Inst. R, AIE(SL) Member ASHRAE.

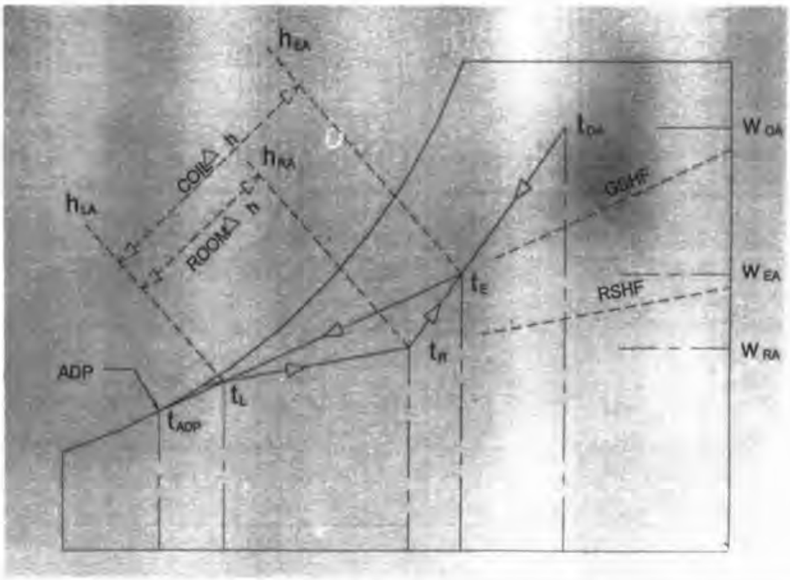

Figure 1: Air conditioning Process without pre-heat/reheat

5. Type of space used for - weather the space used for office, bank, restaurant, conference hall, factory, bedroom etc.
6. Building construction materials - type of materials and thickness, colour of the roof, walls, glasses, floor finishes etc.
7. Type of equipment - water analyses report or sample to determine weather water could be used as condenser media or air cooled system is preferred instead.
8. Suitable location of equipment
9. Electrical power availability
10. Mode of operation - time of day equipment operation.

4.0 Components of the heat load

There are two basic components of the air conditioning heat load;

1. Outdoor loads
2. Internal loads

Outdoor load is due to outside weather conditions and the sun effect through the building envelope. These are solar heat gain from the sun and the transmission heat gain (conduction) due to temperature difference through the building structure.

Internal loads due to heat generation from the people, lights, appliances, electric motors, out-door air for ventilation and by pass air through the cooling apparatus.

5.0 Load calculation methods

There are three types of load calculation procedures established by ASRHAE such as;

1. Transfer Function Method (TFM)
2. Cooling Load Temperature Difference Method (CLTD/SCL/CLF)
3. Total Equivalent Temperature Difference Method (TETD)

The transfer Function method is directly used in computer programmes. TETD method, describes an alternate cooling load calculation method preferred for experienced designer, require greater flexibility in using judgement in computing cooling loads. CLTD method is the manual procedure of calculating loads, which describes in this article.

Carrier E-20 is another famous load calculation procedure, which is the same method, used in CLTD/SCL/CLF.

6.0 Load Calculation Procedure (CLTD/SCL/CLF) Method

Outdoor (external loads) and internal loads are calculated using;

Q = U.A. (CLTD) where, U-factor and t1, t2 have to be calculated. In some cases, U - factors are given for various materials and different combinations. It is preferred that all the U-factors are calculated for the particular composite walls and other materials. In Appendix A, useful U-factors and sungain temperature difference are included for typical cases that can be used in quick heat load calculations.

External Loads

Conduction through

1. Roof
2. Wall

$$\boxed{q = UA\ (CLTD)}$$

U = design heat transfer coefficient (U-factor) Btu/(h.ft².°F)

A = Area calculated from building plans, ft²

CLTD = cooling load temp. difference, °F

Conduction through

3. Glass
4. Partitions
5. Ceiling
6. Floor

$$\boxed{q = UA\ (t_a - t_r)}$$

U = design heat transfer coefficient (U-factor) Btu/(h.ft².°F)

A = Area calculated from building plans, ft²

t_a = temp. of adjacent space, °F

t_r = room design temp., °F

Solar Gain through

7. Glass

$$\boxed{q = A(SC)\ (SCL)}$$

A = Area calculated from building plans, ft²

SC = shading coefficient, dimensionless

SCL = solar cooling load factor, Btu/(h.ft²)

Internal Loads

8. People

$$\boxed{\begin{aligned} q_{sensible} &= N\,F_d\,q_{shg}\,(CLF) \\ q_{latent} &= N\,F_d\,q_{lhg} \end{aligned}}$$

N = number of people in space

F_d = diversity factor

q_{shg} = sensible heat gain per person, Btu/hr. person

q_{lhg} = latent heat gain per person, Btu/hr. person

CLF = cooling load factor by hour of occupancy

9. Lights

$$\boxed{q_{el} = 3.41\ w\ F_{ul}\ F_{sa}\ (CLF)}$$

W = watts input from electrical plans, W

F_{ul} = lighting use factor

F_{sa} = lighting special allowance factor

CLF = cooling load factor by hour of occupancy

10. Power

$$\boxed{q_p = 2545\ P\ E_F\ (CLF)}$$

P = horse power ratings from electrical plans

E_F = efficiency factor

CLF = cooling load factor by hour of occupancy

11. Appliances

$$\boxed{\begin{aligned} q_{sensible} &= q_{sa}\,(CLF) \\ q_{latent} &= q_{la} \end{aligned}}$$

q_{shg} = sensible heat gain per appliance, Btu/hr

q_{lhg} = latent heat gain per appliance, Btu/hr

CLF = cooling load factor

Infiltration Load

12. Infiltration of air (Sensible)

$$\boxed{q_s = 1.10\ (CFM)\ (t_o - t_r)}$$

CFM = volume flow rate of infiltrating air, ft3/min

t_o = outdoor temp.

t_r = room design temp.

13. Infiltration of air (Latent)

$$\boxed{q_l = 4840\ (CFM)\ (w_o - w_r)}$$

CFM = volume flow rate of infiltrating air, ft3/min

w_o = moisture content for outdoor air, lb/lb

w_r = moisture content for room air, lb/lb

Ventilation Load

14. Ventilation air (Sensible)

$$\boxed{q\ s = 1.10\ (CFM)\ (t_o - t_r)}$$

CFM = volume flow rate of ventilation air, ft_3/min

t_o = outdoor temp.

t_r = room design temp.

15. Ventilation air (Latent)

$$\boxed{q\,l = 4840\,(CFM)\,(w_o - w_r)}$$

CFM = volume flow rate of ventilation air, ft^3/min

w_o = moisture content for outdoor air, lb/lb

w_r = moisture content for room air, lb/lb

16. Heat gain in air distribution system

$$\boxed{q = U\,A_s\,(t_a - t_d)}$$

U = design heat transfer coefficient (U-factor) Btu/(h.ft2.°F)

A = out side surface area of duct, ft^2

t_a = temp. of duct surface, °F

t_r = room design temp., °F

NOTE: The heat gains of duct system must be considered when the ducts are not in the conditioned space. Total heat gain from ducts would be 1 to 3 % of the room sensible heat gain, when the ducts are not in the conditioned space and insulate.

Grand Total Heat

Grand total heat (GTH) in Btu/h is the addition of the above individual loads from 1 to 16.
GTH could be given in Tons of Refrigeration (TR);
TR = GTH/ 12'000.
In SI units, KW_R = TR x 3.517.

Computing the required airflow rate and the coil conditions are discussed in Psychrometric Analysis in the preceding sections.

7.0 Typical Format of Cooling Load

ASHRAE cooling loads are more accurate and load can be calculated for deferent ours of the day and as a standard feature, load is calculated for three different times of the day.

For simplicity of the calculation, chart given in Apendix-1 describes the **(CLTD/SCL/CLF)** method.

8.0 Weather Data

Weather data should obtain form the observatory of the particular area or from the ASHARE tables. For Sri Lanka following weather data is given in ASHARE.

Country	=	Sri Lanka
City	=	Colombo
Latitude	=	6° 54' N
Elevation	=	24 ft
Design Dry Bul	=	90 °F
Design Wet Bul	=	81°F
Mean Daily rang	=	15 °F
Wind speed	=	6 knots

These data required to determine the peak solar time and the month of the year and to compute the solar gain through glasses. These data are very useful to determine the solar gain through glass during morning hours of the East exposure and the evening of the West exposure of a building.

9.0 Indoor Design Conditions

Indoor design conditions are given in ASHRAE for deferent space utilisation.

For commercial and public buildings, inside design conditions would be

SPACE USED FOR	°F DB	RH%
Office Buildings	74 / 78	40 / 50
Restaurants	74 / 78	55 / 60
Libraries & Museums	68 / 72	40 / 55
Airport Terminals	74 / 78	50 / 60

However tropical climates with high relative humidity such as Sri Lanka is find it difficult to maintain indoor conditions of 50% RH by a normal air conditioning. Therefore it is much appropriate to maintain indoor conditions between 55 to 65% RH which is still in the comfort zone.

10.0 Outdoor Air Requirement for Ventilation

Indoor air quality largely depends on the amount of outdoor air brought in to the conditioned space. This outdoor air is mainly required for respiration of people, and to keep the CO_2 level down to accepted levels. . Air quantity is proportional to the total occupancy for given application. Outdoor air quantities per person are derived to achieve maximum concentration of 1000 ppm of CO_2 or below.

Typical values are:

Office - 20 CFM/person
Auditorium - 15 CFM/person

Have out door air according to ASHRAE standards. However, considering the quality of the buildings and excessive infiltration in Sri Lanka, these fresh air rates should be corrected to suit our conditions, hence 10 CFM/person would be suitable for most of the cases.

11.0 Psychrometric Analysis

The heat load computed as above is then be used to determined various parameters for selection of equipment and design of the air distribution system.

1. Room sensible heat factor (RSHF)
2. Supply air flow rate, CFM
3. Bypass Factor
4. Coil entering conditions, °F db, °F wb
5. Coil leaving conditions, °F db, °F wb
6. Pre-heating (sensible heating)
7. Re-heating (sensible heating)

Typically an air conditioning system undergoes 'cooling and de-humidification' process with ' heating and humidification ' process.

If we consider the return air duct heat gain and fan motor and supply air duct heat gain, there will be an additional process, namely, sensible heating.

Room sensible heat factor (RSHF)

$$RSHF = \frac{\text{Room sensible heat}}{\text{Room sensible + Room latent}}$$

NOTE: Refer to Figure-1

RSH = add 1 to12 (only sensible portion)

RLH = add 8+11+13 (only latent portion)

Supply air flow rate - VS_A

$$V_{SA} = \frac{\text{Room sensible heat}}{1.10 \times (t_r - t_l)}$$

t_l = temp. of air leaving coil, °F db

t_r = room design temp., °F db

Bypass Factor - BF

$$BF = \frac{t_l - t_{adp}}{t_e - t_{adp}}$$

Coil Entering Temperature

$$= \frac{(CFM_{oa} \times t_{oa}) + (CFM_{ra} \times t_{rm})}{CFM_{sa}}$$

t_e = temp. entering coil, °F db

to_a = temp. outdoor air, °F db

t_{ra} = temp. room, °F db

CFM_{oa} = volume flow rate of out door air, ft^3/min

CFM_{ra} = volume flow rate of return air, ft^3/min

CFM_{sa} = volume flow rate of supply air, ft^3/min

Coil Leaving Temperature

$$t_l = t_{adp} + BF\,(t_e - t_{adp})$$

t_{adp} = temp. apparatus dew-point, °F db

Pre-heating

In winter season, although refrigeration is not required for controlling the dry bulb temperature, it is required to control the relative Humidity. Hence, air conditioning machine has to run despite low ambient conditions. In these conditions, mixed air temperature entering the coil becomes too low, and heating is required, which is usually a waste full of energy. Consequently air undergoes a sensible heating process.

Return air duct heat gain also part of this sensible heating process.

Re-heating

Re-heating is sensible heating, usually occur after air leaves the coil before it enters the room. This is mainly due to Fan motor heat and supply duct heat gain.

However, re-heating is used effectively and economically for reducing the RH% of a given space.

Also it requires in spaces where high latent load are prevails with low RSHF values.

12.0 First cut Analysis

Schematic design phase of a project require to determine the air-conditioning load for the building, which is in a rough assumption stage. There would not be any data for building survey, such as window materials, wall materials, number of people, number of lights, etc. In this event, designer should use check figures, past experience etc. to determine the rough air conditioning load.

SELECTED DESIGN CRITERIA FOR FIRST CUT ANALYSIS (ASHRAE)

General :

450 ± 100 ft²/TR
1.5 cfm/ ft² for exterior spaces
0.6 cfm/ ft² for interior spaces
400 cfm/ TR

Offices

500 ft²/TR, based on;
1.5 W/ ft² for lights
0.75 W/ ft² for fans
0.25 W/ ft² for pumps
1.0 W/ ft² for electrical misc.
200 ft² /person for occupancy

Restaurants

150 ft²/TR,

Shopping centres

400 ft²/TR,

However, above data differs greatly with the country and the weather conditions that you're working with. If we consider the Sri Lanka conditions, following check figures would be much appropriate for first cut analysis.

Offices - Ground floor levels

220 ft²/TR, based on;
1.5 W/ ft² for lights
Ground floor level
less windows
400~350 cfm /TR
200 ft² /person for occupancy

Offices - Upper floor levels

190 ft²/TR

Banks

190 ft²/TR banking area

220 ft²/TR, other areas

Restaurants

190 ft²/TR

Computer rooms- normal

200 ft²/TR

Following areas require specific calculations to determine the load, hence do not apply check figures.

Computer Rooms with closed control, Operation Theatres with 75%~100% fresh air, Printing Plants, Garment Factories, hotels etc.

13.0 Plant Selection

Usually plant selection requires following data form the heat load calculations and Psychrometric analysis;

1. Sensible hat load
2. Latent heat load
3. SHF
4. Temp. entering coil, °F db
5. Temp. leaving coil, °F db
6. Supply air quantity
7. Fresh air quantity
8. Fan Total Pressure required

However we may not require all of the above for a small A/C job, hence following points could be the desirable requirements.

Sensible Load

Total sensible load should be equal or higher than the equipment sensible heat Capacity (SHC). If the equipment SHC of the equipment is smaller than the load, room designed dry bulb temperature could not achieve and discomfort results. Therefore all ways match the SHC and the sensible load and to do this you require equipment performance curves / tables. Because of the standard capacity data in catalogues are based on standard outdoor/indoor conditions they should be corrected for the particular design conditions that the designer has selected before selecting equipment

Latent Load

As shown in the above Total latent capacity of the room also match with equipment latent heat capacity (LHC), unless, relative Humidity control would be impossible.

Usually most of the general A/C applications have 80% SHL and 20% LHL of a building. All new Packaged equipment / factory charged room air conditioners are also having a similar ratio of the SHC and LHC. Hence it is not a problem in selecting packaged equipment for a normal comfort application. However, spaces like Auditoriums, Theatres, and restaurants, Conference halls have much higher Latent heat loads and the above rule may not be true.

14.0 Conclusion

Heat load is depend upon various factors due to weather conditions, building materials, occupancy, equipment etc., hence it cannot be guess or use rule of thumb. However it is, a close assumption could be made with check figures if we use common sense.

References

1. ASHRAE - 1997 Fundamentals Volume
2. ASHRAE - Cooling & Heating Load Manual
3. Air conditioning System Design Manual

Appendix 1

ITEM	AERA (FT²)	CLTD	U-FACTOR	BTU/HR
SOLAR GAIN LOAD - GLASSES				
GLASS (N)				
GLASS (S)				
GLASS (W)				
GLASS (E)				
SOLAR & TRANSMITION GAIN LOAD - WALLS & ROOF				
WALL (N)				
WALL (S)				
WALL (W)				
WALL (E)				
ROOF				
TRANSMITION GAIN - OTHERS				
ALL GLASS				
PARTITION				
CEILING				
FLOOR				
INFILTRATION				
INTERNAL HEAT				
PEOPLE				
POWER				
LIGHTS				
APPLIANCES				
ROOM SENSIBLE HEAT RSH				
OUTDOOR AIR				
LATENT HEAT				
PEOPLE				
STEAM				
APPLIENCES				
OUTDOOR AIR				
OUTDOOR AIR HEAT				
SENSIBLE				
LATENT				
GRAND TOTAL				