Journal of Multidisciplinary Engineering Science and Technology (JMEST)
ISSN: 3159-0040
Vol. 2 Issue 3, March - 2015

Design of Central Air-Conditioning System for a 2,500 Capacity Auditorium

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Abstract—The choice of inside comfort design conditions for an air-conditioned room or building depends on the physiological considerations and economic factors. The aim of this research work is to design a central Air- conditioning system for a 2500 capacity auditorium so that the load calculation in the building conforms to the air distribution system. The system is designed to control the space temperature uniformly by balancing excessive heat gain or losses through wall or window through the out season, as well as to provide the ability to test and balance the system to the specified air flows and temperatures.

Keywords—Central air-conditioning, auditorium, temperature, load estimate, comfort.

Introduction

Air- conditioning is the best means known to man of providing fine control of the environment inside buildings. The inherent advantages of an air-conditioned building have resulted in greater demand for air-conditioning from building owners and users, and over the past thirty years, the number of installations had increased considerably (Sherratt, 1980). (Sherratt, 1980) cited David Alford who cautioned that in designing building for air-conditioning, architects must solve problems of increasing complexity. Innovation has increased the need the range of choice for the solution of technical problems, and the additional need to take into account the energy implications of design. He explained that if energy conservation were the single most important criterion, and perhaps considering possible fluctuation in the prices, building should be designed such that relatively cheap energy will be needed to provide high comfort condition with air- conditioning.

In selecting air-conditioning system it is often found worthwhile to incorporate additional plant and pipe work to enable heat to be re-used and thus reduce running costs and conserved energy.

He went further to explain that in considering the many aspects to ensure that the air conditioning is compatible with the building, many decision were made, not the least of which is the type of the system to be employed. one of the more popular systems selected five years ago related to induction system but of late the trend appears to favour the variables air volume type of system due to the trend towards deep plan form buildings for example, the duct work distribution of a variables air volume system will normally cost three to four times the cost of ductwork distribution of an induction system. If however, a variable air volume system is installed in a simply designed building with relatively unrestricted ductwork routes and this is to be compared with an induction system installed in a building with severe planning restrictions and complex ductwork routes then the cost differential may be reduced to almost 2:1. The rate at which heat energy must be removed from a space in order to maintain the design condition is called cooling load calculation. This deals with heat gains which are of two kinds:

Sensible heat involves direct addition of heat to an enclosure; it is a function of the dry-bulb temperature. Sensible heat gains to a space include: Heat transmission through the building structure as a result of conduction, convection and radiation, Heat entering the space as a result of solar radiation through windows or other transparent or translucent component, Sensible heat produce by occupants, Sensible heat produced in the space by light appliances and motor, Sensible heat brought in as a result of ventilation and infiltration of outside air

Latent heat is associated with increase in the moisture content brought about by vapour emitted by the occupants, appliances and processes. Latent heat gain may be classified as: Latent heat from outside air (both that introduce for ventilation and which infiltrate into the spaces), Latent heat from occupants, Latent heat from cooking, hot baths, moisture producing equipment in the spaces, Latent heat from products or materials brought in to the space.

The major component of the load is from people in all these cases and it is evident that all years systems are required. Low – velocity air – distribution should be used because of low noise levels necessary and because there is usually enough space to run ductwork (Jones, 1980).

An excellent survey of mechanical service in auditoria shows that there are at least six effective possibilities of air distribution (Jones, 1980). Downward air distribution, upward air distribution, Front-to-rear, Front-of stage-to-rear, Rear-to–front, and side-wall air distribution.

Internal Sensible Load Calculation for the Ground Floor

Inside design condition: The inside condition vary in accordance with the degree of activity of the occupants and intended use of the conditioned space. The recommendation inside design condition for comfort in auditorium allowing for present practice is given as:

Dry bulb temperature 25.6^oC (78^oF)

Relative humidity $(60\% - 50\%)$

Source (Norman, 1983).

Outdoor design condition: These highest mean monthly maximum outdoor dry bulb temperature for FUTA environment in the month of September 2011, was given as 32^oC by the metrological department, this form the basis for the outdoor design temperature.

The humidity ratio is calculated as follows:

The weight of water vapour for saturation is 0.454kg of dry air

Doors: solid core flush with – glass storm doors $(u = 1.82\ w/m^2k)$

Floor construction: $152.4\ mm$ concrete slab on grade

Roof construction: steel with $25mm$ insulation with code number B5, the thickness and thermal properties are:$L = 25.4mm$, $K = 0.043W/m$°C, $D = 91Kg/m^3$,

$SH = 0.233KJ/Kg$°C, $R = 0.586m^2$°C$/w$, Mass = $2.3Kg/m^2$(Source: ASHRAE, 2001)

The thermal conductance of the material is obtained by dividing the thermal conductivity of the material by its thickness: Where k = thermal conductivity(w/m°C), L= thickness of the material (mm), and C= conductance (w/m^2°C)

$$C = \frac{K}{L} = \frac{0.043}{0.0254} = 1.693\ w/m^2\ °C \qquad 3.0$$

Thermal resistance

$$R = \frac{1}{C} = \frac{1}{1.693} = 0.591m^2°C/W \qquad 3.1$$

To obtain the total resistance of the building component (R_T)

$$R_T = R_1 + R + R_o \qquad 3.2$$

$$R_T = 0.586 + 0.591 + 0.058 = 1.235$$

$$U = \frac{1}{R_T} = \frac{1}{1.235} = 0.81W/m^2k \qquad 3.3$$

Wall construction: 304.8mm L, W concrete (12 inch). The inside finish is cement mortar and the outside is finished with cement plaster and sand aggregate.

Table 1: The R value of various building elements in determining coefficient heat transfer

Element	R(Insulation)	R (Framing)
Outside surface Exterior wind velocity for summer $3.4m/s$	0.044	0.044
Inside surface (still air)	0.12	0.12
Inside finish (cement mortar)	1.39	1.39
Outside finish of cement plaster , sand aggregate	1.39	1.39
Total	$R_1 = 2.944$	$R_2 = 2.944$

$$U_1 = \frac{1}{2.2994} \text{ and } U_2 = \frac{1}{2.994}$$

$$U_{1=0.34w/m^2k} \text{ and } U_{2=0.34w/m^2k}$$

The average transmittance is then calculated as

$$U_{av} = a(U_a) + b(U_b) + \ldots + n(U_n) \qquad 3.4$$

Where $a, b\ \ldots\ n$ are respectively fractions of a typical basic Area

Assuming 18% framing, the average

U – factor is calculated as follows

$$U_{av} = (0.82\ x\ 0.34) + (0.18\ x\ 0.34) = 0.34w/m^2k$$

Occupancy: Two thousand five hundred persons that is, one thousand nine hundred in the main hall and six hundred in the gallery.

Appliances and light: The ground floor lighting can be calculated from the instantaneous rate of heat gain from electric lighting.

$$U_{el} = W \times F_{ul}, \times F_{sat} \qquad 3.5$$

Where U_{el} = heat gain, W = total light wattage, F_{ul} = lighting use factor, and F_{sat} = lighting special allowance factor

Twin, (2) 18 W lamp

It is considered that there are about one hundred and fifty-six twin fluorescent lamp in the auditorium.

For commercial application such as Auditorium, the lighting use factor will be unity.

$$Q_{el} = 18\ x\ 2\ 156\ 1.06\ x\ 1 = 5963W$$

The conditioning equipment is located in a small mechanical and the construction of the auditorium is considered medium.

Main Hall

Infiltration into the main hall

$$q = 1.2\ Q\ \Delta t \qquad 3.6$$

Where Q = volumetric flow rate(m^3/s), Q_s = sensible heat (KW)

Δt = the temperature difference between the outdoor and inside temperature $(t_o - t_1)$°C

To find the Air Exchange =32℃, from table D (summer Air Exchange Rate ACH) = 0.46

Room volume for the main hall $(L\ x\ B\ x\ H)$

$Q = \frac{0{,}46\ x\ (60\ x\ 60\ 15) x\ 1000}{3600} = 6900\ m^3/s,$ $Q_s = 1.2\ x\ 6900\ x\ (32 - 25.6) = 52992W = 52.992KW$

Occupancy

Q_s= $1900\ x\ 105 = 199{,}500\ W$

Toilet

$Q = \frac{0.46\ x\ (8\ x\ 4\ 2.4)\ x\ 1000}{3600} = 9.81m^3/s$,

$Q_s = 1.2\ x\ 9.81\ x\ (32 - 25.6) = 75W$

Occupancy

$Q_s = 0$

Roof = $8x4 = 32m^2$

Changing Room

$Q = \frac{0.46\ x\ (6\ x4\ x\ 2.4) x\ 1000}{3600} = 7.36m^3/s,$

$Q_s = 1.2\ x\ 7.36\ (32 - 25.6) = 57W$

Occupancy

$Q_s = 0$

Roof = $6x4 = 24m^2$

Electrical Room

$Q = \frac{0.46\ x\ (4.3\ x\ 2\ x\ 2.4) x\ 1000}{3600} = 2.64m^3/s$,

$Q_s = 1.2\ x\ 2.64\ (32 - 25.6) = 20W$

Projector Room

$Q = \frac{0.46\ x\ (6\ x\ 4\ x\ 2.4) x\ 1000}{3600} = 7.6m^3/s$,

$Q_s = 1.2\ x\ 7.36\ (32 - 25.6) = 57W$

Rehearsal Room

$Q = \frac{0.46\ x\ (12\ x\ 12\ x\ 2.4) x\ 1000}{3600} = 44.16m^3/s$,

$Q_s = 1.2\ x\ 44.16\ (32 - 25.6) = 339W$

Side Walk Way

$Q = \frac{0.46\ x\ (12\ x\ 4\ x\ 2.4) x\ 1000}{3600} = 14.72m^3/s,$

$Q_s = 1.2\ x\ 14.72\ (32 - 25.6) = 113W$

Walls

North-wall =$(38\ x\ 2.4) - (1.8\ x\ 4.2) = 83.64m^2$

$Q = \frac{0.46\ x\ (83.64\ x\ 2.4) x\ 1000}{3600} = 10.69m^3,$

$Q_s = 1.2\ x\ 10.69\ (32 - 25.6) = 82W$

South-wall

$= (5\ x\ 2.4) - (0.42\ x\ 0.36) = 11.85m^2$

$Q = \frac{0.46\ x\ (11.85\ x\ 2.4) x\ 1000}{3600} = 3.63m^3$,

$Q_s = 1.2\ x\ 3.63\ (32 - 25.6) = 28W$

West-wall

$= (4\ x\ 2.4) - (1.8\ x\ 4.2) = 2.04m^2$

$Q = \frac{0.46\ x\ (2.04\ x\ 2.4) x\ 1000}{3600} = 0.63m^3$,

$Q_s = 1.2\ x\ 0.63\ (32 - 25.6) = 4.8W$

East-wall

$= (6\ x\ 2.4) - (0.42\ x\ 0.18) = 14.32m^2$

$Q = \frac{0.46\ x\ (14.32\ x\ 2.4) x\ 1000}{3600} = 4.39m^3,$

$Q_s = 1.2\ x\ 4.39\ (32 - 25.6) = 34W$

Doors

North East doors $= (38\ x\ 2.4) - (2.30\ x\ 1.2) = 81.7m^2$

$Q = U\ x\ A\ x\ (\Delta T) = 1.82\ x\ 81.7\ x\ (32 - 25.6) = 951.6W$

South doors = $(0.42\ x\ 0.36) = 0.15m^2$

$Q = U\ x\ A\ x\ (\Delta T) = 1.82\ x\ 0.15\ x\ (32 - 25.6) = 1.75W$

West doors = $(1.8\ x\ 4.2) = 7.56m^2$

$Q = U\ x\ A\ x\ (\Delta T) = 1.82\ x\ 7.56\ x\ (32 - 25.6) = 88.1W$

East Door = $(0.42\ x\ 0.32) = 0.1344m^2$

$Q = U\ x\ A\ x\ (\Delta T) = 1.82\ x\ 0.1134\ x\ (32 - 25.6) = 1.57W$

Glass

Main Hall Glass area

Area = $(60\ x\ 60) = 3600m^2$

$Q = SC\ x\ A\ x(\Delta T)$: SC = Shading co-efficient, A = Area, ΔT = Temperature difference

$Q = 6.02\ x\ 3600\ x\ (32 - 25.6) = 138700W$

Gallery Glass area

Area = $(38\ x\ 38) = 1444m^2$

$Q = SC\ x\ A\ x(\Delta T) = 6.02\ x\ 1444\ x\ (32 - 25.6) = 55634W$

Roof

Area = $(60\ x\ 60) = 3600$

$m^2 Q = U\ x\ A\ x\ (\Delta T) =$

$0.043\ x\ 3600\ x\ (32 - 25.6) = 990W$

Internal Sensible Cooling Load for the Second Floor

Gallery

$Q_s = 1.2Q\ \Delta t$

$Q = \frac{0.46\ x\ (38\ x\ 38\ x\ 2.4)\ x\ 1000}{3600}$

$Q = \frac{0.46 \, x \, (38 \, x \, 38 \, x \, 2.4) \, x \, 1000}{3600} = 443 m^3/s$,

$Q_s = 1.2 \, x \, 443 \, x \, (32 - 25.6) = 3400W$

Occupancy

$Q_s = 600 \, x \, 105 \; = 63{,}000W$

Store

$$Q = \frac{ACH \, x \, (room \; volume) \, x \, 1000}{3600} = \frac{0.46 \, x \, (6 \, x \, 2 \, x \, 2.4) \, x \, 1000}{3600} = 3.68 m^3/s$$

$Q_s = 1.2 \, x \, 3.68 \, x \, (32 - 25.6) = 28W$

Occupancy: $Qs = 0$

Total Latent Load for First and Second Floor

Occupancy

$$q_{el} = 2700 \, x \, 105 = 283500W$$

Electric Lighting

$qel = Total \; wattage \; of \; light \; x \; Use \; factor \; x \; Allowance \; factor$

$q_{el} = 18 \, x \, 2 \, x \, 156 \, x \, 1.06 \, x \, 1 = 5953W,$

$q_{el}(total) = 283500 + 5953 = 289453W$

Total Sensible Load for First and Second Floor

Table 2: The Summary of the Total Sensible Cooling Load

Particulars	Sensible (W)	Latent (W)	Total (W)
Walls.			
North	82		82
South	28		28
East	34		34
West	48		48
Roof.	990		990
Doors			
North	952		952
South	1.75		1.75
East	1.57		1.57
West	88.1		88.1
Glass			
Main Hall	138700		138700
Gallery	55634		55634
Main Hall	52992		52992
Gallery	3400		3400
Store	28		28
Occupants			
Main Hall	199500		199500
Gallery	63000		63000
Toilets			
Male	75		75
Female	75		75
Changing Room			
Male	57		57
Female	57		57
Electric Lighting	5953	289453	295406
Rehersal Room	339		339
Side Walk Way	113		113
Elect Room	20		20
Projector Room	57		57
Total	522185	289453	811638
Safety 10% of Total	52219	28945	81164
Total	**574404**	**318398**	**892802**

$$SHF = \frac{RSH}{RTH}$$

$Total \; sensible \; heat = RSH$

$Total \; latent \; heat = RTH$

Total cooling load = Total sensible + Total latent heat

Tons of refrigeration = $\frac{Total \; cooling \; load}{3500}$

$$SHF = \frac{RSH}{RTH} = \frac{574404}{892802} = 0.643$$

Capacity of the plant = $\frac{892802}{3500} = 255 \, TR$

Install a plant having a capacity of $255 \, TR$

Layout of Distribution System

The volume flow rate can be calculated from the sensible heat formula. Assume the building temperature is to be maintained at 22^{o}C db and the supply air temperature is 10^{o}C.

Q = $Q = \frac{98 \, x \, (273+10)}{351(22-10)} = 6.63 \, m^3/s$

Since the volume flow rate of supply air is 6.63m3/s and there are 18 diffusers each supplying an equal amount of cooled air as the other,

The flow rate of each diffuser is

$\frac{6{,}63}{18} = 0.3684 \, m^3/s$

Duct Design

It is important to know the volume of air to be supplied before determining the size of the ducts needed to carry air to conditioned space.

The problem of sizing of the duct is reduced to the solution of a basic relationship between Q, the quantity of air flowing in m^3/s A cross-sectional area of the duct in M and V the mean velocity of air –flow in m/s , given by the equation

$$Q = AV \qquad 4.0$$

Since Q is known, the problem becomes one of choosing a suitable velocity or an appropriate pressure drop rate if high – velocity systems and industrial exhaust installations are excluded, there are three methods of sizing in use:

These are:

Equal friction method: this is calculated by the equation $\frac{\Delta p_f}{L} = 2.268\ x\ 10^{-3} \frac{Qv^{1.852}}{D^{4.973}} mmH_2\ {}^{O}/_{m}$

Where Q_v = quantity of air measured in m^3/s

Velocity reduction method and

The static regain method: this is calculated by the equation $\Delta P_{f2} + \Delta P_{d2} = R(P_{v1} - P_{v2})$ where ΔP_f = friction pressure and ΔP_d = dynamic pressure losses

In the velocity reduction method, provided the diameter of duct remains unchanged, after a branch off, the velocity of air reduces. To disallow this velocity reduction, the diameter of the duct should be reduced so as to maintain an appropriate static pressure.

In the statics regain method, the relationship between velocities, static, and total pressure is used.

The relationship is given by as: $\Delta \boldsymbol{T}_{\boldsymbol{p}} = \left(\boldsymbol{V}_{\boldsymbol{p1}} - \boldsymbol{V}_{\boldsymbol{p2}}\right)$ ……….. static regain, Where $\Delta \boldsymbol{T}_{\boldsymbol{p}}$= total pressure drop and $\boldsymbol{V}_{\boldsymbol{p}}$ = velocity pressure

Change in static pressure regain is given as: $\Delta P_s = Kr\left\{\frac{V1^2}{2} - \frac{V2^2}{2}\right\}$, Where

ΔP_s = increase in static pressure as a result of decrease in velocity from $V_1 to\ V_2$

K_r = regain co-efficient = 0.04 for an angle taper of 45^o

In the equal friction method, system ductwork is sized for constant pressure loss per unit length of duct; the working drawing calculation is shown below

Main duct section

Volume flow rate of supply air is calculated as $M_{s\,=\,6.63m^3/s}$

Velocity of air supplied to a space through the main duct is recommended as $5 - 8\ m/s$ for public buildings. Using 6m/s in this design, this cross – sectional area of the required duct is

$$A = \frac{6.63}{6} = 1.105m^2$$

Conclusion

The more increasing sophisticated Architectural building design has allowed engineers to design Central Air – conditioning system for building in order to ascertain actual human comfort. In carrying out this design, proper emphasis should be made to determine the load calculation and the ductwork of the building. A defect in either of the two criteria can cause the following: Poor Air distribution leading to discomfort, Lack of sound attenuator permitting objectionable noise levels and It can cause the system to operate incorrectly.

In duct design effort must be made to consider the following: space, availability, initial investment and cost, system operating cost and noise level.

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