Thermal Performance of Buildings: Case Study and Experimental Validation of Educational Building

Mathew Joseph [1], Victor Jose [2], Anjuman Habeeb [3]

Head of the Department, Dept. of Mechanical Engineering, MBC College of Engineering & Technology, Kerala, India[1]

Assistant Professor, Dept. of EEE, Amal Jyothi College of Engineering, Kerala, India[2]

PG Student [Energy Systems], Dept. of EEE, Amal Jyothi College of Engineering, Kerala , India[3]

ABSTRACT: Thermal performance of buildings refers to the process of modeling the energy transfer between the building and the surrounding. With the sound knowledge of energy associated with the building, energy efficiency of the building can be improved. To have a thorough understanding of the same a case study was included. The main objective behind the paper is to analyze the cooling loads associated within a system and thereby the capacity and sizing of the air conditioning equipment can be made. The estimation is based on the steady state approach. Different parameters like heat transfer modes, solar radiation geometry, evaporation, ventilation effects.etc contribute for the heat load estimation. The main purpose behind this is to avoid unwanted wastage in energy as a result of the conventional thumb rule approach. For better understanding, the simulation of heat load estimation in a room was done using LABVIEW software. With the help of simulation tool, different parameters can be monitored. The major heat load was contributed from internal heat gain. It accounts for about 6400W, a total of 42%.

KEYWORDS: Steady state approach, Heat transfer modes, Solar geometry, LABVIEW Simulation software.

I.INTRODUCTION

Thermal performance of a building refers to the process of modeling the energy transfer between a building and the surroundings. Understanding the thermal performance of buildings calculates the cooling load and hence it helps to estimate the capacity, size and selection of an air conditioning apparatus. For an unconditioned building, it calculates the temperature variation within a building. These are very essential and enable us to determine the effectiveness of the design of the building [1]. The design load is based on inside and outside design conditions. It is based on the estimation of steady state approach of various building elements such as wall, roof, door, etc. and the estimation of overall heat transfer rate.

II.HEAT TRANSFER MODES

For analyzing the thermal performance of the building, knowledge of various heat exchange processes are required. Various heat exchange processes are possible between a building and the external environment. Heat flows by conduction through various building elements such as walls, roof, door, windows.etc. Heat transfer also takes place from different surfaces by convection and radiation.
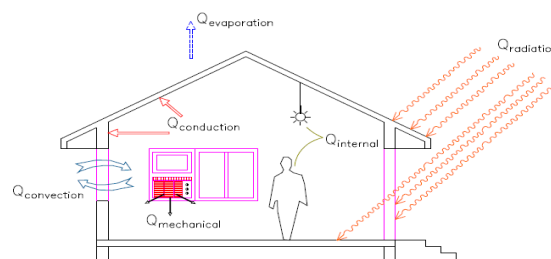

Figure 1. Heat Exchange Processes between a Human Body and the Indoor Environment [1]

A. Ventilation

The heat flow rate due to ventilation of air between the interior of a building and the outside depends on the rate of air exchange. It is given by

$$Q_v = \rho \, V_r \, C \, \Delta T$$

ρ　　　= density of air (kg/ m^3)
V_r　　　= ventilation rate (m^3/ s)
C　　　= specific heat of air (J/ kg-K)
ΔT　　　= temperature difference (To – Ti) (K)
As the ventilation rate increases the heat flow due to ventilation increases.

B. Solar heat gain

Solar gain through transparent elements

$$Q_s = \alpha_s \, \Sigma_{i=1}^{M} \, A_i \, S_{gi} \, \tau_i$$

α_s = mean absorptivity of the spaces
A_i = area of the ith transparent element (m^2)
S_{gi} = daily average value of solar radiation on the ith transparent element (W/m^2)
τ_i = transmissivity of the ith transparent element
M = number of transparent elements

III.SOLAR RADIATION

Sun is the sole source of energy. Sun is a star and is considered as a radiant energy source with surface temperature that is equivalent to a perfect black body at 6000K. Solar radiation stretching from 0.2microns - 4.75microns. Most of the solar radiation lies on the visible radiation and near infrared radiation. It is the only source of heat and light for the entire solar system. Heat is generated by means of various kinds of fusion reactions. Solar constant is defined as the flux of solar radiation on a surface normal to sun's rays beyond the earth's atmosphere at a mean earth-sun distance. Though the solar constant value varies with time, its accepted value is 1367W/m^2. When solar radiation enters into the atmosphere, it gets depleted due to reflection, scattering and absorption.

A. Solar radiation geometry

The incident radiation depends on solar geometry involving several basic and derived angles. Some of the basic angles are:

1.　　　Latitude (φ) indicates the location on the earth's surface. It is the angle made by a radial line joining the given location to the centre of the earth with its projection on the equator plane. The latitude is positive for northern hemisphere and negative for southern hemisphere.

2.　　Declination (δ) is defined as the angular displacement of the sun from the plane of the earth's equator. It is positive when measured above the equatorial plane in the northern hemisphere. It can be approximately determined from the equation
$\delta = 23.45 * \sin[\frac{360}{365}(284+n)]$ degrees

3.　Hour angle (ω). The hour angle at any moment is the angle through which the earth must turn to bring the meridian of the observer directly in line with the sun's rays.

4.　Slope (β), it is the angle between the inclined plane surface and the horizontal. It is taken to positive for the surface sloping towards south.

5.　Surface Azimuth Angle (γ), it is the angle in the horizontal plane ,between the line due south and the horizontal projection of the normal to the inclined plane surface. It is taken as positive when measured from south towards west.

For a surface tilted at an angle β and with no shading, hourly incident solar radiation can be estimated as:

$$I_T = I_g \, r$$

where r is the global radiation tilt factor

$$r = (1- \frac{I_d}{I_g}) \, r_b + (\frac{1+\cos\beta}{2}) \frac{I_d}{I_g} + \rho \left(\frac{1-\cos\beta}{2} \right)$$

$\cos\theta = \sin\varphi \, (\sin\delta\cos\beta + \cos\delta\cos\gamma\cos\omega\sin\beta) + \cos\varphi \; (\cos\delta\cos\omega\cos\beta - \sin\delta\cos\gamma\sin\beta)$
$+ \cos\delta\sin\gamma\sin\omega\sin\beta)$
$\cos\theta_z =$
$\sin\varphi \, \sin\delta + \cos\varphi \, \cos\delta \, \cos\omega$

I_g = mean hourly global solar radiation (W/m^2)
I_d = mean hourly diffuse radiation (W/m^2)
ρ = reflectivity of the ground surface

B. Steady state approach

Heat transfer is the transfer of thermal energy from a body at a higher temperature to a body at a lower temperature. Transfer of heat or heat transfer modes can be modeled in two ways. Under steady state conditions the temperature variation does not change with time. Similarly under, unsteady state conditions the temperature within the system varies with time. Here to make the calculations simpler and easier steady state approach is preferred. In steady state approach the net heat influx is equal to net heat efflux. There is balanced heat load within the system.
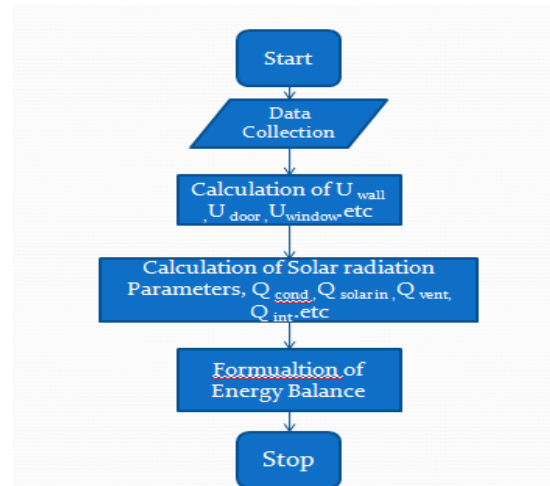

Figure 2: Flow path of heat load

IV. ESTIMATION

Heat load estimation in a classroom is started by having a proper analysis on solar radiation geometry angles acting on each wall namely north, south, west and east. The overall heat transfer coefficient for wall, door, window etc is calculated. Formulated the energy balance equation. Figure 2. shows the flow path of heat load and the estimation of heat load in a room.

V. HEAT LOAD ESTIMATION

General data
Place   : DC 408,Amal Jyothi College of Engineering, Koovappally, Kanjirappally, Kottayam
Month   : November 2014
Ventilation rate   : 3 per hour
Artificial light   : 6 * 40W tube
Latitude: 9˚ 34N
Longitude: 76˚ 47 E

There are several factors which contribute for the heat load in a room. There are several heat gain and heat loss within a system. Sensible heat gain through building structure by conduction, solar radiation, infiltration, ventilation, occupants,

appliances, lighting equipments, etc. the heat gain through different elements that contributes for the heat load within a system is shown in Figure 3.
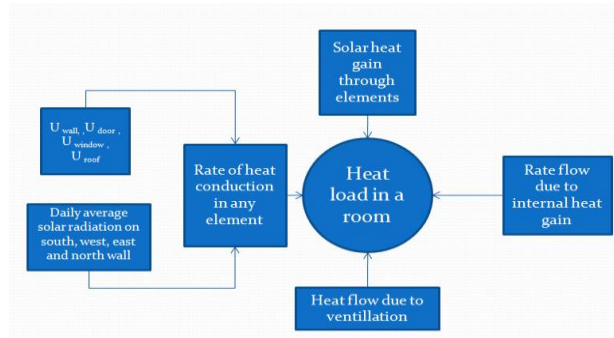
Figure 3. Components of Heat Load

Occupants   : 60 (normal class hours; 24hrs occupancy)
Window   : 196cm * 160cm
Door   : 240cm * 118cm on East side
Wall thickness   : 20cm (brick layer)
Plastering   : 1cm both sides
Ceiling plastering   : 9mm thick(neglect)
Floor   : Tile plastering: 2cm
                               Tile thickness : 1cm

A.overall heat transfer coefficients of different building elements

1. Overall heat transfer coefficient, U_{wall}
Heat transfer coefficient of Brick tile, $h_1 = .798 W/m^2K$
Heat transfer coefficient of Cement plaster, $h_2 = 0.721 W/m^2K$
Length of cement plaster, $L_1 = .01m$
Thermal conductivity of brick, $k_1 = 0.721$ W/mK[1]
        Length of brick, $L_2 = .20m$
Thermal conductivity of brick , $k_2 = 0.798$ W/mK[1]
Length of cement plaster outside, $L_3 = .01m$;
Thermal conductivity of brick, $k_3 = 0.721$ W/mK[1]
Heat transfer coefficient of inside medium, $h_i = 8.3$ W/m^{2}K[1]
Heat transfer coefficient of outside medium, $h_o = 22.7$ W/m^{2}K[1]
        $R_{th} = 0.4429$ m^{2}K/W
        $U_{wall} = 2.257$ W/m^{2}K
2. Overall heat transfer coefficient of door, U_{door}
Thermal conductivity of timber, $k_{timber} = .072$ W/mK
Length of door, $L_{door} = 2.4m$
Width of door $= 3cm$
Breadth of door $= 1.18m$
Heat transfer coefficient of inside medium, $h_i = 8.3$ W/m^{2}K
Heat transfer coefficient of outside medium, $h_o = 22.7$ W/m^{2}K
Thermal resistance, $R_{th} = 33.49$ m^{2}K/W
Area of the door, Area$_{door} = 2.4 *3 *10^{-2}$ m^2

        $U_{door} = 0 .414$ W/m^{2}K

3. Overall heat transfer coefficient of window, U_{window}
Thermal conductivity of glass, $k_{glass} = 0 .814$ W/mK
Thermal resistance ,$R_{th} = 2.13$ m^{2}K/W
Area of window, Area$_{window} = 1.6 *10*10^{-2}$

U_{wall} = 2.93 W/m^{2}K

4. Overall heat transfer coefficient of roof, U_{roof} - neglected.

B. Solar radiation geometry

Daily average outside temperature (November)	- 30°c
Absorptance of external wall surface	- 0.6
Outside heat transfer coefficient, h	- 22.7 W/m^{2}K
Inside design temperature	- 23 °c
Latitude at Kanjirappally	- 9° 34′N
Longitude at Kanjirappaly	- 76° 47′E

1. Daily average solar radiation on south east wall

$$\gamma = -20, \beta = 90, \delta = -18.91, \varphi = 9.56, \ \omega = 0$$

Cos θ = 0.44795
Cos θ_Z = 0.8790
r_b = 0.50951
r = .6053
I_T = 1457.56W/m^2

2. Daily average solar radiation on south west wall
$$\gamma = 70, \beta = 90, \delta = -18.91, \varphi = 9.56, \omega = 0$$

Cos θ =0.1630
Cos θ_Z = 0.8790
r_b = 0.1854
r = 0.4254
I_T = 1024.5 W/m^2

3. Daily average solar radiation on north west wall
$$\gamma = 160, \beta = 90, \delta = -18.91, \varphi = 9.56, \omega = 0$$

Cos θ = -0.44795
Cos θ_Z = 0.8790
r_b = -0.50951

r = 0.04017
I_T = 96.74W/m^2

4. Daily average solar radiation on north east wall
$$\gamma = 110, \beta = 90, \delta = -18.91, \varphi = 9.56, \omega = 0$$

Cos θ = -0.1630
Cos θ_Z = 0.8790
r_b = -0.1854
r   = .2199
I_T = 529.55 W/m^2

C. NET HEAT BALANCE

Q_{total} = Q_c + Q_s + Q_i + $Q v$
Heat flow due to ventilation, Q_v = 2736.79 W
Internal heat gain, Q_I = 6440W

Solar heat gain, Q_s = 2708.08 W
Heat flow due to conduction, Q_c = 1446.55W
Q_{total} = 15635.31W
1tons of refrigeration (TR) =3.52Kw

Therefore it requires a 4.44TR air conditioning equipment. Heat load estimation in a room was carried out. It is found that for a 100m^2 room require a 4TR of air-conditioning equipment. It was estimated for solar noon, therefore it will be having a maximum consumption of power during the day.

VI. SIMULATION SOFTWARE

The simulation of heat load estimation is done using LABVIEW software. It offers several circuit linked operations that can work similar to coded computer languages and provide the output for given input and pre-initialized values. The user interface consists of

 a) Front Panel – where the input and output are shown to the user.

 b) Block Diagram – where the programmer draws the circuit diagram required for the program.

In the program, the input is fed into a "control" and the output is displayed as an "indicator". The operations are done in the block diagram page and controls and indicators are placed in the front panel.

LabVIEW stands for Laboratory Virtual Instrument Engineering Workbench. It was developed by National Instruments to provide a visual programming environment. The latest version of labview is LabVIEW 2013. Execution of commands is as per the graphical block diagram in which the programmer connects functions by wires.

A. Advantages
 i. The graphical environment allows non programmers to develop programs by the drag and drop method.
 ii. It includes a compiler that creates a code for the CPU platform. At the same time, the compiler also detects the presence of any errors.
 iii. A major advantage of the LabVIEW compiler over other coding softwares such as C, C++, etc is that it points out the location of the error. This saves time and lessens effort of the programmer in searching for the error location, especially in lengthy programs.
 iv. LabVIEW has a large library comprising of numerous arithmetic, logical trigonometric, array, matrix and many other types of functions. This helps in reducing code length to a considerable extent.
 v. Code re-use is allowable as long as data types of input and output are consistent.
Parallel Programming can be done by which processes such as test sequencing, hardware interfacing and data recording can be done at the same time.

VII.RESULTS AND DISCUSSION

The paper deals with the study of thermal performance of buildings using steady state approach. Once optimised properly the proper fixation of equipments can be done effectively. By the sub optimal design the energy savings can be achieved.

A. Interpretations
 i. One dimensional steady state heat transfer through buildings, it is possible only when outdoor and indoor temperature do not vary with time.
 ii. The thickness of the building wall is small when compared with other two dimensions.
 iii. Building walls are multi-layered, non homogenous and non isotropic.
 iv. Unshaded area is considered.
 v. Overall heat transfer coefficient of ceiling is neglected.

B. Observation
 1. South wall will have maximum hourly radiation. East and west wall has less radiation. North wall has comparable value.
 2. The building is 20° inclined with respect to east direction.
 3. A simple analysis of Steady state approach is used for the heat load estimation.

C. Results

1	Total heat gain rate	Positive
2	Total heat entering the building	15kW
3	COP of a standard air conditioner of 1.5tons cooling capacity	2.8
4	Power required	5.35kW
5	If the machine is used for 8 hours a day	42.8units consumption & Rs.171.2/-expense daily.
6	Internal heat gain contribution	More

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