BUILDING SIMULATION USING FINITE DIFFERENCE METHOD

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ABSTRACT: This paper presents a transient heat transfer analysis of non air conditioned multi-zone buildings taking into account the effects of heat fluxes through various facades of buildings including windows, air ventilation and infiltration, furnishings and ground heat conduction. User friendly computer software has been developed for the above mentioned purpose. The simulation model presented here uses finite difference method to solve the one dimensional heat conduction equation. The building simulation package developed would be an aid to building architects for better thermal design of non air conditioned buildings.

KEY WORDS: Building Simulation, Multi-zone Buildings, Non Air Conditioned Buildings

1. INTRODUCTION

The fuel crisis in 1972-73 generated worldwide efforts to conserve fossil fuels and search for alternative sources of energy. Approximately one third of our primary energy supply is consumed in buildings. Consequently buildings are primary contributors to global warming. The conservation of heating and cooling loads of buildings through integration of solar passive approaches in non air conditioned buildings therefore assumes considerable importance.

The limitations of designing highly mechanized buildings are readily apparent from the fact that the life of air conditioning equipment is much less than that of building fabric. Space occupied by the air conditioning equipment, noise created, their maintenance and replacement costs are some of the penalties one has to pay for having sealed and completely air conditioned buildings. Evidences even suggest that sealed and highly mechanized buildings may be less healthy to work in. In any case it is better to ensure that buildings are designed from the passive point of view before installing active equipment.

The thermal design of a building for efficient heating/cooling embraces a large number of factors that affect the energy balance and hence energy consumption. Since the role of various design and weather parameters in predicting the thermal behavior of a building is too intricate to be assessed independently it is desirable to develop comprehensive models, which include all the important factors and enable one to indicate the effect of different factors on the building performance. To this end, solar thermal modeling of buildings has attracted a great deal of attention from scientists and engineers all over the world [1, 2].

In this paper, a transient generalized heat transfer analysis has been proposed for non air conditioned multi-zone buildings. Finite difference method is used to solve the one dimensional transient heat conduction equation. Based on this, a computer code has been written and a computer package has been developed which is user friendly and has features comparable to those of commercially available building simulation programs.

2. HEAT TRANSFER ANALYSIS

The heat balance of a non air conditioned building is influenced by (i) weather factors, i.e. the environmental variables like solar radiation and ambient air temperature etc which may be assumed to be periodic functions of time on a daily cycle; and (ii) design factors which are under human control and can be used to maximize energy conservation and thermal comfort inside the building.

A zone is defined as a fully mixed volume of space with a constant concentration level of enclosed gas mixture and it is at a single uniform pressure and temperature. The actual buildings have constructions that would characterize them more accurately as multi-zone structures rather than single zone structures. The estimation of thermal performance of a building involves the calculation of heat fluxes entering various zones through external walls and roof, solar gains through windows, heat interaction with floor and other objects, the infiltration and ventilation exchanges, inter zonal heat transmission and internal heat gains. The variation of inside air temperature of a zone is taken as a measure of the thermal performance of the zone. The energy balance for room air can be written as:

$$[M_{air}C_{air}dT_{air}(\tau)/d\tau]_j = Q_j^{wr}(\tau) + Q_j^{wi}(\tau) + Q_j^{I} - Q_j^{g}(\tau) - Q_j^{s}(\tau) - Q_j^{v}(\tau) - Q_j^{p}(\tau) \qquad \text{----(1)}$$

where the left hand side of the equation represents the change in the internal energy of the inside air of the jth room. The right hand side represents various heat transfer rates to or from the room air through walls and roof ($Q_j^{wr}(\tau)$), windows($Q_j^{wi}(\tau)$), internal gains(Q_j^{I}), floor($Q_j^{g}(\tau)$), isothermal mass($Q_j^{s}(\tau)$), infiltration and ventilation($Q_j^{v}(\tau)$), and to the neighboring zones through partition walls($Q_j^{p}(\tau)$).

Equations similar to Eq.(1) can be written for all zones. The various heat transfers can be expressed in terms of room air temperatures and the resulting equations can be solved for room air temperatures.

In the present analysis the following reasonable assumptions are made:

i) Heat flow through the walls/roof is one dimensional in nature;
ii) The building materials are homogeneous and their thermo physical properties are constant;
iii) The inside air temperature is uniform;
iv) As the time needed for window to reach equilibrium is short compared to any other time scale in the problem, a steady state is assumed for the heat transfer through windows;
v) All furnishings are assumed to be equivalent to an isothermal mass inside the room;
vi) A fixed number of air changes per hour would occur due to the air leakage and opening of doors/windows;
vii) The outside air temperature for all walls/roof is same, which is true for a building of moderate height.

FINITE DIFFERENCE METHOD [3]

Majority of calculations involved in building thermal simulation are concerned with heat transfer through walls roof and floor. The heat flux through any fabric (wall, roof, floor or ceiling) having multilayered structures can be obtained by solving one dimensional transient Fourier heat conduction equation with appropriate boundary conditions. This can be conveniently solved by finite difference equations. The one dimensional transient Fourier heat conduction equation for heat transfer through a slab is given by [4]

$$\partial^2 T / \partial X^2 = 1 / \upsilon \, \partial T / \partial \tau \qquad \text{------------ (2)}$$

where υ is thermal diffusivity. In the form of a difference equation it can be written for two consecutive homogeneous internal slabs in a wall as follows [5]:

$$Area_{N+1} / R_{N+1} (T^{\tau}_{N+1} - T^{\tau}_{N}) - Area_N / R_N (T^{\tau}_{N} - T^{\tau}_{N-1}) = \{ Area_N \rho_N c_{pN} d_N / 2 + Area_{N+1} \rho_{N+1} c_{pN+1} d_{N+1} / 2 \} \{ (T^{\tau}_{N+1} - T^{\tau}_{N}) / \delta\tau \} \qquad \text{------------ (3)}$$

where $(T^{\tau}_{N+1} - T^{\tau}_{N})$ is the variation of temperature at the interface N in the interval $\delta\tau$ between time τ and time $\tau + 1$, as a consequence of the temperature gradient at the interfaces N – 1, N and N + 1 at a distance d_N between them. R_N denotes the thermal resistance between interfaces N - 1 and N.

The solution of above equation for T at the interface N is of the form

$$T^{\tau+1}_{N} = A_N T^{\tau}_{N+1} + B_N T^{\tau}_{N} + C_N T^{\tau}_{N-1} \qquad \text{------------------- (4)}$$

where

$$A_N = (Area_{N+1} / R_{N+1}) \delta\tau / D_N \qquad C_N = (Area_N / R_N) \delta\tau / D_N$$
$$B_N = 1 - (A_N - C_N) \qquad D_N = Area_N \rho_N c_{pN} d_N / 2$$

If the surface N is in contact with air, RN is the thermal resistance due to convection or radiation or both. If N is an internal surface, the effects due to internal heat gain, air infiltration and that of mechanical heating or cooling can be incorporated. If N is an external surface then effects due to long wave radiation exchange with the sky and the incident radiation at the surface can be incorporated. The use of finite difference representation necessitates the use of large digital computers.

3. COMPUTER SOFTWARE

It should be mentioned that the computer package developed for the purpose has some unique features though the analysis part may not represent them. While the calculation can account the various heat transfer rates discussed in this analysis, it can handle any number of layered structures for building fabrics. Similarly, the program can easily incorporate the fact that the building may have any number of zones and a partition wall may be common to any number of zones. It has a user-friendly menu. Input data files can be created or modified by choosing the appropriate options. Obtaining formatted outputs and viewing results graphically are other features of the package.

4. RESULTS AND DISCUSSION

In order to check the validity of analysis and the software developed, a simple hypothetical rectangular building with four zones has been considered as shown in Figure 1.

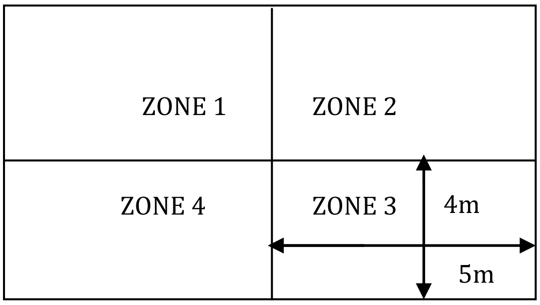

Figure 1. PLAN VIEW OF A SAMPLE BUILDING

The building is simulated using the package developed by authors. The relevant data needed for calculation are listed below:

Day: 10th March Location: New Delhi (28.35° N, 77.2°E), India
Height of the building: 3 meters
Each external wall has one window of 1.4 m^2 area; Transmissivity of glass: 0.85
Absorptivity of room air: 0.1
Air exchange rate for each zone: 0.5 air change per hour
Heat transfer coefficients between outside air and external surface: 22.7 W/m^2K
Heat transfer coefficients between inside air and interior surface:

Wall: 8.29 W/m^2K
Roof: 6.13 W/m^2K
Floor: 9.26 W/m^2K
Heat transfer coefficient for windows: 4.5 W/m^2K
Solar absorptivity of external surface: 0.6

Wall types:

	Layer 1	Layer 2	Layer 3
Normal wall	Plaster	Brick	Plaster
Roof	Plaster	Concrete	Plaster
Floor	Plaster	Concrete	Stone

Wall properties/dimensions:

Type	Conductivity (W/m K)	Density (kg/m^3)	Specific heat(J/kg K)	Thickness (m)
Plaster	0.5	1300	1000	0.025
Brick	0.84	1700	790	0.23
Concrete	1.4	2100	840	0.1
Stone	1.29	2200	712	0.3

The results are presented in the following graph:

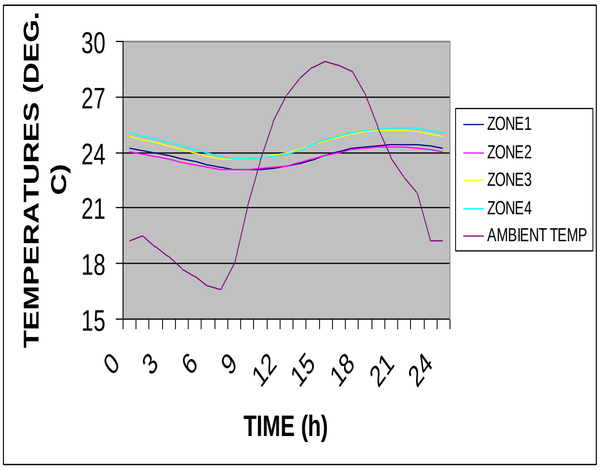

Figure 2. Variation of inside air temperature over 24 hours of a day

From Figure-2 it is evident that the inside air temperature of different zones vary continuously with time implying the need of transient heat transfer analysis for building thermal simulation. The minimum inside air temperature is at 0800 hours and maximum is at around 2000 hours. As expected the inside air temperatures of zone3 and zone4 are nearly same. Similarly zone1 and zone2 temperatures are nearly same.

5. CONCLUSION

A transient heat transfer analysis of non air conditioned multi-zone buildings has been developed, taking into account the effects of heat fluxes through various facades of buildings. The mathematical model is based on finite difference method to solve the one dimensional transient heat conduction equation. The features of the software are comparable to those of commercially available software packages to a reasonable extent. It is obvious that the inside air temperatures of various zones and heat fluxes are sensitive functions of building design parameters and can be adjusted at the design stage to achieve maximum thermal comfort in non air conditioned multi-zone buildings. The building simulation package developed would be an aid to architects/civil engineers for better thermal design of non air conditioned multi-zone buildings.

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