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Prediction of Heat Flux by an Approximate Method in an Unconditioned Room

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This paper analyses the relevance of an approximate method, using factors such as time-lag and decrement factor, in the prediction of heat flow of an unconditioned room. The approximate method, for conditioned environment, suggested by Koenigsberger et al (Ref. 8) has been modified suitable for the unconditioned environment and utilised in this analysis. The theoretical analysis is supported by a case study, which is a room in the top floor a multistorey building. The results show that the approximate method is better in predicting the values of heat flow, but involves less effort than the admittance method.

Introduction

The flow of heat into and out of the fabric of a building, in reality, is dynamic because of the changing environmental elements such as external air temperature, solar radiation, humidity and wind. Therefore, analysis and prediction of hourly, daily and seasonal building performance should be based on dynamic considerations. The basic principles of various methods used for calculating cooling of heating loads have been reviewed by Stephenson (Ref. 1), Gupta (Ref. 2), Gupta et al (Ref. 3), Davies (Ref. 4), Givoni (Ref. 5), Clarke (Ref. 6) and Francisco Arumi-Noe et al (Ref. 7). The calculation of heat, if one in a rigourous way, involves a lot of complexity. The time and expense involved in the calculation sometimes deter practising architects or engineers from using such highly sophisticated procedures to design or monitor the thermal performance of the building.

This paper deals with the relevance of an approximate method in predicting the heat flow in particular, the estimation of heating/cooling load, in an unconditioned room, using empirical fabric performance factors such as time-lag and decrement factor. The approximate method, for conditioned environment, suggested by Koenigsberger et al (Ref. 8), has been modified suitable for the unconditioned environment and utilised in this study. An application of this method is shown, in which the measured and calculated heat fluxes by approximate and admittance methods of an unconditioned room located in the top floor of a brick masonry residential building in Delhi have been compared.

The geographical location of Delhi is $28^{\circ}38'$ N latitude, $77^{\circ}17'$ E longitude with height above mean sea level 218 metres. The climate at Delhi is of composite in nature (Ref. 8). The climate is characterised mainly by three seasons, viz., hot-dry, warm-humid and cool-dry with long transition periods in between these.

Experimental Investigation

Description of Test Room

As detailed in the paper by the author et al (Ref. 9,10) the test room is an unconditioned one located in the top floor of a brick masonry residential building in Delhi and the plan of the same is shown in Fig. 1. The constructional features are the same as given in the above mentioned references. The thermophysical properties and values of coefficients of heat transfer used are the same as those mentioned in the earlier paper (Ref. 9). Throughout the test period, the test room remained closed except for the need to enter the room for the purpose of taking measurements. An infiltration rate of 3 air changes per hour had been considered based on the results obtained from the study (Ref. 10,11).

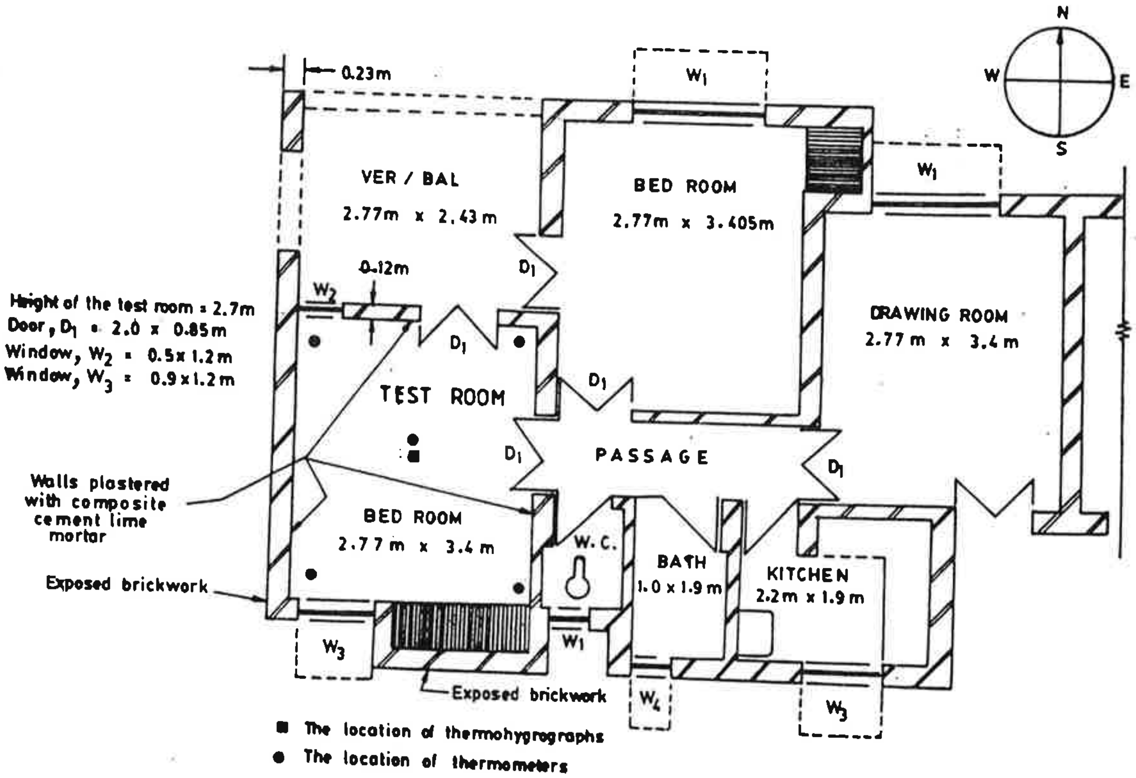

Figure 1: Plan of the test room

Instrumentation

The densities of different surface heat fluxes have been measured by using a Shotherm heat flow meter from Showa Denko K.K., Japan. Hourly observations of heat flow rates (at the centre of each surface) were recorded for a continuous period of 24 to 36 hours at a time, usually at least once a month.

Approximate Method

Koenigsberger et al (Ref. 8) described periodic heat flow rate through a building element under the assumption of constant indoor temperature (considered as a reasonable approximation in controlled environments) as:

$$Q = A \times U \times [(T_m - T_i) + \mu(T_\phi - T_m)] \qquad (1)$$

where Φ and μ are the time-lag in hours and the decrement factor of a building element respectively. T_ϕ is the outdoor temperature Φ hours earlier in ^oC.

In equation (1), the time-lag has been considered as the difference between the time of occurrence of peak indoor temperature and that of outdoor temperature or the difference between the time of occurrence of minimum indoor temperature and that of outdoor temperature, due to a specific building element. Similarly, for a given building element, the decrement factor or amplitude attenuation has also been considered as the ratio of the maximum indoor and outdoor temperature amplitudes taken from the daily mean (Ref. 8).

The values of time-lag (function of density and varying thickness) and the values of decrement factor (function of thickness) for different varieties of construction have been suggested in the literature (Ref. 8) and the same have been adopted while using the equation (1).

In the present study, it has been observed from the recorded temperature data, for a period of one year, mean external and mean internal air temperatures are nearly the same for the room under test (Ref. 11). From the recorded data, it is observed that, generally, during steady cyclic periods, the difference between mean external and mean internal air temperatures did not exceed 2.0^{o}C. To take this aspect in to consideration, the equation (1) is approximated based on the model suggested by D'Cruz and Radford (Ref. 12). The details in the approximation are:

The mean heat flow by conduction heat gain or loss through a opaque surface is given by

$$A \times U \times (T_{mo} - T_{mi}) \qquad (2)$$

The variation from the mean heat flow at time t is

$$A \times U \times \mu \times (T_{\phi} - T_{mo}) \qquad (3)$$

Thus the actual rate of heat flow at a time t is obtained by summing the equations (2) and (3).

$$\text{i.e., } Q = A \times U \times [(T_{mo}-T_{mi}) + \mu(T_{\phi} - T_{mo})] \qquad (4)$$

Values of time-lag and decrement factor for individual elements have been obtained from the relationships suggested by Koenigsberger et al (Ref. 8). Apart from the heat flow due to conduction, a convective heat flow with 3 air changes per hour had been added for the comparison with the measured values of heat flow and predicted values of heat flow by the admittance method.

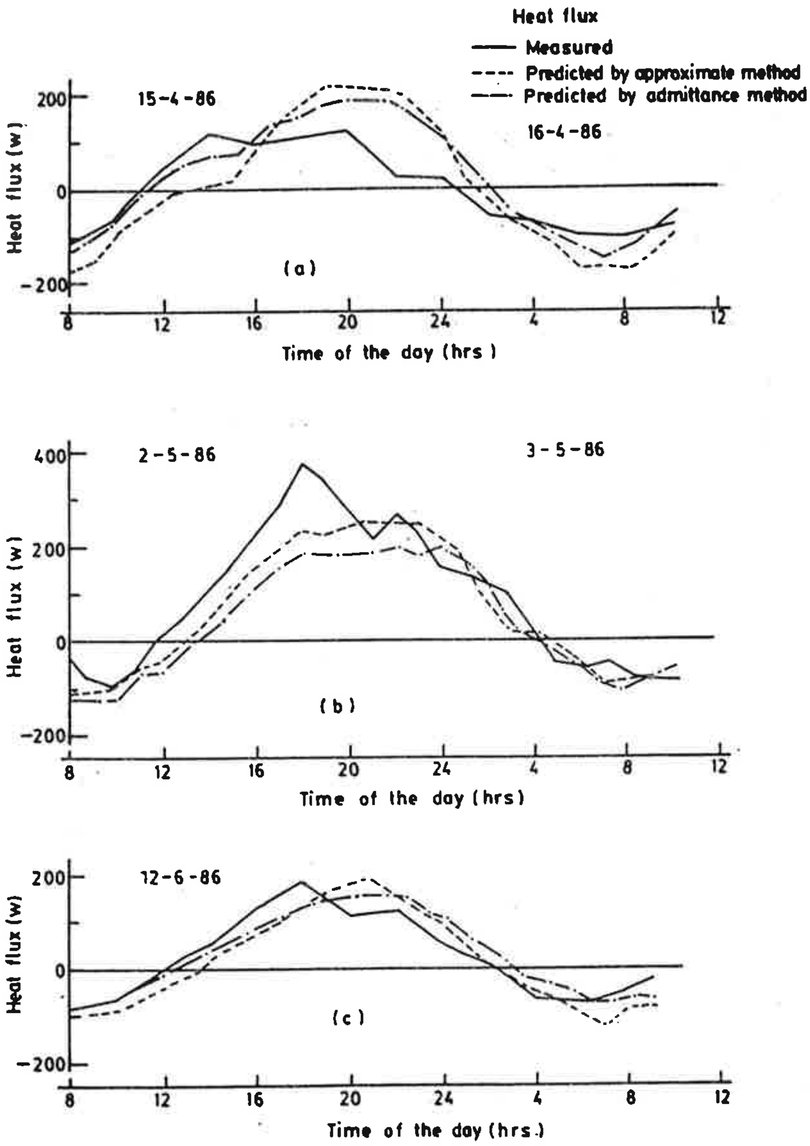

Figure 2(a-c): Variation of heat flux.
2(c) belong to hot-dry, 2(d) to warm-humid, and 2(e) to 2(f) to cool-dry

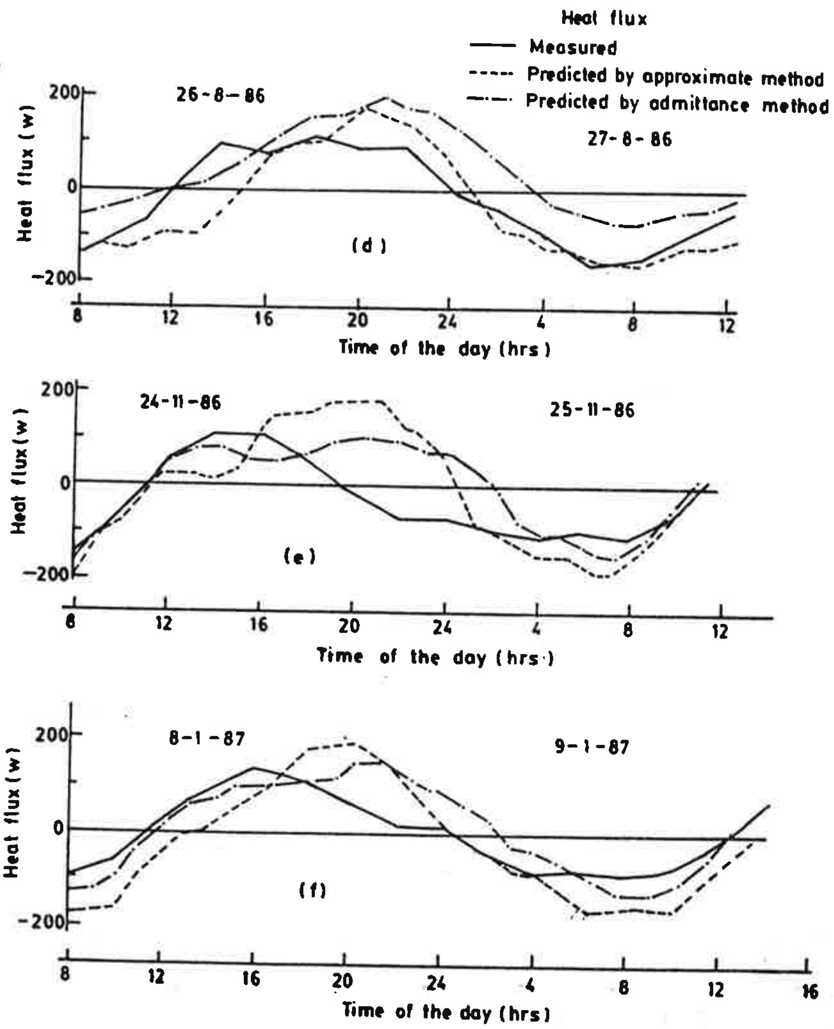

Figure 2(d-f). Variation of heat flow

Whenever the mean external temperature was equal to the mean internal air temperature, the steady-state term in the equation (4) had been considered as zero.

Using the equation (4) the heat flow conducted through the fabric of the building is calculated for all the days during which heat flow measurements had been taken.

The calculated conduction heat flux values have been augmented with the heat flow due to infiltration of three air changes per hour. A sample calculation is given in the Appendix.

Admittance Method

The Admittance Method, developed at B.R.E, U.K., basically consists of two parts. The first one is the 24 hour mean or steady state condition and the second one is the fluctuation about this mean. It has been considered in this method that the net conduction heat flow due to air temperature difference, over the 24 hour cycle is zero.

The details of this method along with the modifications incorporated in the predictive modelling for the case study in question have been mentioned in paper by the author et al (Ref. 9).

Results

The values of the predicted heat flow with approximate method as well as those calculated with the admittance method and the measured values of heat flow are shown in Fig. 2. Figures 2(a) to 2(c) belong to hot-dry, 2(a) to
d

warm-humid, and 2(e) to 2(f) to cool-dry seasons respectively. The agreement between the measured values of heat flow and those obtained by an approximate method is good. It shows the approximate method is equally good in predicting the values of heat flow but in a quick manner. It is also noted that on some days the approximate method predicts better than the admittance method. Since heat flux estimates are required for estimating cooling/heating loads when the buildings are sought to be conditioned, the approximate method suggested by Koenigsberger et al predicts reasonably accurately such heat flows.

Conclusion

This study helped in arriving at a conclusion that, for an unconditioned building with a high thermal damping system (where, in general, the mean ambient temperature is equal to the mean inside temperature except in extreme situations) a rigourous thermal model may not be necessary in calculating the heat flow loads.

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List of Symbols

Q = momentary heat flow rate in W

A = area in m^2

U = transmittance, $W/m^2\,^oC$

T_m = daily mean out-door temperature, ^oC

T_i = indoor temperature (constant), ^oC

$T\phi$ = outdoor (sol-air) temperature ϕ hours earlier, ^oC

ϕ = time-lag in hours

μ = decrement factor

T_{mo} = daily mean outdoor temperature, ^oC

T_{mi} = daily mean indoor temperature, ^oC