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INFLUENCE OF AN 'IMPROVED' AIR INFILTRATION ALGORITHM ON THE NBSLD PROGRAM PERFORMANCE

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1. Introduction

In the context of the present work, it was felt desirable to quantify the influence of input values for air infiltration on the predicted heating/cooling load within typical domestic dwellings.The NBSLD program (1), which is one of the most sophisticated dynamic building thermal model, was chosen for this purpose for two main reasons: firstly because of the author previous experience in its use (2) and secondly because it was well documented.

2. Fundamentals of the NBSLD program

In the NBSLD program the transient heat conduction through exterior walls of a room or space are handled by using the response factor technique. This technique makes extensive use of the 'convolution principle' to account for the thermal storage effect of the building structure. According to this principle any time-dependent variable, A, which may be expressed as a time series, and is influenced by another time series, B, can be written in linear form:

$$A_t = \sum_{j=0}^{m} x_j B_{t-j} \qquad (1)$$

In equation (1), the value of A at time t is expressed as a linear function of all the time values of B at t=t, t-1, t-2... t-m with X_0, X_1, ...X_m being the time-dependent coefficients. The above equation is called the convolution and X_0, X_1,...X_m are called the response factors when refering to wall or roof heat conduction. The value of m in the convolution equation depends upon the degree to which the time parameter B_{t-m}(or B at m hours previous to time t) would influence the value of A. If the response of B_{t-m} upon A_t is insignificant, X_m is nearly zero and values of B beyond the $(t-m)^{th}$ hour are of no importance. If no time lag effect exist between the two time series, A and B, then the value of m will be zero or the response factor X_j will be zero except for the first term X_0. The way the response factors are calculated will not be described here, since it involves lengthy mathematical solutions to the standard transient heat conduction differential equation. Kusuda (3) provides an excellent background to these calculations.

The NBSLD program can be used for estimating the internal air temperature distribution in unconditioned buildings or the heating/ cooling load distribution for constant or varying internal conditions. Alternatively it can determine the prevailing internal air temperature when the plant input or extract does not match the heating or cooling load required to maintain constant temperature conditions. The program can therefore be run in two different modes: room temperature calculation mode or the room load calculation mode. The room temperature mode requires the simultaneous solution of all the balance equations in order to determine the surface temperatures together with the internal air temperature. On the other hand, the room load calculation mode requires the room air temperature to be prescribed and only the room surface temperatures are computed. The convective heat exchange between the room air and the heat emiting surfaces is the cooling load (or the heating load if the heat is lost from the surfaces).

3. The test houses

The FLOW program (4) had been individually verified prior to incorporation into the NBSLD program. Nevertheless it was felt desirable to validate the revised version of the NBSLD program (Standard version + sub-model). Theoreticaly, this can only be performed by comparing the program results with the corresponding field measurement data. In practice, however, such a task is faced with many difficulties. Problems commonly encountered in this area include (i) change experienced in the thermal properties of the building fabric due to fluctuations in moisture content (ii) actions of occupants with regard to window opening and blind operation, (iii), the quality of the building workmanship, (iv) the availability of a comprehensive set of simultaneously recorded climatic data and structural design information, and (v) the expense associated with extensive building instrumentation. Tese comments are in line with one of the conclusions from the IEA annex I (5) which stated that: 'in order to define a building and/or a system in sufficient detail such that analysts need make no assumptions about the input data, an incredible amount of detail has to be provided, which is not realistic in the design situation. Consequently, differences arising from interpretations of the specification are liable to produce significant differences in predicted energy consumption, irrespective of the computer program quality'.

Unfortunately, no field measurements appear to be available to facilitate a proper validation study. For winter conditions it was, therefore, decided to perform only a sensitivity analysis on the NBSLD program by adopting a 'hypothetical' detached house broadly based on the multi-layered construction of the 3-bedroomed, terraced houses in Livingston, Scotland that were studied by Clarke and Forrest (6). In addition, a ground floor insulation slab was included to reflect a 'heavy' (or thermally 'massive') structure, while the height of each room in the two-storey dwelling were assumed to be 2.8 metres.

4. The winter meteorological set of data

In order to simulate the heating load for a typical winter day within the Livingston 'test house', meteorological data for Kew, London (51°28'N,0°19'W) on the 21st December 1964 was employed. This constitutes part of the data base for the CIBSE (Chartered Institution of Building Services Engineers) 'Example Weather Year' (7).

5. Comparative analysis on the NBSLD program

The NBSLD program, although otherwise sophisticated, estimates the air infiltration rates into a building by employing the empirical Achenbach - Coblentz correlation (8) derived by regression analysis of data obtained by Bahnfleth et al (9) from two test houses at the University of Illinois - USA, with the constants arbitrarily multiplied by a correction factor, δ, to "more closely correspond to a typical house" (10). The air infiltration rate, in air changes per hour, I, is calculated using the expression:

$$I = (0.15 + 0.0291V + 0.009\ \Delta T)\delta \qquad (2)$$

where

$$\delta = I_w/0.695 \qquad (3)$$

where I_w, is an assumed typical hourly air change rate during the winter months and ΔT is the indoor-outdoor temperature difference. Care must be taken in using this general regression equation as a predictive model for an arbitrary house because the constants will vary from site to site. Furthermore, this analysis takes no account of the complex interactions between wind-speed, indoor-outdoor temperature difference and fan operation.

Comparisons between the measured air infiltration rates and the estimates made by the FLOW and NBSLD programs for the Maugwill and HUDAC houses (11) are shown in Figures 1 and 2 respectively. Following the NBSLD normal procedure, the I_w value was taken as unity, increasing in this way, the original Achenbach - Coblentz relationship by 44%. The FLOW program, as expected, gives good agreement for both key data sets . The NBSLD relationship, on the other hand, yields large discrepancies between measured and calculated values.

In order to calculate the heating load it was necessary to estimate the leakage distribution of the Livingston 'test house'. The leakage characteristics of windows and doors were determined from published values given by ASHRAE (12). In addition the total building leakage was estimated, again following ASHRAE recommendations, by considering that the leakage from windows and doors represent 15% of its value. The leakage characteristics of windows and doors were used directly, while the deficit between component and total building leakage was evenly distributed along the roof/wall junction and the gable/roof junction for the single-cell version and in accordance with the exposed area for the multi-cell version. The assumed flow networks, and the corresponding leakage characteristics of each flow path, for the single and multi-cell versions, are presented by Melo (12).

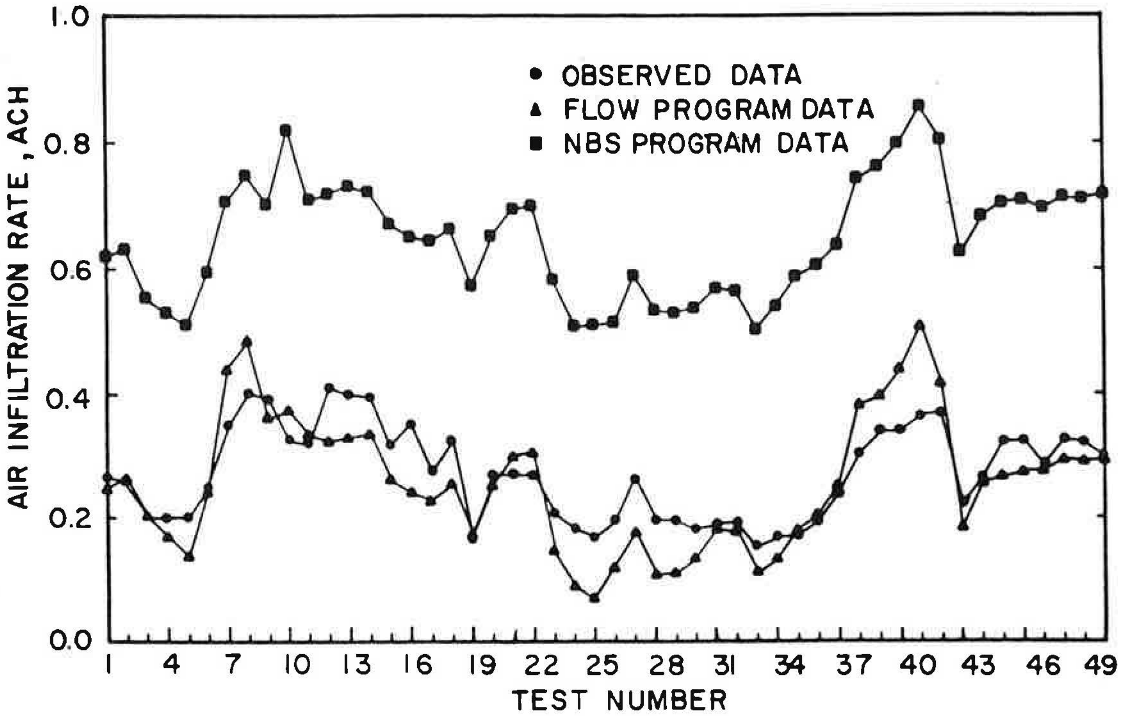

Fig.1 - Measured air infiltration rates compared with the computations of the FLOW and NBSLD programs - Maugwill house.

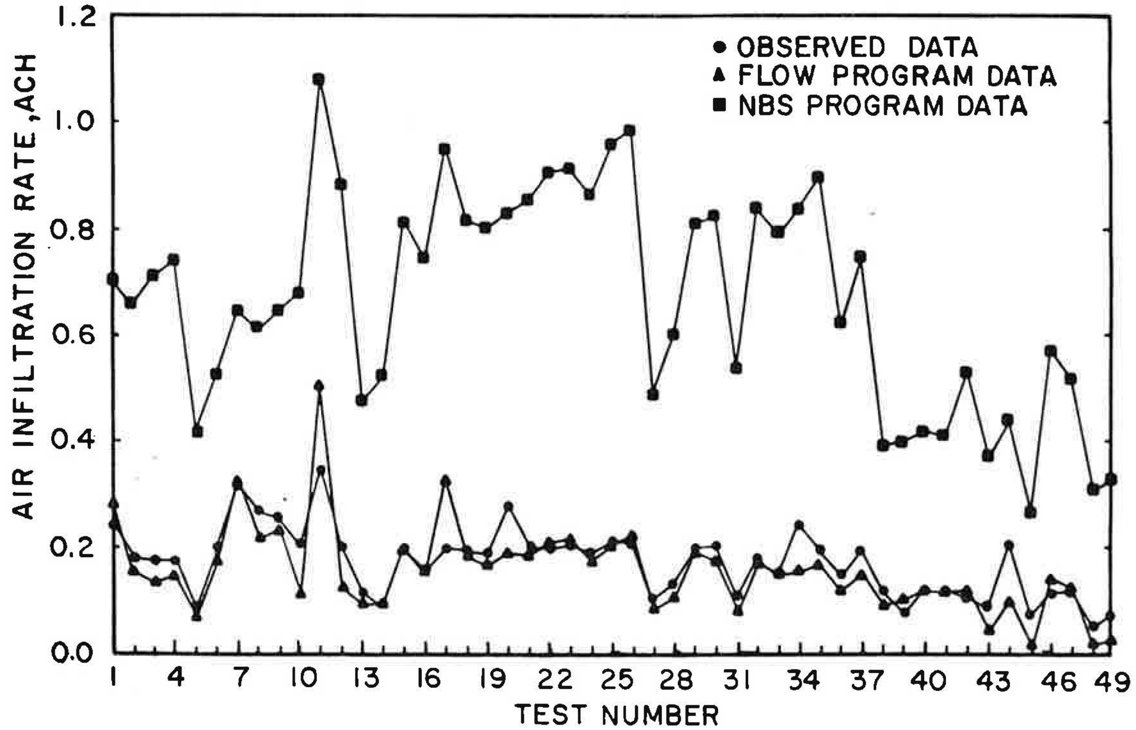

Fig.2 - Measured air infiltration rates compared with the computation of the FLOW and NBSLD programs - HUDAC 'upgraded' house.

The upper part of Figure 3 shows the air infiltration rates computed by the NBSLD program and by both versions (single and multi-cell) of the FLOW program, on a typical winter day. The lower part of this figure shows the resultant heating load profiles when the NBSLD program is 'fed' with these air infiltration rate profiles.

Table 1 shows a comparison between the daily energy consumption computed by the NBLSD and by both versions of the NBSFLOW (NBSLB + FLOW) program on a typical winter day, for each room and for the 'whole house'.

Table 1 - Daily energy consumption computed by the NBSLD and NBSFLOW programs.

ROOM	ENERGY CONSUMPTION(Watth)			$\frac{FLOW(S)^{1}-STD^{2}}{STD}$ x100	$\frac{FLOW(M)^{3}-STD}{STD}$ x100
	NBSLD	NBSFLOW (single)	NBSFLOW (multi)		
Living	19547	21555	19194	10.27	-1.81
Kitchen	12364	12122	11134	-1.96	-9.95
Bedrooml	9113	9697	9331	6.41	2.39
Bedroom2	9864	10753	10853	9.01	10.03
Bedroom3	9922	11009	11621	10.96	17.12
TOTAL	60810	65136	62133	7.11	2.18

1 Single-cell version of the NBSFLOW program
2 NBSLD program
3 multi-cell version of the NBSFLOW program.

It can be seen, in this table, that the 'whole house' energy consumption was approximately 61 kWh and this increased by 7% or 2% as either the single or multi-cell version of the FLOW program were added. The small difference between the results of the original NBSLD code and both versionsof the NBSFLOW program gives a false impression of the accuracy of the NBSLD relationship employed for estimating the air infiltration rates. In reality, a combination of errors in estimating the individual room air infiltration rates leads to a false match with the 'whole house' data.

6. Conclusions

The algorithm employed by the NBSLD program for estimating the air infiltration rates appears inadequate. The NBSLD air infiltration rates are calculated disregarding any influence of the leakage characteristic of the building being simulated. This kind of approach is no longer acceptable for modern purposes since the amount of air infiltration into a building has a instantaneous effect on the resulting heating/cooling load. It therefore needs to be accurately determined.

The NBSLD program, in common with other dynamic building thermal models, can only provide comparative results between various design options, because it cannot, at the moment, accurately compute the heating /cooling capacity of any air conditioning system. The program performance was considerably improved by incorporating the FLOW computer code. However, a lot of research effort has still to be undertaken before this program can be accepted as a general 'tool' for calculating the cooling/ heating requirements of a building.

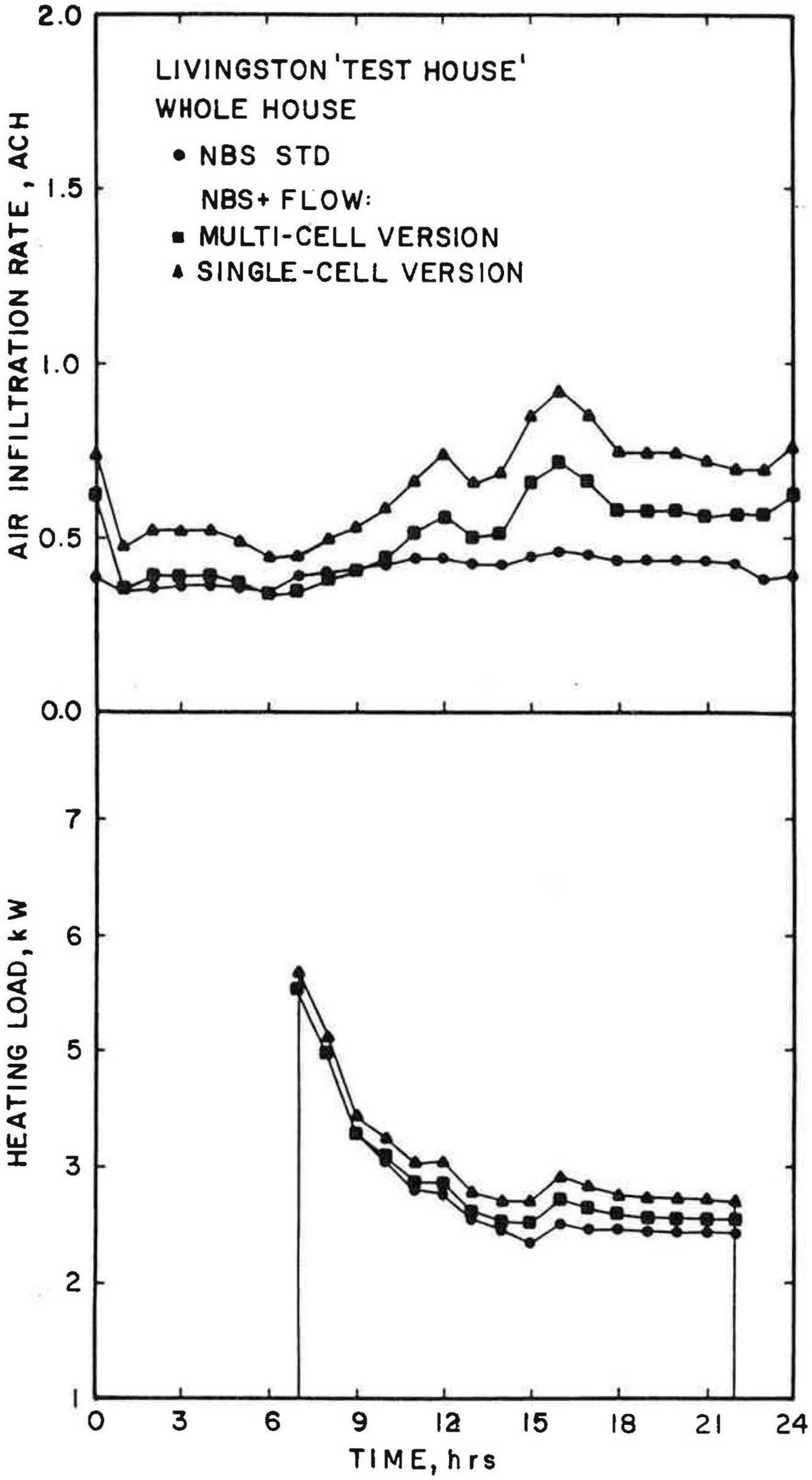

Fig. 3 - Air infiltration rates and heating loads computed by the NBSLD and NBSFLOW programs.

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