Air Distribution in Rooms, (ROOMVENT 2000)
Editor: H.B. Awbi

THE INFLUENCE OF AIR INFILTRATION ON THE THERMAL DYNAMIC BEHAVIOUR OF BUILDINGS

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ABSTRACT

The thermal dynamic behaviour of buildings is solved by different methods; one of them is based on simulation by means of thermal node models. Computed results of the internal air temperature or the surface temperature are influenced by the used method, by the model for a solved problem situation, and by input values of model elements. The influence of the particular model element can be found by means of a sensitivity analysis. An example shows the calculation of the relative sensitivity for all parameters in a model describing the dependence of the interior air temperature changes on the external air temperature changes for one room of a building. Resultant values demonstrate the importance of conductivities related to the window, i.e. the thermal conductivity and the ventilation conductivity. The outcomes of this research reflect the necessity of using accurate air infiltration rate which influences the outputs obtained from a computer simulation much more than other parameters.

KEYWORDS

air infiltration, dynamic behaviour, sensitivity analysis, node model, computer simulation, heat transfer, lumped parameters

INTRODUCTION

The investigation of thermal dynamic behaviour of the building-external environment system leads to the application of thermal node models, Vytlačil (1993). These models help building designers to find optimal values of building parameters for different problem situations related to the summer or winter period. A well-designed building provides a low energy consumption and occupants' comfort.

Since thermal models started to be applied, there have been discussions about the accuracy of the method or used models. This paper is focused on the influence of input values on computed results which is usually an internal air temperature in rooms or a surface temperature of a building shell and other internal structures. Other models can find the optimal power of a heating system or an air-conditioning system, Vytlačil (1994).

THERMAL MODEL

The model describing the dependence of internal air temperature changes on external air temperature changes was developed. The one room model includes the most important building elements which have the influence on the thermal transfer: thermal conductivity of the building shell K_W, window conductivity K_O, ventilation conductivity K_A, thermal transfer conductivity between the shell and the interior K_I, thermal capacity of the shell C_W, thermal capacity of interior C_I, surrounding walls thermal capacity C_S, thermal transfer conductivity between interior and surrounding walls K_S. All elements are considered as lumped parameters. The relationship between thermal flows and temperatures is described in the matrix form in Eqn. 1. External temperature is T_1, internal surface shell temperature is T_2, interior temperature is T_3, internal wall surface temperature is T_4 and s is Laplace operator.

$$\begin{bmatrix} Q_1 \\ Q_2 \\ Q_3 \\ Q_4 \end{bmatrix} = \begin{bmatrix} K_W + K_O + K_A & -K_W & -K_O - K_A & -K_S \\ -K_W & K_W + K_I + sC_W & -K_I & \\ -K_O - K_A & -K_I & K_A + K_O + K_S + sC_I & \\ K_S & & & K_S + sC_S \end{bmatrix} \cdot \begin{bmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \end{bmatrix} \qquad (1)$$

A solution of this matrix after Laplace transformation with algebraic complements is Eqn. 2.

$$T_3 = \frac{\Delta_{13}}{\Delta_{11}} \cdot T_1 = \frac{N(s,x)}{D(s,x)} \qquad (2)$$

$N(s,x)$ and $D(s,x)$ are polynoms with variable s and x.

SENSITIVITY ANALYSIS METHOD

The importance of model parameters is found by means of sensitivity analysis. Principles and a more detailed description of the method are given in Vytlačil & Moos (1993). For solving practical problems we usually use the relative sensitivity, see Eqn. 3, in which F is a function described in Eqn. 2, x is an investigated parameter and F_0 and x_0 are nominal values of the parameter and the function.

$$Sr^F_x(s,x) = \frac{dF(s,x)}{dx} \cdot \frac{x_0}{F_0} \qquad (3)$$

The relative sensitivity can be also determined by Eqn. 4.

$$Sr^F_x(s,x) = x \cdot \left(\frac{N'}{N} - \frac{D'}{D} \right) \qquad (4)$$

After substitution $s = j\omega_0$, where j is an imaginary unit, relative sensitivity can be calculated. The resultant value is a complex number, where the real part expresses the sensitivity of the temperature amplitude and the imaginary part expresses the sensitivity of the phase delay to the change of the parameter x, as written in Eqn. 5.

$$Sr^F_x(j\omega) = ReSr^F_x + j\ ImSr^F_x \quad (5)$$

CASE STUDY

In this section, relative sensitivities are calculated for all parameters in the thermal model. The building shell is made up of bricks. The wall thickness is 0,45 m. The input values of a model are given in Table 1.

TABLE 1
INPUT VALUES

K_W	K_O	K_A	K_I	K_S	C_W	C_I	C_S
		$(W \cdot K^{-1})$				$(Wh \cdot K^{-1})$	
14.7	4.2	5.6	84.4	322.0	1650	55	720

Results of simulation

Resultant values are shown in Figure 1. The relative sensitivity is the most important for the ventilation conductivity K_A that is derived from the air infiltration and depends on window and door properties. The important values are also the window conductivity K_O and the thermal capacity of surrounding walls C_S. Other parameters are less significant. The important elements for the phase delay are the thermal capacity and the thermal conductivity of the building shell C_W, K_W. A particular value means that if the parameter changes by 10% and the relative sensitivity is 0.2, the amplitude of a thermal curve of the internal temperature will increase by 2% and, similarly, from ImSr value we can calculate the change of a thermal curve on a time axis.

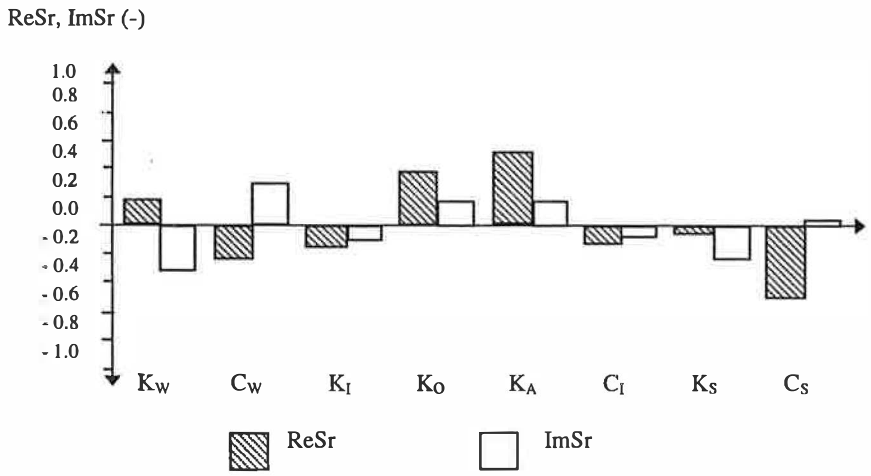

Figure 1: Relative sensitivity of model parameters

Influence of other parameters

The sensitivity is a variable depending on the nominal value of the investigated parameter and on other parameter values. Therefore the amplitude relative sensitivity of the ventilation conductivity was calculated for a range of shell thermal capacity values from 200 to 8000 $Wh.K^{-1}$. This dependence is presented in Figure 2. A graph shows high relative sensitivity values for medium-weight and heavy-weight building shells, which is the highest value among all sensitivity values. In light-weight structures the shell thermal conductivity is the most important parameter. The shell thermal capacity and the surrounding walls thermal capacity are also significant parameters in this model.

Calculated values of sensitivities demonstrate the importance of elements with an attribute of the conductivity that connect an external and internal environment, i.e. the thermal conductivity of windows and the ventilation conductivity.

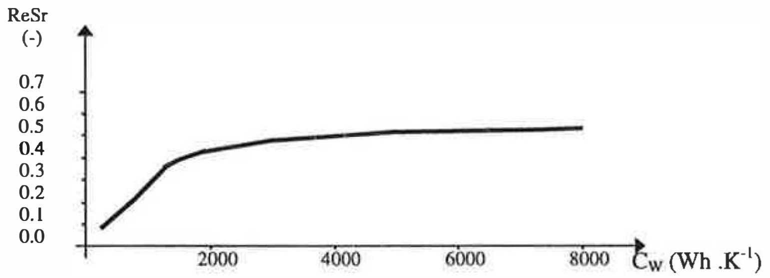

Figure 2: Relative sensitivity of the ventilation conductivity K_A for different values of the building shell thermal capacity C_W

CONCLUSION

This paper should help orientate research efforts in the computer simulation of the thermal dynamic behaviour of buildings. To obtain better outputs, it is necessary to focus the attention on the most sensitive elements. Finding the accurate input values may cause a difficult problem, especially in old buildings where the actual air infiltration rate is different from the building standard values. In the practical domain, it means the measuring of air infiltration in situ, or the investigating of the window condition. Only the correct input values guarantee a correct temperature-humidity building analysis. Massive walls of these structures also require the description by means of distributed parameters, Vytlačil (1997).

This is only one example of using the sensitivity analysis that has a wide range of applications in thermal models.

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