Building Simulation 2003

Eighth International IBPSA Conference
Eindhoven, Netherlands
August 11-14, 2003

DESIGN OF BUILDING PARAMETERS BY MEANS OF THEORY OF TOLERANCES

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ABSTRACT

The paper describes the use of the theory of tolerances in thermal network models that are built as electric circuits. A principle of the method and main equations are given. A calculation of new values of model parameters is based on the assessment of relative sensitivities of model elements. The method is explained in a case study where thermal comfort is analysed in a designed office building in summer. Tolerances make possible to quickly find a new parameter value for the desired air temperature decrease. The limitation of the method is in using differential sensitivities that can be used for relatively small changes of parameter values.

INTRODUCTION

The analysis of the thermal dynamic behaviour of buildings or rooms can be performed by means of the models based on an analogy to the electric circuits that use resistances, capacitances and heat sources (Athienitis et al., 1987).

Optimal model parameters and building parameters are assessed by means of repeating the analysis, it means an iteration process is applied.

The proposed method is based on the direct calculation of the model parameters that can be influenced by the building designer. Generally, these are: the shading coefficient of windows, the absorption of the building envelope surface, the thermal capacitance and the thermal resistance of the building envelope and also the thermal capacitance of internal building structures.

The method is focused on the passive components of the whole complex system.

METHOD

The main steps of the process are described in Figure 1.

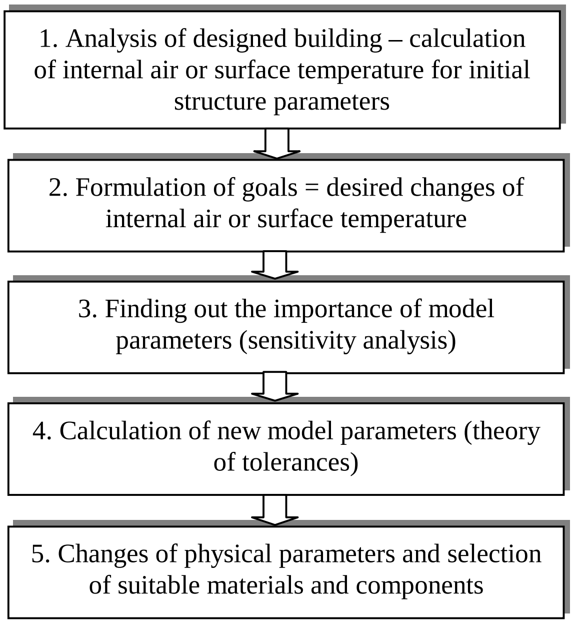

Figure 1 Steps of structure parameter design process

Sensitivity analysis

Relative sensitivity is expressed in equation (Novák, 1987; Athienitis, 1989)

$$Sr_x^F(p,x) = \frac{\partial \ln F(p,x)}{\partial \ln x} = \frac{\partial F(p,x)}{\partial x} \cdot \frac{x_0}{F_0} \quad (1)$$

where p is Laplace operator, x model parameters and x_0, F_0 are nominal values. The system function after assessing algebraic complements is

$$F(p,x) = \frac{N(p,x)}{D(p,x)} \quad (2)$$

where $N(p,x)$ and $D(p,x)$ are polynomials with variable p and x. Relative sensitivities can be calculated from equation (Vytlačil et al., 1993)

$$Sr_x^F(p,x_i) = x_i \cdot \left(\frac{N'}{N} - \frac{D'}{D} \right) \quad (3)$$

The result of the calculation of the sensitivity function (3) after the substitution $p=j.\omega$, where j is imaginary unit and ω is radian frequency, is a complex figure. Real part expresses the amplitude sensitivity. The imaginary part epresses the sensitivity of the phase delay to the change of parameter x. This fact can be written as

$$Sr_{x_i}^F(j\omega) = \operatorname{Re} Sr_{x_i}^F + j \operatorname{Im} Sr_{x_i}^F = \frac{\partial |F(j\omega, x_i)|}{\partial x_i} \cdot \frac{x_i}{|F(j\omega, x_i)|} + j \frac{\partial \{\arg F(j\omega, x_i)\}}{\partial x_i} \quad (4)$$

Graphs of functions $ReSr^F_x(j\omega)$ and $ImSr^F_x(j\omega)$ are sensitivity characteristics of the model parameter x_i.

Tolerances

The tolerance of system function F is a differential defined by the equation

$$\Delta F = \sum_{i=1}^{N} S_{x_i}^F \cdot \Delta x_i \quad (5)$$

Relative tolerances make use of relative sensitivities

$$\frac{\Delta F}{F} = \sum_{i=1}^{N} Sr_{x_i}^F \cdot \frac{\Delta x_i}{x_i} \quad (6)$$

Equations (3) and (6) are the frame for the calculation of new building element values.

EXAMPLE

As an example, the calculation of parameters in an administrative building in summer is presented. One room with a light-weight envelope and corresponding model is drawn in Figure 2.

Model description

The zone model is built as a five-node thermal network. Resultant values of internal air temperature are influenced by changes of the external environment, this means by time-dependent changes of solar radiation and air temperature. The calculation is based on the equation

$$T_4 = \frac{\Delta_{14}}{\Delta_{11}} \cdot T_1 = F(p, x_1, x_2, ..., x_n) \cdot T_1 \quad (7)$$

where T_4 is the output variable (internal air temperature) and T_1 is the input variable (solar radiation), Δ_{14} and Δ_{11} are adjuncts of the system matrix describing the model.

The impact of external air temperature changes is negligible compare to the radiation. Therefore for the sensitivity analysis the example uses only the model in Figure 2. Considered elements are: thermal conductance of the building shell U_w, thermal transfer conductance between the shell and the interior U_i, thermal transfer conductance between interior and surrounding building structures U_s, their thermal capacitance C_s, thermal capacitance of the building shell C_w, thermal capacitance of the interior (air and furnishing) C_i, controlled heat source G_o for heat passage through the window, controlled heat source G_w for the description of heat flow to the external wall. Heat source values include the size of elements and a transmittion or an absorption coefficient. Both sources are controlled from node *1*. G_L represents heat loss from the surface of the building shell.

The analysis is performed in frequency domain by computer program. Resultant values are calculated from the equation

$$T_k(j\omega) = |H_i| \cdot e^{j\gamma_i} \cdot |M_i| \cdot e^{j\gamma_i'} \quad (8)$$

where H_i, γ_i are modules and arguments of the model and M_i, γ_i' are modules and arguments of the input for ***i*** - harmonic component. T_k is the output in node k of the model.

RESULTS

Resultant values of predicted internal air temperature for initial model values are depicted in Figure 3. Calculated temperature peak is 27,3°C. Acceptable air temperature for the analysed room is 26°C.

Relative sensitivities are drawn in Figure 4. The most sensitive model parameter is the heat source that describes the heat flow through the window. Parameters with higher relative sensitivity values influence internal air temperature values more than other model parameters. Another important element is also thermal capacitance of internal building structures.

Parameter G_0 was chosen and its new value was computed from the equation (6) and relative sensitivity value. Input values and computed values are in Table 1. For the verification of the result, internal air temperature was calculated with new G_0 value. Resultant values are in Figure 3. Maximum air temperature in the room achieved 26°C.

The next step is to design physical parameters of the building structure. In this case, three variants were considered. All variants ensure a desired goal – the decrease of air temperature under 26°C. The description of considered variants is in Table 1.

In this case, the change of G_0 value is only strategy how to achieve the goal by means of one element. Other strategies have to be the combination of the change of G_0 value and other parameter values, e.g. G_W or C_S.

The final decision should consider also architectonic and economic limits of the chosen solution.

CONCLUSIONS AND DISCUSSION

The described method can be used for fast design of structure parameters. A computer program for computing relative sensitivities has been developed.

The important fact is the application of differential sensitivities. It means that we can work only with relatively small changes of the parameter values. It depends on the sensitivity charecteristics. For G_0 values it is possible to find stable results of relative sensitivities for wide range of nominal values. In the described case study, the investigated parameter was changed by 25,5 %. The comparison of the calculated air temperature peak for the new parameter value and the desired air temperature peak shows good accuracy of the method.

ACKNOWLEDGMENT

This research has been supported by MSMT grant No. J04/98:210000006.

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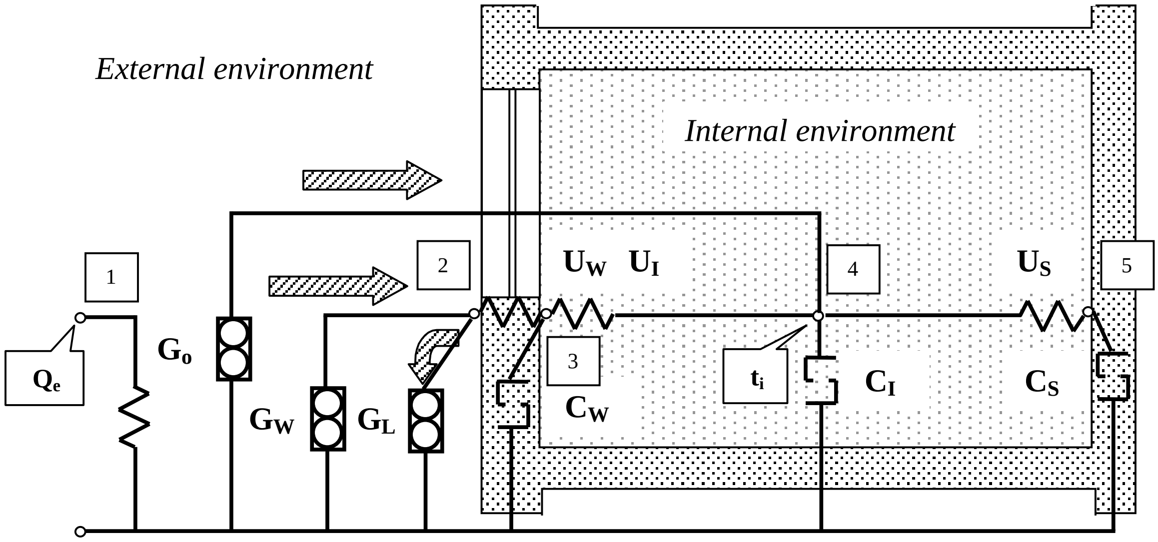

Figure 2 Model for calculation of internal air temperature

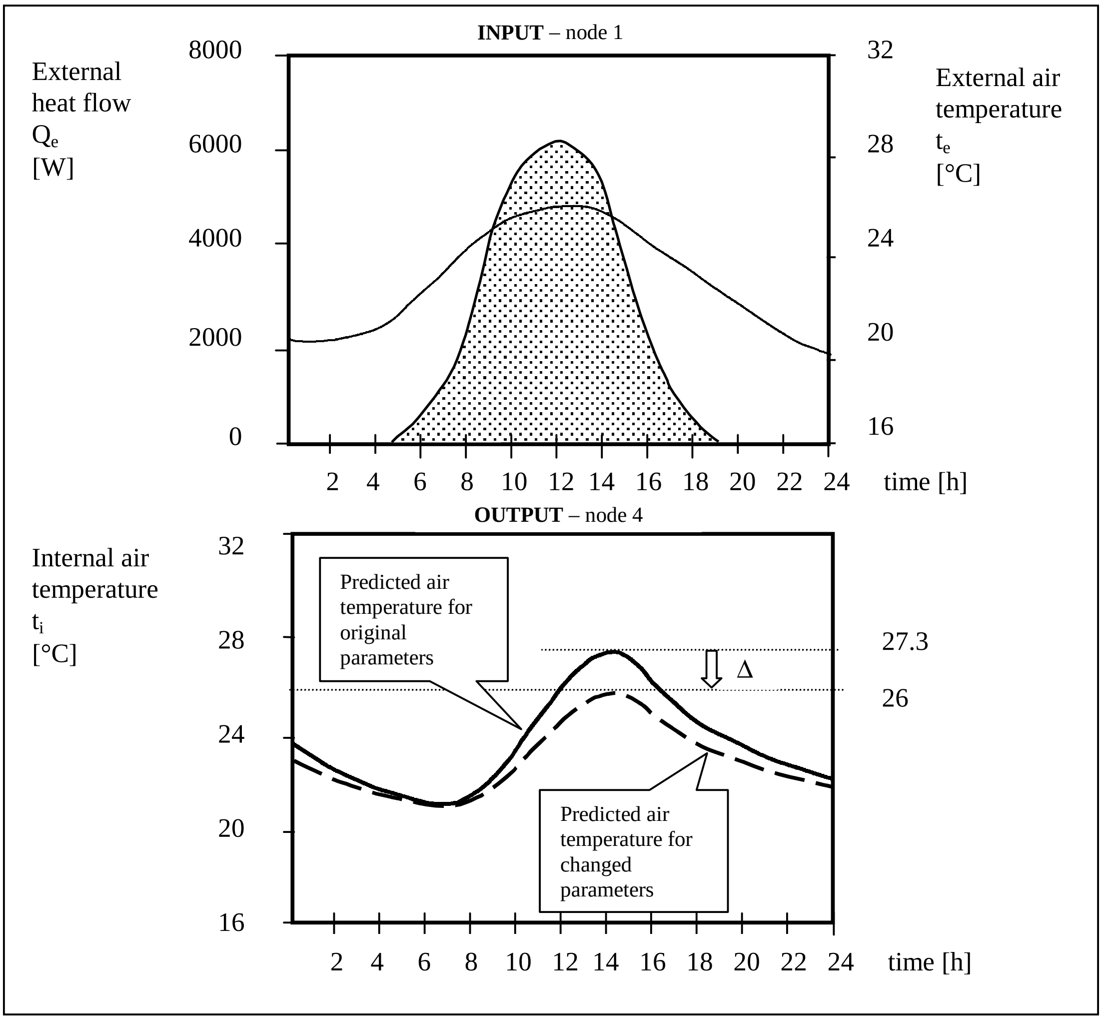

Figure 3 External load and predicted internal air temperatures

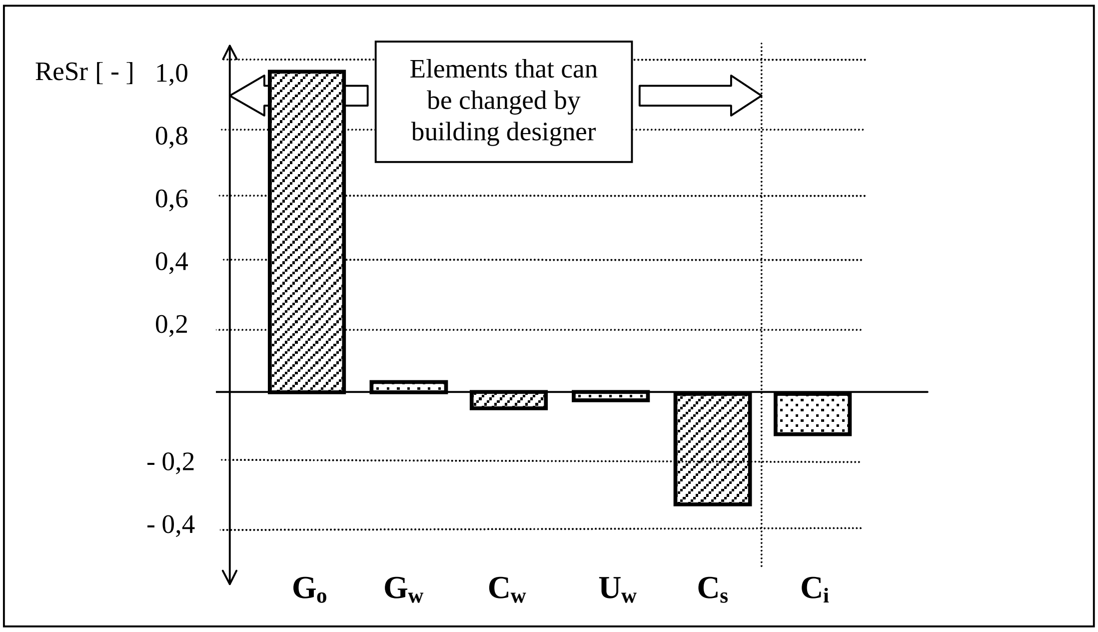

Figure 4 Relative sensitivities of model parameters

Table 1
Input and new calculated model values

	Input parameter values		Calculated parameter values	Strategy - parameter value can be reached by using:	New parameter values
G_O	- 0.292	[W/K]	- 0.219	A. drapes – shading coefficient s = 0.583 [-] B. coating on glass surface (Reflex glass) s = 0.62 C. venetian blind (internal) s = 0.551	- 0.209 - 0.222 - 0.198
G_W	- 0.333	[W/K]			
G_L	96	[W/K]			
U_W	2.6	[W/K]			
U_I	51.2	[W/K]			
U_S	485.3	[W/K]			
C_W	93.5	[Wh/K]			
C_I	308	[Wh/K]			
C_S	1239	[Wh/K]