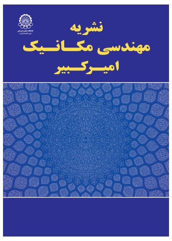

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Simultaneous Estimation of Thermophysical Properties and Convective Boundary Conditions of a Sample Room in Tehran Using Inverse Analysis

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ABSTRACT: In this paper, thermophysical properties and convective heat transfer coefficients of a sample room in Tehran have been estimated separately and simultaneously in an inverse heating-cooling calculation problem. At first the thermal modeling of the room has been performed as a direct problem. In the direct problem, it is assumed that the thermophysical properties and boundary conditions are known. Governing equations for this problem are transient heat conduction equations in the walls with the combined convection and radiation boundary conditions and the consideration of radiation among the room internal walls' surface, and also bulk model for energy conservation in the room. To numerically solve these equations, finite volume method has been employed. In addition, to discretize the equation of bulk model and sensitivity coefficients, a backward finite difference method has been used. Then, the parameter estimation technique based on conjugate gradient method has been used for estimation of the unknown parameters including conductive heat transfer coefficient, volumetric heat capacity, and internal and external convective heat transfer coefficients by with/without noise in measured values. The results show that separate and simultaneous estimations of the parameters that affect the building energy and thermal load of the room are available using the parameter version of conjugate gradient method.

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1- Introduction

The portion of energy consumption in residential and commercial buildings is very high. In Iran, according to statistics from the Iranian company of optimization of fuel consumption, 39 % of the produced energy is consumed in buildings. Thus, for the evaluation and reduction of the energy consumption in the design phase of a building and in the improvement phase of an existing building, building energy consumption should be modeled and simulated.

Modeling is a tool to predict the effect of various parameters and provides the ability to determine appropriate values to achieve the desired goal. For energy modeling and calculation of the energy consumption of buildings (heating and cooling), parameters and a large component of the building (building and wall area, thermophysical properties, etc.), and the boundary conditions (outside and inside temperatures, sunshine, heat transfer coefficients, etc.), ventilation system (type of heating or cooling, primary and secondary equipment specifications and time-dependent performance of such equipment, etc.) and the interactions between them, are required that the performance of each of these components which affect the heating-cooling and energy consumption of buildings. However it is possible that in some cases and in the simulation time, these parameters and conditions are not specified or simplified assumptions are used. Thus, the use of new, efficient and low cost methods such as inverse analysis to estimate the values of the unknown parameters of the building is recommended

Todays, inverse analysis based on measured temperature data to increase the accuracy of the analysis of heat transfer and energy problems are concerned. So that inverse analysis has many applications in various fields of science and engineering, particularly in the analysis and design of heating and energy systems.

In this paper, estimated values of some unknown quantities that may be encountered in building thermal modeling have been computed using inverse analysis. Therefore, as a first step, thermal modeling of the room, as the direct problem, has been performed using transient conductive heat transfer within the walls with the combination of convection and radiation boundary conditions, and bulk model for energy conservation of the room, and the results of the direct problem have been compared to those of Carrier software to confirm the good accuracy of the results. Then, considering the complexity and interaction of the governing equations and independency of the unknown quantities on time and place, the parameter estimation version of the conjugate gradient method has been used to estimate separately and simultaneously boundary conditions and properties of the walls.

2- Thermal Load Modeling

In this study, transient conductive heat equations of the walls are solved completely by taking into account the effect of radiation between the walls [1]:

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$$k\frac{\partial^2 T_{(x,t)}}{\partial x^2} = \left(\rho c_P\right)\frac{\partial T_{(x,t)}}{\partial t} \qquad 0 \langle x \langle l \tag{1}$$

where $T(x,t)$ is walls temperature, k is thermal conductivity, ρ_0 is density, c_p is specific heat and $x=l$ is thickness of walls. Two boundary conditions are needed. The boundary conditions are in the following forms:

$$\begin{aligned} k\frac{\partial T(0,t)}{\partial x^2} &= h_{in}[T_{in} - T(0,t)] + \varepsilon_{\text{int}} q''_{\text{int}} \sum_{i=1}^{n} X_i Y_i \\ k\frac{\partial T(l,t)}{\partial x^2} &= h_{out}[T_{out} - T(l,t)] + \varepsilon_{ext} q''_{ext} \end{aligned} \tag{2}$$

where T_{in} and T_{out} are inside and outside air temperature, h_{in} and h_{out} are internal and external convective coefficients, ε_{int} and ε_{ext} are emissivity of internal and external surfacesand q''_{int} and q''_{ext} are heat fluxes in the internal and external surfaces, respectively.

Heat flux in the internal surfaces is the consequence of thermal radiation between the walls whereas the surfaces of all walls are opaque and gray. Also the radiation is uniform in all directions [2]. Heat flux in the external surfaces (q''_{ext}) is due to solar radiation, which is given in Duffie and Beckman study [3].

After thermal modeling of the walls, room thermal equilibrium must be written. Inside air temperature varies due to heat exchange with the walls and with the inside equipment via convection and also due to the generated heat. Absorbed radiation or emission is negligible. Therefore, the temperature distribution in the building using bulk model is as follows [2]:

$$m_{air} c_{p,air} \frac{dT_{in}}{dt} = \sum_i h_{in} A_i \left(T_{s,i} - T_{in}\right) + h_{fur} A_{fur} \left(T_{fur} - T_{in}\right. \tag{3}$$

where, $T_{s,i}$ and T_{fur} are the temperature of surface i (walls, roof) and the temperature of furniture in the room, m_{air}, $c_{p,air}$ and T_{in} are mass, specific heat capacity and room air temperature, respectively. A_{fur} is furniture surface, and h_{in} and h_{fur} are heat transfer coefficient of surface and furniture in the room, respectively. The furniture may have temperature gradient inside; however, due to complexity of the model, the gradient is neglected in the present work. Heat balance for the furniture is as follows:

$$m_{fur} c_{p,fur} \frac{dT_{fur}}{dt} = -h_{fur} A_{fur}\left(T_{fur} - T_{in}\right) + q_{Rad,in} \tag{4}$$

where $q_{rad.in}$ is the net radiation of heat into the furniture.

3- Direct Problem Results

Before presenting the results of the inverse problem, the direct problem results have been validated. In order to validate the model and computer code, the hourly cooling loads of the current work were compared with those of Carrier software (Fig. 1). This figure shows the current results are in good agreement with those of Carrier software. This figure also shows that the peak cooling loads calculated by these two computer codes have a difference of less than 5%. This difference is due to the models of calculating the cooling load, used by these two computer codes.

4- Inverse Problem Results

In order to estimate the unknown parameters in the inverse problem, a series of experimental data of temperature sensors are required. Instead of experimental data, values of the simulated temperatures are used. In order to find the best location of temperature sensors and to compare the sensitivity of different parameters, sensitivity coefficients with respect to the unknown parameters are calculated using the sensitivity analysis. The results of the sensitivity analysis and inverse analysis for the first three days of January and July are obtained. Based on the sensitivity analysis for July, the eastern wall is selected for the location of the sensor. For example, Fig. 2 shows the sensitivity coefficients of the eastern wall temperature with respect to conductive heat coefficient in three internal nodes of the wall in July. In addition, Table 1 shows the estimation of the unknown parameters by the sensor values without error ($\sigma=0$) and with error ($\sigma=0.05$).

5- Conclusion

The results of the sensitivity analysis and inverse analysis have shown that the conjugate gradient is well suited to estimate individually the parameters of the building and also to simultaneously estimate some parameters of the building. In fact, in this study, the high ability and effectiveness of the inverse method to estimate the unknown parameters in the analysis of a thermal cooling and heating load problem has been shown. Another result of this study which can be concluded is that if some unknown parameters are simultaneously estimated, it is sure each of them can be estimated separately much more accurate.

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Table 1. Estimated values of the unknown parameters

parameter	Initial Guess	Exact Values	$\sigma = 0$			$\sigma = 0.05$		
			Estimated Value	Relative Error	Number of Iteration	Estimated Value	Relative Error	Number of Iteration
k	0.1	0.4987	0.4987	0.000	5	0.4995	0.010	8
C ×e6	0.4	1.1379	1.1367	0.105	3	1.1372	0.07	6
h_i	3	8.29	8.288	0.025	4	8.285	0.061	8
h_o	3	17.05	16.98	0.410	5	17.21	0.938	8

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