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Numerical computation of time lags and decrement factors for different building materials

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Abstract

In this study, time lags and decrement factors for different building materials have been investigated numerically. For this purpose, one dimensional transient heat conduction equation was solved using the Crank–Nicolson scheme under convection boundary conditions. To the outer surface of the wall, periodic boundary conditions were applied. Twenty-six different building materials were selected for analysis. The computations were repeated for eight different thickness of each material and the effects of thickness and the type of material on time lag and decrement factor were investigated. It was found that thickness of material and the type of the material have a very profound effect on the time lag and decrement factor. The results of present study are useful for designing more effective passive solar buildings and other related areas.

Keywords: Building materials; Time lag; Decrement factor; Passive solar building

1. Introduction

For passive solar buildings, heating the building is possible via the direct heat gain and/or thermal storage method and there have been many researches in this area [1–3]. Although the direct heat gain method is simple and inexpensive, it suffers from large temperature swings besides strong directional day lighting [4]. In addition, the direct heat gain method can be affected very fast from outside temperature fluctuations which results in a bed comfort level for indoors [5–7]. For thermal storage buildings on the other hand, walls and floors are used as heat storage elements, and stored energy in the walls and floors during the day period can be used for heating during nights.

At the cross-section of the outer wall of a building, there are different temperature profiles during any instant of a 1-day period. These profiles are function of inside temperature, outside temperature and materials of the wall layers. Since the outside temperature changes periodically during a 1-day period, there will be new temperature profiles at any instant of time of the day. During this transient process, a heat wave flows through the wall from outside to inside and the amplitude of these waves shows the temperature magnitudes, and wavelength of the waves shows the time. The amplitude of the heat wave on the outer surface of the wall is based on solar radiation and convection in between the outer surface of the wall and ambient air. During the propagation of this heat wave through the wall, its amplitude will decrease depending on the material and the thickness of the wall. When this wave reaches the inner surface, it will have an amplitude which is considerably smaller than the value it hat at the outer surface. The times it takes for the heat wave to propagate from the outer surface to the inner surface is named as ‘‘time lag’’ and the decreasing ratio of its amplitude during this process is named as ‘‘decrement factor’’ [8]. Time lag and decrement factor are very important characteristics to determine the heat storage capabilities of any materials. Depending on the material

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and thickness of the wall, different time lags and decrement factors can be obtained. Recently conducted studies by the present author [9–11], different aspects of the time lag and decrement factor for building walls have been discussed.

In the present study, time lags and decrement factors for real building materials have been investigated numerically. For this purpose, one-dimensional transient heat conduction equation was solved for a wall under periodic convection boundary conditions. Twenty-six different building materials were selected for analysis. The computations were repeated for eight different thickness of each material and the effects of thickness and the type of material on time lag and decrement factor were investigated. In was found that different materials result in different time lags and decrement factors. In addition, it was found that the thickness of the material is very deterministic from the time lag and decrement factor point of view. The results of present study are useful for designing more effective passive solar buildings and other related energy saving areas.

2. Time lag ϕ, decrement factor f and sol–air temperature t_{sa}

Time lag and decrement factor are very important characteristics to determine the heat storage capabilities of any material. As mentioned before, the time it takes for the heat wave to propagate from the outer surface to the inner surface is named as "time lag" and the decreasing ratio of its amplitude during is named as "decrement factor". The schematics of time lag and decrement factor are shown in Fig. 1.

In this study, the time lag and decrement factor are computed as follows. The time lag is defined as

$$\phi = \begin{cases} t_{T_o^{\max}} > t_{T_e^{\max}} \Rightarrow t_{T_o^{\max}} - t_{T_e^{\max}}, \\ t_{T_o^{\max}} < t_{T_e^{\max}} \Rightarrow t_{T_o^{\max}} - t_{T_e^{\max}} + P, \\ t_{T_o^{\max}} = t_{T_e^{\max}} \Rightarrow P, \end{cases} \quad (1)$$

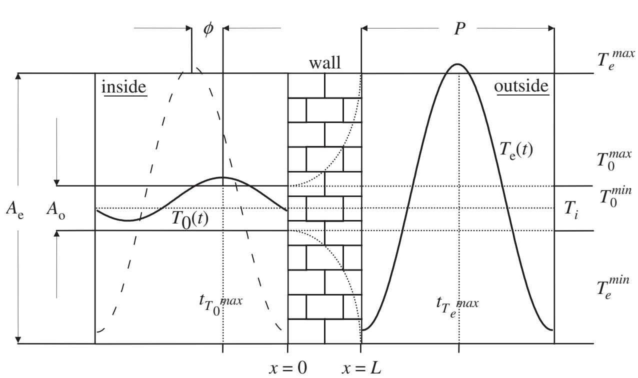

Fig. 1. The schematic representation of time lag ϕ and decrement factor f.

where $t_{T_o^{\max}}$ and $t_{T_e^{\max}}$ (h) represent the time in hours when inside and outside surface temperatures are at their maximums, respectively, and P (24 h) is the period of the wave.

The decrement factor is defined as

$$f = \frac{A_o}{A_e} = \frac{T_o^{\max} - T_o^{\min}}{T_e^{\max} - T_e^{\min}}, \quad (2)$$

where A_o and A_e are the amplitudes of the wave in the inner and outer surfaces of the wall, respectively.

The sol–air temperature, T_{sa}, includes the effects of the solar radiation combined with outside air temperature and changes periodically. This temperature is assumed to show sinusoidal variations during a 24-h period. Since time lag and decrement factor are dependent on only wall material, not the climatological data [12], a very general equation for sol–air temperature is taken as follows:

$$T_{sa}(t) = \frac{|T_{\max} - T_{\min}|}{2} \sin\left(\frac{2\pi t}{P} - \frac{\pi}{2}\right) + \frac{|T_{\max} - T_{\min}|}{2} + T_{\min}. \quad (3)$$

3. Method

In this study, the wall under investigation is assumed to be only in the x direction and time dependent. The problem geometry is shown in Fig. 2. The one-dimensional, transient heat conduction equation for this problem is as follows:

$$k\frac{\partial^2 T}{\partial x^2} = \rho c_P \frac{\partial T}{\partial t}, \quad (4)$$

where k is the thermal conductivity, ρ is the density and c_P is the specific heat of the wall material. To solve this

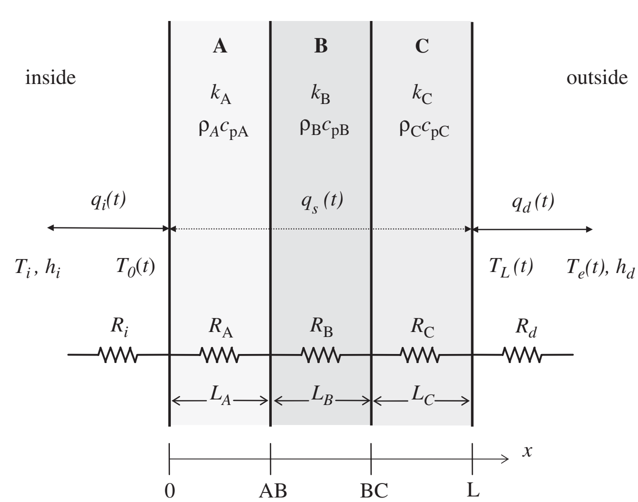

Fig. 2. The schematic of the problem geometry.