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A modified method of calculating the heating load for residential buildings

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ABSTRACT

The accurate techniques of heating loads calculations are essential pace for equipment selection, system sizing and system design. With the help of getting the accurate data of heating loads and seasonal heating demands, the energy sources design for buildings become more effective. The present study highlights the dependence of heating loads values on the thermal properties of buildings envelopes; hence, a modified method of calculating the heating loads values and seasonal heating demands of residential buildings is developed mathematically. The present results are compared with ASHRAE standards. The results show that the data obtained from the present method are more accurate and effective than compared results. Moreover, it proves that the duration of heating seasons for each building even in the same climatic conditions are different. The modified method will open a new horizon in the field of heating system to provide accurate calculations of heating loads for many applications.

1. Introduction

Providing an effective and accurate method for calculating the heating loads for buildings is a great challenge. The accurate calculations of heating loads of many different buildings has enormous impact on energy and fuel saving. This research subject was attractive for many researchers and valuable data has been published in the last two decades. Adnan et al. [1,2] have investigated the characteristics of heating and cooling loads in residential buildings in Jordan. ASHRAE [3,4] has established one of the most widely known and accepted standards data for design heating and cooling loads. The earlier methods that published by ASHRAE, included the Total Equivalent Temperature Differential/Time-Averaging (TETD/TA) method, the Transfer Function Method (TFM) and the Cooling Load Temperature Differential (CLTD)/Solar Cooling Load (SCL)/Cooling Load Factor (CLF) method. Danny et al. [5], Omar et al. [6] and Mui and Wong [7] discussed various methods of determining the heating and cooling loads requirements of buildings. Chua and Chou [8] studied the energy performance of residential buildings in Singapore and they developed an equation for residential buildings called an Envelope Thermal Transfer Value (ETTV)) equation. Joseph et al. [9] investigated the energy requirements and performance of residential buildings in Hong Kong from 1979 to 2001 in terms of the overall thermal transfer value (OTTV). Fouda and Melikyan [10] developed a new mathematical model for determining the cooling load and seasonal cooling load for residential buildings. Lin Duanmu et al. [11] presented a simplified prediction model: Hourly Cooling Load Factor Method (HCLFM) that can provide quick and fair estimate of building cooling load for large-scale urban energy planning. Nurdil and Hamdi [12] presented the interactions between different conditions, control strategies and heating/cooling loads in office buildings in the four major climatic zones in Turkey – hot summer and cold winter, mild, hot summer and warm winter, hot and humid summer and warm winter through building energy simulation program has been evaluated. Jorge et al. [13] discussed several different simplified methodologies for building energy performance assessment during winter time selected based on its large application and/or its user friendly characteristics. Giorgio and Sara [14] presented steady-state inverse modeling procedure to restore the short term heating and cooling loads of a building by using as input aggregated energy consumption data and the short term behavior of the climatic variables. The main focus of this study is to investigate the effect of essential parameters such as the outside air temperature, intensity of solar radiation and walls orientations on the accuracy of calculating the heating loads in residential buildings. These parameters

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Nomenclature

A	apparent solar constant
a	building base side length, m
B	atmospheric extinction coefficient
b	building base side width, m
C	sky diffuse factor
h	building height, m
I_s	intensity of solar radiation on the surfaces of south wall, W/m^2
I_h	intensity of solar radiation on the surfaces of ceiling, W/m^2
I_{si}	average values of solar radiation intensity on south walls, W/m^2
I_{hi}	average values of solar radiation intensity on s ceiling, W/m^2
k_w	heat transfer coefficients of walls, W/m^2 °C
k_c	heat transfer coefficients of ceiling, W/m^2 °C
$k_{wd.}$	heat transfer coefficients of windows, W/m^2 °C
N_i	number of the day in the year
P	solar radiation absorption rate by surfaces of south wall and ceiling
q_{hg}	specific value of heat gain into the building through the external construction elements, W/m^3
q_V	specific value of heat demand for heating the ventilation fresh air, W/m^3
q_{inf}	specific value of heat demand for heating the infiltration fresh air penetrating the gaps of windows and outside doors, W/m^3
$t_{out.st.d}$	daytime starting temperatures of the heating season, °C
$t_{out.st.n}$	nighttime starting temperatures of the heating season, °C
t_{out}	heating design temperature of outside air, °C
t_{in}	required inside air temperature, °C
$t_{out,d,I}$	current daytime heating temperature, °C
S	number of building stories
V_b	volume of building, m-3
$Z_{t_{out},d,i}$	duration of each daytime outside temperature, h
$Z_{I_{si}}$	duration of solar radiation intensity on south walls, h
$Z_{I_{hi}}$	duration of solar radiation on ceiling surface, h

Greek letters

β	solar altitude angle,°
θ	incident angle
ζ	surface tilt from horizontal
λ_w	thermal heat conductivity of material layers of wall, W/m °C
λ_c	thermal heat conductivity of material layers of ceiling, W/m °C
λ_{ins}	thermal heat conductivity of material layers of insulation, W/m °C
α_{in}	inside heat convection coefficient, W/m^2 °C
α_{out}	outside heat convection coefficient, W/m^2 °C
δ_w	thickness of material layers of wall, m
δ_c	thickness of material layers of ceiling, m
δ_{ins}	thickness of material layers of insulation, m
μ	glazing rate of building

are not considered in the previous methods, which affected poorly on the accuracy of those results.

Stable process of heat gain assumes that the outside air temperature and intensity of solar radiation are constant. It is prominent that the eastern and western walls receive higher solar radiation intensity than the southern ones during the day. However, the walls orientation are not considered as design parameters since the exposed time of these wall during the day is too short compared with the southern walls. Moreover, the maximum values of radiation intensity on these walls are calculated only twice at different hours along the day [15–17]. Therefore, the solar radiation is deliberated only through the southern walls and windows, and ceiling during modeling the heating loads, hence avoiding the oversize of heating equipment and proves that the duration of heating seasons for each building even in the same climatic conditions are different.

2. Method of calculating the heating load capacity for residential buildings

The heating load represents the amount of heat that must be added in an hour to maintain a comfort room temperature at given outside design temperature of given climatic conditions. In the present model, the heating load will be estimated for 1 m^3 of a building. This value is called the specific heating load (or specific heating demand, q_{hd}), which can be determined from the following equation:

$$q_{hd} = q_{hg} + q_v + q_{inf} - q_d, \quad (1)$$

where q_{hg}: specific value of heat gain into the building through the external construction elements (W/m^3). q_V: specific value of heat demand for heating the ventilation fresh air (W/m^3). q_{inf}: specific value of heat demand for heating the infiltration fresh air penetrating the gaps of windows and outside doors (W/m^3). q_d: specific internal heat rejection from inhabitants, lighting and domestic appliances (W/m^3).

The calculation of the specific heat gain (q_{hg}), depends of the heat transfer through the outside construction elements and the solar radiation that occurs throughout an opaque south wall, ceiling and transparent surfaces of south oriented windows. The following formula is suggested for the specific heat gain calculations:

$$q_{hg} = \frac{(1-\mu)}{b}k_w\left(t_{in} - t_{out} - \frac{I_s p}{\alpha_{out}}\right) + \left(\frac{2}{a} + \frac{(1-\mu)}{b}\right)k_w(t_{in} - t_{out}) + \frac{k_c(t_{in} - t_{out} - (I_h p/\alpha_{out}))}{h} + \frac{2\mu}{b}k_{wd}(t_{out} - t_{in}) - \frac{\mu}{b}I_s n_1 n_2 n_3 \beta \quad (2)$$

Eq. (2) can be rearranged in the following form:

$$q_{hg} = (t_{in} - t_{out})\left[2k_w\left(\frac{(1-\mu)}{b} + \frac{1}{a}\right) + \frac{k_c}{h} + \frac{2\mu}{b}k_{wd}\right] - \left[\frac{(1-\mu)}{b}k_w\frac{I_s p}{\alpha_{out}} + k_c\frac{I_h p}{\alpha_{out} h} + \frac{\mu}{b}I_s n_1 n_2 n_3 \beta\right] \quad (3)$$

where n_1, n_2 and n_3: coefficients represent the dust level, windows frames and shadow zones on windows surfaces respectively. β rate of inside curtain effect.

The glazing rate (μ) of the building is determined by the following fraction:

$$\mu = \frac{\Sigma F_{wd}}{2(a+b)h} \quad (4)$$

where F_{wd}: total surface area of windows on all vertical surfaces of building, m^2.

The heat transfer coefficients for the wall (k_w) and the ceiling (k_c) are determined by following equations respectively:

$$k_w = \frac{1}{(1/\alpha_{in}) + (\delta_w/\lambda_w) + (\delta_{ins}/\lambda_{ins}) + (1/\alpha_{out})} \quad (5)$$