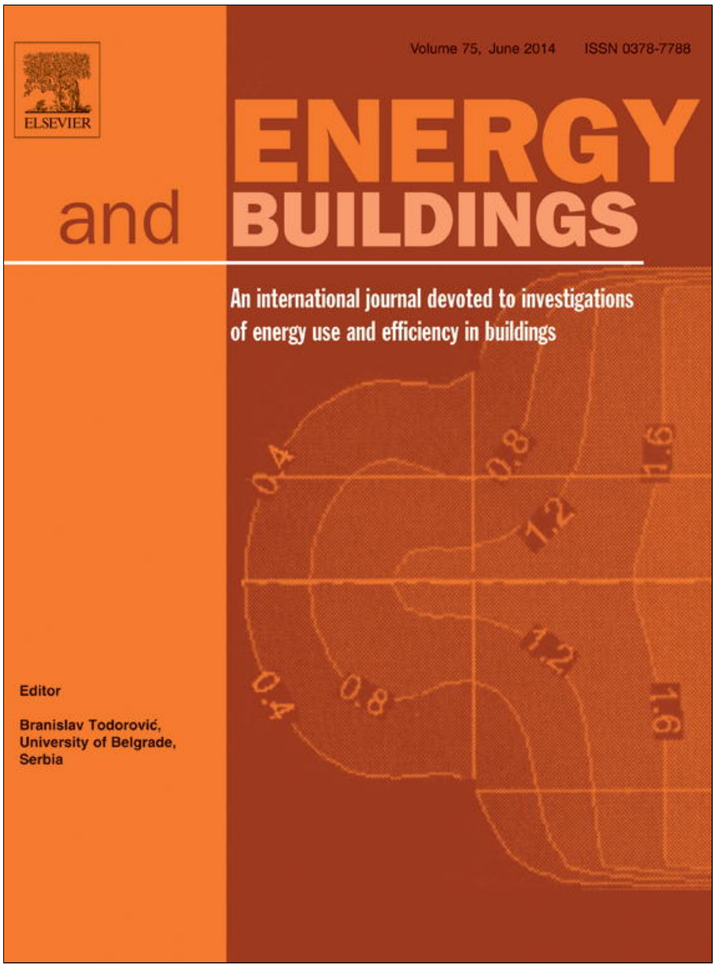
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A modified method of calculating the heating load for residential buildings

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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:

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

$$k_c = \frac{1}{(1/\alpha_{in}) + (\delta_c/\lambda_c) + (\delta_{ins}/\lambda_{ins}) + (1/\alpha_{out})} \quad (6)$$

where δ_w, δ_c and $\delta_{ins.}$: thickness of material layers of wall, ceiling and insulation of the studied building respectively, (m). λ_w, λ_c and λ_{ins}: thermal heat conductivity of material layers of wall, ceiling and insulation of the studied building respectively, W/m °C. α_{in} and α_{out}: inside and outside heat convection coefficient on the wall and ceiling of the studied building, W/m^2 °C.

The values of heat transfer coefficient for windows depend on the number of glass layers. For example, the heat transfer coefficient of double glazed windows (k_{wd}) is equal to 2.9 W/m^2 °C. The specific values of q_V, q_{inf} can be calculated using the following equations respectively [18]:

$$q_V = 0.181(t_{in} - t_{out}) \quad (7)$$

$$q_{inf} = \frac{4.012\mu(t_{in} - t_{out})}{b} \quad (8)$$

The total value of specific internal heat rejected (q_d) from inhabitants, lighting and domestic appliances depends on the electric power of lighting, domestic appliances and number of occupants being simultaneously at home. In the present work, this value can be calculated from the equation that has been developed by Melikyan [18] as follows.

$$q_d = 2.0566 + 0.576S - 0.0622S^2 + 0.0016S^3 \quad (9)$$

where S: the number of building stories.

Eq. (9) was developed based on the analysis of data obtained during a survey that has been carried out to inhabitants of 1000 apartments in Yerevan city, Armenia.

To facilitate the calculation of specific heating load, the internal heat rejection is taken as a constant value of q_d = 2.88 W/m^3 [18]. Consequently, the value of specific heating load (q_{hd}) for any kind of building can be calculated by substituting the values of Eqs. (3)–(9) in Eq. (1) as follows:

$$q_{hd} = (t_{in} - t_{out})\left[2k_w\left(\frac{(1-\mu)}{b} + \frac{1}{a}\right) + \frac{k_c}{h} + \frac{2\mu}{b}k_{wd} + 0.181 + \frac{4.012\mu}{b}\right] - \frac{(1-\mu)}{b}k_w\frac{I_s p}{\alpha_{out}} - k_c\frac{I_h p}{\alpha_{out} h} - \frac{\mu}{b}I_s n_1 n_2 n_3 \beta - q_d \quad (10)$$

Eq. (10) can be used to determine the specific values of heating load (q_{hd}) for any kind of residential buildings. The absolute value of heating load (Q_{hd}), can be calculated by multiplying the specific value (q_{hd}) with the volume of studied building (V_b) as follows:

$$Q_{hd} = q_{hd} V_b \quad (11)$$

In Eq. (10), the intensity of solar radiation on the south oriented wall (I_s) and on the horizontal surface (I_h), should be taken as the design values for given geographical area. These design values of (I_h) and (I_s) can be calculated from Ref. [3]. Those two design values can be determined at any time of the day if the latitude and local longitude of the geographical area are known, using the following equations [3]:

$$I_s = \left(\frac{A}{\exp(-B/\sin\beta)}\right)(\cos\theta + 0.45C + 0.2(C + \sin\beta)(1 - \cos\zeta)) \quad (12)$$

$$I_h = \left(\frac{A}{\exp(-B/\sin\beta)}\right)(\cos\theta + C) \quad (13)$$

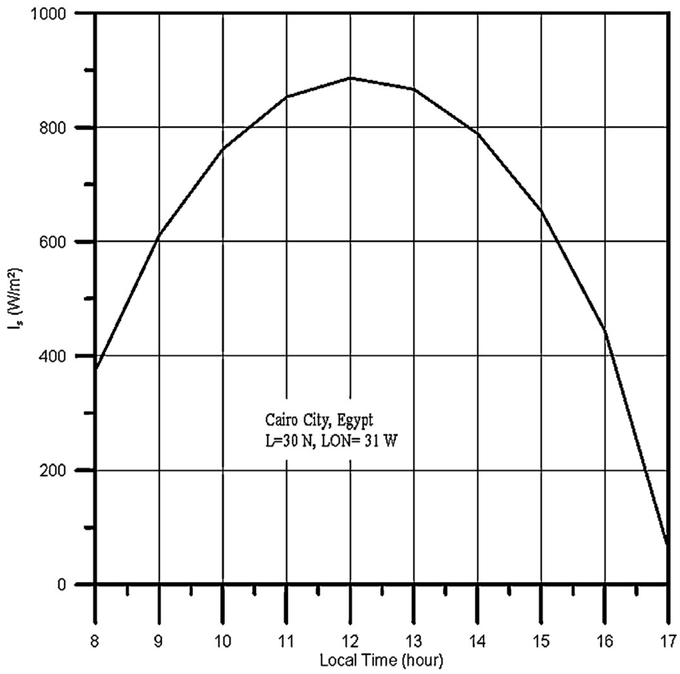

Fig. 1. Variation of solar radiation intensity on the surface of south wall (I_s) in Cairo city, Egypt.

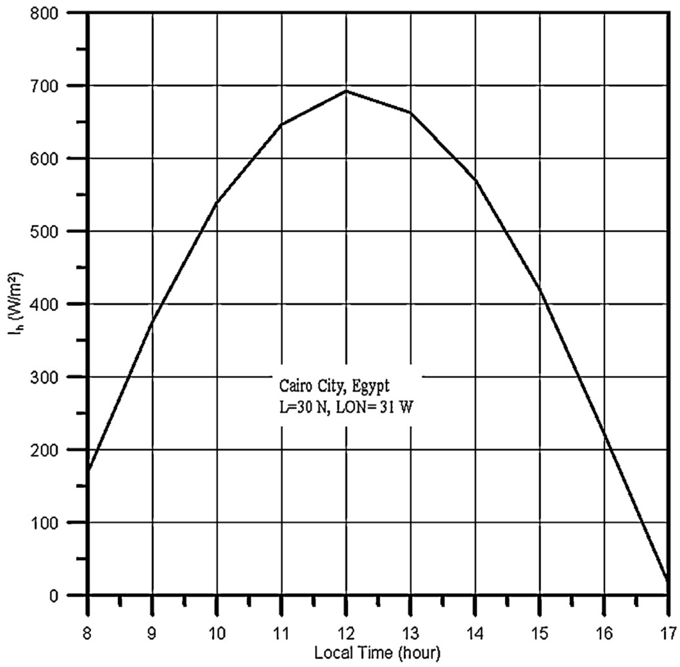

Fig. 2. Variation of solar radiation intensity on the surface of ceiling (I_h), in Cairo city, Egypt.

where A, B and C: constants depend on the number of day in the year [3]. β: solar altitude angle,°. θ: incident angle. ζ: surface tilt from horizontal.

In the present research – as an example – the variation of solar radiation intensity on the south walls and ceiling surface of the studied building that located in Cairo city, Egypt is calculated by considering the outside design temperature of t_{out} = 7 °C [3] on 21st, January.

The obtained results from this method of calculation are represented in Figs. 1 and 2 as follows.

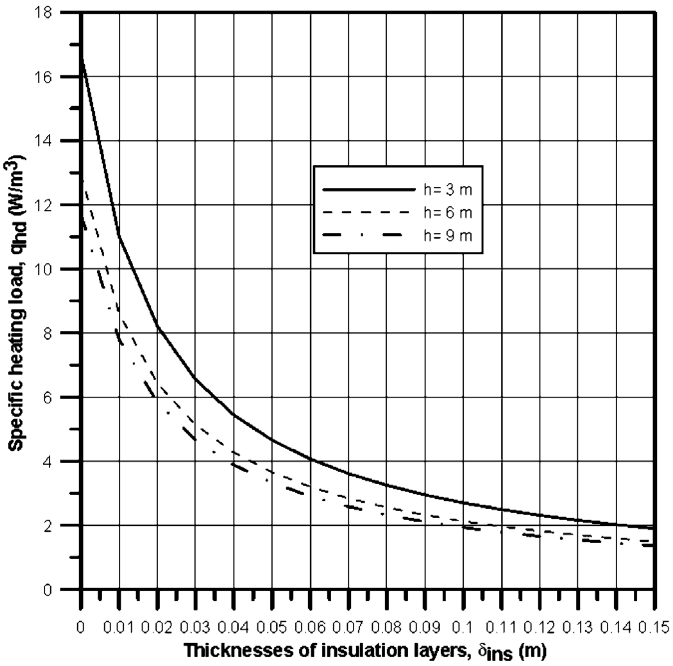

Fig. 3. Effect of building height (h) and insulation layers thickness (δ_{ins}) of walls and ceiling on the specific heating demand values, (q_{hd}).

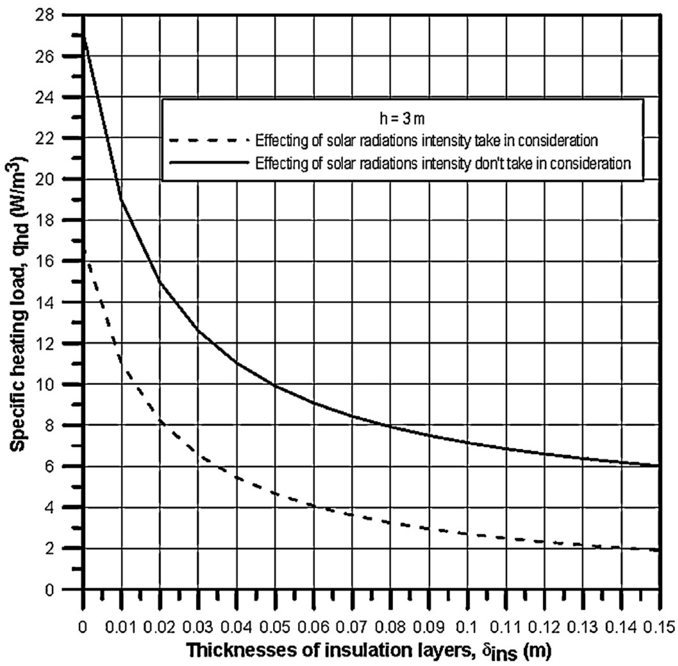

Fig. 4. Effect of solar radiation intensity (I_s) and insulation layers thickness (δ_{ins}) of walls and ceiling on the specific heating demand values, (q_{hd}).

Figs. 1 and 2 show the variations of solar radiation intensity on the surface of the south wall and on the ceiling of the studied building during the mentioned day, respectively. As it can be seen from the figures, the solar radiation intensity has maximum values at the noon for both surfaces. In this method of calculation, the design value of solar radiation intensity is taken as the average value during the day. As a result, the following design values of solar radiation intensity are obtained as follows:

$$I_{s,dsg} = 300 \quad \mathrm{W/m^2}, \quad \text{for south wall.}$$

$$I_{h,dsg} = 400 \quad \mathrm{W/m^2}, \quad \text{for ceiling surface.}$$

In the present study, the developed mathematical model is used to calculate the heating load for a residential building located in the climatic conditions of Cairo city, Egypt. The characteristic dimensions of the building are $a = 12$ m, $b = 12$ m, $h = 3$ m, 6 m and 9 m. The thermal resistance of walls and ceiling materials are $R_w = 1.12\mathrm{m^2\,^\circ C/W}$ and $R_c = 0.65\mathrm{m^2\,^\circ C/W}$, respectively. The comfort temperature inside the building is taken as $t_{in} = 25\,^\circ$C. Furthermore, the thickness of the insulation layers (δ_{in}) of walls and ceiling is changed during the study to investigate its effect on the obtained results. The obtained results show that the specific heating demand, (q_{hd}) depends on the height of the building and on the variable thickness of insulation layers as illustrated in Fig. 3.

As can be seen from Fig. 3, the values of specific heating demand (q_{hd}) for higher and huge buildings are small, which indicates that the efficiency of heating energy of huge buildings is high. Moreover, it can be seen that the specific heating demand (q_{hd}) values decreases with increasing the thickness of insulation layers (δ_{ins}). However, when the insulation layers of walls and ceiling become thicker, the initial cost of the building will increase. Consequently, extensive investigation is needed to determine the economic value of insulation layer thickness.

Fig. 4 shows the effect of both the solar radiation intensity (I_s) and insulation layers thickness (δ_{ins}) of walls and ceiling on the specific heating load values, (q_{hd}). It shows that when the effect of solar radiation intensity is neglected, the value of specific heating demand (q_{hd}) will increase.

3. Mathematical model validation

The results of the present mathematical model, which are obtained using advanced computer languages, are compared with the results that obtained from solving those equations manually. Moreover, the results obtained from this mathematical model are compared with ASHRAE example-1 in chapter-28 [3] as a validation since there is no available examples related to the heating load calculation. In the present mathematical model, the data available in ASHRAE example-1 such as building characteristics, dimensions, the thermal resistance of main constructions of walls and ceiling, outdoor design temperature and inside design conditions is illustrated in Table 1, which is taken as input data. The absolute value of heating load (Q_{hd}), that calculated by authors' mathematical model

Table 1
Building characteristics, its dimensions and the thermal resistance of its walls and ceiling [3].

A single-family detached house is located in the south central United States at 36° N latitude.
$a = 22.6$ m, $b = 7$ m and $h = 3$ m.
Roof construction. Conventional roof-attic-ceiling combination, vented to remove moisture with 150 mm of fibrous batt insulation and vapor retarder [$k_c = 0.28$ W/(m^2 K)].
Wall construction. Frame with 100 mm face brick, 90 mm fibrous batt insulation, 19 mm polystyrene sheathing, and 13 mm gypsum wallboard [$k_w = 0.34$ W/(m^2 K)]. Ceiling height is 2.4 m throughout.
Fenestration. Clear double glass, 3 mm thick, in and out. Assume closed, medium-color venetian blinds. The window glass has a 600 mm overhang at the top. Doors. Solid core flush with all-glass storm doors [$k_{wd} = 1.82$ W/(m^2 K)].
Occupancy. Four persons based on two for the master bedroom and one for each additional bedroom. Assign to the living room.
Appliances and lights. Assume 470 W for the kitchen, and assign 50% to the living room. Assume 470 W for the utility room, and assign 25% to the kitchen and 25% to the storage room.

Note: In the present method, $q_d = 2.88$ W/m^3 or Eq. (9) can be employed.

is Q_{hd} = 7.2 kW and by ASHRAE [3] method is 6.33 kW. The comparison between two values shows that the heating load obtained from the mathematical model is very closed to the value calculated from ASHRAE method. Therefore, the present mathematical model can be used to calculate the heating load for any kind of residential building more accurately and simple rather than ASHRAR method.

4. Method of calculating the seasonal heating demand for residential buildings

The radiation temperature of the surface of a body is formed during daytime; hence, it can be evaluated from the daytime outdoor temperature ($t_{out.d}$) during the heating period. Consequently, the method of determining the seasonal heating load for residential buildings is divided into two main parts. The first part is called the daytime seasonal heating load ($q_{hd.d.seas}$) and the second part is nighttime seasonal heating load ($q_{hd.n.seas}$). As a result, the total seasonal heating load can be calculated by summing the daytime and nighttime parts as follows:

$$q_{hd,seas} = q_{hd,d,seas} + q_{hd,n,seas} \quad (14)$$

In the present study, the solar radiation is assumed to be calculated on south oriented walls and ceiling surface of the studied building. Therefore, the value of heat gain (Q_{hg}) into building through these construction elements during a day should be determined from the difference between the radiation temperature (t_R), (radiation temperature is the short name of conditional temperature of the air boundary layer on the surface of a construction) and the inside temperature (t_{in}). For the other construction elements of a building, the value of the heat gain is calculated from the difference between the outside daytime temperature ($t_{out.d.i}$) and inside temperature (t_{in}). Therefore, the specific value of heat gain (q_{hg}) through all walls and roof of a building for the daytime period of the winter season is determined by the following equation:

$$q_{hg,d,seas} = \sum_{i=Z_{t_{out,d,i}}}^{Z_{t_{out,dsg}}} Z_{t_{out,d,i}}(t_{in} - t_{out,d,i}) \left[2k_w\left(\frac{(1-\mu)}{b} + \frac{1}{a}\right) + \frac{k_c}{h} + \frac{2\mu}{b}k_{wd}\right] - \sum_{i=N_i}^{N_{dsg}} Z_{I_{si}}\left(\frac{(1-\mu)}{b}k_w\frac{I_{si}p}{\alpha_{out}} + \frac{\mu}{b}I_{si}n_1n_2n_3\beta\right) - \sum_{i=N_i}^{N_{dsg}} Z_{I_{hi}}k_c\frac{I_{hi}p}{\alpha_{out}h} \quad (15)$$

where $t_{out,d,i}$: current daytime heating temperature. $Z_{t_{out},d,i}$: duration (h) of each daytime outside temperature ($t_{out.d.i}$) occurring between day heating season starting temperature ($t_{out.dst.d}$), and heating design temperature, ($t_{out.dsg}$). I_{si} and I_{hi}: average values of solar radiation intensity on south walls and ceiling surfaces respectively (W/m^2). $Z_{I_{si}}$: duration (h) of solar radiation intensity on south walls ($Z_{I_{si}} = 9$ h). $Z_{I_{hi}}$: duration (h) of solar radiation on ceiling surface ($Z_{I_{hi}} = 12$ h). N_i: number of the day in the year (start from beginning of January $N_i = 1$ to end of March $N_i = 89$).

The typical daytime seasonal specific heating demands for a building ($q_{hd,d,seas}$) can be determined by summing the daytime seasonal parts of the specific internal heat rejection from inhabitants, lighting and domestic appliances ($q_{d,d,seas}$), specific heat demand for heating the ventilation fresh air ($q_{v,d,seas}$). Moreover, the specific heat demand for heating the infiltration fresh air penetrating the gaps of windows and doors ($q_{inf,d,seas}$) as follows:

$$q_{hd,d,seas} = \sum_{i=Z_{t_{out},d,i}}^{Z_{t_{out},dsg}} Z_{t_{out},d,i}\left\{(t_{in} - t_{out,d,i})\left[2k_w\left(\frac{(1-\mu)}{b} + \frac{1}{a}\right) + \frac{k_c}{h} + \frac{2\mu}{b}k_{wd} + 0.181 + \frac{4.012\mu}{b}\right] - q_d\right\} - \sum_{i=N_i}^{N_{dsg}} Z_{I_{si}}\left(\frac{(1-\mu)}{b}k_w\frac{I_{si}p}{\alpha_{out}} + \frac{\mu}{b}I_{si}n_1n_2n_3\beta\right) - \sum_{i=N_i}^{N_{dsg}} Z_{I_{hi}}k_c\frac{I_{hi}p}{\alpha_{out}h} \quad (16)$$

At the nighttime of seasonal heating load, the heat gain through all external constructions of a building is determined from the difference between the outside nighttime temperature ($t_{out.n.i}$) and inside temperature (t_{in}). Accordingly, the specific value for the nighttime seasonal heating gain of a building, ($q_{hg.n.seas}$) can be determined from the following equation:

$$q_{hg,n,seas} = \sum_{i=Z_{t_{out,n,i}}}^{Z_{t_{out,dsg}}} Z_{t_{out,n,i}}\left\{(t_{out,n,i} - t_{in})\left[2k_w\left(\frac{(1-\mu)}{b} + \frac{1}{a}\right) + \frac{k_c}{h} + \frac{2\mu}{b}k_{wd}\right]\right\} \quad (17)$$

Similarly, the night-time seasonal specific heating demands for a building ($q_{hd,n,seas}$) can be determined by adding the night-time seasonal specific heating demands of ventilation fresh air ($q_{v,n,seas}$), and infiltration fresh air ($q_{inf.n.seas}$), then subtracting the seasonal specific value of heat gain ($q_{d,n,seas}$) as follows:

$$q_{hd.n.seas} = \sum_{i=Z_{t_{out.n.i}}}^{Z_{t_{out.dsg}}} Z_{t_{out.n.i}}\left\{(t_{out.n.i} - t_{in})\left[2k_w\left(\frac{(1-\mu)}{b} + \frac{1}{a}\right) + \frac{k_c}{h} + \frac{2\mu}{b}k_{wd} + 0.181 + \frac{4.012\mu}{b}\right] - q_{d,n,seas}\right\} \quad (18)$$

From Eqs. (16) and (18), the seasonal daytime specific heating demands ($q_{hd.d.seas}$) and seasonal nighttime specific heating demands ($q_{hd.n.seas}$) can be calculated respectively. Therefore, the values of duration ($Z_{t_{out.d.i}}$) of each daytime outside temperature ($t_{out.d.i}$) and the values of durations ($Z_{t_{out,n,i}}$) of each night-time current temperatures ($t_{out.n.i}$) should be determined for each climate zone and substituted in these equations. In case of the Cairo city, Egypt, the following empirical equations have been obtained [3,19]:

Daytime:

$$Z_{t_{out,d,i}} = 40998.305 - 10687.44t_{out,d,i} + 1092.509t^2_{out,d,i} - 54.74t^3_{out,d,i} + 1.345t^4_{out,d,i} - 0.0130t^5_{out,d,i} \quad (19)$$

Nighttime:

$$Z_{t_{out,d,i}} = -26.94 - 27.417t_{out,d,i} + 10.479t^2_{out,d,i} - 0.9413t^3_{out,d,i} + 0.02503t^4_{out,d,i} \quad (20)$$

$$I_{si} = 774.5 + 0.864N_i + 0.0113N_i^2 - 0.00124N_i^3 + 7.22\times10^{-6}N_i^4 \quad (21)$$

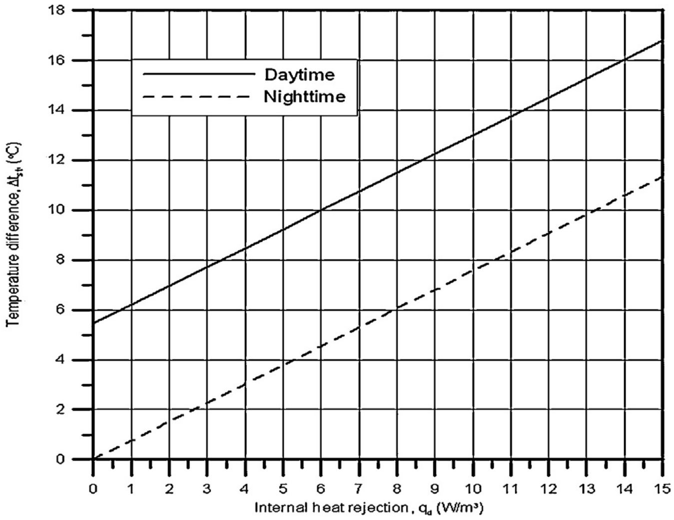

Fig. 5. Impact of internal heat rejection (q_d) on the daytime and nighttime temperatures ($t_{out.st.d}$) and ($t_{out.st.n}$).

$$I_{hi} = 488.74 + 1.082N_i + 0.073N_i^2 - 4.37\times 10^{-4}N_i^3 - 8.1\times 10^{-8}N_i^4 \qquad (22)$$

The starting time of the heating season depends on the value of both the daytime ($t_{out.st.d}$) and nighttime ($t_{out.st.n}$) starting temperatures. Therefore, when the outside temperature (t_{out}) is less than or equal to the values of ($t_{out.st.d}$) or ($t_{out.st.n}$), the seasonal heating period stars. The values of starting daytime temperature ($t_{out.st.d}$) and nighttime temperature ($t_{out.st.n}$), can be calculated analytically from Eqs. (10) and (18), by assuming that the value of the current outside temperature ($t_{out.i}$) is equal to starting outside temperature ($t_{out.st}$). Consequently, the following equations can be employed.

$$t_{out,st,n} = t_{in} - \frac{q_d}{2k_w(1/a) + (1-\mu/b) + (k_c/h) + (2\mu/b)k_{wd} + 0.181 + (4.012\mu/b)} \qquad (23)$$

$$t_{out,st,d} = t_{in} - \frac{(1-\mu/b)k_w(I_s p/\alpha_{out}) + k_c(I_h p/\alpha_{out} h) + (\mu/b)I_s n_1 n_2 n_3 \beta + q_d}{2k_w((1/a) + (1-\mu)/b) + (k_c/h) + (2\mu/b)k_{wd} + 0.181 + (4.012\mu/b)} \qquad (24)$$

Eq. (23) used to get the starting nighttime outside temperature ($t_{out.st.n}$), which starts the nighttime heating season for any kind of building. However, Eq. (24) used to determine the starting daytime outside temperature ($t_{out.st.d}$), which starts the daytime heating season. The impact of internal heat rejection (q_d) on values of ($t_{out.st.d}$) and ($t_{out.st.n}$), is significant and this result can be demonstrated in Fig. 5, which is illustrated for a building has dimensions of a = 12 m, b = 12 m, h = 6 m, and δ_{ins} = 0 m. Fig. 5 shows that the growth of internal heat rejection (q_d), increases the difference between inside temperature (t_{in}) and heating season's starting temperature ($t_{out.st}$) as follows:

$$\Delta t_{st} = t_{in} - t_{out,st} \qquad (25)$$

Eq. (25), indicates that, for the buildings with higher internal heat rejection (q_d), the heating starts at higher outside temperatures and ends earlier.

5. Conclusions

1 The new method of determining the heating load for any residential building located in any climatic conditions gives reasonable and accurate results.
2 For seasonal heating load calculations, it is important to carry out climatologic investigations and develop empirical equations for determining the total durations of current daytime temperatures and solar radiation intensities. Moreover, for determining the duration of nighttime temperatures, the climatic conditions should be given.
3 Each building has its own heating season starting temperature, regardless of climatic conditions and internal heat rejection.
4 The similar buildings in various climatic conditions have the same heating season's starting outside temperature. On the other hand, the heating period of a building depends on the total duration of outside temperatures, the intensities of solar radiation and the difference between the heating season's starting temperature and the heating design temperature in a given area.

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