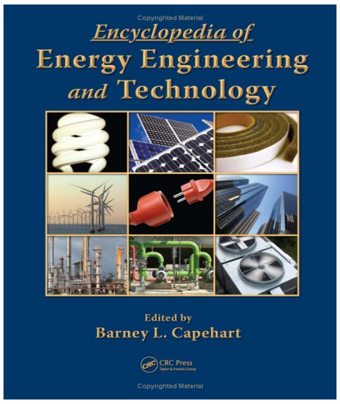
Residential Buildings: Heating Loads



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Abstract

In designing energy-saving heating systems, it is important to have the exact values of heating loads and seasonal heating demands of buildings. The existing methods for determining these values are not accurate enough, because they do not take into account important factors such as the impact of solar radiation on the surfaces of south walls and roofs, the significant difference between daytime and nighttime outside temperatures, as well as daytime and nighttime temperatures' durations in the heating season. Apart from the stated disadvantages, the existing methods do not take into consideration the fact that each building has its own heating season duration.

The mentioned imperfections do not allow finding out the correct values of the heating demands of buildings, which may become the primary cause of wrong designs of heat supply systems.

In this entry, new and improved methods are presented for the correct determination of heating loads of buildings.

INTRODUCTION

This entry was prepared based on summarizing the results of a research work accomplished by the author within a program of heating efficiency. For providing energy and fuel savings in heating systems, the exact values of heating loads of buildings are needed first. The newly developed method provides high accuracy in determining heating loads of buildings, as it takes into account the impact of more factors. It particularly highlights the impacts of sizes and the thermophysical properties of buildings' envelopes, irradiation and outside daytime and nighttime temperatures, durations of heating season, and internal thermal rejections on the values of heating loads of buildings. The proposed method discovers that heating seasons are different for each building, even in the same climatic conditions. It can be used for designing energy-efficient houses. The proposed method is designed for experts but it can be used by students too.

METHOD FOR HEATING LOAD OF BUILDING

The heating load is the quantity of heat needed to provide the given inside temperature of a building under the outside design temperature, $t_{\text{out.d}}$ (°C), of given climatic conditions. As a rule, it is more convenient and more exact to calculate the heating load referring to 1 m^3 of a building. This value is called specific heating demand, q_{hd} (W/m^3), which can be determined by Eq. 1:

$$q_{\text{hd}} = q_{\text{hl}} + q_{\text{v}} + q_{\text{inf}} - q_{\text{int}} \tag{1}$$

where

q_{hl} total specific heat lost (W/m^3)
q_{v} specific quantity of heat required for heating the outside fresh air, supplied into the building for ventilation (W/m^3)
q_{inf} specific quantity of heat lost for heating outside fresh air, which has penetrated into the building through gaps of windows and doors (W/m^3)
q_{int} specific quantity of heat gain in the building from lighting, electrical devices, and inhabitants (W/m^3).

For calculation of specific values q_{hl} (W), q_{v} (W), q_{inf} (W), the following equations are suggested:

$$\Sigma q_{\text{hl}} = \left(t_{\text{int}} - t_{\text{out.dsg.}}\right)\left[2\left(\frac{a+b}{ab}\right)\left(k_{\text{w}}(1-\mu) + k_{\text{wd}}\mu\right) + \frac{k_{\text{r}}}{h}\right] \tag{2}$$

$$q_{\text{v}} = 0.181\left(t_{\text{in}} - t_{\text{out.dsg}}\right) \tag{3}$$

$$q_{\text{inf}} = \frac{4,4\mu(a+b)\left(t_{\text{in}} - t_{\text{out.dsg.}}\right)}{ab} \tag{4}$$

Eqs. 2–4 do not take into consideration the impact of solar radiation on the surfaces of the building; therefore,

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by substituting Eqs. 2–4 into Eq. 1, we obtain the following equation for determining the design values of nighttime-specific heating demand $q_{\text{hd.n}}$ (kW), for any kind of building:

$$q_{\text{hd.n.}} = \left(t_{\text{int}} - t_{\text{out.dsg.}}\right)\left\{\begin{array}{l} 2\left[\dfrac{a+b}{ab}\right][k_{\text{w}}(1-\mu) + k_{\text{wd}}\mu] + \\ + \dfrac{k_{\text{r}}}{h} + 0.181 + \dfrac{4.4\mu(a+b)}{ab} \end{array}\right\} - q_{\text{int}} \tag{5}$$

where k_{w} and k_{r} are heat transfer values of walls and ceiling, calculated in W/m^2 °C.

Heat transfer values of walls (k_{w}) and ceiling (k_{r}) are determined by Eq. 6:

$$k_{\text{w}} = \frac{1}{\left(\frac{1}{\alpha_{\text{in}}} + \frac{\delta_{\text{w}}}{\lambda_{\text{w}}} + \frac{\delta_{\text{ins.}}}{\lambda_{\text{ins.}}} + \frac{1}{\alpha_{\text{out}}}\right)} \tag{6}$$

The obtained Eq. 5 is applicable for designing heating systems, which are able to maintain a comfortable temperature t_{in} (°C) inside the building at both nighttime (when there is no solar radiation) and still more in the daytime (when there is solar radiation).

In Eqs. 5 and 6, the values take on the following meaning:

$t_{\text{out.dsg}}$	outside design temperature (°C)
k_{w}, k_{wd}, k_{r}	heat transfer coefficient of walls, windows, and ceiling (W/m^2 °C)
μ	glazing rate of the building normally $\mu = 0.12$
δ_{w} and δ_{r}	thickness of the construction materials of walls and ceiling of the building (m)
λ_{w} and λ_{r}	heat conductivities of the construction materials of walls and ceiling of the building (W/m °C)
δ_{ins}	thickness of the insulation material covering the walls and ceiling of the building (m)
λ_{ins}	heat conductivity of the insulation material covering the walls and ceiling of the building (W/m °C)
$\alpha_{\text{in}} = 8$ W/m^2 °C	heat convection coefficient on the inside surfaces of the walls and ceiling of the building
$\alpha_{\text{out}} = 23$ W/m^2 °C	heat convection coefficient on the outside surfaces of the walls and ceiling of the building

The values of length a, width b, and height h of the building (m) are taken from the building plan and section:

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

$$\mu = \frac{\Sigma F_{\text{wd}}}{2(a+b)h} \tag{7}$$

where ΣF_{wd} is the total surface of windows on the vertical surfaces of the building (m^2).

The values of specific heating demands, q_{hd}, depending on the lengths a and heights h of the buildings in case of their constant widths $b = 12$(m) were calculated by Eq. 5. The results are displayed in Fig. 1.

The diagrams of Fig. 1 show that the specific heating demands, q_{hd}, for bigger buildings are less, which indicates higher energy efficiency of heating big buildings.

Daytime Heating Load

The obtained Eq. 5 does not include the impact of solar radiation; therefore, it can be used for determining nighttime-specific heating demands $q_{\text{hd.n}}$ (kW/m^3).

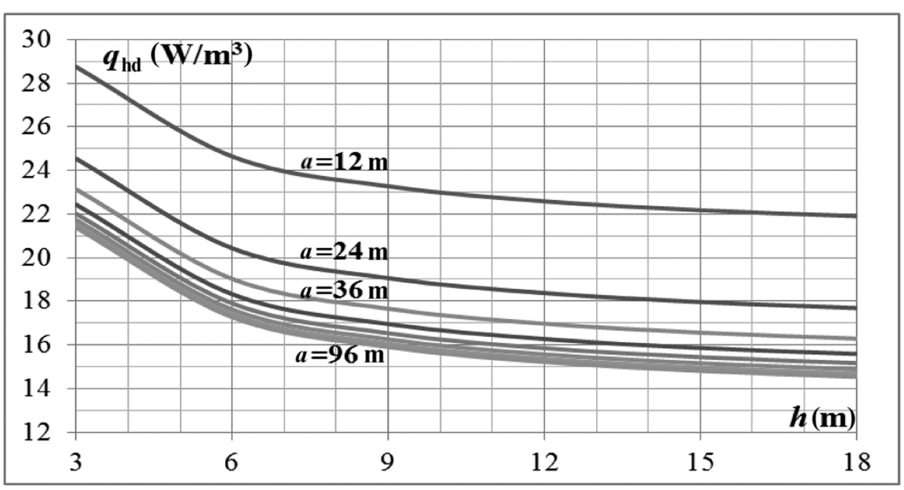

Fig. 1 Values of specific heating demand q_{hd} (W/m^3) of a building depending on sizes a and h (m), in case of constant width $b = 12$ m.

In the daytime, besides heat lost, which is determined analogous to nighttime, there are implicit and immediate direct heat gains because of the impact of solar radiation. The useful impact of solar radiation on heating demand can be evaluated by the help of radiation temperatures, t_R (°C), which are formed on external opaque surfaces of walls and ceiling of the building. The radiation temperature, t_R (°C), on a given surface is formed during the daytime period; therefore, it should be evaluated by daytime outside temperatures, $t_{out.d}$, of the heating period by using Eq. 8:

$$t_R = t_{out.day} + \frac{Ip}{\alpha_{out}} \tag{8}$$

In such circumstances, the specific heat losses through the south-facing wall $q_{hl.w.S}$ and ceiling $q_{hl.r}$ are determined by Eqs. 9 and 10:

$$q_{hl.w.S} = (t_{in} - t_{R.w.S})\left(\frac{k_{w.S}(1-\mu)}{b}\right) \tag{9}$$

and

$$q_{hl.r} = (t_{in} - t_{R.r})\frac{k_r}{h} \tag{10}$$

By substituting the values $t_{R.w.S} = t_{out.d.} + \frac{I_S p_S}{\alpha_{out}}$ and $t_{R.r} = t_{out.d.} + \frac{I_r p_r}{\alpha_{out}}$ in Eqs. 9 and 10 and making some simplifications, we obtain the following equation for determining the daytime total heat lost through the south wall and ceiling (opaque constructions) $\Sigma q_{hl.op.d}$ of the building:

$$\begin{aligned}\Sigma q_{hl.op.d} = {} & \left(t_{in} - t_{out.d.} - \frac{I_S p_S}{\alpha_{out}}\right)\left(\frac{k_{w.S}(1-\mu)}{b}\right) \\ & + \left(t_{in} - t_{out.d.} - \frac{I_r p_r}{\alpha_{out}}\right)\frac{k_r}{h}\end{aligned} \tag{11}$$

After making some mathematical manipulations and simplifications in the previous equation, Eq. 12 was developed for determining the daytime total heat lost trough the walls and ceiling:

$$\begin{aligned}\Sigma q_{hl.op.d.} = {} & (t_{int} - t_{out.d.})\left(\frac{k_{w.S}(1-\mu)}{b} + \frac{k_r}{h}\right) \\ & - \frac{I_S p_S}{\alpha_{out}}\left(\frac{k_{w.S}(1-\mu)}{b} - \frac{I_r p_r}{\alpha_{out}}\frac{k_r}{h}\right)\end{aligned} \tag{12}$$

There are also heat losses through the walls and windows that are not exposed to the sun having other non-south-facing orientation; this can be calculated as $\Sigma q_{hl.ot}$, as shown in Eq. 13:

$$\Sigma q_{hl.ot.} = (t_{in} - t_{out.d})\left[\frac{k_w(1-\mu)(a+2b) + 2k_{wd}\mu(a+b)}{ab}\right] \tag{13}$$

So the total heat loss $\Sigma q_{hl.d.}$ from the building in the daytime is the sum of Eqs. 12 and 13:

$$\begin{aligned}\Sigma q_{hl.d} = {} & (t_{int} - t_{out.d.})\left(\frac{k_{w.}[(1-\mu)(a+2b)]}{ab} + \frac{k_r}{h}\right) \\ & - \frac{I_s p_s k_{w.S}(1-\mu)}{\alpha_{out} b} - \frac{I_r p_r}{\alpha_{out}}\frac{k_r}{h}.\end{aligned} \tag{14}$$

Direct specific heat gain by the penetration of solar radiation $q_{wd.R}$ through the south-facing windows should also be taken into account, and its value can be determined by Eq. 15:

$$q_{wd.R} = \frac{\mu I_s n_1 n_2 n_3}{b} \tag{15}$$

where n_1, n_2, and n_3 are the rates of reduction of radiation heat penetrating through the south-facing windows due to reflection, the window frames, and the dust on glazed surfaces, respectively.

By substituting the value of the direct specific heat gain $q_{wd.R}$ through the south windows from Eq. 15 into Eq. 14, and adding heat losses of ventilation and infiltration given earlier as well as internal heat gain q_{int}, we can obtain Eq. 16 for determining the daytime heating demand q_{hd} (W/m^3):

$$\begin{aligned}q_{hd.d} = {} & (t_{int} - t_{out.d.})\left(\frac{2(a+b)(k_w(1-\mu) + k_{wd}\mu)}{ab}\right. \\ & \left. + \frac{k_r}{h} + 0.181 + \frac{4.4\mu(a+b)}{ab}\right) - \\ & - \frac{I_r p_r}{\alpha_{out}}\frac{k_r}{h} - \frac{I_S p_S}{\alpha_{out}}\frac{k_{w.S}(1-\mu)}{b} - \frac{\mu I_s n_1 n_2 n_3}{b} - q_{int}\end{aligned} \tag{16}$$

where

$t_{out.d.}$	outside air daytime temperature (°C)
I_s and I_r	intensities of solar radiation on the south wall and ceiling surfaces of the building (W/m^2)
p_s and p_r	rates of solar radiation absorption by the surfaces of the south wall and ceiling

Internal heat gains q_{int} (W/m^3) from lighting, electrical devices, and occupants have a considerable impact on the heating demand of the building.

For revelation of values of internal specific heat gains, surveys were conducted of inhabitants from 1000 apartments in the city of Yerevan under the direction of the author. With the results of the survey, processed by methods of mathematical statistics, the following formulas

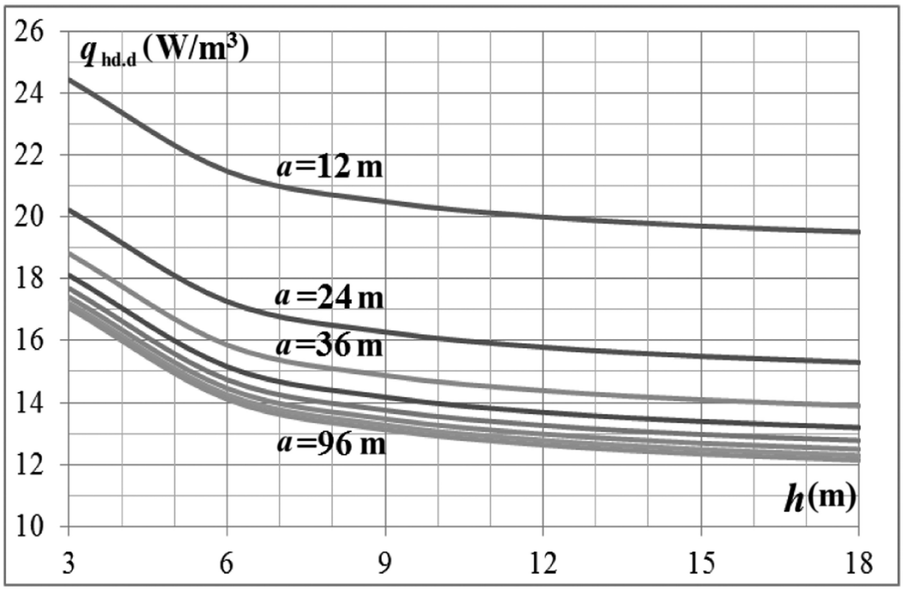

Fig. 2 Daytime-specific heating demands, $q_{hd.d}$, depending on sizes of buildings.

were developed for identifying the values of specific internal heat gains for winter ($q_{int..w}$) and summer ($q_{int..sum}$) periods:

$$q_{int.w} = 0.0016S^3 - 0.0622S^2 + 0.576S + 2.0566,$$
$$q_{int.sum.} = 0.0044S^3 - 0.1047S^2 + 0.6551S + 1.9572 \tag{17}$$

where S is the number of storeys in the building.

The values of daytime-specific heating demands, $q_{hd.d}$, depending on the lengths a and heights h of the buildings, in the case of constant widths b= 12(m), were calculated by Eq. 16. The results are displayed in Fig. 2.

METHOD FOR SEASONAL HEATING DEMAND OF BUILDINGS

At present, the methods for determining the seasonal heating demands of buildings are based on the use of heating degree days or heating degree hours and, therefore, do not take into account the useful impact of daytime solar radiation on the surfaces of buildings and the significant difference between daytime $t_{out.d}$ and nighttime $t_{out.n}$ temperatures.

Seasonal heating demands $q_{hd.seas}$ should be calculated by substituting the values of the durations of each current temperature $t_{out..i}$ occurring between nighttime and daytime heating seasons starting with outside temperature $t_{out.st.n}$ and heating design temperature $t_{out.dsg}$. For this reason, it is necessary to have the durations $Zt_{out.i}$ of each temperature $t_{out.i}$ in each climatic zone, which can be established by special climatologic investigations. For example, in the conditions of Yerevan city, Armenia, for determining durations $Zt_{out.i}$ (hour) of each temperature $t_{out.i}$, the following empirical equations were obtained by special research of the author:

$$\text{Daytime}: \quad \begin{aligned} Zt_{out.d.i} = {} & 0.00003t^5_{out.d.i} + 0.0006t^4_{out.d.i} \\ & -0.0133t^3_{out.d.i} - 0,25t^2_{out.d.i} + 3,92t_{out.d.i} \\ & +61, \text{hours} \end{aligned} \tag{18a}$$

$$\text{Nighttime}: \quad \begin{aligned} Zt_{out.n.i} = {} & 0.000006t^5_{out.n.i} + 0.0014t^4_{out.n.i} \\ & -0.031t^3_{out.n.i} - 0,59t^2_{out.n.i} + 9,15t_{out.n.i} \\ & +142, \text{hours} \end{aligned} \tag{18b}$$

For finding out the duration $Zt_{out.d.i}$ (h) of any current daytime temperature $t_{out.d.i}$ within the heating season, the value of that daytime temperature should be substituted in the daytime empirical equation (Eq. 18a). The same procedure should be followed to find out the duration $Zt_{out.n.i}$ (hr) of any current nighttime temperature $t_{out.n.i}$ by using Eq. 18b.

The method for determining seasonal heating demands of buildings is divided into two parts: daytime, $q_{hd.d.seas}$ (Wh/m^3), and nighttime, $q_{hd.n.seas}$ (Wh/m^3). The total seasonal heating demand will be the sum of the daytime and nighttime heating demands:

$$q_{hd.seas.} = q_{hd.d.seas.} + q_{hd.n.seas.} \tag{19}$$

DAYTIME SEASONAL HEATING DEMAND OF BUILDINGS

The useful impact of solar radiation on the value of daytime heating demand is evaluated by the methods described earlier.

According to the concepts presented, Eq. 20 was carried out for determining the specific value of daytime seasonal heat loss $q_{\mathrm{hl.d.seas}}$ (Wh/m^3) for all constructions of buildings:

$$\Sigma q_{\mathrm{hd.d.seas.}} = \sum_{i=Zt_{\mathrm{out.st.d}}}^{Zt_{\mathrm{dsg}}} Z_{t_{\mathrm{out.d.i}}} \left(t_{\mathrm{int}} - t_{\mathrm{out.dsg.}}\right) \left[\begin{array}{l} 2\left(\frac{a+b}{ab}\right)(k_{\mathrm{w}}(1-\mu) + k_{\mathrm{wd}}\mu) + \frac{k_{\mathrm{r}}}{h} + \\ 0.181 + \frac{4.4\mu(a+b)}{ab} \end{array}\right] - \sum_{i=Zt_{\mathrm{out.st.d}}}^{Zt_{\mathrm{dsg}}} Z_{t_{\mathrm{out.d.i}}} \left(\frac{I_s p_s k_w (1-\mu)}{\alpha_{\mathrm{out}} b} + \frac{I_{\mathrm{r}} p_{\mathrm{r}} k_{\mathrm{r}}}{\alpha_{\mathrm{out}} h} + \frac{\mu I_s n_1 n_2 n_3}{b} + q_{\mathrm{int}}\right) \tag{20}$$

where

$t_{\mathrm{out.d.i}}$	current daytime temperatures between the heating season's starting temperature $t_{\mathrm{out.st.d}}$ and the heating season's design temperature $t_{\mathrm{out.dsg}}$ of a given area. As a rule, the heating season's starting temperature $t_{\mathrm{out.st.d}}$ = +8°C
$Zt_{\mathrm{out.d.i}}$	duration (hr) of each outside daytime temperature, $t_{\mathrm{out.d.i}}$, occurring between the heating season's starting daytime temperature, $t_{\mathrm{out.st.d}}$, and the heating season's design temperature, $t_{\mathrm{out.dsg}}$
I_{s} and I_{r}	seasonal average intensities (W/m^2) of solar radiation on the surfaces of the south wall and roof of the building

NIGHTTIME SEASONAL HEATING DEMAND OF BUILDINGS

Because of the absence of solar radiation during the nighttime period of the heating season, the heat losses through all external constructions of a building are calculated by the difference of the inside given temperature t_{in} and the current outside night temperatures $t_{\mathrm{out.n.i}}$. Therefore, the nighttime seasonal value of heat lost of a building, $q_{\mathrm{hl.n.seas}}$ (Wh/m^3), can be determined by Eq. 21:

$$q_{\mathrm{hd.n.seas.}} = \sum_{i=Zt_{\mathrm{out.st.n.}}}^{Zt_{\mathrm{out.dsg}}} Z_{t_{\mathrm{out.n.i}}} (t_{\mathrm{in}} - t_{\mathrm{out.n.i}}) \left\{ 2\left[\frac{a+b}{ab}\right] [k_{\mathrm{w}}(1-\mu) + k_{\mathrm{wd}}\mu] + \frac{k_{\mathrm{r}}}{h} + 0.181 + \frac{4.4\mu(a+b)}{ab} \right\} - q_{\mathrm{int}} \cdot \sum_{i=Zt_{\mathrm{out.st.n.}}}^{Zt_{\mathrm{out.dsg}}} Z_{t_{\mathrm{out.n.i}}} \tag{21}$$

where

$t_{\mathrm{out.n.i}}$	current night temperatures occurring between heating season's starting nighttime temperature, $t_{\mathrm{out.st.n}}$, and the heating design temperature, $t_{\mathrm{out.dsg}}$ (°C)
$Zt_{\mathrm{out.n.i}}$	duration (hr) of each outside nighttime temperature, $t_{\mathrm{out.n.i}}$, occurring between the heating season's starting nighttime temperature, $t_{\mathrm{out.st.n}}$, and the heating design temperature, $t_{\mathrm{out.dsg}}$
$\sum_{i=Zt_{\mathrm{out.st.n.}}}^{Zt_{\mathrm{out.dsg}}} Z_{t_{\mathrm{out.n.i}}}$	duration of nighttime heating season in hours

Heating Season's Starting Daytime Temperature $t_{\mathrm{out.st.d}}$ and Nighttime Temperature $t_{\mathrm{out.st.n}}$

The heating season's starting daytime temperature $t_{\mathrm{out.st.d}}$ and outside nighttime temperature $t_{\mathrm{out.st.n}}$ are due to which the internal heat gain q_{int} is able to fulfill the heating demand of the building and maintain the inside comfortable temperature. This means that if the outside temperature becomes lower than $t_{\mathrm{out.st.d}}$ or $t_{\mathrm{out.st.n}}$, the building needs to be heated, as the value of a building's heating demand q_{hd} becomes higher than q_{int} (W/m^3).

The values of the heating season's starting temperatures at daytime $t_{\mathrm{out.st.d}}$ and at nighttime $t_{\mathrm{out.st.n}}$ can be found analytically, assuming that in Eqs. 5 and 16, the values of outside current temperatures $t_{\mathrm{out.i}}$ are considered equal to $t_{\mathrm{out.st}}$, and $q_{\mathrm{hd}} = q_{\mathrm{int}}$. As a result of conducting such a procedure, we obtain Eqs. 22 and 23 for determining the values of $t_{\mathrm{out.st.n}}$ and $t_{\mathrm{out.st.d}}$:

$$t_{\mathrm{out.st.n.}} = t_{\mathrm{in}} - \frac{2q_{\mathrm{int}}}{\left\{2\left[\frac{a+b}{ab}\right][k_w(1-\mu) + k_{\mathrm{wd}}\mu] + \frac{k_{\mathrm{r}}}{h} + 0.181 + \frac{4.4\mu(a+b)}{ab}\right\}} \tag{22}$$

$$t_{\mathrm{out.st.d.}} = t_{\mathrm{in}} - \frac{2q_{\mathrm{int}} + \frac{I_{\mathrm{r}} p_{\mathrm{r}}}{\alpha_{\mathrm{out}}} \frac{k_{\mathrm{r}}}{h} + \frac{I_{\mathrm{S}} p_{\mathrm{S}}}{\alpha_{\mathrm{out}}} \frac{k_{\mathrm{w.S}}(1-\mu)}{b} + \frac{\mu I_{\mathrm{s}} n_1 n_2 n_3}{b}}{\left(\frac{(a+b)[2[k_{\mathrm{w}}(1-\mu) + k_{\mathrm{wd}}\mu] + 4.4\mu]}{ab} + \frac{k_{\mathrm{r}}}{h} + 0.181\right)} \tag{23}$$

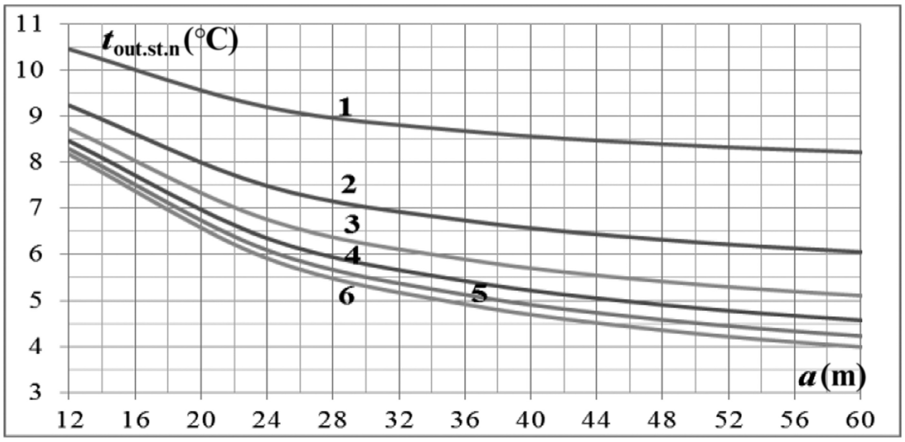

Fig. 3 Heating season's starting nighttime temperatures $t_{out.st.n}$ in Yerevan city. Sizes of buildings: 1-h = 3 m; 2-h = 6 m; 3-h = 9 m; 4-h = 12 m; 5-h = 15 m; 6-h = 18 m.

With the help of Eqs. 22 and 23, the values of the heating season's starting nighttime $t_{out.st.n}$ and daytime $t_{out.st.d}$ temperatures for the climatic conditions of Yerevan city for buildings of different sizes were calculated. The results of the calculations are presented in Figs. 3 and 4.

A comparison of Figs. 3 and 4 proves that the impact of daytime solar radiation helps lowering the heating season's starting temperatures $t_{out.st.d}$ for buildings of all sizes. For instance, for a standard residential house with sizes a = 12 m, b = 12 m and h = 3 m, the daytime heating AQ1 season starts at an outside temperature $t_{out.st.d.}$= + 6°C, whereas the nighttime heating season starts earlier, at $t_{out.st.n.}$= 10.5°C. In addition, the duration of the nighttime heating season is longer and the seasonal heating demand is bigger, respectively.

Based on the suggested methods and formulas, simulation software was developed that enabled computer-aided calculations for determining the exact values of seasonal heating demands of houses. The results of the calculations of day and night seasonal heating demands for standard residential houses in Yerevan city climatic conditions are presented in Fig. 5.

The diagram proves that for the examined house, the nighttime-specific heating demand, $q_{hd.n..i}$, becomes zero ($q_{hd.n..i}$ = 0) when the outside temperature $t_{out.n.i} \geq$ 12°C. The daytime-specific heating demand, $q_{hd.d..i}$, becomes zero ($q_{hd.d..i}$ = 0) when outside temperature $t_{out.d.i} \geq$ +6.5°C. These results correspond well with the data in Figs. 3 and 4.

The sum of all day and night current heating demands for all possible outside heating season temperatures is shown in Fig. 5; these values represent the total seasonal heating demand for the house.

By multiplying the total seasonal heating demand by the volume of the house, we will obtain the absolute value of the seasonal heating demand: AQ2

$$Q_{hd.seas.} = q_{hd.seas.} V_b \tag{24}$$

The experimental calculations of the seasonal heating demands for the same building by the existing and suggested methods prove that the correct value of the heating demand, defined with the help of the new method, is 25–30% less than in the case calculated with the existing method. This difference is explained by the

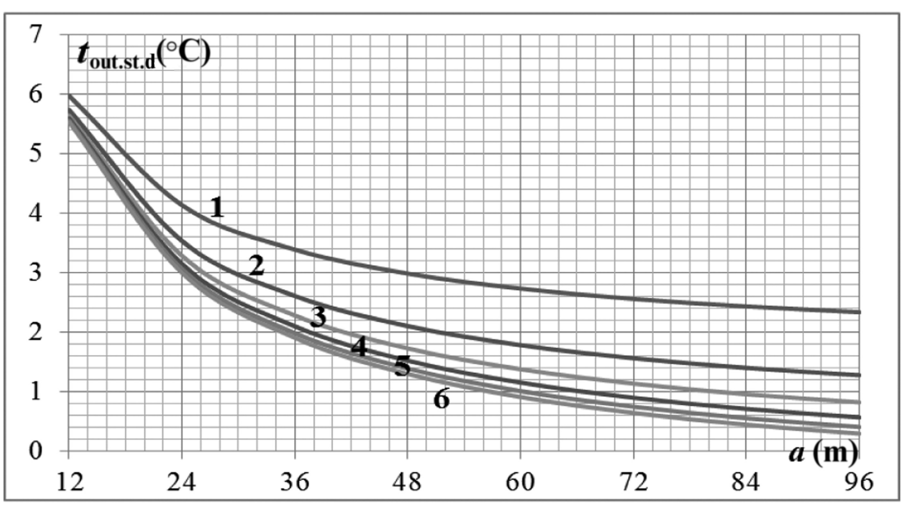

Fig. 4 Heating season's starting daytime temperatures $t_{out.st.d}$ in Yerevan city. Sizes of buildings: 1-h = 3 m; 2-h = 6 m; 3-h = 9 m; 4-h = 12 m; 5-h = 15 m; 6-h = 18 m.

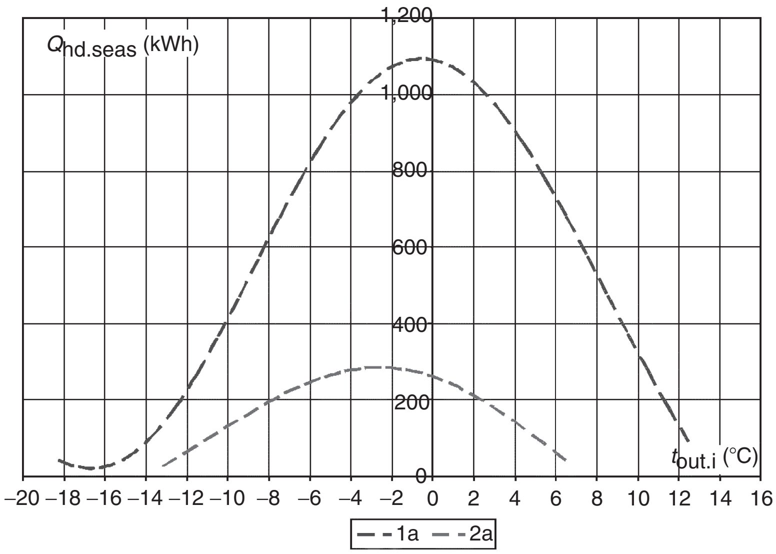

Fig. 5 Daytime and nighttime seasonal heating demands for a residential family house in the climatic conditions of Yerevan, Armenia: (1a) nighttime seasonal heating demands, $q_{\mathrm{hd.n..i}}$ (kWh/m^3); (2a) daytime seasonal heating demands, $q_{\mathrm{hd.d..i}}$ (kWh/m^3).

impact of solar radiation and by the use of a more correct method for determining seasonal heating demands.

APPLICATION OF SPECIFIC HEATING DEMAND METHOD FOR DESIGNING ENERGY-EFFICIENT HOUSES

The energy efficiency of a building is characterized by its required heating and cooling demands. The lower the heating and cooling demands, the more energy-efficient is the building. Therefore, the energy efficiency of a building can be established not only by its appropriate thermal insulation and by improving the technical characteristics of the heating and cooling systems, but also by dimensioning its sizes in such a way as to provide the minimum possible heating demand for a building of a given volume. In this case, the building itself becomes energy-efficient. For defining such dimensions of a building with a given volume, the method suggested earlier for determining the specific heating demands of houses can be applied.

At first glance, the solution of this problem is connected to the minimization of the external surface of the building of a given volume. Nevertheless, according to this concept, the building should have the form of a sphere or of a cube, which, as a rule, is not expedient, especially for residential houses. Besides, a building has different surfaces, transparent to solar radiation. These particularities make a building a geometrically irregular construction. Therefore, the lateral surface becomes irregular too. In this case, unexpected heat losses from different parts of a building's envelop will take place, the sum of which would not be the minimum possible loss. This means that despite minimum lateral or total surface, the heating demand of the building is not the minimum possible.

By this reasoning, it becomes clear that the inherent solution of the problem is conditioned by the real heating demand of the building, not by the external surface of the building's envelope. From this point of view, the suggested Eq. 5 can help, as it allows determining the specific heating demands depending on the sizes a, b, h of buildings. On the other hand, the given volume of the building represents the sizes according to the following fraction:

$$h = \frac{V_{\mathrm{b}}}{ab} \tag{25}$$

Assuming a constant width b =12 m and a variable length a = var, the height h of the building for each length a (m) is determined. Farther, the obtained sizes a, b, h are substituted in Eq. 5, and by the help of the program EXCEL, the specific heating demands q_{hd} (W/m^3) of a building of given volume are determined for all combinations of sizes. Then the minimum values of heating demand for the respective sizes a, b, h are selected, as shown in Fig. 6. The building of a given volume, designed by the determined sizes, is distinguished by its minimum value of heating demand and is considered to be an energy-efficient option.

From Fig. 6, we can see that for a building with a given volume V_{b} = 5000 m^3 to be energy-efficient, that is, to have the minimum heating demand, it should be designed with the following dimensions: length a = 40 m, height h_{min} = 10.4 m, width b = 12 m. If the same volume V_{b} = 5000 m^3 is provided by dimensions that differ from these given values, the heating demand of that house will be higher compared with the house with the previous dimensions.

From Fig. 6, it is clear that for buildings with bigger volumes to be energy-efficient, they require expanded dimensions a_{min} and h_{min}. In case of very big volumes, when $V_{\mathrm{b}} \geq$ 50,000 m^3, starting with a length of a_{min} = 95 m, the height h_{min} reaches an extreme limit, which for

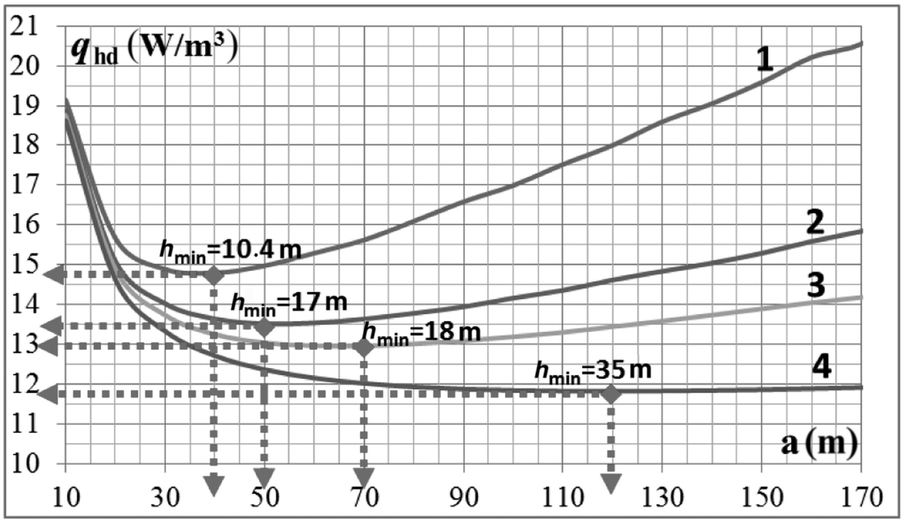

Fig. 6 Diagrams of required length a (m) and height h (m) of energy-efficient buildings of different volumes V_b (m^3). Curves: 1-V_b = 5000 m^3, a = 40 m, h_{min} = 10.4 m; 2-V_b = 10,000 m^3, a = 50 m, h_{min} = 16.7 m; 3-V_b = 15,000 m^3, a = 70 m, h_{min} = 18.0 m; 4-V_b = 50,000 m^3, a = 120 m, h_{min} = 35.0 m.

climatic conditions of Yerevan city cannot exceed h_{min} = 35 m regardless of the building's volume. This means that for designing energy-efficient buildings with volumes exceeding 50,000 m^3, the heights of buildings should be kept always at $h_{min} \leq 35$ m and, accordingly, the required length a (m) should to be determined.

As h_{min} = 35 m corresponds to the height of a 12-storey building, the executed research concludes that under conditions of Yerevan city, the heights of buildings should not exceed 12 storeys in order to provide energy efficiency.

The application of the discovered condition will also support the seismic stability of the buildings.

CONCLUSIONS

1. The suggested methods in this entry can be applied for the accurate calculation of the design and seasonal heating demands of any kind of building, with a given combination of thermal and physical properties of constructions and in any climatic condition. For achieving this target, it is necessary to conduct climatological investigations and to develop empirical equations for determining the total duration of current daytime and nighttime temperatures in the given climatic conditions.
2. Each building has its own heating season's starting outside temperature, regardless of the climatic conditions. The same building in various climatic conditions has the same heating season's starting outside temperature, but the heating season period of a building depends on the total duration of the temperatures having values between the heating season starting temperature, $t_{out.st.n}$, and the heating design temperature, $t_{out.dsg}$, in a given area.
3. The accurate values of seasonal heating demands allow determining and planning accurate values of fuel consumption for heating purposes.
4. Despite certain complications, the suggested methods can find large use by designers because of their rather high accuracy.
5. The suggested methods in this entry can be applied for designing buildings with special configurations that will provide energy efficiency.

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Author Queries

AQ1 The subscript terms are abbreviated inconsistently, e.g., $t_{out.st.d}$ vs. $t_{out.st.d.}$; $\sum q_{hl.op.d}$ vs. $\sum q_{hl.op.d.}$, etc. Please check and confirm.

AQ2 Unnumbered equations have been numbered and renumbered sequentially. Please check if okay.