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# THE SEASONAL HEAT DEMAND FOR HEATING, CALCULATED ON THE BASIS OF PEAK POWER VALUES IN EDUCATIONAL BUILDINGS

# SEZONOWE ZAPOTRZEBOWANIE NA CIEPŁO DO OGRZEWANIA OBLICZONE NA PODSTAWIE MOCY SZCZYTOWEJ W BUDYNKACH EDUKACYJNYCH

A b s t r a c t

This paper presents the selected results of examinations connected with a seasonal heat consumption ($Q$) and thermal power ($q$) for heating in educational buildings. The purpose of the analysis presented here was to examine the influence of possible occurrence and level of differences between the seasonal heat consumption ($Q$) and the seasonal heat demand ($Q_q$) for heating, calculated on the basis of $q$ values. A modification in the method for determination of $Q_q$ for room heating on the basis of available data on $q$ was introduced. A linear function, describing the changes in ($Q_q - Q$) depending on the changes in $q$ values, which was applied for that purpose, made it possible to improve the consistency of obtained heat demand values in relation to measured consumption of heat for heating by 65.6%.

*Keywords*: *educational buildings*, *heating*, *thermal power*, *heat demand*, *heat consumption*

S t r e s z c z e n i e

W artykule przedstawiono wybrane wyniki analiz związanych z sezonowym zapotrzebowaniem na ciepło ($Q$) i mocą szczytową ($q$) do ogrzewania budynków edukacyjnych. Celem tej analizy było ustalenie wystąpienia różnic pomiędzy sezonowym zużyciem ciepła ($Q$) a sezonowym zapotrzebowaniem na ciepło ($Q_q$) do ogrzewania, obliczonym na podstawie znanej wartości szczytowej mocy cieplnej $q$. Realizacja ww. analizy stanowiła podstawę do zaproponowania zmiany w metodzie obliczania wartości zapotrzebowania na ciepło $Q_q$ do ogrzewania pomieszczeń na podstawie dostępnych danych. Wykorzystanie tutaj funkcji liniowej opisującej zmiany ($Q_q - Q$) w zależności od zmian wartości q umożliwia zmniejszenie rozbieżności pomiędzy obliczonymi wartościami zapotrzebowania na ciepło a zmierzonym zużyciem ciepła do ogrzewania o 65,6%.

*Słowa kluczowe*: *budynki edukacyjne*, *ogrzewanie*, *moc cieplna, zapotrzebowanie na ciepło*, *zużycie ciepła*

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## 1. Introduction

The calculative methods, which are applied in various fields of engineering, are usually a certain kind of theoretical approximation of reality.

Estimated and simplified calculations of the seasonal heat demand ($Q_q$) based on the known value of thermal power ($q$) are used quite often in engineering practice [5]. The using of available base quantities for calculation of sought quantities, the physical interpretation of which is often different from the "base", is not a new phenomenon [2, 4–7] and, despite its disadvantages, it will probably still be applied. Despite the simplifications introduced in such cases, the obtained results of calculations should correlate with the results of measurements. It should be so also in case of theoretical heat demand ($Q_q$) for heating, calculated on the basis of the thermal power ($q$) and the actual (measured directly or indirectly) seasonal heat consumption ($Q$) for heating.

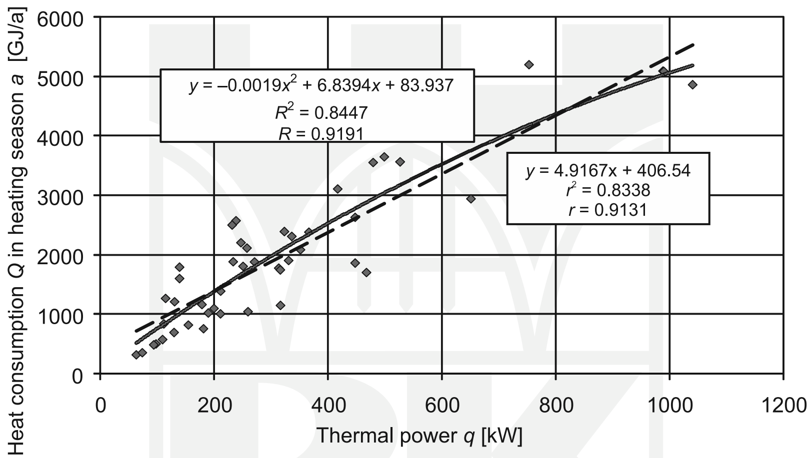


Fig. 1. Graph for the relationship between heat consumption $Q$ and thermal power q for heating

The association between $Q$ for heating and the calculated q as well as the discrepancies appearing here and the aforementioned use of q values for estimating of the heat demand ($Q_q$) in engineering practice were the main reason inducing the undertaking of the examinations and analyses, the results of which will be presented.

## 2. Description of the conducted examinations and analyses

The material presented in this work is a fragment of wider analysis and relates to 46 of 50 educational buildings, which were constructed in 1913–1992 (data for 4 objects were questionable in the author's opinion). The basic characteristic of these buildings is presented in the Table 1.

The statistical description of this group does not differ significantly from the description of the entire group of 50 buildings [6]. Difference from this analysis of heat consumption in educational buildings is also presented, inter alia, Butala V. and Novak P. [1], Corgnati S. P., Corrado V., Filippi M. [2], Desideri U., Proietti S. [3].

Table 1

**Selected measures of statistical description for the values characterizing 46 of 50 educational buildings forming the municipal group of objects of this type**

| Value $x$ | Selected measures of statistical description | | | |
|---|---|---|---|---|
| | Average value $x_{śr}$ | Standard deviation $s(x)$ | Limits of typicality $x_{yp}$ | Coefficient of variation $v_k(x)$ [%] |
| Cubic capacity $V$ [m$^3$] | 14682.37 | 9674.55 | 5007.82 – 24356.92 | 65.89 |
| A/V [m$^{-1}$] | 0.40 | 0.09 | 0.31 – 0.50 | 23.43 |
| Thermal power for heating $q$ [kW] | 323.38 | 235.15 | 88.23–558.54 | 72.72 |
| $q/V$ [W/m$^3$a] | 21.93 | 5.11 | 16.81–27.04 | 23.32 |
| Heat consumption for heating in stand. heating seas. $Q$ [GJ/a] | 1996.52 | 1266.14 | 730.38–3262.66 | 63.42 |
| $Q/V$ [GJ/m$^3$a] | 138.36 | 39.26 | 99.10–177.62 | 28.37 |

The heating season used in the analyses can be considered as typical for multiannual period in statistical respect (min. 30 years). In the examined group, 23 educational buildings were provided with heat for heating by HPC (Heat Power Company), while 27 buildings had their own boiler-rooms.

Returning to the relationship shown in the Fig. 1, it was noticed that about 84% of changes in Q depends on the changes in q, while 16% does not depend on the changes of this quantity. This state can be caused by not very accurate consideration of the actual conditions of buildings' heating in the methodology of thermal power ($q$) calculation.

Bearing in mind the practice that the demand for heat needed for buildings' heating is estimated on the basis of thermal power ($q$) as well as the conclusion formulated above, the following important question arises: Will the relationships and discrepancies revealed in the analysis of graphs in Fig. 1 be analogous in calculating the heat demand for buildings' heating ($Q_q$) on the basis of thermal power ($q$) (should it be expected)?

## 3. Results of examinations

In order to give an answer to the question, the values of $Q_q$ for examined buildings, which are a "representative" of the buildings' thermal needs mentioned in the title and connected with heating in calculation – theoretical conditions, were calculated and they were compared graphically with the corresponding values of heat consumption ($Q$) for heating in the actual conditions (Fig. 2).

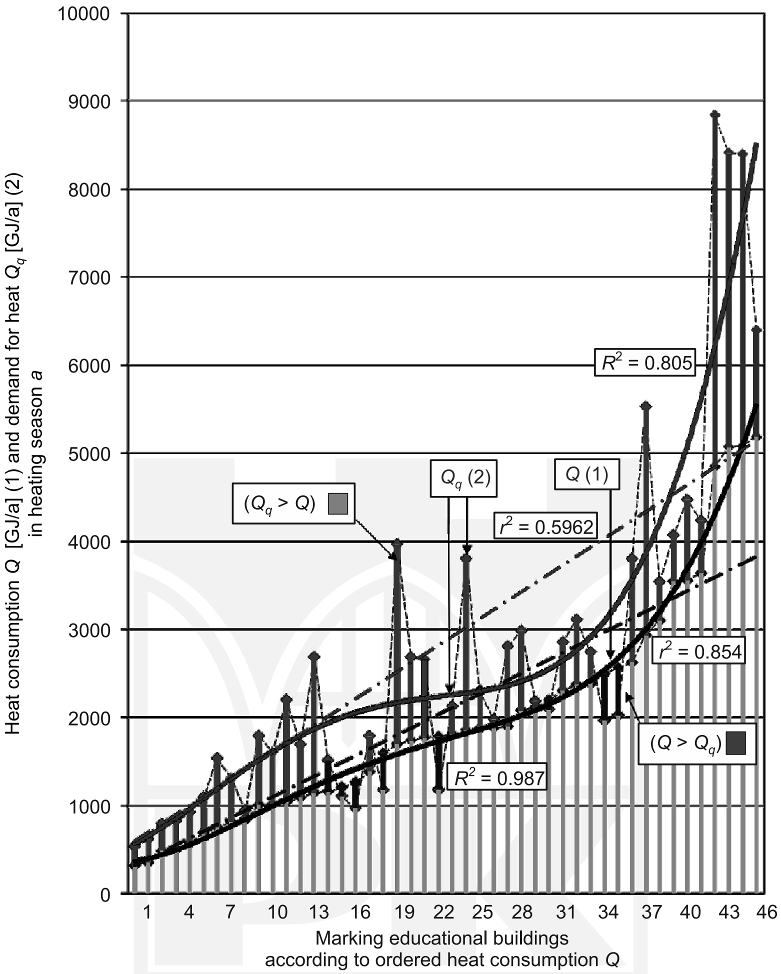


Fig. 2. Graph for the relationship between heat consumption $Q$ and thermal power $q$ for heating

The heat demand ($Q_q$) in analysed heating season for a given building calculated with the use of known value of thermal power ($q$), on the basis of equation (1), which is quoted, directly or indirectly, also in other publications [4–6]:

$$Q_q = q \cdot Nd \cdot 24h \cdot \frac{(T_{ical} - Teav)}{(T_{ical} - T_{e\min})} \cdot 0.0036 \quad (1)$$

where:

- $Q_q$ – heat demand for heating in heating season *a* [GJ/a],
- $q$ – thermal power [kW],
- $Nd$ – number of heating days in the considered heating season [days],
- $24h$ – duration of a day [h],

$T_{i\,cal}$ – calculative temperature of air inside of heated building assumed in the considered case ($T_{i\,cal\,av}$ = +20°C) [°C],

$T_{e\,av}$ – average temperature of air outside in the heating season for the considered period and for determined area (town) ($T_{e\,av}$ = +2.9°C) [°C],

$T_{e\,min}$ – calculative temperature of air outside, ($T_{e\,min}$ = –20.0) [°C],

0.0036 – conversion factor for values expressed in various physical units.

In the analysed case this relationship will have the following form:

$$Q_q = q \cdot 230 \cdot 24h \cdot \frac{(20\,^{o}\mathrm{C} - 2.9\,^{o}\mathrm{C})}{(20\,^{o}\mathrm{C} - (-20\,^{o}\mathrm{C}))} \cdot 0.0036 \tag{2}$$

The equation (2) is the result of comparison of algorithms for calculation of heat demand for heating in the conditions of the previously characterized heating season and thermal power necessary for fulfilling these needs in extreme conditions. Obviously, it is an imperfect comparison due to the applied "conversion factor", which "eliminates" only the difference of temperatures outside of a heated building, included in the considered algorithms.

## 4. Discussion of examination results

An indirect target of the analysis was to establish if there are essential differences between the actual seasonal heat consumption ($Q$) for heating of the examined buildings and the seasonal heat demand ($Q_q$) for heating, calculated on the basis of thermal power ($q$) value. The realization of such formulated task should make it possible to achieve the direct target, i.e. proposing a modified version of the method for calculating the seasonal heat demand ($Q1_q$). The modification should make it possible to reduce the differences between the thermal needs of educational buildings in actual and theoretical conditions, in case when these needs are estimated on the basis of known values of thermal power ($q$).

The analysis of relationships (Fig. 2) reveals the differences between seasonal heat consumption ($Q$) for heating and calculated (with the use of known values of thermal power ($q$) seasonal heat demand ($Q_q$). Occurrence of these differences confirms the divergence of trends for changes in the analyzed quantities, which are shown on the graph.

The described differences could be considered as resulting only from the discrepancies between the calculative assumptions and the actual conditions of heating season. However, it seems that their level (Fig. 2) in the examined educational buildings and the course of trend line do not incline towards such a statement. The calculated heat demand ($Q_q$) is bigger by 41.6%, on the average, than the actual consumption ($Q$). However, there are objects (7 of 46), in which the situation is opposite, i.e. $Q > Q_q$ (Fig. 2). In the analysed group of buildings the maximal discrepancy between the values of $Q$ and $Q_q$ amounted to 134% ($Q_q > Q$), while minimal discrepancy amounted to (–34)% ($Q > Q_q$). A percentage relation of the difference's value ($Q_q - Q$) to the value of $Q$ is diverse in individual objects.

## 5. The proposal of reducing discrepancies between the thermal needs of educational buildings in actual and calculation conditions

The relationships presented in the Figs. 3, 4 and 5 were used to propose a method for calculation of modified heat demand ($Q1_q$). For some of them $r^2 = 1$, which is a result of $Q_q$ and $Q1_q$ calculation using thermal power, and not of an "ideal" adjustment of function to the points of data on a graph. Using functional description of changes in the ($Q_q - Q$)

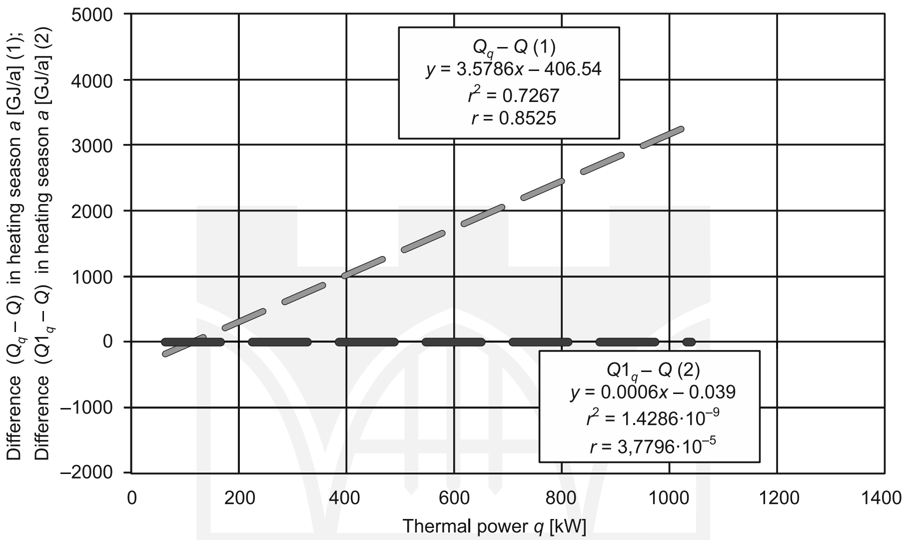


Fig. 3. Graph for the relationship between differences ($Q_q - Q$), ($Q1_q - Q$) and thermal power $q$

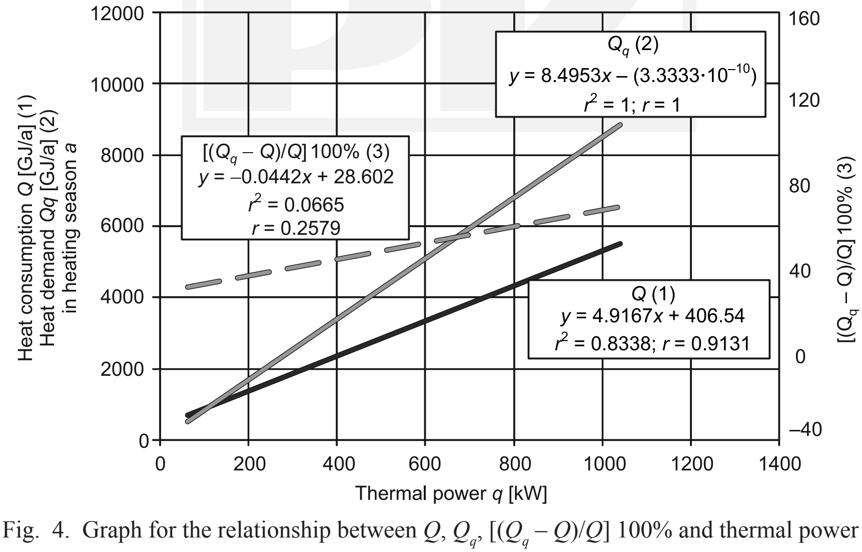


Fig. 4. Graph for the relationship between $Q$, $Q_q$, $[(Q_q - Q)/Q]$ 100% and thermal power $q$

difference depending on the changes in the thermal power ($q$) (Fig. 3) made it possible to create the relationship allowing the theoretical $Q1_q$ to be determined. A similar, but quantitatively worse effect, can be achieved by replacing the mentioned functional notation with a multiplier, equal to the average difference between $Q_q$ and $Q$, which in the analysed case amounted to 0.416. The method of $Q1_q$ determination allowed making the difference ($Q1_q - Q$) independent of the changes in thermal power ($q$) (Fig. 3).

Bearing in mind the results of previous analyses, in the next stage a trial to modify the relationship (1) was undertaken. The effect of such modification should be determining a method for calculating the values of seasonal heat demand for heating ($Q1_q$), which would, on the average, differ less from the heat consumption ($Q$) in the examined objects in relation to the difference occurring if the $Q_q$ quantity is used (Fig. 4). Its course in the graph (Fig. 3) was described by using the linear function $y = 3.5786x - 406.54$ for that purpose. The determination of the difference in form of decimal fraction 0.416 is simple, but not sensitive to the changes in the thermal power. Therefore, in further part, the mentioned linear function was used for quantitative determination of differences between the heat demand ($Q_q$) and the heat consumption for heating of educational buildings, including the changes in thermal power ($q$), according to the following equation:

$$(Q_q - Q) = 3.5786q - 406.54 \tag{3}$$

Equation (3) was used to create the relationship allowing for calculation of a modified seasonal heat demand for heating $Q1_q$:

$$Q1_q = Q_q - (Q_q - Q) \tag{4}$$

By substituting the relationships (1) and (3) to the equation (4), we obtain:

$$Q1_q = q \cdot Nd \cdot 24h \cdot \frac{(T_{ical} - T_{eav})}{(T_{ical} - T_{e\min})} \cdot 0.0036 - (3.5786q - 406.54) \tag{5}$$

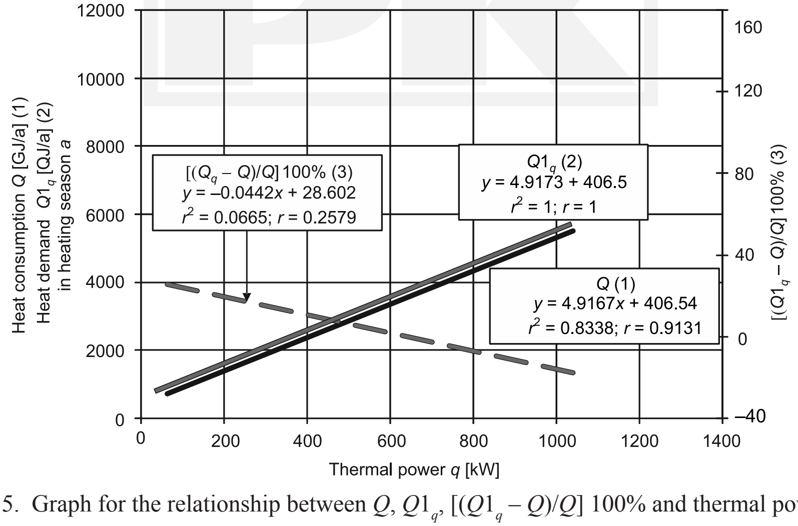


Fig. 5. Graph for the relationship between $Q$, $Q1_q$, $[(Q1_q - Q)/Q]$ 100% and thermal power $q$

The symbols used in equation (5) are the same as in case of equation (1) and they were described above. The values of $Q_q$ and $Q1_q$, calculated with two various methods, were compared and differentiated in relation to $Q$ (Fig. 3), in order to determine if the performed transformations allowed for reduction (mentioned in the title) of the differences between the thermal needs of educational buildings in actual and theoretical conditions. The qualitative effect of the described actions is presented in the Fig. 5, in the form of graph.

## 6. Conclusions

To sum up, it can be repeated that the occurrence of differences between the seasonal heat consumption ($Q$) and the seasonal heat demand ($Q_q$) for schools heating, calculated in the proposed manner, was found. The quantitative level ($Q_q - Q$) is different in the analysed educational buildings. It does not result only from the differences between the methodology of $Q_q$ calculation and the actual heating process, which results in generating the seasonal heat consumption (Q) for heating of the examined buildings. If it is so, then it seems that the points of data for individual buildings should overlap with the trend of changes in $Q_q$ and $Q$ values (Fig. 2).

The comparison of graphs presented in Fig. 4 and 5 make it possible to state, that if the equation (4) is applied for calculating heat demand ($Q1_q$) on the basis of thermal power ($q$), then the obtained difference of theoretical values in relation to the heat consumption ($Q$) is smaller than it was in case of using the equation (1) and calculation of $Q_q$. An average level of the mentioned differences amounted to 14.3% and 41.6%, respectively. A modification in the method for determination of heat demand for room heating on the basis of available data on thermal power ($q$) was introduced. A linear function, describing the changes in ($Q_q - Q$) depending on the changes in thermal power ($q$) values, which was applied for that purpose, made it possible to improve the consistency of obtained heat demand values in relation to the measured consumption of heat for heating by 65.6%. An even better effect can be expected by applying a function in the form of a polynomial, which is better adjusted to the data included in the Fig. 3. However, the selection of such a function is connected with complication of the calculation method, which is "simplified" by assumption.

The proposed comparison of the $Q$ and $Q_q$ values and the graphical methods applied in the analysis may be used in order to determine the scope of such incorrectness, in the analysis of the heating of similar groups of educational buildings and also as a help in providing other information connected with the specificity of heating of such objects'.

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