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ENERGY CONSUMPTION AND FINAL ENERGY DEMAND FOR HEATING IN EDUCATIONAL BUILDINGS - IDENTIFICATION OF THE PROBLEM

Piotr LIS*, Jolanta PIESYK

Politechnika Częstochowska, Instytut Inżynierii Środowiska, Zakład Ciepłownictwa, Ogrzewnictwa i Wentylacji
ul .Brzeźnicka 60a, 42-200 Częstochowa, e-mail: polis@is.pcz.czest.pl

Summary: This work presents the selected results of examinations connected with an annual energy consumption C_H and annual final energy demand $Q_{k,H}$ for heating and conducted on the group of educational buildings. The presented analysis and its results regard the group including 46 of 50 educational buildings, which form a municipal group of the buildings of this type and in which the educational institutions are located. The purpose of presented analysis was to examine the influence of possible occurrence and level of differences between the annual energy consumption C_H and annual final energy demand $Q_{k,H}$ for heating of examined buildings. The realization of this purpose is the basis for further research and analysis aimed at determining the dominant reasons of mentioned differences, establishing their level and propose a calculative method for reducing the differences between the values "picturing" the thermal needs of educational buildings in actual (energy consumption C_H) and theoretical (final energy demand $Q_{k,H}$) conditions.

Keywords: educational buildings, energy certification, energy consumption, final energy demand, heating.

1. INTRODUCTION

The calculative methods, which are applied in various fields of engineering, are usually a certain kind of theoretical approximation of reality. The main problem, which occurs here, is the degree of consistency of theoretical description of some phenomenon or process with the actual conditions of its course.

The deviations from a full consistency of actual conditions and theoretical assumptions occur also in case of building's heating. The building is considered as a constructional and installation entirety and constitutes a set of many installation, architectonic-building, constructional-material and operational properties, which have a direct or indirect connection with its heating.

When preparing a building energy certificate, one of the basic calculated quantities is the annual final energy demand $Q_{k,H}$ for heating. Not so long ago, also the thermal power (q) and the seasonal heat demand (Q) in a standard heating season were one of the basic quantities calculated in the projects of heating systems. Several years ago, in the design studies, the value of thermal power (q) was replaced by so-called design heat load, which is calculated according to PN EN ISO 12831:2006. However, there are no obstacles to use still the thermal power (q) in various considerations. One should only remember to apply only one of mentioned quantities consistently. A change of methodology in the design calculations regards also the seasonal heat demand (Q) for buildings' heating. In spite of the differences occurring in physical interpretation and the method of calculation of these quantities, all of them can be considered as theoretical, in contrast with the annual energy consumption C_H for building heating, the amount of which was determined by measurement and, in a sense, "describes the actual conditions of heating". The value of energy consumption C_H is the effect of, inter alia, the duration of the heating season and the conditions inside and outside of a room. Estimated and simplified calculations of the annual final energy demand $Q_{k,H}$ for heating based on the known value of thermal power (q) are also used in the engineering practice. 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 [1, 2, 3, 4, 5] and, despite of its disadvantages, it will be probably still 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 cases of theoretical annual final energy demand $Q_{k,q,H}$ for heating, calculated on the basis of the thermal power q, theoretical annual final energy

*Autor korespondencyjny, e-mail: polis@is.pcz.czest.pl

demand $Q_{k,H}$ for heating used in energy certification of buildings and the actual (measured directly or indirectly) annual energy consumption C_H for heating. The connection between discussed quantities should be the stronger, the better are rendered the heating conditions and the specificity of an operated object.

2. DESCRIPTION OF CONDUCTED EXAMINATIONS AND ANALYSES

The association between the energy consumption C_H for heating and the annual final energy demand $Q_{k,q,H}$ for heating, calculated on the basis of the thermal power q as well as the discrepancies appearing here [5] and mentioned using of q values for estimating of the annual final energy demand (Q) in the engineering practice were the main reason inducing to undertake the examinations and analyses.

The presented analysis and its results are a fragment of wider examinations of educational buildings, which were constructed in years 1913÷1992. They form a full municipal complex of 50 objects, in which the primary schools and junior high schools are located. The full statistical examinations, which were carried out in years 1992÷2016, included all the units of this complex and they were conducted by stages, in cooperation with the Municipal Office. A method of ad hoc statistical census was applied here, with using of selected measures of descriptive statistics and correlation analysis. The statistical observation was carried out by correspondence and direct surveys, interviews, site inspections and personally conducted measurements. The research material obtained in this manner is a primary material, collected especially for the purposes of conducted statistical examinations.

The heating season used in the analyses was characterized by the average outdoor temperature of air for analyzed period and determined area (town) $\Theta_{e,\,av} = +\,2.9\ ^{O}C$ and the duration 230 days. This season can be considered as typical for multiannual period in statistical respect (min. 30 years), which was confirmed by a positive result of testing a hypothesis on its statistical typicality. The average temperature inside of heated educational buildings achieved the value $\Theta_{int,\,av} = +\,19.9^{O}C$. The average grade of thermal comfort assessment made by the employees and students in examined objects amounted to 3.98 point in 7-point scale (from 1 to 7) and is within so-called thermal comfort zone. The procedure described above was conducted in order to assure that there are no too big differences of temperatures in heated rooms between examined buildings, which could have a significant influence on analyzed values of annual (seasonal) energy consumption C_H for heating.

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.

The amount of energy (C_H) consumed in a base heating season (in the year) was determined in two manners, depending on the source supplying the heat to the central heating system. In the buildings equipped with remote systems of central heating the actual energy consumption (C_H) was determined on the basis of readings from installed heat meters, with the measuring accuracy not lower than 2%. In case of own gas or coal-coke boiler-rooms, the amount of annual energy consumption (C_H) was calculated on the basis of information on fuel consumption in the base heating season, kind of used fuel and its calorific value, average nominal efficiency and estimated average operational efficiency of the central heating boilers, kind of losses in the heat production and their average levels for various types of boilers.

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

Tabela 1. Wybrane miary opisu statystycznego dla wielkości charakteryzujących 46 z 50 budynków edukacyjnych tworzących miejską zbiorowość tego typu obiektów

Value x	**Average value x_{av}**	**Stand. deviation $s(x)$**
Cubic capacity V, m^3	14682.37	9674.55
Usable area A_u, m^2	3194.09	2161.41
Number of classrooms, rooms	21	12
Average area of classroom, m^2	50.36	8.45
Relation of the building external partitions' area to the building volume A/V, m^{-1}	0.40	0.09
Relation of the classrooms' area to the usable area, -	0.37	0.10
Relation of windows' area to the area of facade, -	0.25	0.05
Weighted average heat transfer coefficient for external partitions, $W/(m^2K)$	1.27	0.20
Thermal power for heating q, kW	323.38	235.15
Index of thermal power for heating of 1 m^3 of cubic capacity q/V, $W/(m^3a)$	21.93	5.11
Annual energy consumption for heating in standard heating season C_H, GJ/a	1996.52	1266.14
Index of annual energy consumption for heating of 1 m^3 of cubic capacity in standard season (C_H / V), $GJ/(m^3a)$	138.36	39.26

The material presented in this work is a fragment of wider analysis and regards 46 of 50 educational buildings, in which the educational institutions are located (data for 4 objects were questionable in the author's opinion). The total amount of heat used for heating of analyzed objects was $\Sigma Q = 91.840$ GJ/a, with their total cubic capacity

$\Sigma V = 675.389\ m^3$ and heated area $\Sigma A_u = 146.013\ m^2$. Average values of $C_{H,av}$ (0.10) and q_{av} (0.10), calculated after eliminating of 10% of extreme values of Q and q, constitute about 96% of average values for the entire analyzed group. About 70 ÷ 80% of analyzed buildings were considered as typical in respects of the actual energy consumption (C_H) for heating of rooms and the thermal power (q). The basic characteristic of this group of 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 [4].

3. RESULTS AND DISCUSSION OF EXAMINATIONS' RESULTS

Bearing in mind the realization of article purpose which will be the basis for further research and analysis the, following important questions arise:

1) Are there discrepancies between the actual and theoretical heating conditions of the analyzed buildings, which are quantitatively characterized by appropriate values?;
2) What is a quantitative range of possible discrepancies?;
3) What may be the reasons of such situation?

Before calculations, the examined buildings were sorted from the smallest to largest annual energy consumption for heating. The energy consumption for building heating is strongly related to its size. In order to give an answer to the first question, the annual final energy demand $Q_{k,H}$ for heating used in energy certification of buildings were calculated, the final energy demand $Q_{k,q,H}$ for heating calculated on the basis of the thermal power q were calculated and presented in earlier studies among others: [4, 5] and they were compared graphically with the annual energy consumption C_H for heating (Fig. 1÷3). Based on the methodology of energy certification of buildings in Poland and EN ISO 13790:2008 "Energy performance of buildings - Calculation of energy use for space heating and cooling", calculations $Q_{k,H}$ were made. At the stage of the diagnosis problems, the calculation $Q_{k,H}$ was made for two quantities of ventilation air change. The annual final energy demand $Q_{k,H}$ for heating were calculated for n=1 h^{-1} and n=3 h^{-1}. The results of analysis are shown on the graphs (Fig. 1÷3) and their interpretation should enable to answer the last of the previously asked questions in the next, more detailed analysis. In order to answer the second question, the differences between the theoretical values - the annual final energy demand $Q_{k,H}$ for heating, the final energy demand $Q_{k,q,H}$ for heating calculated on the basis of the thermal power q and the actual annual energy consumption C_H for heating were calculated and presented in Figs. 4÷6.

In addition, Fig. 7 show trends in changes in energy demand and energy consumption in educational buildings. Fig. 8 show trends in differences between:

– annual final energy demand and annual energy consumption for heating: $(Q_{k,H} - C_H)\cdot 100\%$. The annual final heat demand $Q_{k,H}$ for heating was calculated for two quantities of air exchange n=1 h^{-1} and n=3 h^{-1};
– annual final energy demand calculated on the basis of the thermal power q and annual energy consumption C_H for heating: $(Q_{k,q,H} - C_H)\cdot 100\%$;

One should remember, however, that the graphs were drawn for the group of buildings diverse in respect of properties, which influence significantly on the amount of heat consumed for heating.

All figures are presented at the end of the article.

The analysis of calculated values and graphs (Fig. 1 ÷ 8) reveals the differences between annual energy consumption (C_H) for heating and calculated annual final energy demand ($Q_{k,H}$, $Q_{k,q,H}$). Occurrence of these differences confirms the course of trend lines for changes in analyzed quantities, which are shown on the graphs – Fig. 7.

Calculated annual final energy demand $Q_{k,H}$ for n=3 h^{-1} is bigger by 11.4% and 192.2 GJ, on the average, than the actual energy consumption for heating C_H , but final energy demand $Q_{k,H}$ for n=1 h^{-1} is smaller by 20.9% and 450.0 GJ, on the average, than the actual energy consumption for heating C_H. Calculated annual final energy demand $Q_{k,q,H}$ is bigger by 25.2% and 794.4 GJ, on the average, than the actual energy consumption for heating C_H. However, there are few buildings, in which the situation is opposite.

The courses of trend lines for the theoretical value ($Q_{k,H}$, $Q_{k,q,H}$) and for actual energy consumption for heating (C_H) are similar on all graphs, with presented in Fig. 7. In each of cases presented in Fig. 7, the directions of trend lines for analyzed quantities are less or more divergent. It means that the increase of calculated value ($Q_{k,H}$, $Q_{k,q,H}$) is quicker than the increase of the actual energy consumption for heating (C_H). Simultaneously, it causes the increase of the value of differences (($Q_{k,H} - C_H$), ($Q_{k,q,H} - C_H$)) for these objects.

4. SUMMARY

To sum up, it can be repeated that the occurrence of differences between the annual energy consumption (C_H). and the annual final energy demand ($Q_{k,H}$) for buildings heating, calculated in proposed manner, was found. The quantitative level ($Q_{k,H} - C_H$) is different in analyzed educational buildings. It does not result only from the differences between the methodology of $Q_{k,H}$ calculation and the actual heating process, which results in generating of the annual energy consumption (C_H) 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 $Q_{k,H}$ and C_H values (Fig. 1, 2, 4, 5).
A phenomenon, which was observed for several buildings and consists in a considerable diversity between the values of annual final energy demand ($Q_{k,H}$, $Q_{k,q,H}$) and annual energy consumption (C_H) for heating of rooms in relation to its average level, in connection with presented results, may prove:

- an incorrect determination of thermal power (q) or incorrect making energy certificate and incorrect assumptions used in calculating the values of annual final energy demand $Q_{k,H}$ for the part of objects. Such errors may be a reason of insufficient heating of educational buildings or paying of excessive fixed duties for thermal power (q);
- an improper operation of schools in the scope of appropriate ventilation of rooms, which is always connected with cubic capacity of examined buildings, mentioned here.

Proposed comparison of the theoretical ($Q_{k,H}$, $Q_{k,q,H}$) and actual (C_H) values and the graphical methods applied in the analysis may be used in order to determine the scope of such incorectnesses, in the analysis of heating of similar groups of educational buildings and also as a help in providing other information connected with the specificity of such objects' heating.
A relation of the difference's value ($Q_{k,H}$ - C_H) to the value of C_H expressed in GJ and percentage is also diverse in individual objects.
The values specified above have a certain common property, which is a direct or indirect connection with the size of examined buildings. During the years 1913 ÷ 1992, when the analyzed objects were constructed, a tendency toward the construction of bigger and bigger educational objects was noticed. All these reasons incline to the interpretation that presented relationships are, to a bigger or smaller degree, determined by the size of examined objects, which is described quantitatively by their cubic capacity (V) and the factors connected with that. Thus, the cubic capacity of examined objects has a significant and often dominant influence on analyzed relationships. Obviously, also the other factors have their influence, but it is less significant.
Does this diversity remain dependent on certain factors characterizing the selected objects, such as, inter alia, the architectonic shape of a building, energy consumption by heating and thermo-insulating power of external particles? Answers to this question will need to be made during further research and analysis aimed at determining the dominant reasons of mentioned differences, establishing their level and propose a calculative method for reducing the differences between the values "picturing" the thermal needs of educational buildings in actual (energy consumption C_H) and theoretical (final energy demand $Q_{k,H}$) conditions.

ZUŻYCIE ENERGII I ZAPOTRZEBOWANIE ENERGII KOŃCOWEJ DO OGRZEWANIA W BUDYNKACH EDUKACYJNYCH – IDENTYFIKACJA PROBLEMU

Streszczenie: W pracy zaprezentowano wybrane wyniki badań zbiorowości budynków edukacyjnych związane z rocznym zużyciem energii C_H i rocznym zapotrzebowaniem na energię końcową do ogrzewania $Q_{k,H}$. Przedstawiona analiza i jej wyniki dotyczą grupy 46 spośród 50 budynków edukacyjnych tworzących miejską zbiorowość obiektów tego typu, w których mieszczą się placówki oświatowe. Celem zaprezentowanej analizy było identyfikacja i zbadanie poziomu różnic pomiędzy rocznym zużyciem energii C_H i rocznymi zapotrzebowaniem na energię końcową $Q_{k,H}$ do ogrzewania badanych budynków. Osiągnięcie wymienionego celu stanowi podstawę do dalszych badań i analiz zmierzających do ustalenia dominujących przyczyn wspomnianych różnic, określenia ich poziomu i zaproponowania sposobu obliczeniowego zmniejszenia różnic pomiędzy wielkościami „obrazującymi" potrzeby cieplne budynków edukacyjnych w warunkach rzeczywistych (zużycie energii C_H) i teoretycznych (zapotrzebowanie na energię końcową $Q_{k,H}$).

Słowa kluczowe: budynki edukacyjne, charakterystyka energetyczna, zużycie energii, zużycie energii końcowej, ogrzewanie.

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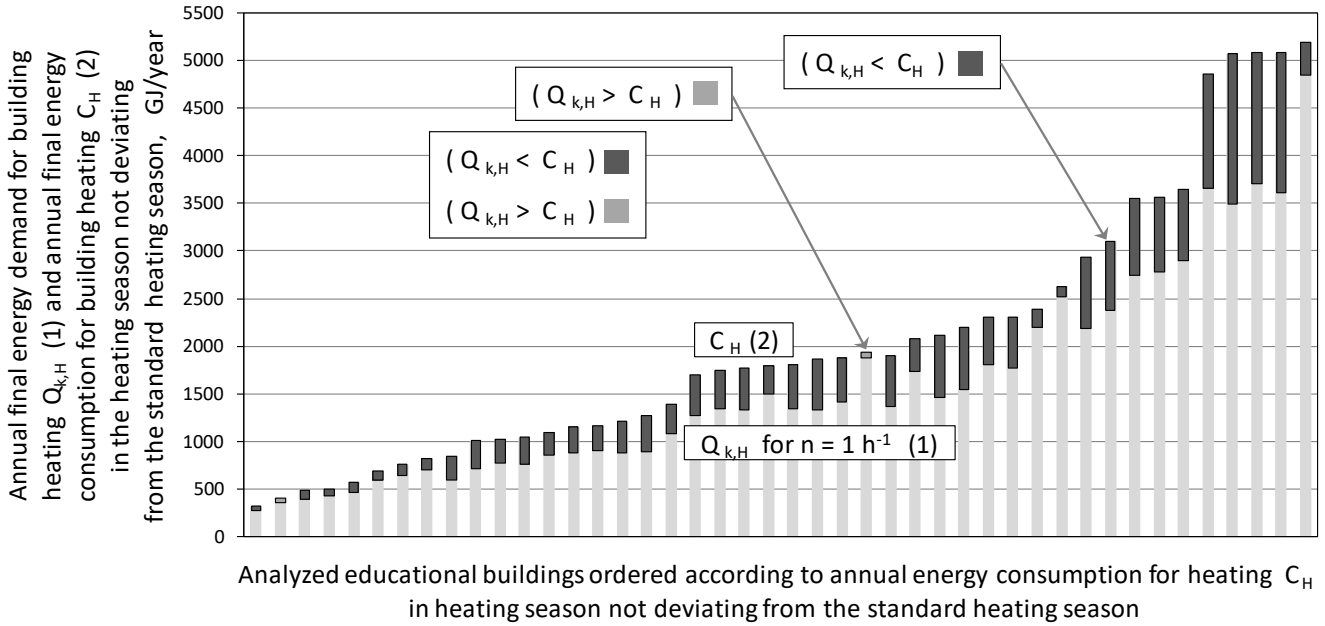

Fig. 1. Annual final energy demand for building heating $Q_{k,H}$ for n = 1 (1) and annual final energy consumption for building heating C_H (2) in the heating season not deviating from the standard heating season, GJ/year

Rys. 1. Roczne zapotrzebowanie na energię końcową do ogrzewania budynku $Q_{k,H}$ dla n = 1 (1) i roczne zużycie energii do ogrzewania budynku C_H (2) w sezonie grzewczym nie odbiegającym od standardowego sezonu grzewczego, GJ/rok

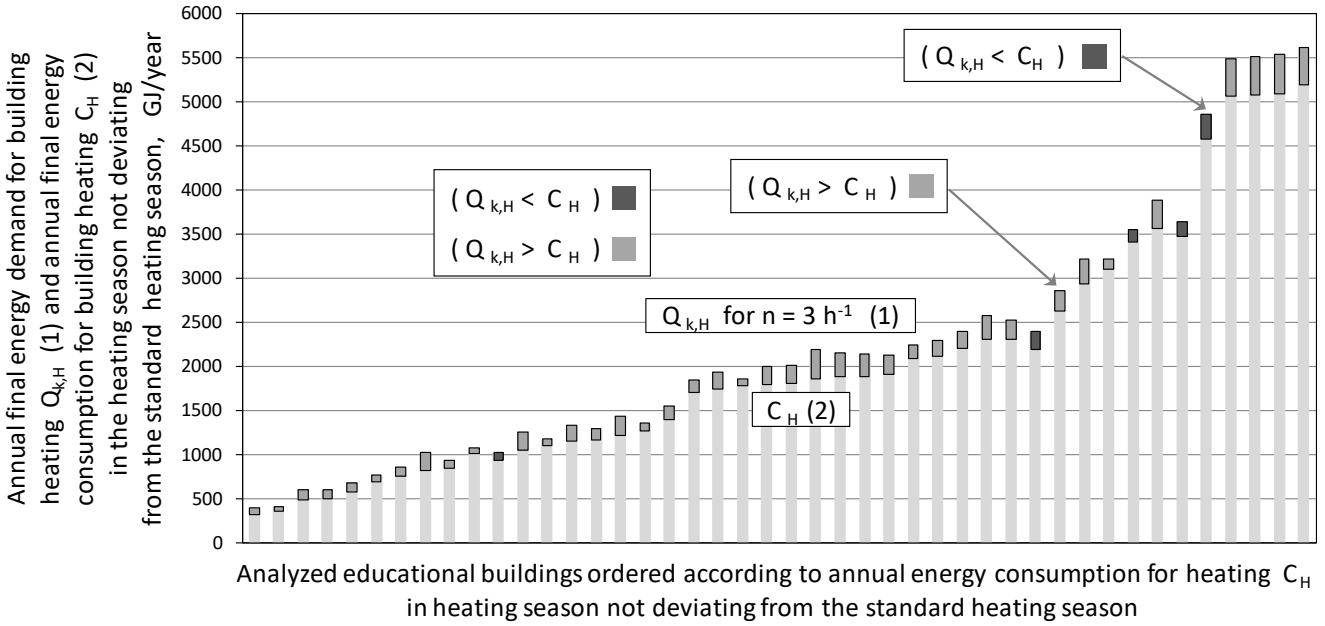

Fig. 2. Annual final energy demand for building heating $Q_{k,H}$ for n = 3 (1) and annual final energy consumption for building heating C_H (2) in the heating season not deviating from the standard heating season, GJ/year

Rys. 2. Roczne zapotrzebowanie na energię końcową do ogrzewania budynku $Q_{k,H}$ dla n = 3 (1) i roczne zużycie energii do ogrzewania budynku C_H (2) w sezonie grzewczym nie odbiegającym od standardowego sezonu grzewczego, GJ/rok

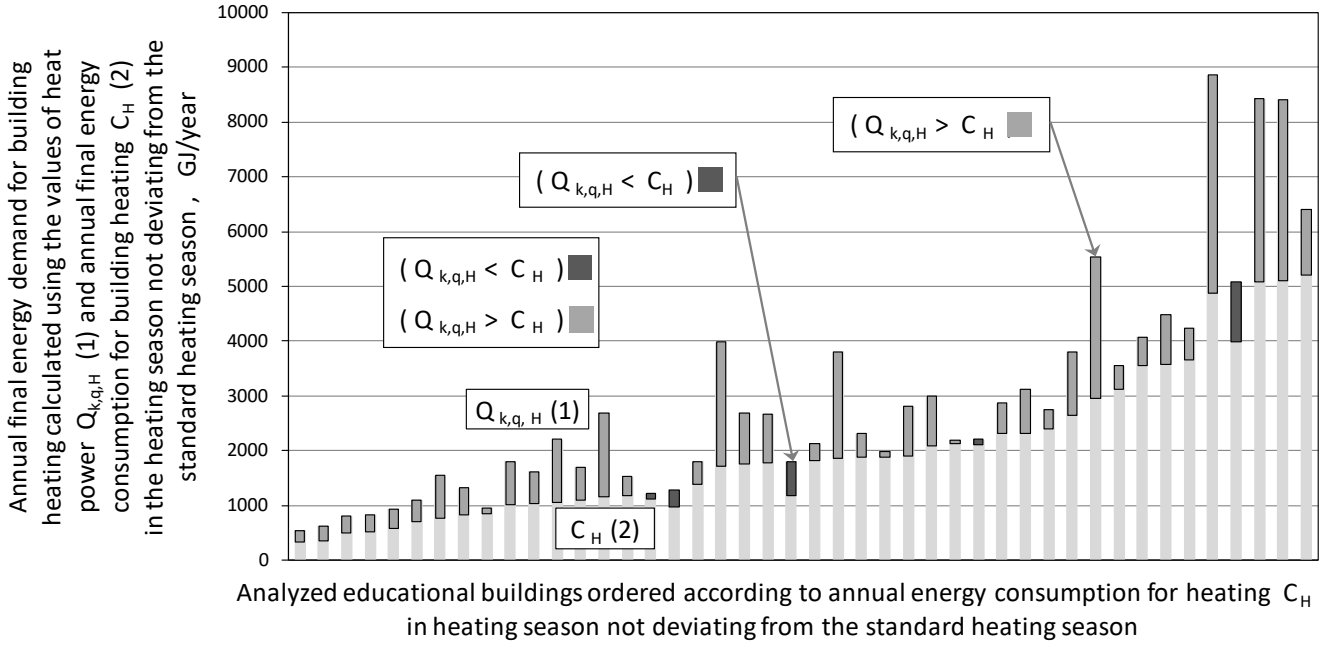

Fig. 3. Annual final energy demand for building heating $Q_{k,q,H}$ (1) and annual final energy consumption for building heating C_H (2) in the heating season not deviating from the standard heating season, GJ/year

Rys. 3. Roczne zapotrzebowanie na energię końcową do ogrzewania budynku $Q_{k,q,H}$ (1) i roczne zużycie energii do ogrzewania budynku C_H (2) w sezonie grzewczym nie odbiegającym od standardowego sezonu grzewczego, GJ/rok

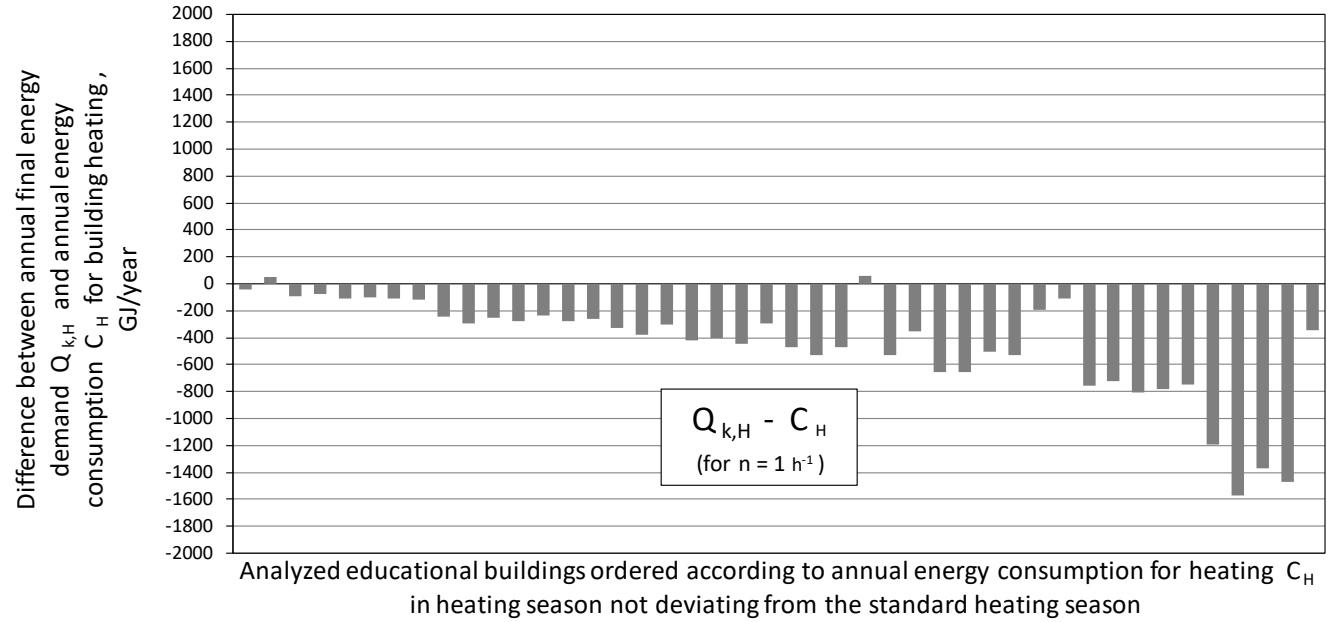

Fig. 4. Differences between annual final energy demand for building heating $Q_{k,H}$ for n = 1 (1) and annual final energy consumption for building heating C_H (2) in the heating season not deviating from the standard heating season, GJ/year

Rys. 4. Różnice pomiędzy rocznym zapotrzebowaniem na energię końcową do ogrzewania $Q_{k,H}$ dla n = 1 (1) i rocznym zużyciem energii do ogrzewania budynku C_H (2) w sez. grzewczym nie odbiegającym od standardowego sez. grzewczego, GJ/rok

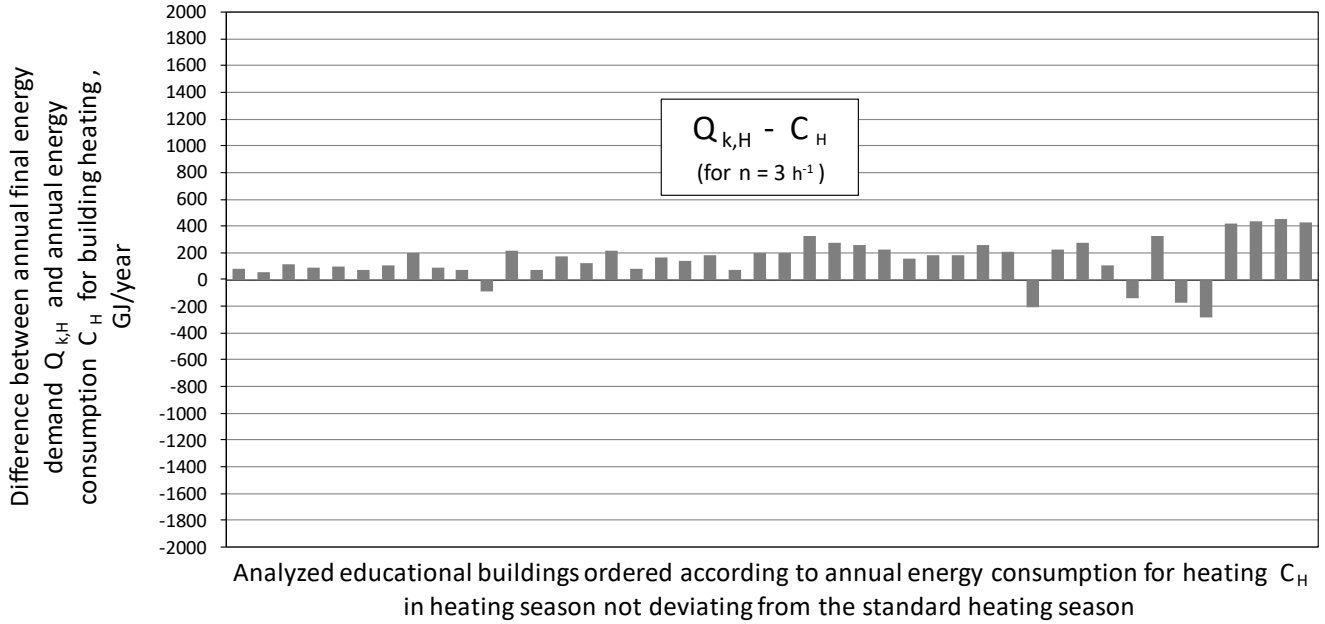

Fig. 5. Differences between annual final energy demand for building heating $Q_{k,H}$ for n = 3 (1) and annual final energy consumption for building heating C_H (2) in the heating season not deviating from the standard heating season, GJ/year

Rys. 5. Różnice pomiędzy rocznym zapotrzebowaniem na energię końcową do ogrzewania $Q_{k,H}$ dla n = 3 (1) i rocznym zużyciem energii do ogrzewania budynku C_H (2) w sez. grzewczym nie odbiegającym od standardowego sez. grzewczego, GJ/rok

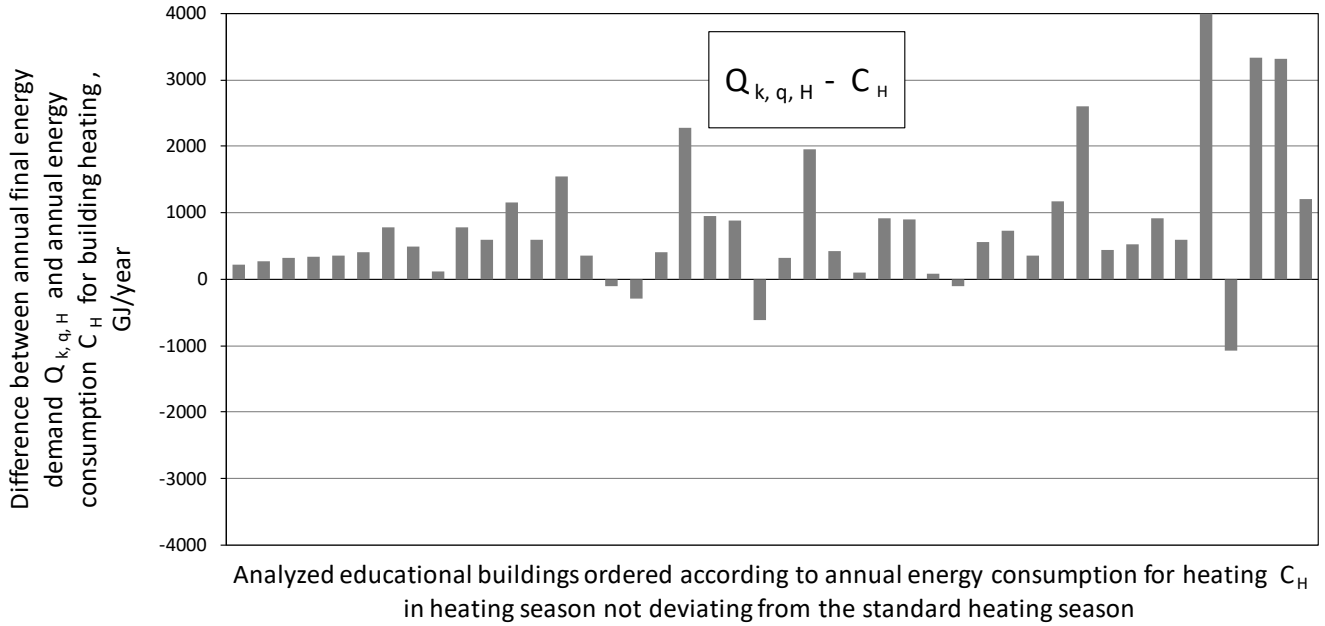

Fig. 6. Differences between annual final energy demand for building heating $Q_{k,q,H}$ (1) and annual final energy consumption for building heating C_H (2) in the heating season not deviating from the standard heating season, GJ/year

Rys. 6. Różnice pomiędzy rocznym zapotrzebowaniem na energię końcową do ogrzewania $Q_{k,q,H}$ (1) i rocznym zużyciem energii do ogrzewania budynku C_H (2) w sez. grzewczym nie odbiegającym od standardowego sez. grzewczego, GJ/rok

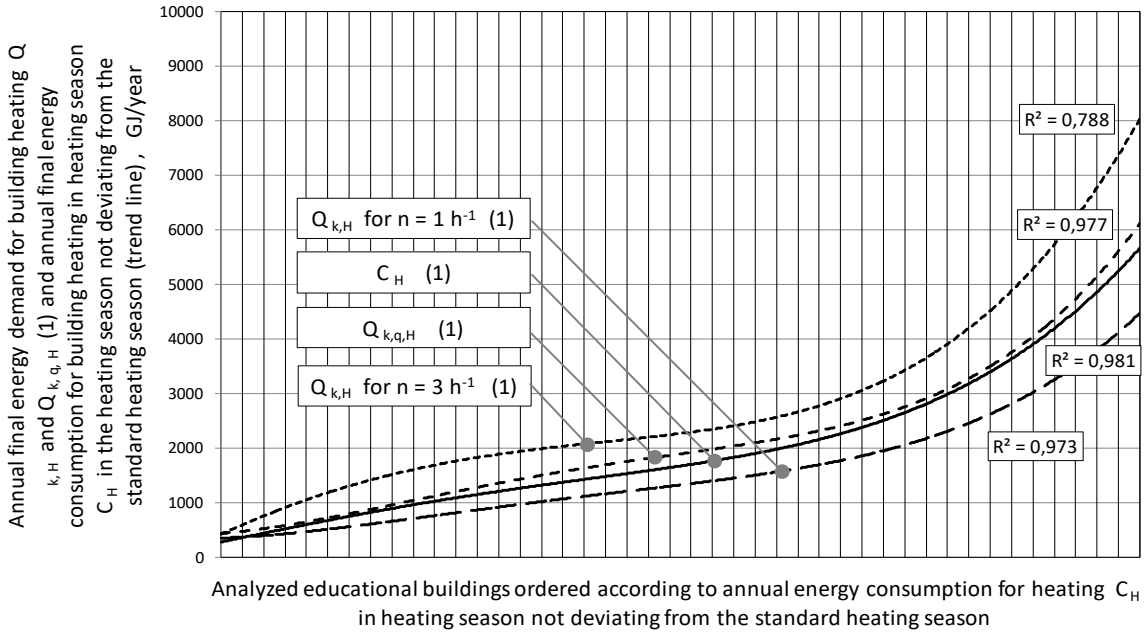

Fig. 7. Trend line for annual final energy demand for building heating $Q_{k,H}$ and $Q_{k,q,H}$ (1) in analyzed educational buildings ordered according to growing annual energy consumption for heating C_H in heating season not deviating from the standard heating season, GJ/year

Rys. 7. Linie trendu dla rocznego zapotrzebowania na energię końcową do ogrzewania budynku $Q_{k,H}$ i $Q_{k,q,H}$ w analizowanych budynkach edukacyjnych uporządkowanych według rosnącego rocznego zużycia energii do ogrzewania C_H w sezonie grzewczym nie odbiegającym od standardowego sezonu grzewczego, GJ/rok

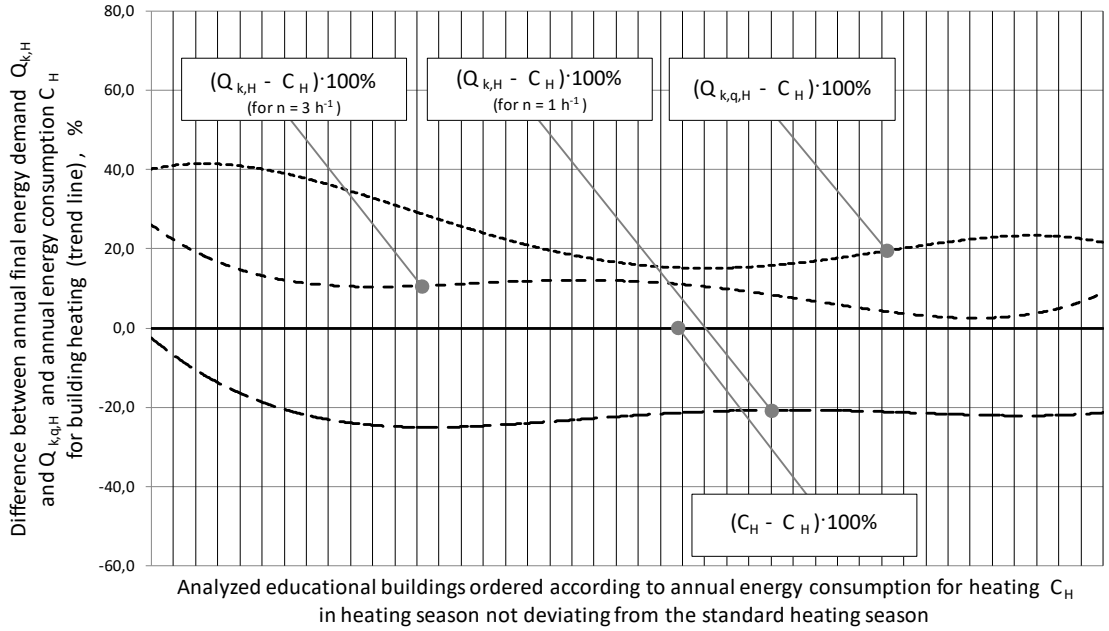

Fig. 8. Trend line for difference between annual final energy demand $Q_{k,H}$ and $Q_{k,q,H}$ (1) and annual energy consumption C_H (2) for heating in analyzed educational buildings ordered according to growing annual energy consumption for heating C_H in heating season not deviating from the standard heating season, %

Rys. 8. Linia trendu dla różnicy pomiędzy rocznym zapotrzebowaniem na energię końcową $Q_{k,H}$ lub $Q_{k,q,H}$ (1) a rocznym zużyciem energii C_H (2) do ogrzewania w analizowanych budynkach edukacyjnych uporządkowanych według rosnącego rocznego zużycia energii do ogrzewania C_H w sezonie grzewczym nie odbiegającym od standardowego sezonu grzewczego, %