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THE CONSUMPTION OF FINAL ENERGY FOR HEATING EDUCATIONAL FACILITIES LOCATED IN RURAL AREAS

Summary

The dissertation includes an analysis of the consumption of final energy for heating 73 educational facilities situated in rural areas of the Kraków poviat. Calculating the unit rate for final energy demand EK w kWh/m^2 was carried out applying two methods, according to the methodology of estimating the energetic performance of buildings. The value of the unit rate for the final energy demand EK depends on the assumed calculation method and equals (average value for the analyzed group of facilities), respectively: 171 kWh/m^2 for the method based on the actually used energy and 203 kWh/m^2 for the calculation method based on the standard manner of use. Majority (70%) of the educational facilities situated in rural areas of the Kraków poviat are effective in the field of using heat energy (unit use of the final energy above 240 kWh/m^2); 30% of these can be described as energy-efficient (EK<140 kWh/m^2). 7% of the educational facilities (EK >341 kWh/m^2) require carrying out thermo-modernization procedures. Calculation of the value of the EP rate using the two methods allowed to compare the results for which the average relative error of the MAPE estimate for the analyzed educational facilities is 17% (the results obtained according to the method based on the actually used energy). Therefore, when estimating the consumption of the final energy according to the calculation method based on the standard manner of use, the values of the rates are significantly over-specified.
***Key words**: consumption of energy in educational facilities, final energy, energy performance, degree days of heating season*

ZUŻYCIE ENERGII KOŃCOWEJ NA OGRZEWANIE OBIEKTÓW OŚWIATOWYCH ZLOKALIZOWANYCH NA OBSZARACH WIEJSKICH

Streszczenie

W pracy dokonano analizy zużycia energii końcowej na ogrzewanie 73 obiektów oświatowych zlokalizowanych na obszarach wiejskich powiatu krakowskiego. Obliczenia jednostkowego wskaźnika zapotrzebowania na energię końcową EK w kWh/m^2 wykonano dwoma metodami zgodnie z metodologią szacowania charakterystyki energetycznej budynków. Wartość jednostkowego wskaźnika zapotrzebowania na energię końcową EK, zależna jest od przyjętej metody obliczeń i wynosi (wartość przeciętna dla analizowanej grupy obiektów) odpowiednio 171 kWh/m^2 dla metody opartej na faktycznie zużytej energii i 203 kWh/m^2 dla metody obliczeniowej opartej na standardowym sposobie użytkowania. Obiekty oświatowe zlokalizowane na obszarach wiejskich powiatu krakowskiego w większości (70%) są efektywne w wykorzystaniu energii cieplnej (jednostkowe zużycie energii końcowej poniżej 240 kWh/m^2), a trzydzieści procent z nich można określić jako energooszczędne (EK<140 kWh/m^2). Siedem procent obiektów oświatowych (EK >341 kWh/m^2) wymaga zabiegów termmodernizacyjnych. Obliczenie wartości wskaźnika EP dwoma metodami pozwoliło na porównanie otrzymanych wyników, w tym celu wyznaczono średni błąd względny oszacowania MAPE (przyjmując jako poziom odniesienia wyniki uzyskane według metody opartej na faktycznie zużytej energii), który dla analizowanych obiektów oświatowych wynosi 17%. W związku z powyższym, szacując zużycie energii końcowej według metody obliczeniowej opartej na standardowym sposobie użytkowania w sposób znaczący zawyża się wartości wskaźników.
***Słowa kluczowe**: zużycie energii w obiektach oświatowych, energia końcowa, charakterystyka energetyczna, stopniodni sezonu grzewczego*

1. Introduction

The act of 15 April 2011 on energy performance implemented the provisions of the 2006/32/EC on the effectiveness of the final consumption of energy and energy services [17]. It points at the leading role of the public sector facilities in the area of economical energy management. According to the provisions of the act, citizens should be informed of the actions taken as a part of playing this exemplary role. The actions taken by the public sector units, including municipalities and poviats, are primarily focused on increasing energetic standards of educational facilities, among others, carrying out their thermo-modernization. Acting according to the provisions of the 2010/31/EU Directive on energetic performance of buildings [7], introducing the obligation of creating energy performance certificates for each new building for which, due to rebuilding or renovation (carried out thermo-modernization) their energy performance changed.

In 2014 the Act on buildings energy performance [18] was introduced; the Act specified:

- The rules for preparing energy performance certificates;
- The rules for the heating and air conditioning systems control in the buildings;
- The rules for keeping the central register of the energy performance of buildings;
- The method of developing a state action plan aiming at increasing the number of low energy consumption buildings.

Item 15 of the Act states that:
1) The minister competent for the construction, local planning, and land development and housing shall specify, by ordinance, the methodology of setting the energy performance of a building or a part of a building, the method of preparing of energy performance certificates and their models.
2) The minister competent for the construction, local planning, land development and housing, when issuing the ordinance mentioned in paragraph 1, shall include the following:

- technical parameters of the building structure or a part of the building,
- types of technical systems in the building or a part of the building,
- methodology of setting the energy performance based on the standard manner of use of the building or a part of the building,
- methodology of setting the energy performance based on the actually used amount of energy.

Pursuant to this Act, the Minister of Infrastructure and Development issued a new ordinance on the methodology of calculating the energetic performance of buildings and residential units or a part of a building constituting an independent technical-service entity, as well as the method of preparing the models of energy performance certificates (hereinafter referred to as the methodology), where two methods of setting energy performance were introduced, i.e. the method based on the standard manner of use and climatic data assumed from the nearest weather station database, and the other one, based on the quantity of the actually used energy [13]. Heat demand is calculated assuming that the normative conditions of use, i.e. the temperatures in the premises set in the ordinance on the technical conditions that the buildings and their location should meet [15]; the most favorable outdoor temperatures set for a given climate zone in the PN-82/B-02403 [11] norm, average monthly outdoor temperatures and the solar radiation rates for separate months - according to the multi-annual average data specified for the nearest weather station; the size of the stream of ventilation air which relates to the usable area of the building and is set by the indicator value method.

Calculations concerning energy demand in an educational facility include, among others:

- the energy used for heating and ventilation,
- the energy used for heating the water, where also in this case the indicator value method calculations were employed applied to the usable area of the building.

Energy demand is subsequently calculated for: usable energy (used directly), final energy (supplied to the building and including the losses resulting from the energy conversion efficiency of the installation systems) and primary energy (including the losses occurring during generation and energy supply as well as the type of energy carrier).
Evaluation of the size of demand for the usable energy for heating, ventilation and cooling is performed by applying the monthly balance sheet method according to the PN-EN ISO 13790:2008 norm [12]. In the case of the use-based method, yearly demand for the final energy supplied to the building, for the heating system and the usable water heating system are set based on the documents confirming the actual use of the district heat or natural gas for the needs for heating and usable water heating. The Q_{W+Hk}, value in the kWh/year units is the average of the district heat or natural gas consumption of the last 3 years before issuing the energy performance certificate. Despite the methodology does not assume recalculation (correction) these calculations for the conditions of a standard season, the person carrying out the calculations of the energy performance should also perform these calculations in order to be objectively able to show the energy quality of the building, due to the provisions of the 2006/32/EC Directive [8] on the effectiveness of the final energy consumption. This person is obliged by legislation that clearly suggest that for the sake of objectivity in estimating energy consumption - the results of actual energy consumption in the previous heating seasons should be compared with the consumption calculation, assuming weather conditions prevailing in the compared periods.

Bearing in mind the provisions contained in the quoted legal acts and the fact that there is scarcity of studies providing information on heat consumption by educational institutions, which in rural and semi-urban areas are the dominant part of the buildings of the public sector, the aim of the study was to determine the energy performance of educational buildings (located in the rural district of the Kraków poviat), expressed by the individual indicator of demand for final energy EK kWh/m^2. The calculations were carried out by two methods of determining energy performance, i.e.: based on the actual amount of energy consumed (adjusted to the conditions of the standard season), and based on a standard method of use of the building, according to the Ordinance of the Minister of Infrastructure of 2 July 2014 on the methodology of preparation energy performance certificates [13]. This allowed objective comparison of the obtained results.

2. Study subjects and methodology

Based on data from the Information Center of Education [2] the following information was obtained: as of 2015 in the rural areas of the Kraków poviat there were 267 educational institutions located in 194 buildings (79 kindergartens, 125 primary schools, 44 junior high schools and 19 secondary schools) attended by approximately 29 thousand students, approximately 2 thousand teachers were employed. On this basis the minimum sample number of the buildings was specified; it is 64 facilities (for a confidence level $\alpha = 0.95$ and a maximum error of 10%), where the calculations of final energy consumption for heating were performed. The study was conducted in 73 educational institutions located in 17 rural and urban-rural areas of the poviat of Kraków. The analyzed facilities in recent years, for the most part (53 buildings) have undergone the process of thermo-modernization based on thermal insulation of the building envelope (including the replacement of windows) and the modernization of their heating systems. All of the buildings are heated with boilers with gas burners. The total area of the facilities analyzed is 87 thousand m^2; they are attended by approximately 8.3 thousand students. A characteristic feature of educational facilities in rural areas is wide variation in their areas and in the number of students. The areas of the analyzed facilities range from 150 m^2 to appropriately 3500 m^2 and from 36 to 570 students learning there.

Data concerning the partition materials, surface areas and volumes, as well as the data on the surface of the partitions (walls, ceilings, windows and doors) subject to heat loss were obtained in the analyzed facilities. In addition, the information on the amount of gas consumed for heating the buildings was obtained. The data include heating seasons of

the years 2013, 2014 and 2015. Calculations of the final energy, EK, demand were carried out in accordance with the methodology for calculating energy performance of a building or and a residential unit or a part of the building constituting an independent technical-service entity, using the use-based method (based on the actual energy consumption) and the calculation method based on the standard method of use (hereinafter referred to as the calculation method) [13].

In the method, based on the actually consumed energy, the data on the heat of the combusted gas supplied to the buildings (used to calculate the final energy consumption) are assumed on the basis of information for the Settlement Area of the Heat of Combustion (ORCS) in Polska Spółka Gazownictwa Sp. o.o. for the area of settlement, including the municipality of Zabierzów, and for the analyzed years, it amounts to an average of 11.09 kWh/m^3 which gives the calorific value of the gas at the level of 10.11 kWh /m^3 [10]. Although the methodology [13] does not assume recalculation (correction) the actual energy consumption for heating and ventilation conditions of the standard season, such calculations were carried out here using the following formula:

$$Q_{K,H} = \sum_{i=1}^{3} \frac{Sd(t_b)_i}{Sd(t_b)_0} \cdot Q_{K,H_i} \cdot \frac{1}{3}, \qquad (1)$$

where:

$Q_{K,H}$ - the final energy demand for the heating season standard, [kWh],

$Sd(t_b)_0$ – the number of degree days in a standard heating season, [^{o}Cd],

$Sd(t_b)_0$ – the number of degree days for the "i" of this year, [^{o}Cd],

$Q_{K,H\ i}$ – final energy consumption for heating in a measurement period for the "i" of this year [kWh].

Climatic data on the basis of which the calculations were conducted, were taken from the database of the Kraków-Balice weather station for the standard year [9] and for the years 2013, 2014 and 2015 [19]. These were used to determine the degree days of the heating season Sd (15° C) in the standard year [5] and for the "i" of this year, calculated based on the Hitchin formula [3]:

$$Sd(t_b) = \sum_{i=1}^{9} Sd(t_b)_m = \frac{t_b - t_{śr}}{1 - \exp^{[-k\cdot(t_b - t_{śr})]}} \cdot L_m, \qquad (2)$$

where:

$^{Sd(t_b)0}$ – the number of degree days in a heating season, [^{o}Cd],

$Sd(t_b)_m$ – the number of day degree for each month of the heating season, [^{o}CD], according to the methodology [] the heating season lasts nine months, i.e. from January to May and from September to December,

t_b – assumed base temperature, [15^{o}C] [6],

$t_{śr}$ – average monthly temperature, [^{o}C],

k – constant for Kraków = 0,821 [4],

L_m– numbers of days in a month [d].

The calculated number of degree days in the standard heating season $Sd(t_b)_0$ is 3615,9 [^{o}Cd], and in the years of 2013, 2014, and 2015 it is, respectively, $Sd(t_b)_i$: 2789,1; 2766,9; 2542,6 [^{o}Cd] which gives the average of the 3 years on the level of 2699,5 [^{o}Cd]. Comparing the results obtained, it can be concluded that the number of degree days of the standard season is higher by approximately 34% compared to the number of degree days in the measuring period (2013-2015).

3. Study results and analysis

The results of the calculation of the annual energy demand expressed by the indicator EK kWh/m^2, calculated by using the method based on the actual energy consumed EK_{rz} and the calculation method EK_t are summarized in Fig. 1.

The analyzed group of educational facilities shows the final energy consumption expressed by the unit demand indicator for final energy EK ranging from approximately 60 to 450 kWh/m^2 (in one building the recorded energy level was 600-650 kWh/m^2).

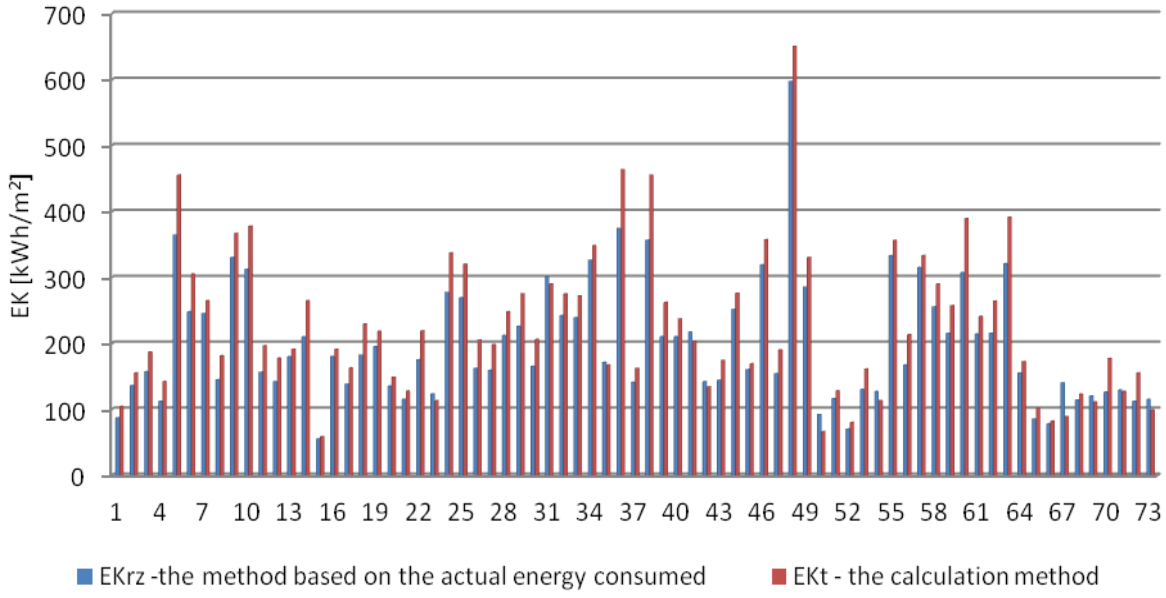

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Fig. 1. The indicator unit consumption of final energy EK in the group of buildings analyzed was set applying the use-based method and the method based on the standard use

Rys. 1. Zużycie energii końcowej w analizowanych budynkach wyznaczone metodą eksploatacyjną oraz obliczeniową

The average value of this indicator depends on the applied calculation method and amounts to 171 kWh/m^2 for the method based on the actual energy consumed and to 203 kWh/m^2 for the calculation method. According to the data available in the literature [1], the value of the unit indicator of the demand for final energy EK (calculated according to [14]) for this type of buildings in the province of Małopolska is 185 kWh/m^2, and therefore it can be concluded that the results obtained for the analyzed buildings do not deviate significantly from this value (they vary by approximately 8%). The confidence interval for the methods compared amounts respectively to 156 to 185 kWh/m^2 (use-based method) and to 187-219 kWh/m^2 (calculation method). Fig. 2 shows the structure of the building in terms of the amount of energy consumption.

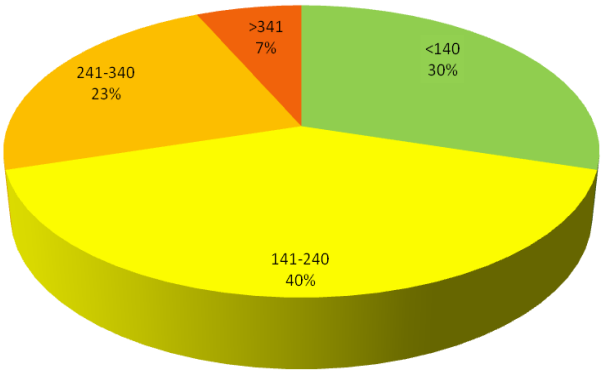

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Fig. 2. The structure of educational buildings in terms of the value of the EK indicator
Rys. 2. Struktura budynków oświatowych ze względu na wartość wskaźnika EK

Analyzing the structure of educational buildings in terms of the amount of heat energy, it can be stated that for the most part these buildings make an effective use of heat energy (unit final energy consumption below 240 kWh / m^2), and that 30% of them can be described as energy-efficient (EK<140 kWh/m^2). 7% of the educational facilities (EK >341 kWh/m^2) require carrying out thermo-modernization procedures.

To compare the method based on the actual energy used to the calculation method, the average relative error of estimate was determined (MAPE), according to formula 3.

$$MAPE = \frac{1}{n} \cdot \sum_{t=1}^{n} \frac{\left| d_a - d_a^p \right|}{d_a} \cdot 100\,[\%], \qquad (3)$$

where:
d_a – the indicator of the unit demand for final energy determined by the use-based method, [kWh/m^2],
$^{d}{}_{a}$ – the indicator of the unit demand for final energy determined by the calculation method, [kWh/m^2],
n – the number of the educational building for which the calculations were made.

The average relative error of estimate (MAPE) for the analyzed group of 73 educational facilities is 17%. The relative error between the average values of EK indicator (taking as a reference level - as in the calculation of MAPE - the index obtained by the use-based method), was also calculated; in this case the error value is - 19%, and therefore the right choice of the method of calculation is not without significance - lower scores of the EK indicator are obtained when using the method based on the actual energy consumed. Similar conclusions (based on calculations made for a residential detached house) were obtained in study [16] where the relative estimate error between use-based method and the calculation method was also 17%.

4. Conclusions

The analysis of energy consumption for heating educational facilities in the rural areas in the poviat of Kraków carried out in this study allowed us to estimate the size of the unit indicator of demand for final energy EK kWh /m^2, whose average value is dependent on the assumed method of calculation and amounts, respectively, to 171 kWh / m^2 for the method based on the actually consumed energy and 203 kWh / m^2 for the calculation method based on a standard method of use.

The confidence interval for the final energy EK unit indicator amounts respectively to 156 to 185 kWh/m^2 (use-based method) and 187-219 kWh/m^2 (calculation method).

For the analyzed area of the Kraków poviat, the number of degree days of the standard season (which constitutes the point of reference) is higher by approximately 34% compared to the number of degree days in the measuring period (2013-2015). Thus, even though the provisions of the methodology for estimating energy do not assume recalculation (correction) of the calculations obtained by the use-based method of the standard season conditions, the results obtained should be corrected and the obtained results and referred to the standard conditions of the season, in order to be objectively able to specify the quality of energy performance of buildings.

Majority (70%) of the Educational facilities situated in rural areas of the Kraków poviat are effective in the field of using heat energy (unit use of the final energy above 240 kWh/m^2); 30% of these can be described as energy-efficient (EK<140 kWh/m^2). 7% of the educational facilities (EK >341 kWh/m^2) require carrying out thermo-modernization procedures.

Drawing up the energy performance of buildings should be carried out, as far is it is possible, by applying the use-based method on the basis of the actual energy consumed. This is due to the fact that the average relative error of estimate (MAPE) for the analyzed educational facilities is 17%, while the relative error between the average values of the index is -19%. Therefore, when estimating the use of the final energy according to the calculation method based on the standard manner of use, the values of the rates are significantly over-specified.

5. References

[1] Builddesk 2012. Jakość energetyczna budynków w Polsce. http://www.builddesk.pl/files/BuildDesk/Consultancy/PL%20BD%20Analytics/2010-12-stan-energetyczny-budynkow.pdf.
[2] Centrum Informatycznego Edukacji http://www.cie.men.gov.pl/index.php/sio-wykaz-szkol-i-placowek/26-wykaz-wg-wojewodztw.html.
[3] Degree-days: theory and application TM41. 2006. The Chartered Institution of Building Services Engineers 222 Balham High Road, London SW129BS.
[4] Dopke J.: Liczba stopniodni grzania dla dwudziestu sześciu miast Polski w 2010 r. www.cire.pl 07.11.2011.

[5] Dopke J. Zużycie energii do ogrzewania budynków w trzydziestu trzech miastach Polski w 2013 r. Ciepłownictwo, Ogrzewnictwo, Wentylacja. Wydawnictwo SIGMA-NOT, 2014. Tom 45, 5, 171-178.
[6] Dopke J.: Wyznaczanie temperatury bazowej budynku, www.ogrzewnictwo.pl 24.09.2012 r.
[7] Dyrektywa 2010/31/UE Parlamentu Europejskiego i Rady z dnia 19 maja 2010 r. w sprawie charakterystyki energetycznej budynków.
[8] Dyrektywa 2006/32/WE Parlamentu Europejskiego i Rady z dnia 5 kwietnia 2006 r. w sprawie efektywności końcowego wykorzystania energii i usług energetycznych oraz uchylająca dyrektywę Rady 93/76/EWG.
[9] Ministerstwo Infrastruktury i Rozwoju. Typowe lata meteorologiczne i statystyczne dane klimatyczne dla obszaru Polski do obliczeń energetycznych budynków; http://www.mir.gov.pl/budownictwo/rynek_budowlany_i_technika/efektywnosc_energetyczna_budynkow/typowe_lata_meteorologiczne/strony/start.aspx.
[10] Obszary Rozliczeniowe Ciepła Spalania nr ORCS 040027 (oddział PSG - Tarnow, gmina Zabierzów) http://www.psgaz.pl/dlaklienta/18869/21361 dostęp 18.05.2016.
[11] PN-82/B-02403 Temperatury zewnętrzne obliczeniowe.
[12] PN-EN ISO 13790:2009 Energetyczne właściwości użytkowe budynków - Obliczanie zużycia energii na potrzeby ogrzewania i chłodzenia.
[13] Rozporządzenie Ministra Infrastruktury i Rozwoju z dnia 2 lipca 2014 r. w sprawie metodologii obliczania charakterystyki energetycznej budynku stanowiącej samodzielną całość techniczno-użytkowa oraz sposobu sporządzania i wzorów świadectw ich charakterystyki energetycznej. Dz. U. 2014 poz. 888.
[14] Rozporządzenie Ministra Infrastruktury z dnia 6 listopada 2008 r. w sprawie metodologii obliczania charakterystyki energetycznej budynku stanowiącej samodzielną całość techniczno-użytkowa oraz sposobu sporządzania i wzorów świadectw ich charakterystyki energetycznej. Dz.U. 2008 nr 201 poz. 1240.
[15] Rozporządzenie Ministra Transportu, Budownictwa i Gospodarki Morskiej z dnia 5 lipca 2013 r. zmieniające rozporządzenie w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie. Dz.U. 2013 poz. 926,
[16] Szul T. Comparison of Methods in the Definition of Home Energy Characteristics in the Context of the European Union Directives, Barometr Regionalny. Analizy i Prognozy, 2015, 3(41), 73-80.
[17] Ustawa z dnia 15 kwietnia 2011 roku o efektywności energetycznej. Dz.U. 2011 nr 94. poz. 551.
[18] Ustawa z dnia 29 sierpnia 2014 r. o charakterystyce energetycznej budynków. Dz.U. 2014 poz.1200.
[19] Weather History for Kraków http://www.wunderground.
[20] com/history/airport/EPKK/2015/2/14/CustomHistory.html.

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