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ASSESSMENT OF THE ACCURACY OF THE APPROXIMATE METHOD USED TO ESTIMATE THE HEATING POWER DEMAND FOR SINGLE-FAMILY HOUSES

Summary

Total design heat load as well as the approximate method based on the thermal characteristics of the building were determined in accordance with the PN-EN 12831 standard for 84 randomly selected single-family residential buildings located in rural areas. Calculations were carried out to assess the accuracy of the approximate method for estimating the heating power demand for single-family houses, as compared to the detailed method, and allowed to determine the Mean Absolute Error (MAE) which is 1.1 kW and the Mean Absolute Percentage Error MAPE which is approx. 10% for the analyzed group of buildings. The resulting error values form grounds to the declaration that in absence of construction documentation the approximate method provides good results when estimating the demand for power for heating buildings.
***Key words**: single-family residential buildings, demand for heating power, design heat load*

OCENA DOKŁADNOŚCI METODY ORIENTACYJNEJ SŁUŻĄCEJ DO SZACOWANIA ZAPOTRZEBOWANIA NA MOC DO OGRZEWANIA BUDYNKÓW MIESZKALNYCH JEDNORODZINNYCH

Streszczenie

Dla 84 losowo wybranych budynków mieszkalnych jednorodzinnych, znajdujących się na obszarach wiejskich, wyznaczono całkowite projektowe obciążenie cieplne zgodnie z normą PN-EN 12831, a także metodą orientacyjną bazującą na charakterystyce cieplnej budynku. Przeprowadzone obliczenia mające na celu ocenę dokładności metody orientacyjnej, służącej do szacowania zapotrzebowania na moc do ogrzewania budynków mieszkalnych jednorodzinnych w porównaniu z metodą szczegółową, pozwoliły określić wartości średniego błędu bezwzględnego MAE, który wynosi 1,1 kW oraz średniego bezwzględnego błędu procentowego MAPE, który dla analizowanej grupy budynków wynosi ok. 10%. Otrzymane wartości błędów dają podstawę do twierdzenia, że w przypadku braku dokumentacji budowlanej metoda orientacyjna daje dobre rezultaty przy szacowaniu zapotrzebowania na moc do ogrzewania budynków.
***Słowa kluczowe**: budynki mieszkalne jednorodzinne, zapotrzebowanie na moc do ogrzewania, projektowe obciążenie cieplne*

1. Introduction

According to the CSO data, there are approximately 3.1 million single-family residential buildings in rural areas [3]. It is estimated that approx. 222, 4 PJ of energy is used for heating the buildings annually, which constitutes approx. 33% of the total energy consumption for heating buildings in Poland. The buildings are largely equipped with individual heat sources whose average age is 11.5 years, while nearly 25% of boilers are more than 15 years old [2]. The existing boilers are characterized by low heat generation efficiency, which is estimated as 55-65% [10], and therefore there is a need for replacing the exhausted heat sources with new ones characterized by better parameters.

The demand for heating power is the basic parameter characterizing the energy quality of a building. It is primarily dependent on the thermal insulation of the partitions used in the building and the intensity of air exchange, as well as on the nature of their use and the area and volume of buildings. The temperature of the outside air is the external factor that mainly affects the energy needs. The method of heat load calculation is very precisely described in the PN-EN 12831 standard [5]. The design heat load - peak power - is determined under the extreme temperature conditions that can be recorded during the year. The load is the minimum power of the heat source (boiler) necessary to ensure thermal comfort for building users. In calculating the power, the most unfavorable outside temperatures that can be recorded in a given climate zone are taken into account without the heat gains related to insolation as well as internal heat [1]. In addition, in the calculation of the peak power, a lower intensity of room ventilation is allowed, unlike in the calculation of heat demand. The mathematically designed heat load for a building can be calculated as follows [5]:

$$\Phi_{HL} = \Phi_{Tj} + \Phi_{Vj} + \Phi_{RHj} \text{ [W]} \tag{1}$$

where:
Φ_{Tj} – the sum of heat losses through the penetration of all heated spaces in the building excluding the heat exchanged inside the building [W],
Φ_{Vj} – the sum of ventilation heat losses of all heated spaces in the building excluding the heat exchanged inside the building [W],
Φ_{RHj} – the sum of excess heat power of all spaces required to compensate for the effects of weakening the heating [W].

Taking into account surplus power in the design of thermal load makes it possible to achieve the required internal temperature at a certain time after the period of weakening, e.g. when heating with breaks per day or lowering the room temperature during the absence of users.

Design calculation of heat load requires detailed data on the materials of partitions, surface areas through which heat losses can take place and volumes (heated and ventilated). While designing heating in a new building, obtaining this data is not a major problem, in the case of existing buildings, especially those that do not have construction documentation - obtaining the information will be extremely difficult and time-consuming. In this case, the most commonly used are the indices of unit power demand for heating - where the year of construction is the most important from the point of view of thermal needs. The construction law, modified in subsequent years, strictly defined the minimum parameters, among others, for thermal insulation of buildings. Here, it can be assumed that once the construction standards were changed, the newly constructed buildings had to meet the requirements and, consequently, the standard demand for certain building groups could be determined.

In the literature on the issue, one can find individual power demand indices that refer to a unit of surface [1, 4, 7, 9] or a unit of building volume [11]. Examples of values are summarized in Table 1.

Table 1. Values of power demand indices for heating buildings

Tab. 1. Wartości wskaźników zapotrzebowania na moc do ogrzewania budynków

The type / age of the building	The power demand indicator for a building heating in relation to	
	the surface unit [W·m^{-2}]	the volume [W·m^{-3}]
Old buildings without insulation (before 1966)	120 – 150	48 – 60
Non-insulated building from the 70's or 80's	100 – 120	37 – 42
Pre-1990 building	70 – 80	28 – 35
A building from the 90's	60 – 70	23 – 27
A building from 2000-2010	50 – 60	20 – 22
A building constructed after 2010	40 – 45	17 – 19
A building constructed after 2014	38 – 40	15 – 16
A building constructed in accordance with current requirements	35 – 38	14 – 15

Source: own study based on [1, 4, 7, 9, 11]
Źródło: opracowanie własne na podstawie [1, 4, 7, 9, 11]

In the literature [6, 8] one can find another way of estimating the power demand for heating buildings that do not have full construction documentation. The so-called thermal characteristics are used. This was determined empirically on the basis of the statistical data prepared for over a dozen or so years (mainly before 1980). The thermal performance of a building is equal to the loss of the thermal power of 1 m^3 of the heated building volume, related to the unit difference of air temperature inside and outside the building. An approximate unit power requirement for heating a building that does not have construction documentation can be determined by the formula [8]:

$$q = \frac{1{,}6}{\sqrt[6]{V}} \text{ [W·m}^{-3}\text{ K}^{-1}] \qquad (2)$$

And the approximate demand for thermal power of a building is determined using the formula:

$$\Phi_o = q \cdot V \cdot (t_i - t_e) \text{ [W]} \qquad (3)$$

where:

q – thermal characteristics of a building [W·m^{-3} K^{-1}],
V – volume of a building [m^3],
t_i – internal air temperature [°C],
t_e – outside air temperature [°C].

On the basis of statistical surveys in the existing facilities, it was found that the adjustment factor for the unit heat demand in buildings with a volume capacity above 1000 m^3 is 1 [6].

The factor after conversion has been used to estimate the power demand for heating the single-family residential buildings located in rural areas which have a volume capacity of less than 1000 m^3. The correlation after transformation was as follows:

$$\Phi = 0{,}064 \cdot \sqrt[6]{V_e^{\,5}} \cdot w \cdot s \text{ [kW]} \qquad (4)$$

where:

Φ – approximate power demand for heating the building [kW],
V_e – heated volume of the building calculated with external dimensions [m^3],
w – adjustment factor,
s – factor taking into account the climate zone in the area where the building is located.

The values of the adjustment factor *w* which correlates with the period of the establishment of buildings created until 2006 are presented in the publication [12], and then updated by the author of this work. The mean values of the adjustment factor depending on the age of the building (including those updated for buildings created after 2006) are shown in Table 2.

Table 2. Values of the adjustment factor depending on the age of the building

Tab. 2. Wartości współczynnika korygującego w zależności od wieku budynku

Construction time	Adjustment factor *w**
to 1957	1.92
1958 – 1974	1.78
1975 – 1982	1.58
1983 – 1991	1.34
1992 – 2002	1.21
2003 – 2008	1.00
2009 – 2013	0.92
after 2014	0.74

* if the buildings have undergone thermomodernisation, the value of the factor should be reduced by 23% (it applies to buildings of the age range 1957–2002) / ** jeżeli budynki zostały poddane zabiegom termomodernizacyjnym wartość współczynnika należy zmniejszyć o 23% (dotyczy budynków z przedziału wiekowego 1957–2002)*

Source: own study / Źródło: opracowanie własne

However, the value of the factor taking into account the climatic zone is presented in Table 3.

Table 3. Values of the factor taking into account the climatic zone in the area where the building is located

Tab. 3. Wartości współczynnika uwzględniającego strefę klimatyczną, na obszarze której zlokalizowany jest budynek

Climatic zone	I	II	III	IV	V
Adjustment factor's	0,9	0,95	1	1,05	1,1

Source: own study / Źródło: opracowanie własne

2. Aim and scope of study

The aim of the study was to check and determine the correctness of the calculations of the approximate demand for heating power according to the modified method based on the thermal characteristics of the building (described by formula 4) with the reference method included in the PN-EN 12831 standard for single-family residential buildings.

The research was carried out in rural areas of the Krakow district located in the Małopolska Region. For the analyzed area, the minimum sample size was defined, being 81 objects (for the confidence level α = 0.95 and the maximum error of 10%) in which the tests should be performed. The research was carried out in 84 single-family residential buildings. Information was collected on, among others, the construction year, heated floor area, surfaces of the partitions through which there are heat losses, heated and ventilated volumes, the materials from which the partitions are made, types of windows and information on the thermal modernization carried out in the buildings.

Fig. 1 shows the buildings divided by their construction year. It compares the structure of buildings, as can be read in the Central Statistical Office reports [3] compared with the buildings in which the study was carried out.

The age ranges were established in accordance with the applicable legal regulations regarding the maximum values of U_{max} heat transfer coefficients for external partitions, i.e. during the periods of the validity of the standards and relevant industry regulations. As can be seen in the chart, the age structure of the buildings analyzed does not differ much from the data compiled in the Central Statistical Office and so it can be considered as representative. The weighted average heated area of the buildings analyzed is 118 m^2 and the heated volume is 354 m^3.

3. Methodology

The total design heat load was calculated in accordance with the PN-EN 12831 standard and compared with the approximate power demand for heating buildings calculated according to formula 4. In both cases, the normative temperature, i.e. the internal temperature 20ºC and the external for the III Climatic zone for which the computational the outside temperature is -20°C were assumed.

In order to check the accuracy of the estimation of the demand for heating power in buildings, the following were calculated:

- mean absolute error MAE:

$$MAE = \frac{1}{n}\sum_{1}^{n}\left|y_t - y_t^P\right| \tag{5}$$

- and, the mean absolute percentage error of the MAPE:

$$MAPE = \frac{1}{n}\sum_{1}^{n}\frac{\left|y_t - y_t^P\right|}{y_t}\cdot 100\% \tag{6}$$

where:

y_t – design heat load calculated according to the PN-EN 12831 standard [kW],

y_t^P– approximate power demand for heating the building [kW],

n – number of buildings for which calculations were made.

4. Discussion on the results

The calculations made it possible to determine the power demand for heating single-family residential buildings located in the rural areas of the Krakow district. The results of calculations for individual objects are depicted in Fig. 2.

The total design heat load of buildings calculated in accordance with the PN-EN 12831 standard ranges from 6 to 27 kW, with the average value of approx. 12 kW. The highest power demand is characteristic for buildings constructed in 1975-1991 for which the design heat load is on average 13.8 kW, while in the case of the buildings constructed after 2003 it is on average approx. 10.4 kW. The power demand value calculated using the approximate method is in the range of 7 to 25 kW, with an average value of 11.2 kW.

In order to determine the accuracy with which the estimated power demand for heating buildings was estimated, the MAE and MAPE error values for individual age ranges and the overall value for the whole group of buildings were calculated. The results of the calculations are presented in Table 4.

Analyzing the results obtained, it can be concluded that the mean absolute error MAE varies from 0.66 to 1.96 kW with an average value of 1.1 kW. Using the simplified method of calculation, the most accurate results can be obtained for the buildings constructed in the years 2003-2008 and also before 1957 and in the years 1992-2002, for which the difference between the values calculated according to PN-EN 12831 is less than 1 kW.

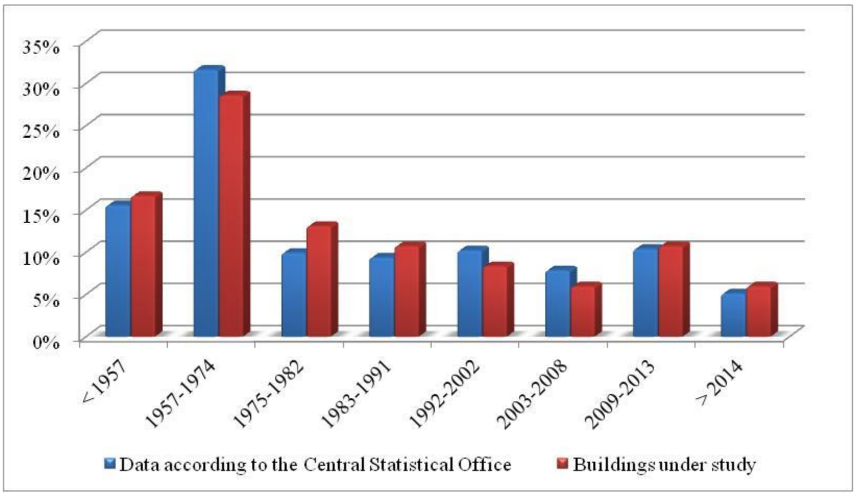

Fig. 1. Age structure of residential buildings in rural areas of the Krakow district [3]
Rys. 1. Struktura wiekowa budynków mieszkalnych na obszarach wiejskich powiatu krakowskiego [3]

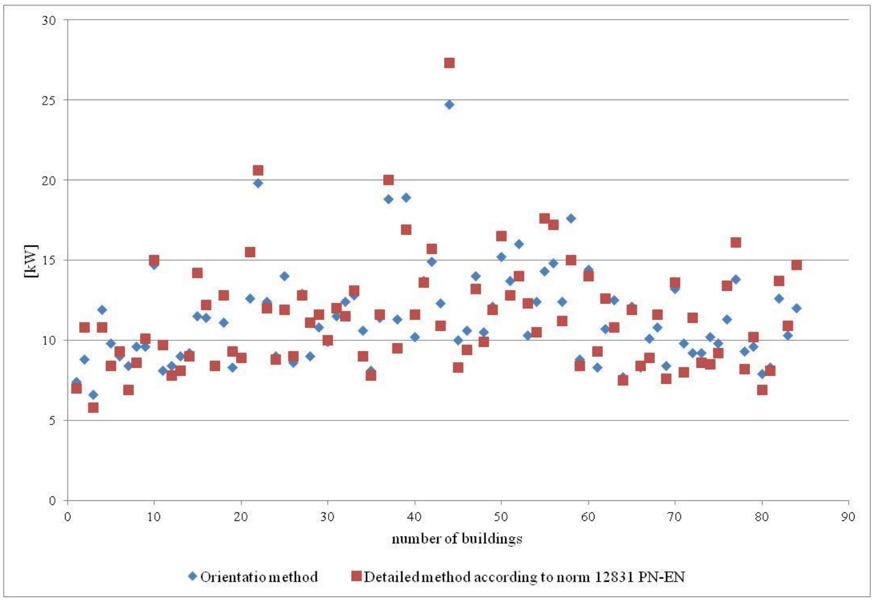

Fig. 2. Demand for power for heating residential buildings calculated according to the PN-EN 12831 [5] standard and based on the approximate method

Rys. 2. Zapotrzebowanie na moc do ogrzewania budynków mieszkalnych obliczone wg normy PN-EN 12831 [5] oraz w oparciu o metodą orientacyjną

Table 4. Estimates of the mean absolute errors (MAE and MAPE) of the power demand for heating buildings

Tab. 4. Wartości średnich błędów oszacowania (MAE oraz MAPE) zapotrzebowania na moc do ogrzewania budynków

Specification	Age range of the buildings								Total
	<1957	1957-1974	1975-1982	1983-1991	1992-2002	2003-2008	2009-2013	>2014	
MAE [kW]	0.82	0.95	1.16	1.96	0.83	0.66	1.44	1.12	1.1
MAPE %	9.7	7.9	9	13.9	7.6	7	13.8	9.8	9.6

Source: own study / Źródło: opracowanie własne

Estimation of power demand in the buildings constructed in 1983-1991 and 2009-2013 will differ from the reference value by approx. 1.5 to 2 kW. Considering the value of the mean absolute percentage error (MAPE), it can be noticed that by estimating the heating power demand for heating buildings according to the approximate method, the error value can range from 7 to approx. 14%. With the average value not exceeding 10% - which can be considered a satisfactory value in the case of calculations for the existing buildings without construction documentation.

5. Summary

The total design heat load of residential buildings located in the rural areas of the Krakow district ranges from 7 to 26 kW, and its average value is 12 kW. The calculations made to assess the accuracy of the approximate method for estimating the heating power demand for single-family houses, as compared to the detailed method based on the PN-EN 12831 standard, enabled the determination of the values of the absolute error of the IEA, which varies from 0.66 to 1.96 kW, with an average value of 1.1 kW and an average mean absolute percentage error MAPE which covers the range of 7 to 14% for the analyzed group of buildings, and equals approx. 10% for the entire group of buildings. Therefore, in the case of incomplete data or lack of construction documentation for the existing buildings it can be stated that the modified approximation method presented in the paper - as based on the so-called thermal characteristics - can be successfully used to estimate the power demand for heating single-family residential buildings.

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