Energy Consumption Indicators in Residential Buildings in North-Eastern Poland

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Abstract

Thermal energy consumption in selected buildings in three residential estates in a city in northeastern Poland was analysed based on recorded data from 2010 to 2021. Multifamily buildings of varying construction technology, floor area, and number of stories were examined. 47 residential buildings were analysed, some of which contained commercial premises related to services for the estate's residents. These buildings meet current thermal protection standards, have unheated basements, and the top floors are generally heated and occupied. Outside air temperature was considered based on archived meteorological data and standard climate data. Electricity and gas consumption in this city was also analysed for selected apartments occupied by one adult, two adults, and a family of four, based on actual consumption. The aim of this article is to obtain better energy consumption estimates in the event of metering device failures, as well as to better forecast energy consumption based on the size of residential buildings and the number of occupants than is possible based on building design data. The findings may be useful in estimating lump sum fees that consider actual energy consumption in the form of heat, electricity, or gas combustion, as well as in planning residential renewable energy sources. The analysis of buildings' thermal energy consumption is particularly interesting because in recent years, there have been no occurred values of calculated outside air temperatures for winter. The calculations consider real outside air temperatures based on historical meteorological measurement data.

Keywords: *Degree Days, Meteorological Measurement Data, Energy Consumption, Residential Buildings. (Total) Heat Consumption Index*

1. Introduction

The analysed buildings are in a climate zone with a design outdoor air temperature of -22°C. The housing estates are stable, meaning no significant thermal modernization work was carried out during the period under review, and the number of residents in these buildings can be assumed constant. The buildings meet current thermal protection requirements and average heating demand indicators for these buildings are in the range of 90 - 120 kWh/m^2 [1].

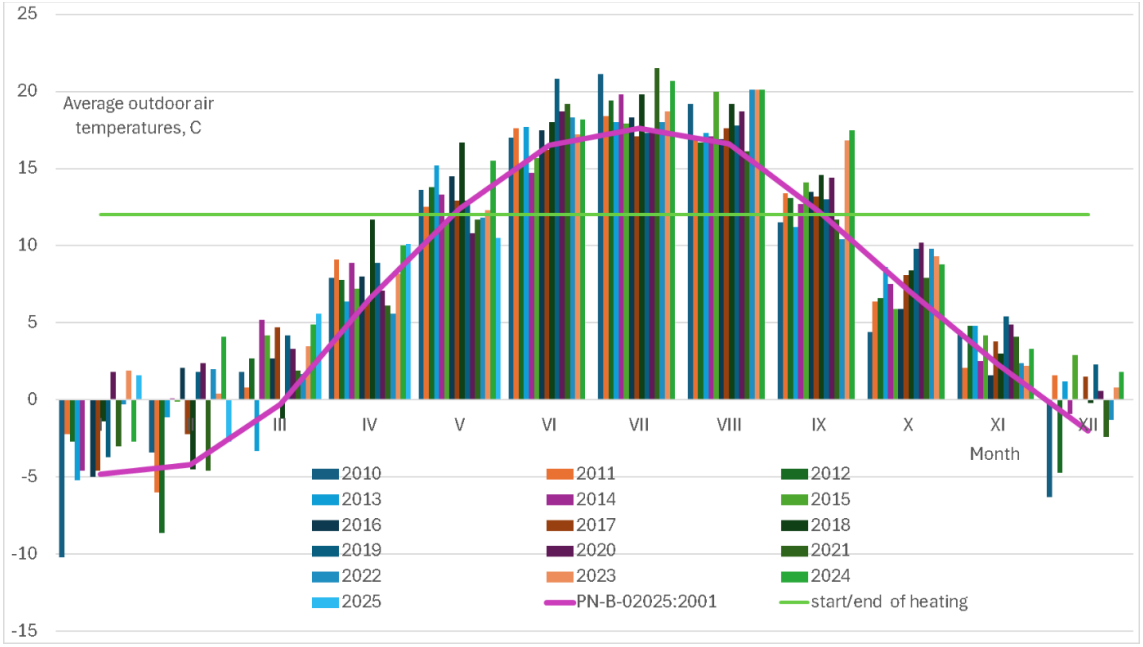

Fig. 1. Monthly average outdoor air temperatures in a city with a design outdoor air temperature of -22°C [2, 3].

Studies [4] and [5] analysed buildings located in milder climates with a design temperature of -20°C and concern unstable buildings. This means that in study [4], the heat demand decreased in subsequent years due to thermal modernization work. Study [5] concerns a new multi-family building put into use in the autumn and initially inhabited by one family. In the following months, the apartments were gradually occupied, and the overall heat consumption in this building increased. Currently, solar gains [6] are not included in building heat loss calculations. It seems that for multi-family buildings, renewable energy sources will be small, individual installations [7], also installed on balconies and used by groups of residents, installed on roofs [8, 9], building facades [10], or previously unoccupied areas [11, 12].

1.1 Aim

Aim of this study is to analyse energy consumption (heat, gas and electrical energy) in buildings in housing estates in Poland, in the fourth climatic zone with the design temperature of the outside air -22°C [13] to obtain better energy consumption estimates in the event of metering device failures, as well as to better forecast energy consumption based on the size of residential buildings and the number of occupants than is possible based on building design data. The findings may be useful in estimating lump sum fees that consider actual energy consumption in the form of heat, electricity, or gas combustion, as well as in planning residential renewable energy sources. The analysis of buildings' thermal energy consumption complements the measurement works [14, 15] and is particularly interesting because in recent years, there have been no occurred values of calculated outside air temperatures for winter. The calculations consider real outside air temperatures based on historical meteorological measurement data.

2. Materials and Methods

The study was based on average monthly outdoor air temperatures [2] and heat consumption [16] (heating and hot water), as well as electricity and gas consumption data received from the building manager and residents'. It was sometimes assumed that if the outside air temperature dropped fell below 12°C at 9 p.m. for three consecutive evenings, the heating would be turned on. Today's buildings have better thermal insulation, and considering internal heat gains, daytime solar gains, and the thermal inertia of buildings, the temperature at which the heating is turned on can be lower and depends on other outdoor air parameters, such as wind speed and outdoor air humidity. Currently, heating is usually turned on automatically based on the controller settings. Figure 1 shows the average monthly outdoor air temperatures, the temperature according to [3] and the 12°C line as the start of the heating season.

Seven buildings were analysed in the housing estate marked with the letter k, 12 buildings in the housing estate marked with the letter n, and 21 buildings in the housing estate marked with the letter w. The area occupied by the building ranges from 300 to 1050 m^2, and the number of heated floors ranges from 1 to 12. The tables give value 4,200-degree days for the location where the buildings are analysed, hence we obtain indicator values:

$$\frac{120\ kWh}{4200\ DD} = 0.029\ \frac{kWh}{m^2 DD} = 1.190\ \frac{W}{m^2 K} \tag{1}$$

and

$$\frac{90\ kWh}{4200\ DD} = 0.021\ \frac{kWh}{m^2 DD} = 0.893\ \frac{W}{m^2 K}. \tag{2}$$

The indicator values given above consider heat only for the purposes of central heating of rooms.

The number of degree days in each month DD(m) was calculated using the formula:

$$DD(m) = (T_{int} - T_{ext}) Ld(m)\ [day \cdot K] \tag{3}$$

The calculation results are presented in Table 1. The author assumed T_{int} = 20°C, T_{ext} as the average temperature in the month *m*, *Ld(m)* = 10 for May (*m* = 5) and September (*m*=9). The initial heating temperature was assumed to be 12ºC, i.e. if $T_{ext}(m)$ was greater than or equal to 12, then *DD(m)* = 0.

Tab. 1. Degree days calculated using various methods.

Period	According to equation 3	According to reference [2]	Difference in %: 1 - column 2/column 3
2012-13	4139	3938	5
2013	3983	3830	4
2013-14	3592	3430	5
2014-15	3701	3537	4
2015-16	3614	3426	5
2016-17	3879	3715	4
2017-18	3684	3421	7
2018-19	3563	3380	5
2019-20	3357	3209	4
2020-21	3821	3597	6
2021-22	3844	3617	6
2022-23	3576	3446	4
2023-24	3378	3059	9
2024-25	3457	3161	9
According to reference [3]	4245		

3. Results and Discussions

The lowest total heat consumption index (including heat for central heating, domestic hot water preparing and heat losses in circulation pipes) of 105 kWh/m² (Fig. 2.) was determined during the heating season 2022-23 for buildings n16 and w12, 106 kWh/m² for building n1, and 107 kWh/m² for building n15. The buildings n1 and w12 with a cube-like shape were constructed using small-

scale masonry. These two buildings are in various housing estates, have five heated floors, and have commercial premises on the ground floor. Similar value of the total heat consumption index 106 and 107 kWh/m² was determined during the heating season 2022-23 for buildings with a shape like an elongated cuboid, constructed using small-scale masonry. These buildings have five heated floors, and in the heated sixth floor part, the attics were converted into two-level apartments.

The greatest total heat consumption index of 256 kWh/m² was determined during the heating season 2012-13 for building k7 also constructed using small-scale masonry. It's a complex of three small commercial and office buildings connected by a ground-floor terrace. The buildings' basements are unheated; one has one heated floor, and the other two have two heated floors.

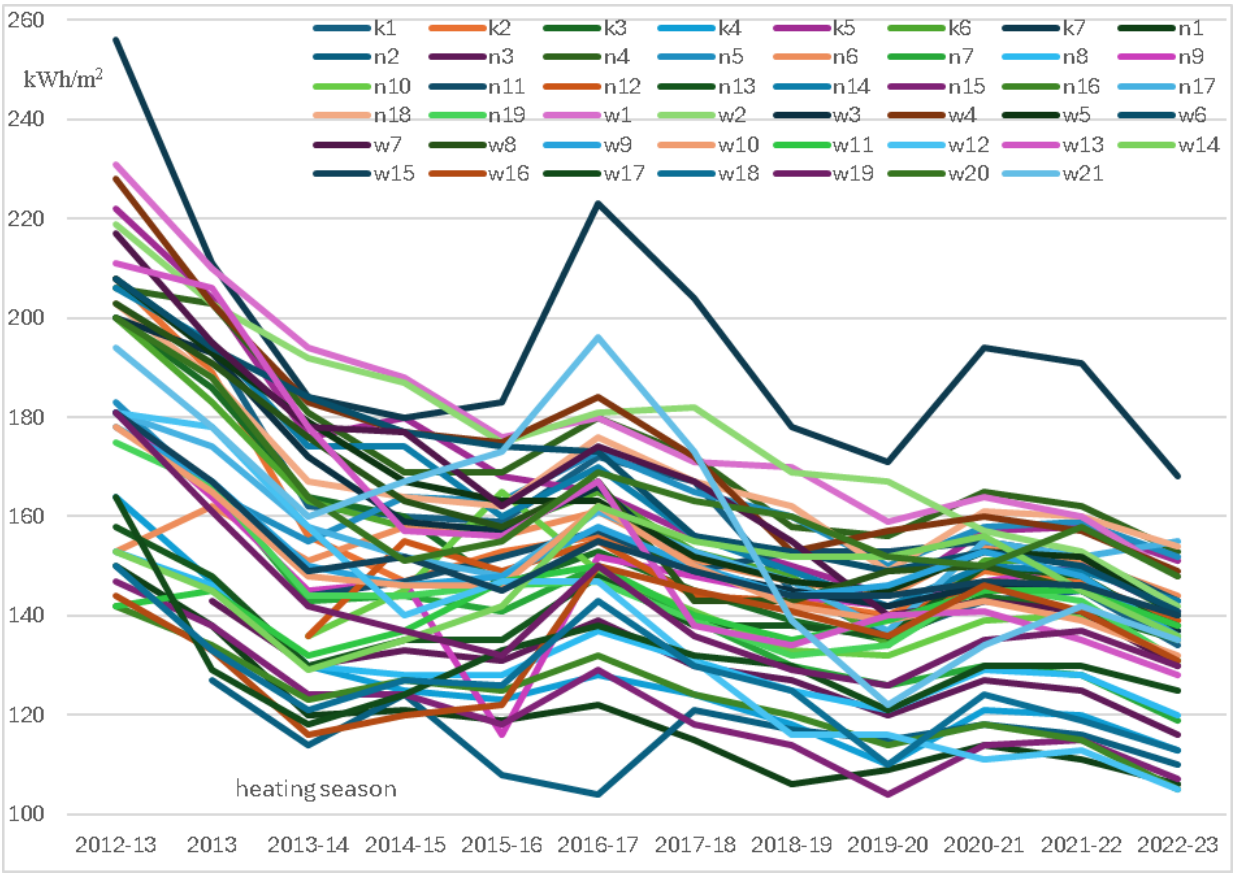

Fig. 2. Values of the total (central heating and domestic hot water) heat consumption indicator kWh/m² versus heating seasons.

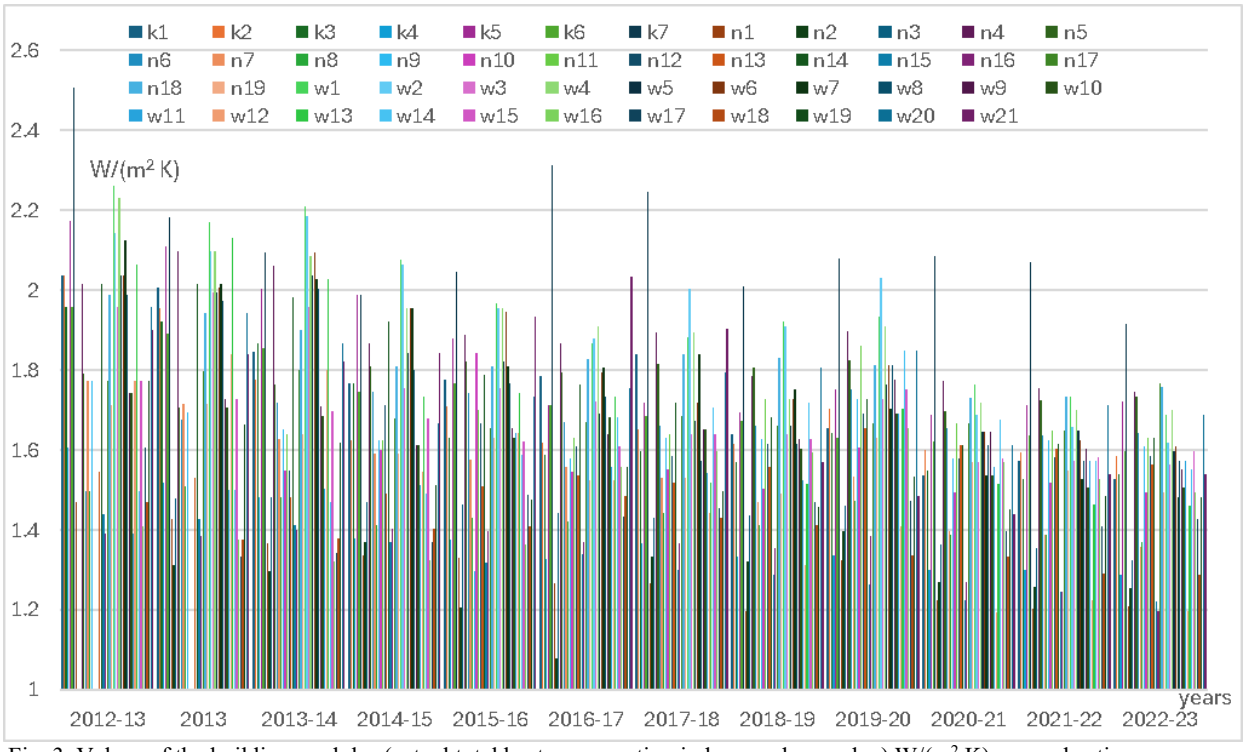

Fig. 3. Values of the building modules (actual total heat consumption index per degree day) W/(m² K) versus heating seasons.

During the 2022-23 heating season, this building k7 also had the highest index of 168 kWh/m^2. Building n17 had the highest rate of 155 kWh/m2 among residential buildings. No cost accounting devices were installed in these buildings. To more easily relate the obtained results to buildings in other cities with different number of degree days, building modules (Equations 1, 2) were determined based on the total (central heating and domestic hot water) heat consumption indicator. The results obtained are presented in Figure 3. A short analysis of the results obtained is presented in Figure 4.

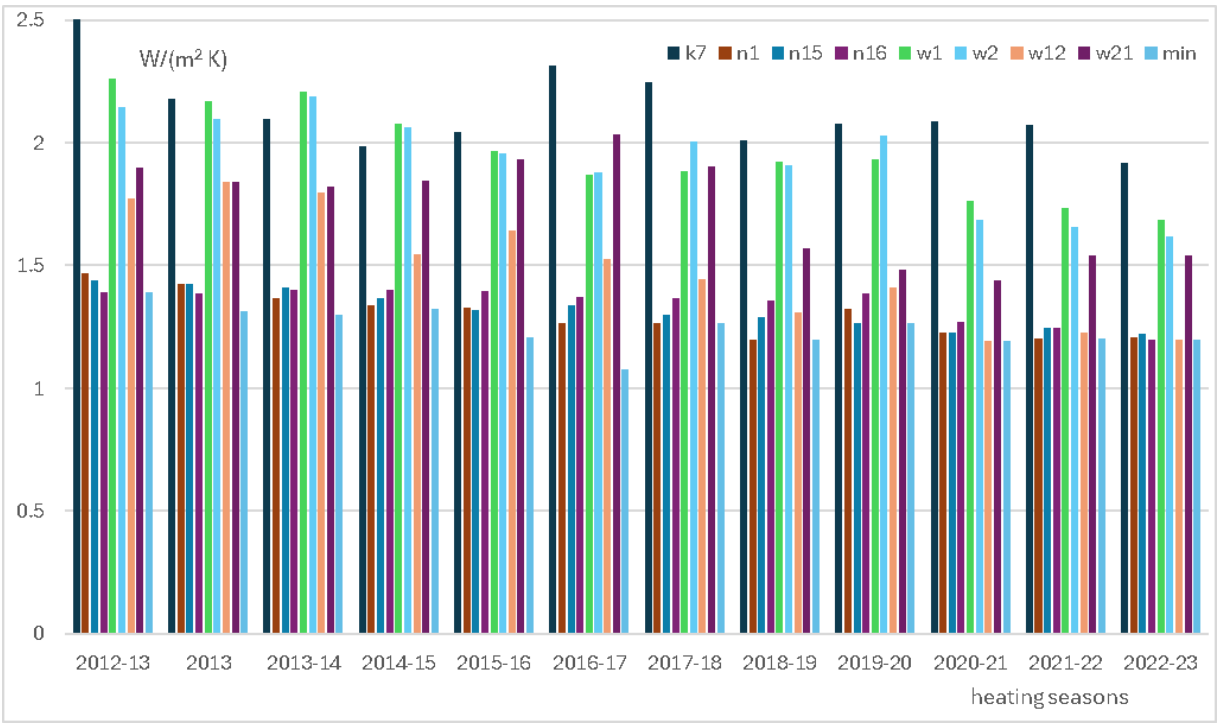

Fig. 4. Values of the building modules W/(m^2 K) for selected buildings versus heating seasons.

Electricity and gas consumption in this city was also analysed for selected apartments occupied by one adult, two adults, and a family of four, based on actual consumption. In the homes from which the data was taken, electricity is used for lighting and powering household appliances. It is not used for cooking, charging electric cars, or powering central heating or hot water pumps. Gas is used only for cooking.

3.1 Analysis of electricity consumption

The average consumption of electricity by a single individual is approximately 200 to 300 kWh over a period of six months (Fig. 5). The collective consumption of energy by two or more people residing in the same dwelling is estimated to be between 150 and 200 kWh per person over a period of six months.

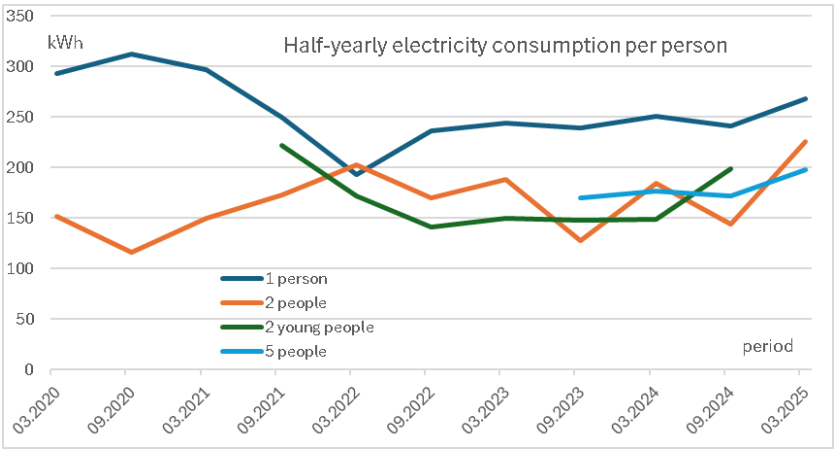

Fig. 5. The mean electricity consumption per capita over a period of six months.

3.2 Analysis of gas consumption

In this section, an analysis of gas consumption will be conducted.

As demonstrated in Figure 6, the available data indicates that the average annual consumption of gas for a single individual is approximately 200 to 300 kWh. The average consumption of gas required to meet the domestic energy needs of two people residing in a shared domicile is estimated to be between 160 and 185 kWh/(person year), or approximately 320 to 370 kWh per annum. It is estimated that two young people who rarely prepare their own evening meals consume 150 to 180 kWh of gas per person per year.

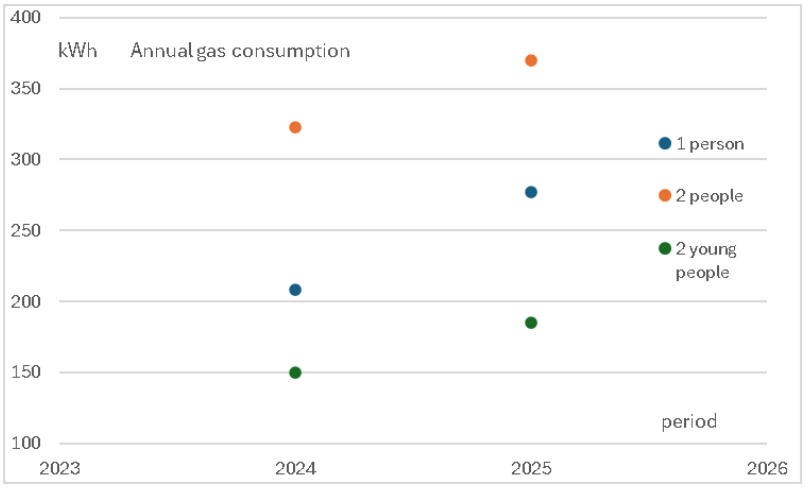

Fig. 6. Values of annual gas consumption

4. Conclusions

The average temperatures recorded in consecutive months over the period 2010-2025 are higher than the values suggested by climate data [3] based on long-term observations in earlier years. This is completely different in January 2010 with an average temperature of -10.2°C, against a value of -4.8°C from long-term earlier observations, December 2010 with an average temperature of -6.3°C, against a value of -2.0°C, and February 2012 with an average temperature of -8.6°C, against a value of -4.2°C, and December 2012 with an average temperature of -4.7°C.

The calculations in this paper are based on the readings of the main heat meters in 47 buildings (mainly residential, but also commercial and office buildings) across three housing estates in a large city in north-eastern Poland, from 2012 to 2023.

The main heat meters also record heat losses in the pipes inside the buildings and report them as part of the total measurement result. However, the measurements and calculations do not consider heat losses in the heat supply networks leading to individual buildings. Values of the total (central heating and domestic hot water) heat consumption indicator q_{ch+dhw} [kWh/m^2] were approximated by a linear function depending on the number of degree days

$$q_{ch+dhw}(DD) = a\,DD + b,\ [kWh/m^2]\,. \tag{4}$$

The approximations for the buildings on housing estate *k* are included between the approximations:

$$\text{for building } k4\text{: } q_{ch+dhw}(DD) = 0.0584\,DD - 90.789 \text{ with } R^2 = 0.6942, \tag{5a}$$
$$\text{and for building } k7\text{: } q_{ch+dhw}(DD) = 0.1028\,DD - 188.18 \text{ with } R^2 = 0.7627. \tag{5b}$$

The approximations for the buildings on housing estate *n* are included between the approximations:

$$\text{the lower limit results from the approximation for buildings } n15\text{: } q_{ch+dhw}(DD) = 0.0488\,DD - 61.073 \text{ with } R^2 = 0.709, \tag{6a}$$
$$\text{and } n2\text{: } q_{ch+dhw}(DD) = 0.0094\,DD + 81.29 \text{ with } R^2 = 0.06, \tag{6b}$$

and the upper limit results from the approximation for building *n4*:

$$q_{ch+dhw}(DD) = 0.0631\,DD - 62.378 \text{ with } R^2 = 0.6162. \tag{6c}$$

The approximations for the buildings on housing estate *w* are included between the approximations:

$$\text{for building } w15\text{: } q_{ch+dhw}(DD) = 0.0434\,DD - 35.239 \text{ with } R^2 = 0.6617, \tag{7a}$$

and the upper limit results from the approximation for buildings *w1* and *w2*:

$$q_{ch+dhw}(DD) = 0.0756\,DD - 102.55 \text{ with } R^2 = 0.471, \tag{7b}$$
$$q_{ch+dhw}(DD) = 0.0557\,DD - 30.423 \text{ with } R^2 = 0.3002. \tag{7c}$$

To make the calculation results as useful as possible, we also worked out the actual building modules (equations 1 and 2). These are the total heat consumption indicators for central heating and domestic hot water, related to 1 degree day. We also proceeded in the same way for the data in subsequent years. The greatest value of the total building module (central heating and domestic hot water) was 2.51 W/(m^2 K), computed for building *k7* in 2012-13 heating season. The lowest value 1.08 W/(m^2 K) was computed for building *n2* in the 2016-17 heating season (Fig. 7).

Electricity consumption [4] and gas combustion (Figs 5 and 6) represent a negligible proportion of the buildings' overall energy balance. However, given the proportion of prices, it is a significant part of household budgets when central heating and central hot water preparation are considered.

These findings could be useful for estimating lump sum fees based on actual energy consumption in the form of heat, electricity or gas combustion, as well as for planning residential renewable energy sources. Accurate estimates of heat, electricity and gas consumption depend on the correctness of the consumption indicators used.

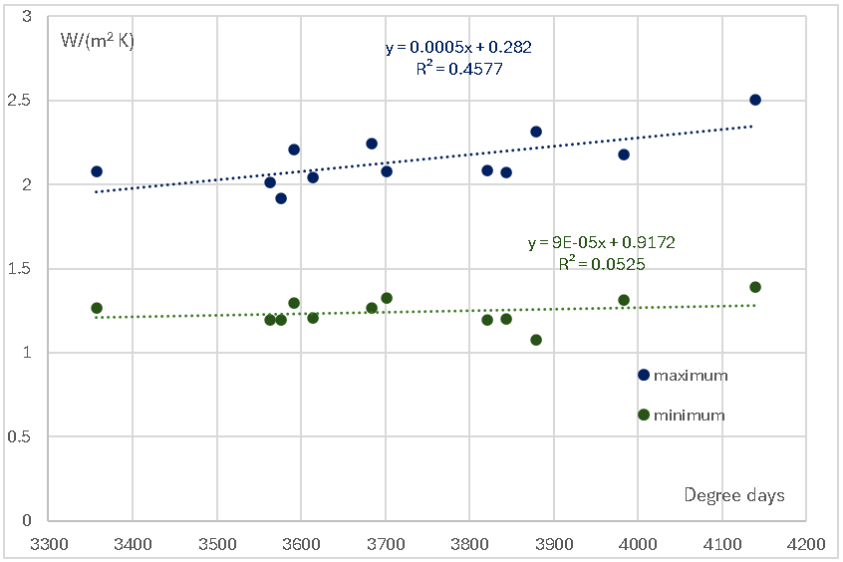

Fig. 7. Values (minimum and maximum) of the building total (central heating and domestic hot water) module v. degree days

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