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THE IMPACT OF CLIMATE CONDITIONS ON ENERGY CONSUMPTION FOR HEATING AND COOLING OF RESIDENTIAL BUILDINGS

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ABSTRACT: This paper attempts to determine the influence of various climate conditions on energy consumption for heating and cooling of residential buildings. Ecological and economic aspects were also analysed. A single-family building erected in energy quality variants was considered. Its energy performance as well as heating and cooling costs in two locations in Poland were examined. The impact of predicted climate changes on energy consumption and costs related to these changes were also analyzed. It was found that climate conditions and their predicted changes have a significant impact on energy consumption for heating and cooling of buildings, and consequently on the costs associated with maintaining adequate indoor air quality.

KEY WORDS: climate conditions, building energy performance, energy costs

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Introduction

Nowadays, energy policy enforces improvements in the construction sector, which accounts for 40% of total energy consumption in the European Union (EU, 2010). Reducing energy consumption is also an important measure when it comes to reducing greenhouse gas emissions that affect global warming. One of the actions in this direction, contained in the Energy Performance of Buildings Directive, is the resolution, that all new buildings in EU countries will be nearly zero-energy by 31 December 2020 (public-utility buildings by 31 December 2018).

Newly-erected buildings should be constructed in accordance with the energy efficiency levels set out in national legislation. In Poland, the current legal document is the Regulation of the Ministry of Transport, Construction and Marine Economy from 5 July 2013 (PL, 2013). It contains minimum requirements for thermal protection of buildings (heat transfer coefficients of building partitions, window areas and *EP* indicator [kWh/a/m^2] determining the annual demand for non-renewable primary energy for heating, ventilation, hot water preparation, cooling and sometimes lighting). The types of energy that are included in the requirements depend on the type of building. The type of building also determines the required level of the *EP* indicator.

According to the buildings database (the EU Building Stock Observatory) published by The European Commission to track the energy performance of buildings across all Member States, most of the floor area belongs to residential buildings. The share varies considerably, from around 60% in Slovakia, Netherlands and Austria to more than 85% in the southern countries of Cyprus, Malta and Italy.

In Polish residential buildings, most of the energy is used to meet space heating requirements (69% of total energy consumption), followed by water heating (37%), cooling (8%), electrical appliances (7%) and lighting (2%). Three most significant types of energy (for heating, domestic hot water preparation and cooling) are included in the energy assessment of residential buildings in Poland. The smallest share, among those assessed, currently pertains to cooling of residential buildings, however – considering global warming – this situation may change.

Over the last decades there has been an increase in the Earth's average surface temperature. According to the Assessment Report on the state of knowledge on climate change, published by the IPCC (IPCC, 2014), warming is largely caused by anthropogenic greenhouse gas emissions. Continued emissions will cause further warming. The topic of climate changes in Poland was discussed in (Kaszewski, 2015). Future scenarios of climate change in Poland, developed for the KLIMADA project (KLIMADA, 2013), present –

especially towards the end of the 21st century—a trend of increasing temperatures. These scenarios are collected in table 1.

Table 1. Changes in selected climate characteristics by the end of the 21st century in Poland

Parameter / Period	1971-1980	1981-1990	1991-2000	2001-2010	2011-2020	2021-2030	2041-2050	2061-2070	2071-2090
Annual average temperature [°C]	7,4	7,8	8,0	8,2	8,6	8,7	9,3	10,1	10,6
No. of days with temperature <0°C	114	107	101	102	97	97	82	72	65
No. of days with temperature >25°C	27	27	30	29	36	35	37	46	52

Source: KLIMADA, 2013.

Temperature increases are additionally varied regionally and seasonally. The strongest variation will be observed during the winter in the north-east of Poland in the lower temperature range (2.5°C in period from 1971-2000 to 2021-2050 and above 4.5°C to 2071-2100) and in the summer in the south-east of Poland in the higher temperature range. One area affected by climate change is the energy consumption for heating and cooling. The impact of climate change on the energy demand of buildings in various locations in the world was discussed e.g. in (Kevin et al., 2011; Mingcai et al., 2015). Narowski and Panek (2012) presented analyses for Polish climatic conditions.

This paper deals with the analysis of the influence of various climate conditions on energy consumption for heating and cooling of residential buildings as well as on their costs. The climatic conditions in two locations in Poland and the expected temperature increase of 1.5°C were considered. For a typical meteorological year, climatic data available at www.miir.gov.pl were used.

Research methods

The analysis was performed as a case study for an existing single-family low-energy house. Its low energy consumption has been confirmed by research (Sadowska, 2010). Two additional variants of this building's energy quality (conventional and passive) were analysed. General description of the building is presented in table 2.

Table 2. Description of the subject building

Type of building Description		Conventional (CB)	Low-energy (LEB)	Passive (PB)
Floor area		177 m^2		
Volume		732 m^3 (house with two heated floors, without a basement)		
Design air tightness		3.0 h^{-1}	1.5 h^{-1}	0.6 h^{-1}
Heat transfer coefficient of building envelope	external walls	0.20 $W/m^2/K$	0.20 $W/m^2/K$	0.12 $W/m^2/K$
	roof	0.17 $W/m^2/K$	0.18 $W/m^2/K$	0.13 $W/m^2/K$
	floor on the ground	0.30 $W/m^2/K$	0.18 $W/m^2/K$	0.13 $W/m^2/K$
	windows	1.10 $W/m^2/K$	1.70 $W/m^2/K$	0.80 $W/m^2/K$
Ventilation system		natural	mechanical, 75% heat recovery + ground heat exchanger	mechanical, 90% heat recovery + ground heat exchanger

Source: author's own work.

The building is heated with gas and hot water is prepared in the same gas boiler. The total efficiency of the heating system was 0.874. Ground heat exchanger was used in low-energy and passive variants of the building. Experimental data and calculation results for low-energy building, presented in (Żukowski et al., 2011), indicate that earth tube can reduce operative temperature inside the tested building (Sadowska, 2010) by the average of 1.9°C.

The annual energy demand in two locations in Poland (Bialystok and Wroclaw) was calculated according to the International Standard (PN, 2009) and, in order to estimate the efficiency of the heating system, the Regulation of the Ministry of Infrastructure of Poland (PL, 2002) was used. An increase in outdoor air temperature by 1.5°C and constant solar radiation was investigated.

During the heating season, the indoor temperature was set at 20°. In conventional houses in Poland, mechanical cooling is very rarely used. Excess heat is removed by ventilating or blocking access to sunlight. Mechanical cooling in the summer will be used in the building when the indoor temperature exceeds 26°C. It was assumed that cooling would be achieved by using electricity.

The ecological analysis was performed considering:

- carbon emission factor for a gas: 56.10 kg CO_2/GJ (KOBIZE, 2017a),
- carbon emission factor for an electrical grid: 806 kg CO_2/MWh (KOBIZE, 2017b).

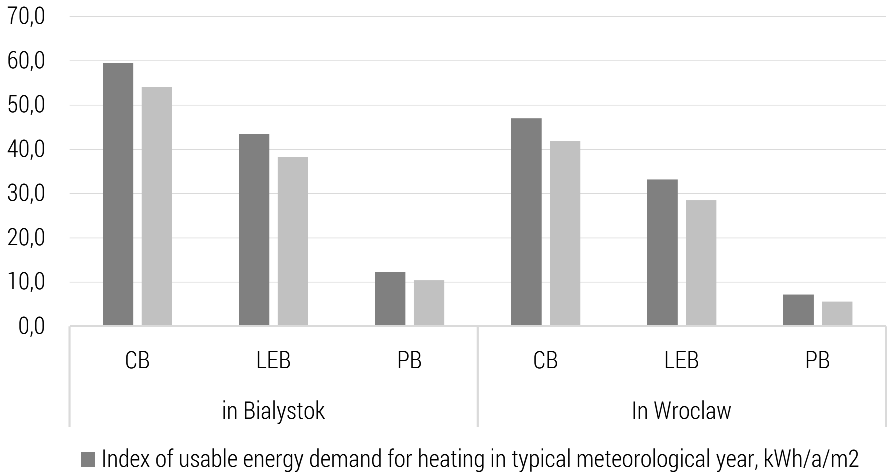
Unit energy prices were assumed at the level of: 0.12 PLN/kWh for gas and 0.55 PLN/kWh for electricity. In the case of cooling, it is assumed that 0.5 kWh of electricity is required to produce 1 kWh of cold.

Results and discussion

The calculation results are collected in figure 1. The demand for usable energy for the purpose of heating a residential building located in Bialystok is by 21% higher (in the case of a conventional building) and by over 40% (in the case of a passive building), than the same building located in Wroclaw.

An increase in the outdoor temperature reduces space heating demands. In the case of a temperature increase of 1.5°C, the percentage changes are the highest for the passive version of the building (by 15.4% in Bialystok and 22.2% in Wroclaw), for the low-energy version, they respectively amount to 12 and 14.2%, and for the conventional version, 9.1 and 10.9%. The demand for cooling increased by approx. 20.0% in buildings located in Bialystok and approx. 7% in buildings located in Wroclaw.

Figure 1. The index of annual usable energy demand for heating of single-family house (LEB: low-energy; PB: passive building, CB: conventional building) located in Bialystok and Wroclaw, in various climate conditions



Source: author's own work.

Total cost of energy is lower in more energy-efficient buildings (table 3). Because in conventional houses in Poland mechanical cooling is very rarely used, two variants of this part of energy need were analysed. In the first one, it was assumed that existing residential buildings are not cooled, and in the second one they have mechanical cooling. The cost of heating a building erected in accordance with the current requirements of thermal protection is more than 5 times higher (in Bialystok) and 7 times higher (in Wroclaw) than in the passive house. Ensuring proper internal environment parameters throughout the year (with the cost of cooling) is only less than 1.5 times more expensive. At current prices of electricity and gas, the cooling cost of the conventional house account for 33-44% of total costs, in the low-energy building 45-57% and in the passive house 84-91%.

Table 3. Annual heating and cooling costs of the subject building

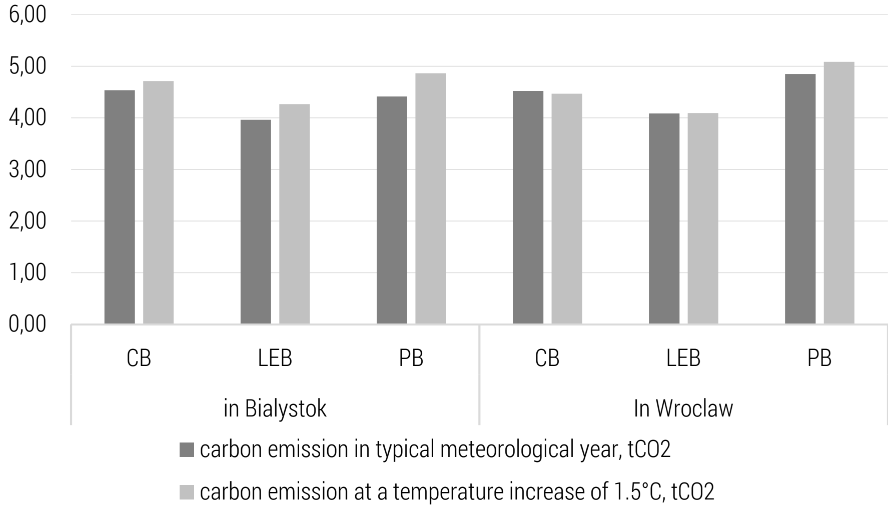
Type of building		Conventional (CB)		Low-energy (LEB)		Passive (PB)	
Climate conditions		c 0	c +1,5	c 0	c +1,5	c 0	c +1,5
Location		Bialystok					
Annual costs [PLN]	heating	1446	1149	924	813	261	221
	cooling	716 0 *)	852 136 **)	745 0 *)	1012 267 **)	1334 0 *)	1514 180 **)
	total	2161 1446 *)	2001 1285 **)	1669 924 *)	1825 1081 **)	1595 261 *)	1735 401 **)
Location		Wroclaw					
Annual costs [PLN]	heating	1142	890	705	605	153	119
	cooling	886 0 *)	939 54 **)	930 0 *)	1098 168 **)	1553 0 *)	1655 102 **)
	total	2028 1142 *)	1829 943 **)	1635 705 **)	1703 773 **)	1706 153 **)	1774 221 **)

*) it was assumed that the existing residential buildings were not cooled
**) the demand for cooling in climate c+1,5 is the difference in computational demand and demand for climate c0
Source: author's own work.

The analysis of the results shown in table 3 indicates a growing share of cooling costs with an increase in outdoor temperature of 1.5°C. Cooling cost of the conventional house account for 43-51% of total costs, in the low-energy building 55-64% and in the passive house 87-93%.

The lowest level of CO_2 emission was achieved in low energy-houses (in all considered cases) and it was about a dozen percent smaller than in the passive building and about 10% lower than in the conventional building. In buildings located in Bialystok, in all cases CO_2 production increased due to global warming (by 1.5°C) and amounted to 3.9-10.2%. In the low-energy and passive building in Wroclaw, CO_2 emissions also increased, but in a lower percentage than in buildings in Bialystok (0.2-4.8%). In contrast, in a conventional building in Wroclaw, the CO_2 emission decreased slightly (by 1.1%). The reasons for this situation should be sought not only in the change in the structure and amount of energy consumption, but also in the different level of unitary emission of various fuels.

Figure 2. CO_2 emission in a single-family house (LEB: low-energy; PB: passive building, CB: conventional building) located in Bialystok and Wroclaw, in various climate conditions



Source: author's own work.

Conclusions

The study has been focused on the influence of various climate conditions on energy consumption for heating and cooling a single-family house.

The results of the research confirmed the high impact of the location of the building, and thus the climatic conditions for the demand for usable energy for heating and cooling. Differences between individual locations can reach over 40%. Despite the diversity of climatic conditions in Poland, the requirements for thermal protection of buildings are uniform all over the territory of our country. To erect a building with the same heat consumption, more thermal insulation or energy-efficient solutions must be applied in cooler regions of Poland in comparison to the warmer ones.

The results also reveal what effects global warming has on buildings. An increase in the external air temperature by 1.5°C decreases the energy demand for heating by 9.1-10.9% in a conventional building, by 12-14.2% in low-energy building and by 15.4-22.2% in a passive building. The demand for cooling increased by approx. 20% in buildings located in Bialystok and approx. 7% in buildings located in Wroclaw. However, not always does the economic and ecological efficiency goes together with changes in the demand for heating and cooling energy. These efficiencies depend on the type of fuels used in the building and the price relations between them.

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