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The Effect of Lowering Indoor Air Temperature on the Reduction in Energy Consumption and CO_2 Emission in Multifamily Buildings in Poland

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Abstract: This article analyzes the possibility of reducing the energy consumption from building heating as a result of lowering the indoor air temperature, which is recommended as a response to the energy crisis. Various values of the set-point temperature (16–22 °C), as well as different scenarios for their changes, were assumed for analysis. Changes in clothing that were determined to maintain the same level of thermal comfort after a temperature change were determined. The associated reduction in CO_2 emissions emitted into the atmosphere was determined. The effect of reducing CO_2 emissions was studied depending on the type of heating source. Simulation calculations were carried out for an exemplary multifamily building. The effect of different building insulations required in Poland over the years 1964–2022 was considered. Analyses were performed for the climatic conditions of cities located in different climatic zones of Poland: Koszalin, Wroclaw, Warsaw, Bialystok, Suwalki. Depending on the scenario, the insulation standard of the building, and the variant of location, the energy reduction achieved ranges from 6.6%/K to 13.2%/K. Taking into account the type of heating source, the reduction in CO_2 emissions is from 0.7 to 7.5 $kgCO_2/(K{\cdot}m^2)$. The reduction in temperature by 1 or 2 K can be compensated for by wearing an additional sleeveless vest (0.12 clo) or sweater (0.28 clo).

Keywords: energy crisis; energy savings; reduction of emission; thermal comfort

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1. Introduction

The energy crisis of 2022/2023 [1,2], caused by Russia's aggression in Ukraine, Poland's and Europe's dependence on gas and other fossil fuels, and Russia's aggressive energy policy, made ad hoc methods of saving energy, especially natural gas, a particularly important topic. Fearing shortages of natural gas and electricity, authorities [3,4] made numerous appeals regarding the need to reduce the consumption of heat and electricity by, for example, lowering the indoor air temperature in apartment buildings during the heating period, even if this would result in a decrease in the thermal comfort of residents. The energy and ecological awareness of Poles is growing systematically [3]. It cannot be denied that the economic factor also plays a very important role. Constant fluctuations and the growing trend of fuel, heating, and electricity prices are becoming more and more acute, and the ongoing war only deepens this problem. All of this leads to the search for solutions to reduce growing bills. An effective motivator of the desire to save energy was the recent increase in the prices of natural gas and electricity [4], which had a significant impact on household budgets.

An additional positive effect of reducing energy consumption on the microclimate will be the reduction in air pollutant emissions, which, given the scale of the energy needs of the housing sector, may have a significant impact on the quality of outdoor air and the condition of the natural environment.

1.1. Energy Consumption in the Residential Sector in Poland and the EU

The GUS (Polish Central Statistical Office) report "Energy consumption in households in 2021" [5] reports that the share of households contributing to the national energy consumption was 20.2%. The average consumption per capita was 24.6 GJ with the European average of 24.5 GJ. In all, 65.1% of this energy was used for building heating, and this value decreased by 3.7% compared to 2012.

The dominant heating method for Polish buildings in 2021 was district heating (52.2% in 2021, an increase of 10.7% compared to 2012). The share of natural gas in 2021 was 14.6% and has increased by 5.8% since 2012. At that time, there was also a several-fold increase in the share of heat pumps, from 0.05% to 0.69%. On the other hand, the shares of hard coal and firewood decreased significantly, respectively from 40.8% to 20.9% and from 40.0% to 20.7% [6].

A typical urban household is defined as a household in a multifamily building heated with district heating (49.1% of all domestic households and 72.6% for urban households in 2021) [5].

A typical rural household is defined as a household in a single-family house heated with solid fuel (21.6% of all domestic households and 66.8% of households in rural areas in 2021) [5].

1.2. CO_2 Emission in Poland

The main source of anthropogenic origin air pollutant emissions in 2020 in Poland was, as in previous years, combustion processes of fuels from stationary sources: the energy production and transformation sector, industry and small combustion sources (mainly households), and a significant part of the emissions was also generated by transport [7].

The volume of CO_2 emissions (excluding emissions related to biomass) in Poland in the years 2008–2016 did not change significantly and increased from 316 (in 2014) to 340 (in 2010) million tons annually, and about 14% of them were CO_2 emissions from households [8].

1.3. Possibilities to Reduce Energy Consumption and Pollutant Emissions of Building Heating

Reducing energy consumption in buildings is an issue widely discussed in the literature. The possibility of reducing energy consumption in residential buildings is an important issue and is often discussed in the literature on energy usage in buildings. Ref. [9] compares the calculation methods for determining the building energy demand for heating with the measured heat consumption, while [10] presents the impact of the results of the building blower door test on energy consumption.

Ref. [11] presents an overview of solutions in ventilation systems that have the potential to reduce energy consumption in buildings, such as demand-dependent ventilation, decentralized ventilation, ground heat exchangers, and heat recovery exchangers.

Ref. [12] presents the possibility of using mechanical ventilation exhaust air to increase the efficiency of the heat pump and thus reduce energy consumption for building heating and preparing domestic hot water. The impact of a similar solution for an air conditioner was presented in [13], showing the possibility of reducing energy consumption for the heating and cooling of buildings.

Refs. [14–18] present the possibilities of reducing energy consumption for the heating purposes of a building by using a system for the recovery of heat from gas radiators.

However, these are solutions whose implementation takes time and in a situation such as the current energy crisis, [1,2] are difficult and often impossible to implement quickly. A possible solution that could have immediate effects is a change in the way buildings and their installations are used, in particular, by changing microclimate parameters to values outside the standard range but still acceptable by residents, resulting in reduced building energy consumption [19,20]. The analysis presented in [19] indicates a significant reduction in the heating energy demand of the building in the case of lowering the indoor air temperature even by 1 K.

1.4. Design Values of Indoor Air Temperature in Poland

For buildings located in Poland, when designing heating installations, the indoor air temperature is assumed according to the regulation [21]. The heating system must be designed in such a way that during the occurrence of design outdoor air temperatures (ranges from −24 °C to −16 °C, depending on the climate zone of Poland [22]) it should be able to maintain, for example:

- a temperature of 20 °C for rooms intended for the permanent residence of people without external clothing, not performing continuous physical work (for example: living rooms, halls, individual kitchens equipped with gas or electric hearths),
- a temperature of 24 °C for rooms intended for undressing and for unclothed people (for example: bathrooms).

Furthermore, the regulation in [21] stipulates that when designing ventilation and air conditioning installations, the parameters of indoor air must comply with the PN-78/B-03421 standard [23]. This determines the indoor air temperature and relative humidity, maximum air flow velocity in zones intended for the permanent residence of people, depending on the season (summer, winter) and physical activity of residents. In the winter season, indoor air temperature values are set at 15–18 °C, 18–20 °C, 20–22 °C for high, medium, and low activity, respectively.

1.5. Indoor Air Operating Temperatures

The operating indoor air temperatures in apartments may differ from the design values. Reductions may be implemented to decrease energy consumption at night, in the absence of residents, or reductions suggested during the energy crisis of 2022–2023 owing to possible shortages of natural gas and electricity in the national grid.

However, lowering the indoor air temperature should not be excessive. air temperatures that are too low can reduce gravitational ventilation efficiency, create water condensation on the inner surfaces of external building constructions, and cause user discomfort. The relationship between the need to maintain the thermal comfort of the residents of the building and the energy efficiency of its heating system is a current topic discussed in the literature [19,20,24].

Regulation [21] specifies that in Poland, heat supply controllers should allow users to obtain a temperature in apartments lower than the design indoor air temperature, but not lower than 16 °C in rooms with a design indoor air temperature of 20 °C or higher.

In the literature, reductions to various values of indoor air temperatures are analyzed. In [20], simulations of the impact of HVAC installation settings on the energy demand for the heating and cooling of the building were carried out. The indoor air temperature range was analyzed in the heating mode with values between 17–22 °C during the exploitation hours and values between 14–17 °C outside the exploitation hours. The analyses were conducted for a typical office building in seven climate zones in the US, and their results indicated differences in building energy demands. Ref. [19] analyzed the impact of the reduction in indoor temperature on the demand for heating energy and the costs of this energy in the era of the energy crisis. For three cities in Italy, simulations were carried out for temperatures between 18–22 °C in bathrooms and 18–20 °C in the rest of the rooms. The analyses were carried out for two heat generation systems: one based on an air-to-water heat pump and another on a natural gas boiler.

The indoor air temperatures measured during operation were presented in [25] for the rooms of the educational building and in [26] for several residential apartments. Ref. [26] analyzed the impact of user behavior resulting from the desire to save money or reduce excessive energy consumption, as well as energy poverty or technical limitations, on indoor air temperature and energy consumption for building heating. The results of continuous measurements of the indoor air temperatures recorded in the period from 14 January 2020 to 8 March 2020 were presented in 18 apartments heated with various heat sources and energy carriers. The data presented demonstrated that the operating temperatures maintained by users are sometimes lower than the typical range of thermal comfort. In some apartments, indoor air temperature drops to an average value of approximately 16 °C were observed, and the lowest recorded temperature in the bathroom was 13 °C. However, the highest average indoor air temperature values in the tested apartments were around 22 °C.

1.6. Research Gap and the Aims of the Paper

A review of the literature shows that, apart from long-term measures such as designing and building energy-efficient buildings and heating installations, as well as the standard periodic reduction in indoor air temperature outside the period of use of apartments, as a response to energy crises, it is possible for residents to set apartment temperatures outside the typical parameters of thermal comfort. In the case of a permanent reduction in indoor air temperature, in addition to determining possible energy savings, it is also important to determine the resulting reduction in CO_2 emissions. It is also important to indicate actions that allow the maintenance of similar levels of thermal comfort despite a decrease in temperature. It is obvious that the fulfillment of this condition can be realized by changing the behavior of users—wearing thicker clothing indoors.

The publications presented do not consider this issue comprehensively. They do not specify at the same time:

- what level of reduction in energy consumption can be achieved at a given indoor temperature reduction, depending on the features of buildings such as the standard of thermal insulation of the building envelope or the climate conditions of Central and Eastern Europe,
- what level of reduction in CO_2 emissions can be caused by these reductions in energy need, depending on the type of heat source of the building,
- to what level clothing insulation should be increased at a given temperature reduction to not to decrease thermal comfort.

Because of the existing potential for energy savings, a broader look at the usage of apartments during the ongoing energy crisis is needed in the context of the need to reduce the consumption of natural gas and electricity in the face of its possible outage or significant reduction in supplies. It is also important to identify additional positive effects such as reducing the consumption of fossil fuels or reducing CO_2 emissions. Therefore, the aim of the work is as follows:

- verification of popularly used indicators of possible reductions in energy needs for heating related to a 1 K reduction in indoor temperature,
- determination of the impact of different scenarios of changes in indoor air temperature in residential buildings with different standards of thermal insulation of the building envelope, different ventilation rates, and internal heat gains on the change in energy need for building heating in moderate climate conditions, using the example of Polish climate zones,
- determination of the reduction in CO_2 emissions into the atmosphere as a result of these reductions, analyses to be performed for the cases indicated above, and different types of heat sources to be considered,
- indication of exemplary clothing changes that enable the maintenance of the desired thermal comfort of residents at lower indoor air temperatures.

2. Materials and Methods

In Figure 1, the framework for the analysis presented in the article is shown. Detailed descriptions of the particular methods are presented in the following sections.

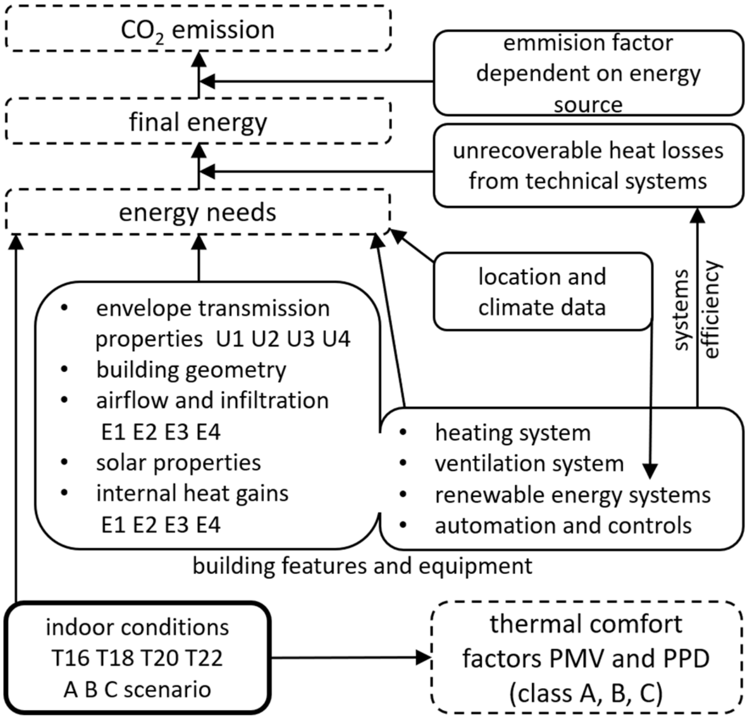

Figure 1. Framework for the presented analysis.

2.1. Influence of Lowering Air Temperature in the Room on Thermal Comfort

The thermal comfort model created by Fanger [27] described in PN-EN ISO 7730 [28] allowed us to assess the possibility of lowering the air temperature in the room according to the feeling of thermal comfort of the users. These methods have been widely used in the literature [29–32]. Using the relations presented in [28], an exemplary effect of the air temperature in the room on the parameters of thermal comfort *PMV* (Predicted Mean Vote) and *PPD* (Predicted Percentage Dissatisfied) with constant thermal insulation of the clothing set of occupants 1 clo (shorts, shirt, trousers, jacket, socks, shoes—typical for the winter season according to [28]) and their constant activity 1.2 met (sitting activity, place of residence according to [28]) was determined. Radiation temperature of 1 °C lower than the air temperature in the room, constant relative air humidity in the room of 40%, and constant air speed in the room of 0.1 m/s were assumed.

Ref. [28] distinguishes 3 categories of thermal environment, where the values $PPD < 6\%$ and $-0.2 < PMV < 0.2$ are for class A, $PPD < 10\%$ and $-0.5 < PMV < 0.5$ are for class B, $PPD < 15\%$ and $-0.7 < PMV < 0.7$ are for class C. *PPD* and *PMV* are calculated as follows:

$$PPD = 100 - 95 \cdot exp\left(-0.03353 \cdot PMV^4 - 0.2179 \cdot PMV^2\right) \tag{1}$$

$$PMV = [0.303 \cdot exp(-0.036 \cdot M) + 0.028] \left\{ \begin{array}{c} (M-W) - 3.05 \cdot 10^{-3} \cdot [5733 - 6.99 \cdot (M-W) - p_a] - 0.42 \cdot [(M-W) - 58,15] \\ -1.7 \cdot 10^{-5} \cdot M \cdot (5867 - p_a) - 0.0014 \cdot M \cdot (34 - t_a) \\ -3.96 \cdot 10^{-8} \cdot f_{cl} \cdot \left[(t_{cl} - 273)^4 - (\overline{t_r} - 273)^4\right] - f_{cl} \cdot h_c \cdot (t_{cl} - t_a) \end{array} \right\} \tag{2}$$

$$t_{cl} = 35.7 - 0.028 \cdot (M-W) - I_{cl} \cdot \left\{3.96 \cdot 10^{-8} \cdot f_{cl} \cdot \left[(t_{cl} + 273)^4 - (\overline{t_r} - 273)^4\right] + f_{cl} \cdot h_c \cdot (t_{cl} - t_a)\right\} \tag{3}$$

$$h_c = \begin{cases} 2.38 \cdot |t_{cl} - t_a|^{0.25} \text{ for } 2.38 \cdot |t_{cl} - t_a|^{0.25} > 12.1 \cdot \sqrt{\vartheta_{ar}} \\ 12 \cdot \sqrt{\vartheta_{ar}} \text{ for } 2.38 \cdot |t_{cl} - t_a|^{0.25} > 12.1 \cdot \sqrt{\vartheta_{ar}} \end{cases} \quad (4)$$

$$f_{cl} = \begin{cases} 1.00 + 1.290 \cdot I_{cl} \text{ for } I_{cl} \le 0.0078 \text{ m}^2 \cdot \text{K/W} \\ 1.05 + 0.645 \cdot I_{cl} \text{ for } I_{cl} > 0.0078 \text{ m}^2 \cdot \text{K/W} \end{cases} \quad (5)$$

where:

M—metabolism rate, from 46 to 232 W/m^2 (from 0.8 to 4 met)
W—external work, W/m^2
I_{cl}—thermal insulation of clothing, from 0 to 0.310 m^2·K/W (from 0 to 2 clo)
f_{cl}—clothing area factor
t_a—air temperature, from 10 °C to 30 °C
$\overline{t_r}$—from 10 °C to 40 °C
ϑ_{ar}—from 0 to 1 m/s
p_a—from 0 to 2700 Pa
h_c—heat transfer coefficient by convection
t_{cl}—surface temperature of clothing, °C

2.2. Influence of Lowering the Air Temperature in the Building on Energy Consumption and CO_2 Emissions

To determine the impact of lowering the maintained air temperature in the building on energy consumption for heating purposes, usable energy calculations were carried out for a selected multifamily residential building. The calculations were carried out for decreases in various constant values of the internal temperature. Additional temperature reductions during the night and during the day were also analyzed. The influence of the building location, different building envelope insulation standards, and different operating variants (internal heat gains, ventilation air volume) on different scenarios of temperature reduction were taken into account.

2.2.1. Parameters and Location of the Analyzed Building

Regardless of the calculation variant, the following assumptions were made regarding the analyzed building:

- Multifamily building, 5 floors, 3 apartments per floor, basement. Ground floor plan according to Figure 2. Two heated calculation zones (residential part: volume of 2220 m^3, area of 888 m^2; staircase—volume of 188 m^3 and an area of 75 m^2).
- No external shades.
- The solar radiation transmittance coefficient of the glazing g = 0.75, glazing in the windows C = 0.7.
- The regulated temperature in the residential part was calculated as the weighted average of the temperatures in the individual rooms shown in Figure 2. The temperature on the staircase was set as the resulting temperature.
- Natural ventilation and radiator heating with all radiators under the external walls.
- Solar radiation heat gains and internal heat gains in the building were also included.

Contrary to the parameters presented above, the values of the heat transfer coefficients for individual partitions of the building (variants of the thermal insulation standards of the building envelope according to Table 1 were assumed) and the location of the analyzed building (Table 2) were changed in the calculations.

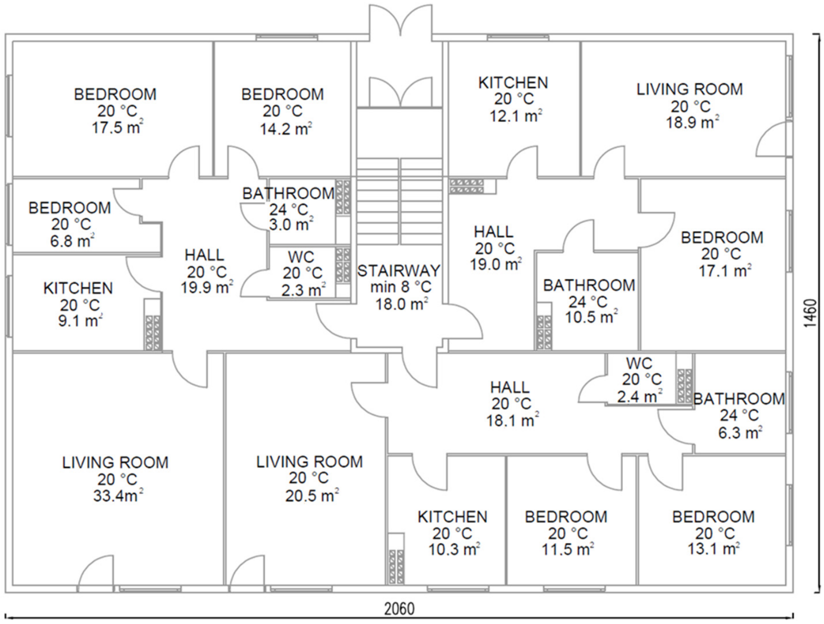

Figure 2. Ground floor plan.

Table 1. Heat transfer coefficients taken for analysis for individual calculation variants (for design indoor air temperature above 16 °C).

Construction Variant	Regulations	External Wall	Roof	Ceiling of the Unheated Basement	Windows
		W/(m^2 K)	**W/(m^2 K)**	**W/(m^2 K)**	**W/(m^2 K)**
U1	Technical and construction regulations (2021) [21]	0.20	0.15	0.25	0.90
U2	Technical and construction regulations (2002) [21]	0.30 $^{(3)}$	0.30 $^{(3)}$	0.60 $^{(3)}$	2.0 $^{(1)}$/2.6 $^{(2)}$
U3	PN-82/B-02020	0.75	0.45	1.16	2.0 $^{(1)}$/2.6 $^{(2)}$
U4	PN-64/B-03404	1.16	0.87	1.16	- $^{(4)}$

$^{(1)}$ I, II, III climatic zone; $^{(2)}$ IV, V climatic zone; $^{(3)}$ as for a single-family building and a layered outer wall; $^{(4)}$ no requirements, taken for analysis 3.0 W/(m^2 K).

Table 2. Outdoor air temperatures depending on location [33].

Location	Outdoor Air Temperature from June to September			Average Daily Global Radiation
	Minimum	**Maximum**	**Seasonal Average**	
-	°C	°C	°C	Wh/day
Koszalin	−16.5	27.1	4.5	1604
Wroclaw	−18.8	24.0	4.2	1953
Warsaw	−12.3	24.5	4.2	1870
Bialystok	−17.6	26.9	2.9	1709
Suwalki	−26.2	27.3	2.1	1634

The analyses presented in the article were carried out for five cities located in Poland. Poland is divided into five climatic zones (I, II, III, IV, and V) [22]. The design outside air temperatures used in the design of building heating systems are, respectively, −16 °C, −18 °C, −20 °C, −22 °C, −24 °C. Cities selected for analysis: I—Koszalin, II—Wroclaw (Wro), III—Warsaw (War), IV—Bialystok (Bia), V—Suwalki (Suw). Official climatic data for determining the energy performance of buildings in Poland published in [33] were used. In Table 2 a summary of the minimum, average, and maximum values of outdoor air temperatures (excluding the months from June to September) and the values of average daily global radiation are presented in individual locations.

2.2.2. Calculation Scenarios

Analysis of the impact of the operating air temperature in the building was carried out by calculations of energy need using the hourly method according to the European standard PN-EN ISO 13790 [34], national methods [35] in terms of estimated heat gains for the set-point scenarios, the temperature schedule scenarios, and the building operation scenario.

Temperature set-point scenarios with reduced constant temperature (except for bathrooms):

T16—16 °C temperature set point, T18—18 °C temperature set point, T20—20 °C temperature set point (baseline scenario), T22—22 °C temperature set point.

Temperature schedule scenarios:

A. Constant reduction—constant temperature in apartments during the heating season according to scenarios T16, T18, T20, T22; temperature in bathrooms set to 24 °C for all scenarios.
B. Night reduction—at night (hours 23:00–5:00) the temperature in apartments (except in bathrooms) lowered by 2 K relative to the temperatures in scenarios T18, T20, T22; temperature in bathrooms set to 22 ° C for all scenarios.
C. Night reduction and during work hours—at night (hours 23:00–5:00) and during working hours (hours 10:00–16:00), temperature in apartments (except in bathrooms) lowered by 2 K relative to temperatures in scenarios T18, T20, T22; temperature in bathrooms set to 22 °C for all scenarios.

Building operating scenarios:

- E1—outdoor air flow and internal heat gains according to the national method to determine the energy performance of buildings [35] equal to $0.32 \cdot 10^{-3}$ $m^3/(s{\cdot}m^2)$ and 7.1 W/m^2, respectively.
- E2—outdoor air flow according to the Polish standard PN-83/B-03430 [36], used to design ventilation systems in residential buildings, equal to $0.47 \cdot 10^{-3}$ $m^3/(s{\cdot}m^2)$ (100 m^3/h for a single apartment, 1500 m^3/h in total), internal heat gains the same as in E1.
- E3—outdoor air flow same as in E1 [35], internal heat gain values and schedules according to the European standard PN-EN 16798-1:2019 [37] for a residential building equal to 2.8 W/m^2 (occupancy), 3.0 W/m^2 (equipment), 10.0 W/m^2 (lighting—assumed), which gives an average of 6.68 W/m^2.
- E4—outdoor air flow is the same as in E2, and internal heat gains are the same as in E3.

2.2.3. Heating System and Heat Source Variants

The internal heating installation in each scenario is the same: central heat distribution in the building and radiators equipped with thermostatic valves as heat receivers, characterized by transmission efficiency $n_{H,d}$ = 0.96 [35] and regulation and heat supply efficiency $n_{H,e}$ = 0.88 [35].

Heat sources with different levels of efficiency of heat generation ($n_{H,g}$) and heat accumulation ($n_{H,s}$) were considered:

1. GB—Gas condensing boiler (70/50°C)—$n_{H,g}$ = 0.91 [35], $n_{H,s}$ = 1.0 [35].
2. CC—coal CHP plant—hard coal, compact district heating substation—$n_{H,g}$ = 0.98 [35], $n_{H,s}$ = 1.0 [35].
3. EAHP—Air/water heat pump, compressor, electrically powered. The SCOP seasonal energy efficiency coefficients were adopted from [38], in which the same climatic

zones of Poland were analyzed and determined according to the EN 14,825 standard for the average climate (A). Adopted accordingly $SCOP_{Wro}$ = 4.15, $SCOP_{Kos}$ = 4.50, $SCOP_{Suw}$ = 3.27, $SCOP_{Bia}$ = 3.61, $SCOP_{War}$ = 4.44. The accumulation efficiency, regardless of the location, was assumed to be equal to $n_{H,s}$ = 0.95 (estimate calculation according to [35]).

2.2.4. CO_2 Emission

Calculations of CO_2 emission into the atmosphere were carried out according to the national method [35]. After determining the demand for the energy need for heating $Q_{H,\ nd}$ for each of the calculation variants, taking into account the efficiency of the heating system and individual variants of heat sources, the demand for the final energy for heating $Q_{k,H}$ of the building was determined for the gas condensing boiler and district heating station, as follows:

$$Q_{k,H} = \frac{Q_{H,\ nd}}{n_{\mathrm{H,g}} \cdot n_{\mathrm{H,d}} \cdot n_{\mathrm{H,s}} \cdot n_{\mathrm{H,e}}} \quad (6)$$

and for the heat pump:

$$Q_{k,H} = \frac{Q_{H,\ nd}}{\mathrm{SCOP} \cdot n_{\mathrm{H,d}} \cdot n_{\mathrm{H,s}} \cdot n_{\mathrm{H,e}}} \quad (7)$$

Then, based on the final energy and emission indicators W_e, published by KOBIZE (The National Centre for Emissions Management) [39,40], the CO_2 emissions were determined as follows:

$$E_{CO_2} = 36 \cdot 10^{-7} \cdot (Q_{k,H} \cdot W_e) \quad (8)$$

for:

- Natural gas W_e = 55.39 tCO_2/TJ
- Combined generation of electricity and heat from hard coal W_e = 93.54 tCO_2/TJ
- Electricity W_e = 196.7 tCO_2/TJ.

3. Results and Discussion

The results of the calculations of the energy need, CO_2 emission, and thermal comfort indicators for the analyzed building are presented below.

3.1. Possibility of Reducing the Indoor Air Temperature

Reducing the air temperature by 1 K from 20 °C to 19 °C lowers the comfort category to category C, further reducing the belief that the lowest category should not be maintained. The significant reduction in the category of thermal comfort may be difficult for users to accept. Therefore, it is necessary to take measures to maintain the category of thermal comfort when lowering the temperature. The simplest solution is to increase the thermal insulation of residents' clothing. Tables 3 and 4 show the relationship between the air temperature in the indoor room and the thermal insulation coefficients I_{cl} required for clothing to maintain the categories of thermal environments B and C. For example, the design temperature of 20 °C for living rooms required by the regulation [21] indicates the comfort category B according to [28]. When the air indoor temperature is lowered from 20 °C by 1 K to 19 °C, an increase in I_{cl} of 0.14 clo is needed to maintain category B (for a sleeveless vest, I_{cl} is 0.12 clo according to [28]). On the other hand, provided that the reduction of the comfort category to category C is acceptable, the insulation of the clothing may remain the same. When the temperature is lowered to 18 °C, it is necessary to increase I_{cl} by 0.28 clo (for a sweater, I_{cl} is 0.28 clo according to [28]) to maintain category B and by 0.13 clo when category C is acceptable. Reducing the temperature to 16 °C while maintaining category B would require an additional 0.55 clo, the use of outer clothing would be required (for a coat, I_{cl} is 0.60 clo according to [28]) in addition to the standard set of inner clothing for winter. However, with an acceptable reduction in the comfort category to category C (Table 5), an additional 0.38 clo would be sufficient (for a sweater, I_{cl} is 0.28 clo and for underwear, 0.10 clo according to [28]).

Table 3. Relationship between indoor air temperature, *PMV* and *PPD* comfort indicators, and thermal environment category.

No.	t	t_r	φ	v	PMV	PPD	I_{cl}	M	Thermal Environment Category
-	°C	°C	%	m/s	-	%	clo	met	-
1	22	21	40	0.1	0.05	5.04	1.0	1.2	A
2	21	20	40	0.1	−0.17	5.59	1.0	1.2	A
3	20	19	40	0.1	−0.38	8.02	1.0	1.2	B
4	19	18	40	0.1	−0.59	12.36	1.0	1.2	C
5	18	17	40	0.1	−0.80	18.62	1.0	1.2	-
6	17	16	40	0.1	−1.02	27.02	1.0	1.2	-
7	16	15	40	0.1	−1.24	37.18	1.0	1.2	-

Table 4. The relationship between the indoor air temperature and required thermal insulation coefficient of clothing to maintain thermal environment category B.

No.	t	t_r	φ	v	PMV	PPD	I_{cl}	M	Thermal Environment Category
-	°C	°C	%	m/s	-	%	clo	met	-
1	22	21	40	0.1	−0.48	9.74	0.73	1.2	B
2	21	20	40	0.1	−0.47	9.59	0.87	1.2	B
3	20	19	40	0.1	−0.48	9.80	1.00	1.2	B
4	19	18	40	0.1	−0.47	9.71	1.14	1.2	B
5	18	17	40	0.1	−0.46	9.37	1.28	1.2	B
6	17	16	40	0.1	−0.45	9.17	1.43	1.2	B
7	16	15	40	0.1	−0.47	9.67	1.55	1.2	B

Table 5. The relationship between the indoor air temperature and required thermal insulation coefficient of clothing to maintain the thermal environment category C.

No.	t	t_r	φ	v	PMV	PPD	I_{cl}	M	Thermal Environment Category
-	°C	°C	%	m/s	-	%	clo	met	-
1	22	21	40	0.1	−0.69	14.90	0.63	1.2	C
2	21	20	40	0.1	−0.68	14.85	0.75	1.2	C
3	20	19	40	0.1	−0.68	14.66	0.88	1.2	C
4	19	18	40	0.1	−0.67	14.53	1.01	1.2	C
5	18	17	40	0.1	−0.69	14.89	1.13	1.2	C
6	17	16	40	0.1	−0.68	14.81	1.25	1.2	C
7	16	15	40	0.1	−0.68	14.81	1.38	1.2	C

3.2. Changes in Energy Consumption Depending on the Indoor Air Temperature

Tables 6–8 present the results of calculations of demand for usable energy for heating of the analyzed building. Table 6 shows the reduction results for scenario A, Table 7 for scenario B, and Table 8 for scenario C. Each of the tables presents the results of calculations for variants of thermal insulation of the building envelope and different building locations, as well as for individual scenarios of temperature set-point and operating scenarios.

Table 6. Summary of results for reduction scenario A.

Scenario	**A**																**Insulation**
	E1				**E2**				**E3**				**E4**				
	T16	**T18**	**T20 ***	**T22**	**T16**	**T18**	**T20 ***	**T22**	**T16**	**T18**	**T20 ***	**T22**	**T16**	**T18**	**T20 ***	**T22**	
Units	%	%	**kWh/a**	%	%	%	**kWh/a**	%	%	%	**kWh/a**	%	%	%	**kWh/a**	%	
Koszalin	−42.9	−22.7	**34,275**	26.4	−40.3	−21.7	**47,826**	23.6	−38.7	−20.6	**44,235**	22.5	−36.5	−19.0	**58,227**	21.9	**U1**
	−38.8	−20.4	**86,181**	23.3	−37.4	−19.8	**101,591**	22.6	−36.3	−19.4	**98,697**	21.9	−35.3	−18.8	**114,590**	21.5	**U2**
	−36.5	−19.4	**110,851**	22.1	−35.6	−18.9	**126,893**	21.7	−34.7	−18.5	**124,064**	21.2	−34.2	−18.1	**140,694**	20.9	**U3**
	−33.8	−18.0	**174,789**	20.5	−33.5	−17.8	**191,969**	20.2	−32.9	−17.5	**189,813**	19.7	−32.7	−17.4	**207,204**	19.4	**U4**
Wroclaw	−41.3	−21.7	**35,836**	24.1	−38.2	−19.9	**49,513**	21.8	−36.2	−18.9	**45,585**	20.8	−34.4	−17.9	**59,005**	19.7	**U1**
	−37.1	−19.5	**84,704**	21.8	−35.9	−18.8	**99,251**	21.0	−35.2	−18.5	**95,675**	20.5	−34.1	−18.0	**110,246**	20.3	**U2**
	−35.1	−18.4	**107,677**	20.7	−34.1	−18.0	**122,378**	20.6	−33.4	−17.6	**118,742**	20.2	−32.8	−17.4	**133,913**	20.2	**U3**
	−32.6	−17.4	**151,602**	20.1	−32.3	−17.2	**167,595**	19.9	−31.8	−17.0	**164,555**	19.6	−31.7	−16.9	**181,028**	19.4	**U4**
Warsaw	−43.1	−22.9	**33,817**	25.9	−39.9	−21.2	**47,808**	23.4	−37.8	−20.0	**44,327**	22.2	−36.0	−18.8	**58,686**	21.1	**U1**
	−37.8	−19.9	**87,119**	22.5	−36.5	−19.3	**102,914**	21.6	−35.7	−18.9	**99,213**	21.1	−34.8	−18.4	**115,107**	20.1	**U2**
	−36.3	−19.2	**103,320**	21.5	−35.3	−18.6	**119,155**	20.6	−34.7	−18.3	**115,480**	20.0	−33.8	−17.8	**131,571**	19.3	**U3**
	−33.0	−17.3	**159,018**	18.9	−32.3	−16.9	**175,195**	18.5	−31.6	−16.5	**171,584**	18.0	−31.1	−16.2	**188,012**	17.7	**U4**
Bialystok	−35.9	−18.5	**44,269**	20.4	−33.3	−17.3	**59,357**	19.5	−32.1	−16.9	**53,916**	19.0	−30.9	−16.3	**69,238**	17.6	**U1**
	−33.5	−17.7	**90,473**	19.3	−32.5	−17.2	**105,938**	18.5	−32.2	−16.8	**100,452**	18.2	−31.0	−16.2	**116,081**	18.0	**U2**
	−31.8	−16.7	**115,217**	18.2	−30.8	−16.1	**131,035**	18.1	−30.1	−15.6	**125,726**	18.0	−29.2	−15.3	**142,513**	18.1	**U3**
	−28.9	−15.2	**173,658**	18.0	−28.8	−15.3	**192,000**	17.8	−28.4	−15.2	**188,031**	17.5	−28.4	−15.2	**206,843**	17.2	**U4**
Suwalki	−34.1	−17.7	**48,494**	19.3	−31.5	−16.4	**65,253**	17.9	−30.4	−15.9	**59,246**	17.2	−28.8	−14.9	**76,743**	16.0	**U1**
	−31.4	−16.4	**97,477**	17.7	−30.0	−15.6	**115,014**	16.8	−29.5	−15.2	**109,077**	16.5	−28.3	−14.7	**126,552**	16.2	**U2**
	−29.2	−15.0	**125,707**	16.5	−28.2	−14.6	**143,335**	16.3	−27.6	−14.3	**137,206**	16.2	−27.0	−14.1	**155,131**	16.3	**U3**
	−26.7	−14.0	**188,241**	16.4	−26.5	−14.0	**206,827**	16.4	−26.3	−14.0	**201,487**	16.2	−26.3	−14.1	**220,720**	16.1	**U4**

* reference scenario, without reductions—scenario A, temperature 24 °C in bathrooms and 20 °C in other rooms of the building.

Table 7. Summary of results for reduction scenario B.

Scenario	**B**																**Insulation**
	E1				**E2**				**E3**				**E4**				
	T18	**T20**	**T20 ***	**T22**	**T18**	**T20**	**T20 ***	**T22**	**T18**	**T20**	**T20 ***	**T22**	**T18**	**T20**	**T20 ***	**T22**	
Units	%	%	**kWh/a**	%	%	%	**kWh/a**	%	%	%	**kWh/a**	%	%	%	**kWh/a**	%	
Koszalin	−28.3	−6.3	**34,275**	19.1	−26.9	−6.0	**47,826**	17.1	−25.6	−5.7	**44,235**	16.2	−23.8	−5.3	**58,227**	15.8	**U1**
	−25.5	−5.7	**86,181**	16.8	−24.7	−5.6	**101,591**	16.3	−24.2	−5.4	**98,697**	15.8	−23.5	−5.3	**114,590**	15.5	**U2**
	−24.2	−5.4	**110,851**	15.9	−23.6	−5.3	**126,893**	15.6	−23.0	−5.2	**124,064**	15.3	−22.6	−5.1	**140,694**	15.0	**U3**
	−22.4	−5.1	**174,789**	14.8	−22.2	−5.1	**191,969**	14.6	−21.8	−4.9	**189,813**	14.2	−21.7	−4.9	**207,204**	14.0	**U4**
Wroclaw	−27.1	−6.0	**35,836**	17.4	−25.0	−5.6	**49,513**	15.7	−23.7	−5.2	**45,585**	15.0	−22.5	−5.1	**59,005**	14.2	**U1**
	−24.4	−5.4	**84,704**	15.7	−23.6	−5.3	**99,251**	15.1	−23.2	−5.2	**95,675**	14.8	−22.4	−5.0	**110,246**	14.5	**U2**
	−23.0	−5.2	**107,677**	14.9	−22.5	−5.1	**122,378**	14.7	−22.1	−5.0	**118,742**	14.5	−21.7	−4.9	**133,913**	14.4	**U3**
	−21.6	−5.0	**151,602**	14.4	−21.5	−5.0	**167,595**	14.3	−21.2	−4.9	**164,555**	14.1	−21.1	−4.8	**181,028**	13.9	**U4**
Warsaw	−28.4	−6.4	**33,817**	18.7	−26.4	−5.9	**47,808**	16.9	−24.9	−5.6	**44,327**	16.1	−23.6	−5.2	**58,686**	15.2	**U1**
	−24.9	−5.6	**87,119**	16.3	−24.1	−5.4	**102,914**	15.6	−23.6	−5.3	**99,213**	15.3	−23.0	−5.1	**115,107**	14.6	**U2**
	−24.0	−5.4	**103,320**	15.5	−23.3	−5.2	**119,155**	14.9	−22.8	−5.1	**115,480**	14.5	−22.3	−4.9	**131,571**	14.0	**U3**
	−21.7	−4.8	**159,018**	13.6	−21.2	−4.7	**175,195**	13.3	−20.7	−4.6	**171,584**	12.9	−20.4	−4.5	**188,012**	12.7	**U4**
Bialystok	−23.3	−5.2	**44,269**	14.7	−21.8	−4.8	**59,357**	14.1	−21.1	−4.7	**53,916**	13.8	−20.4	−4.5	**69,238**	12.8	**U1**
	−22.1	−5.0	**90,473**	14.0	−21.5	−4.8	**105,938**	13.4	−21.1	−4.7	**100,452**	13.1	−20.3	−4.5	**116,081**	12.8	**U2**
	−20.9	−4.6	**115,217**	13.1	−20.2	−4.5	**131,035**	12.9	−19.6	−4.4	**125,726**	12.9	−19.2	−4.4	**142,513**	12.9	**U3**
	−19.0	−4.4	**173,658**	12.8	−19.1	−4.5	**192,000**	12.7	−18.9	−4.4	**188,031**	12.5	−19.0	−4.4	**206,843**	12.4	**U4**
Suwalki	−22.3	−4.9	**48,494**	14.0	−20.6	−4.6	**65,253**	13.0	−19.9	−4.4	**59,246**	12.5	−18.8	−4.1	**76,743**	11.6	**U1**
	−20.5	−4.6	**97,477**	12.8	−19.5	−4.3	**115,014**	12.2	−19.2	−4.2	**109,077**	11.9	−18.4	−4.1	**126,552**	11.7	**U2**
	−18.9	−4.2	**125,707**	11.9	−18.4	−4.1	**143,335**	11.7	−18.0	−4.0	**137,206**	11.6	−11.2	3.0	**155,131**	11.6	**U3**
	−17.5	−4.0	**188,241**	11.7	−17.5	−4.0	**206,827**	11.7	−17.5	−4.0	**201,487**	11.6	−17.5	−4.1	**220,720**	11.5	**U4**

* reference scenario, without reductions—scenario A, temperature 24 °C in bathrooms and 20 °C in other rooms of the building.

Table 8. Summary of results for reduction scenario C.

Scenario	C																Insulation
	E1				E2				E3				E4				
	T18	T20	T20 *	T22	T18	T20	T20 *	T22	T18	T20	T20 *	T22	T18	T20	T20 *	T22	
Units	%	%	kWh/a	%	%	%	kWh/a	%	%	%	kWh/a	%	%	%	kWh/a	%	
Koszalin	−32.1	−10.6	**34,275**	14.2	−30.3	−10.1	**47,826**	12.6	−29.0	−9.7	**44,235**	12.0	−27.1	−8.9	**58,227**	11.7	U1
	−29.0	−9.6	**86,181**	12.4	−28.0	−9.3	**101,591**	12.0	−27.4	−9.2	**98,697**	11.6	−26.5	−8.9	**114,590**	11.4	U2
	−27.4	−9.1	**110,851**	11.7	−26.7	−8.9	**126,893**	11.5	−26.1	−8.7	**124,064**	11.3	−25.6	−8.6	**140,694**	11.1	U3
	−25.4	−8.5	**174,789**	10.9	−25.1	−8.4	**191,969**	10.8	−24.8	−8.3	**189,813**	10.5	−24.6	−8.2	**207,204**	10.4	U4
Wroclaw	−30.7	−10.1	**35,836**	12.9	−28.4	−9.3	**49,513**	11.7	−27.0	−8.9	**45,585**	11.1	−25.7	−8.4	**59,005**	10.5	U1
	−27.7	−9.1	**84,704**	11.6	−26.8	−8.8	**99,251**	11.2	−26.3	−8.7	**95,675**	10.9	−25.5	−8.5	**110,246**	10.7	U2
	−26.2	−8.6	**107,677**	11.0	−25.5	−8.4	**122,378**	10.9	−25.0	−8.3	**118,742**	10.7	−24.6	−8.2	**133,913**	10.7	U3
	−24.5	−8.2	**151,602**	10.7	−24.3	−8.1	**167,595**	10.6	−24.0	−8.0	**164,555**	10.4	−23.9	−8.0	**181,028**	10.2	U4
Warsaw	−32.2	−10.9	**33,817**	13.9	−29.8	−9.9	**47,808**	12.5	−28.3	−9.3	**44,327**	11.8	−26.9	−8.8	**58,686**	11.3	U1
	−28.2	−9.3	**87,119**	12.1	−27.4	−9.0	**102,914**	11.6	−26.8	−8.9	**99,213**	11.3	−26.0	−8.6	**115,107**	10.8	U2
	−27.2	−9.0	**103,320**	11.5	−26.4	−8.7	**119,155**	11.0	−25.9	−8.5	**115,480**	10.7	−25.3	−8.3	**131,571**	10.3	U3
	−24.6	−8.1	**159,018**	10.1	−24.1	−7.9	**175,195**	9.9	−23.6	−7.7	**171,584**	9.5	−23.2	−7.6	**188,012**	9.4	U4
Bialystok	−26.6	−8.7	**44,269**	10.9	−24.8	−8.1	**59,357**	−24.8	−24.0	−7.9	**53,916**	10.2	−23.1	−7.6	**69,238**	9.4	U1
	−25.1	−8.2	**90,473**	10.3	−24.3	−8.0	**105,938**	9.9	−23.9	−7.9	**100,452**	9.7	−23.0	−7.6	**116,081**	9.5	U2
	−23.7	−7.8	**115,217**	9.6	−22.9	−7.6	**131,035**	9.6	−22.4	−7.4	**125,726**	9.5	−21.8	−7.3	**142,513**	9.5	U3
	−21.6	−7.2	**173,658**	9.6	−21.6	−7.2	**192,000**	9.5	−21.4	−7.2	**188,031**	9.3	−21.4	−7.2	**206,843**	9.2	U4
Suwalki	−25.3	−8.3	**48,494**	10.4	−23.4	−7.6	**65,253**	9.6	−15.9	0.0	**59,246**	17.2	−21.4	−7.0	**76,743**	8.6	U1
	−23.3	−7.7	**97,477**	9.5	−22.3	−7.3	**115,014**	9.0	−21.9	−7.1	**109,077**	8.8	−21.1	−6.9	**126,552**	8.6	U2
	−21.6	−7.0	**125,707**	8.8	−20.9	−6.8	**143,335**	8.7	−20.5	−6.7	**137,206**	8.6	−20.1	−6.6	**155,131**	8.6	U3
	−19.9	−6.6	**188,241**	8.7	−19.8	−6.6	**206,827**	8.7	−19.8	−6.6	**201,487**	8.6	−19.8	−6.6	**220,720**	8.5	U4

* reference scenario, without reductions—scenario A, temperature 24 °C in bathrooms and 20 °C in other rooms of the building.

The tables show the absolute values of the demand for usable energy for the baseline scenario (reference scenario, without temperature reductions—scenario A, temperature 24 °C in the bathrooms and 20 °C in other rooms of the apartments) for individual variants of thermal insulation of the building envelope and different locations of the building. However, for individual temperature set-point scenarios and operating scenarios, percentage changes in the demand for usable energy are given in relation to the base scenario.

Furthermore, Figures 3 and 4 present a comparison of the absolute values of the usable energy demand for the reduction scenario A, assuming the operating scenarios E1 (Figure 3) and E4 (Figure 4), with a distinction between individual variants of insulation of the building envelope, different locations of the building, and for individual temperature set-point scenarios.

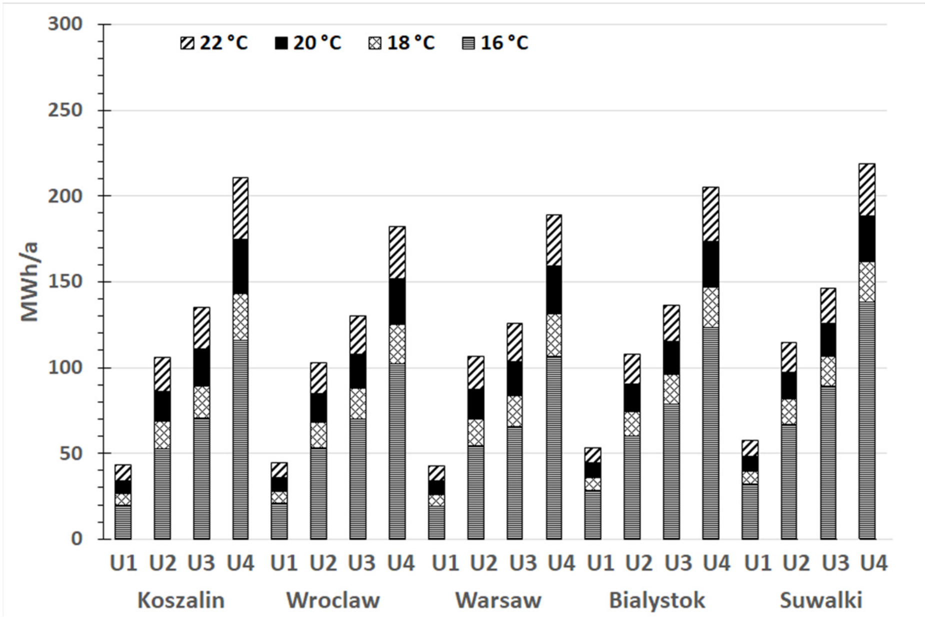

Figure 3. Usable energy demand for building heating of reduction scenario A and operation scenario E1.

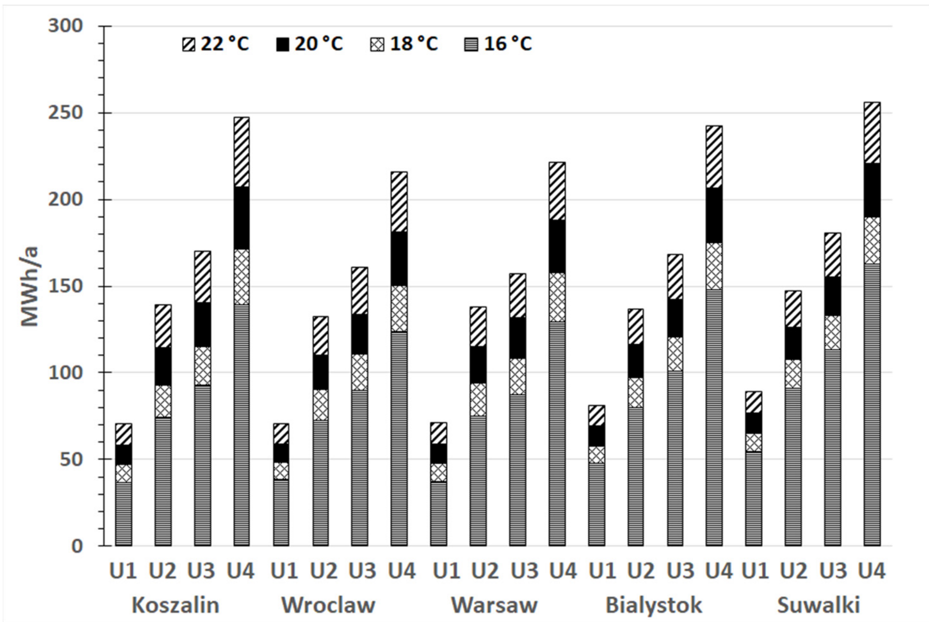

Figure 4. Usable energy demand for building heating of reduction scenario A and operating scenario E4.

Based on the results presented, it was observed that in the baseline scenario, the absolute values of the usable energy demand for heating are the following:

- they increase with the lowering of the thermal insulation standard of the building envelope (variants from U1 to U4),
- they decrease with increasing internal heat gains (operational scenarios from E1 to E4),
- they increase with increasing ventilation air volume (operation scenarios from E1 to E4),
- for the locations of Wroclaw, Warsaw, Bialystok, and Suwalki and variants with low insulation of building envelope U3 and U4, they increase with the increase in the average outdoor temperature, characteristic for the location of the building, in the period from October to May,
- in Koszalin, despite the highest average outdoor air temperatures in the period from October to May, they are lower than in Wroclaw and Warsaw, which indicates the impact of lower solar radiation values in Koszalin compared to other locations.

Energy savings resulting from lowering the internal air temperature, expressed in absolute values of the usable energy demand for heating are the following:

- they increase with the lowering of the insulation standard of the building envelope (variants from U1 to U4),
- they decrease with increasing internal heat gains (scenarios from E1 to E4),
- they increase with the increase in the ventilation air volume (scenarios from E1 to E4).

On the other hand, percentage changes in energy demand related to the baseline scenario are as follows:

- they increase with an increase in the insulation standard of the building envelope (variants from U1 to U4),
- they reach the highest values for scenario E1, lower for E2, even lower for E3, and the lowest for E4,
- in variants with better insulation of building envelope U1 and U2, only in the case of locations with the lowest values of the average outdoor air temperature, Suwalki and Bialystok, are they always the lowest and the second lowest, respectively.

For scenario A, changes in the usable energy demand related to the change in the indoor air temperature by 1 K were obtained, from 6.6%/K to 13.2%/K. In which:

- in the case of a constant increase in indoor air temperature from 20 °C to 22 °C (scenario T22), increases in energy demand from 8.0%/K to 13.2%/K were obtained,
- in the case of a constant decrease in indoor air temperature from 20 °C to 18 °C (scenario T18), a reduction in energy demand from 7.0%/K to 11.4%/K was obtained,
- in the case of a constant decrease in the indoor air temperature from 20 °C to 16 °C (scenario T16) the reduction in the energy demand was obtained from 6.6%/K to 10.8%/K.

3.3. Changes in CO_2 Emission

Figures 5 and 6 show a comparison of CO_2 emissions generated by heating the building with three different heat sources for the reduction scenario A, with two configurations of operating scenarios and different location variants, for which the lowest and highest absolute values and changes in energy demand were observed. Figure 5 presents the results for the Warsaw location and scenario E1 (lowest values), and Figure 6 for the Suwalki location and scenario E4 (highest values).

CO_2 emission values changed in proportion to changes in the demand for usable energy described in Section 3.2.

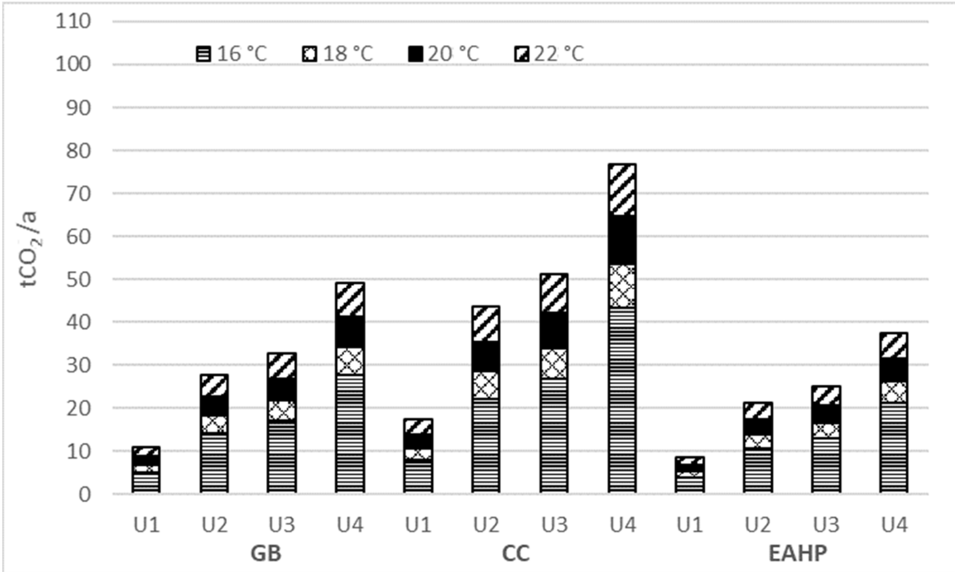

Figure 5. CO_2 emissions for the Warsaw location, reduction scenario A and operation scenario E1, GB—gas condensing boiler; CC—coal CHP plant; EAHP—air-to-water heat pump.

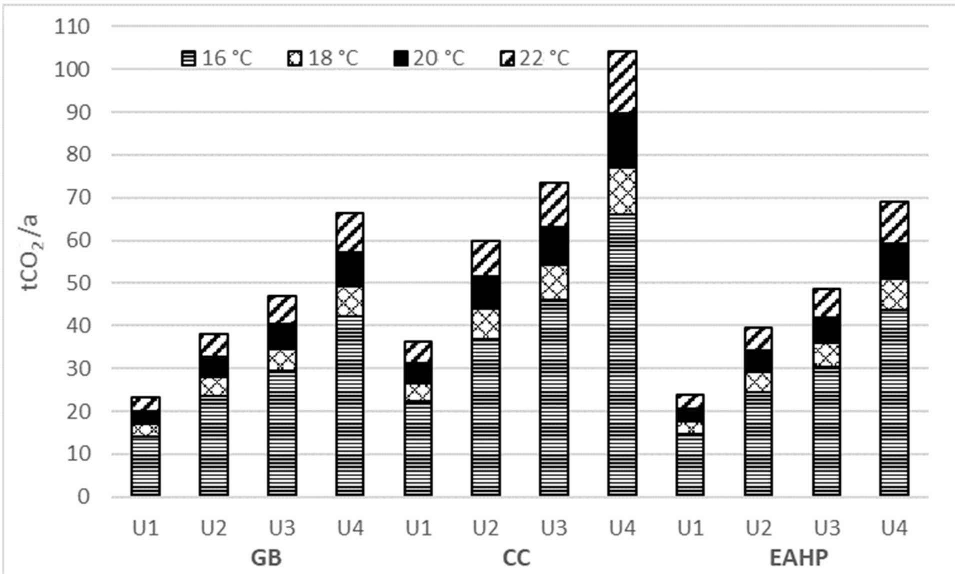

Figure 6. CO_2 emissions for the Suwalki location, reduction scenario A and operation scenario E1, GB—Gas condensing boiler; CC—Coal CHP plant; EAHP—Air-to-water heat pump.

For the cases shown in Figures 5 and 6, changes in CO_2 emissions were obtained per 1 m^2 of the heated area of the building and changes in the internal temperature by 1 K, from 0.7 to 7.5 $kgCO_2/(K{\cdot}m^2)$. In which:

- in the case of a constant increase in temperature from 20 °C to 22 °C (scenario T22), an increase in CO_2 emissions was obtained for:
    - gas boiler from 1.2 to 4.8 $kgCO_2/(K{\cdot}m^2)$,
    - coal CHP power plant from 1.8 to 7.5 $kgCO_2/(K{\cdot}m^2)$,
    - compressor air/water heat pump from 0.9 to 5.0 $kgCO_2/(K{\cdot}m^2)$,
- in the case of a constant increase in temperature from 20 °C to 18 °C (scenario T18) an increase in CO_2 emissions was obtained for:
    - gas boiler from 1.0 to 4.2 $kgCO_2/(K{\cdot}m^2)$,

    - coal CHP power plant from 1.6 to 6.6 $kgCO_2/(K·m^2)$,
    - compressor air/water heat pump from 0.8 to 4.3 $kgCO_2/(K·m^2)$,
- in the case of a constant increase in temperature from 20 °C to 16 °C (scenario T16) an increase in CO_2 emissions was obtained for:
    - gas boiler from 1.0 to 3.9 $kgCO_2/(K·m^2)$,
    - coal CHP power plant from 1.5 to 6.1 $kgCO_2/(K·m^2)$,
    - compressor air/water heat pump from 0.7 to 4.1 $kgCO_2/(K·m^2)$.

4. Conclusions

The presented analyses show that even a slight decrease in the internal air temperature in the building can contribute to a significant reduction in energy demand and CO_2 emissions. For the building analyzed, lowering the temperature by 1 K changed the energy demand for heating from 6.6%/K to 13.2%/K and CO_2 emissions from 0.7 to 7.5 $kgCO_2/(K·m^2)$, depending on the analyzed reduction scenario and variant. Therefore, the work allowed us to verify and systematize the savings reported in the press reports and information folders at the levels of 6%/K and 8%/K [41], 6%/K [42], 6–11%/K [43], making the individual values dependent on the variants analyzed for the location and insulation of the building, as well as the reduction scenarios and the operating scenarios of the building. For older buildings with a lower standard of thermal insulation, the absolute values of energy saved were higher than in the case of newer buildings. On the other hand, savings expressed in percentages related to the base scenario were higher for newer buildings. As expected, the savings achieved were also influenced by factors such as the location of the building, internal heat gains, and ventilation air volumes.

Achieving energy savings by lowering the indoor air temperature may take place at the expense of a decrease in thermal comfort in rooms or while maintaining the same level of thermal comfort, but at the expense of increasing the insulation of clothes. The reduction in the category of thermal comfort caused by the reduction in indoor air temperature by 1 K or 2 K can be compensated for by supplementing the personal wardrobe with, for example, a vest (I_{cl} = 0.12 clo) or a sweater (I_{cl} = 0.28 clo), respectively.

On a national scale, a reduction in the energy consumption in each building, owing to a significant share in the energy balance of the heating needs of households (20.2% [6]), can bring desirable savings in gas and electricity, especially in the era of energy crisis, and thus help avoid discontinuation of their supplies. An additional positive effect of such activities is the reduction in pollutant emissions into the atmosphere. This work offers a broad look at the possibilities of energy savings by reducing the indoor air temperature in residential buildings. However, it can be extended by analyzing other categories of buildings, using different scenarios or dynamic calculation methods.

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