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The Effect of the Temperature Increase on Heat Demand Calculation for Building in the Polish Climatology

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Abstract: Heat demand calculation procedures for buildings are currently being conducted based on the Polish Standard grounded on the European Standard for heat losses methodology. Poland was divided into several climatic zones with given calculations and annual average external air temperature values. In each zone, the technical committee gives the temperature that must be considered. The data included in the Polish Standard preparation concern several years backwards. However, throughout the previous years, we have observed the tendency of the temperature to increase throughout the year, not only in Poland. The phenomenon provides scientists with the conclusion that the temperatures will continue to increase yearly. The low temperatures in the winter season will no longer occur. Therefore, it is necessary to analyse the possibility of lowering the heat demand calculation, including the actual prevailing temperature values. The study was conducted regarding possible economic benefits for the building users due to the lower temperature difference between the internal and external temperatures. Three types of heating systems were analysed. The calculations were conducted for air to water heat pump, pellet boiler and gas condensing boiler, proving that regarding the actual meteorological data, the average annual cost reduction will be in the range of 858 PLN to 1,035 PLN.

Keywords: temperature change, heat demand, global warming, economics, heat pumps

1. Introduction

In recent years, external temperatures in Poland have undergone notable changes, prompting a closer examination of their implication on the selection of heat sources and associated operating costs. This article delves into the evolving climate dynamics of Poland and explores consequential considerations for optimal heating solutions and financial considerations. The history of design temperature standards for heating in the Polish region was extensively described by Narowski (Narowski 2011) in his work. As stated, the first articles on heating were published in 1817, but in 1836 Koncewicz (Koncewicz 1836) wrote an article that considered the impact of climate on the materials used to construct the new building to overcome coldness and humidity. The first work on heat loss calculations was published at the beginning of the twentieth century. Orębowicz (Orębowicz 1913) in 1913 assumed the exterior design temperature at -30°C. Then, a book by Wójcicki (Wójcicki 1929) showed that in 1929, -25°C was the lowest design temperature; since then, the external design temperatures described in the studies have varied. In 1929 Dawidowski, as described by Narowski (Narowski 2011), presented, in table format, corrections to the average outside air temperature for 86 Polish cities, taking into account the appearance of occasional frosts. The first map that divided Poland into climatic zones was published in 1934 as a Polish standard (PN/B-102), as shown by Narowski (Narowski 2011). The Polish region was divided into several zones with the lowest design temperature -25°C as zone IV for the foothill and mountain areas with an altitude above 600 m above sea level and the highest temperature -15°C located on the coast of the Baltic Sea as zone I. Rodowicz's studies (Rodowicz 1932), which were the basis for creating the first temperature divisions, included a formula to determine the design temperature. The mean between the lowest average daily temperature and the absolute minimum temperature increased by 10°C. In several articles, Mielnicki (Mielnicki 1954, 1958) has justified the increase, among others, due to the cessation of winds during severe frosts or the phenomenon of thermal inertia of buildings. The adoption of external temperatures that were too low was discussed in 1936 by Nierojewski (Nierojewski 1936) during the first heating congress. At that time, the design external temperatures were questioned as to whether they were too low and whether they would not provide too large reserves considering the frequency of their occurrence. After World War II, in 1946, the division of the territory of the Republic of Poland into climatic zones was updated, taking into account new borders and based on collected meteorological data. The new division introduced five zones: zone I -15°C, zone II -18°C, zone III -20°C, zone IV -23°C and zone V -25°C (PN-50/B-02403,1950). Ten years later, in 1957, a new edition of the standard PN-57/B-02403 (1957) was published, in which six climatic zones were shown on the Polish map. It was decided to increase the lowest temperatures by just one degree in some zones, showing the lowest temperature as -24°C and the highest as -14°C. The next update of the standard took place in 1974 when the map of Poland showed the division into five climatic zones, which have not changed to the present day. Interestingly, one outside design temperature -20°C was introduced for all zones, and a multiplier was used to differentiate temperatures between zones, which ranged from 0.9 to 1.1. The introduction of the multiplier resulted in incorrect calculations of the external temperatures because of their dependence on the internal temperatures. In 1982, a new standard PN-B-02403:1982 (1982) was published in which the five preserved climate zones of 1974 were assigned design temperatures with design values of max -24°C and min -16°C. The current European standard PN-EN 12831:2006 (2006), published in 2004 and updated in 2006, has not changed the division of Poland into climatic zones and the calculated external temperatures assigned to them.

Outdoor temperatures used by designers to calculate the heat demand for buildings have not been updated for 41 years despite detailed climate data collected by the Institute of Meteorology and Water Management (IMGW) since 1951. Each year, the institute publishes detailed data covering 350 stations (70 synoptic and 280 climatological) since the year the stations were launched. Annual, seasonal, and monthly bulletins are prepared based on operational data from selected monitoring stations. They contain detailed analyses of selected meteorological and hydrological aspects in a given period, including atmospheric circulation, solar, thermal, and precipitation conditions, sea level, and weather extremes. Detailed meteorological data is also collected by the vast majority of countries in the world, making it possible to prepare global reports that analyse meteorological changes worldwide. In 1990, the First Assessment Report (FAS) of the Intergovernmental Panel of Experts on Climate Change (IPCC) was published.

Subsequently, each report stated that the Earth's climate has been changing since the mid-19th century at an unprecedented rate and that progressive global warming threatens the well-being of the planet, its ecosystems, and human life (IMGW 2022). According to Prof. Zbigniew Ustrnul and his team, who work on Polish Climate Monitoring Bulletins (IMGW 2022), and based on the latest published data, the average area temperature in Poland in 2022 reached 9.5°C and was 0.8°C higher than the annual long-term average according to the climatological normal period 1991-2020. Furthermore, the analysis of the historical series shows that, based on the temperatures since 1851, the air temperature in selected large Polish cities has increased from 1.49°C to 2.30°C. As part of the work on the extensive monograph "Climate Change in Poland" (Falarz 2021), more than 30 Polish climatologists from numerous scientific centres conducted comprehensive research on several issues: how the climate in today's Poland has changed over the last thousand years, how it has changed since regular instrumental measurements (since the end of the 18th century), and what future climate change scenarios look like for Poland. Researchers looked at changes in air temperature, precipitation, and time trends in other climate elements (such as sunshine, wind, and snow cover), circulation and biometeorological indicators, weather types, and atmospheric phenomena. The impact of climate change on the demand for heating and cooling for semi-detached houses was also addressed by New Zealand scientists, who, in their work (Zahra et al. 2023), showed how important it is to take into account current and future climatic conditions in the design and creation of the basis for activities aimed at the resilience of buildings to climate change. Annual heating requirements for the predicted period range from 38% to 15% by 2090 with the 4 kWh/m^2 fall in heating load in Auckland (New Zealand) representing a 71% decrease compared to 2030. The study allowed for the conclusion that warmer climate zones will change from zones dominated by heating to zones dominated by cooling. The temperature rise until 2090 is predicted to be in the range between 2.2°C and 4.8°C and a mean temperature increase of 2.7-5.8°C in summer and 2.4-4.1°C in winter compared to baseline temperature data (1999-2015). A case study by Nematchoua et al. (Nematchoua et al. 2023) was applied to 16 locations in the world, eight desert locations and eight coldest regions, such as the Dallol Desert in Ethiopia and the Alaska State in the USA. Simulation analyses of the potential impact of climate on thermal comfort, heating, and cooling energy were carried out for selected facilities: a school building, a hospital, a hotel, and a residential house. The predictable increase in temperature for cold regions is up to 5.5°C in the next 100 years, influencing the heating load to decrease by up to 15.5%. The coldest regions have the highest annual solar passive heating potential; for example, Antarctica increased from 43.6% to 92.9%, but it also has the highest annual heating energy consumption, from 192.6 kWh/m^2 residential unit to 692.4 kWh/m^2 hotel. Climate change is undeniable and needs to be slowed down, but adaptive solutions must also be developed to adapt. One of the examples of changes is the impact on electricity consumption – less energy will be used to heat buildings in winter and more energy will be needed to air-condition buildings in summer; therefore, increased use of renewable energy sources is one of the key elements to be focused on. Caneles et al. (Caneles et al. 2020), in their study using data from more than a dozen Polish meteorological stations, assessed and quantified long-term changes in temperature trends that affect the operation of renewable energy sources and national power demand. Scientists have shown that increasing external temperatures affect renewable energy sources. On the one hand, it develops the increase in their applications, but on the other, we may observe a reduction in usage of some of them. For example, air source heat pumps (ASHPs) increase operating time and efficiency due to increased external temperatures. However, the production of photovoltaic systems could decrease due to the reduction in the system's efficiency. For wind turbines, higher temperatures in winter reduce the icing effect and their forced shutdown. Congedo et al. (Congedo et al. 2023) concentrated on the effects of ASHP on climate change as the most promising technology to decarbonise the construction sector worldwide. Their analysis of ASHP and Fan Coils (FC) operations was prepared in 26 cities in 18 countries and took into account climate change scenario predictions for 2030, 2050 and 2070 across the globe. The locations were selected considering the diversity of climate: from tropical through continental to polar and alpine. The results for the cold climate with winter regime show an increase in the annual heat pump working hours and will allow ASHP to be used in locations where extremely low winter temperature is not currently allowed. The researchers showed how significantly energy consumption in winter would be reduced for all locations, with the largest differences in Hanoi in Vietnam (-48.24%) and Cairo in Egypt (-39.59%) in 2070. The selected European cities by D'Agostino et al. (D'Agostino et al. 2022), such as Stockholm, Milan, Vienna, Madrid, Paris, Munich, Lisbon, and Rome, show the climatic diversity between them. The future scenario of climate change was analysed until 2060. The energy balance of buildings changes significantly under the influence of weather; heating will decrease by 38-57%, while cooling will increase by 99-380%, depending on the location. The various probability scenarios developed for the next 42 years suggested that the increase in temperature for the city of Milan, Italy, is estimated to be between 1.8 and 4.4°C due to metrological changes and urbanisation. Among the locations studied, several had a colder climate, such as Stockholm, Munich, and Vienna, for which annual space heating was compared between 2018 and 2060, and a decrease of 45%, 50% and 36% was observed, respectively. In addition, researchers analysed the impact of climate change on zero-energy buildings and the use of renewable energy sources, which would also be powered only by electricity. As expected, in all surveyed locations, the PV output increased due to climate change from 3% in Lisbon to 20% in Vienna.

Due to climate changes, environmental protection (Gawdzik et al. 2011), and the increase in external temperatures, the focus would also be included in heat transfer technologies that should be strongly numerically and experimentally analysed. The research is concentrated on areas such as heat exchange enhancement by means of phase change processes, heat exchangers area development (Chatys et al. 2017, Orman et al. 2011) or nanofluids applications (Mukherjee et al. 2023) in order to implement new and more effective solutions. What is more, the investigation includes the progress in modern thermal insulation technologies implementation (Pavlenko et al. 2018) or waste heat recovery and its utilisation (Pilat et al. 2022, Latosińska et. al. 2023, Carsky et. al 2022). Moreover, developing intelligent buildings is crucial in relation to energy management systems and sick building syndrome presence (Krawczyk et. al. 2023). Renewable energy sources allow for achieving the standard of an energy-efficient and ecological heating system in the case of further development in district heating systems (Turski 2018). Therefore, extensive heat storage technology is necessary (Turski et al. 2022) and hybrid systems development with several renewable energy methods cooperation (Stokowiec et al. 2023).

The work aimed to compare the external temperatures in Poland applied in the building heat demand procedure with the actual temperature values that appear and investigate the need to involve meteorological data to increase energy savings in residential buildings.

2. Methodology

2.1. Conducted research and testing device

The analyses involved the calculated building heat demand for a single-family residential two-storey building with a heated area of 106 m^2. The room arrangement is presented in the figure below.

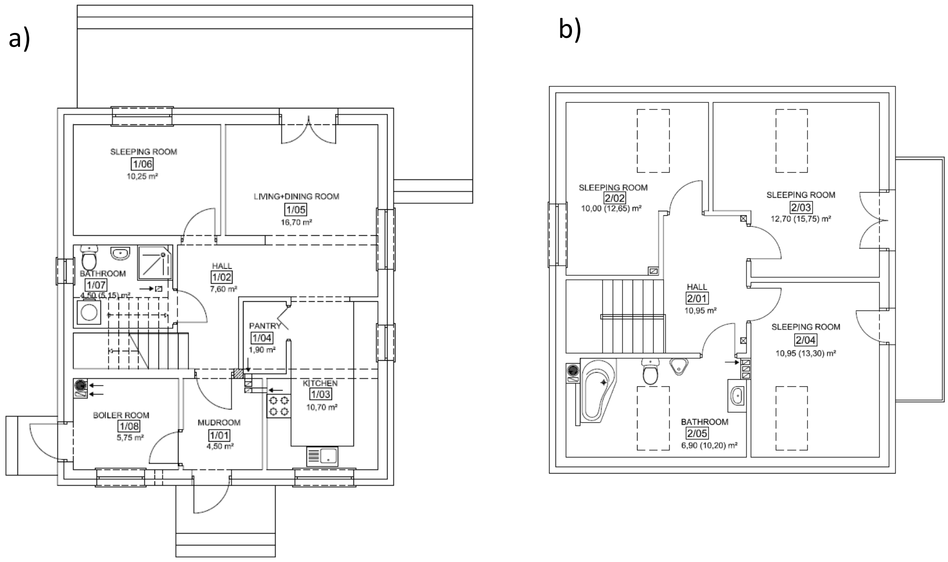

Fig. 1. Analysed building layout: a) first floor, b) habitable attic

The calculations were conducted in each of Poland's climatic zones for winter. Firstly, the considered calculation temperatures (Te) and annual average external air temperatures (Tm,e) values were assumed, as assigned in the Polish Standard (PN-EN 1283, 2006). The comparison included the actual temperature values that have occurred for the previous five years in Poland in each climatic zone read from data presented in the meteorological annual (2018-2022) (Meteorological Annual IMGW 2018-2022). The calculation of external air temperatures was identified as the average value involving the lowest values each month of the heating season (November to April). The differences in the temperature values compared in the calculation procedure are presented in the figure below. The blue lines represent the temperature values according to Polish Standard PN-EN-12831, whereas the red ones read from the meteorological annuals.

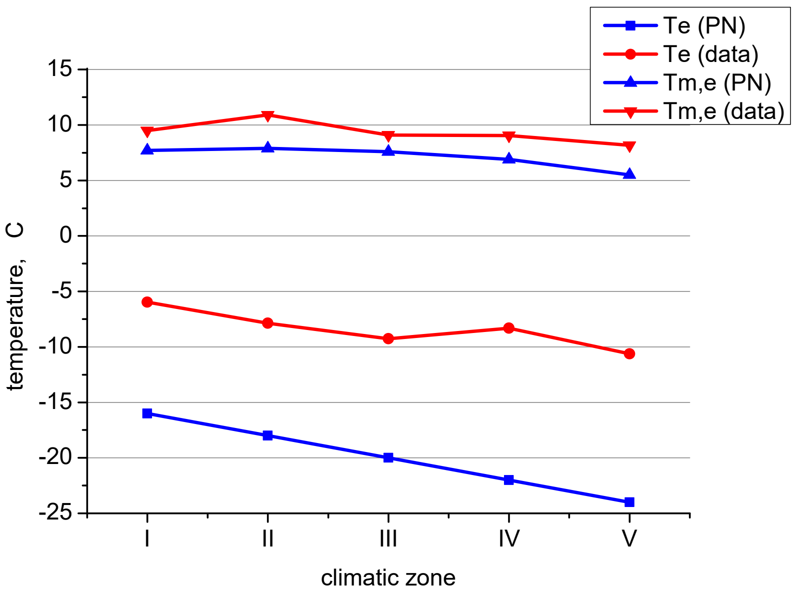

Fig. 2. Temperatures comparison

2.2. Results

The calculations of heat demand were conducted with the present building envelope standard, which means that the heat transfer coefficients for each partition: external wall, internal wall, window, door, floor, roof and ceiling are within the limit for the current regulations (Dz.U. poz. 1422 2015) in both assessment, e.g. $U_{window} = 0.9$ W/(m^{2}K). The study involves analysing each of the climatic zones separately. The calculations were conducted using the software available for this purpose, Kan-OZC. The results of the annual heat demand in the building are presented in the diagram below.

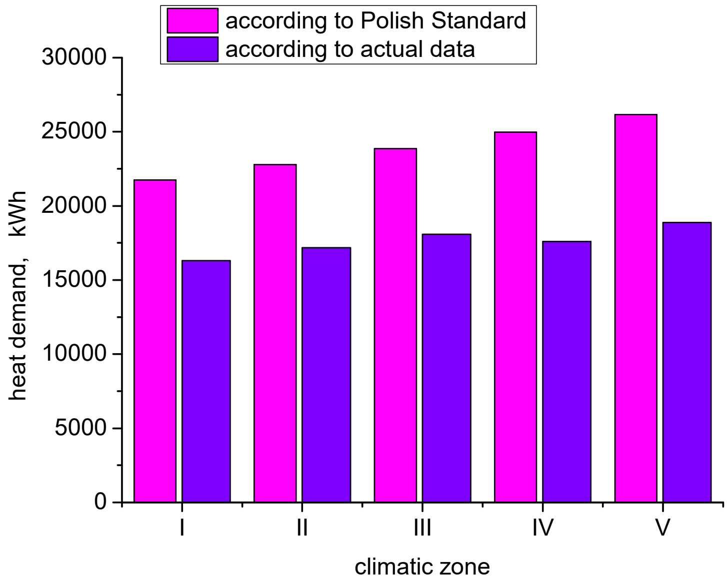

Fig. 3. Annual heat demand comparison for calculation and annual average external air temperatures values according to Polish Standard and actual values from meteorological annual

The average share of the heat demand calculated using the data from the meteorological statistics compared to the Polish Standard is 74%, with the highest value of 75.8% for the III climatic zone and the lowest 70.4% for the IV one.

The energy savings contribute to the financial benefits for the heating system user. The conducted study involved three heating sources with different heating systems: (1) an air-to-water heat pump (HP) with a floor heating system in the building, (2) a pellet boiler with heaters or (3) a gas condensing boiler with heaters. The initial costs due to the different temperature calculations are not significant since the value for data from meteorological annual compared to the Polish Standard is only 11% lower on average. The lowest investment expense reduction appears for the third option studies (ca. 2%), whereas the highest is for HP calculations (ca. 17%).

However, the annual cost savings for each methodology are notable, as presented in the figure below. The calculations were conducted for the assumed air-to-water heat pump with a coefficient of performance 4.7 (1). The calorific value of a pellet is 18,300 kJ/kg (2), and for natural gas, 9.44 kWh/m^3 (3). The prices of electricity, pellets and natural gas are included according to the current suppliers' information.

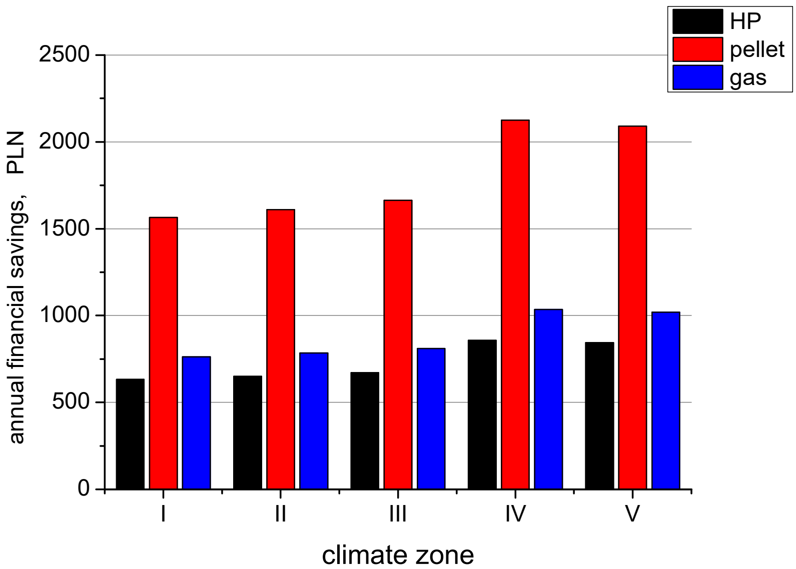

Fig. 4. Annual operational cost savings

As presented in the diagram, the decrease in annual expenses strongly depends on the climatic zone due to the differences in heat demand and energy savings during the heating period. Heating the building with a pellet boiler gives the most significant financial benefit, even over 2,000 PLN/year. However, the lowest economic profits are received when the heat pump is the building heating source. Still, considering the life cycle of the units for 20 years, the savings reach 12,500 PLN up to even 42,500 PLN for option (1). The most profitable temperature changes, resulting in the highest operational expenses decrease, are for the IV climatic zone. Even though the percentage share of the heat demand for the actual data compared to Polish Standard is for the IV climatic zone the lowest, in absolute terms, the presented heat demand decrease is the highest (1,692 W) resulting from the highest calculation external temperature difference between the temperature assigned to the climatic zone and the actual data (see Fig. 2).

The economic benefits involve several index calculations. Since the examinations presented in the paper consider the building that requires heating system equipment, the issue involves deciding on the calculations' approach. Therefore, the research index was a payback period, calculated as the initial cost difference between the Polish Standard regulations and actual temperature values relative to annual operational expense savings. The examinations were presented for 3 heating sources and V climatic zones, and the results were calculated over the years.

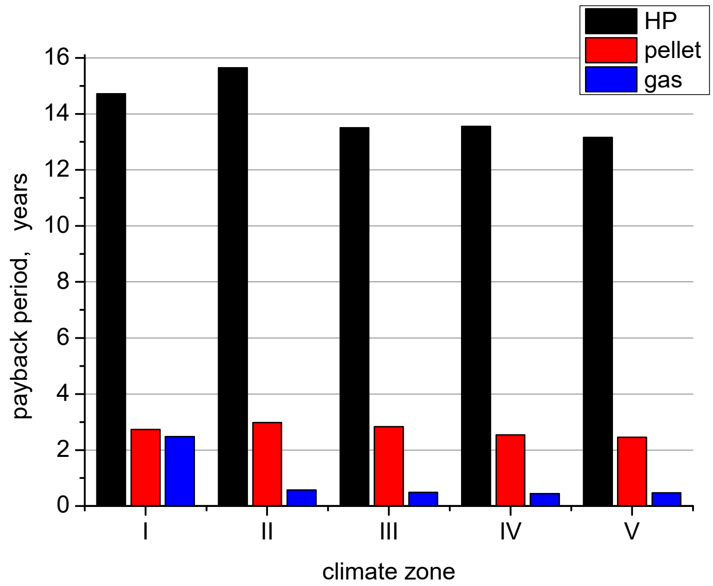

Fig. 5. Investment costs difference payback period

Heating systems based on pellet and natural gas as a fuel present low index values (pellet around 3 years and natural gas generally below 1 year), which are strongly expected values. However, the heat pump's annual cost decrease is low compared to the difference in initial expenses; therefore, the payback index is above 13 years. However, the air-to-water heat pump is a renewable energy source, and therefore, the purchasers can benefit from several endowment programs with the decline of investment costs for the heating source acquisition, which are available for HP installation for every heating system investor in Poland. The decrease of initial costs of heat pump purchase by half results in the lowest payback periods for the heat pump option presented in the figure below (straight line) compared to incurring all the expenses by the system occupant (see Fig. 5). The investors can receive the subsidies to cover all the expenditures for the heat pump acquisition, thus significantly lowering the payback period presented in the grid (see figure below).

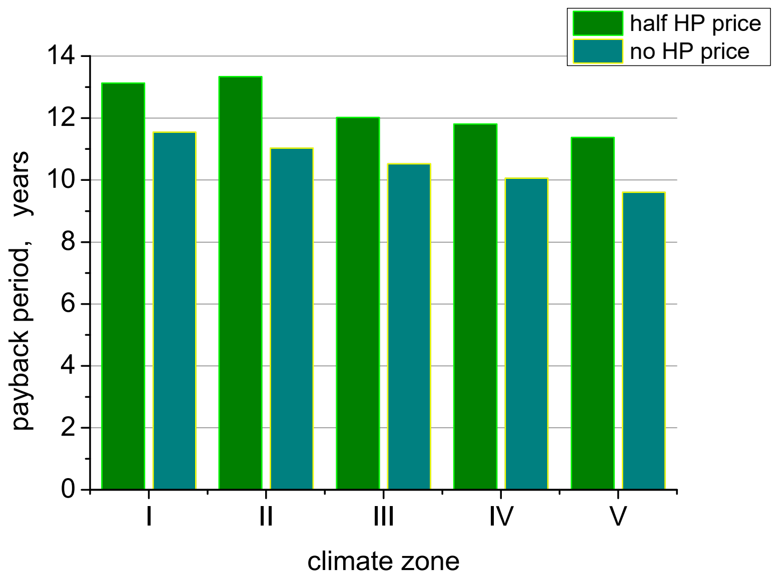

Fig. 6. Investment costs difference payback period for heat pump system with the subsidies for heat pump purchase obtained by the investor

The only investment costs incurred for the floor heating system in the building strongly prove the financial benefits for the heating system user when applying the actual temperature data in the heat demand calculation procedures. The payback period decreases the highest from 15.6 years to 11 years in the II climatic zone and the lowest from 13.5 years to 10.5 years in the III climatic zone, with an average shortage of 3.5 years. The decline is lower for the subsidies, reaching half of the heat pump purchase expenses since the average value is 1.8 years.

3. Conclusions

The research proved that comparing actual temperature data and the temperature values given in standards is crucial. Several analyses of the issue, presented in the introduction, were conducted based on other countries' climatology (Zahra et al. 2023, D'Agostino et al. 2022). Moreover, the temperature increase in Poland has not been included, and external calculation temperatures have not been modified for 40 years (1982). However, the required heat transfer coefficient values have been gradually reduced to obtain the lower heat transfer demand.

The lower heat demand in a building results in reduced operation costs of the heating system and decreased investment costs. On the one hand, the heating device cost decreases with its lower thermal output; on the other hand, the heating pipes require smaller diameters. Moreover, the power consumption in the case of heat pump or fuel consumption when considering the conventional heating source will decrease the system users' expenses. The analyses involved three types of heating systems: (1) air-to-water heat pump with COP = 4.7 / (2) pellet boiler / (3) gas condensing boiler. In the first case, the average annual cost reduction reaches 858 PLN, whereas in the third, it is 1,035 PLN. The highest expenses decrease is observed in pellets as a heating fuel with an average value of 2,125 PLN/year. Moreover, the payback periods presented in the paper allow us to conclude the financial benefits of such an approach to heat demand techniques due to their short values. Involving the possible subsidies in decreasing the investment costs of the heating source, the payback periods prove economic gains resulting from the increase in external temperatures. Therefore, it is necessary to include the differences in climate changes in calculation procedures for energy and financial reasons.

However, further calculations should be conducted for previous years, including most of the cities in Poland. The analyses, therefore, would become more accurate and could present the response to the problem of temperature differences between the calculation and actual values, allowing advanced development in heating systems designing and planning. However, the improvement proved to be crucial in the case of financial benefits for the system user.

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