Analysis of the Use of RES for Heating and Cooling in Different Climatic Zones in Poland and Spain

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Abstract. Energy consumption for heating and cooling in buildings depends on climatic conditions. This paper compares heat losses and gains for four locations - two in Poland and two in Spain. Results show similar cool load in three variants: Burgos in Spain and Bialystok and Wroclaw in Poland, while the highest cool load was recorded in Cordoba (Spain). In case of winter season, also results obtained in Cordoba differed significantly and its heat load was more than twice lower than in other cases. Economic comparison was prepared for two variants: first – heating with a gas boiler and cooling with multi-split air conditioners and second – heating and cooling with a reversible air-water heat pump. Taking into account national prices the total cost of heating and cooling was estimated and found higher for both analysed in Spanish locations, especially high in Cordoba due to high annual demand for cooling. Using reversible air-water heat pump is definitely more favourable than gas boiler with multi-split. For Polish locations it gives 17.4% - 24.6% cost reduction, whereas for Cordoba annual operating costs are more than twice lower when using a reversible heat pump.

1. Introduction
The Paris Convention sets out a global action plan to protect us from the threat of far-reaching climate change by limiting global warming below 2°C and keeping it at 1.5°C. The Paris Convention also aims to improve and support countries’ ability to cope with the effects of climate change. Almost 190 countries have acceded to the Paris Convention, including the European Union and its member states. As a result of the constantly growing requirements imposed by the European Union (EU) regarding the share of renewable energy sources (RES) in energy production, member states are obliged to introduce changes in their energy policy. In this way, the EU wants to become independent of imported energy through more efficient use of its own energy resources and the diversification of energy sources and supplies. EU rules on construction, industry, consumer products and transport are helping the EU to increase its energy efficiency and transform into a low-carbon society. One of the sectors where the potential for using renewable sources is very high is single-family housing.

Private investors, encouraged by many programs offering subsidies and technical assistance, more often decide to use RES in their homes. Also due to the constantly growing ecological awareness of the society, RES are becoming more popular. Jain et al. [1] conducted a survey to find out about opinions on RES for a clean environment. To investigate people’s emotions about alternative energy sources, they conducted a comparative sentiment analysis of different RES using data from Twitter. It has been found that people's opinion about renewable energies - mainly solar and wind power - attracts most tweets, and people are more positive about renewable energies for a better environment.
Due to the rising prices of electricity and environmentalists' demands, the prospect of using renewable energy seems more and more tempting. RES are those whose natural resources recover very quickly. Using them is not a deficit and they are not so dangerous to the environment. In the case of RES, in addition to environmental aspects, social aspects are also important, as mentioned Czekala et al. [2]. The aim of their work was to discuss selected social benefits resulting from the production of renewable energy. One of them were local aspect because many regional problems, mainly related to its transport, had to be solved. The use of renewable energy directly improves the environment, which in turn has a positive effect on people. Shahbaz et al. [3] conducted an empirical analysis which confirmed that there was a long-run relationship between renewable energy consumption and economic growth. They noted that in 58% of analyzed countries positive impact on economics growth had particularly the renewable energy consumption. They suggested that governments, energy organizers and international cooperation agencies should cooperate together in increasing renewable energy investment for low carbon growth. Using RES brings both ecological and economic benefits. Niekurzak et al. [4] presented results of the analysis of the return on investment in solar collectors on the example of a household in Poland. Results showed that an operating installation would bring measurable economic and environmental benefits. The amount of purchased energy decreased by 6756 kWh per year and emission of carbon dioxide decreased by 2.4-3.6 mg per year. Systems with solar collectors in Poland and Spain were compared by Krawczyk et al. [5]. Alshehri et al. [6] performed the analysis of vertical geothermal heat pump system in hot dry climate. Show in it that ground source heat pumps are very efficient air conditioning system, and helps to achieve sustainable development goals as well as reducing carbon dioxide emissions and electricity consumption. The results showed that the most important four design parameters are the: fluid flowrate, soil temperature thermal conductivity and building load. By increasing these values, they have an opposite effect on dry environmental conditions. The power consumption in proposed design could be reduced up to 15%.

The aim of this paper is to compare possibility of selected RES usage for heating and cooling in different climatic zones in Poland and Spain.

2. Methodology
The analysis was conducted for a single-family, two-storey building with a total area of 220 m². The analyzed building was designed from materials that meet current standards. To compare, the heat and cooling load calculations were conducted for four different climate localizations: two in Spain (Burgos, Cordoba) and two in Poland (Bialystok, Wroclaw). The main climatic parameters for selected locations are presented in Table 1.

|                  | Cordoba | Burgos | Wroclaw | Bialystok |
|------------------|---------|--------|---------|-----------|
| Indoor temperature for heating, °C | 20      | 20     | 20      | 20        |
| Indoor temperature for cooling, °C | 22      | 22     | 24      | 24        |
| Designed outdoor temperature, °C   | -0.3    | -5.6   | -18     | -22       |
| Average annual outdoor temperature, °C | 18.2    | 10.7   | 7.9     | 6.9       |

It should be noted that the average annual outdoor temperature in Burgos (north part of Spain) is more similar to the average value in Wroclaw (south of Poland) than Cordoba (south of Spain). Moreover, for detailed prediction of the annual temperatures and solar irradiance models proposed by Zhang et al. [7] can be used.

The heat transfer coefficients and the energy demand for heating the building were calculated using the Audytor HL 7.0 Pro software [8]. The calculations of energy demand for cooling were conducted using the tools prepared under Vipskills project (Virtual and Intensive Course Developing Practical Skills of
Future Engineers) implemented as part of the Erasmus+ program. The characteristic values of the building entered for the calculations are presented in Table 2.

Table 2. Main parameters of building

| Building partition | U-value [W/m² · K] | Area [m²] |
|--------------------|-------------------|-----------|
| External walls     | 0.19              | 132       |
| Internal walls     | 2                 | 234       |
| Floor              | 0.27              | 103.66    |
| Roof               | 0.15              | 103.11    |
| Windows            | 0.9               | 37.8      |
| External doors     | 1.3               | 2         |

3. Results and discussion
The results of design heat losses calculations with division into heat losses by transmission and ventilation are presented on the Figure 1.

![Figure 1. Total designed heat losses.](image)

The noticeable difference in heat losses between Poland and Spain results mainly from climatic conditions. The design outdoor temperature and average annual outdoor temperature has a decisive influence here.

The results of cool load calculations with division into gains of sensible heat and gains of latent heat are presented on the Figure 2. According to [9], the cool load calculations were conducted for temperature of comfort, which in Poland is equal to 22°C and in Spain 24°C.
In Spain higher cool load was recorded in Cordoba – 12747 W, lowest in Burgos – 9094 W. The difference between them is 29%. For Polish locations cool load was 9457 W in Wroclaw and 8902 W in Bialystok. In Wroclaw cool load is only 6% higher than in Bialystok.

To estimate the real costs of heating and cooling, the annual energy consumption calculation were initially made. The calculations were conducted on the basis of Heating Degree Days (HDD) and Cooling Degree Days (CDD). This parameters are a measure of how much (in degrees), and for how long (in days), outside air temperature was lower – HDD or higher - CDD than a specific base temperature [10]. The results of annual energy consumption for all analyzed locations is presented below [Figure 3].

On the basis of the obtained results, the annual operating costs of the building were calculated for two variants: first – heating with a gas boiler + cooling with multi-split air conditioners and second – heating
and cooling with a reversible air-water heat pump. According to [11] the energy price in Poland was assumed to 0,14 €/kWh and in Spain 0,22 €/kWh. While the price of natural gas was assumed 0,035 €/kWh in Poland and 0,065 €/kWh in Spain. The annual cost of energy consumption for all locations is presented on the Figure 4.

![Figure 4. Annual cost of energy consumption.](image)

Higher total cost of heating and cooling for both analyzed variants occurred in Spanish locations. This is mainly due to very high costs of electricity and gas in this country. The highest cost was recorded in Cordoba, mainly due to very high demand for cooling during the year. In Cordoba CDD is equal to 584 [°C·d], while in Burgos it is only 92 [°C·d], in Wroclaw 129 [°C·d] and in Bialystok 97 [°C·d]. For locations in Poland annual cost of energy consumption is on similar level. For locations in Spain the results are more varied because of geographic location and climate conditions. Comparing the annual costs of energy consumption in the case of two analyzed variants, using reversible air-water heat pump is definitely more favourable. For Polish locations the differences are 17.4% lower cost in Bialystok and 24.6% in Wroclaw. For Cordoba, where the difference is the highest, annual operating costs are more than twice lower when using a reversible heat pump.

4. Conclusions
The presented results of calculations allow to conclude that due to the climatic conditions, the heating demand is higher in Poland, while the cooling demand is higher in Spain. For all locations assumed U-value on the same level, meeting the requirements in Poland, which are very restrictive. If the Spanish guidelines were to be followed, the cooling and heating demand would change. The annual energy consumption costs were much higher in Spain due to the high energy consumption for cooling during the summer months and energy prices. It is also worth noting that the prices of traditional fuels in Spain are very high. They have one of the highest energy prices in Europe. Therefore, investing in renewable energy is becoming the best alternative.

5. References
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