Comparison of cooling load and air conditioning systems in a lecture hall located in Poland and Spain

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Abstract. This paper discusses issues related to cooling load and energy consumption for air conditioning systems and presents the results of calculations conducted for six different climate localizations: three in Poland (Bialystok, Warsaw, Wroclaw) and three in Spain (Burgos, Madrid, Cordoba). Analysis was conducted for a same lecture hall design for 100 users locates in the different cities. During cooling load calculations, we focused on gains from diverse type of heat sources: electrical devices, air infiltration, heat transfer trough envelope and occupants. Calculations were made for a comfort temperature that was set at 22°C in Poland and 24°C in Spain following previous studies [11]. The highest contributions to cooling load correspond to occupancy and solar gains which depends mainly on outdoor conditions. In Poland, cooling load was found similar for different locations, while in Spain, they are big differences between cities located in North and South of this country by effect of different outdoor conditions. The work also compares cost of air condition annual energy consumption costs for the air conditioning system. Highest cost for cooling was found in Spain (Cordoba) with value (2629 €) almost 378% higher than average Polish cost.

1 Introduction

Almost three of every four houses in United States have any kind of an air-conditioning system. In Europe, this tendency is not so high. However, with the global warming of the climate and the increasing occurrence of hot summers, Europeans more often decide on cooling systems in their buildings. While in the United States air-conditioning sales have been rather stable, in Europe they have grown by more than 10% a year. The reason for this growth is partly the world economy, which is forcing European people to work in summer. But people in Europe have also seen the benefits of using air conditioning in their cars and offices and decided that they want it at their homes, too. Noticing a trend, air-conditioner

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manufacturers, especially from Japan, South Korea and China, cause this countries produce affordable units, filled the market inexpensive models well suited to small European houses [1]. Although, there are a lot of hurdles to the spread of air-conditioning. Air-conditioners and the power to run them are quite expensive, and in the European Union there are significant restrictions both in energy use and the gases generally used as coolants. Furthermore, many Europeans still do not agree with air-conditioning, some think it's unhealthy, others that we should rely on nature [1]. In spite of all, in Europe number of buildings which are provided with space cooling and electricity consumption of air-conditioning has been increasing for several decades. Cooling systems are used in order to obtain comfortable indoor conditions during hot and warm summer periods [2, 3]. Indoor microclimate includes temperature and humidity, which maintained at the appropriate level provide comfortable working conditions and human functioning.

1.1 Types of air-conditioning systems

There are three basic categories of the air conditioning systems, which are used to provide comfort cooling conditions. Some of them need to work in conjunction with auxiliary systems, other are self-contained products. The following categories may itself contains a few types of products [3].

- Moveable units – devices bought non-prescription or through Internet suppliers and not require any installation knowledge,
- Fixed room air conditioners/packaged systems – self-contained units produced in series or systems containing a unit designed for single room, which need to be installed by professional,
- Central systems – definitely larger systems that operate more than one room (usually large numbers of rooms). They are bespoke systems composed of standardised component products, generally designed for specific buildings [3].

To varying degrees, all of this systems are used in both public/commercial and residential buildings. In Europe, most of moveable units are found generally on residential buildings, central systems are used in non-residential buildings and fixed room air conditioners both in residential and non-residential market sectors [3]. More or less, each of the categories of the air conditioning system is proper in different climates and building types. The choice is also important whether a system or product will be installed in a new building, in an existing building or will be a replacement for an existing system (at times part of a system) [3].

1.2 Air conditioners preferred in Poland and Spain

Recently, both in Poland and in Spain, the most frequently chosen solution for comfort, efficiency and low noise level is a split type air conditioner, which is suitable for different types of rooms: smaller and larger ones. There are also multisplit air conditioners that can be installed in several rooms of the house. These types of air conditioners are costly, but they are also distinguished by modern technology. They can be equipped with remote controls to make using the air conditioner easy and trouble-free. However, it requires installation by experienced professionals. In addition, there is the possibility of heating the rooms with an air conditioner, which provides much lower heating costs compared to the heating of electric heaters [4, 5].

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1.3 Cooling demands in Poland and Spain

The energy rating of the building is currently one of the main tools for raising the energy awareness of the public and exerting pressure on both investors and users of buildings so that energy-saving buildings are commonly built in the future. In case of air-conditioned objects one of the important elements of energy assessment is the calculation of the annual (seasonal) energy demand for cooling [6]. The average annual specific space cooling demands estimated for Poland and Spain are benchmarked in Fig.1.

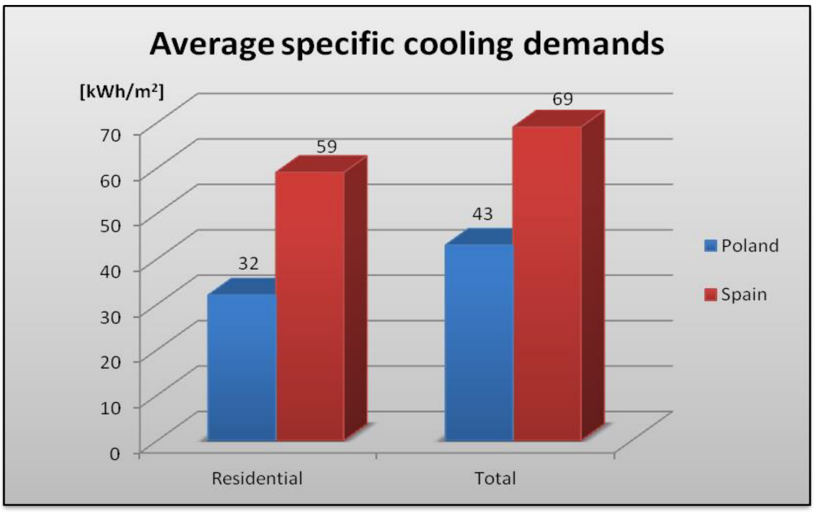

Fig. 1. Specific space cooling demands in Poland and Spain [2].

After Greece, Cyprus and Malta, in Spain specific cooling demands are the highest in Europe. While Poland belongs to countries with moderate cooling demands. Cooled areas are products of total floor areas and corresponding saturation rates [2]. Comparing the total cooled floor areas (Fig. 2), the difference between Poland and Spain is very large. After Italy, Spain is the best in the amount of cooled floor areas in Europe.

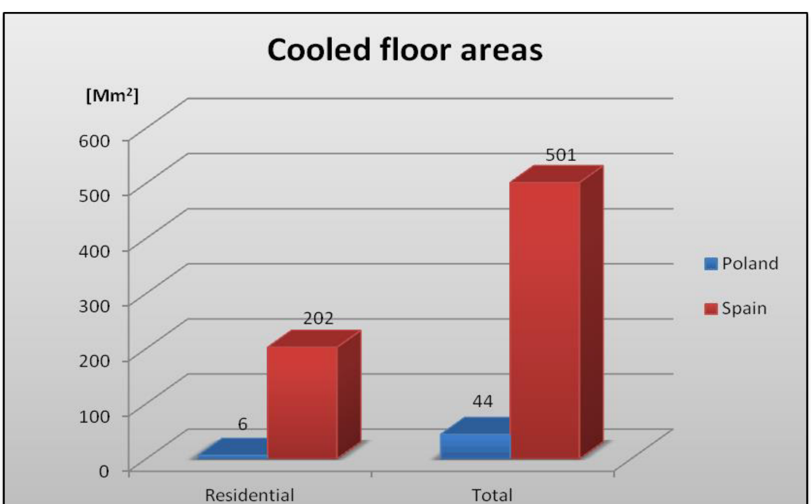

Fig. 2. Cooled floor areas in Poland and Spain [2].

2 Methodology

The paper focuses on the real classroom located in Bialystok University of Technology building (Fig. 3). To compare, Cooling load calculations were conducted for six different climate localizations: three in Poland (Bialystok, Warsaw and Wroclaw) and three in Spain: Burgos (one of the coldest cities in Spain), Madrid and Cordoba (one of the hottest cities in Spain). The design indoor and outdoor conditions for all cities are shown in Table 1.

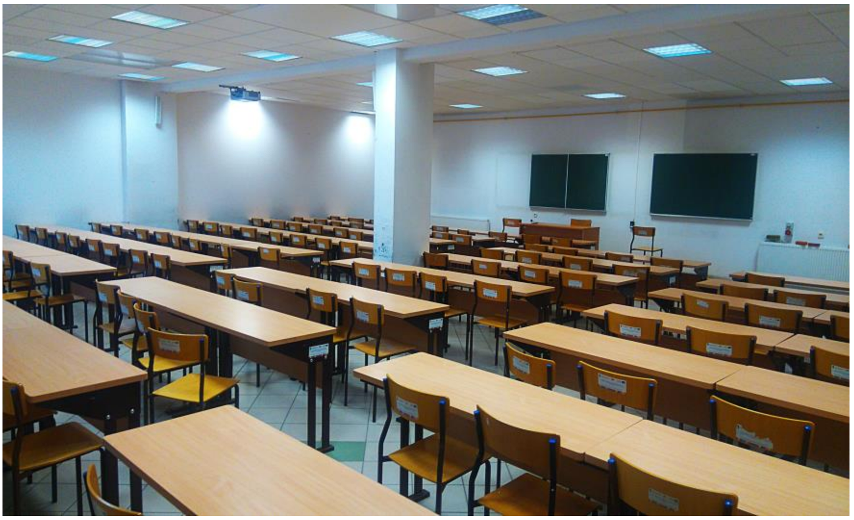

Fig. 3. Classroom of Bialystok University of Technology (Poland) analyzed for different Polish and Spanish localizations [photo by B. Wądołowska].

Table 1. Design indoor and outdoor conditions (*values for 2% annual cumulate frequency of occurrence) [7, 8].

Parameter	Bialystok	Warsaw	Wroclaw	Burgos	Madrid	Cordoba
Geographic localization	53°07'N Latitude 23°10'E Longitude 151 m Altitude	52°14'N Latitude 21°00'E Longitude 106 m Altitude	51°07'N Latitude 17°01'E Longitude 124 m Altitude	42°20'N Latitude 3°42'W Longitude 890 m Altitude	40°25'N Latitude 3°42'W Longitude 687 m Altitude	37°53'N Latitude 4°46'W Longitude 91 m Altitude
Indoor temperature, °C	22	22	22	24	24	24
Indoor relative humidity, %	50	50	50	52	52	52
Outdoor Dry Bulb / Wet Bulb temperature* °C	24.9/17.9	26.0/18.3	26.3/18.2	29.5/19.2	33.3/19.6	36.8/23.4

Outdoor relative humidity*, %	50.8	47.8	45.8	39.3	28.5	32.4
Indoor absolute humidity, g/Kg	8.37	8.33	8.35	10.35	10.10	9.40
Outdoor absolute humidity*, g/Kg	10.17	10.15	9.92	11.25	9.86	12.75

Bialystok University of Technology building was built in 1988 and consists of two parts: the lower building (one floor and basement) and the higher (three floors and basement) [9]. An analyzed classroom is located in first part of the building. The characteristic parameters of the room were presented in Table 2. U values were estimated based on [10].

Table 2. The characteristic parameters of analysed classroom.

Localization	**Dimensions [m] and area [m^2]**	**U [W/m^2·K]**
External wall	11.85 m x 3 m = 35.55 m^2	0.21
Internal partition	35.15 m x 3 m = 105.35 m^2	1.0
Roof	11.85 m x 11.65 m = 138.05 m^2	0.2
Floor	11.85 m x 11.65 m = 138.05 m^2	0.4
Windows	2.6 m x 2 m x 4 = 20.8 m^2	1.5
Doors	1.5 m x 2 m = 3 m^2	3.0

Other information necessary to accomplish the calculations:

- Occupancy: 100 Persons
- Air changes per hour: 0.5
- Sensible heat/Person: Poland – 70 W, Spain – 64 W
- Latent heat/Person: Poland – 30 W, Spain – 41 W
- Windows type: double glass with chamber
- Electrical devices: 1 computer (300 W), 26 fluorescents lights (26 x 40 W = 1040 W)

3 Results and discussion

The calculations 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. Results of cooling load calculations were presented in Figure 4.

Calculations were made for the comfort temperature. Previous studies [11] showed that this temperature for students of Bialystok University of Technology was found as 22°C and for students of University of Cordoba as 24°C.

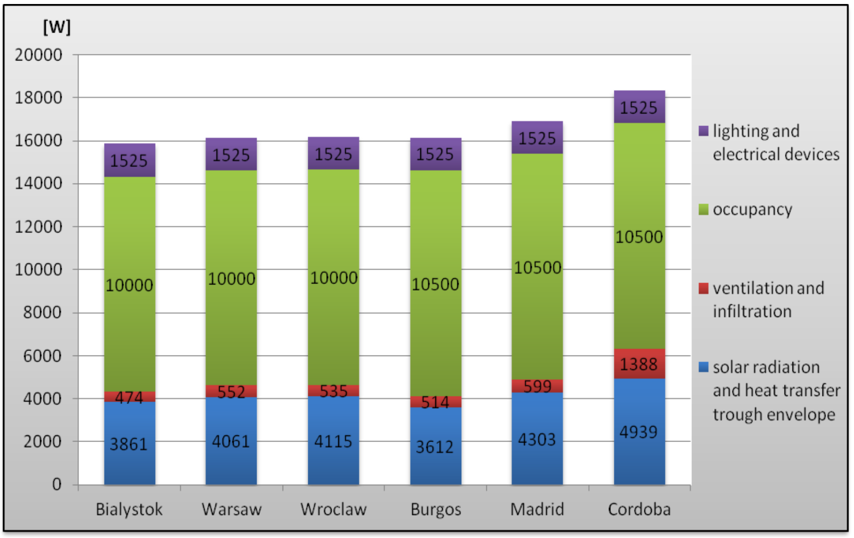

Fig. 4. Results of cooling load calculations.

For Spanish locations, the highest cooling load was recorded in Cordoba, where it amounted to 18352 W, while the lowest in the Burgos (16151 W). In Cordoba, cooling load is 12% higher than in Burgos. For Polish locations, the highest cooling load was in Wroclaw – 16175 W and the lowest one was found in Bialystok – 15860 W. The difference between them is 1.9%. In Poland, the cooling load is similar for different locations, while in Spain the differences are larger and cooling load has a growing tendency with the increase of the outdoor temperature. Moreover it is worthy to note that value in Burgos was nearly the same as in Wroclaw and Warsaw.

Based on total cooling load calculations, for all locations LG's split air conditioners, species Deluxe were selected. Table 3 shows the selection of an air conditioners, their quantity, type, basic parameters and price.

Table 3. The selection of air conditioners.

Localization	Number of air conditioners	Type	Cool load [kW]	Power of units [kW]	Price [Euro]
Bialystok	3	DM09RP 2x DM24RP	15,86	15,9	4433
Warsaw	3	2x DM18RP DM24RP	16,14	16,6	4602
Wroclaw	3	2x DM18RP DM24RP	16,18	16,6	4602
Burgos	3	2x DM18RP DM24RP	16,15	16,6	4602
Madrid	4	2x DM12RP 2x DM18RP	16,93	17,0	4771
Cordoba	4	2x DM12RP DM18RP DM24RP	18,35	18,6	5108

The highest cost related to the purchase of air conditioners (Fig. 5) was found for the classroom located in Cordoba, while the lowest in Bialystok. In Warsaw, Wroclaw and Burgost costs would be the same.

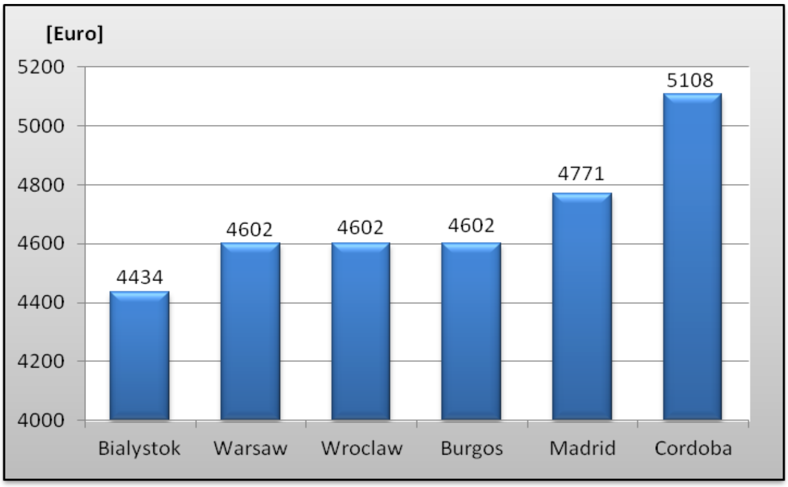

Fig. 5. Cost of air conditioners.

To show the real cost of using of the air conditionig system, the annual energy consumption calculations were made. Calculations were based on Cooling Degree Days (CDD) method, that is giving information about how much (in °C), and for how long (in days), outside air temperature was higher than a specific base temperature (comfort temperature, so cooling needs can be estimated. According to [12], energy cost in Poland is 0.13 (€/kWh) and in Spain 0.14 (€/kWh). Estimated annual cost of energy consumption are presented in Figure 6.

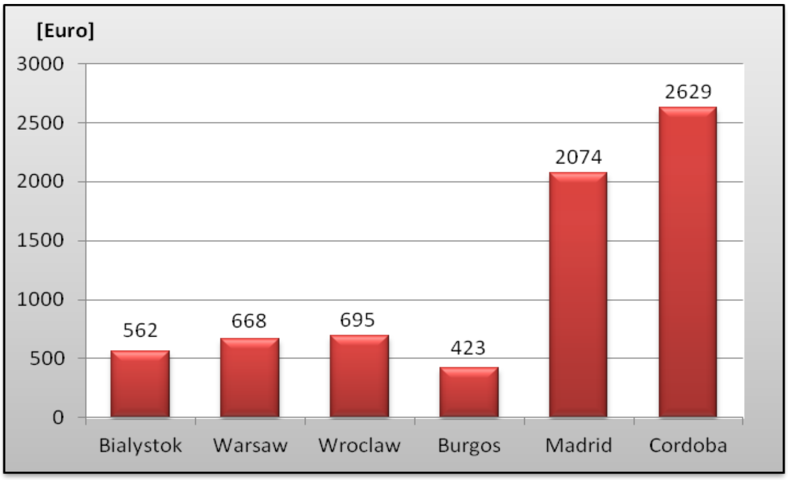

Fig. 6. Annual cost of energy consumption.

The highest cost related to energy consumption was obtain for the classroom located in Cordoba, while the lowest in Burgos. This high difference is conected with CDD values, which in Cordoba is 584°C·d, while in Burgos is only 92°C·d. In Polish localizations costs will be on the similar level, because CDD is equal to: Bialystok – 97°C·d, Warsaw – 110°C·d and Wroclaw 129°C·d.

4 Conclusion

In this work, the energy demand for cooling of a classroom with 100 occupants in different locations of Poland and Spain has been calculated. The U-value for all these locations was assumed to be very low, at the level of Polish requirements. In this conditions, highest contributions to cooling load corresponds to occupancy and solar gains which depends mainly on outdoor conditions So, results of calculations showed that in Spain demand for cooling educational buildings is higher than in Poland. The highest results were obtained in Cordoba where cooling load is about 11.9% and annual cost of using air conditioning system is about more than 3 times higher than the highest one in Poland – Wroclaw. In Poland, cooling load and annual energy demands were found similar for different locations, while in Spain, they are big differences between cities located in North and South of this country by effect of different outdoor conditions. In Burgos, cooling load and cost of energy consumption are similar to Polish localizations, on account of its climate conditions: low temperatures and low CDD.

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