Energy consumption patterns in a hotel building – A case study

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Abstract. The hospitality industry is one of the most energy-intensive subsectors of the tourism sector. Most of the total energy consumption is due to maintaining an optimal temperature inside the occupied rooms. Conditions inside hotel rooms, hotel infrastructure, including tourist attractions such as swimming pools, restaurants, conference rooms, have a significant impact on the overall energy consumption of this sector. Hotels, unlike other commercial buildings, are characterized by the separation of functional areas. Additionally, the heat loads that change over time are difficult to estimate. The research was carried out in the historic hotel Turówka, which is a reconstruction of the historic salt sales point from 1812. Due to the historical nature of the building (entered in the register of monuments), the thermal modernization of the hotel, adjusting it to the prevailing energy standards, is a big challenge for designers. The work aims to determine the structure of the building's heating and cooling energy demand. Additionally, the factors influencing the building's energy demand in the building during the summer period are determined. The analysis focused on identifying typical patterns of weekly and daily demand and examining the correlation between meteorological parameters and the observed energy consumption. Based on the obtained results, factors that significantly affect the consumption of thermal energy in the building were identified. The article covers the analysis of the energy performance of the building, including the energy demand of three systems in the building: the cooling system, domestic hot water preparation, and the demand of the swimming pool area. Measurements of energy consumption were carried out continuously, using installed heat and cooling energy meters in key places of the installation. An in-depth energy analysis of a building is a necessary element to improve its energy performance and adapt it to the requirements of low-energy buildings. Monitoring the energy consumption of your building system can help you optimize energy use.

Keywords. Energy demand, energy consumption pattern, hotel building.
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1. Introduction

Nowadays, reducing energy consumption is one of the fundamental challenges of civilization. This is the result of both economic reasons and environmental aspects. Reducing energy demand allows lower operating costs of the building or installation and minimizes the negative impact of human activity. Together, the building and construction sector accounts for more than one-third of global final energy consumption. There are many methods to reduce energy consumption. Firstly, the crucial sources of energy consumption should be identified. At this stage, an analysis of energy consumption throughout the year is necessary. In this way, the focus may be on the most energy-consuming system or parts of the facilities. The energy consumption in buildings depends to a large extent, on the losses caused by heat exchange between the building and its surroundings. Therefore, the most popular method of reducing energy consumption is to increase the thermal insulation of partitions and to replace the windows. The appropriate management of energy and the environment in buildings can also bring significant benefits. In this way, it is possible to identify areas where savings can be made and implement improvements that increase the energy efficiency of the building.

The hotel is a specific type of facility due to the separation of various zones of use and functionality. Creating the ideal indoor environment in this type of building is crucial, as it affects the economic benefit and profitability of the facility. Requirements for hotels, including those relating to providing customers with adequate thermal comfort - both in the winter and summer months, make the issues of economic energy management a priority due to the profitability of this type of activity. Hotel facilities rank among the top five in terms of energy consumption in the service sector [1]. The predominant part of the energy consumed in hotels is the energy required to provide a comfortable indoor environment for users. The main energy-consuming activities in hotel buildings include space heating, cooling, lighting, preparing hot water, preparing meals, and systems of swimming pools [1].

The energy consumption of a hotel is influenced by both the physical parameters and operating conditions of the building. Physical parameters include, but are not limited to, the size, structure, facility, its geographic and climatic location, the age of the facility, and the type of energy and water systems installed. Operational parameters that affect energy consumption in hotels include the operating schedules of functional parts, services offered, fluctuations in occupancy levels, differences in customer preferences for indoor comfort. Moreover, crucial factors are local energy-savings practices, the culture, and awareness of resource consumption among users [1] [2].

The literature includes many papers [2-6] on monitoring energy consumption and analysis of energy demand in hotel buildings. Bohdanowicz and Martinac [3] studied water and energy consumption in hotels of two different brands. Besides the difference between the two brands, many important factors that influenced the energy demand in hotels were identified. These parameters include the standard of the hotel, location/climate, size of the facility, occurrence of energy- and water-intensive services, the number of hired rooms, and amount of laundry washed on site. Santiago [4] presented and compared energy models of six hotels in Gran Canaria. According to this study, the highest energy consumption of the facilities is due to the food services, followed by the hot water preparation system. The regression analysis showed that among 31 different characteristics, revenue per available room, swimming pool size, number of guests, and average number of guests per occupied room could explain the total energy demand of the studied hotels. Wang et al. [5] present an analysis of hotel building energy performance using BEMS and energy modelling data. The authors noticed the decisive influence of two parameters on energy consumption: the ambient temperature and the occupancy of hotel rooms.

The paper presents the consumption of heat and cooling energy divided into three systems inside the facility: a cooling system, a system for preparing hot water, and a heating system for the swimming pool. The analysis considered the energy characteristics of the facility from May to September 2019. The variability of parameters on a weekly and monthly basis over the study period was examined.

2. Research Methods

2.1 Characteristics of the building

The subject of the study is the historic hotel Turówka, entered in the register of monuments. The analysed building is a 5-story hotel, four of which are above ground and one underground. The usable area of the hotel facility is 4,620.00 m^2, with a built-up area of 1,370.00 m^2. The facility has 49 double rooms, one single room, and an apartment. The hotel features a recreational facility, including a swimming pool, salt cave, sauna. There is also a restaurant, drink bar, and conference room. The ventilation air is supplied to separate zones using independent installations. Separate installations are equipped in individual air handling units with heat recovery without recirculation. In summer, air cooling is provided by a chilled water system with a chiller located outside the building. The temperature of ventilation air is regulated centrally in the heat exchanger located in the air-handing unit. Additionally, the inside temperature could be controlled locally by using fan coils in rooms. The hot water installation is supplied from the gas boiler room located on the top floor. A detailed description of the systems inside the building can be found in the paper by Borowski et al. [6].

2.2 Measurements and analysis method

The paper includes an analysis of the energy performance of a building. The cooling demand of the facility is examined. The study also considers the heating energy consumption of two systems, i.e., the domestic hot water (DHW) system and the heating system of the swimming pool area. The study covers five months period from May to September 2019. In this period, both heating and cooling energy consumption are observed. The systems were analysed both on a monthly and weekly basis. The systems have been equipped with Kamstrup Multical 403 heat meters. Data were transmitted via a serial communications protocol - MODBUS RTU and stored in a database system. The measurements also included the outdoor temperature directly at the hotel area. Readings were taken at one-minute intervals. Then, to simplify the further analysis, the values were presented with hourly averaging. The prepared data was used to develop variation charts and to examine the impact of identified factors on the energy demand of analysed systems. The factors included outdoor temperature, hotel occupancy, and hour of operation or the day of the week. The occupancy level was assumed as the percentage of occupied rooms in the hotel. To determine the variability of energy demand, one week from each month was selected. Based on this data, a detailed analysis was carried out. The average daily energy demand for each of the systems was also determined separately for the months included in the analysis. The monthly demand for cooling and heating energy was also calculated. The heating energy consumption included both heating systems: a domestic hot water preparation system and a pool area heating system.

3. Results and discussion

The following chapter contains the results of the analysis and the most important observations. Sections below include the preliminary analysis of the collected data, weekly analysis, and the impact of the identified factors on the energy consumption in the hotel.

3.1 Preliminary analysis

In the beginning, the range of measured parameters considered in further analysis was determined. Table 1 contains ranges of the analysed values for five months. As is shown, the observed temperatures dropped even below the value of 5 °C during the analysed period. The occupancy rate varied between 11 and 100%. Energy consumption did not exceed 141.3 kWh/h for the cooling, and 87 kWh/h for the DHW system. The maximum demand for heating energy in the swimming pool area was 63.7 kWh/h.

Tab. 1 - The range of measured parameters.

Parameter/ Energy consumption	Min	Max
Outdoor temperature, °C	3.2	36.2
Occupancy level, %	11.3	100.0
Cooling energy, kWh/h	0.0	141.3
Heating energy (DHW), kWh/h	0.0	87.0
Heating energy (Pool), kWh/h	0.0	63.7

In the next stage, the distribution of external temperature during the research period was analysed.

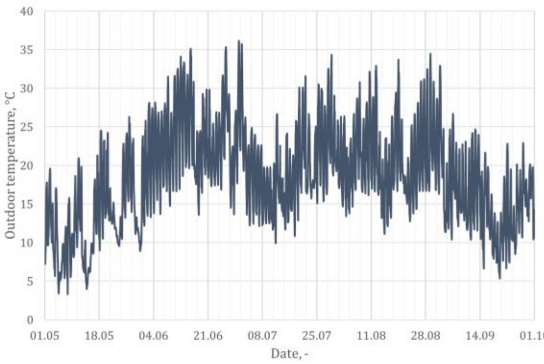

Fig. 1 - Distribution of outdoor temperature on the hotel area from May to September 2019.

In the climate characteristic of this area, the highest temperatures usually occur in July. As can be seen, in the hotel area in 2019, the highest indications were recorded in June. In July, a clear decrease in temperature is visible.

In the next step, the average daily energy consumption for each month was determined. Figure 2 presents the results with the average outdoor temperature marked.

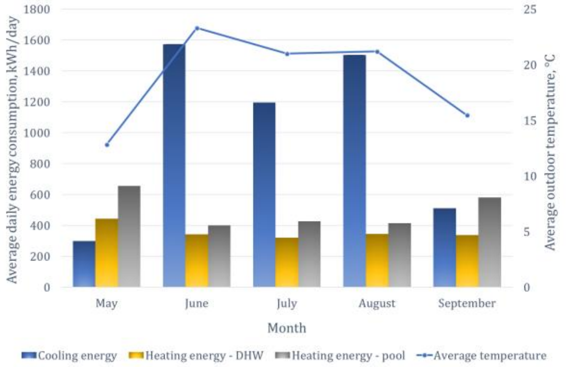

Fig. 2 - Average daily energy demands for each of the systems with the average outdoor air temperature marked.

Then, the monthly energy consumption was estimated with division into individual months of the analysis. Figure 3 shows results with average outside air temperature.

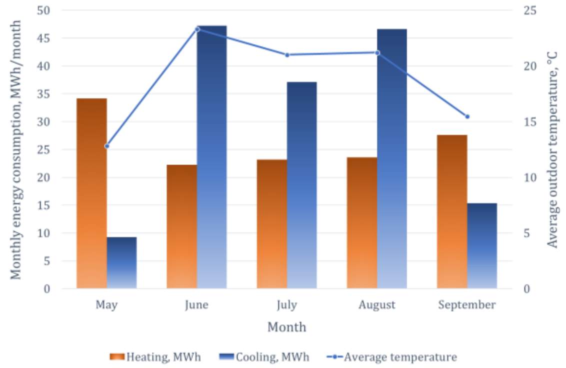

Fig. 3 - Monthly energy demands for the heating and cooling system.

Figure 3 shows that the greatest energy demand is observed in the three hottest months. As shown, during this period, the energy consumption of cooling systems is much higher than heating demand, accounting for even twice the value of heating energy demand.

3.2 Weekly energy consumption variability

The analysis of the energy demand of hotels is a very complex task due to many factors that can affect consumption. At the same time, these factors may change in a very dynamic and often unpredictable way. Due to the wide period of the analysis, it was decided to check the weekly variability of particular parameters. One week was selected from each of the months included in the analysis. The results are presented on the charts below. Figure 4 shows the weekly distribution of demand in May, using the example of days from May 19 to 25, 2019.

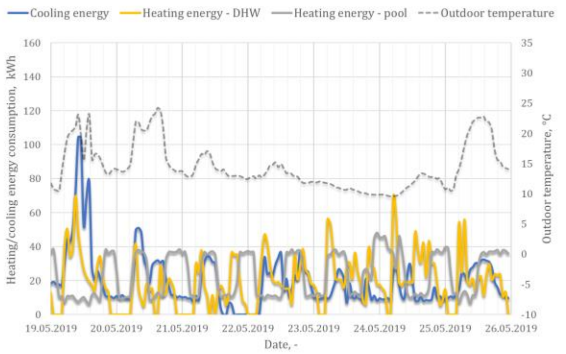

Fig. 4 - Variability of the energy demand of the cooling system, DHW system, and swimming pool heating system - on the example of the period from 19 to 25 May 2019.

During this period, the air temperature is quite low compared to the other months and does not exceed the value of 25 °C. At night, the temperature drops to 9 - 14 °C. Consequently, the cooling demand is kept low. The exception is May 19, when a temporary increase is more than twice the size of the other days. As can be seen, there is also a high demand for the DHW system. It should be noted that on that particular day, the occupancy level amounted to almost the value of 95%. Therefore, the increase may be the effect of a large number of users. Similarly, Figure 5 shows the variation graph for the selected week from June 16 to 22, 2019.

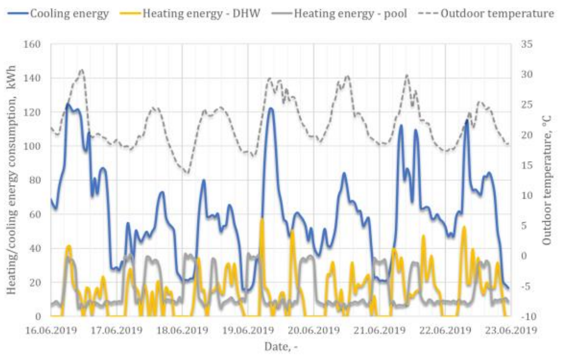

Fig. 5 - Variability of the energy demand of the cooling system, DHW system, and swimming pool heating system - on the example of the period from 16 to 22 June 2019.

The highest temperatures during the entire measurement period were recorded in June Obviously, this also causes an increase in cooling energy consumption this month. The chart shows an increase in consumption during the day (most often in the morning) and a significant decrease in the night hours. The next analysed period is from 21 to 27 July. The graph for this period is shown in Figure 6.

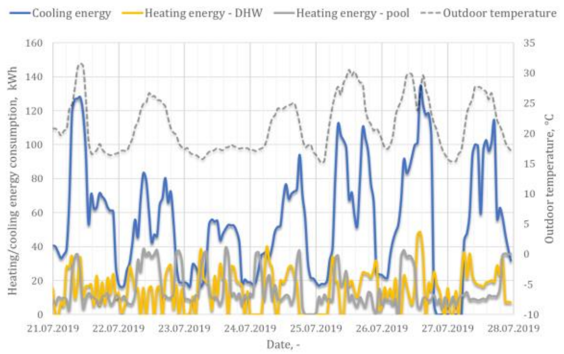

Fig. 6 - Variability of the energy demand of the cooling system, DHW system, and swimming pool heating system - on the example of the period from 21 to 27 July 2019.

Due to the similarity in outside air temperatures and the variability of this parameter during the days, the course of the variability of the demand for cooling energy is analogous to the previous period. As shown in the figure, the temperature decreased below the value of 20 °C on 23 July. It results directly in the reduction of cooling energy consumption this day. In this example, it is noticeable that the outside temperature is a crucial parameter for cooling energy demand estimation. The next chart shows the changes of the analysed values in the period from 18 to 24 August.

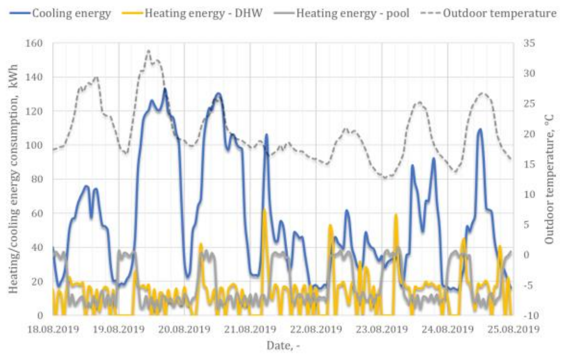

Fig. 7 - Variability of the energy demand of the cooling system, DHW system, and swimming pool heating system - on the example of the period from 18 to 24 August 2019.

Similar to figures for June and July, this chart also allows noticing the importance of outdoor air temperature in the context of changes in cooling demand. In this month, significant fluctuations in the heating energy consumption needed for the DHW system were observed. These values change very dynamically over a wide range and in a short time. The week selected from the last of the analysed months covers the days from 22 to 29 September. The results are shown in Figure 8.

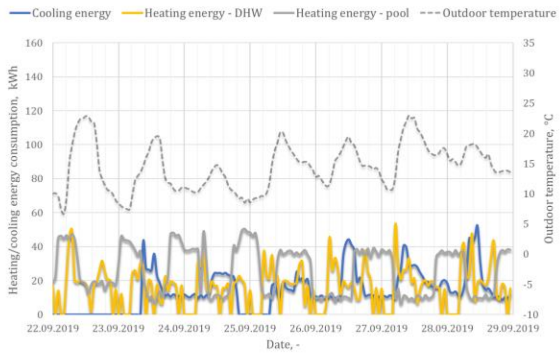

Fig. 8 - Variability of the energy demand of the cooling system, DHW system, and swimming pool heating system - on the example of the period from 22 to 28 September 2019.

In the last of the analysed month, a significant decrease in temperature leads to reducing the cooling demand. It can be seen that despite the temperatures kept below 25 °C during the day and falling below 12 °C at night, some users still use the room cooling system.

Daily energy demand is characterized by clear and repeatable patterns, mainly shaped by changes in the outside temperature and the habits of the average room user. The increase in demand for cooling energy is usually visible around the morning hours, and the amount of consumption depends, among other things, on the temperature of the outside air. The energy demand in the hotel is characterized by typical monthly and daily patterns mainly due to the amplitudes of the outside temperature. The lack of schedules for users' presence and uniform behaviour standards may cause the energy patterns to be less noticeable than, for example, in residential buildings or offices.

3.3 Factors influencing energy consumption

In the next step, the authors decided to check the relationship between the energy demand of individual systems and the parameters defined in the previous chapter. For this purpose, correlation indicators were used, which were calculated for each pair of variables. The results are summarized in Table 2.

Tab. 2 – Correlation coefficients between the hourly energy demand of the systems and defined factors.

Variables	Cooling energy	Heating energy DHW	Heating energy Pool
Outdoor temp	0.831	0.069	-0.410
Occupancy level	0.085	0.137	-0.111
Hour	0.127	0.144	-0.054

Except for the relationship between the cooling load and outdoor temperature, the remaining indicators do not show significant correlations between the variables. Nevertheless, the authors decided also to focus on the relationship between the heating demand of the swimming pool area and the outside temperature. The value of the correlation coefficient for this relation amounts to -0.410. It indicates a slight correlation. As can be seen in the table, the heating demand of the DHW system shows no clear dependence on any of the adopted parameters. Although the time of measurement was expected to affect the results obtained, the coefficient of 0.144 indicates the correlation as low. Figure 9 shows the relationship between the cooling demand and the outside temperature.

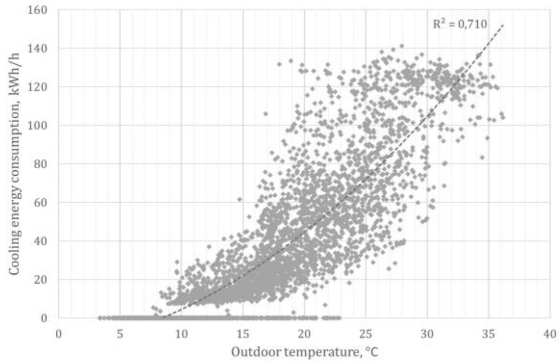

Fig. 9 - The relationship between the hourly cooling demand and the outside air temperature.

Figure 10 shows the relationship between the heating energy consumption for the needs of the swimming pool area and the temperature of the outside air. On the chart, a second-order polynomial trendline was added.

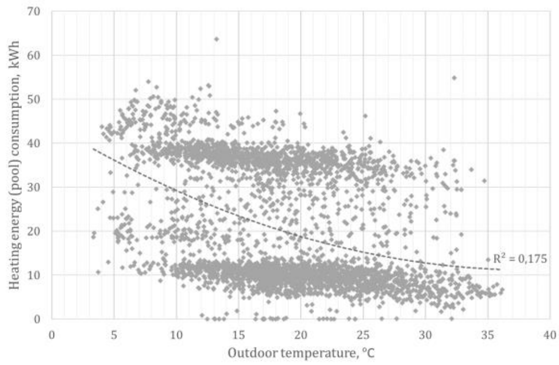

Fig. 10 - The relationship between the hourly heating demand of the swimming pool area and the outside air temperature.

Interestingly, the diagram clearly shows the division of energy consumption results into two groups arranged in parallel sections. However, no parameter has been identified that could lead to such a split.

Due to a large number of measurements and relatively low correlation coefficients in the hourly analysis, it was decided to carry out a correlation analysis for the daily average values. Therefore, the next step was to determine the correlation coefficients between the daily energy demand of individual systems and the three variables. In this case, the average daily outside temperature, the occupancy level, and day of the week (Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, Sunday) were used. The results are summarized in Table 3.

Tab. 3 – Correlation coefficients between the daily energy demand of the systems and defined factors.

Variables	Cooling energy	Heating energy DHW	Heating energy Pool
Outdoor temp	0.903	-0.355	-0.803
Occupancy level	0.107	0.480	-0.239
Day of the week	-0.040	0.343	-0.106

Of course, the change of the analysis from the hourly to the day values led to an increase in the values of individual factors. In this case, the dependence of the cooling demand and the pool heating energy demand on the outside temperature is determined by the correlation coefficients 0.903 and -0.803, respectively. For the energy consumption of the DHW system, a slight correlation was noticed for each of the three independent variables.

As in the case of the hourly analysis, it was decided to present the relations with the highest correlation coefficient on the chart. Figure 11 shows the relationship between the daily cooling demand and the outdoor air temperature.

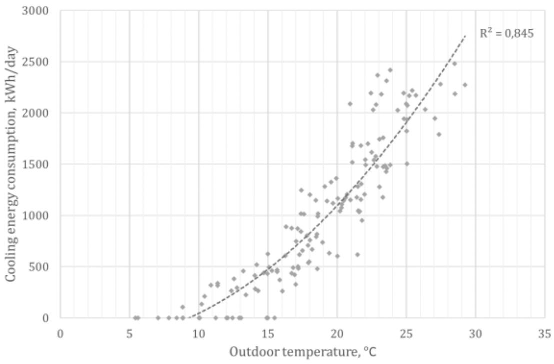

Fig. 11 - The relationship between the daily cooling demand and the outside air temperature.

Similarly, Figure 12 shows the relationship between the daily heating demand for the swimming pool area and the outside air temperature.

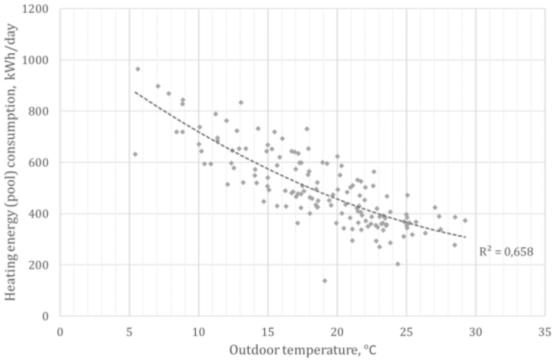

Fig. 12 - The relationship between the daily heating demand of the swimming pool area and the outside air temperature.

The highest correlation coefficient in the case of heating energy consumption for the DHW system was obtained for the relationship with the occupancy level. However, many values deviating from the determined trend were noticed. Therefore, it was decided to present this relationship in a categorized form. The data were divided into nine groups according to the occupancy level. The first category covers days with an occupancy in the range of 10 to 20%. The subsequent groups include ranges of every 10% up to the ninth category, which contains values between 90 and 100%. The results in the form of a box plot are shown in Figure 13.

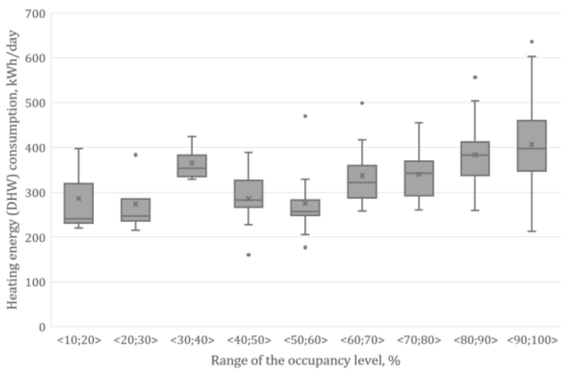

Fig. 13 - Relationship between daily heating demand for DHW and hotel occupancy.

As it is noticeable, there is an upward trend in energy consumption as hotel occupancy increases. The most deviating values were obtained for the range from 30 to 40%. It can be concluded that the presence factor is significant, but it does not completely define the energy demand. In this case, the preferences and habits of users, including the environmental awareness of hotel guests in terms of saving water, may be of key importance.

4. Conclusion

The analysis of the energy performance of the hotel facility was carried out for the summer period and considered both weekly and monthly variability. The research covered the energy demand of three systems of the hotel building, including the cooling system, DHW system, and pool heating system.

An in-depth energy analysis of the building is essential for reducing energy consumption in the facility. It also helps in adapting the building to current trends and energy requirements. As research has shown, in the summer period from June to August, the energy necessary to cool the building was significantly dominant. A relationship between the cooling load and the outside temperature was observed. High-level correlation is noticeable both for the analysis of hourly and daily values. In a daily analysis, for the outside temperature in the range of 10-15 °C, the energy needed for the proper operation of the cooling system is in the range of 0-625 kWh/day. On the other hand, for a temperature of 25-30°C, the energy consumption of the cooling system is in the range of 1500-2500 kWh/day. Such a wide range of changes may result from the preferences of users, who can individually regulate the temperature in their rooms. The average daily cooling demand in the analysed period varies from 299.4 kWh/day for May to 1,573.6 kWh/day for June. For a pool area heating system, the average daily energy consumption varies from 399.6 kWh/day for June to 657.4 kWh/day for May. The average daily heat demand for the DHW system for the research period was 358.6 kWh/day, changing from 322.2 to 445.1 kWh/day for months.

As the analysis showed, the energy performance of a hotel depends on many factors, sometimes very difficult to define and predict. The essential parameter influencing the energy demand in such facilities is the presence of users, including their behaviour, environmental preferences, or environmental awareness. The results showed a significant influence of the outside temperature on the cooling and heating demand of the swimming pool area. The hotel occupancy level is also a significant factor, especially for the DHW system demand. In the future, the research will be extended with other parameters of the outside air. This approach will allow providing a multi-parameter analysis. It may be crucial for their proper management and, as a result, reduction of energy consumption, especially in the case of energy consumption for the swimming pool part and the DHW system.

5. Acknowledgement

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Data Statement

The datasets generated during and analysed during the current study are not publicly available due to privacy restrictions but are available on request from the corresponding author.