Impact of Building Location on its Energy Demand

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Abstract. The paper presents the analyses involving energy demand of a single-family building located in various climatic zones. When designing buildings, special attention is paid to material and technological solutions, but often the climatic zone in which the building is to be located is not taken into account. Therefore, the article considers the location of building in five climatic zones in Poland and it investigates the impact of the location on its energy demand. It turned out that the location of the building in zone V, i.e. in the north-east of the country, determines the highest energy demand for heating compared to the rest of the country. The work demonstrates the impact of a climatic zone in which the building is located on its energy demand.

1. Introduction

The so-called sustainable construction can be considered in many perspectives. These comprise principally material modification [1], [2], [3] environmental acoustics [4], interior acoustics [5] or thermal protection [6]. Legal requirements involving the need to protect the environment have contributed to a dynamic development of interest in energy-efficient construction [7]. Energy-efficient buildings ensure low energy consumption, higher comfort (healthy microclimate inside the building), higher market value of the building, and additionally saving natural resources and lower environmental pollution. A very important role in sustainable construction is played by the impact of solar radiation on materials [8] or generally on the aging of materials subjected to the impact of weather conditions [9], [10].

In the energy-conscious designing process of a building, the following factors have to be considered among others:
- location on the land and shape of the building,
- proper shaping of the building's body - compact body, minimum number of north-facing windows,
- layout of rooms, depending on their purpose and duration of use,
- very good thermal insulation of envelopes,
- very efficient heating installation,
- ventilation, preferably mechanical one with heat recovery,
- applied renewable energy sources.

Properly adopted solutions regarding the body [11] and location of a building as well as structural, material [12], [13] and installation solutions of a building can significantly improve its heat balance.

The developing construction market is introducing solutions that are intended to significantly reduce the realization time of projects and to reduce the costs of their implementation. The choice of typical
projects is at present a common practice followed by investors in terms of the execution of investment projects. Time and costs have influence on their decisions, and therefore they often ignore the recommendations indispensable for an appropriate long-term use of buildings, which greatly affects energy efficiency of such buildings. In typical projects, heat balances for specific locations are already applied, but in many cases they are not modified [14]. The use of typical projects for the construction of energy-efficient buildings is associated with the need to adapt the energy balance to the conditions of a given location. The heat balance of energy-saving objects in view of a typical project assumes the maximum use of external and internal heat gains. The quantity and quality of gains and their impact on the object change with the location change of the building, and therefore, for energy-efficient buildings, it is essential to re-analyze the factors occurring at a given location, as they affect the annual energy balance of the object.

The impact of local external climate necessitates its identification, description and balancing, as it essentially determines the choice of architectural and structural solutions for the building and affects the implementation of the requirements for the building's interior [15], [16].

The influence of the location of residential buildings on their energy efficiency is still a current issue. In this study, the impact of the location of a single-family building on its energy demand was assessed. The values of the residential building's demand for usable energy for heating and ventilation were determined.

2. Methodology
Numerical analyses [17] were carried out involving the impact of building location on its demand for usable energy for heating and ventilation. The location of the object was assigned in line with 5 climatic zones into which the country's territory is divided. Additionally, the simulation results for the building in question located in one of the cities were compared with the results of the calculations. The calculations of energy demand were carried out using the calculation method in accordance with the methodology for determining energy performance of the building [18].

2.1. Description of the building
The analysis involved a single-family, one-story building with an unused attic, free-standing, without a basement. The residential building was designed for the purposes of this study.

The building sized 9.98 x 6.68 x 2.60 m (5.20 m in roof ridge) was designed with reference to the solutions for energy-efficient buildings. The designed building had the most compact shape possible, with the layout of the rooms allowing to meet the basic living needs of a family of three. Figure 1 shows the ground floor plan of the building.

The usable part of the building consists of 5 rooms. On the south side, in the living room with a kitchenette (day zone), there are two large windows, which are to increase heat gains from the environment through solar radiation. Above the heated part, a non-usable attic was designed which limits heat loss from the usable part.

Continuous heating was applied, maintaining a constant temperature of 20°C in the usable room, and natural ventilation (gravity ventilation and infiltration) was adopted. Internal gains from the user and devices were ignored.
Figure 1 Projection of the usable part of the building

All envelopes were selected to meet the requirements of the current technical regulations in Poland - Table 1.

Table 1. Properties of the envelope

| No | Envelope type / envelope thickness, m | Structure | Thermal transmittance $U(U_{in})$, W/m²K | Thermal transmittance $U_{C(max)}$, W/m²K (from 2021) |
|----|--------------------------------------|-----------|----------------------------------------|--------------------------------------------------|
| 1  | External wall 0.480                  | Cement-lime plaster EPS polystyrene Solid brick wall Gypsum plaster | 0.19 | 0.20 |
| 2  | Internal wall 0.280                  | Gypsum plaster Solid brick wall Gypsum plaster | 0.75 | 1.00 |
| 3  | Ceiling over usable area 0.495       | Concrete screed Mineral wool (ceiling) Reinforced concrete ceiling Gypsum plaster | 0.15 | 0.15 |
| 4  | Floor on the ground 0.890            | Ceramic tiles Concrete screed Polystyrene Lean concrete Compact gravel Native soil | (0.28) | 0.30 |
| 5  | Windows                              | Triple glazing | 0.90 | 0.90 |
| 6  | Exterior door                         | Insulated | 1.30 | 1.30 |
2.2. Climatic data

Data from a typical meteorological year (TMY) for 10 Polish cities was used in the numerical analyses. Two cities were selected from each of the 5 climatic zones due to diversity of microclimates. The TMY data for the selected cities was developed based on 30-year (1971-2000) measurements. Table 2 presents the distribution of cities for which the simulations involving the demand for usable energy were performed.

Table 2. Location of the examined cities

| No | Zone | City     | Latitude | Longitude |
|----|------|----------|----------|-----------|
| 1  | I    | Szczecin | 54°36’N | 18°49’E  |
| 2  | I    | Łeba     | 54°45’N | 17°33’E  |
| 3  | II   | Zielona Góra | 51°56’N      | 15°32’E |
| 4  | III  | Koło     | 52°12’N | 18°40’E  |
| 5  | III  | Katowice | 50°14’N | 19°02’E  |
| 6  | III  | Warszawa | 52°10’N | 20°58’E  |
| 7  | IV   | Olsztyn  | 53°46’N | 20°25’E  |
| 8  | IV   | Białystok| 53°06’N | 23°10’E  |
| 9  | V    | Zakopane | 49°18’N | 19°58’E  |
| 10 | V    | Suwałki  | 54°06’N | 22°57’E  |

2.3. Computer simulations

The numerical analyses were carried out in the program Environmental Systems Performance ESP-r. The ESP-r program permits to model the flow of mass and energy, giving results which reflect the actual building environment [17]. In this program the discretization of space is carried out using the finite volume method.

The model of the object is built by dividing it into zones. Each zone is assigned material and construction parameters, flows of energy and mass, heating and air conditioning systems. The interactions between individual zones are sequentially determined.

Figure 2. Numerical model of the residential object
The numerical model of the building corresponds to the designed residential building (geometry of the object, boundary conditions, building envelopes with specific physical properties of materials, heating and ventilation system) – Figure 2.

The energy analysis performed in the computer program required the use of data in the form of hourly values available on the MIiR website. The TMY climatic data was prepared in a text file, and then converted (from a text file to the ASCII format) and implemented into the simulation program.

2.4. Calculations

The calculations involving energy demand were made in line with the methodology for determining energy performance of a building presented in the Regulation [18]. The calculations were used to compare the results of the calculation method with the results of the simulation method to confirm the correctness of the numerical analyses.

The following items were determined in succession:
- heat loss coefficient by transmittance through the outer envelope and ventilation,
- monthly heat losses by transmittance and ventilation,
- monthly heat gains by insolation and internal heat gains as well as their utilization factor,
- monthly demand for usable heat for heating and ventilation,
- annual demand for usable heat for heating and ventilation.

3. Results and discussions

Figures 3 and 4 illustrate the demand for usable energy for 10 locations for which simulation was made in the ESP-r program. The presented data clearly demonstrates that the lowest energy demand was obtained for the building located in the city of Koło, which was over 5% lower compared to Katowice and amounted to 5920.1 kWh/year. The highest energy consumption was obtained in Suwałki, where the demand was over 18% higher than that in Katowice and amounted to 7605.7 kWh/year. Only two cities had lower value of energy consumption - Koło and Szczecin (6031.4 kWh/year), which was lower by over 3% than that in Katowice. These cities are located in the climatic zones I and II. And Łeba (by 7%), Zielona Góra (by 2.5%), Warsaw (by 3%), Olsztyn (by 12%), Białystok (by 13%), Zakopane (by 13%) had respectively higher demand for usable energy as compared to Katowice.

![Figure 3](image-url)  
**Figure 3.** Annual energy demand of a building for 10 locations - numerical method.
The value of annual usable energy demand for heating and ventilation obtained by means of the simulation program for the building located in Katowice was 6231.10 kWh/year. Table 3 presents the values of annual energy demand for individual rooms in the building. The highest demand was obtained for the living room - salon with a kitchenette (01 - 2334.5 kWh/year), while the lowest one for the bathroom (04 - 724.1 kWh/year).

**Table 3. Annual usable energy demand in individual rooms of the building for the city of Katowice - numerical method**

| Zone | Town       | Room | Usable energy demand for heating and ventilation, kWh |
|------|------------|------|-------------------------------------------------------|
| III  | Katowice   | 01   | 890.0                                                 |
|      |            | 02   | 2334.5                                                |
|      |            | 03   | 914.8                                                 |
|      |            | 04   | 724.1                                                 |
|      |            | 05   | 1367.7                                                |

**Figure 4. Monthly usable energy demand of the building for 10 locations - numerical method**

Also the real, dynamic response of the investigated object should be examined, which can only be obtained through simulations:
- variability of internal temperature in the selected room, with the preset internal temperature \( T_i \geq 20^\circ C \) (Figure 5),
- variable, dynamic demand for energy (Figure 6).
Then, the methods were compared and the correctness of the numerical analyses, which enable much more detailed analyses, was confirmed. The values involving the demand for usable energy for heating and ventilation - obtained by the numerical and calculation methods - are presented in Table 4. The differences in the supplied energy between the two applied methods do not exceed 1%.

Figure 7 presents the difference in the assessment of monthly usable energy demand obtained with the calculation method according to [18] and with the numerical method in the ESP-r simulation program [17].

| Zone | City    | Method      | Usable energy demand for heating and ventilation, kWh |
|------|---------|-------------|------------------------------------------------------|
| III  | Katowice| calculation | 6177.67                                              |
|      |         | numerical   | 6231.10                                              |
Figure 7. Monthly usable energy demand for the building in Katowice - numerical and calculation methods

4. Conclusions
The designing process of a single-family building, with special attention paid to the selection of appropriate thermal parameters of envelopes and to the shape of the building's body, can significantly contribute to the reduction of thermal energy consumption. The examined residential building was designed to meet the requirements for thermal insulation of envelopes. Also the layout of the rooms and the use of glazing aligned with the directions of the world were carefully planned. Additionally, the most compact body of the building was adopted, which is characteristic of energy-saving buildings. Finishing elements such as loggias or balconies were not used, in order to reduce the development of thermal bridges which increase heat loss of the building.

The simulations performed in the ESP-r program allowed to determine differences in the demand for usable energy for the same building but located in a different city.

The location of a single-family house in the climate zone V (Suwałki), where the average annual outside temperature is the lowest (5.5°C), demonstrated that the demand for usable energy for heating is the highest. And the location of the building in zone II (Koło) demonstrated that the demand is the lowest compared to the other 9 locations, where the average annual outside temperature is the highest in relation to the entire country and amounts to 7.9°C.

The comparison of the obtained results for the selected locations demonstrated the importance of the external factor such as local climate of the residential building. It should be remembered that a change in the location of the building is associated with a simultaneous change in climatic parameters affecting the building, such as insolation of the object or average air temperature. For the designed building, each time located in the same way in terms of world sides orientation, the value of the demand for usable energy changed.

References
[1] M. Małek, W. Łasica, M. Jackowski, M. Kadela, “Effect of waste glass addition as a replacement for fine aggregate on properties of mortar”, Materials, 13(14), 3189, 2020, doi: 10.3390/ma13143189.
[2] M. Kadela, A. Kukielska, M. Małek, “Characteristics of lightweight concrete based on a synthetic
polaryzacyjne właściwości tego obiektu”, *Materials*, 13(21), 4979, 2020, doi: 10.3390/ma13214979.

[3] A. Nowoświat, J. Golaśzewski, “Influence of the variability of calcareous fly ash properties on rheological properties of fresh mortar its additions”, *Materials*, 12(12), 1942, 2019, doi: 10.3390/ma12121942.

[4] J. Sadowski, J. Nurzyński, “Architectural and environmental acoustics as an aspect of sustainable development”, *Archives of Acoustics*, 32(4), pp. 971-982, 2007.

[5] A. Nowoświat, M. Olechowska, “Investigation Studies on the Application of Reverberation Time”, *Archives of Acoustics*, 41(1), pp. 15-26, 2016, doi: 10.1515/aoa-2016-0002.

[6] T. Hong, M. Ferrando, X. Luo, F. Causone, “Modeling and analysis of heat emissions from buildings to ambient air”, *Applied Energy*, 277, 115566, 2020, doi: 10.1016/j.apenergy.2020.115566.

[7] L. Belussia, B. Barozzia, et al., “A review of performance of zero energy buildings and energy efficiency solutions”, *Journal of Building Engineering*, vol. 25, 100772, 2019, doi: 10.1016/j.jobe.2019.100772.

[8] P. Krause, A. Nowoświat, “Experimental studies involving the impact of solar radiation on the properties of expanded graphite polystyrene”, *Energies*, 13(1), 75, 2020, doi: 10.3390/en13010075.

[9] J. Bochen, A. Nowoświat, “Service life assessment of renders on the basis of changes of physical and mechanical properties during simulated weathering”, *Construction and Building Materials*, 229, 117003, 2019, doi: 10.1016/j.conbuildmat.2019.117003.

[10] A. Nowoświat, J. Bochen, L. Dulak, R. Żuchowski, “Investigation studies involving sound absorbing parameters of roadside screen panels subjected to aging in simulated conditions”, *Applied Acoustics*, 111, pp. 8-15, 2016, doi: 10.1016/j.apacoust.2016.04.001.

[11] I. Pokorska-Silva, M. Kadela, and L. Fedorowicz, “A reliable numerical model for assessing the thermal behavior of a dome building”, *Journal of Building Engineering*, 32, 101706, 2020, doi: 10.1016/j.jobe.2020.101706.

[12] I. Pokorska-Silva, A. Nowoświat, and L. Fedorowicz, “Estimation of heat retention index basing on temperature measurements,” *IOP Conference Series: Materials Science and Engineering*, 471, 062014, 2019, doi:10.1088/1757-899X/471/6/062014.

[13] I. Pokorska-Silva, M. Kadela, M. Małek and L. Fedorowicz, “An assessment of the thermal behavior of envelope surface coatings with different colors”, *Polymers*, 13(1), 82, 2021, doi: 10.3390/polym13010082.

[14] K. Kurtz-Orecka, M. Najder, “Building location and orientation and energy demand for space heating and ventilation of low energy building“ (“Lokalizacja i orientacja budynku niskoenergetycznego a zapotrzebowanie na energię do ogrzewania i wentylacji”), *Rynek Instalacyjny*, 7-8, pp. 30-34, 2014.

[15] A. Nowoświat, and I. Pokorska-Silva, “Outdoor climate parameters and heat energy consumption for the needs of heating the building”, *IOP Conference Series: Materials Science and Engineering*, 960, 032009, 2020, doi:10.1088/1757-899X/960/3/032009.

[16] I. Pokorska-Silva, M. Kadela, and L. Fedorowicz, “Variations of ground temperature in shallow depths in the Silesian region”, *IOP Conference Series: Materials Science and Engineering*, 603, 052024, 2019, doi: 10.1088/1757-899X/603/5/052024.

[17] J.A. Clarke “Energy Simulation in Building Design” 2nd ed. Oxford, UK: Butterworth-Heinemann, 2001.

[18] Rozporządzenie Ministra Infrastruktury i Rozwoju z dnia 27 lutego 2015 r. w sprawie metodologii wyznaczania charakterystyki energetycznej budynku lub części budynku oraz świadectw charakterystyki energetycznej (Dz. U. 2019 poz. 1829).