The influence of climate change on the energy performance and thermal comfort in building

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The article describes the conducted simulations of changing temperatures in individual zones of the exemplary building and its energy demand for the needs of ventilation, heating and air conditioning related to the forecasted changes in external temperatures.

The research show that the average global temperature on Earth has increased by around 0.8°C since 1880. Two-thirds of the global warming has happened since 1975, at a rate of about 0.15 – 0.20°C per decade [1]. This value does not reflect real global warming effect, particularly in Europe. The average, global temperature increase refers to the entire surface of the planet. Temperatures that we experience locally and in short periods may differ significantly due to predictable cyclical events i.e. night and day, summer and winter, as well as difficult to predict climate factors such as wind speed and precipitation height.

The current warming process is of particular importance because climate change has been the effect of human activity since the mid-twentieth century and the speed of change is very fast. In addition, the largest increases in average annual temperature have been recorded in the last 35 years, and since 2010, the 5 warmest years have been recorded since global temperature measurements are being conducted. 2016 was not only the warmest year, but its 8 from 12 months (January to September except June) proved to be the warmest in the register for the corresponding months. The above phenomena have a significant impact on the variability of climatic factors, which determine the basis of the technical regulations referring to buildings. Their proper consideration and adaptation to real conditions is the foundation for the proper functioning of the construction sector. It will also help in reducing the negative influence of buildings on natural environment [2]. The environmental impact of buildings has been most frequently analysed yet, limiting itself to the analysis of energy demand [3].

The subject of the paper is the analysis of the impact of climate change on the energy performance and comfort of use of the building. The object on which the simulation was carried out is the Maison Air et Lumière building [4], which concept was developed as part of the Model Homo 2020 project.

The analysis was based on the study of climate change in Poland over several decades and on the simulation results determining the energy consumption and thermal comfort parameter of the building now and for forecast climate data. After analyzing the current climate, the predicted climatic scenarios were determined using scientific sources, and simulation calculations were performed based on them. The obtained results were the basis for comparative analysis in the field of energy consumption and comfort. Calculations were made for various equipment variants and climate change scenarios.

Climate change variants

The analysis of the current climate was made on the example of the city of Kielce and next the predicted values of the climatological factors were estimated using and the tool WeatherShift [5] and the Municipal Adaptive Plan for the city of Kielce [6]. Calculations were made for RCP (Representative Concentration Pathways) 4.5 and RCP 8.5 scenarios for 2035 and 2065. In case of RCP 4.5 there is an additional 4.5 W/m^2 of radiation excitation in 2100, and in the case of RCP 8.5 there is an additional 8.5 W/m^2 of radiation excitation. It is the result of increasing in the concentration of carbon dioxide CO_2 in the atmosphere in the 21st century.

The scenarios were developed by the Intergovernmental Panel on Climate Change (IPCC) as the basis for climate forecasts. Based on the adopted greenhouse gas concentration values, climate models were developed for subsequent years.

Undoubtedly, the most pessimistic picture of climate change considered by the IPCC is the RCP 8.5 scenario called "business as

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usual". Extreme, but likely, assumptions were made that represent the worst possible climate forecast. For the RCP 4.5 and RCP 8.5 scenarios a forecast of the average monthly temperature change was prepared using the WeatherShift tool. A forecast climate was simulated for 2035 and 2065 for two scenarios. The carried out calculations were the basis for development of weather data for scenarios 2035 RCP 4.5, 2065 RCP 4.5, 2035 RCP 8.5 and 2065 RCP 8.5. Comparison of changes in extreme temperatures is shown in Figure 1.

According to the RCP 8.5 scenario, the average monthly temperature will increase in each month of the year. What's more, in the following years the temperature will maintain the increase trend and the intensity of this increase will be at a similar level. There was also a lack of significant difference between individual month increases during the year for the periods analyzed. The RCP 8.5 scenario presents a significantly more dangerous vision for the climate, than the RCP 4.5 scenario. Analyzing only temperatures, it can be stated that for 2065 the average monthly temperature values are higher for the RCP 8.5 scenario by about 40% compared to the RCP 4.5 scenario. The analysis of climate took additionally into account the change of relative humidity of the outside air, wind speed and solar radiation intensity.

The projected relative humidity values for the RCP 8.5 scenario indicate a greater decrease in the relative humidity value over the years compared to the RCP 4.5 scenario. These values still do not change significantly for the winter months, i.e. December, January, February, while in the summer months these changes already reach significant values and the relative humidity is reduced by a few percent. As for wind speed no major changes are expected for the analyzed scenarios.

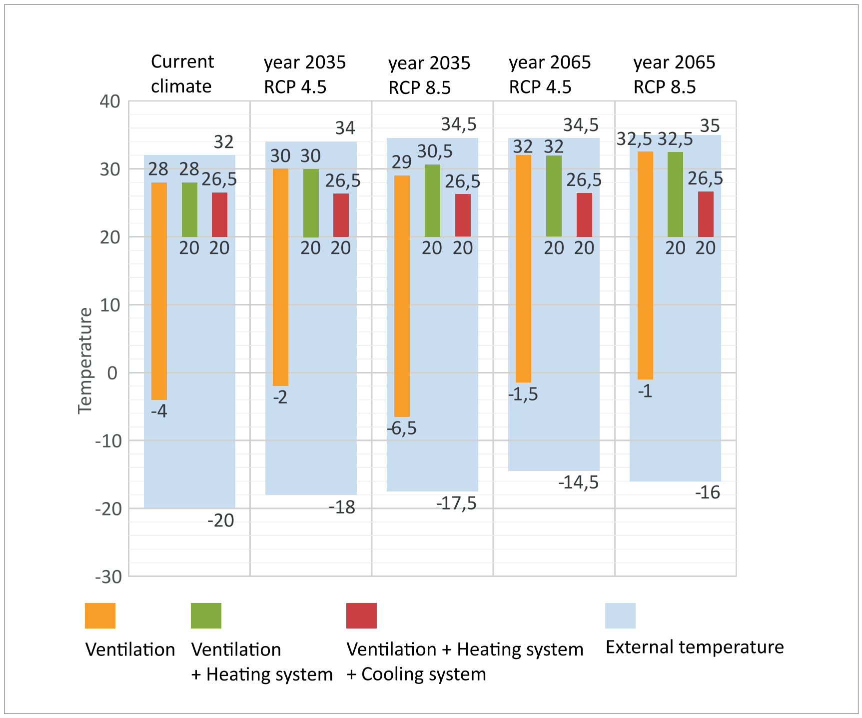

Figure 1. Change of external and internal temperature for various climate change scenarios and variants of equipping the building with installation systems

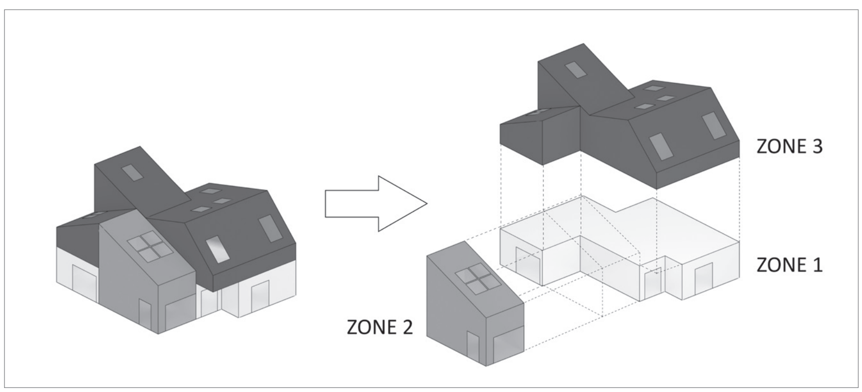

Figure 2. 3D building model and division into three thermal zones

Building model

The subject of the analysis was a single-family residential building Maison Air et Lumière. It represents a new generation of houses that put the greatest emphasis on the quality and comfort of life of their residents. The building was part of the Model Homo 2020 project, whose vision was climate neutral buildings with a high standard of use. The whole project was initiated in 2009 and included the construction of 6 houses in 5 European countries.

The building itself is based on the modular architectural concept of a gable roof, thanks to which it can be adapted to various variants depending on location, orientation and use, which increases its ability to capture sunlight and makes it an energy-efficient home. The architecture of the building combines 3 modules matched to each other. In addition, the modular concept of the house allows for adaptation to other arrangements such as terraced houses or semi-detached houses. Regardless of the size of the planned building, urban or rural environment, the flexibility of the architectural concept allows to create an original design built from any configuration of modules, taking into account the needs of high comfort of living and achieving optimal energy efficiency.

Before starting the simulation, the building 3D model was created in SketchUp. Using the dedicated tool, the developed model was imported into the TRNSYS program to analyze the impact of climate change. The building model was divided into 3 thermal zones, taking into account the various purposes of the rooms in the building (Figure 2).

Research method

In the main part of the analysis, the energy and temperature simulation of the designed building was carried out in the TRNSYS software for the current climate and forecasted climate changes. It is an extremely flexible software environment used to simulate the behaviour of technical systems and energy performance calculation. Connections between individual systems and the building are created in a friendly graphic environment.

The input files to the program were:

- the climate data for the city of Kielce saved in the .epw format for the current climate and scenarios the RCP 4.5 and RCP 8.5 for year 2035 and 2065,
- the designed and defined Maison Air et Lumière building model in TRNBuild software, which is an integral TRNSYS tool.

As a result of the simulation, the following output data was obtained:

- temperature data needed to assess comfort in an hourly schedule for the entire year,
- monthly energy consumption values for energy performance analysis.

The analysis of the impact of climate change on the climate comfort and characteristics

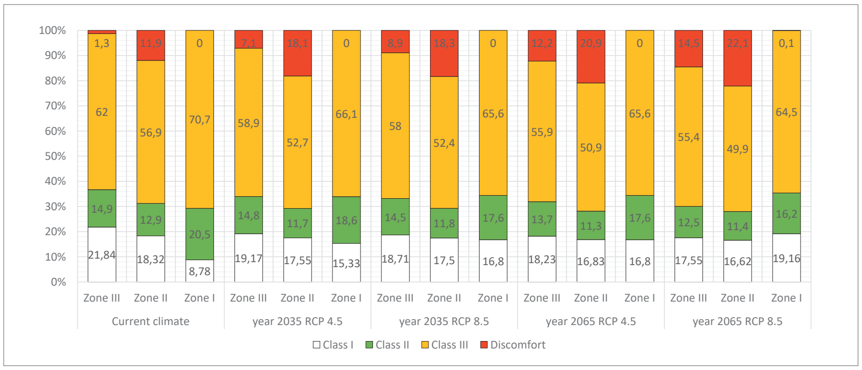

Figure 3. Comfort assessment for a variant with a heating system for different climate change scenarios

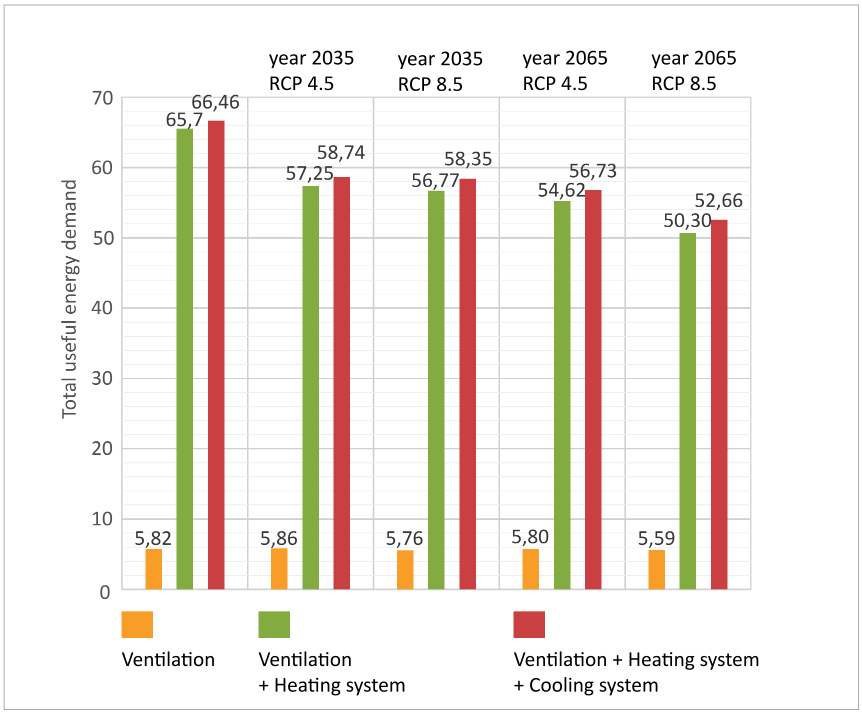

Figure 4. Consumption of useful energy for ventilation, heating and cooling – summary

was made for four different scenarios and current climate as well as three different variants of building technical systems. The level of comfort was assessed in accordance with standard PN-EN 15251 regarding the criteria of the internal environment and available studies [7, 8]. The calculated values of the indoor temperature (operating temperature) were compared with the minimum values for the heating season and the maximum values for the cooling season.

The thermal comfort categories refer to the following classes:

- Class I – rooms with high requirements, recommended for very sensitive people (disabled, young children, the elderly), operating temperature ≥ 21.0°C in the heating season, operating temperature ≤ 25.5°C in the cooling season,
- Class II – rooms with normal requirements (new and modernized buildings), operating temperature ≥ 20.0°C in the heating season, operating temperature ≤ 26.0°C in the cooling season,
- Class III – rooms with an acceptable level of requirements (existing buildings), operating temperature ≥ 18.0°C in the heating season, operating temperature ≤ 27.0°C in the cooling season,
- Class IV – values outside the range of the above categories hereinafter referred as discomfort.

Results and discussion

The simulation carried out in TRNSYS 17 software provided operating temperature values for 8760 hours a year for three thermal zones. These values were compared with the criteria for thermal comfort of classes I, II, III and IV (discomfort). For a building located in Kielce with only ventilation switched on, a very high discomfort was registered for all analyzed variants can be determined at the level of 70% (average). In the same time it was observed that with the warming of the climate an increase in discomfort during the summer season was observed for subsequent climate variants. Almost 100% of the discomfort was reported in the heating season, which is the result of the fact that there is no heating system. After its application, the lack of discomfort was noted for each variant only in thermal zone 1, while the greatest discomfort occurs regularly in thermal zone 2. The discomfort due to too high operative temperature in rooms during the summer season still occurs as shown in Figure 3.

After the application of ventilation, heating and cooling, almost no discomfort for each examined climatic scenario was noted. With global warming, the consumption of usable energy for ventilation and heating is reduced, but increases for cooling, which is only requested in the summer months, i.e. June, July and August. Total useful energy demand for ventilation, heating and cooling for the current climate is 66.46 [kWh/(m^2·year)] and according to RCP 4.5 will decrease to 58.74 for 2035 and 56.73 for 2065. The slightly larger decrease is projected for RCP 8.5 and according to it, energy consumption will decrease to 58.35 [kWh/(m^2·year)] in 2035 and 52.66 in 2065. The results of the demand for usable energy are shown in Figure 4.

Conclusions

On the foundation of the tests, simulations and analyses conducted, it is concluded that:

- as a result of global warming, it is forecasted that the temperature will increase and the relative humidity will decrease over the years,
- the comfort of the building is largely dependent on the external environment and the technical systems used,
- for predicted climate scenarios, there is the increase in discomfort with respect to the current climate during the summer season without the use of a cooling system:
  - from 2.6% to 29% (increase of 1156 hours with temperatures above 27°C) in the thermal zone of the building model 3,
  - from 23.7% to 44.2% (increase of 897 hours with temperatures above 27°C) in the thermal zone of the building model 2.
- for the predicted climate scenarios, the heating utility energy consumption decreases to 23.44% in relation to the current climate and the cooling utility energy consumption increases to 232.35% in relation to the low energy consumption (0.88 [kWh/(m^2·year)]) of the current climate.

The analyses confirm that buildings will use less energy for heating. The discomfort during the summer will increase, which may have a negative impact on the health of the residents. Therefore buildings should be designed to provide comfort in summer, also in locations such as Kielce. One of the solutions could be the systems for solar heat gains storage [9].

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Summary: Global warming causes changes in the buildings' demand of energy and the comfort of their users. This requires the modification of heating systems and air conditioning systems. The article describes the conducted simulations of changing temperatures in individual zones of the exemplary building and its energy demand for the needs of ventilation, heating and air conditioning related to the forecasted changes in external temperatures. The obtained results show decreasing energy demand for heating and its increasing demand for cooling. This is particularly important for designers, both architects and constructors and installers, who will have to face changing climatic conditions in their projects.
Key words: climate change, energy performance, thermal comfort, TRNSYS

Streszczenie: WPŁYW ZMIAN KLIMATU NA CHARAKTERYSTYKĘ ENERGETYCZNĄ I KOMFORT CIEPLNY BUDYNKU. Obserwowane obecnie ocieplenie klimatu powoduje, ze zmienia się zapotrzebowanie budynków na energię oraz komfort ich użytkowników. Wiąże się to z koniecznością modyfikacji systemów instalacji cieplnych i stosowania systemów klimatyzacji. W artykule opisano przeprowadzone symulacje zmieniających się temperatur w poszczególnych strefach przykładowego budynku oraz jego zapotrzebowania na energię na potrzeby wentylacji, ogrzewania i klimatyzacji związanych z prognozowanymi zmianami temperatur zewnętrznych. Uzyskane wyniki pokazują zmniejszające się zapotrzebowanie energii na ogrzewanie oraz jej rosnące zapotrzebowanie na chłodzenie. Jest to szczególnie istotne dla projektantów, zarówno architektów i konstruktorów, jak i instalatorów, którzy będą musieli zmierzyć się w swoich projektach ze zmieniającymi się warunkami klimatycznymi.
Słowa kluczowe: zmiana klimatu, charakterystyka energetyczna, komfort cieplny, TRNSYS