WARSAW UNIVERSITY OF TECHNOLOGY Index 351733
FACULTY OF CIVIL ENGINEERING
COMMITTEE FOR CIVIL AND WATER ENGINEERING
POLISH ACADEMY OF SCIENCES ISSN 1230-2945

DOI: 10.24425/ace.2021.138041

ARCHIVES OF CIVIL ENGINEERING

Vol. LXVII ISSUE 3 2021

s. 29–42

Research paper

Analysis of climate change and its potential influence on energy performance of building and indoor temperatures, part 1: Climate change scenarios

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Abstract: The subject of this paper is to analyse the climate change and its influence on the energy performance of building and indoor temperatures. The research was made on the example of the city of Kielce, Poland. It was was carried out basing on the Municipal Adaptive Plan for the city of Kielce and climate data from the Ministry of Investment and Development.The predicted, future parameters of the climate were estimated using the tool Weather Shift for Representative Concentration Pathways (RCP). The analysis took into consideration the RCP4.5 and RCP8.5 scenarios for years 2035 and 2065, representing different greenhouse gas concentration trajectories. Scenario RCP4.5represents possible, additional radiative forcing of 4.5 W/m^2 in 2100, and RCP8.5 an additional 8.5 W/m^2. The calculated parameters included average month values of temperature and relative humidity of outdoor air, wind velocity and solar radiation. The results confirmed the increase of outdoor temperature in the following year. The values of relative humidity do not change significantly for the winter months, while in the summer months decrease is visible. No major changes were spotted in the level of solar radiation or wind speed. Based on the calculated parameters dynamic building modelling was carried out using the TRNSYS software. The methodology and results of the calculations will be presented in the second part of the paper.

Keywords: climate change, outdoor parameters, climate change scenarios, Representative Concentration Pathways

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1. Introduction

Climate change is one of the major challenges of our century and is becoming one of the greatest challenges of our society. Climate change for the next decades is faster than anything world has experienced since the beginning of our civilization and will led us to unprecedented conditions for our society [1]. Studies and measurements of climatic factors carried out in various parts of the world proves that the climate is warming up [2], [3], [4]. The temperature rise in the world is an unfavorable phenomenon, that increase in the intensity and frequency of climatic events and several derivative instruments that are not neutral to economic and social development the world. They can lead to more frequent occurrences of anomalies weather such as flood [5], drought [6], [7], [8], [9] or tornadoes, as well as animal migration [10]. In addition, the result of a global increase in average temperature of air and oceans is melting of glaciers [11], [12], which, on the other hand, leads to an increase in the average sea level [13], [14], [15]. Intensity of growth temperature is geographically diversified [16] and has a higher intensity in higher latitudes of the northern hemisphere. With the projected amplified increase in surface air temperature in the Arctic until 2100 [17] the active layer, will warm and thereby thawing currently perennially frozen ground [18], [19]. The trend of global warming fosters the expansion of areas not yet affected by drought, but also increases the frequency of extreme rainfall in other areas [20]. Regardless of whether the reason for this trend human activity is [21], or natural variability, evidence points to growth of temperature all over the world since the beginning of the revolution industry.

Allowing for serial correlation and annual uncertainties the increase in the average global temperature on Earth was 0,2°C per decade (0,61 ±0,16°C) over last 30 years (up to 2000) [4], [22]. Another study indicates that this value does not reflect the real scale of global warming in Europe. Global temperature value represents the average on the entire surface of the planet. Temperatures that we experience locally and in short periods may be significantly different due to predictable cyclical events, i.e., night and day, summer, and winter, and difficult to predict wind [23] and precipitation patterns.

The current global warming tendency is of importance because climate variability is the result of human activity from the mid-twentieth century [24] and is proceeding at an unprecedentedly fast pace. In addition, the largest increases in the average annual temperature were recorded in the last 35 years, and since 2010 have been recorded the 5 warmest years since the temperature's studies are conducted in the world. However, 2016 was not only the warmest year, but its 8 out of 12 months (from January to September except for June) proved to be the warmest month in the registry. The above phenomenon has a significant impact on variable climate parameters, which, apart from losses on heat transfer through external partitions and heating of ventilation and infiltrating air [25], have a significant impact on the comfort of the use [26]. Climate change may have several direct and indirect adverse health effects in the indoor environment related to building overheating, indoor air pollution, biological contamination, and flooding and water damage. [27] From the energy performance perspective some studies, e.g. made for Italy indicate a general reduction in energy consumption [[28]]. However, there is a certain lack of material concerning the implication of climate change and relevant adaptation measures in cold climates [29]. Therefore, it is very important to appropriate consider and analyze the changes in order to secure proper functioning of the construction sector [[30]]. New climate parameters can have influence on construction practice and standards. The need of buildings stock decarbonization in EU by 2050 is a very good example. The conducted studies should include possible changes of renewable energy sources and insulation performance [31], [32]as well as economic aspect (change of exploitation cost due to change of energy demand) especially by developing the NZEB for new [33] and renovated buildings [34]. This two part publication cycle tries to answer on question regarding the scale of possible changes and their influence building performance.

2. The analysis of the climate change in Kielce, Poland

To check the connection with the occurring climate changes and its impact on the comfort of use of residential premises (located in Poland) it is necessary to consider the range of weather conditions, that include:

- air temperature,
- relative humidity,
- wind speed and solar radiation.

2.1. Temperature

Kielce was selected for a more detailed analysis of climate change. The analyze was carried out basing on the following documents and tools:

- the Municipal Adaptive Plan for the city of Kielce [35],
- the tool Weather Shift which uses the climate data for modelling the climate change results due to Representative Concentration Pathways (RCP) [36],
- data from the Ministry of Investment and Development [37].

All measurement data were taken from the meteorological station Kielce – Sukow, which is located at 260 m above sea level, 8 km from the capital of the Swietokrzyskie province.

This article uses two RCP scenarios for changing the carbon dioxide concentration. The values specify the estimated amounts of radiation forcing by greenhouse gases in 2100. The analysis included changes for 2030 and 2050. Representative Concentration Pathway 4.5 (RCP4.5) means an additional 4.5 W/m^2 of radiative forcing in 2100, and Representative Concentration Pathway 8.5 (RCP8.5) [38] an additional 8.5 W/m^2 [39]. These scenarios were developed by the Intergovernmental Panel on Climate Change (IPCC) [40] as the basis for climate forecasts.RCP 8.5 is the least favourable scenario, but represents a situation where emissions continue to rise throughout the 21st century. RCP 4.5 is an intermediate scenario and, according to the Authors, much more probable than RCP 2.6, because of the constantly increasing CO_2 emissions (disregarding the impact of a pandemic). Therefore, this two scenarios were considered – the most pessimistic and an intermediate scenario. Based on the obtained data, climate models were developed for subsequent years. Based on data published by the polish Ministry of Investment and Development, the monthly average temperature values were compiled in the form of a chart (fig. 1).

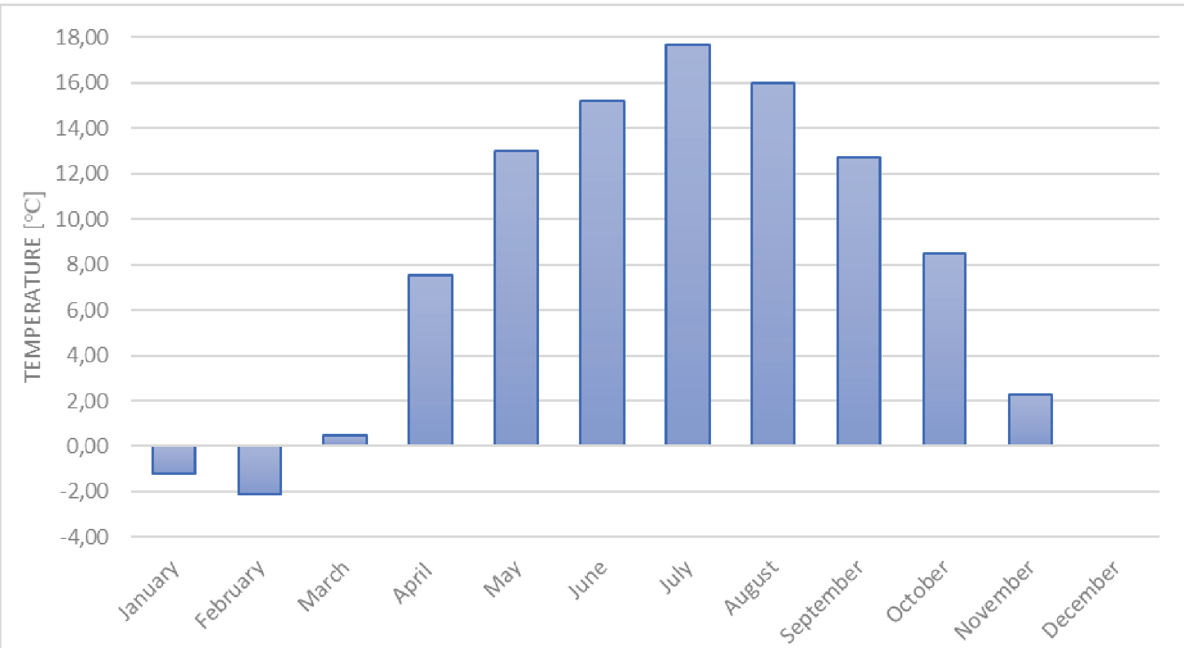


Fig. 1. The monthly average dry bulb temperature in Kielce [37]

The annual distribution of temperatures represents a typical moderate European climate. In the winter months, the temperature fluctuates around 0°C (January, February, March, and December). It is worth noting, however, that the minimum temperature values for these months can reach values below –10°C (e.g., for January the minimum recorded temperature is –19,5°C). The amplitude of measured, extreme monthly temperatures for the winter season is significant and ranges from 30,1 K (for January) to 20,5 K (for December). Comparable relationship can be noticed in the summer period, where the average monthly temperature indicates that the studied area is in a temperate climate. The largest amplitudes can be seen in the months of January (30,1 degrees) and August (29,6 degrees), which are the coldest and the warmest months in the year.

According to forecast data published in the CAP (Climate Adaptation Plan) [35], the number of days of the year with the temperature above 30°C will grow at a small pace, from 12,6 days in 2006–2015, through 13,9 days in 2026–2035, until to the value of 16,5 days in the decade 2046–2055. The above data show that because ofthe progressive change in the climate, the number of hot days will increase in Poland. The incident of long-term and very serious heat-related events is also confirmed by other scientific studies [41]. In the summer of 2015, a heat wave was recorded in Poland – the strongest since 1950 [42], [43].

A similar analysis as for the summer season was carried out for the winter period (CAP). Analogously, extremely low temperatures (below –10°C) in a series of 3 days have been defined as periods of cold. Kielce, due to its location in the vicinity of the Swietokrzyskie Mountains are more exposed to the occurrence of periods of cold weather than heat waves. It is worth noting, however, that the disproportions in this area are decreasing as a result of progressive global warming.

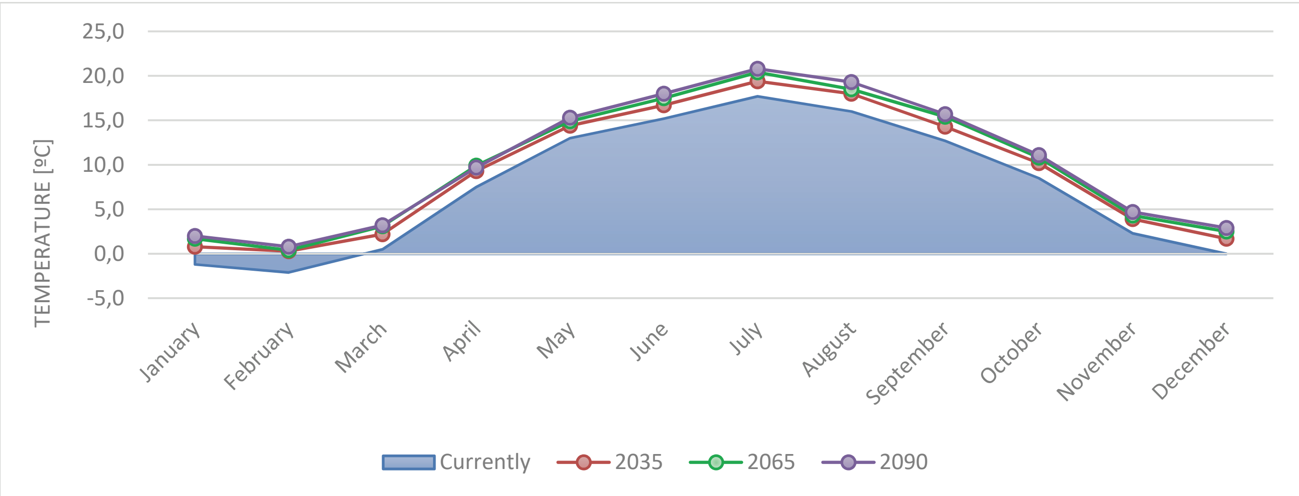
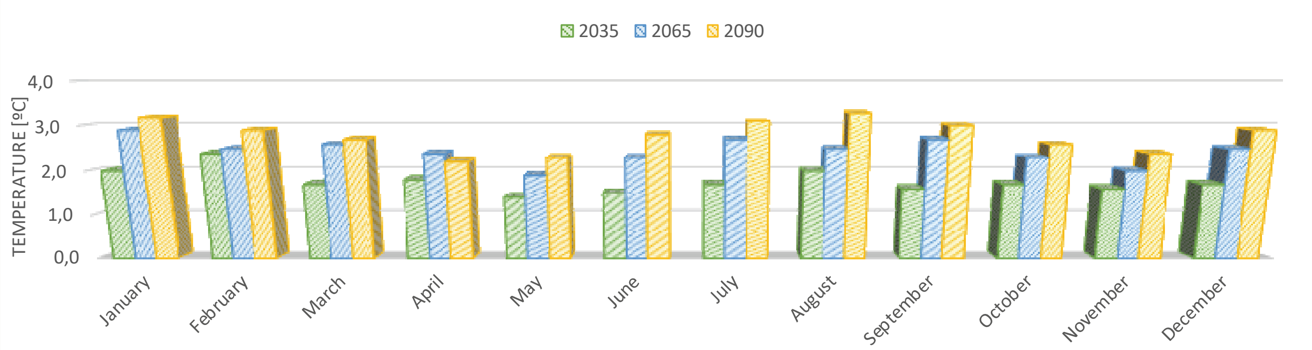


Fig. 2. The forecast of the monthly average temperature for RCP4.5 scenario [36]

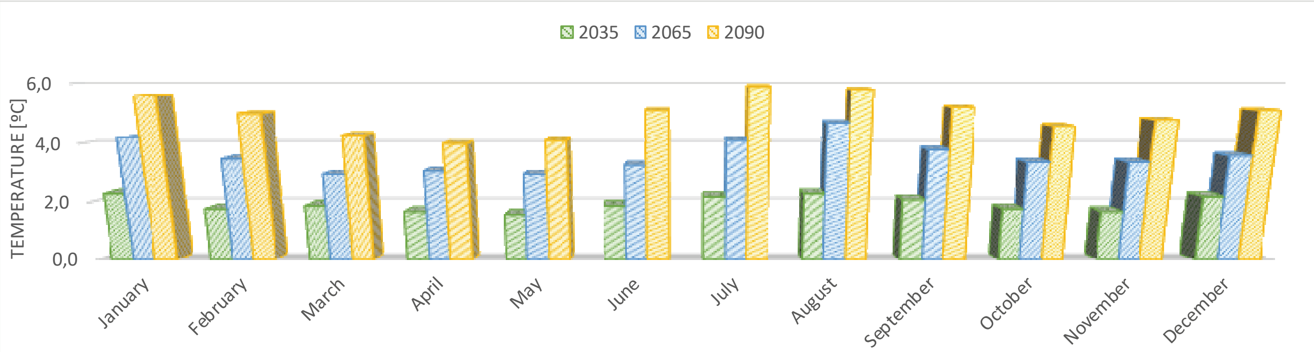
For the RCP4.5 scenario developed by the Intergovernmental Panel on Climate Change (IPCC), a forecast of changes in the average monthly temperature was made using the Weather Shift tool. The simulation of the forecast was presented for the year 2035, 2065 and 2090 and plotted in the form of a curve (fig. 2). For comparison of the above values, the average monthly temperature values for the current climate coming from the polish the Ministry of Investment and Development are also shown.



	January	February	March	April	May	June	July	August	September	October	November	December
2035	2,0	2,4	1,7	1,8	1,4	1,5	1,7	2,0	1,6	1,7	1,6	1,7
2065	2,9	2,5	2,6	2,4	1,9	2,3	2,7	2,5	2,7	2,3	2,0	2,5
2090	3,2	2,9	2,7	2,2	2,3	2,8	3,1	3,3	3,0	2,6	2,4	2,9

Fig. 3. The increase of temperature compared to current climate for RCP4.5 scenario [36]

According to the RCP4.5 scenario, the average monthly temperature will increase for each month of the year (fig. 3). According to the scenarios, the highest temperature rise will occur from now to 2035, but in subsequent periods (until 2065 and until 2090).The temperature rise will also be noticeably high. Evaluating temperature increases in individual years, there are no visible jumps in values between individual months. A similar analysis was also made for the most pessimistic scenario against climate change – RCP8.5 (fig. 4).



	January	February	March	April	May	June	July	August	September	October	November	December
2035	2,3	1,8	1,9	1,7	1,6	1,9	2,2	2,3	2,1	1,8	1,7	2,2
2065	4,2	3,5	3,0	3,1	3,0	3,3	4,1	4,7	3,8	3,4	3,4	3,6
2090	5,6	5,0	4,3	4,0	4,1	5,1	5,9	5,8	5,2	4,6	4,8	5,1

Fig. 4. The increase of temperature compared to current climate for RCP8.5 scenario [36]

According to the RCP8.5 scenario, the average monthly temperature will increase each month of the year (fig. 4). What is more, in the following years, the temperature will keep growing and the intensity of this growth will be at a similar level between successive researched periods. There are no significant value jumps in values between months during the year for the analyzed periods. The RCP8.5 scenario presents a vision much more dangerous for the climate than the RCP4.5 scenario. Analyzing the temperature only, it can be concluded that for the years 2065 and 2090 the monthly average temperature values are higher for the RCP8.5 scenario by around 40% compared to the RCP4.5 scenario.

2.2. Relative humidity

Another climatic factor is Relative Humidity (RH), which determines the percentage to which the air is saturated with water vapor. This factor is directly related to the air temperature, because as the temperature increases, more water vapor is needed to reach the same relative humidity than at a lower temperature. The reason for this is the fact that as the temperature rises, the amount of water vapor that the air can take in increases. When the relative humidity reaches 100%, it means that the air has reached its maximum saturation. The graph (fig. 5) shows the relative humidity [g/m^3] of the outside air (for the whole year, with an hourly time step) depending on the outside air temperature. The data included in the analysis were adopted from climate data for Kielce prepared by the Polish Ministry of Investment and Development. On the Figure 5 the red line shows the relative humidity of air relative to temperature.

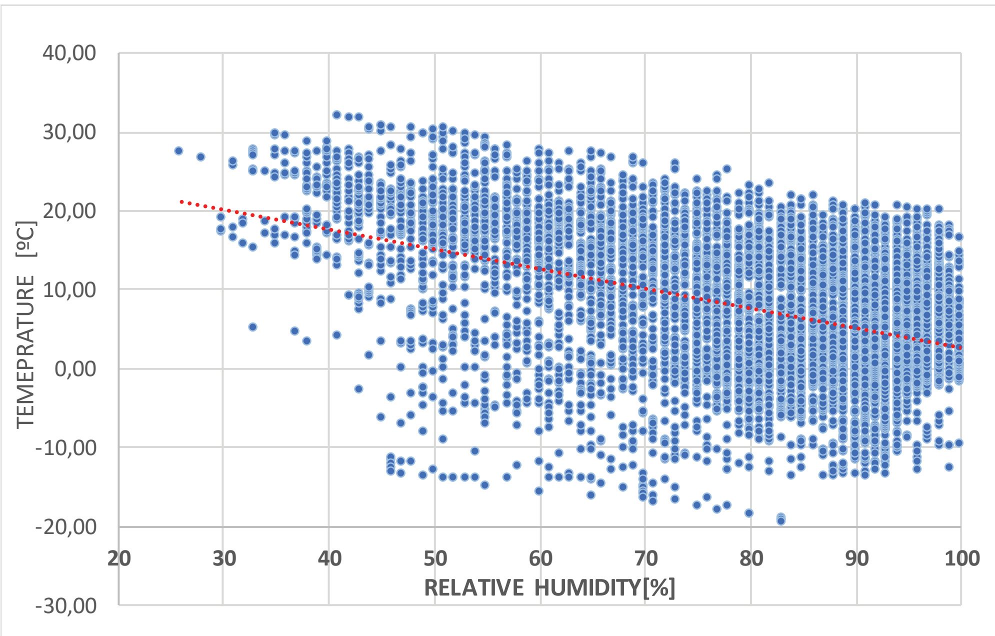


Fig. 5. Temperature – relative humidity graph [37]

The graph (fig. 5) shows that the relative humidity varies from 30% to 100% throughout the whole year, while the total water vapor saturation (RH = 100%) is within –10°C to 20°C. What is more, as the temperature drops, higher relative humidity values are achieved. Also, individual cases of relative humidity of less than 30% were recorded and occurred at a temperature of about 30°C.

To perform the relative humidity forecast, we used the Weather Shift tool developed by Arup and Argos Analytics, which is based on the RCP4.5 and RCP8.5 scenarios identified in the ICCP report. The tool provides future projection of weather data for three periods: 2026–2035 (referred to as "2035"), 2056–2075 (referred to as "2065"),

2081-2100 (referred to as "2090") in relation to the base period 1976–2005. The graph (fig. 6) of the predicted relative humidity value for the RCP4.5 scenario illustrates a slight decrease in the relative humidity over the years. The smallest changes were observed for winter months, while the largest for summer months, i.e., June, July, August, and September.

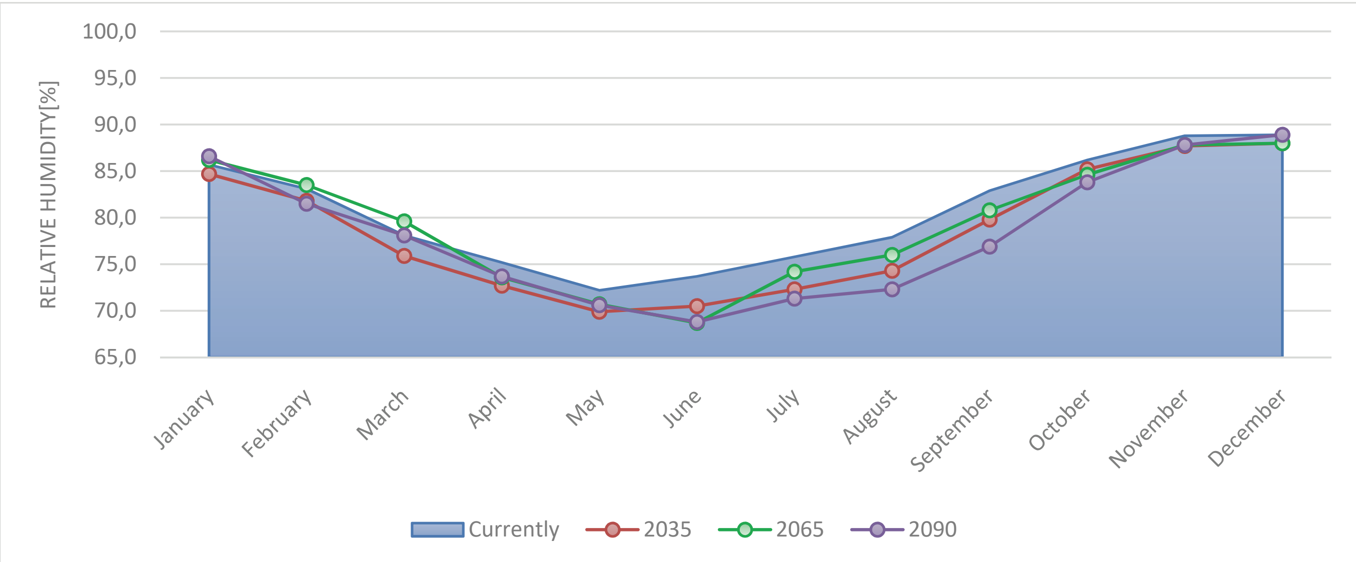


Fig. 6. The forecast of relative humidity for RCP4.5 scenario [36]

The table (tab. 1) shows how the monthly average relative humidity values will change over the years for the city of Kielce. In less than 15 years (until 2035 year), this value will decrease in the summer months by approximately 3%, while in the last 70 years (until 2090) – by approximately 5%.

Table 1. Current and forecasted relative humidity for RCP4.5 scenario [36]

	June	July	August	September
Currently	74%	76%	78%	83%
2035	71%	72%	74%	80%
2065	69%	74%	76%	81%
2090	69%	71%	72%	77%

The graph of the predicted relative humidity value for the RCP8.5 scenario (fig. 7) already shows a greater decrease in the relative humidity over the years compared to the RCP4.5 scenario (fig. 6). 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.

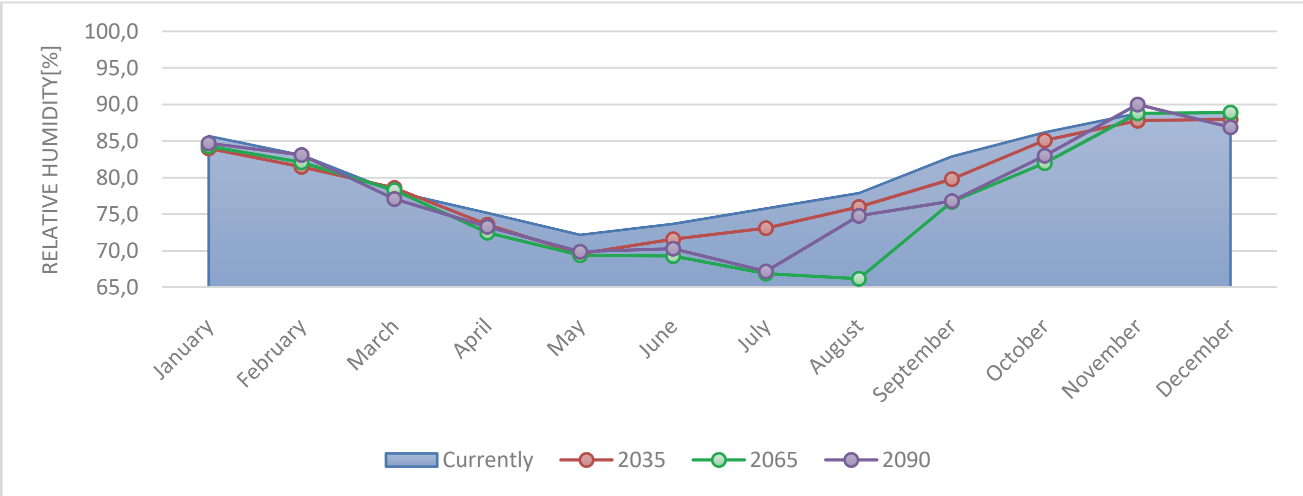


Fig. 7. Forecast of relative humidity for RCP8.5 scenario [36]

What is worth noting, for June the average relative humidity values are slightly higher in the RCP8.5 scenario (tab. 2) than in the RCP4.5 scenario (tab. 1). Nevertheless, the tendency of these values is falling, which is confirmed by the results for the following summer months, i.e., July, August, and September. The biggest difference can be seen in July, where over the next 50 years relative humidity will drop by about 8%.

Table 2. Current and forecasted relative humidity for RCP8.5 scenario [36], [37]

	June	July	August	September
Currently	73,7%	75,8%	77,9%	82,9%
2035	71,6%	73,1%	76,0%	79,8%
2065	69,3%	66,9%	66,2%	76,7%
2090	70,3%	67,2%	74,8%	76,8%

2.3. Wind velocity and solar radiation

Kielce is colloquially considered one of the “windier” cities in Poland. In the Świętokrzyskie Province, there is a prevailing wind blowing from the north-west and west directions. The average wind speed during the year is about 3 m/s. The strongest winds occur in Kielce in March and in December. In addition, there is a noticeable decrease in wind speed in the summer months.

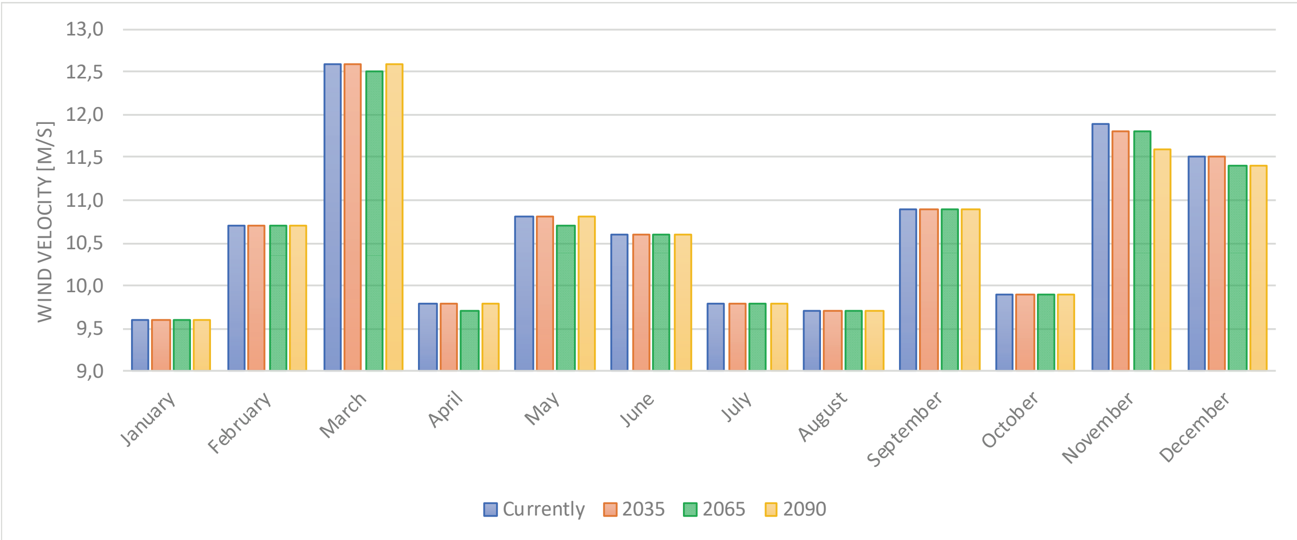


Fig. 8. Average daily max. wind velocity [m/s] for RCP4.5 scenario [36], [37]

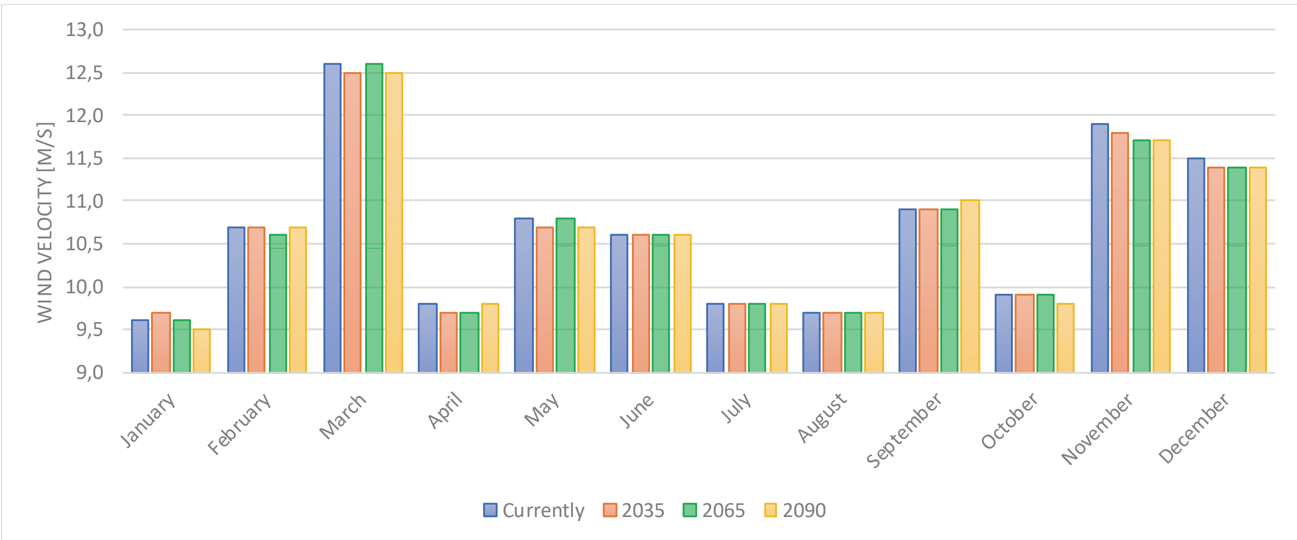


Fig. 9. Average daily max. wind velocity [m/s] for RCP8.5 scenario [36], [37]

From above figures (fig. 8, fig. 9), it can be observed that both scenarios (RCP4.5 and RCP8.5) do not predict major changes and increases in the daily maximum wind speed. In addition, there is a slight slowdown in the next forecast periods.

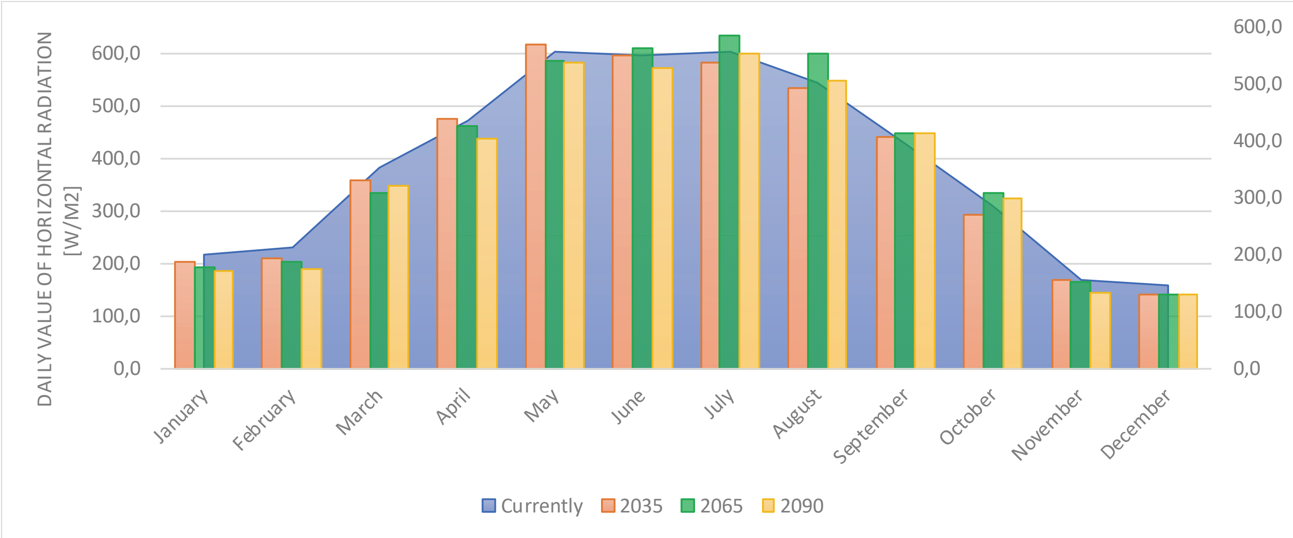


Fig. 10. Daily value of horizontal solar radiation [W/m^2], [36], [37]

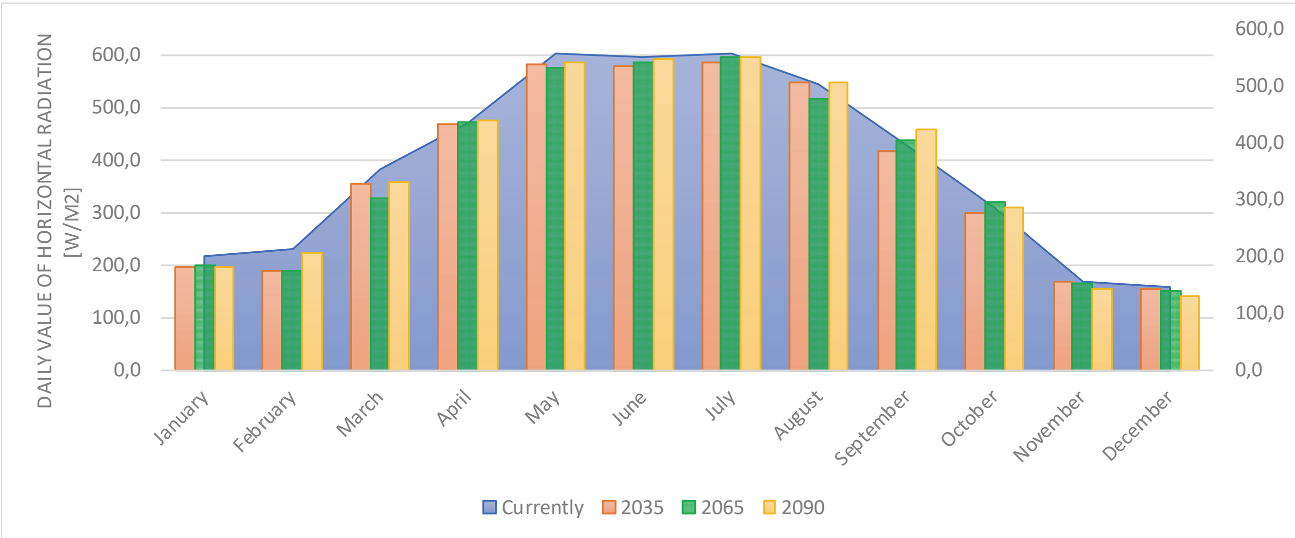


Fig. 11. Daily value of horizontal solar radiation [W/m^2], [36], [37]

As with wind speed, the situation is for solar radiation (fig. 10, fig. 11). In the analyzed scenarios (RCP4.5 and RCP8.5), there are no major changes expected in the level of solar radiation in the forecasted years. It cannot be excluded that with the use of other dedicated climate change simulation tools, the values of solar radiation and wind velocity could achieve greater deviations for the analyzed RCP scenarios than those obtained with the Weather Shift tool.

3. Summary and conclusions

The article presents the problem of climate change and analyses possible scenarios. The meteorological conditions of Kielce city for years 2035, 2065 and 2090 were checked and compared with current values. The calculations were made for two scenarios representing different greenhouse gas concentration trajectories (RCP4.5 and RCP8.5). The results confirm the increase of outdoor temperature in the following years. According to the RCP4.5 scenario, the average monthly temperature will increase for each month of the year. Depending on the years the temperature will increase in the range from 1.9°C to 2.9°C for 2065 and from 2.2°C to 3.3°C for 2090. The RCP8.5 scenario presents a vision much more dangerous for the climate and buildings than the RCP4.5 scenario. For the years 2065 and 2090 the monthly average temperatures are higher by around 40% compared to the RCP4.5.

The values of relative humidity do not change significantly for the winter months, i.e., December, January, February, while in the summer months these changes are already visible. The biggest difference can be observed in July, where over the next 50 years relative humidity will drop by about 5% for RCP4.5 and 8% for RCP8.5. There are no major changes visible in the level of solar radiation or wind speed.

It can be expected that change of the climate will have influence on buildings construction, performance, and indoor conditions. Newly designed and constructed buildings as well as renovated should consider the occurrence (from year to year) of higher outdoor temperature and increase of heat gains during the summer. To check the possible influence dynamic calculations of single family building model were carried out using the TRNSYS software. The input data were based on calculated, future climate parameters for analyzed scenarios. Climate parameters like outdoor air temperature and relative humidity were modified according to the studied scenarios. The energy performance and indoor air temperature was compered in regard to base case. This allowed to determine possible the scale of changes. The results of the calculations will be presented in the second part of the paper.

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Analiza zmiany klimatu i jego wpływu na charakterystykę energetyczną budynku oraz temperatury wewnętrzne, część 1: Scenariusze zmian klimatu

Słowa kluczowe: zmiana klimatu, parametry zewnętrzne, scenariusze zmiany klimatu, Representative Concentration Pathways

Streszczenie:

Przedmiotem artykułu jest analiza zmiany klimatu oraz jej wpływu na charakterystykę energetyczną budynku i temperaturę wewnętrzną. Badania przeprowadzono na przykładzie miasta Kielce. Ich podstawą był Miejski Plan Adaptacyjny dla miasta Kielce oraz dane klimatyczne z Ministerstwa Inwestycji i Rozwoju. Przewidywane, przyszłe parametry klimatu zostały oszacowane za pomocą narzędzia Weather Shift dla Representative Concentration Pathways (RCP). W analizie uwzględniono scenariusze RCP4.5 i RCP8.5 na lata 2035 i 2065, reprezentujące różne trajektorie wzrostu stężenia gazów cieplarnianych. Scenariusz RCP4.5 reprezentuje przewidywane, dodatkowe wymuszenie radiacyjne wynoszące 4,5 W/m^2 w 2100 r., a RCP8.5 dodatkowe 8,5 W/m^2. Wyznaczone parametry obejmowały średnie miesięczne wartości temperatury i wilgotności względnej powietrza zewnętrznego, prędkości wiatru i wielkości promieniowania słonecznego. Wyniki obliczeń potwierdziły wzrost temperatury zewnętrznej w kolejnych latach. Wartości wilgotności względnej powietrza nie zmieniają się znacząco dla miesięcy zimowych, natomiast w miesiącach letnich widoczny jest ich spadek. Nie zaobserwowano większych zmian w poziomie promieniowania słonecznego i prędkości wiatru. Na podstawie obliczonych parametrów przeprowadzono dynamiczne modelowanie budynku przy użyciu oprogramowania TRNSYS. Metodologia i wyniki obliczeń zostaną przedstawione w drugiej części artykułu.

Received: 2020-05-07, Revised: 2021-02-15