Outdoor Climate Parameters and Heat Energy Consumption for the Needs of Heating the Building

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Abstract. In this study, meteorological data were analyzed for the needs of heating the building. For this purpose, data from a typical meteorological year were used, which allow determining the general characteristics of the building. Temperature analyses were carried out, modeling its changes over time. To this end, time series theory was used. In this analysis, the decomposition of the original time series was used. As a result, the obtained results were used for computer simulation for the test object.

1. Introduction
The consumption of thermal energy in buildings is heavily dependent on the insulation of the walls [1], [2] or their heat accumulation [3], [4]. For this purpose, recycled materials are often used [5], [6]. According to various studies, the consumption of thermal energy in construction also depends on the outdoor climate [7]. Climatic parameters are subjected to both regular deterministic changes related to the movement of the Earth around its axis and around the Sun, as well as geographical location and are characterized by high stochasticity.

For energy analyses (especially the irradiation conditions of any surfaces of external partitions), real ordered data is necessary, using an appropriate methodology for their description.

There are many studies available for typical meteorological years around the world. Most commonly used according to Polish authors [8] are:

- Typical Reference Year,
- Weather Year for Energy Calculations, Version 2,
- Typical Meteorological Year, Version 2,
- Typical Meteorological Year according to ISO 15974-4.

For Poland, we find studies including those of the Institute of Meteorology and Water Management (IMWM) [9].

After the entry into force of the regulation on determining the energy performance of buildings, climate databases from 61 stations in the form of typical meteorological years (TMY) and statistical data developed for them calculated on the basis of the ISO standard were made available on the website of the Ministry of Infrastructure. IMWM also provides climate maps with characteristics of average
temperature, total rainfall, sunshine duration and extreme temperatures for individual months, seasons and years.

Energy calculations in construction use local climate data based on long-term measurements. Depending on the purpose of the calculations, it uses average or extreme values for winter and summer periods.

Calculations of the energy performance of buildings are based, among others on the sums of total radiation per plane (horizontal or inclined, as well as oriented relative to the directions of the world) and average monthly air temperatures. Complex energy analyses, performed in simulation programs, however, require the use of more detailed data - in the form of hourly values. Conducting analyses in a simulation program (including ESP-r) therefore requires the introduction of an appropriate climate base, consisting of hourly values for the following climatic variables: intensity of diffused solar radiation, intensity of direct solar radiation, air temperature, wind speed and direction, relative humidity.

Numerical analyses carried out with the use of TMY allow you to create general building characteristics by assessing energy needs and indoor climate conditions and comparing selected variants of solutions in the building, or comparing with other objects. Obtaining a reliable energy assessment of a building requires the use of harmonized climate data. The full analysis of the results should, however, take into account differences in real local conditions resulting even from the observed global warming.

2. Methodology and results of measurement and analysis of climate parameters

For the purposes of simulation analyses in this work, the following were used:

- full climate data available for the city of Katowice - TMY based on climate data from 1971-2000,
- actual courses of climate parameters from 2015-2017, measured at the research stand of the Department of Building Engineering and Building Physics of the Silesian University of Technology in Gliwice (Figure 1-2).

![Figure 1. View of the measuring stand - meteorological multisensor](image1)

![Figure 2. View of the measuring stand - pyranometer](image2)

Local climate research included measuring the following physical quantities:

- outdoor air temperature,
- total solar radiation intensity,
- relative humidity of the outdoor air,
- atmospheric pressure,
• wind speed and direction,
• amount of precipitation.

In the measurements, the following were used:
• ALMEMO 5690-2M09 recorder,
• SP Kipp & Zonen SP LITE pyranometer for measuring total solar radiation,
• Ahlborn FMA510H meteorological multisensor - measurement of outdoor air temperature, relative humidity, atmospheric pressure, wind direction and speed, amount of precipitation.

2.1. Typical Meteorological Year (TMY)
A Typical Meteorological Year is a collection of data reflecting the annual courses of significant climatic parameters specific to a particular location.

2.2 Actual courses of local climate parameters
The study of the local climate included the measurement of: outdoor air temperature, total solar radiation intensity, relative air humidity, atmospheric pressure, wind speed and direction, as well as precipitation in the years 2015-2017 at the research stand of the Silesian University of Technology in Gliwice.

Based on the received data, as part of the work, analyses of variability and statistical characteristics of selected climate parameters were carried out, which are presented below.

• Variation of selected climate parameters

Selected local climate parameters of Gliwice - outdoor air temperature and solar radiation intensity - measured in 2015-2017 were compared with data from the Typical Meteorological Year (TMY) and referred to studies from 1994-2002 [10].

For the results of studies from 2015-2017, an analysis of local climate changes was carried out and on this basis, attempts were made to determine current trends.

The average values were calculated for the compared climate parameters according to the formulas below:

- arithmetic average:
  \[ \chi_a = \frac{\sum_{0}^{n} \chi(t)}{n} \quad (1) \]

- mean of a function:
  \[ \chi_c = \frac{1}{n} \int_{0}^{n} \chi(t) dt \quad (2) \]

where:
\( \chi \) – tested climate parameter,
\( t \) – time,
\( n \) – length of the measuring interval.

Figure 3 summarizes the average annual TMY temperatures and those obtained from tests at the Silesian University of Technology in the years 2015-2017 and Figure 4 - the average monthly temperatures of the outdoor air measurements from 1994-2002 and 2015-2017.

It was noticed (Figure 3) that the air temperature values in subsequent years 2015-2017 obtained on the research stand take values significantly higher than the values of TMY. On the other hand, Figure 4 shows, despite a relatively short measurement period and incomplete data, a slight upward trend in the value of air temperatures.
In the next step, using the average daily values of the climate elements for all measurement years, the average year was determined. The course of the average statistical year of temperature is shown in Figure 5, where the smoothing of the arithmetic average using the mean integral is brought.

The averages of the surveyed years and the data of a typical meteorological year were also compared with each other.

Based on Figure 6, it was found that air temperature has been higher in recent years.

Figure 3. Average monthly temperature in 2015, 2016, 2017 and TMY

Figure 4. Average annual temperature in 1994-2002 and 2015-2017

Figure 5. Average temperature course from 2015-2017

Figure 6. Average outdoor air temperatures from the surveyed years and TMY data

Figure 7 summarizes the monthly sums of total solar radiation incident on the vertical surface for 2015-2017 measured at the research stand at the Silesian University of Technology and TMY, and Figure 8 - the annual sums of total solar radiation obtained from studies in 1994-2002 and 2015-2017.
It can be observed that the values of monthly sums of total solar radiation in the subsequent years 2015-2017 obtained at the research stand take values lower than the values of TMY (Figure 7), which is clearly visible in the months from April to June. Despite the relatively short measurement period and incomplete data in Figure 8, it can be observed that at the turn of the years the radiation intensity values decrease.

- Statistical characteristics of climate parameters

In the analysis of dynamic processes of heat exchange between the building and the external environment, climate data representative of the given location are used. The usefulness of climate data is based on the assumption of some repetition of occurring phenomena in the future. Climatic parameters are subjected to both regular deterministic changes and are characterized by high stochasticity. Statistical identification of climate parameters supports proper modeling of heat exchange processes caused by random changes of these parameters.

As a result of the above, further statistical analyses were carried out for the data from 2015-2017.

Temperature analyses were carried out, modeling its changes in time using time series. To analyze temperature changes over time, spectral analysis methods can be used by decomposing the original series into basic sine and cosine functions at different frequencies. One known way of performing such decomposition is the use of multiple regression, in which the time series would be observed as the dependent variable, and as the independent variables sine or cosine functions at all discrete frequencies. Such a model can be saved as:

\[ T = T_0 + \sum_k \left[ a_k \cos(\lambda_k t) + b_k \sin(\lambda_k t) \right]. \]  \hspace{1cm} (3)

Using the classical markings of harmonic analysis in the equation (3), \( \lambda = 2\pi \cdot v_k \) means frequency.

The value of the observed phenomenon was considered as a function of the time variable \( \chi_t(t) \) and random disturbances. Thus, the process can be described by the dependence:
\[ \chi_t = T_t + S_t + \varepsilon_t, \quad (4) \]

where:

- \( T_t \) – trend,
- \( S_t \) – seasonal fluctuations (with a period of one year),
- \( \varepsilon_t \) – random fluctuations.

An additive process was assumed, which is shown in Figure 9.

The large amplitude of seasonal fluctuations means that it is difficult to see if the values rise, fall or remain on the same level on average. Therefore, the moving average method was used, i.e. arithmetic means calculated from a fixed number of adjacent observations, using the formula:

\[ T_{t(k)} = \frac{1}{k} (T_{t-k} + \cdots + T_{t-1} + T_t + T_{t+1} + \cdots + T_{t+k}), \quad (5) \]

where:

- \( T_{t(k)} \) – smoothed value of the series at \( t \),
- \( k \) – smoothing window length.

The smoothed series is shown in Figure 10, while the random component in Figure 11.

**Figure 9.** Outdoor air temperature
It was noticed that in the three-year research period the trend of temperature changes is decreasing. However, the study period is too short to define a multi-year trend.

Solar radiation, as a climate process, creates a time series with a deterministic component and a random component. Thus, the process can be described by the dependence:

$$\chi_p = T_p + S_p + \varepsilon_p,$$

where:

- $S_p$ – seasonal component,
- $\varepsilon_p$ – random component, noise string.

An exponential smoothing analysis was performed for given daily sums of total solar radiation intensity on a surface with S orientation and inclination up to 90°, isolating the deterministic and random components (Figure 12-13).
3. Methodology and results of simulation analyses for the test object

For an object on a "semi-real" scale (Figure 14) - for which temperature and energy consumption for heating were previously measured - numerical analyses were performed.

The object in question with lightweight wooden skeleton partitions is located on the research stand at the Faculty of Civil Engineering of the Silesian University of Technology. The tested object has external dimensions: 6.0 x 4.15 x 5.2 m (to the ridge). All partitions, external and internal, are characterized by very good insulation (external walls: \( U = 0.09\div0.19 \) W/m²K). The interior door was open during the tests. During the tests in the facility maintaining a minimum temperature: between 10:00 p.m. and 6:00 a.m. equal to 16±0.5°C and between 6:00 a.m. and 10:00 p.m. the temperature 18±0.5°C, energy consumption was measured.

In measurements, the following were used:

- USB st-171 recorders - indoor air temperature and humidity measurement,
- energy consumption meter Voltcraft Energy Logger 4000 - measurement of energy consumption for heating,
- ts20 thermostat,
- heater with a maximum power of 2000 \( W \).
- The results of the measurements are presented in the paper [11].

The development of a numerical model corresponding to the real object involved, among others determining the geometry of the object (shape and dimensions), introducing boundary conditions (climate parameters), building partitions with specific physical properties of materials and introducing heating and ventilation system. The numerical analyses were carried out in the program Environmental Systems Performance [12]. The description of a reliable numerical model for this object is described in the paper [13].
In the analysis of dynamic processes of heat exchange between the building and the external environment, climate data representative of a given location is most often used - a typical meteorological year (TMY). However, the best situation is when actual measured values for climate elements are also available.

The created numerical model was analyzed assuming as boundary conditions climate data available data for the nearest location - TMY for the city of Katowice (based on data from 1971-2000) and actual local climate data (September-December 2015).

The results of the simulation are shown in Figure 15, 16.

For the above numerical model - for the period from September 1 to December 31, entering TMY data instead of real data, the demand for energy needed for heating in the facility increased by as much as 36%.

![Figure 14. Test object: a) cross-section, b) projection](image)

**Figure 14.** Test object: a) cross-section, b) projection

**Figure 15.** Energy demand for heating, TMY 2015

**Figure 16.** Scatter and regression chart of energy demand for heating: TMY-2015

Energy delivered TMY: $y = 0.5697 + 0.4915x$; $r = 0.7272; p = 0.0000; r^2 = 0.5288$.
4. Conclusions
The analyses presented in this paper allow drawing some conclusions:

- Conducting an analysis using data from a typical meteorological year allows determining the general characteristics of a building – assessment of energy demand, assessment of indoor climate conditions, comparison of selected variants of solutions in the building or comparison with other objects. For a full analysis of the results, however, it is beneficial to take into account the measured real local climate conditions.

- To determine the actual characteristics of the building - especially energy-saving buildings equipped with active or passive (direct and indirect) solar energy systems - it is therefore necessary to conduct systematic measurements of local climate parameters.

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