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Numerical analysis of outdoor climate conditions based on the 3-years measurement for Zilina

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Numerical analysis of outdoor climate conditions based on the 3-years measurement for Zilina

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Abstract. The need for reference files resulted from the development of advanced simulation models. Few methodologies for creation of test reference years were developed in last decades. Most common are following two methods: a simple selection of worst year from recommended period or the numerical analysis of months and then the combination of months into one reference file, which in is not real, because the months are selected from various years. It is necessary to temper the connection of individual months. With the outdoor climate change and therefore the synthetically (combined) based reference years for many areas can not satisfy more and more advanced simulation models. Reference years are created from values measured mostly by weather stations belonging to the national weather forecast service, which is not very dense and the resolution and measured climate data are insufficient. Problems of urban heat islands in the cities is also widely discussed. In this paper, the outdoor climate characteristics measured by the mobile weather station located in the University of Zilina campus are analyzed. The station records most of the climate parameters required for HAM simulations since 2014. Measured data are also compared to data obtained from national weather forecast service stations located nearby.

1. Introduction

During last years it is to observe that the climate as a long-term weather regime is visibly changing [1, 2, 3]. It has its prior role and strongly influences the indoor environment of buildings. Nowadays, the climate change is becoming crucial. It is not just about predictions, the result is visible right now. The analysis presented in this article should emphasize the importance of use as accurate boundary conditions for HAM simulations as possible. Building simulation assumes dynamic boundary conditions (continuous in time). From this fact it follows that creating suitable reference file is one of the most challenging parts how to obtain meaningful results. Area of Slovakia has not its actual reference complex files usable for building simulations, HAM and wind-driven rain simulations. Test reference years (TRYs) for several places, based on the long-term measurement exist [4, 5]. These were created as average ones, without severe years. The existing TRYs for Slovakia need to be updated due to changing climate conditions and resulting new requirements at the user side. They are basically based on the 30-year climate normal period 1961-1990 [13]. Researchers often tend to use files of similar climate – not really measured right at the experiment site. Actual trends are focused on obtaining not only random numbers [6, 7, 8]. So which data file is the right exterior boundary condition for numerical simulation? Possibilities in mentioned area of research are wide. This study is based on the need of precise integration of boundary condition for analysis of hygrothermal behavior e. g. of building envelope structures [9, 10, 11]. Choosing them in the right way is a key aspect for relevant results [12, 13]. Role of the building envelope in area of sustainable building and energy assessment is vital. Hygrothermal conditions (humidity and temperature) inside the building depend on the outside climate [9, 14, 15].

For needs of energy simulations in area of Civil engineering, relevant data about exterior boundary conditions are mostly needed in shorter time periods. This highlights the advantage of having own experimental weather station. Building simulation tools need the right interval of data recording. The data should be complete, consistent and logical. Typical weather data files contain incorrect or missing entries caused mostly by malfunction. Correction and adding of optimal values are crucial aspects of climate data preparation especially for numerical simulations. The used external boundary conditions should be representative of the building location [5, 11, 16]. According to the territorial study of Slovakia about climate change, the global warming could reflect in our area by increase of temperature averages till the year 2075 at about 2 – 4 °C [2, 3].

Gridded climate datasets are required for numerous purposes in applied and theoretical climate and environmental sciences [17]. Often is also combination of observed weather (temperature, humidity, wind, …) data with modeled solar radiation data, transforming these into Actual Meteorological Year [16].

2. Input data

Measurement of possible meteorological parameters runs with a 10-minute recording interval. For needs of this article, air temperature and relative humidity were chosen, as two important characteristics for hygrothermal simulations. Measuring interval of experimental weather station is adjustable as required. Results of measurement were elaborated in a way of hourly means and described.

Exterior air temperature changes relatively slow. Mentioning solar radiation, it is possible to come to big and quick changes of values within a few minutes. Simplifying of climate factor course to hourly values can be misrepresentative in this case. Experimental weather station (Figure 2, left) is a benefit.

Figure 1. Location of weather stations (Dolny Hricov, DH (3) and Zilina, ZA, EX (2, 1), Slovakia).

For the analysis in this article, years 2014 (partly), 2015, 2016 and 2017 were selected. Using the reference file from Dolny Hricov (DH) and Zilina (ZA), based on measuring range 1961-1990 (Table 1), it could be determined, e. g. for evaluation of individual years, if these years were above or below the reference value. The files were obtained from Slovak Hydrometeorological Institute (SHMI).

Figure 2. Measuring devices (from left: experimental weather station – EX, DH, ZA).

Table. 1 Reference file, weather station DH and ZA – Air temperatures [°C]

Time period	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**
Monthly min. DH	-9.2	-7.4	-2.8	4.9	10.2	13.1	14.8	14.1	10.2	5.0	-2.0	-5.6
Monthly min. ZA	-9.1	-6.8	-2.3	5.4	10.4	13.1	15.2	14.0	10.4	5.3	-1.8	-5.3
Monthly max. DH	1.2	4.2	5.9	10.7	15.0	18.8	19.3	18.1	15.8	12.2	7.2	2,.2
Monthly max. ZA	1.5	4.0	6.3	11.1	15.5	18.6	19.4	18.0	15.8	12.4	7.3	2.4
Monthly av. DH	-3.6	-1.4	2.5	7.7	12.8	15.6	17.0	16.3	12.7	8.1	3.1	-1.7
Monthly av. ZA	-3.4	-1.1	2.9	8.1	13.1	15.6	17.0	16.3	12.8	8.2	3.2	-1.5

January is usually the coldest and July the warmest month of the year. It is visible that values for both weather stations are closely similar. The same can be said about seasons, summer and winter periods and years. Data were obtained from a long-time period (30 years). Measuring devices are located in a distance of about 20 km from each other (Figure 1). The experimental meteorological station is surrounded by buildings and forest – it is placed on the roof nearby the laboratory. The meteorological station Zilina-Borik is situated in urban area, but surrounded by low trees and flat terrain (Figure 2, right). Dolny Hricov is paced near the airport runway in flatland surrounded by meadow. General face of surroundings is absolutely free (Figure 2, middle).

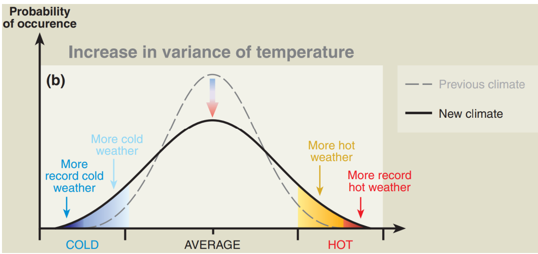

Figure 3. Diagram showing the climate change effect on extreme temperatures [3].

2.1. Air temperature

Year 2017 reached average monthly values closest to the average from all 3 evaluated experimental yearly data (Figure 4). The coldest month should be January and the warmest one should be July (according to long-term past measurements and knowledge). Yearly course of the year 2015 shows February as the coldest and August of the warmest month. Year 2016 is represented by January as the coldest and June as the warmest month. Watching the year 2017 it can be seen that June and August were warmer than July. January 2017 reached the lowest value of average temperature. As it is clear from the graph (Figure 4, left), the biggest differences among individual summer periods are for June, July and August. These months can be marked as critical for building indoor environment (focused on the overheating during summer). Summer 2016 seems to be closest to the average. The biggest differences among measured values and its averages during winter period were recorded in January (Figure 4, left), which is critical for energy use and heating.

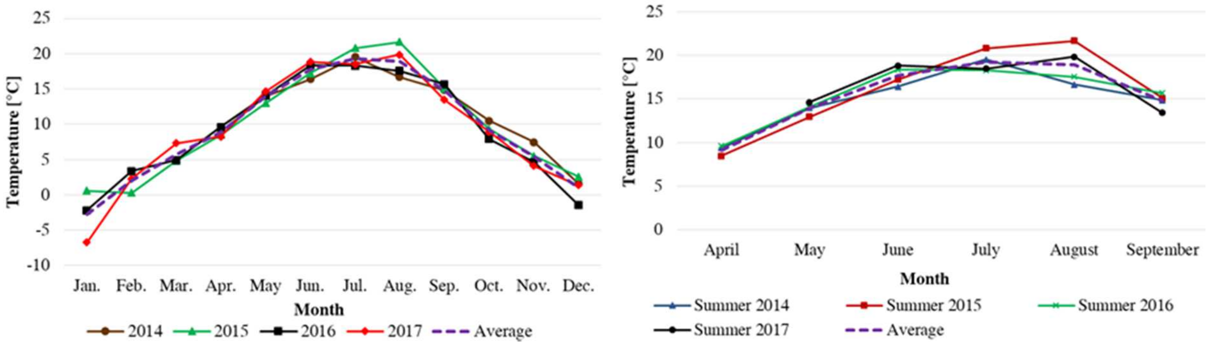

Figure 4. Annual (left), summer (right) air temperature, experimental weather station (EX).

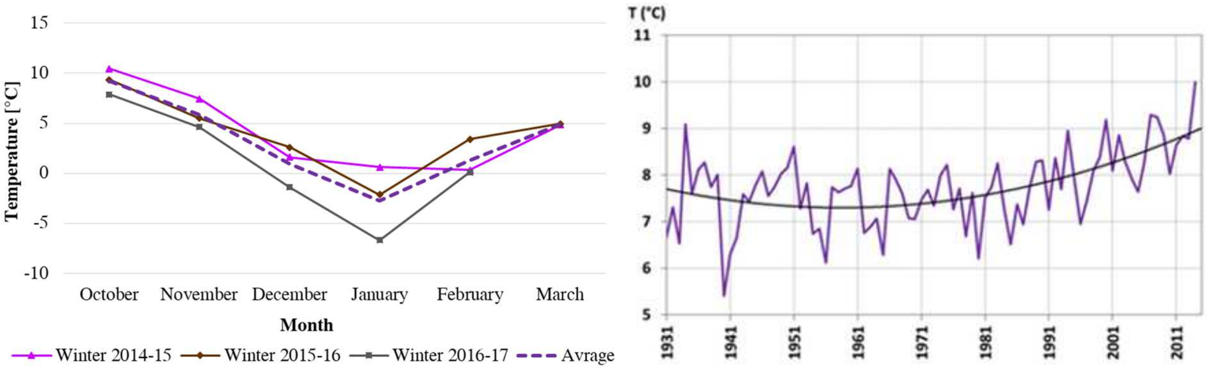

Figure 5. Exterior air temperature, winter period, experimental weather station (EX, left), spatial average annual air temperature since 1931, the area of Slovakia (right) [2]

Highlighting the trends, January becomes colder from year to year (according to monthly averages). December measurement shows a trend of changes. The coldest was December 2016, subsequently 2014 and later on 2015. Winter 2015-16 seems to suit best to the average from assessed period. Winter 2016-17 forms the lower boundary of temperature courses, the bottom one is a combination of winter 2014-15 and 2015-16.

Table 2. Monthly means [°C] for various locations (from EnergyPlus) vs. measured by EX.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Bratislava	0	0	5	10	15	18	21	20	15	9	5	1
Kosice	-2	-1	4	9	15	17	19	19	14	9	3	-1
Ostrava	-1	-1	3	8	13	16	18	17	13	9	3	0
Zilina	**-2**	**1**	**5**	**8**	**13**	**18**	**19**	**19**	**14**	**8**	**4**	**1**

Monthly temperature means available through IWEC files for EnergyPlus [19] are quite similar e. g. to Ostrava (Table 2, deviation by around 1 °C), but focusing on extremes in individual days, the differences are more visible and influencing. Analyzing Table 3 it is visible that monthly temperature averages of selected years 2015, 2016 and 2017 recorded by experimental weather station (EX) are closer to values obtained in Zilina-Borik (ZA), which was expected. These weather stations are at a 3-km distance.

Direct temperature readings dating back to the 19th century show that the last 10 years had 8 of the 10 warmest years on record [3]. In Hurbanovo (Slovakia), from 10 highest values of yearly air temperature means since 1901, 8 were recorded since 2000 [2].

Table 3. Monthly temperature averages, weather stations DH, ZA, EX.

	2015 EX	**2015** DH	**2015** ZA	**2016** EX	**2016** DH	**2016** ZA	**2017** EX	**2017** DH	**2017** ZA
Jan.	0.58	-0.18	0.6	-2.17	-2.59	-2.43	-6.72	-3.88	-7.12
Feb.	0.33	-0.78	0.16	3.40	3.51	3.77	2.33	0.71	1.47
Mar.	4.85	4.27	4.35	4.93	4.54	4.68	7.33	6.08	6.55
Apr.	8.50	7.89	8.2	9.60	9.13	9.48	8.28	7.24	7.58
May	12.97	12.18	12.87	14.07	13.84	13.76	14.66	14.08	14.66
Jun.	17.22	17.36	17.27	18,36	18,17	17.93	18.83	18.57	19.16
Jul.	20.80	20.46	20.06	18.28	19.06	18.8	18.49	18.63	19.2
Aug.	21.65	21.09	20.82	17.55	17.27	16.65	19.85	19.52	19.89
Sep.	15.09	13.17	14.54	15.69	15.49	15.15	13.45	13.21	13.53
Oct.	9.34	8.72	8.82	7.90	7.78	7.86	8.95	8.72	8.98
Nov.	5.51	4.55	4.9	4.63	4.10	4.58	4.13	3.79	4.26
Dec.	2.60	2.28	2.58	-1.39	-1.45	-1.42	1.36	0.94	1.27

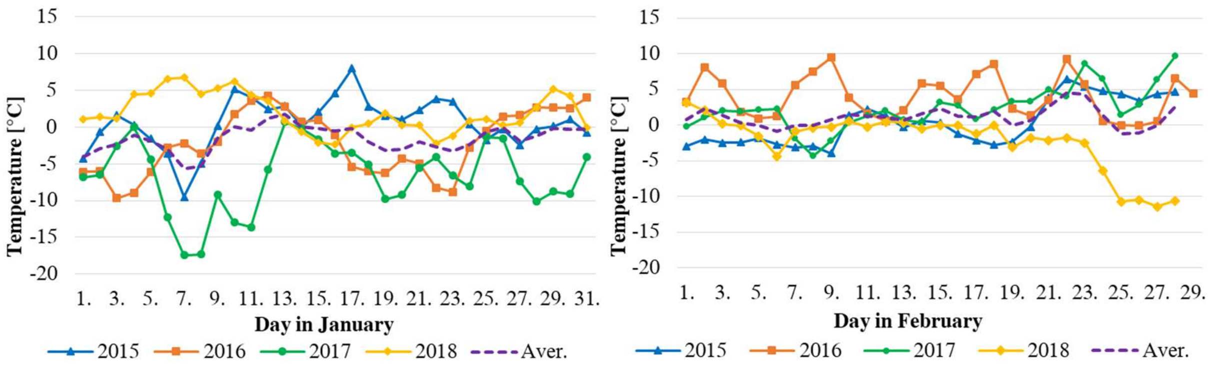

Figure 6. Daily averages, experimental weather station (EX), January (left) and February (right).

In winter period, 12-14 January and 11-13 February (middle of the month), all the curves have closely identical courses (Figure 6, left, right). But there are also visible significant differences, which is interesting e. g. from the point of view of building simulations. Noticeably coldest February from selected years was in 2018. The biggest temperature difference was 20.32 °C. First 11 days of January 2016 and 2017 (Figure 8) show reversed temperature courses. The same is visible during last 5 days of the month. 7 January shows maximum contrast of recorded daily averages among selected years. The difference reached up to 24.14 °C. A lot of differences but also similarities in individual courses are evident. The lowest yearly temperature was measured in 2017. The difference reached up to 8.63 °C in yearly average (2017, 2018).

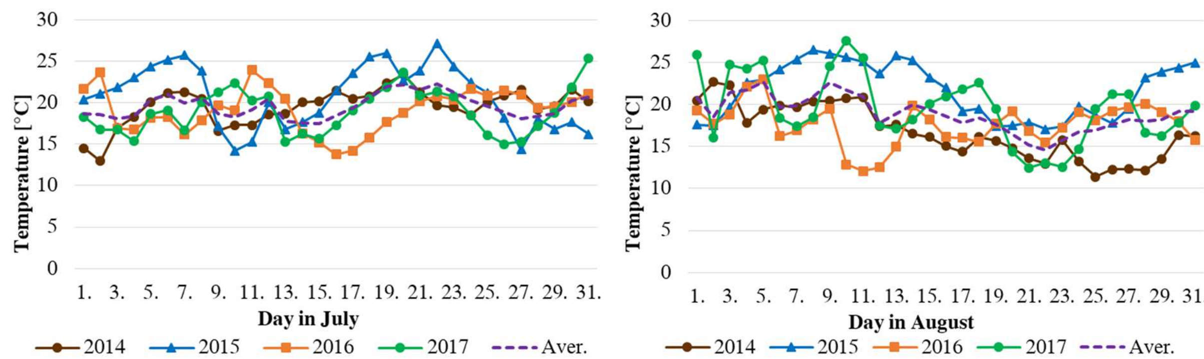

Figure 7. Daily averages, experimental weather station (EX), July (left) and August (right).

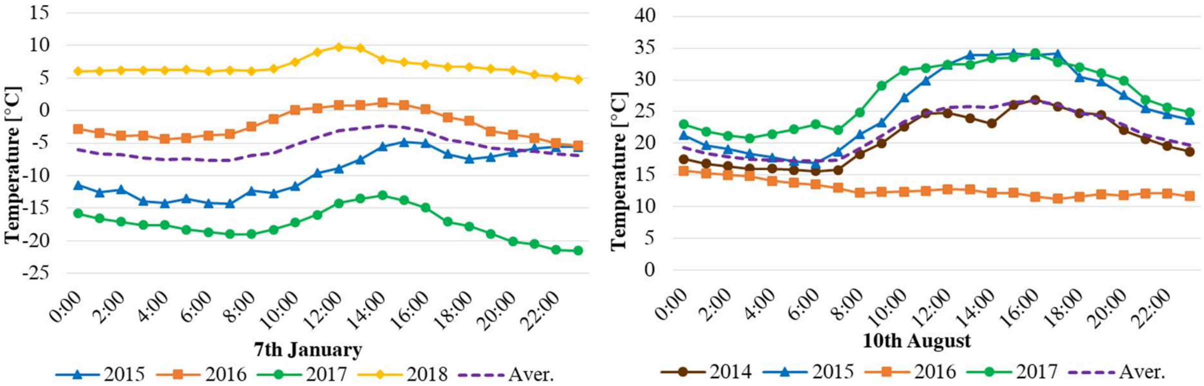

Figure 8. Hourly averages, experimental weather station (EX), selected days (cold-left, warm-right).

2.2. *Relative air humidity*

Relative humidity is a more changeable and unexpected parameter than the temperature. It shows wider differences among individual years (Figure 9, left, right). To illustrate some facts, annual, summer and winter periods were selected. Year 2016 seems to be closest to average (Figure 9, left).

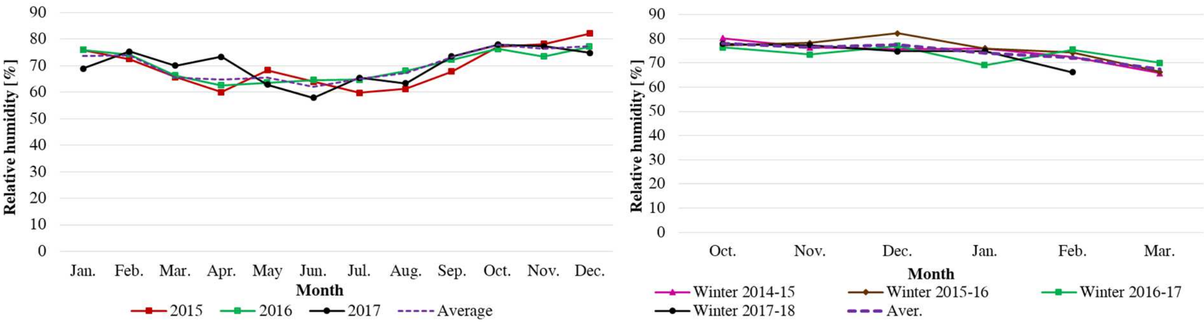

Figure 9. Monthly means, exterior air humidity (left), exterior air humidity, summer period (right).

Implementing building envelopes into real climate conditions is a current trend of research in area of building simulation. In hygrothermal simulations, the initial boundary condition of temperature and water content in the structure is representative and crucial [13, 14, 18].

Winter 2014-15 puts well to the average of evaluated period (Figure 9, right).

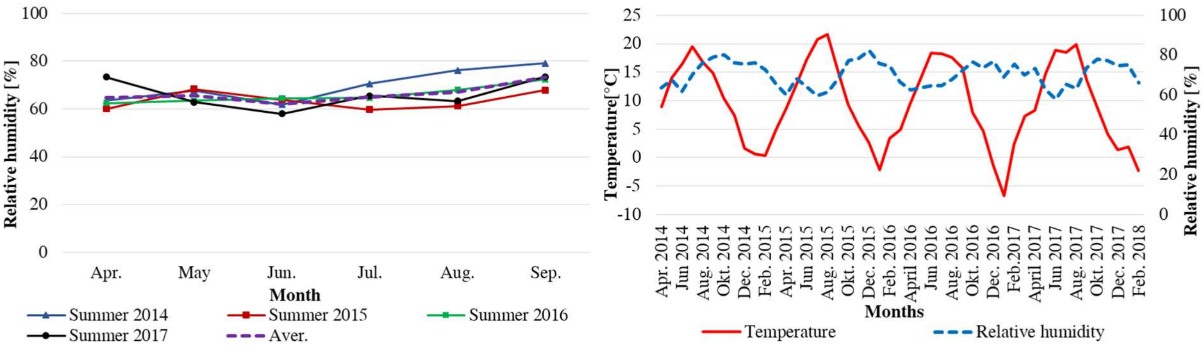

Figure 10. Relative humidity-summer (left), temperature and relative humidity-whole period (right).

Calculation of monthly mean was processed according to [20]. Hourly data were used for the monthly mean calculation.

Table 4. Measured air temperature (T) and relative humidity (RH), vs. reference values.

Year	2015	2016	2017	Average
T EX [°C]	9.95	9.24	9.25	**9.48**
T DH [°C]	9.25	9.07	8.97	**9.10**
T ZA [°C]	9.60	9.07	9.12	**9.26**
RH EX [%]	69.42	69.92	70.07	69.80
RH DH [%]	78.39	79.56	78.84	78.93

Reference file	
RF1 DH [°C]	**7.4**
RF1 ZA [°C]	**7.6**
RF2 DH [°C]	**8.1**
RF2 ZA [°C]	**8.1**

As Table 4 presents, increase of yearly average temperature is visible (in comparison to the reference file). Use of the reference data sets for example 1961-1990 (RF1) or 1981-2010 (RF2) could not be suitable enough for numerical simulations during these and future days. Relative air humidity is a strongly influencing parameter for building simulations (e. g. WUFI) [9, 14]. This parameter is more depending on the location (Table 4, 5) closely related to wind driven rain.

Table 5. Monthly means of relative humidity for various locations (fromEnergy Plus files).

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Bratislava	85	84	67	61	63	72	62	65	75	76	85	81
Kosice	82	81	67	64	70	69	70	65	73	84	82	84
Ostrava	83	83	73	69	69	71	76	68	70	76	82	87
Zilina	**73**	**74**	**66**	**65**	**66**	**62**	**65**	**67**	**73**	**78**	**76**	**77**

As precisely the relative air humidity will be implemented, so exact will be the results [12, 13]. Table 6 shows variability of measured relative humidity for various locations in comparison to the near-real time experimental measurement in Zilina.

3. Results and discussion

The WMO has set a 30-year period for a meteorological standard, which should cover all extremes at a given interval. Analysis for Zilina was done for time period April 2014 – March 2018. Over time the database becomes more extensive. Purpose of this analysis for the future is to suggest some optimum yearly reference file for computer simulations, as well as an extreme reference file, which would allow monitoring of selected parameters of building envelope under non-standard conditions. These should be the most critical ones. The deeper analysis of measured data requires a wider range of measured data, which will be at disposal by ending each following year. Most suitable way is construction of a year from 12 months of real measured weather data. Generated data are usable, but they cannot predict all extremes, which locally occur in last decades also in Slovakia. Existing reference files need the reanalysis. In a long-time point of view, there are smaller differences, but analyzing monthly, daily or hourly values it is visible that the differences are bigger. December, January and February often reach some extremes, which are crucial from the point of view of variable measured data. In 2017, the temperature for 8 January was registered as the lowest for last 20 years (-24.6 °C).

Slovakia is orographically a very ragged country. Climate character has its typical changes according to the altitude and characteristic daily and yearly regime of meteorological variables. Region of Slovakia is missing actual reference files suitable for building simulations. All these problems are complicated and complex. Crucial are also winter and summer period with their extremes. Some years can be exceptionally wet, which more influences the hygrothermal behavior of a building envelope. In general, it is usual to use the arithmetic mean to give a picture of more measured values with one number.

Future predictions are also possible to do, but it is dependent on a measurement quality, methodology of used computing tools and character of monitored variable. First of all, data have to be professionally assessed. The next step after evaluation of recorded parameters will be creation of characteristic reference file for Zilina, which would serve best for numerical simulations, e. g. WUFI, ESP-r, Delphin.

The wider database of measurement, the better. Having a period of 3 complete years at the disposal enabled first analysis, which is planned to be continuously updated and repeatedly analyzed.

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