sciendo

Civil and Environmental Engineering
Vol. 16, Issue 2, 370-378, DOI: 10.2478/cee-2020-0037

OUTDOOR CLIMATE CHANGE ANALYSIS IN UNIVERSITY CAMPUS: CASE STUDY WITH HEAT-AIR-MOISTURE SIMULATION

Peter JURAS[1,*], Daniela JURASOVA[1]

[1] Department of Building Engineering and Urban Planning, Faculty of Civil Engineering, University of Zilina, Univerzitna 8215/1, 010 26 Zilina, Slovakia.
[*] corresponding author: peter.juras@uniza.sk

Abstract

The standard weather station network, belonging to the national weather forecast service, cannot satisfy the requirements of advanced simulation tools because of the network density, time interval of recording, collections of measured values or availability of measured data and its price. Due to the outdoor climate change, urban heat islands and advance in research it is vital to obtain precise data sets for the measured location. Since 2014, also the experimental weather station, which continuously records the wind flow, air temperature, humidity, solar radiation, rain and atmospheric air pressure, is a part of University of Zilina campus.
In this paper, measured values of selected climate parameters are analyzed in terms of raw data and also in the case study of two wall types – traditional masonry brick wall and lightweight wooden-frame wall. Behavior of these walls is simulated by the impact of a non-steady state with use of WUFI Pro software. The impact on the hygro-thermal regime of walls – water content, simulated under various boundary conditions, is analyzed and the differences between measured years are quantified.

Keywords:

Climate change;
Mitigation;
Simulation;
HAM;
Case study.

1 Introduction

Outdoor climate is an important part of the set-up of simulation in civil engineering of any kind (heat-air moisture transport, heat and cool demand, overheating, etc.). Not only detailed outdoor boundary conditions but also the material properties of used materials and the used simulation tool and appropriate model from vast selection are important. Several works deal with the accuracy of used outdoor climate. The resolution of data (time step) and the number of climate parameters differs from one simulation toll to another. The ability to predict rains and floods based on annual cycles was evidently used by humans at least from the time of agricultural settlement if not earlier.

Later the national weather institutes built their weather station network to obtain selected climate parameters such as temperature, humidity, rain, wind etc. In Slovakia, the Slovak Hydrometeorological Institute (www.shmu.sk) has a network of 96 climatological stations. Some of them are not automated, so the time step is limited to three time period daily (at 7, 14 and 21 o'clock). Also the measured parameters are limited within some stations. With the advance of simulation tools and requirements towards zero net buildings, very accurate models need small time step and denser network. Also the urban heat islands have a big impact on the accuracy [1] because the temperatures differ between parts of the city or street canyons [2].

Therefore, the standard weather institutes network cannot satisfy the advanced simulation tools. In addition, the nearest climatological station is not far away from the campus location but it is only manned with three times per day data collection with limited quantity of parameters (no solar radiation). Next automated weather station is about 20 km far away. It is situated on the open ground at the airport. Due to effect of urban heat islands the measured values differ from the habituated area [3].

Test reference years became more important with development of advanced simulation models. Few methodologies for creation of test reference years were developed through several decades. The most common ones are following two methods: a simple selection of worst year from a 10-year period or the numerical analysis of months and then the combination of months from different years into one test reference year, which in fact is not real, because the months are selected from different years. With the outdoor climate change the synthetically based (combined) reference years for many areas cannot capture this change and they impair the accuracy [4, 5].

In the area of outdoor climate research, there are some tools which can predict the climate change for the location based on the long term records (e.g. Meteonorm). For location of Zilina any design or reference year, based on the measurements, which can be used in advanced simulation, is not available so far. Comparison made only for temperatures difference for area of Zilina is stated in [6].

Heat-air-moisture (HAM) simulation advanced over time, from the steady state Glaser method to the non-steady transient simulation tools, which meet the EN 15026. From the one dimensional fragments to the 2 and 3D ones. Specialized tools for HAM or energy simulations changed or better said developed to the more complex, advanced tools. The ANNEX 41 [7] deals with whole building Heat-Air-Moisture response. The project aimed to acquire better knowledge of whole-building heat, air and moisture (HAM) balance and their effects on the indoor environment, on energy consumption for heating, cooling, air humidification and air drying, and on building envelope durability [8].

The University of Zilina Campus is since 2014 equipped with its own weather station, which results are analyzed in this paper as the climate parameters among the years and also in a case study with HAM simulation in WUFI Pro. Main reason for obtaining own weather station was to have as accurate outdoor climate for the lightweight wooden walls research as possible and the opportunity to conduct simulations [9, 10]. Also another universities use own weather stations nowadays, to increase accuracy of comparison [11].

2 Weather station

Used climate data are recorded by a weather station (Fig. 1). This weather station (WS) is placed on the roof of one University´s building (3-story building). The exact location of the station is shown in Table 1. The University campus is located in the suburbs of the city of Zilina and surrounded by the forest from three sides and meadow from the fourth one and slightly uphill compared to the rest of the city.



Fig. 1: Weather station located on the roof of University´s building.

The manufacturer is Ahlborn and the device consist of the Meteo-Multisensor FMA-510, which measures temperature, relative air humidity, air pressure, wind velocity and direction and rainfall. The station is equipped also with two pyranometers for measuring of short wave irradiation, one – Star Pyranometer FLA 628 S is on the horizontal plane. The other one on the vertical plane is not used in

this case [9]. All devices are connected to the Almemo 2590 datalogger. Recording time step was set to ten minutes, since 2017 is one minute. Data collection is carried out wirelessly by Bluetooth.

Table 1: Location of the weather station.

Longitude	Latitude	Altitude ASL [m]
18° 45´ 23.6´´	49° 12´ 8.26´´	386.44

The weather station is in operation from March 2014 with some minor malfunction or gaps during the data downloads, which were filled in by a linear interpolation. The partial data files from WS were compared to the data from National weather forecast institute in the previous papers, in terms of pure climate comparison and validation [12] and to results of simulation in ESP-r [3].

Multiple sensors of the WS are regularly calibrated according to the manufacturer prescription in accredited laboratory. Relative humidity sensors often need to be shifted (8 % of relative humidity during the years). Other sensors are more or less stable with small variance.

3 Climate analysis

Measured and recorded period is since March 2014 to December 2017. That is almost 4 years with missing January and February of 2014 (without measurement). The monthly averages of temperatures are summarized in Table 2.

From the table and also from the Fig. 2 it can be seen that the averages are quite similar in some parts. Lower values than average are highlighted The January 2017 was extreme cold, compared to the other years, with temperatures up to - 25 °C.

Monthly averages of relative air humidity are shown in Table 3. As by temperatures, the differences are not significant as expected.

Scatter plots of temperature and relative air humidity for selected time (midnight, 00:00) and noon (12:00) are in Fig. 3 and 4. The movement of values to the left for the year 2017 is caused by a cold winter in January. Also at noon there is a low relative humidity during the summer period so the cloud of points is descending.

For the year 2017, there were more values in the part 30 °C + compared to the previous year 2016 (Fig. 5). Year 2015 was the warmest one. It seems that the warmer years are odd numbered ones but the only four years period is too short to confirm this observation. All parameters measured by the weather stations are stated as annual average, total sum or the highest value in Table. 4.

Table 2: Monthly averages of temperature.

	2014	2015	2016	2017	Average
January	-	0.58	-2.17	**-6.72**	-2.77
February	-	**0.33**	3.40	2.33	2.02
March	**8.52**	4.85	4.93	7.33	6.41
April	8.95	8.50	9.60	8.28	8.83
May	13.98	12.97	14.07	14.66	13.92
June	16.41	17.22	18.36	18.83	17.71
July	19.51	20.80	18.28	18.49	19.27
August	16.67	**21.65**	17.55	19.85	18.93
September	14.86	15.09	15.69	13.45	14.77
October	10.48	9.34	7.90	8.95	9.17
November	7.46	5.51	4.63	**4.29**	5.47
December	1.61	2.60	**-1.39**	2.2	1.26
Average	n.a.	9.95	9.24	9.33	9.58

Considering the differences of statistical variables, none of the four years seems to be any kind of special or more severe with exception of the January 2017. This is partly expected, because the period of measurement is too short from statistical matters, where recommended more than 10 years of measurements for design reference years are required and recommended [5].

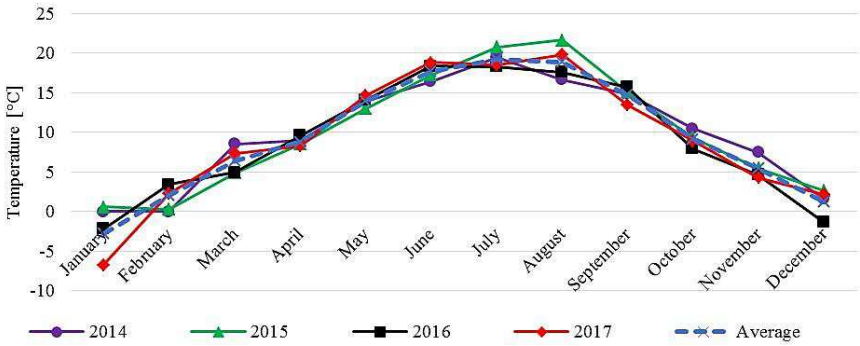


Fig. 2: Yearly courses from monthly average temperatures.

Table 3: Monthly averages of relative air humidity.

	2014	2015	2016	2017	Average
January		76.0	76.0	68.9	73.6
February		72.5	74.2	75.4	74.0
March	60.2	65.7	66.3	70.0	65.6
April	63.4	60.0	62.5	73.4	64.8
May	67.6	68.3	63.5	62.8	65.6
June	61.9	63.9	64.6	58.0	62.1
July	70.5	59.7	64.7	65.5	65.1
August	76.2	61.3	68.1	63.3	67.2
September	79.2	67.9	72.3	73.5	73.2
October	80.2	77.3	76.4	77.9	77.9
November	76.3	78.2	73.5	77.1	76.3
December	75.6	82.2	77.1	80.2	78.8
Average	71.1	69.4	69.9	70.5	70.4

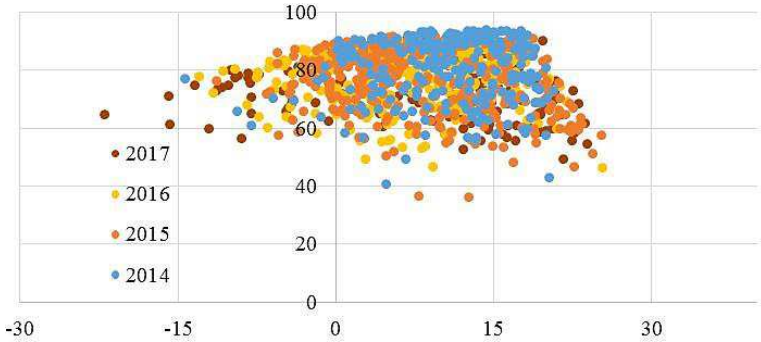


Fig. 3: Chart showing dependency between temperature and relative humidity for measured years at midnight (0:00).

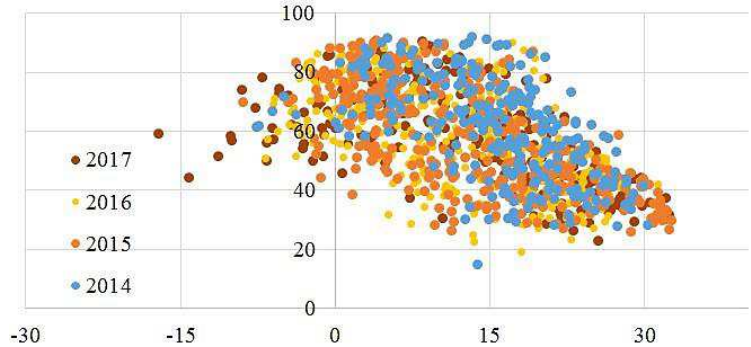


Fig. 4 Chart showing dependency between temperature and relative humidity for measured years at noon (12:00).

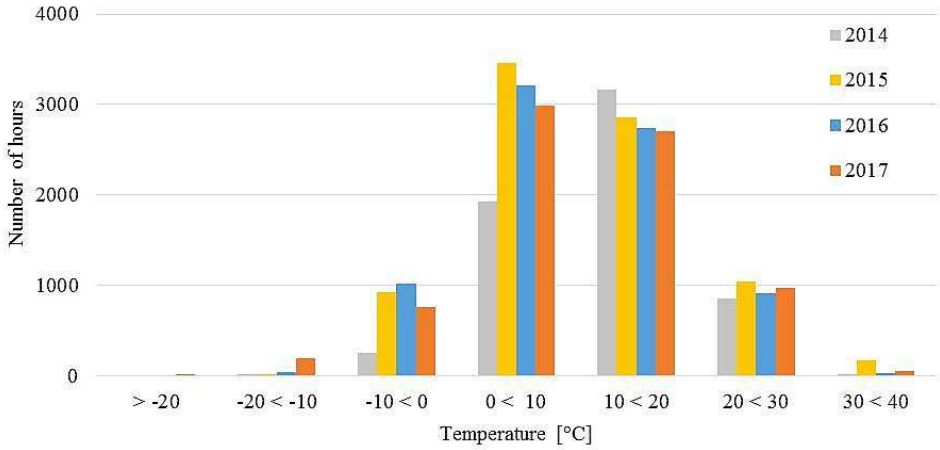


Fig. 5 Histogram showing annual sum of hours for different temperatures.

Table 4: Annual averages, summation or maximal climate parameters measured by the weather station.

	2014	2015	2016	2017
Air temperature [°C]	12.3	10.1	9.1	9.7
Max. air temperature [°C]	32.2	35.2	33.2	34.2
Min. air temperature [°C]	-14.3	-14.3	-16.2	-24.3
Relative air humidity [%]	72.7	69.2	70.0	69.7
Wind gust [m/s]	22.5	19.8	23.2	11.6
Annual Rainfall [mm/m^2·a]	616.1	633.0	611.4	724.7
Atmospheric air pressure [hPa]	968.7	970.2	969.0	968.7
Irradiation sum [kWh/m^2·a]	855.0	1097.7	1041.0	1026.5
Wind velocity [m/s]	1.0	1.1	1.1	1.0
Wind direction [°]	167.5	169.4	166.5	172.1

4 Heat and air-moisture simulation

To compare the measured values not only in form of raw climate data but also in the “practical” influence on the hygrothermal regime of the building envelope a heat-air-moisture (HAM) simulation was made. The years were simulated individually. As the simulation software served WUFI Pro developed from Fraunhofer Institute for Building Physics, based on the equation from Kunzel [13]. Version 5.1 of WUFI was used. Two things are constantly challenging by simulations, use of climate data with a good resolution and suitable material properties [11,14], which are in non-steady HAM simulation much more complicated than in steady state or by simply calculation according to the standards for water vapor condensation or heat transfer.

The software library contains many reference years, but as stated before, neither for this location, nor for Slovakia. Therefore the climate measured by WS served as the outdoor boundary conditions.

Indoor temperature was set to 20 °C and relative humidity to 50 % with 10 % amplitude (medium moisture load) to minimize the influence of variable indoor climate on the simulation results.

Two types of walls were simulated to observe the differences between the years. First solid masonry wall based on the aerated clay brick with use of traditional cement lime coatings and second timber framed wall with MDF board on the outer side and acrylic coating broadly used with ETICS these days. This composition was selected because it is used in the test wall, which was the reason that the WS was set-up in the place [15]. Exact composition of structures is in Table 5. Properties of used materials are summarized in Table 6 and are combined from the wind-driven rain research of cement-lime coatings [16] and from timber framed wall research [15]. Missing or not measured parameters were compared and best suitable materials were chosen from WUFI Material Library. Measured values are in bold.

Start date of calculation was set to 1 March, to avoid missing January and February from year 2014. Simulation was made for 20 months. To have complete year 2014, January and February from

2015 were used. In other cases were simulated exactly the measured years and after December followed by the same year.

Table 5: Detailed construction of the reference walls from outside.

Aerated clay brick wall	AC	EdelPutz - scraped coating th. 10 mm	MVR Uni th. 15 mm	Aerated clay brick (ACB) th. 365 mm	Gypsum plaster th. 15 mm
Wooden framed wall	**WF**	External acrylic coating th. 4 mm	Woodfiber MDF Board th. 100 mm	Mineral wool insulation th. 220 mm	Vapor barrier and OSB Board th. 12 mm

Table 6: Properties of used materials in the wall fragments, bold stated values were exactly measured, for coatings [14].

Name	Bulk density [kg/m^3]	Porosity [-]	Thermal conductivity (dry state) λ [W/((m·K)]	Diffusion resistance factor μ [-]	Water absorption coefficient A [kg/(m^2·s^{0,5})]	Capillary water content w_{cap} [kg/m^3]
Cement-lime scraped coating	**1303**	**0.11**	0.8	15	**0.0123**	**71.31**
Cement-lime universal coating	**1015**	**0.18**	0.5	20	**0.0154**	**109.55**
Aerated clay brick	600	0.77	0.12	16	-	188
Gypsum plaster	850	0.65	0.2	8.3	-	400
External plaster	1900	0.12	0.7	40	-	100
Woodfiber MDF board	210	0.83	0.045	5	-	107
Mineral wool insulation	40	0.95	0.035	1	-	-
Vapor barrier	2000	-	1	100000	-	-
OSB board	700	0.9	0.14	165	-	814

As initial condition in the wall, the water content in materials was matching to the 80 % relative humidity. This in the masonry wall represents the wet process of construction and in timber-framed wall construction in the spring. Some authors prefer comparison after simulation the same year for few times [4, 13, 18] to avoid influence of the construction. In this case, comparison was made during the first year after built of the wall.

Considering more authors, such as [4, 17, 18] wind-driven rain (WDR) has biggest influence on the hygrothermal regime of the wall. Rain reduction factor used in WUFI for cement-lime plaster was 1.0 based on the experimental measurement [16] and for acrylic coating no absorption because these coatings should be water resistant.

To set the proper orientation of the wall, wind rose was created. It represents the wind driven rain loads on the differently oriented facades (Fig. 6). Orientation of the windward façade changed a little bit during the years. Selected was north orientation. That was the best one because of highest WDR load and quite comparable windward orientation between the years. From WUFI option, building with height between 10 - 20 m and with constant R_2 = 0.1 as reduction from horizontal rainfall, was selected.

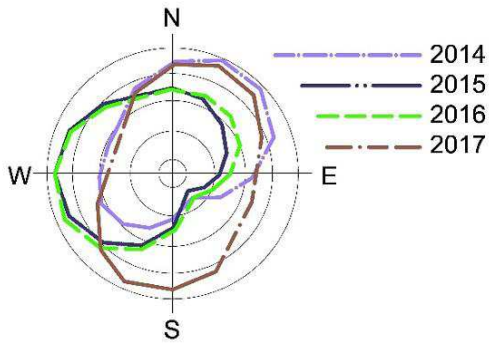


Fig. 6: Wind rose showing the wind-driven rain quantity and differences between windward facades for University location during the measured years.

5 Simulation results

Simulation results can be analyzed in many ways, such as temperature courses, heat fluxes etc. for individual simulated years and wall types. In this paper was selected as basic parameter the water content in the core layer of the wall. For masonry wall it is the aerated clay brick in Fig. 7 and in the timber framed wall in the MDF board in Fig. 8. The increased water content could cause various defects, from aesthetic, increased heat flow to durability and structural failures. For the masonry wall is for illustration and confirmation of the highest influence of WDR also year 2017 calculated without the WDR to show the impact and difference between the courses. On the other hand in the timber framed wall was added course for little rainwater absorption (rain water absorption factor 0.2), which can simulate small cracks in the coatings caused by the bad workmanship, weather during the work etc.

Fig. 9 represents comparison between the year 2017 for Zilina, moisture reference year (location Holzkirchen, Germany) and for Bratislava 2010.

Moisture reference year from Holzkirchen, combined out of 1st half year 2006 followed by 2nd year 2005 and it is used by the Fraunhofer Institute. Year for Bratislava was a most severe year considering the WDR load [18]. For the last two locations calculation was made with the west orientation, because it is the windward one.



Fig. 7: Annual courses for different calculated years in the masonry wall in the aerated concrete brick. Dash line represent year 2017 without influence of WDR.

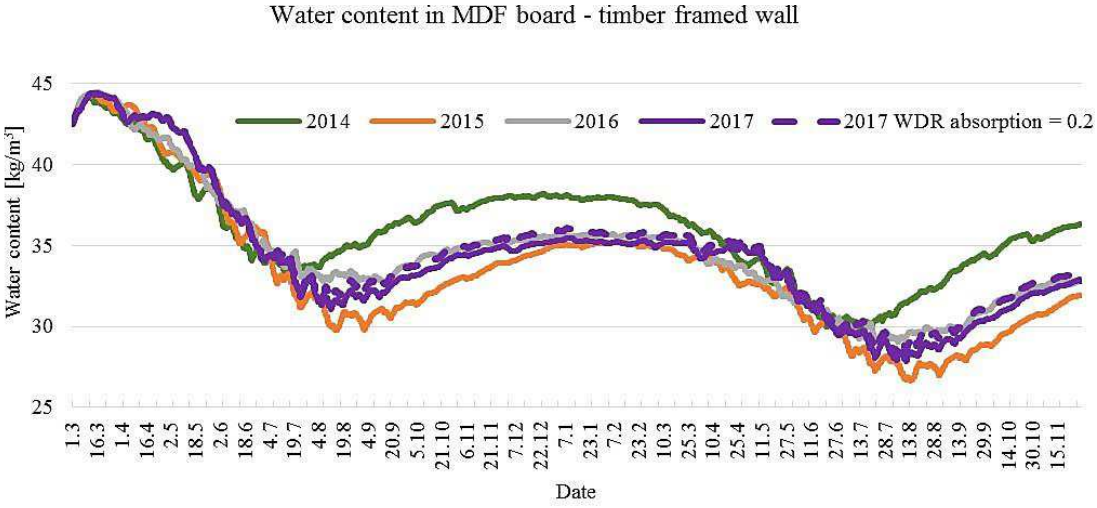


Fig. 8: Annual courses for different calculated years in the timber framed wall - water content in the MDF board. All calculated years are without WDR (no water absorption caused by use of acrylic coating) Dash line represents water absorption 0.2 - small cracks on the surface and little water penetration.

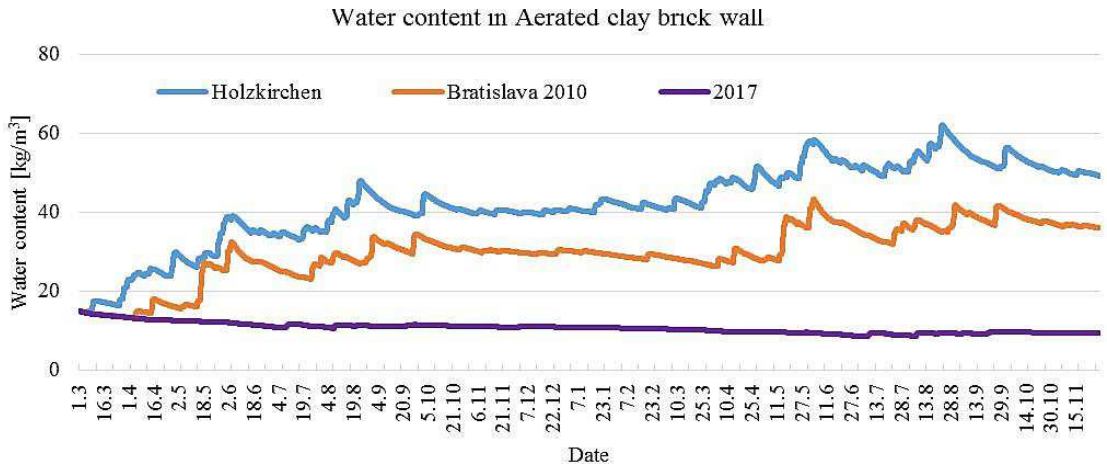


Fig. 9: Annual courses for various locations: Zilina 2017, Holzkirchen – IBP Moisture reference year and Bratislava 2010.

6 Discussion and results analysis

Analysis of pure measured climate values showed small differences for the period of years 2014 - 2017. As mentioned before, this time period is too short. Only two months were out of average - December 2016 and January 2017. Based on the histogram comparison (Fig. 5) it can be seen that the main part (0 - 10 °C and 10 – 20 °C) is decreasing (about 200 hours yearly) and the part 30 °C + is increasing.

In the part of HAM simulation, which is focused on the water content courses in the core layer of the walls two findings were observed. The difference between the annual courses are about 2 kg/m^3 in the terms of water content in the masonry wall and about 5kg/m^3 in the MDF board of timber-framed wall.

Second is the influence of wind-driven rain on the hygrothermal regime. Without the WDR absorption is the wall going to dry relatively fast, without any unusual movement and it is about another 2 kg/m^3 lower for comparison the year 2017 with and without WDR. Compared to the other two selected reference locations (Bratislava as the only location in Slovakia where is such design year with WDR is available) and Holzkirchen could be seen that the impact of WDR exists, but has not such importance in this area.

If we compare the yearly (annual –a) rainfall, the values are about 30 percent lower for Zilina (725 to 1000 mm/(m^2.a)) but the amount of wind-driven rain is in Zilina very small (100 mm/(m^2.a)) compared to Holzkirchen or Bratislava with cca 600 mm/(m^2.a). This is caused by the low average wind velocity (Bratislava 2010 has about 2.8 m/s while Zilina about 1 m/s).

7 Conclusion

In this paper, results measured by weather station located within the University of Zilina campus, were compared. Its intended use was to record outdoor climate for simulation and verify other experimental measurement conducted in the laboratory. Also the lack of weather stations in nearby location, which can be used for simulation inputs, was important. Measured results served also as the basis for this article and were analyzed as raw data and with help of HAM simulation.

Analysis shows small differences between the years in the analytical approach and also these small differences showed HAM simulation on the modeled two different walls.

The simulation confirmed the fact, that the WDR has an impact on the hygrothermal regime. The impact was not as huge as for other locations, which were added for comparison, but it exists. Lower impact is caused by the lower wind-driven rain amount for this location. This is caused by the low average wind velocity.

More differences between the individual years could be seen in simulation of energy for heating or cooling, which will be aimed in the future.

Acknowledgment

The research is supported by the research project VEGA No. 1/0673/20.

References

[1] IMHOFF, M. L. et al.: Remote sensing of the urban heat island effect across biomes in the continental USA. Remote Sensing of Environment, Vol. 114, Iss. 3, 2010, pp. 504-513.
[2] ZHANG, Y. et al.: Study on Urban Heat Island Effect Based on Normalized Difference Vegetated Index: A Case Study of Wuhan City. Procedia Environmental Sciences, Vol. 13, 2012, pp. 574-581.
[3] STAFFENOVA, D. - PONECHAL, R.: Comparison of meteorological climate data sets from Greater Žilina and their influence on temperatures within the experimental wall. Applied Mechanics and Materials, Vol. 861, 2016.
[4] KÜNZEL, H. M. - SCHMIDT, T. Wetterdaten fur rechnerische Feuchteschutzbeurteilungen. IPB – Mitteilung 27, Teil 364, 2000.
[5] DEUTSCHE WETTERDIENST 2017. Handbuch Ortsgenaue Testreferenzjahre von Deutschland für mittlere, extreme und zukünftige Witterungsverhältnisse. http://www.bbsr.bund.de/BBSR/DE/FP/ZB/Auftragsforschung/5EnergieKlimaBauen/2013/testreferenzjahre/try-handbuch.pdf?__blob=publicationFile&v=3
[6] JURASOVA, D.: Analysis of long-term measured exterior air temperature in Zilina. Civil and Environmental Engineering, Vol. 14, Iss. 2, 2018, pp. 124-131.
[7] HENS, H.: EBC Annex 41 Whole Building Heat-Air-Moisture Response (MoistEng) Project Summary Report, 2013.
[8] WOLOSZYN M. - RODE C.: Modelling Principles and Common Exercises. ACCO, Leuven, 2008, 234 pp.
[9] DURICA, P. et al.: Long time testing of temperature parameters of wooden lightweight external walls. STRUCTURA, 7 - 8. 11. 2013, VSB - Technicka univerzita Ostrava, 2013.
[10] STAFFENOVA, D. et al.: Intention, Principle, Outputs and Aims of the Experimental Pavilion Research of Building Envelopes Including Windows for Wooden Buildings. Civil and Environmental Engineering, Vol. 13, Iss. 1, 2017, pp. 42-51.
[11] VERTAL, M. et al.: Case study investigations on drying process cellular concrete external walls with ETICS. Bauphysik, 38, 2016, pp. 378-388 (in German).
[12] STAFFENOVA, D. et al.: Climate data processing for needs of energy analysis. Advanced Materials Research, Vol. 1041, 2014.
[13] KÜNZEL, H. M.: Simultaneous Heat and Moisture Transport in Building Components. One- and two-dimensional calculation using simple parameters. Stuttgart, IBP Verlag, 1995.
[14] VERTAL, M. et al.: Hygrothermal initial condition for simulation process of green building construction. Energy and Building, Vol. 167, 2018, pp. 166-176.
[15] DURICA, P. et al.: Lightweight wood-based walls with various thermal insulations: long- time measurement and subsequent comparison with HAM simulation. Building simulation 2015, 14th international conference of IBPSA, December 7 - 9, 2015, Hyderabad, India. BS Publications, 2015.
[16] JURAS, P. - ZILINSKY, J.: Measurement of wind-driven rain absorptivity of various coatings in rain chamber. ATF 2013, 2nd Conference on Acoustics, Light and Thermal Physics in Architecture and Building Structures.Book of proceedings. Leuven, Belgium 2 - 3. 5. 2013. Leuven: Katholieke Universiteit Leuven, 2013.
[17] BLOCKEN, B. - CARMELIET, J.: A review of wind-driven rain research in building science. Journal of Wind Engineering and Industrial Aerodynamics, 13, 2004.
[18] JURAS, P. - ZILINSKY, J.: Comparison of HAM Simulation with Different Reference Years for Bratislava. Advanced Building Construction and Materials, Vol. 855, 2014.