TECHNICAL TRANSACTIONS | **CZASOPISMO TECHNICZNE**
CIVIL ENGINEERING | BUDOWNICTWO

3-B/2014

AGNIESZKA SADŁOWSKA-SAŁĘGA*, JAN RADOŃ*

EXPERIMENTAL AND THEORETICAL STUDY OF MICROCLIMATE IN HISTORICAL CHURCH IN WIŚNIOWA

EKSPERYMENTALNE I TEORETYCZNE BADANIE MIKROKLIMATU W KOŚCIELE W WIŚNIOWEJ

A b s t r a c t

The paper presents a comparison of calculation and measurement results of interior air temperature and humidity in the historical wooden church in Wiśniowa. WUFI®plus software was used for these calculations. A concurrence between calculated and measured parameters allows the presupposition that calculation accuracy is sufficient for the purposes of determining thermal comfort in buildings where the indoor climate is shaped passively. Statistical analysis of the trend changes seems to also be sufficient to assess dynamic impact.

Keywords: *microclimate*, *comparative calculations*, *historical churches*

S t r e s z c z e n i e

W artykule przedstawiono porównanie wyników pomiarów i obliczeń wewnętrznej temperatury i wilgotności powietrza wykonanych w zabytkowym kościele w Wiśniowej. Zbieżność obliczonych za pomocą programu WUFI®plus i zmierzonych parametrów pozwala przypuszczać, że dokładność obliczeń jest wystarczająca do celów określenia komfortu cieplnego w budynkach z pasywnym kształtowaniu klimatu. Analiza statystyczna zmiany trendu wydaje się być wystarczająca do oszacowania dynamiki zmian mikroklimatu.

Słowa kluczowe: *mikroklimat*, *obliczenia porównawcze*, *kościoły zabytkowe*

* M.Sc. Agnieszka Sadłowska-Sałęga, Assoc. Prof. Ph.D. Jan Radoń, Department of Rural Building, Faculty of Environmental Engineering and Land Surveying, University of Agriculture in Cracow.

1. Introduction

Historical buildings constitute an essential part of our cultural heritage. Valuable objects such as wall paintings, sculptures and other furnishings form an integral part of a building. Scientific research shows that the preservation of artefacts and building components is particularly sensitive to the microclimate. High temperature and relative humidity both increase biological risks. Too low humidity often causes cracks due to the shrinkage of the painting substratum and leads to other mechanical damages.

Current valuations of the microclimate in historical buildings show that the indoor air parameters often exceed restoration demands. Global climate change and its negative potential impact constitutes another challenge. The preservation measures, therefore, need reliable calculation results of a building's hygrothermal performance nowadays and in the future.

The software used for calculating hygrothermal performance of the building's envelope is state-of-the-art. However, historic buildings differ from each other in their usage and design. Hygrothermal conditions often shape passively, as in unheated churches. The physical properties of the materials historic building are constructed of differ from contemporary materials. Also, defining internal heat and moisture sources proves difficult due to the specific uses of historic buildings, such as tourism, and so the number of tourists in the museums, their age, weight, clothing, etc., need to be considered.

The paper presents a comparison of calculation and measurement results of interior air temperature and humidity in a historical wooden church in Wiśniowa. WUFI®plus software was used for these calculations.

2. Historical wooden church in Wiśniowa

Wiśniowa village is located in the Małopolska province, 50 km south of Krakow. The church of Saint Martin in Wiśniowa was built around 1730 on the site of a previous one, which burned down. The church was renovated and expanded in the early twentieth century. The church has a wooden log construction. From the outside, the building is boarded with larch paneling. The church is oriented east to west. The church's interior is decorated in Baroque style. The walls bear colorful paintings made in 1910 (Fig.1). The church is located on the so-called "Wooden Architecture Route" in Małopolska province.

Fig. 1. Church of St. Martin in Wiśniowa

It is heated using seven electric storage heaters (only during extreme cold, and immediately before the services). Mass is celebrated at 7 am on weekdays, and at 6pm every Saturday (in wintertime, from October to April – at 5 pm). Four church services are held every Sunday at the following times: 7 am, 9 am, 11 am and 6 pm (in wintertime – at 5 pm).

3. Measurements

Experimental studies in the church in Wiśniowa have been conducted within the scope of "Possibilities and limitations of computational designation of temperature and humidity in historical buildings", research project funded by Narodowe Centrum Nauki (2011/01/N/ST8/02534).

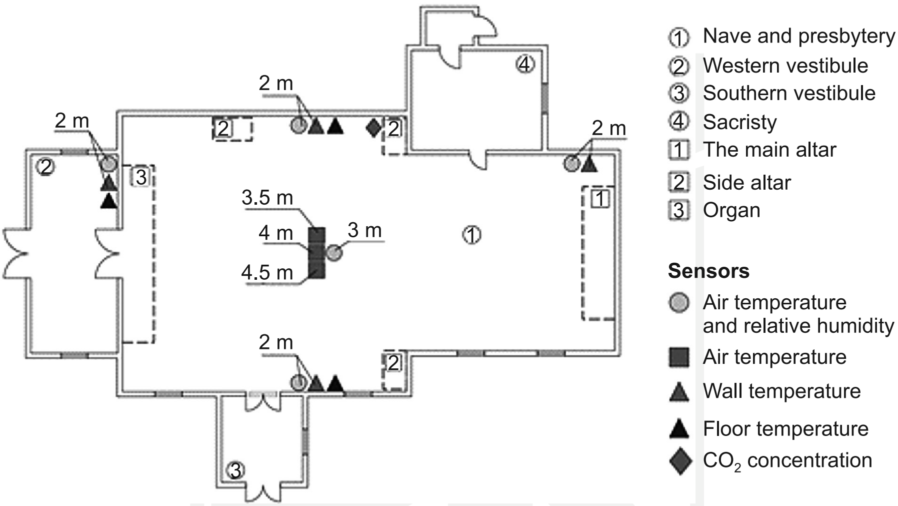

Fig. 2. Placement of sensors in the church in Wiśniowa

The measuring system, due to the historic character of the building, has been based mostly on battery powered measuring devices with radio communication features. The measuring elements have been arranged in two locations – inside the church (measuring internal parameters, see Fig. 2), and outside the church (evaluating external parameters).

The temperature and relative humidity are measured at six points:

– against the southern and northern walls of the nave (at a height of 2.0 m),
– against the northern wall of the presbytery (at a height of 2.0 m),
– in the middle of the nave (sensor hidden in the chandelier at a height of 3.0 m),
– against the western wall of the vestibule,
– and in the central part of the attic (at a height of 1.5 m).

In addition, to recording the vertical temperature stratification in the middle aisle, three supplementary temperature sensors have been mounted (at 3.5 m, 4.0 m and 4.5 m heights), which are hidden in the chandelier as temperature and relative humidity sensors.

Floor temperature is measured at three points: near the southern and northern walls of the nave and in the vestibule (against the wall connecting the vestibule with the nave). The surface temperature is measured at the southern and northern walls of the nave (at 2.0 m height) and at the northern wall of the presbytery (at 2.0 m height). At the northern wall a CO_2 concentration sensor has been mounted.

The weather station was placed in the vicarage, just about 100 m in a straight line from the church. The choice of the location was limited due to numerous trees (the church is surrounded by a historic linden avenue) and other buildings. The weather station includes air relative humidity and temperature sensors and converters of solar radiation (diffuse and global).

4. Theoretical calculations

Hygrothermal conditions in the church in Wiśniowa were calculated using the WUFI®plus software designed for whole building simulations [1, 2].

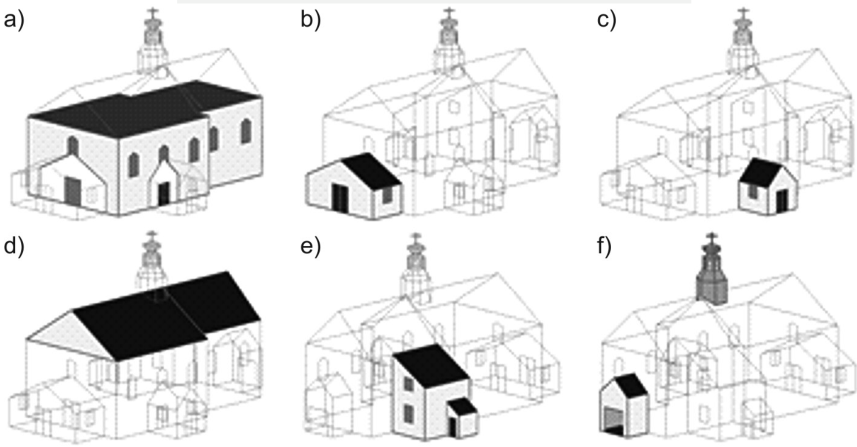

Fig. 3. Division of the church in Wiśniowa by zone: a) nave and presbytery, b) western vestibule, c) southern vestibule, d) the attic, e) sacristy, f) outer altar

The model of the building model takes into account one simulated zone (nave and presbytery: its cubic capacity – 1883.2 m^3, and area – 243.7 m^2) and 5 attached zones (western and southern vestibules, sacristy and the attic). An additional outer altar is attached to the eastern façade (Fig.3). Material data for particular assemblies was obtained from the WUFI®plus database.

Based on the data obtained from the rector of the Wiśniowa Parish, the number of participants at church services was estimated as outlined in Table 1. The simulation also includes church services such as "Midnight Mass", which involved far more participants. Heat and moisture gains from people were taken from the WUFI®plus database (activity – 0.97 met).

Based on the CO_2 concentration, the air change rate in the church was estimated as summarised in [3]. At the closed door, the air change rate was about 0.8 h^{-1}. Before each service, and in the summer time, the air change rate increased (Table 1).

Two versions of the boundary conditions were taken into account for the purposes of the calculations (see Table 2). The first set involved statistical data only, i.e. Typical Meteorological Year (TMY), while the second set consisted of parameters measured in 2013. Comparing these calculation results obtained using statistical climate data with the measurement results does not make much sense. The authors, however, wanted to show the extent of the differences when measurement results are not available and TMY is used as a boundary condition. This, on the other hand, is common practice nowadays.

Table 1

Number of participants (A) and ventilation rate (B) during mass in St. Martin church in Wiśniowa (times provided are consistent with daylight saving time)

January–March and November–December					April–October				
Time	Saturdays		Sundays and holidays		Time	Saturdays		Sundays and holidays	
	A [–]	B [h⁻¹]	A [–]	B [h⁻¹]		A [–]	B [h⁻¹]	A [–]	B [h⁻¹]
6 am		0.8	30	0.9	7 am		0.8	30	1.0
7 am		0.8	80	0.8	8 am		0.8	80	0.9
8 am		0.8	30	0.9	9 am		0.8	30	1.0
9 am		0.8	100	0.8	10 am		0.8	100	1.0
10 am		0.8	30	0.9	11 am		0.8	30	1.1
11am		0.8	300	0.8	12 am		0.8	300	1.1
12 am		0.8	50	0.9	13 pm		0.8	50	1.1
4 pm	25	0.9	30	0.9	18 pm	25	1.0	30	1.1
5 pm	50	0.8	200	0.8	19 pm	50	0.9	200	1.1
6 pm	5	0.9	10	0.9	20 pm	5	1.0	10	1.1

Table 2

Number of participants (A) and ventilation rate (B) during mass (times consistent with daylight saving time)

Simulation	Outer climate	Ground parameters	Climate in attached zones
1	TRM for Kraków form WUFI®plus database	– Temperature – sine curve (9.2 ± 7.2; max 01.08.2013) – 100% RH	Outer climate
2	From measurements: – temperature – relative humidity – solar radiation	– Temperature of the floor in the church – 100% RH	From measurements: – temperature – relative humidity

To ensure proper initial conditions, the calculations started at the beginning of November 2012 although the results were evaluated starting on January 1st 2013. Calculation time was 12 months (until the end of December 2013).

5. Results and discussion

As a result of the simulation the hourly patterns of temperature and relative humidity inside St. Martin church in Wiśniowa have been obtained. Figure 4 shows a comparison of the simulation results with the measured values for sample winter and summer months, December, 2013 and July, 2013, respectively. Statistical analyses were conducted separately for seasonal, weekday, Saturday and Sunday data sets (Fig. 5–7 and Table 3). A correlation was calculated based on the Spearman R test (the distribution of variables differs from a normal distribution) [4].

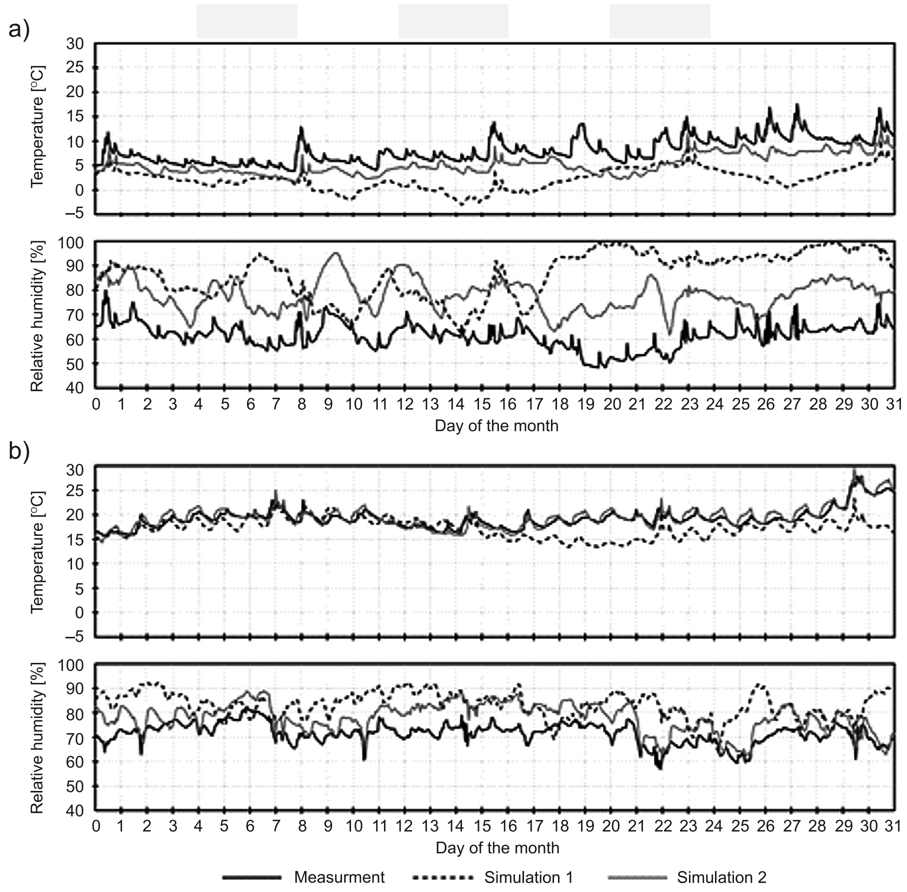

Fig. 4. Measurement results of temperature and relative humidity inside St. Martin church in Wiśniowa and simulation results for: a) December, 2013 b) July, 2013

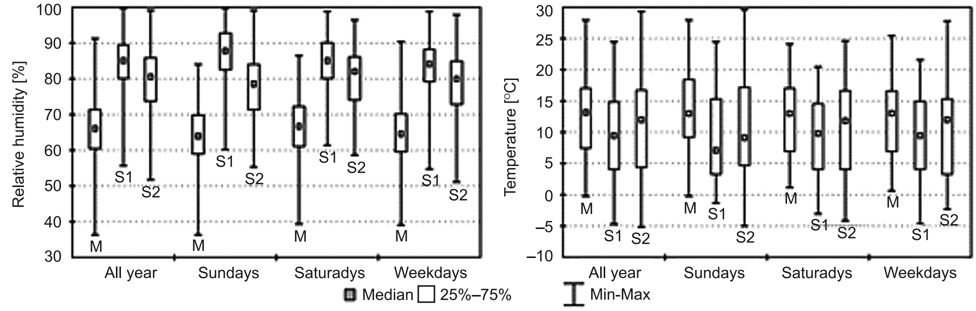

Fig. 5. Median, 25–75% percentile and min.-max. scope of measured (M) and calculated (S1, S2) inside air relative humidity and temperature

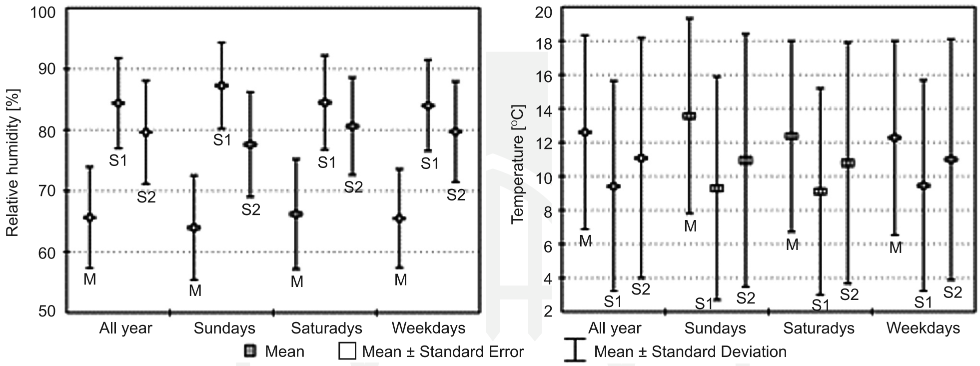

Fig. 6. Average, standard error and deviation of measured (M) and calculated (S1, S2) inside air relative humidity and temperature

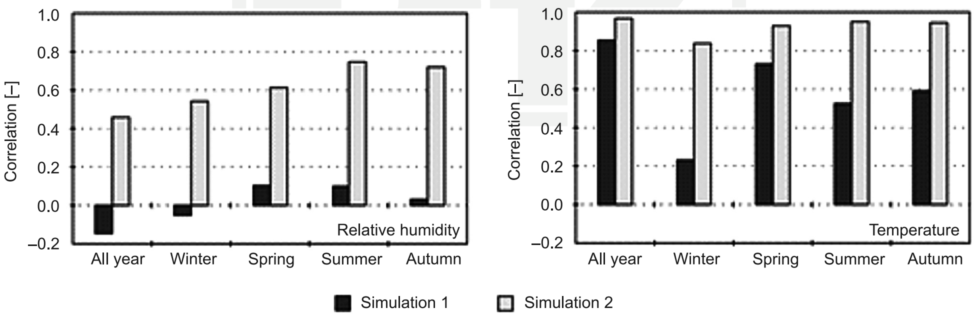

Fig. 7. Correlation between measurement and simulation for indoor air temperature and relative humidity depending on the season

Temperature calculations demonstrate a better agreement with the measurements. In all of the analyzed cases the correlation is positive. Over the course of a year, statistical climate correlation can be described as average-strong to strong, while real climate as strong. In both cases there are fewer errors than the average error rate of more than 62%.

Clear differences can be noted between the accuracy of the calculations for the summer and winter. For weekdays, the mean absolute error, in the case of statistical climate for the winter, is equal to 3.9°C, while for the summer it is 2.3°C. For external climate – on the basis of measurements – the mean absolute errors for the winter and summer are equal to 3.3°C and 0.9°C respectively.

Table 3

Correlation, mean and maximal absolute error

	All year		Sundays		Saturdays		Weekdays	
	Sym 1	Sym 2	Sym 1	Sym 2	Sym 1	Sym 2	Sym 1	Sym 2
Temperature								
Mean absolute error [°C]	3.6	1.9	4.5	2.8	3.7	1.9	3.4	1.8
Max. absolute error [°C]	17.3	12.1	17.3	11.5	13.9	12.1	14.7	12.1
Correlation	0.85	0.97	0.85	0.95	0.87	0.97	0.86	0.97
Relative humidity								
Mean absolute error [%]	19.3	14.2	23.4	13.9	19.3	14.5	19.0	14.4
Max. absolute error [%]	54.1	42.7	51.8	35.7	48.2	35.2	54.1	42.7
Correlation	–0.14	0.46	–0.34	0.51	–0.31	0.50	–0.12	0.42

In the case of relative humidity calculation accuracy is lower. Over the period of one year, in the case of statistical climate, the correlation proves negative. For the climate based on measurements, the correlation is positive and it can be describes as average-strong. Analogous to the temperature, clear differences between the accuracy of calculations for summer and winter can be noted. For weekdays, mean absolute error, in the case of statistical climate for the winter is equal to 30.6%, while for the summer it is 14.9%. For external climate – on the basis of measurements – the mean absolute errors for the winter and summer are equal to 24.0% and 8.1% respectively.

6. Conclusions

The concurrence of the calculated and measured parameters allows the presupposition that calculation accuracy is sufficient for the purposes of determining thermal comfort in buildings where the indoor climate is shaped passively. A statistical analysis of the trend changes seems to also be sufficient to assess the dynamic impact. Absolute temperature and humidity values, however, depend strongly on the accuracy of the definition of boundary conditions.

The authors were able to reach a much better agreement by modifying some parameters slightly (e.g. heat and/or moisture sources) and applying a more precise heat and moisture exchange model of the floor. Nevertheless, the presented results are very likely to be obtained based on partly rough estimated data, when exact solutions (in the form of measurement data) are unknown.

References

[1] Holm A., Radon J., Künzel H.M., Sedlbauer K., *Berechnung des hygrothermischen Verhaltens von Räumen*, WTA Schriftenreihe H., 24, 2004, 81-94.

[2] Karagiozis A., Künzel H.M., Holm A., *WUFI-ORNL/IBP – A North American Hygrothermal Model*, Contribution to "Performance of Exterior Envelopes of Whole Buildings VIII", 2–7 Dec. 2001, Clearwater Beach, Florida.

[3] Mattsson M., Lindström S., Linden E., Sandberg M., *Tracer Gas Techniques For Quantifying The Air Change Rate In Churches – Field Investigation Experiences*, 12th International conference on air distribution in rooms, Paper No 235, Trondheim, Norwey 2011.

[4] Aczel A.D., *Statystyka w zarządzaniu* (original title: *Complete Business Statistics*), Wydawnictwo Naukowe PWN, Warszawa 2011.