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THE INFLUENCE OF THE ENVIRONMENT ON OBJECTS OF HISTORICAL VALUE

The result of the environment's influence on objects of historical value is the ongoing process of their deterioration. The main cause for the deterioration process is the flow of heat and moisture which also brings salinary solutions. The correct diagnosis on the causes of adverse effects affecting buildings of historical value serves as the basis for further activity which can result in protecting an object of value against further deterioration. Dampness issues which occur in buildings are usually caused by the lack of proper anti-dampness insulation and an incorrect micro-climate inside (temperature and air humidity outside). In order to evaluate the influence of a micro-climate on dampness processes, the selected buildings of historical value had air temperature and relative air humidity monitors installed, each having the capacity for continuous data retrieval. Every month, examinations of wall dampness are being carried out using a PWM-3 hygrometer. Based on the measurements from the first two months, initial conclusions were drawn. Deeper analyses and the conclusions stemming from these will be drawn after the entire cycle of measurement ends at the end of 2018 (after one, full year of measurements).

Keywords: buildings of historical value, partition microclimate, humidity measurements, wall dampness measurement, microclimate measurement

1. Introduction

Sustaining (survival) of objects of historical value depends on regular conservation efforts which should focus primarily on the correct building exploitation, maintaining the conditions of interactions with the surroundings on a natural level, and quick prevention of destructive actions.

The concept of the natural level is in other wordsa system of external physical parameters such as: temperature, relative humidity, ground moisture content, salinization of walls [1].

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The main factors affecting the durability of historically significant buildings are varied forms of moisture and salts which are diluted in it and which move inside the capillary tubes. A diverse internal surface of the buildings materials used in those times which are porous-capillary contributed to the specific properties of such materials, as well as mechanisms of their destruction [2–4]. Dampness appears initially on external walls, which are the primary cause of visible damage. It is both the water originating in acidic rain as well as capillary tubes rising damp from subsoil. This form of damp is dangerous in the winter due to the cycles of freezing and unfreezing of free moisture. In the water present in the capillary tubes there are salinary solutions originating in the subsoil or flushed out of the ceramics and plasters. The most commonly present are: chlorides ($CaCl_2$, $MgCl_2$), nitrates (NO_3) i sulfates (K_2SO_4, $MgSO_4$), these are hygroscopic easily soluble in water. Salts precipitated from the solution damage both plasters and brick layers [6, 7].

2. Description of the phenomenon of how buildings of historical value are impacted

The main phenomena causing the processes of degradation of objects of historical value are:
– heat flows,
– diffusion of moisture,
– salinary solutions flows.

2.1. Heat flow

The distribution of heat flow in the wall forces the place of moisture condensation, freezing of water into ice, and as a consequence the damaging of protective layers. Analyzing one-dimensional heat flow (Fourier's law), distribution of temperatures inside a partition can be determined, and next based on such distribution water vapor pressure in capillary walls can be evaluated. Comparing real distribution of pressures in walls with limit values, when condensation of water vapor in capillary tubes occurs, an area of partition dampness can be determined.

On this basis, a scope of dampness with condensation damp can be determined, whichas a consequence can lead to the development of molding fungi on the wall surface. The basic dependencies for a single layer wall is presented below. The heat flow is described by the Fourier law of heat conductivity [3, 4].

$$q = -\lambda \frac{\Delta T}{d} \tag{1}$$

On the border, q flux is the same.

$$q_1 = -\lambda_1 (\frac{T_1 - T_0}{d_1}) \tag{2}$$

where: q– heat flux [W/m^2];

λ– heat conductivity rate, [W/m·K];

d – layer thickness [m];

(T_0 –T_2) – temperature increase from the initial state T_0 [^{O}C];

ΔT – temperature difference [°C].

2.2. Moisture diffusion – moisture condensation zones

The diffusion process is described by the diffusion equation, which stems from the balance of diffusing mass inside the partition (Fick's law) and initial-boundary condition. In the simplest case (stationary, one-dimensional) this equation is: [3, 7];

$$D = \frac{d^2 c^\alpha}{dx^2} = 0 \tag{3}$$

where:

$$c^\alpha = \frac{\rho^\alpha}{\sum_\alpha \rho^\alpha}, \quad \rho = \sum_\alpha \rho^\alpha \tag{4}$$

c^α – mass participation of the diffusing component of the solution in capillary tubes;

ρ^α– mass density of the unit of volume for component α, α=1,2..n;

ρ – density of the entire body.

Moisture flow inside the wall are more complex than heat flow. The cause for this is a multi-element composition of the diffusing solution, phase shifts and component reactions. Stationary distribution of temperature and damp on wall thickness make it possible to relatively easily determine the scope of the zone that is subject to dampness. The obtained results make it possible to establish approximate real values. Determining the zone of condensation depends on the distribution of temperature and subsequently partial pressure of water vapor in the subsequent layers [3, 6].

3. Wall dampening based on buildings of historical value in northern-eastern Poland

Issues with dampening in buildings which occur are usually caused by the lack of appropriate anti-dampness insulation and inappropriate microclimate of the interior (temperature, air humidity) [1].

The cause of dampness in construction objects is not only capillary damp but also condensation damp. The state of partition dampness caused by condensation damp has significant impact on the state of the object's usage. In un-utilized buildings or buildings used periodically (such as places of worship), the temperature of interior air is on average ±5°C (depending on exterior temperatures). For that reason, the wall surface temperature on the inside is relatively low. Such a state is very „conducive" to precipitation of surface and internal condensation damp (the wall surface temperature is lower than the dew point) [4]. For that reason, an un-utilized (unheated) building is more quickly subject to damage from wall dampness. The accumulated damp (free moisture) during periods of negative temperatures is subject to freezing, and as a result, to bursting the subsequent sub-surface layers.

To sum up, the phenomenon of partition dampness in buildings can occur as:
– damp penetration via hygroscopic water input,
– damp penetration due to lack of proper anti-damp insulation (capillary water rising),
– damp condensation of cold wall surfaces.

3.1. Buildings selected for examination

In order to determine the influence of interior microclimate on the level (state) of dampness of partitions in buildings of historical value, 3 example churches were selected. The selected objects have been struggling with the increasing issue of the deterioration of substance in historically significant walls are:
– St. Andrew's church in Barczewo,
– St. Anna's church in Barczewo,
– A church under the invocation of St. Mary's Immaculate Conception – Wigry.

At the beginning of the examination, the history of the building, history of repairs and renovations, with the emphasis on materials used, as well as whenever possible archival documentation were all analyzed. Interviews were held with the current users and administrators of the buildings.

A historical church in Barczewo under the invocation of St. Andrew the Apostle was erected in XIV century as a a single-nave, gothic church made of ceramic bricks. The scale of damage caused by damp is very significant (fig. 1).

a) b) c)

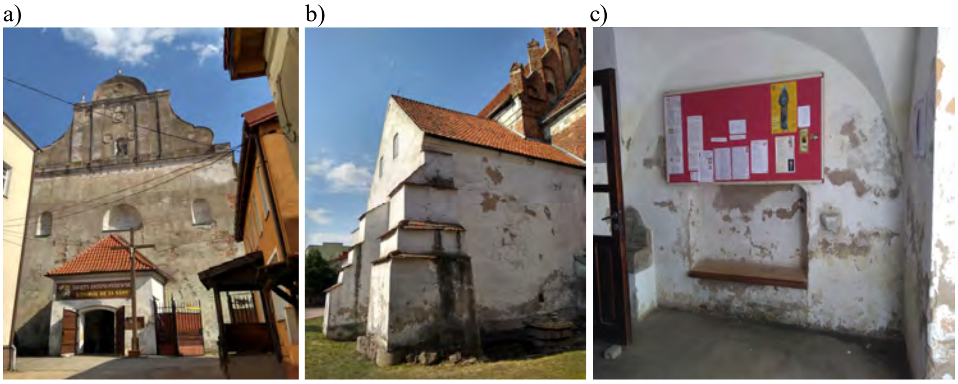


Fig. 1. St. Andrew's church in Barczewo - a) main entrance b) damaged side elevation c) multiple traces of damp visible on the walls from the inside

A historical St. Anna's church in Barczewo

The church was erected in XIV century; gothic. The church's vaulting were designed as arch and stellar vault. The church is made of full ceramic brick, plastered interior (fig. 2).

a) b)

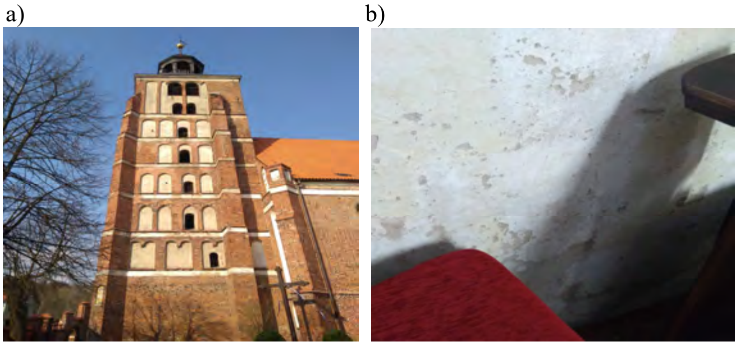


Fig. 2. St. Anna's Church in Barczewo- a) general view of the elevation, b) visible signs of damage cause by capillary and condensation damp

A historically significant church under the invocation of St. Mary's Immaculate Conception in Wigry, erected in XVII century, a baroque, single-nave design made out of full ceramic bricks, plastered on the inside (fig. 3).

a) b) c)

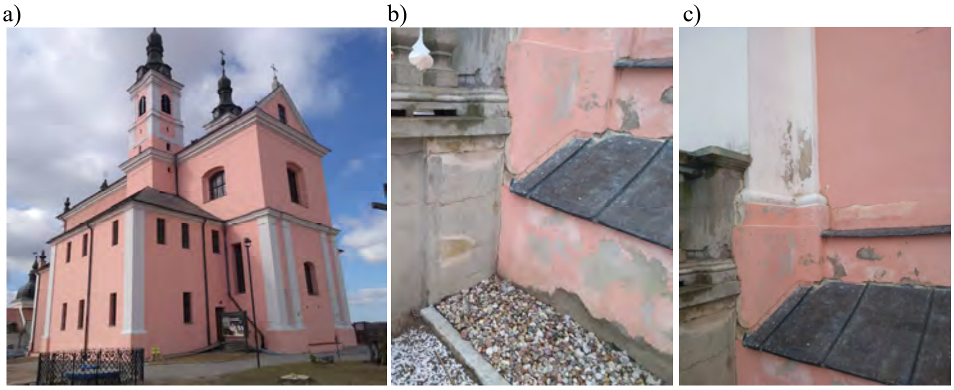


Fig. 3. A church under the invocation of St. Mary's Immaculate Conception - Wigry, a) general view of the building complex b) and c) visible outer layer damage caused by damp

3.2. Examination – interior microclimate and wall dampness

In order to carry out a precise analysis of the conditions occurring inside of the selected buildings, wireless Efento recorders were utilized. These recorders make it possible to register temperature and humidity in buildings with the option of saving data. These recorders also have the capacity for notifying when safe levels of temperature and humidity are being exceeded and generating automatic reports.

The recorders that were used are powered by batteries (2 years of continuous operation). The recorders were mounted on the objects between January and February 2018. With the goal of correctly interpret the conditions present in the churches, the recorders were mounted on 2–3 places in equal distances from each other. The recorders mounted in 3 churches are shown in fig. 4.

a) b) c)

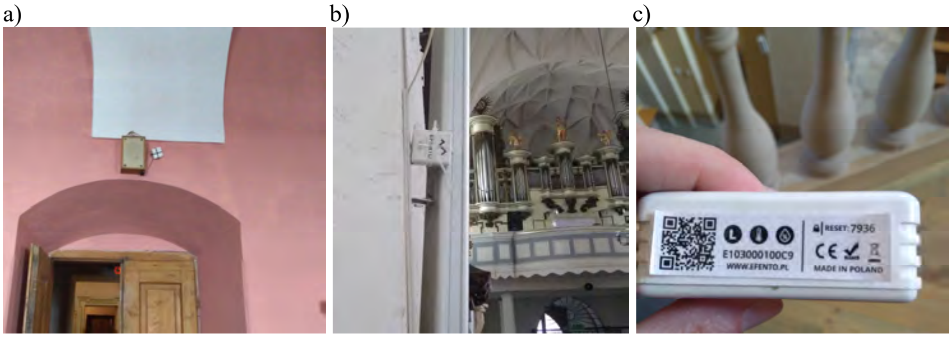


Fig. 4. Mounted sensors for measuring the temperature and humidity of the interior air a) in a church in Wigry over the entrance b) in the St. Andrew the Apostle's church in Barczewo c) in St. Anna's church in Barczewo d) general view of the mounted sensors

The recorders were mounted on 7.01.2018 in the church in Wigry and on 9.03.2018 in both churches located in Barczewo. In the St. Andrew the Apostle's church, 3 sensors were mounted, in the side nave, in the main nave and at the matroneum.

Apart from continuous measurements of the microclimate, once a month measurements of wall dampness are performed using the PWM – 3 hygrometer. This gauge is used to investigate the mass dampness levels of construction elements via the measurements of the difference in electrical capacitance of the condenser built out of a measurement electrode and the examined element; depending on its water content. The range of the gauge is 0÷25% with the margin of error at 0.5%.

Dampness measurements are carried out at the floor level, for all objects, and at the level of 1.2 m and 1.8 m. The values recorded in measurement points in the selected points are compiled in table 2.

In order to interpret the measurement results, a table specifying the level of mass dampness of walls made of ceramic bricks (Table 1).

Table 1. Recommended level of wall dampness by [5]

Dampness level	**Mass dampness [%]**	**Wall**
I	0÷4	of acceptable dampness
II	4÷5	of elevated dampness
III	5÷8	medium damp
IV	8÷12	highly damp
V	>12	wet

Sorption dampness of a full brick in room temperature should not exceed 4% of the material mass value [8].

4. Results and analysis

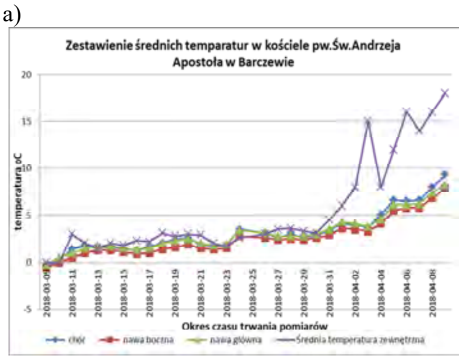
The results of wall dampness measurements for the selected churches are compiled in table 2.

The results of the air temperature and humidity measurements between 07.01.2018 and 09.03.2018 from the church in Wigry, the St. Andrew the Apostle's church in Barczewo and St. Anna's church, also in Barczewo, are shown in graphs (fig. 5a–d).

Table 2. The results of wall dampness between 07.01.2018 and 09.03.2018 for the church under the invocation of St. Mary's Immaculate Conception – Wigry and between 09.03.2018 and 09.04.2018 for St Andrew the Apostle's church in Barczewo (1) and St. Anna's church in Barczewo (2)

Measurement date	**Location**	**Mass dampness [%] (level of wall dampness)**		
		at floor level	at 1.20 m	at 1.80 m
07.01. – Wigry	Wigry	17% (wet)	17% (wet)	15% (wet)
09.02. – Wigry	Wigry	18% (wet)	17% (wet)	16% (wet)
09.02. – Barczewo 09.03. – Barczewo	Barczewo (1)	22% (wet)	19% (wet)	16% (wet)
	Barczewo (1)	22% (wet)	18% (wet)	17% (wet)
	Barczewo (2)	19% (wet)	18% (wet)	16% (wet)
	Barczewo (2)	18% (wet)	17% (wet)	16% (wet)

a)



b)

Fig. 5. Temperature and dampness levels as a function of time; 5a) levels of interior air temperature in 3 measurement points + the temperature of exterior air, 5b) temperatures and humidity of interior air – Barczewo (1)

a)

b)

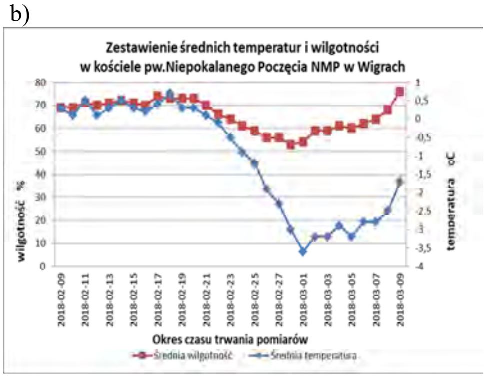


Fig. 6. Temperature and dampness levels as a function of time) a) temperatures and humidity of interior air - Barczewo (2) b) temperatures and humidity of interior air – Wigry

4.1. Results analysis

Diagrams of air temperature and humidity values included in fig. 5–6 pertain to 3 churches (Wigry and 2 Barczewo churches). In order to determine whether the location of gauge placement in the building had influence on the levels of temperature and humidity (fig. 5a), the gauges in St. Andrew the Apostle's church were located in the side-nave and at the matroneum. It turned out that the differences in temperature values are insignificant and amount to between 0.8°C and 1.5°C. The highest temperatures were recorded at the matroneum but a significant influence of the exterior temperature on the interior temperatures.

Measurements from both Barczewo churches were included for the period of 9.03.2018 and 8.04.2018. Diagrams 5b and 6c show the dependence of the relative air humidity on interior air temperature in Barczewo churches. Due to low temperature fluctuations (max. 3°C) in the period of 15.03 and 4.04. the air humidity values were also not significatnly different and remained at the level of ~70% in St. Andrew the Apostle's church and in St. Anna's church between 60% and 70%. Noticeable differences in humidity occurred in the first week of measurements and in the last couple of days, where the exterior air temperature has increased significantly. In the Wigry church, measurement results were included for the period between 9.02. and 9.03.2018, which causes the distribution of temperature and humidity values to be significantly different (fig. 6d). A conspicuous dependence of interior air humidity on temperature was observed. It was also noticed that the decrease in interior air temperature happened when interior air temperature was negative. Despite the interior temperatures in St. Anna's church being relatively stable, a noticeable spike of ~ 30% in relative air humidity values within a few days was noticed. This phenomenon poses a challenge to be interpreted (fig. 5a). Based on wall dampness results, it was concluded that in all the analyzed cases, the walls are wet within their entire measured height (from 0.2 m to 1.80 m). The dampness of walls exceeded the allowed value of 4% and was recorded at between 17% and 22%.

5. Summary and conclusions

The analysis presented initial results of microclimate measurements from the interior of 3 building of historical value (a Wigry church and two Barczewo churches) and the results of wall dampness measurements.

For the purpose of wall dampness analysis, a theory of heat and humidity flow, presented in p.2.1 i 2.2 was used, as well as the results obtained during the microclimate and partition dampness measurements.

Based on the analysis of the obtained data (measurement results), it can be concluded that:

– 24h temperature fluctuations on days when service is being held exceed the recommended value of 1^0C and are above 2.0^0C, and relative air humidity increases by 6÷7% with the recommended value being 5%. Such a state can be the cause for the excessive humidity being precipitated out of the air on cold walls, windows, stained glass and the floor.

– Wall dampness level measurements indicate that they are wet and exceed by over 4 times the recommended value of up to 4%.
– It is difficult to conclude, based on the analysis of wall dampness from one month only, whether the influence of the environmental microclimate has a significant impact on wall dampness levels. The results from 1 month (March), where their differences amounted to 1% indicate that in the winter (February – March) this impact was insignificant.
– The correct interpretation of these results can take place after the analysis of phenomena recorded at least after a 1-year cycle.
– Such analysis will allow us to notice how the cycle of building dampness in the summer and winter periods occurs and how construction partitions behave and how the microclimate which can be significantly influenced by exterior temperature, rainfall, atmospheric pressure, insolation or windis structured.
– In the analyzed objects, especially on St Andrew the Apostle's church in Barczewo, with walls being wet to such an extreme degree, (22% on the floor level and between 17% and 18% at 1.80 m) the analyzed walls should bewithout a doubt subject to dynamic drying, using the most efficient drying method.
– It has to be taken into consideration, however, that the protection of the analyzed objects against the damaging influence of dampness and adverse influence of the environment can pose a significant challenge and would require an in-depth analysis of the phenomenon.

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