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Thermal and mycological active protection of historic buildings on the example of the baroque residence of Polish kings in Wilanów

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ABSTRACT
Protection of the external partitions of historic buildings is a broad topic due to the limited possibilities of interfering with the structure. Restoration restrictions on prevention in the mycological protection of historic buildings are so large that, from the broad list of possible protective measures, practically only the heating of the nodes and the control of air parameters are practically safe. The reason for restrictions is the lack of possibility of introducing architectural changes and the limited possibility of interfering into the structure of external partitions.

A fast method that uses fluorescence was used for quantitative assessment of the mycelium development during the research and design work preceding the revalorization of the baroque seat of Polish kings in Wilanów (Warsaw). Mould mycelium were found mainly in the areas of increased humidity of the substrates. The use of an innovative method of local reheating of thermal bridge areas has been proposed there. Systems for reheating with halogen radiators using various infrared radiation (IR) bands were analyzed. There was also designed an anti-condensation system consisting on electric heating cables. The proposed solutions prevent the development of mould mycelium to a satisfactory degree. Finally, the interior of the palace regained its beautiful appearance and healthy microclimate.

KEYWORDS
Historical buildings, mycological protection, thermal bridges, anti-condensation systems, infrared heating.

INTRODUCTION
Historical buildings, especially those from the Baroque period, are often exposed to moisture and mycological problems. The baroque style developed mainly in Italy, where, due to the warm climate, the departure from the massive Gothic architecture did not result in the mould mycelium growth. Significantly lighter construction, with numerous niches intended for extended architectural details, may result in moisture degradation of the building in less than favourable Central European climate conditions. Mycological problems were found in the royal palace in Wilanów in Warsaw. The building was erected for Polish King Jan III Sobieski in the years 1681-1696, according to the design of Augustyn Locci, stylized on Italian styles. The problems were mainly concerned the surface of thermal bridges within the connection of external walls and ceiling, where in the winter time, condensation of water vapour occurs. An intervention was needed, due to the indoor environment deterioration and threats to the valuable interior design of painting and sculpting. Despite the numerous reconstruction changes resulting from the destruction that occurred during World War II, the architecture of the palace is original and required full protection. It is a particularly valuable combination of European art and the old Polish tradition of construction. One of the most important and difficult problems requiring an urgent solutions in the palace, was the necessity

to increase the surface vapour condensation resistance of the palace enclosure. It is a complicated issue which should be considered individually for each building. (Bomberg et al. 2016, Wójcik et al. 2017). Figure 1 presents the building and its interior designs.

Figure 1. Baroque palace in Wilanów. The façade and ceilings.

In the Baroque historical facilities, the thermal and moisture problems of the external partitions usually concern roofs in the zone of attic walls and cornices. Due to the valuable design of both external and internal façades, the classic procedure of implementation additional thermal insulation was unacceptable in the analyzed case. On the example of the palace in Wilanów it was possible to present the scope of research and computational analyzes that were used to develop innovative solutions in the field of thermomodernization of museum rooms, using local heating of thermal bridges.

ASSESSING THE MYCOLOGICAL CONDITION OF THE SURFACE

A non-destructive method, based on fluorimetry detection of the enzyme in filamentous mycelium was used (Rylander et al. 2010). A total of 47 surface sampling points were selected. Each sample was taken using sterile cotton swabs from a surface of 9 cm^2. The selected positions of samplings were characterized with visible surface changes.

The fluorimetry method, a quantitative method, is based on the determination of the mycelium mass density on the tested surface using a fluorocarbon substrate that releases a fluorescence fluorophore under the influence of division process. The intensity of the light emission phenomenon by a substrate excited by electromagnetic radiation depends on the mycelium biomass density. The method serves both to diagnose areas of mycelial growth as well as to control the effectiveness of cleaning the mould, which is particularly important in facilities requiring urgent intervention.

The mycelium density is categorized into three levels:

- category A - up to 25 units - normal level of mycelium- typical for clean surfaces,
- category B - 25÷450 units - level of mycelium above normal - indicates the growth of mycelium,
- category C - more than 450 units - very high mould level - high density of biomass.

Amongst 47 tested samples. 18 were classified in category A, 13 in category B and 16 in category C. The results presented in the Figure 2 clearly indicates that there was a serious mycological problem in palace and it required urgent intervention. It concerned not only the elements of the roof construction, but also the internal surfaces and external walls. Mould growth were closely related to the level of moisture content in the substrate material.

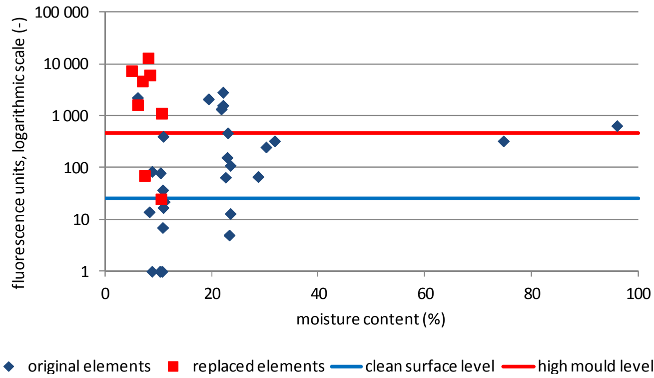

Figure 2. Illustration of the results of the mycelium density as a function of the moisture content in substrate of wooden elements.

An analysis of mycelium distribution, combined with measurements of moisture contents in substrates and with IR detection, clearly indicated that excessive cooling of the surface during the low outside temperature periods caused growth of mould. At first, the hygrothermal state of attics over the endangered museum rooms was analyzed. Unfortunately, two of required conditions for mould growth were fulfilled there: periodically an air temperature over 25°C and wood moisture content over 8%, theoretically it corresponds to relative air humidity around 40%. It was found during the investigation, that the air humidity in the closed zones of roof trusses exceeded 76% at 19°C. The moisture content in wood elements reached 90%. Poorly ventilated attics underwent heating during the insolation of the roof, while night cooling of the roof sheet caused 'morning dew' of the inner surfaces of the not insulated roof covering. Thus favoured the wetting of the timber roof construction. Fortunately, the protection of the roof truss zone was relatively an easy task. The problem can be solved by improving ventilation and by using chemical protection of elements. More complicated and difficult was to solve the problem of ventilated and full roofs, where the risk of excessive cooling occurred in the joints of ceiling and attic walls.

HYGROTHERMAL SIMULATIONS OF THE AREAS OF THERMAL BRIDGES

When it is impossible to avoid thermal bridges in the renovated building, their impact on additional heat demand for heating the facilty ought to be calculated as well as the risk of condensation and mould growth in areas of lowering temperatures on internal surfaces. Particularly endangered, during insulation, areas of roof and wall joints are those adjacent to geometrical type thermal bridges.

Temperature field analyzes were performed using the Finite Element Method in Autodesk Simulation Multiphysics 2013 software. The heat flow distribution is presented in the form of coloured diagrams. Calculations of thermal bridges include two or three dimensional heat flow analyzes. The sample calculation results of wall-roof joints are shown in Figure 3. Boundary conditions: standard conditions (based on ISO 6946), t_i=20°C, t_e = -20°C, indoor air relative humidity 55%. The calculated dew point 10.7°C. Figure 3a presents the first corner. The computational calculated temperature in the corner was 12.12°C, what indicated on no water vaporization on the inner surface, but IR measurements indicated that the risk was present. Much more serious situation is presented in Figure 3b where the computational temperature was 5.85°C. The interior insulation of such knee wall will cause the movement of the temperature front into the wall and cooling the ceiling-wall joint (Figure 3c). Even, if the interior insulation layer was implemented, full protection against condensation would not be obtained (8.73°C). The periodically condensation of water vapor during the lower outside temperature periods can be eliminated by installing infrared radiators or by performing an anti-condensation installation consisting of heating cables or mats and control automation.

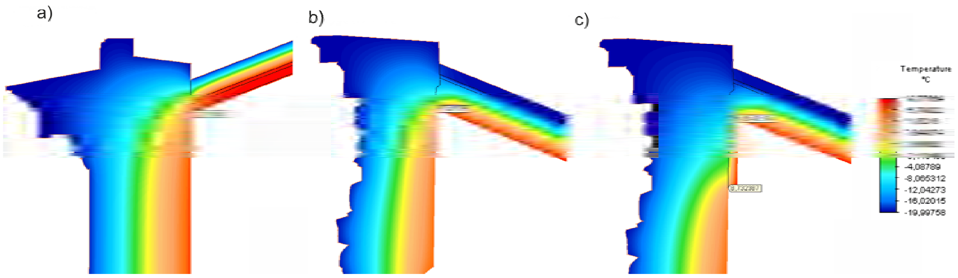

Figure 3. Temperature distribution in the flat roof section. a, b) roof corners, c) interior insulation of the corner – incorrect solution due to the dew point.

SELECTION OF THE METHOD FOR HEATING OF THE NODES

The IR radiators were investigated as the periodically solution to increase the temperature of the excessively cooled internal surfaces of the partitions. Generally, wave emission in the range 0.76÷1000 μm can be used to increase the surface temperature of partition. However, the most effective radiators that can be used to heat the surface operate in one of the IR range:

– IRS (Infrared Short) - shortwave radiation, IR wavelength 1.2 μm
– IRM (Infrared Medium) - medium wavelength radiation, IR wavelength 3 μm,
– IRL (Infrared Long) - long wave radiation, IR wavelength 5 μm.

The division is contractual, because the ranges of emitted spectra waves overlap.

Originally, convection was the basic form of energy exchange in the palace rooms, only partially it was radiation. The use of additional radiators means that the transfer of heat to the partition surfaces will depend mainly on the temperature difference between the emitter and the partition surface. Thus, the length of emitted wave plays the main role. In the analyzed case, IR should be absorbed mainly by water vapor molecules. This is possible only when the energy of intra-particle vibrations is on the same level as the energy of the quanta of IR. The phenomenon of IR absorption by moisture should bring significant benefits. Infrared radiator, depending on the temperature, emit an energy wave length in the range 1.2-5.6 μm. Due to the drying properties, quartz-halogen heaters with a temperature of wolfram fiber of about 2 000°C give the best results. On the other hand, in museum conditions (gilded surfaces), other aspects of IR emission should be taken into account. An important role is played by the effect of reflecting radiation – changing the direction of the wave propagation at the boundary of the surface with the internal environment. In practice, surfaces requiring heating to a safe level are very diverse. Thus, there is simultaneous almost perfect reflection, reflection scattering and absorption on such surfaces. The surface can thus absorb energy in a very diversified range depending on the reflective properties and the ratio of surface roughness to wavelength. So, the longer the wave and the smoother surface, the weaker the scattering. From this point of view, longer waves have the significant advantages of evenly heating the surface. Quartz-halogens, which emit the highest energy, but in the range of shorter reflected waves pose a threat to the polychrome. The share of radiation in the total energy balance would be too diverse in the case of valuable decorations, so it should be considered as disadvantageous phenomenon.

For the sake of problems related to one-side cooling of the partition joints, it is recommended to use the anti-condensation installation, for example the author's IN method (Polish patent nr

212791 – the method of insulation building partition from the inside). Positive results of the first implementations of the method in the historic town hall in Mrągowo and Social Security building in Bartoszyce influenced the choice of the IN method for the palace. In this case, the heating cables were designed from the attic side. Local reheating of excessively cooled areas prevents condensation due to local energy transfer. The method is easy to install, and what is more, it does not pose a threat to polychrome. The heating system may be constructed of the intelligent cables that detect other heat sources such as solar radiation and automatically adjust their heating power to receive the heat by environment (Figure 4). More heat is generated in cooler areas (e.g. window covers), less in warmer areas (e.g. the heater zone). Two parallel supply wires are embedded in a conductive polymer core. With decreasing the ambient temperature, the core of the conductor shrinks microscopically and the number of electric paths in the core increase, thus results in increased heat generation. Due to the variable power of the heating cables, the system is high efficient, because it only slightly increases heating costs. The system can be implemented in various insulation and finishing material solutions.

Figure 4 A self-regulating heating cable with possibility of adapting heating power to ambient temperature. 1-power supply cables, 2-conductive polymer, 3-insulation cover, 4-screen, 5-outer cover.

According to the patent description, in order to eliminate the negative impact of excessive cooling of the thermal bridges zones, the thermal insulation material should be placed leaving gaps for the heating conductors and temperature sensor. The heating system is initiated by the small controller located in a flush-mounted box (diameter of 60 mm). The thermal insulation layer can be covered with tight vapor barrier (e.g. in accordance with the principles of the single-sided internal barrier method) or panels separated by specially shaped joints with the function of linear reverse capillarity. The heating cable installed in critical heating areas can be treated as a supplement to the existing heating system, however, due to the small and variable power of 5 to 20 W/m, depending on the ambient temperature, the range of influence is limited to the most cooled zone of the thermal bridge. This sufficiently eliminates harmful phenomena associated with the cooling of the partition surface, condensation of water vapor and the development of mould. During warmer spring and autumn days, external partitions can be effectively protected when the basic heating is turned off, because the temperature in the connector is regulated by the automatically activated anti-condensation system. The areas exposed to surface moisture condensation of the water vapor remain dry, making the rooms hygienic and clean, as dust does not settle as on the wet surfaces.

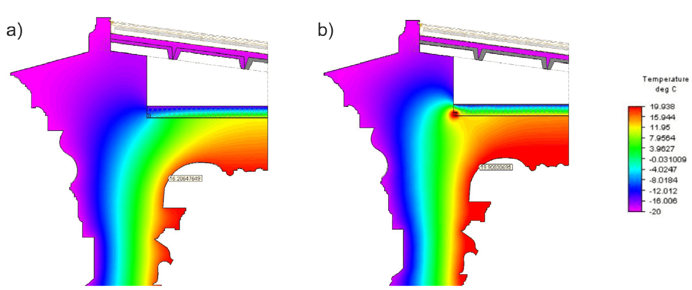

Figure 5 Temperature distribution in the heated node in winter. a) no heating b) heating

Positive thermal effects were obtained by placing the heating cable in the decorated attic of the palace (presented in Figure 1). The cable was placed on the outside, invisible to users. Thanks to this, it was possible to preserve historical matter without any interference in its structure. The obtained results for winter season (same boundary conditions as for Figure 3) are shown as false-color temperature distributions in Figure 5.

DISCUSSION

An implementation of the anti-condensation system was examined also on the thermal bridges presented in the Figure 3. Under the same boundary conditions as the 1st simulation (t_i=20°C, t_e = -20°C), in case of the corner 3b, the 5W power of heating cables resulted in rising the corner temperature up to 18.01°C (12.16°C more). While in case of the internal insulation layer (Figure 3c), the temperature of the contact point insulation-wall raised up to 13.09°C (4.36°C more). Both results are above the dew point.

CONCLUSIONS

The following conclusions can be made on the basis of mycological studies, analyzes and calculations:

1. The fluorescence method used to determine the mass of mycelium allows a full quantitative assessment of the mycological risk of the building.
2. Placing the insulation in the roof slope layers does not solve the problem of excessive cooling of internal surfaces in the areas of thermal bridges occurrence.
3. Good effects are achieved in the case of full roof by the introduction of heating of the attic zones with ventilation ensuring that the attics maintain a temperature of not less than 20°C, and humidity up to 55%.
4. In the case of flat and ventilated flat roofs, adequate protection against condensation in the thermal bridge zone can be achieved by introducing linear heating with self-regulating heating cables.
5. The hygrothermal calculations showed the correctness of the designed solutions, while maintaining the appropriate materials and proper ventilation performance of individual layers. Not insulated alcove knee wall require additional thermal energy supply. The use of shortwave radiation to avoid periodic condensation of moisture on their internal surfaces can be dangerous for the durability of polychrome.
6. The optimal solution seems to be performing the air heating of the attic with the air nozzles directed partly to the knee walls and the implementation of an intelligent anti-condensation installation consisting of heating cables and control automation.

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