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Condensation risk assessment and IEQ in Pilgrimage chapel of Holy stairs

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Abstract

Any historically significant interior require special attention in connection with indoor climate and air quality control, especially hydro – thermal microclimate is essential. Air temperature and relative humidity, and in particular their sudden fluctuation over the time, have a wide implication for preservation. Unfortunately, in many historical interiors these parameters lie far beyond the tolerated range. In this case it is necessary to carry out measures leading to improvement conditions and, at the same time, take into account economic aspect and the request for more and more decreasing energy consumption. Any intervention or restoration action should be preceded by a thorough analysis of current situation. This statement applies to all building, but for historical objects this is especially true. In order to proper determinate of initial conditions, monitoring in appropriate time period has to be done.

This paper presents a study performed on the Pilgrimage Chapel of Holy Stair in Rumburk, Czech Republic, that proposes the use indicators of preservation risk as tools for indoor environmental assessment. Monitoring data, which are basis of examining initial condition in the Chapel, allows a calibration of numerical simplified model in the software Design Builder GUI with calculation core Energy+. The 3D model assesses improvement of indoor environmental quality in the chapel depending on various measures leading to better condition and the building plant system characteristic. The analysis highlights to the relationship between level of quality of the internal microclimate a requirements for potential HVAC systems.

Keywords – indoor environmental quality, historical building, condensation risk

1. Introduction

Most of historic interior contends with problems in relation of high moisture value, which lead to cultural heritage deterioration, up to destruction. Leaving aside the structural faults, one of the most common problems occur due to the high level of air temperature stability in the interior, which is caused by massive structures. Especially in the spring, when the temperature of walls is still low, the condensation of atmospheric humidity outside warmer air begins to appear on their surfaces. This results irreversible damages to historical frescoes in particular. The ideal solution for maintaining an appropriate conditions and thereby perfect preservation of artefact could represents the installation of full control air system with active monitoring. Nevertheless, this solution may be unacceptable expensive. For this reason, this variant is unrealistic for most of historical building.

This study is aimed at outlining possible solution leading to improvement Indoor Environmental Quality (IEQ) and investigation the relationship between indoor environment quality and energy consumption, considering associated cost on the operation of the Chapel as well.

2. Case study

Pilgrimage chapel of Holy Stairs is a part of important cultural monument Loreto in Rumburk on the north of Czech Republic. It has been included among the significant place on pilgrim path: “Via Sacra” since 2014. The Chapel was built in the year 1767-1770 and its staircase is surrounded by unique sculptural decoration and historical ceiling frescoes, which underwent a complete renovation in the year 2007 – 2012. However shortly after reconstruction the fresco painting and artefacts began to show a sign of damage [5].The reason of these damages is the high value of air moisture which leads to the condensation of water vapour on cold surfaces of wall. Moreover, air temperature during the winter period falls below freezing level. This means that condensed water vapour transforms into hoarfrost (Fig. 1).

Fig. 1: Pilgrimage Chapel of Holy Stairs [4], frozen condensation on the walls during the winter

3. Method

The study was carried out at two levels. Both parts, experimental and numerical campaign, were evaluated by indicators of preservation risk assessment.

Firstly, IEQ assessment was based on Performance index (PI) determination, defined as the percentage of time in which the parameters lies within the required (tolerance) parameters [2]. This assessment approach can quickly analyze indoor parameters and thereby contribute overall understanding hydro-thermal conditions. In this case, PI is evaluated based on two microclimatic parameters at the same time: indoor air temperature (T) and indoor relative humidity (RH). The threshold interval of T and RH considering acceptable, were determined according to standard ASHRAE Application Handbook [1].

Secondly, another criterion evaluating condensation risk has been applied. This indicator, called a safety index (SI), highlight how often comes the condensation on the surface of walls. It is defined as a percentage of time in which indoor dew point temperature achieves lower value than surface temperature of the walls.

3.1 Experimental campaign

In order to understand hygrothermal conditions in the interior, the monitoring of air temperature and relative humidity of interior and exterior was carried out in a sufficiently long time period [5]. Measured data were evaluated by performance index assessment. Due to the fact, that surfaces temperature measures were not included in the monitoring, SI determination was not subject of experimental campaign. This monitoring has enabled a calibration of the 3D numerical model, therefore it has become the basis for numerical campaign.

3.2 Numerical simulation

Simplified 3D numerical model was created in the software Design Builder GUI with calculation core Energy+. This calibrated model made possible to implement a criterion SI. The model assesses improvement of indoor environmental quality (IEQ) in the chapter depending on various measures leading to better condition and the building plant system characteristic. The IEQ was initially evaluated on the basis prevent condensation, which has an essential impact to the historical frescoes. Subsequent the improvement of PI value was evaluated as well. One of the issues of the analysis is provided the relationship between indoor environmental quality and energy consumption and associated cost on the operation of building as well as.

4. Monitoring data assessment

The sensors for monitoring air temperature and relative humidity were located in 15 sites in the chapel and adjacent cloister in the period from 8 November 2012 to 20 June 2013 (Fig. 2) [5].

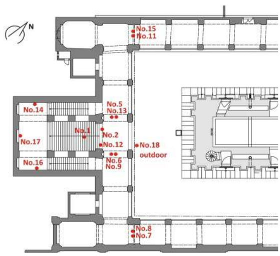


Fig. 2: Position of sensors in the Chapel and Cloister

Sensors No. 14 and No.16 shows only inconsiderable differences during measured period. The same is true for sensors No. 2 and No. 12. The sensor No. 17 shows higher fluctuation of measured values than other sensors. This fact is due to the open windows during the monitoring. Subsequent analysis has focused on sensor No. 1, which is located in the area of reconstructed frescos and sculptures.

Interesting determination indicates comparison of measured values located in the individual corridors and area of stairs (Fig. 3, 4). Although values of air temperature do not indicate significant difference, values of the relative humidity show considerable dissimilarities. Based on these results, additional source of moisture (for example in form of rising damp) is expected in some parts of the object. From the above it is obvious a higher value of specific humidity in the north oriented corridor. There is presumption of solar radiation effect in the south oriented corridor and thereby overall favourable impact to the moisture conditions. Whereas accumulation of the moisture in cold north oriented corridor is evident.

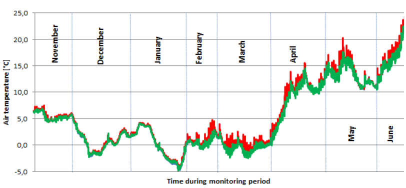


Fig. 3: Monitoring indoor air temperature (red: south oriented corridor, blue: norht oriented corridor, green: area of stairs)

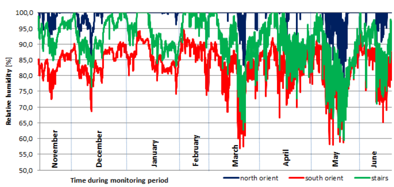


Fig. 4: Monitoring indoor relative humidity (red: south oriented corridor, blue: norht oriented corridor, green: area of stairs)

The entire measured period was allocated to the three seasons and subjected to investigation (winter: 8 November 2012 – 31 May 2013; middle: 1 April 2013 – 15 March 2013; summer: 16 March 2013 – 19 June 2013)

Results of analysis confirmed the assumption about completely inconvenient conditions in the Chapel. During the monitoring period could not be reached (in any of evaluated period) by the percentage representation within the acceptable zone (see in Fig. 5, 6 and 7), where all values lie beyond the pale of 60% RH for any time measured period. On the basis of previous results, it is possible to estimate the behaviour of hydro-thermal parameters in combination with additional installation of HVAC system. Due to the fact of not exceeding temperature above 25°C and extremely high value of RH, the following measures will focus on the heating and dehumidification.

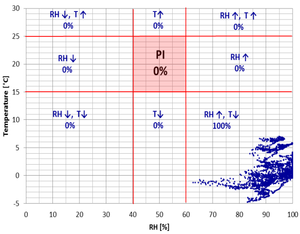


Fig. 5: Performance index of T and RH in the tolerance matrix during winter period

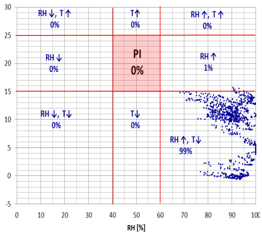


Fig. 6: Performance index of T and RH in the tolerance matrix during middle period

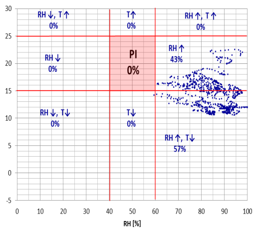


Fig. 7: Performance index of T and RH in the tolerance matrix during summer period

5. Numerical model and calibration

To investigate the subsequent measures leading to better indoor conditions in the Chapel was necessary to create numerical 3D model. DesignBuilder GUI software and the ENERGY+ calculation core, which is based on a dynamic one-dimensional model of heat transfer by conduction in multilayer structures, was used for simplified model of Chapel.

In order to simplify, the model geometry was limited only to area of Chapel, which considers chapel energy independent of the corridor. Actually, similar effect could be achieved by installation additional construction (for example glassed wall). The model works as a four – zones model: two for no occupancy basement and loft, last two zones for area of chapel and staircase, which interact each other by holes in walls.

To ensure the relevance of the results is imperative a calibration of the 3D model. This validation of the numerical model was allowed by application of measured data (T and RH in the exterior) from the monitoring to the software. For this reason, it was necessary to create a new epw (Energy Plus Weather) file, which is able to include a climatic conditions occurring during the monitoring. Air temperature and dew point temperature was applied from monitoring data. On the other hand the wind speed and wind direction values, where are important for modelling natural ventilation and infiltration, were not involved by monitoring. In this case, the database NOAA from National Climatic Data Centre [3] was used. This database allows download the weather data history for the same time period as the monitoring was carried out.

The numerical 3D model took into account no heating in the building. Two small windows in the chapel were set to open throughout year on 15%. It is the typical configuration that was checked during the actual operation of the space. Infiltration of air was calculated for poor construction and model considered constantly operation of natural ventilation.

The calibration of the numerical model confirmed an assumption about occurrence some added source of moisture (Fig. 8, Fig. 9 and 10), which is probably caused by poor waterproofing of building. In this case it was necessary to include further added source of moisture in the model. Ground moisture is replaced by the added process with latent faction set to 1, which causes an increasing of relative humidity in the zones with minimal heat gains.

From Fig. 8 are noticeable differences of indoor air temperature between results from numerical model and monitoring. Higher values of air temperature obtained from BPS can be attributed to the changing operation. In case of opening of windows in the numerical model, the software generates lower value of indoor air temperature.

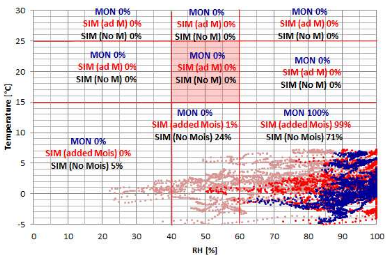


Fig. 8: PI (T and RH) in tolerance matrix during winter period, blue(monitoring), red (simulation with added moisture), purple (simulation with no moisture)

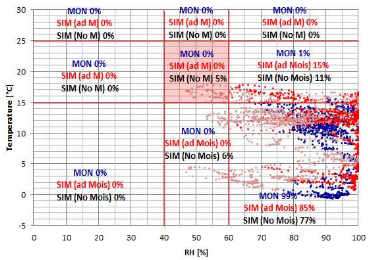


Fig. 9: PI (T and RH) in tolerance matrix during middle period, blue(monitoring), red (simulation with added moisture), purple (simulation with no moisture)

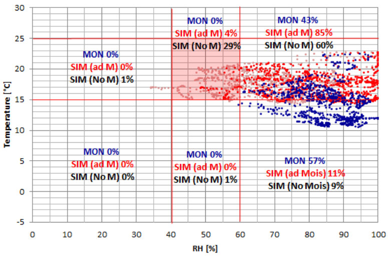


Fig. 10: PI (T and RH) in tolerance matrix during summer period, blue(monitoring), red (simulation with added moisture), purple (simulation with no moisture)

6. Condensation risk

Condensation on the cold surfaces of walls in the interior has a catastrophic impact to the historical frescoes. For this reason, assessment of condensation incidence during model year has become the main subject of evaluation IEQ. In this case, indicator "safety index" was used, which highlight how often the condensation appears on the surfaces of walls. That occurs when dew point temperature in the interior fall down below surface temperature of walls.

Surface temperature history of selected structural elements was calculated by using Design Builder GUI software and ENERGY+ calculation core. One of the parts of the energy balance calculation in this software is performing a calculation of heat transfer through structures. It is possible to acquire the development of the surface temperatures of selected structures of the wall as a partial result of this calculation.

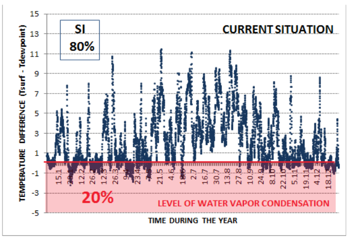


Fig. 11: SI during model year in current situation

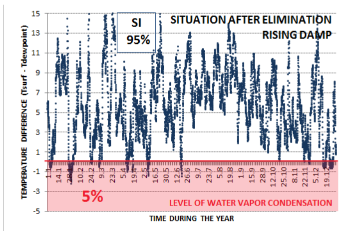


Fig. 12: SI during model year after removing the reasing damp

Critical conditions for historical frescoes represent graphs below, which are addressed SI assessment. Graph in fig. 11 shows condensation risk in current situation. On the other hand, graph in fig. 12 shows SI evaluation in case of elimination rising damp (for example added waterproofing).

Although structural invention removing rising damp leads to better parameters of SI, condensation on the walls is not completely eliminated. Critical conditions for preservation of historical frescoes occur during the winter period and spring time in particular. In this time, the development of indoor T and RH is fully depended only on external climatic conditions and material characteristic of the structure. Graph in fig. 13 shows the relationship between value of specific humidity in the exterior (expressing by dew point temperature) and condensation risk in the interior (expressing as differences between surface temperature and dew point temperature of interior air). It is possible to see a clear correlation between both values.

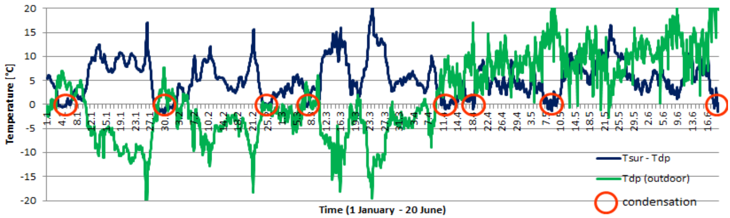


Fig. 13: Correlation between outdoor conditions and condensation risk in the interior

Interesting findings demonstrates analysis, which deals with the rate of natural ventilation in the chapel. In case the windows are fully closed during all year, the condensation risk will be reduced from 5% to 3% of time. On the contrary, RH, and thus the specific humidity as well, value will increases.

7. Measures leading to stop condensation on walls

From the above statements, it is obvious the necessity of additional HVAC system installation in order to stop condensation on the frescoes. Increase surfaces temperature of cold walls with frescoes is only one possibilities lead to elimination condensation risk.

In order to increase indicator SI (values close to 100 %), installation of additional heating system was evaluated in the numerical model. This system can easily guarantee the stop condensation and of course, improvement the value of PI. Despite the possibility of increasing PI value up to 56 %, the most of values related to RH still falls outside tolerance range.

It is generally known, the control system setting has a directly impact to the level of IEQ and related to energy consumption as well. In this case, temperature control for 15 °C during winter period, 19 °C during middle period and no heating during summer is able to reliably eliminated condensation on the walls. The most significant problem with condensation occurs during winter and especially middle period (Fig. 12), for this reason it is not necessary to heat during summer time. On the other hand, PI evaluation can achieve only 30 % (Fig. 14). In case the heating throughout year, PI value can reach 56 % (Fig. 15). Of course, this increase will be reflected in energy consumption.

Subsequent improvement of PI and related to increase cost operation can be acquired by air control system. Whereas the most relevant problem represents a high value of RH, heating with dehumidification was assessed. This system is able to achieve 89 % of PI (Fig. 16). In order to prevent overdrying of interior during very cold days, all air control system was investigated as well. In this system, PI is able to reach almost 100 %. In both cases, values of SI fall far in the field of security.

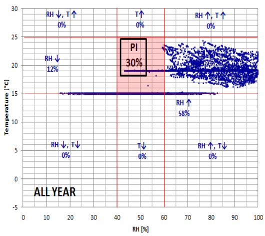


Fig. 14: PI in tolerance matrix during model year with heating system only (no heating during summer period)

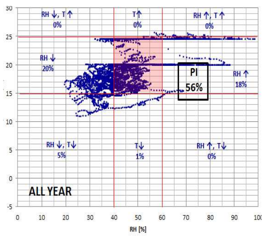


Fig. 15: PI in tolerance matrix during model year with heating system only (heating trouhout year)

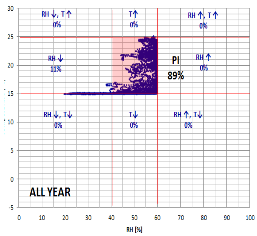
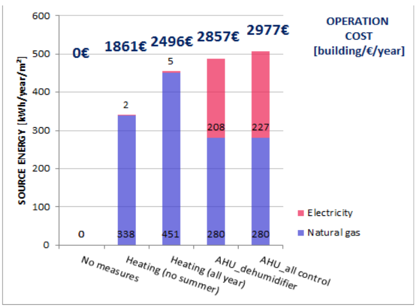


Fig. 16. PI in tolerance matrix during model year with heating and dehumidification systems

Constantly increasing requirement on IEQ and related PI is naturally reflected in energy consumption for HVAC system. This improvement will have a directly impact for occupant in terms of energy cost for system operation.



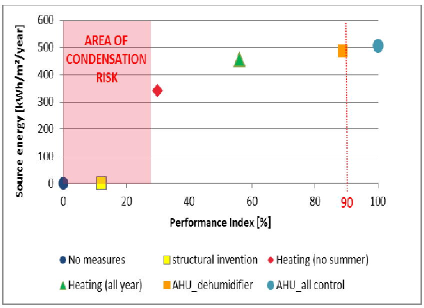


Fig. 15: Primary energy demand and cost operation for individual variant

Fig. 16: Primary energy demand in context of improvement PI

8. Discussion

Generally looking for additional funds for HVAC system operation is obviously difficult. Presented study tries to minimalize operation cost as much as possible. Nevertheless, in order to elimination a condensation risk, installation of additional HVAC system is essential. On the other hand, the acceptable level of IEQ, which guarantee discontinuation condensation on the frescoes, can be keep by relatively low cost (1861 €/year). Moreover, these costs would be more decreased by subsequent reconstruction eliminating rising damp.

9. Conclusion

In this paper, the procedure leading to improvement IEQ was assessed. Especially the condensation on historical frescoes and artefact was essential. Hydro-thermal parameters in chapel were investigated based on results of experimental campaign. These monitoring data was applied during experimental campaign as well, as an important input parameters for calibration numerical 3D model in software Design Builder with calculation core Energy+. The aim of the numerical study is a proposal leading to stop a degradation of interior due to the unsuitable of parameters of indoor environment. For this reason various options were examined in the context of relationship between microclimate lever requirement and energy consumption. In order to evaluation condensation risk a criterion SI was introduced.

Acknowledgment

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