NUMERICAL PREDICTION OF THE AIR EXCHANGE IN THE MUSEUM PREMISES EQUIPPED WITH NATURAL VENTILATION SYSTEMS

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ABSTRACT

Ensuring a proper indoor environment in the museum exhibition rooms requires, among others, the achievement and maintenance of the proper air change rate. It is important because of the minimum rate necessary to remove the excessive heat gains and moisture and energy demand for the ventilation purposes.

Two existing museum buildings were selected for the research purposes. First is located in a historical small castle built in 14th century and the second one is a modern building constructed as the a museum in the 20th century. Both buildings are equipped with the natural ventilation system.

The numerical models of both buildings were created and the simulations of the air changes were performed using the CONTAM software. The simulations were carried out for the winter period on the basis of the measured and recorded at this time weather data. As the result of simulations the air change rate in the selected museum rooms are presented against a background of the external temperature.

KEYWORDS
Natural ventilation; museum building; simulation methods; CO_2 concentration.

INTRODUCTION

Museum buildings belong to the special group of buildings where the indoor air quality (IAQ) is important. Particularly, the certain parameters, such as indoor air temperature, relative humidity and solar radiation decide on the IAQ. Ensuring the proper conditions in connection to the safety of the exhibits sometimes stands in contradiction to the primary function of museum – making the exhibits available for visitors. The large number of visitors can make the IAQ unsuitable because of the sudden growth of the internal heat gains and the air humidity that can be even dangerous for the exhibition [1]. Fluctuations of temperature and humidity in time affect the exhibits even more than their - although unfavourable - but constant level. Recommended parameters of the internal climate in museums are a relative humidity of 50 % and the temperature of 15 ^{o}C ÷ 25 ^{o}C. Deviations of ± 10 % for humidity are admitted, as well as deviations of temperature by ± 2 K (these ranges concern short fluctuations of the parameters due to instantaneous redundant gains and the non-homogenous environment – gradients of these parameters over the space of the museum) [2].

Additional difficulties in ensuring the proper IAQ in the museum buildings results from their historical value. Very often those buildings are lack of proper heating and ventilating systems, and because of their heritage importance there is no allowance for rebuilding and reconstruction of the HVAC system.

The paper presents the preliminary results of the investigations carried out within the frame of the research project which targets the identification and assessment of the indoor air quality in the museum buildings and points out the possible activities leading to the improvement of it.

BUILDINGS DESCRIPTION

The investigation concerns two museum buildings located in different cities in southern part of Poland in the Upper Silesia region. The buildings differs significantly in relation to the construction, materials used as well as the size and volume (Fig. 1).

The first museum is located in a historical small castle built in 14th century. The exhibition rooms are located on three levels of the building. Besides the exhibition rooms there are also storage rooms, offices and laboratories located on the floors. Internal structure of the building is rather complicated because the castle was rebuilt many times giving the existing state. The building is equipped with the ventilating duct system connecting some rooms with the outlet chimneys on the roof. The fresh air infiltrates through the window cracks. Originally probably all castle rooms were ventilated but now because of some alterations of the building a few exhibition rooms are lacking the ventilation. The total exhibition area amounts to 68 m^2, 104 m^2 and 114 m^2 on the 1st, 2nd and the 3rd floor respectively.

The second museum was erected in 1929 - 1930 and was specially designed to serve exhibition purposes. It is a five-storey, double-winged building with the exhibition rooms on the 2nd, 3rd and 4th storey. The total exhibition area is much greater than in the previous building: 400 m^2, 900 m^2 and 650 m^2 on particular floors. The very unfavourable feature of this building is total lack of any ventilating system. The whole building ventilation is maintained only by infiltration mode.

Figure 1. Selected museum buildings.

METHOD

The aim of the work – assessment of the ventilation in the investigated museums – was realized by the numerical simulation.

The calculations of the ventilation air flows within the considered building was made by CONTAM program. This program is designed for multizone analysis of the ventilation and indoor air quality in buildings [3]. CONTAM can be applied to the global assessment of the ventilation effectiveness in the whole building, search for the time variation of the ventilation air flows in the particular zones or for checking the influence of building air-tightness on the air infiltration. The research program comprises continuous measurement of the main indoor environmental parameters: air temperature and humidity and CO_2 concentration.

The measurement campaign was carried out for whole heating season. In both museum buildings all main exhibition rooms were equipped with the measurement sensors located in selected points of every room. The local weather station provided the set of the meteorological data necessary for simulations.

MODELS

Two numerical models of both museums were built reproducing internal structure of the whole buildings. Figure 2 presents, as an example, the CONTAM models of the third floors of both buildings. All identified flow paths were modelled, mainly through the windows cracks. The stairwells in both building were also included in the model as the important flow path in case when the ventilation is realized by stack effect. For the model of the museum located in the old castle the system of the ventilating ducts was identified and modelled.

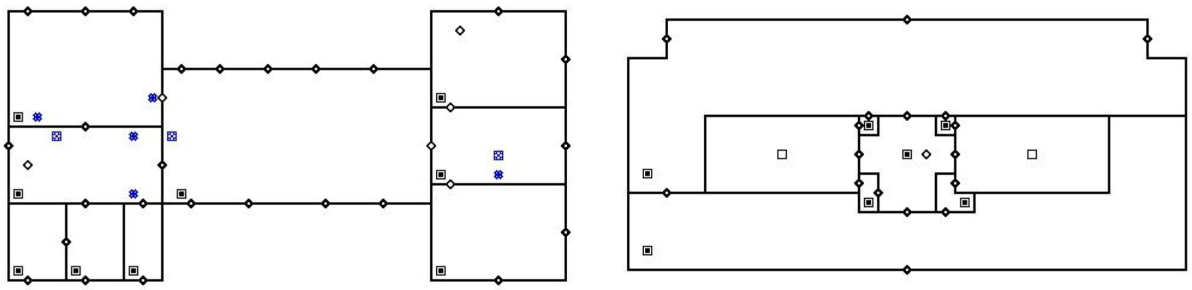

Figure 2. CONTAM models of the museum buildings

One of the biggest uncertainties when the model is created is the value of the air infiltration coefficient which describe the air tightness of the windows. Because of the lack of the windows characteristics the assessment of these parameters were based on the authors experience. In the contemporary building three types of windows were identified: metal, wooden and PVC – all are weather-stripped and double glazed. For the preliminary simulations the air infiltration coefficient was assumed to be equal to 0.2 $m^3/m \cdot h \cdot Pa^{0.67}$ which means that the windows were tight. In the old castle this issue was more complicated: almost all window openings were different and for this reason 16 types of windows were declared. After inspection in the building the air infiltration coefficient was taken on the level of 1 $m^3/m \cdot h \cdot Pa^{0.67}$ because the windows were old and not airtight.

The model was adjusted and tuned using the results of the CO_2 concentration measurements. It was assumed that the CO_2 concentration changes because of the presence of the people in the exhibition rooms. The levels of concentration differs for both buildings and for different storey. Thanks to the recording of the CO_2 concentration variation it was possible to apply the concentration decay method [4] to determine the air change rate in particular exhibition rooms in the buildings. After that the results were compared with the simulation results giving the possibility to correct the air infiltration coefficients for windows.

RESULTS

Measurements

The measurements were performed during the last year's heating season, between October and April. In the paper some results for February and March are presented. From the effectiveness of ventilation point of view the CO_2 concentration was interesting. Figure 3 presents the variation of the CO_2 concentration in the chosen exhibition rooms in both buildings. The repeatable changeability of the CO_2 level can be observed: increase of the concentration during the day results from the presence of the personnel and visitors in the museum. In the museum located in the small castle the actual concentration reached sometimes even more than 2400 ppm. In the largest exhibition rooms of the newer building these concentrations are much lower, the maximum was about 1100 ppm. It can be explain by the greater cubature of these rooms when the source of contamination (number of people) is usually comparable in both museums.

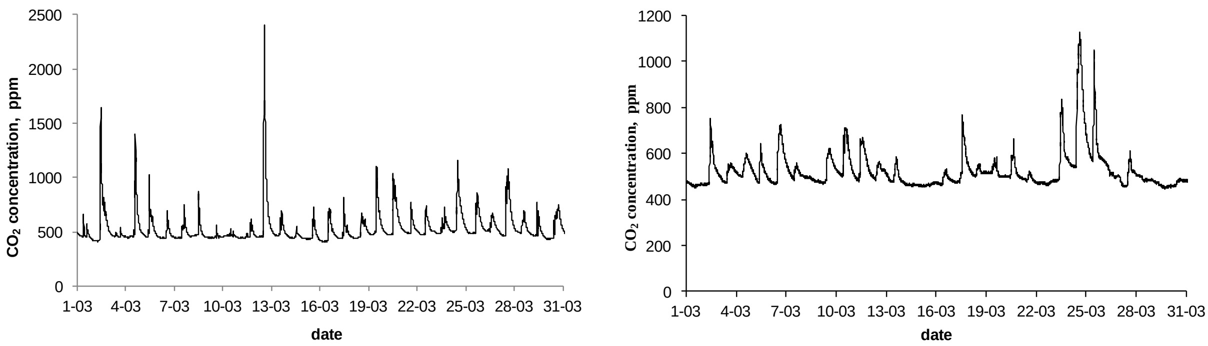

Figure 3. Variation of the CO_2 concentration on the selected storey's of the museum buildings (left – castle, right – modern building)

For several cases the CO_2 concentration decay was calculated giving the air change rate in the particular exhibition rooms. The results could serve for models adjusting and validation.

Simulations

The series of ventilating air flows simulations were performed using the meteorological data recorded during the heating season by the local weather station. The results of the air change rate simulation were compared with the data resulting from the CO_2 concentration decay measurement. After that the tuning of the models was made – that was done mainly changing of the air infiltration coefficients of particular type of windows. Thanks to the number of simulations performed the new value of the air tightness of windows were assumed. In case of the greater building the air infiltration coefficient of the new PVC windows was equal 0.2 $m^3/m \cdot h \cdot Pa^{0.67}$ and 0.5 $m^3/m \cdot h \cdot Pa^{0.67}$ for other type of windows (wooden and metal). Regarding the windows in the small castle where the windows were old and not so airtight the air infiltration coefficient was established 0.5 and 1.0 $m^3/m \cdot h \cdot Pa^{0.67}$.

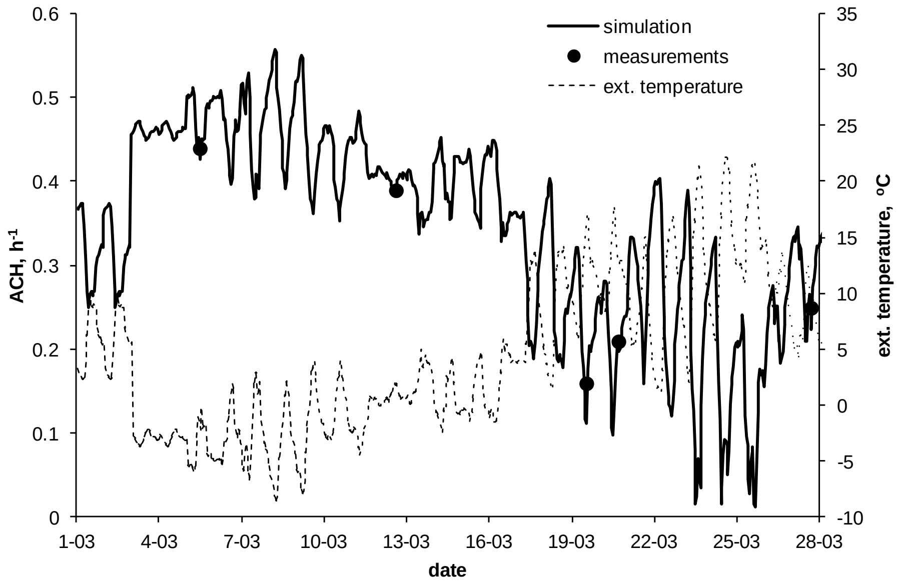

Figure 4. Air change rate in the selected exhibition room in the castle

Figures 4 and 5 show the run of air change rate variation. The measured values of the air change rate were marked with points. In case of the museum located in the old castle quite good compliance was achieved. The results for the second museum are not so good. In fact in the most cases simulation results differ from the measurements. The reason for that is not obviously the fault of the numerical model. The analysis of the measurement data shows not a very big difference between the high level of the CO_2 concentration and the basic level. Hence the calculation of the CO_2 concentration decay can be imprecisely. The second reason of the incompatibility is that in the large cubature of the exhibition room the CO_2 concentration was measured only by one detector. On the other hand the proper use of the concentration decay method consist on the excellent mixing of the contaminant in the whole volume. The ventilation of the exhibition rooms in the considered museum was very poor so the perfect mixing is also uncertain.

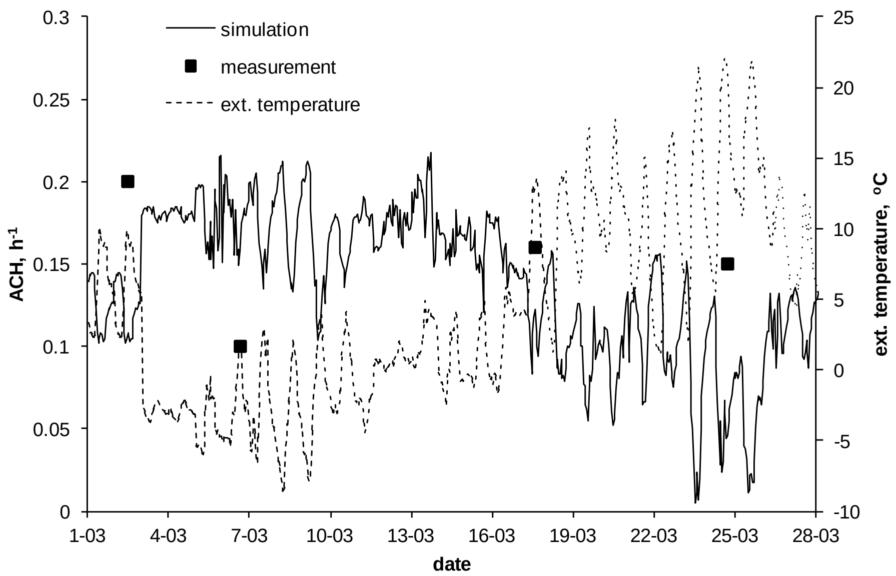

Figure 5. Air change rate in the selected exhibition room in newer building

CONCLUSIONS

Ventilation of museums in most cases is limited to natural ventilation. Sometimes the air is exchanged only by opening windows or doors what may cause rapid change in temperature and humidity indoors and may be dangerous for artefacts. Insufficient ventilation and lack of natural ventilation systems may also create problems by excessive increase in humidity and temperature in the exhibition rooms.

The research performed shoud be treated as the introduction to the complex analysis of the ventilation effectiveness in the selected museum buildings.

The work performed gives only preliminary results concern a short period of time. Based on these results some potential problems with ventilation was indicated.

The numerical models presented here were adjusted and partially validated by measurement of CO_2 concentration. The next analysis for the longer period of time (e.g. for the whole heating season) will give more precise assessment of the reliability of simulation models.

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