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Controlled Ventilation of Historic Churches – Assessment of Impact on the Indoor Environment Via Hygrothermal Building Simulation

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ABSTRACT

Historic churches, when they are unheated, often face problems of summer condensation. After the cold season warm, humid air enters the building and condenses on the walls, a problem that can occur during the entire warm season. This leads to moisture related problems such as mould or algae growth on building surfaces. High humidity can also damage works of art inside these churches. One possibility to lower the level of relative humidity is by bringing dryer air inside the church whenever this is suitable to lower relative humidity On the other hand, too many fluctuations may also cause damages on works of art and bringing in cold air will further lower the temperatures of the whole building and its walls thus being conter productive to the drying process. An automatic system for ventilating historic, unheated churches is assessed using building simulation software (WUFI Plus) on a case study of the St. Margaretha church in Roggersdorf, near Holzkirchen, Germany.

KEYWORDS

Historic Building, Controlled Ventilation, Whole Building Simulation, Summer Condensation

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1 INTRODUCTION

1.1 The Chapel of Ease St. Margaretha in Roggersdorf

After a complete renovation of the chapel of ease St. Margaretha (Fig. 2) in September 2004, the churchwarden again noticed moisture damage on the walls. A subsequent climate measurement showed that the damage was a matter of condensation that occurs mainly in the transitional period during spring-time. At that time of the year the building is still cold because of the winter. If warm, humid air enters the building due to natural air flow or uncontrolled ventilation inside, it condenses on the cold wall surfaces. But even in the summer and fall warm humid weather conditions can cause problems due to condensation.

From December 2004 to August 2006 the temperature and relative humidity were measured inside and outside the church. To asses condensation events the wall surface temperature was also measured on the Western wall at the joint to the floor. Weather data was available from the Fraunhofer IBP outdoor testing facility at Holzkirchen, only 5 km away from Roggersdorf. During the period when measurements were taken the climate inside the church showed a high average humidity with values over 75% rh for more than half of the time of the year (Fig. 1). During winter time the church also freezes with temperatures below 0° C for more than six weeks in a row [Kilian 2007]. Subsequently, the church starts with very low wall temperatures into spring time and the warm season.

Another problem that became evident was the uncontrolled opening of windows and doors over the warming period of spring, , that was supposed might reduce the moisture levels in the space by ventillating. In the summer 2005 “vetilation traffic lights” showing the times when the water content of the outdoor air was lower than indoors were used to give advice to the guardian of the church. This significantly increased the daily fluctuations of rh; in the spring and summer 2005 the fluctuations were above 15% rh for more than 30 days. Daily changes above 15% rh are thought to be critical to works of art [Holmberg 2001], as the risk of structural damages due to swelling and shrinking of materials increases with the range of rh change per day. Also the newly restored altarpiece from the 19th century started showing additional damages at the gilding.

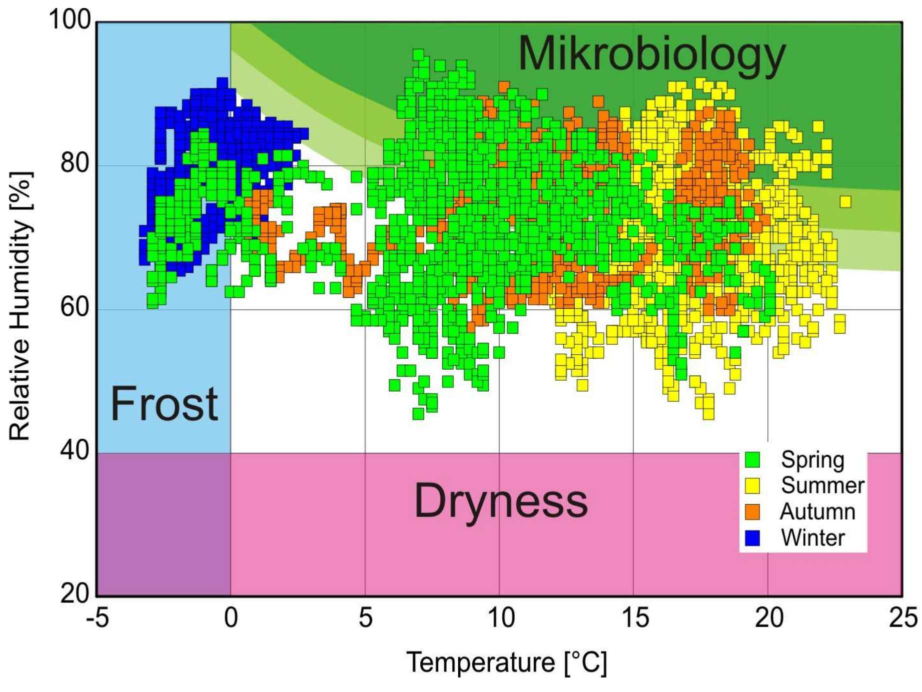

Figure 1. Temperature and humidity during 2005. Half of the time rh lies above 75 %, during winter the church freezes for 6 weeks.

As a consequence, the installation of a controlled ventillation system was discussed with the church authorities. Such systems permit comparing the absolute humidity inside and outside the building. Whenever the outer humidity is lower, a ventilator starts bringing dryer air into the building. Also, boundary conditions for the lower temperature can be given, as well as a maximum allowed range of RH change in the last 24 hours. Practical experience has shown that this type of ventilation system can help reduce the RH range and reduce the overall moisture in a room over the year, as was done for the church located in Urschalling, Bavaria [Künzel 2003]. However, the open questions are: how good is the system for the respective location; what can it achieve; how much energy does it use; and, what is the overall impact when bringing colder air into the building during winter and in summer nights? To assess the possibilities and limitations of these systems, whole building simulation was used to predict the indoor environment in the church using weather data from Holzkirchen.

2 METHODS

For the simulation of the hygrothermal building behaviour the software tool WUFI Plus was used [Holm et al. 2003]. In the following the general conditions, the assumed building geometry and materials as well as the heating, ventilation and air conditioning are described.

2.1 Boundary Conditions

The time of calculation lasted from January, 1st to December, 31st of the year 2005. The simulation was carried out in time steps of 5 minutes to reproduce a realistic ventilation control. Given that the location of the church was in Roggersdorf, which is located near Holzkirchen, the meteorological data of Holzkirchen for the year 2005 was used for the simulation. A weather file was created which consisted of 5-minutes values of exterior temperature, relative humidity (both in Fig. 3), global and diffuse radiation, rain, wind and barometric pressure. Additionally a file with ground temperatures at a depth of 0.5 m in the soil was generated to take into account conditions below the foundation of the church. Inner loads were not taken into account for the base case, assuming that there is no church service.

2.2 Building Geometry and Material Data

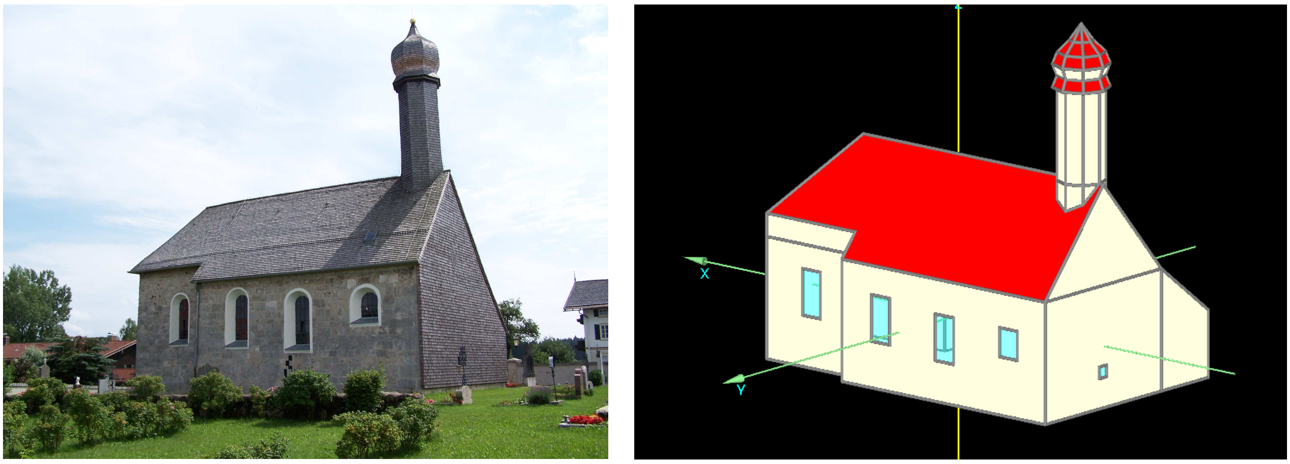

Figure 2. Picture and screenshot of the computer model of the exemplary church.

A detailed model of the chapel's geometry was created in WUFI Plus (Fig. 2). The main building is about 12 m long and 9 m wide. The height from the ground to the top of the roof is about 6m and to the top of the tower about 9 m. For the simulation the main body was divided into three zones where the climate was modelled: the nave, sacristy and the attic. In the nave a ventilation system was assumed with a control to ventilate this zone with outside air with an air exchange rate of 5 1/h, in that instance when the outside absolute humidity was lower than the absolute humidity inside the church with the limitation that the exterior temperature had to be above 0°C. The infiltration ventilation air was taken from outside, with an infiltration air exchange rate of 0.4 1/h for the nave. The tower as well as the entrance area was treated as an attached unheated zone with assumed exterior temperature and relative humidity in the zones.

The outer walls of the chapel are built from sandstone with a thickness of 0.52 to 0.77 m. At the inner surfaces there is a layer of lime plaster which is 2 cm thick. The base plate exists of a layer with loose material (0.15 m) which is mainly covered by natural stone plates with a thickness of 5 cm. Under the benches at the north and south side of the church there are panels of hard wood instead. The ceiling to the attic has an overall thickness of 0.3 m consisting of 2.5 cm softwood, a 15 cm thick air layer, 10 cm mineral wool and again 2.5 cm softwood. The chapel's roof and its covering with a thickness of 3 cm is mainly built with softwood and shingles on the outside. The windows have a single glazing with an overall thermal transmission value of 3.7 W/m²K.

2.3 Parameter Variations

The simulations were run with different parameter variations. The base case is a simulation as that described in the previous section. The simulation results of this variant are always compared to a variant without any ventilation control, i.e. only natural ventilation mainly by infiltration. Further simulations were run with air change rates of 1 1/h and 10 1/h to show the influence of the capability of the ventilation system. A further simulation was run where only the energy transport was modelled whereas the coupled equations for heat and moisture transport in the building envelope were not modelled. This simulation allowed assessing the necessity of a simulation model capable of modelling the coupled transport equtions.

3 RESULTS

Figure 3 shows the modelled temperature and relative humidity inside the nave without additional ventilation and with an assumed air change rate of 5 ACH for ventilation during all periods with lower exterior absolute humidity than inside and while exterior temperatures are above 0 °C. The inner climate conditions are compared to outer climate conditions.

Expectedly lower fluctuations for temperature as well as for relative humidity are found for the interior conditions compared to the outside climate. Not only the peaks are damped, but also in longer periods with very low exterior temperatures the inner temperatures do not reach the mean low temperature. The fluctuations are lowest in the model without additional mechanical ventilation. Especially in spring, the relative humidity is reduced in the controlled ventilation case, but also the temperature inside the church. No effect is found in the cold month due to the temperature limitation at 0° C of the ventilation control.

The modelled ventilation control acts on abolute humidity. A comparison in Fig. 4 for absolute humidity inside and outside shows also a dampening of the fluctuations from outside to inside for the case without ventilation. The general trend is followed pretty close. The above mentioned effectiveless of the ventilation control in the cold month is reflected by the related ventilation status. Almost no ventilation actions are performed from mid November until end of March. In warm month the peaks in exterior absolute humidity appear reduced inside, but the minima can be followed by ventilation control which shows the lowering of absolute humidity in the ventilation case.

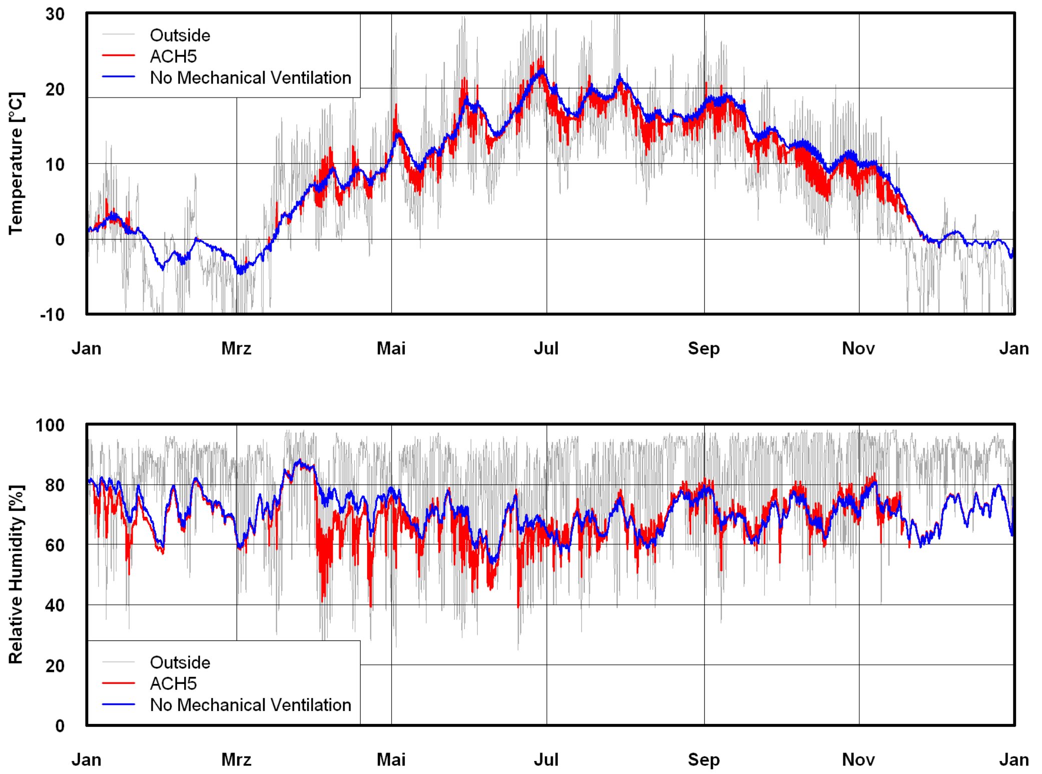

Figure 3. Temperature and relative humidity outside and modelled conditions inside the church during the whole simulation period with (Air Exchange 5 1/h) and without mechanical ventilation

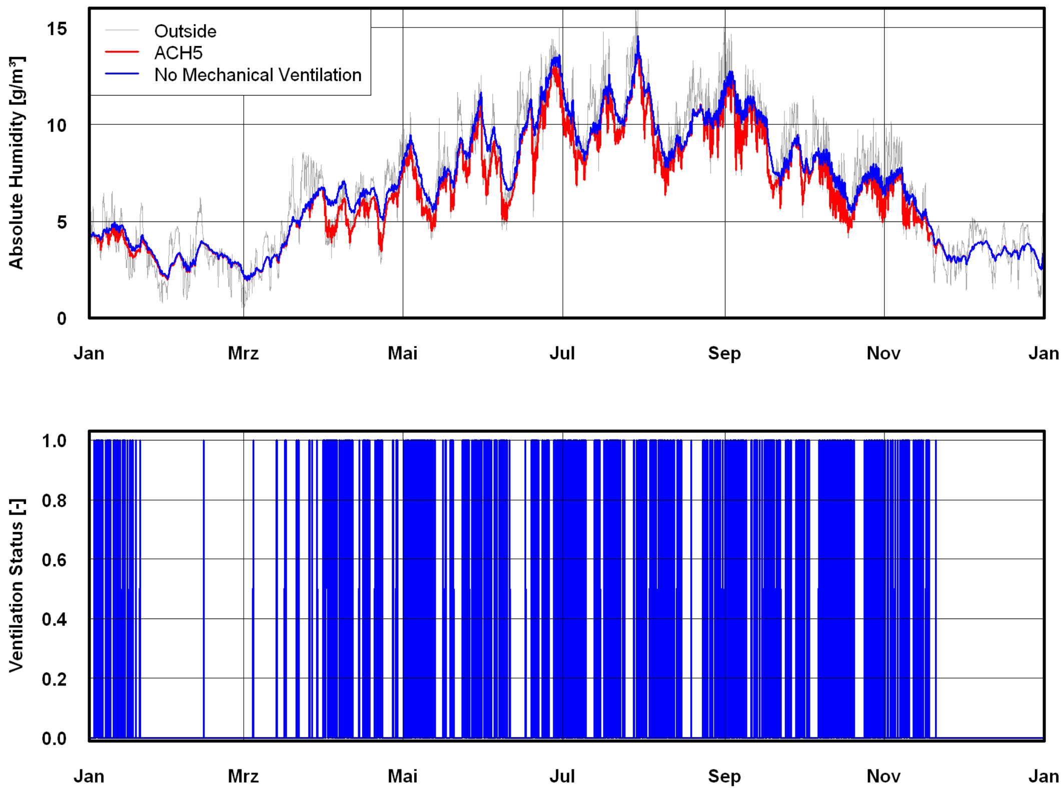

Figure 4. Absolute humidity outside and inside the church as well as ventilation status during the whole simulation period

A closer look on the absolute humidity conditions only in October are given in Fig. 5; details are provided of the resulting higher fluctuations of absolute humidity – and with it relative humidity – inside the building because of active ventilation control. But it also clearly shows that lower interior absolute humidities are achievable with effective ventilation during periods with lower exterior humidity.

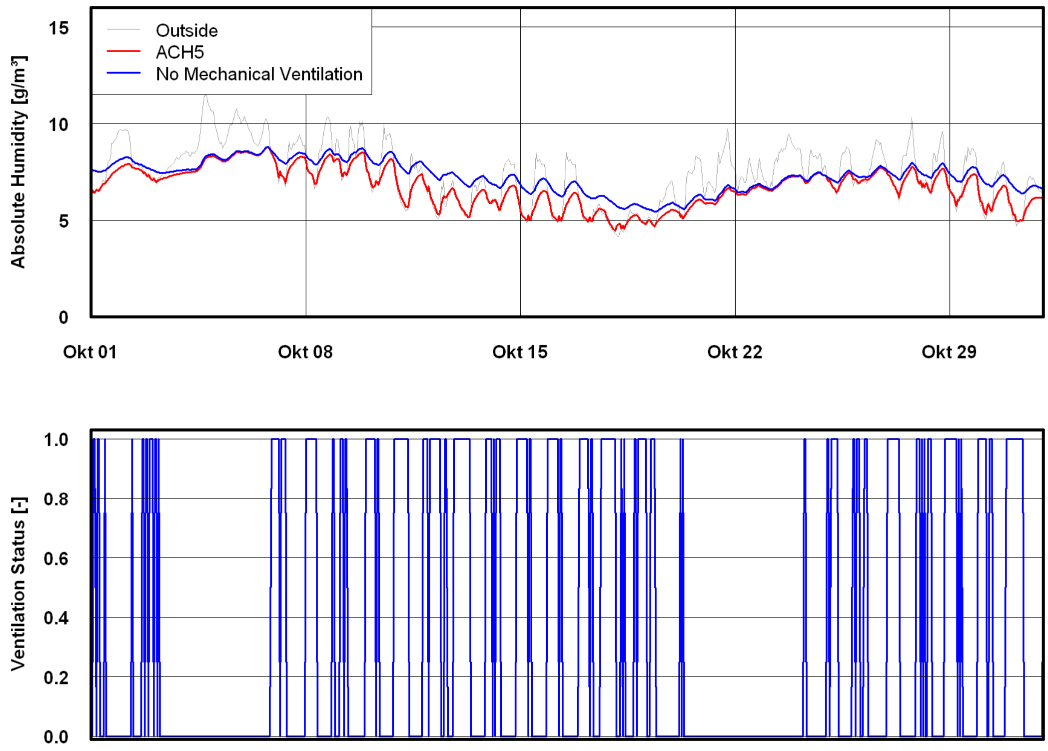

Figure 5. Absolute humidity outside and inside the church and ventilation status for simulation in October

A variation of different air change rates as well as a simulation without moisture buffering – therefore only a building energy simulation – was performed and the results for October are shown in Fig. 6. An improvement in efficiency is achievable by increasing the air change rate during control action from 1 ACH to 5 ACH. In the modelled case, a further increase up to 10 ACH does not further reduce the absolute humidityindoors , as the exterior minimum absolute humidity is also reached with 5 ACH. In the case of a simulation without modelling the coupled heat and mass transfer in the building envelope but using only a mass balance for interior humidity, the interior absolute humidity follows very closely the exterior absolute humitidy.

4 DISCUSSION

It was found, that daily fluctuations of temperature and relative humidity are much higher with mechanical ventilation control compared to the climatically free floating church. Especially in cases with valueable interior artifacts that are sensitive to high RH fluctuations, this potentially can cause problems. The daily fluctuations are compared in Fig. 8 for the case without mechanical ventilation and the ventilation control case with 5 ACH during operation of the mechanical ventilation. The average daily variation is 3 % RH without and 7 % RH with ventilation with maximum daily fluctuations of 15 % and 39 % respectively.

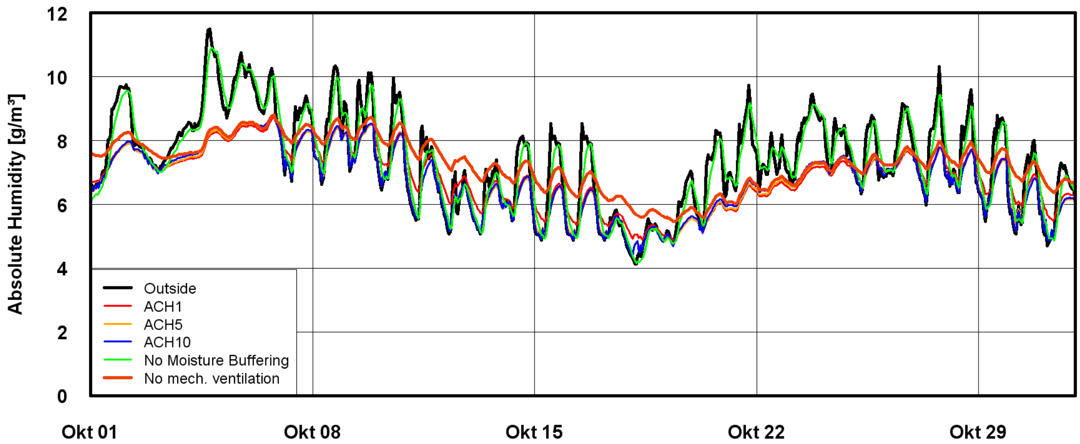

Figure 6. Absolute humidity outside and inside the church with different parameters for simulation during representative month October

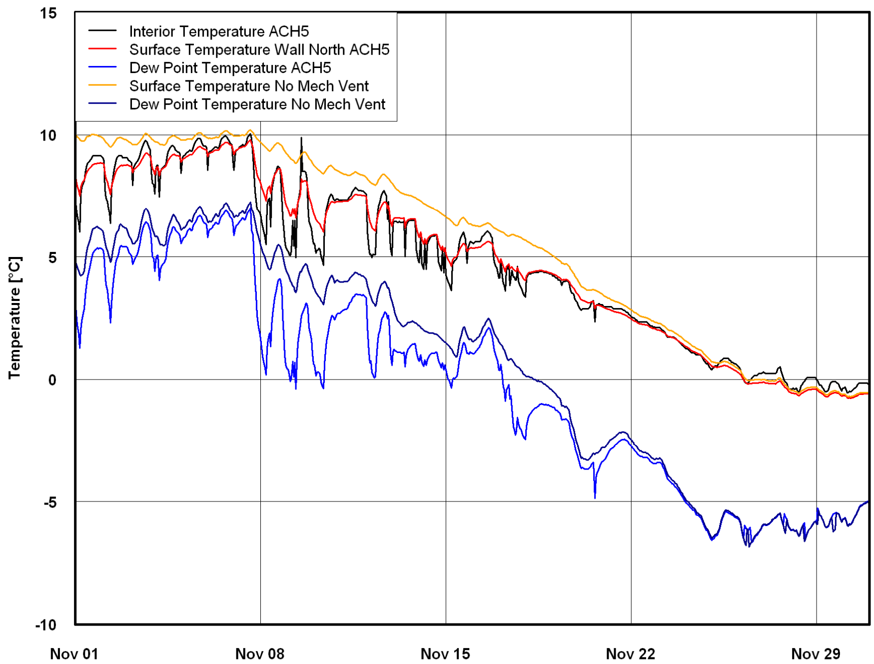

Figure 7. Surface temperature and dew-point temperature for North wall without mechanical ventilation and with ventilation control and ACH 5 1/h

5 SUMMARY AND CONCLUSIONS

A simulation model of a church was implemented. Parameter variations were undertaken, to assess the effectiveness of a controlled ventilation to lower humidity conditions inside the church. A model of the free floating building without mechanical ventilation was compared to the same building with a mechanical ventilation system. This ventilation system was controlled to be active while inner absolute humidity was higher than exterior absolute humidity with the limitation that exterior temperature had to be above 0°C.

The results of the simulation permited determing that it is possible to lower the inner absolute humidity during some times of the year with the ventilation control system assesed in this study. The main limitation of the system is that moisture removal can never reduce the inner absolute humidity to a level below exterior conditions. This limits its effectiveness in cases of a free floating building with low inner moisture loads.

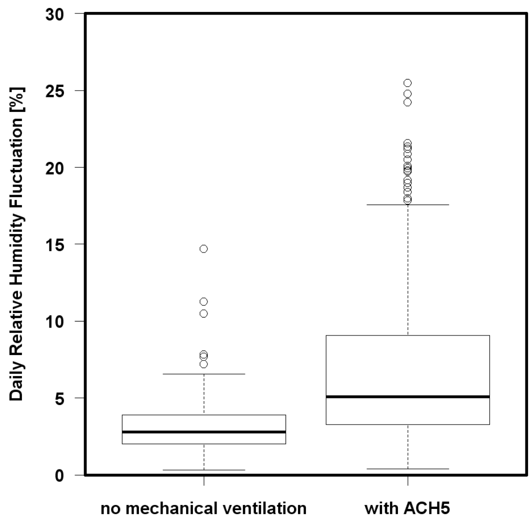

Figure 8. Boxplots of simulation results for all daily fluctuations of relative humidity in the space without ventilation and the space with ACH 1/h

Critical conditions due to moisture vented or infiltrated into the building leading to high relative humidity or even fluid water on the envelope surface can not always be avoided. The daily cycle and other fluctuations in exterior absolute humidity are low. Potential for active ventilation is not always available. Therefore also ventilation systems that create low air change rates allow the full removal of excess moisture. A further increase in air change rate is not necessary. In compareable free floating cases with no inner loads humidity condtions can still be critical. Improvement in the indoor humidity level is bought at the expense of stabile humidity conditions. Fluctuations of temperature and humidity are much higher with controlled ventilation than without. This effect has to be balanced with the small improvements in moisture level. To undertake a similar assessment, it was shown that it is critical to model coupled heat and moisture transport processes in the envelope and its interaction with the room. Relative humidity level and fluctuations can only be represented if moisture buffering effects are taken into account in the simulation.

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