The Gate Hall of Lorsch – Comprehensive Assessment Methods to calibrate Simulation Models and adapt Conservation Strategies

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Abstract

The Torhalle ("Gate Hall") of Lorsch, also called King's Hall, is one of the best preserved examples of Karoling architecture in Germany, dating back to 760 A.C. The hall is located on the first floor above an entrance gate to a monastery and is believed to have been used as a church originally. It features valuable Romanic wall paintings. In the 1980ies thorough investigations were conducted on the building and its indoor environment which shows high relative humidity all year round. In 1991 a controlled ventilation system was introduced that promised to lower RH significantly. Already in 1992 it was turned off by a sceptical conservator. Now the building faces the same problems as before and new research is taking place, looking at collected climate data and past experience. The aim is to develop a new climatisation strategy for the Gatehall. For this purpose the whole building simulation tool WUFI Plus is applied, to assess the use of different HVAC systems for the specific building and location at Lorsch and also to research the possible effects on indoor environmental fluctuations that might be harmful to the ancient wallpaintings. This research is part of the European project Climate for Culture on the effects of climate change on cultural heritage.

Keywords – Risk Assessment; Building Simulation; Preventive Conservation; Torhalle Lorsch; Statistical Assessment; Salt Damage; Cultural Damage

1. Gate Hall Lorsch

The "Gate Hall," of Lorsch (see Fig. 1), built in the 9th Century A.C. is one of the most outstanding examples of Carolingian architecture in Germany. Regarding building physical matters the building is also interesting because the hall is situated above a pathway and therefore, with exception of two staircases, is completely surrounded by outer climate. Rising humidity is not an issue. The motivation for investigations is the question for a new climate concept for the "Gate Hall", which at present is not air conditioned.

Fig. 1. Gate Hall of Lorsch. The upper floor houses valuable Romanic wall paintings. There are two small towers on both sides of the building with staircases leading upwards. One of the towers was used in the 1990's for controlled ventilation.

History of Examinations and an Intermezzo of Climatization

The King's Hall Lorsch is one of the best examined and documented historical buildings in Germany. In the 1980's and 90's several researchers worked on the special research topic of "Stone Deterioration" with art historical, but also with art technological and conservational questions. Hence the construction of the walls and the ceiling, all stones and mortars are well analysed and documented [1]. Aim of these examinations was beside the development of methods for restoration of the wall paintings and stone surfaces the elaboration of a sustainable concept for preventive conservation in form of a climate control system for the King's Hall.

The Fraunhofer-Institute of Building Physics carried out climate measurements in the years from 1984 to 1985. The result was that the climate was generally in a region of high humidity [3]. To counteract the continuing deterioration of the valuable mural paintings a controlled ventilation system was recommended, to reduce the humidity in the room. The idea is that absolute humidity inside and outside are compared and under favourable conditions dryer air is brought into the room by a ventilator. Follow up measurements from 1991 to 1992 showed a positive result in this respect. These evaluations were published 1995 in [4] and described as a successfully concept. But the researchers didn't expect a conservator of the Hessischen Schlösserverwaltung, who already pulled the plug 1992, because he found the system suspicious and thought it was useless – a typical example that the development of concepts alone isn't enough.

2. Model Calibration

During the calibration processes the simulation results are checked and different parameters are changed. In this case indoor climate measurements are not available for a whole year. That is the reason why it is necessary to get some kind of “dynamic” to the input parameters like the air change rate or the number of visitors. This means the simulation model has no rigid, but a seasonal changing air change rate. But it is difficult to fix this realistically without a full year of measurements of the air change rate, though this parameter must be fixed iteratively by hand to get the best result.

It is a similar issue with the number of visitors. In this case there are only average statistic which cannot reproduce every hour and every day exactly and realistic. Also the inner heat and humidity loads are estimated. Altogether a building simulation model is a more or less sensitive system of different parameters. It is important to avoid artificial effects e.g. through overrating artificially the number of visitors. In addition it must be made sure, that different effects don’t overlay each other. A wrong relation between input parameters and the result could arise. When comparing the simulation results and the measurements it becomes more clearly, that not every day can match in detail. It is more important to get the general characteristics of the indoor climate and to compare those.

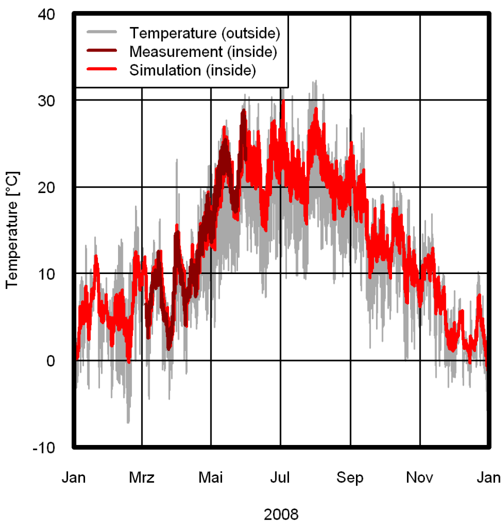

Fig. 2. Inner temperature of measurement and simulation.

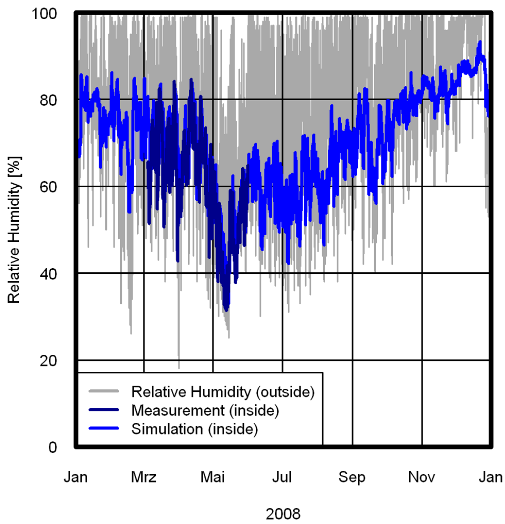

Fig. 3. Inner relative humidity of measurement and simulation.

In this paper a new look at the comparison of measurement and simulation results is taken. Fig. 2 and 3 show the year 2008 with measurement and simulation results. It is obvious that the trend of the simulation fits well, but single days differ from each other. This fact leads into new assessments strategies to calibrate a building simulation model.

3. Statistical Assessment

Statistical assessment and comparison of two datasets is made in this paper with “Ferro-Hypotheses” [2]. Ferro describes four hypotheses to test and compare two different datasets. Figure 4 and 5 show the hypotheses for temperature and relative humidity. The straight line H0 implies no difference between the two datasets and is shown as a 45 ° line in the diagram. HS shows the difference in scale, HL the difference in location. HLS combines the difference in scale and location. The single data points are additional shown in the diagram as a QQ-plot, which means both datasets are sorted and plotted. A desirable result is a HS, HL and HSL line near by the H0 line. It is obvious, that the simulated indoor temperature (see Fig. 4) is almost identical with the H0 line. Also the simulated data of the indoor relative humidity (see Fig. 5) is close to H0, it is about 2 - 3% RH higher than in the measurements. This difference lies within the uncertainty of the measurement.

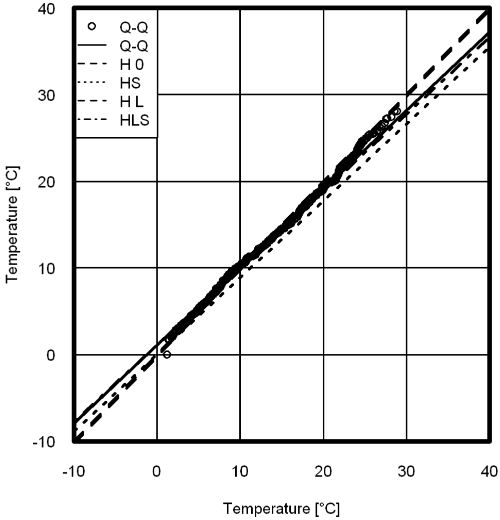

Fig. 4. Ferro-Hypotheses of temperature-datasets of measurement and simulation during calibration period.

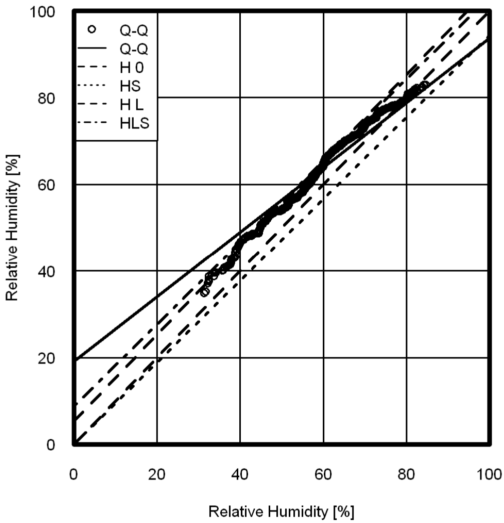

Fig. 5. Ferro-Hypotheses of relative humidity-datasets of measurement and simulation during calibration period.

4. Risk Assessment

Another assessment of the accuracy of the simulation is made by taking a look at existing damages and affiliated damage functions. In the plaster and stone of the walls of the Gatehall a high salt load was established in the research project in the 1980ies. The salt was analysed as NH_4NO_3, nitrate of ammonium, brought in by pigeon excrements. The deliquescence relative humidity (RHD) is strongly temperature dependant and can be calculated with a simple model for this special salt [5]. Compared to the RHD in Fig. 6 one third of the calibrated simulation results and measurement points are above the limit. So there is the assumption, that temperature and relative humidity will change inopportunely and that the salt in the walls will get in solution and crystallize several times a year. This leads to progressive damages like flaking off of plaster or paintings.

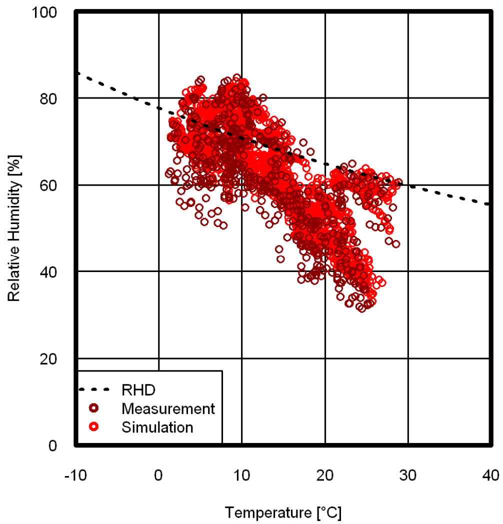

Fig. 6. Temperature and relative humidity of measurement and simulation related to the deliquescence relative humidity (RHD) of NH_4NO_3 ammonium nitrate.

To understand this damage mechanism and its effects, the phase changes of the salt were calculated for the measurement period and the identical simulation period data. Fig. 7 shows the difference between the RHD, calculated with the actual inner temperature and the actual inner relative humidity for the measurement. Fig. 8 shows the same time period, but for the simulated data. A value > 0 % RH difference means the salt crystallizes, a value < 0 % RH means the salt goes into solution. One phase change describes the change of the indoor climate from an environment where the salt is in solution to an environment where the salt crystallizes and the other way round.

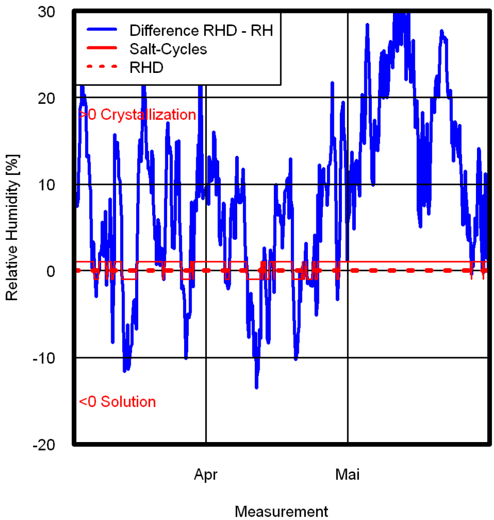

Fig. 7. Crystallisation cycles and difference between deliquescence relative humidity and measured inner relative humidity during calibration period.

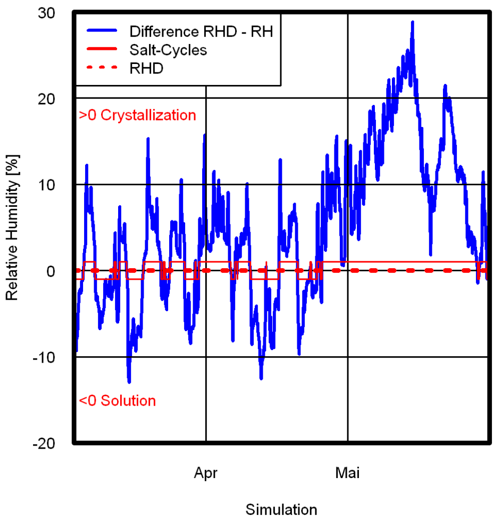

Fig. 8. Crystallisation cycles and difference between deliquescence relative humidity and simulated inner relative humidity during calibration period.

42 phase changes were calculated in the measurement period, 38 changes in the identical simulation period. For the whole year 2008 simulation period 203 phase changes are calculated. The comparison of results for risk assessment is a good way to get to know the effects of the climate on a building structure when it is not possible to model and simulate the identical climate in detail.

5. Possible Adaption Strategies

To reduce the number of phase changes and the damage potential in the King's Hall, Controlled Ventilation and Dehumidification are compared via building simulation and are presented as two possible preventive conservation strategies.

Fig. 9 shows an overview for the year 2008 for the simulated inner relative humidity, the RHD, inner absolute humidity and outer absolute humidity. The inner relative humidity is especially in the winter months higher than the RHD, during the rest of the year the relative humidity often fluctuates around the RHD. The fluctuations cause the phase changes of the salts and are the reason for continuing damage to surfaces.

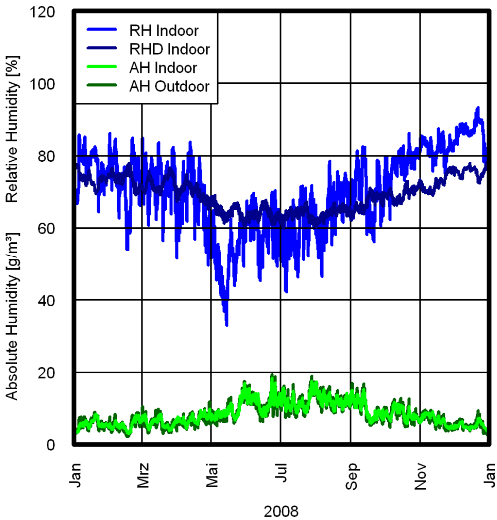

Fig. 9. Overview for comparisons between simulated actual indoor relative humidity and relative humidity deliquescence and between indoor and outdoor absolute humidity.

Controlled Ventilation by Outdoor Air

To assess the possible efficiency for controlled ventilation, three cases were distinct: the hours either the ventilation is not necessary, the ventilation is necessary and possible or the ventilation is necessary but not possible. The ventilation criterion in this example is also the RHD. If the indoor relative humidity is higher than the RHD, ventilation is necessary.

Table 1. Hours of possible Ventilation

Ventilation	Hours of the year [h]
Not necessary	5111
Necessary and possible	2309
Necessary but not possible	1316

Table 1 shows the calculated hours for the presented ventilation strategy. In about 41 % of all hours in the year ventilation would be necessary, because the relative humidity is higher than the RHD. At least in one fourth of the year this ventilation strategy would lead to an improvement.

Dehumidification

A dehumidifier is another alternative to keep RH below the deliquescence point for the salts that can damage historic surfaces. The big advantage against controlled ventilation is that the system will work all year round.

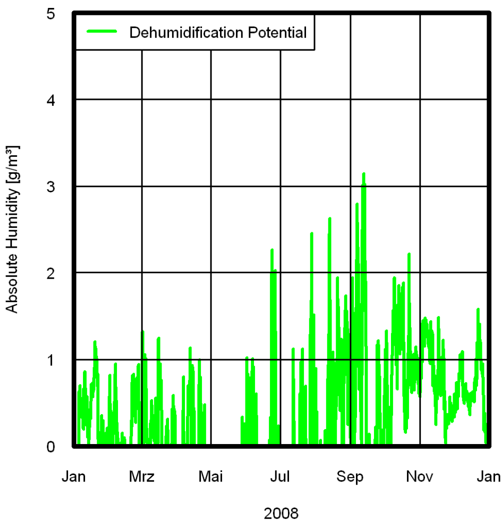

Fig. 10. Potential of dehumidification for the King’s Hall Lorsch.

Fig. 10 shows the theoretical potential of dehumidification. Over the year 2008 the system has to dehumidify 1440 kg of water.

6. Conclusions and Discussion

As seen in this paper it is a possible and purposeful strategy to calibrate building simulation models with statistical methods and damage functions.

For this assessment it is important to know the relevant damage mechanisms as exactly as possible. Only with certain damage functions it is possible to assess the quality of a building simulation model for risk assessment in preventive conservation. A further benefit of this method is the comparison of effects to the building structure. With damage-function-based calibrated simulation models different scenarios can be examined in regard to respective damage potential and preventive conservation strategies. In this paper two conservation strategies were presented. Both strategies aim to reduce the relative humidity in the King’s Hall to reduce the phase changes of the salt in the walls. A controlled ventilation system is a low-energy-system which can be effective. But at some times a year, e.g. rainy days, the ventilation cannot deliver drier air into the room, even it is necessary. Quite in reverse a dehumidification-system works the whole year and can guarantee the necessary climate conditions. But this system requires more installation costs, maintenance and energy. In the end a specific solution has to be found for each building and each situation. A cost-benefit evaluation can be an appropriate tool for decision making.

Acknowledgements

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