**Ralf Kilian, Johanna Leissner, Florian Antretter, Kristina Holl, Andreas Holm**

# Modeling climate change impact on cultural heritage – The European project Climate for Culture

## Summary

The CLIMATE FOR CULTURE project, funded by the European Commission since 2009, will assess the damage potential of climate change on European cultural heritage, its socio-economic impact and possible mitigation strategies. Collections in historic buildings in different parts of Europe will be included for in situ investigation of contemporary problems and for the projection of future demanding issues. For this purpose, high resolution climate evolution scenarios will be coupled with whole building simulation models to identify the most urgent risks for specific regions with the aim of developing mitigation strategies.
The identified economic and substantial risks for the European cultural heritage will be communicated to policy makers together with possible mitigation strategies to be included in the future IPCC Reports.

## 1. Introduction – Climate Change and Cultural Heritage

Climate change is one of the most critical global challenges of our time. This factor, coupled with the increasing demand our society has on energy and resources, has forced sustainable development to the top of the European political agenda. Scientific research shows that the preservation of the cultural heritage is particularly vulnerable in this regard. As a non-renewable resource of intrinsic importance to our identity, there is a need to develop more effective and efficient sustainable adaptation and mitigation strategies in order to preserve these invaluable cultural assets for the long-term future. More reliable assessments will lead to better prediction models, which in turn will enable preventive measures to be taken, thus reducing energy and the use of resources.

For this purpose the CLIMATE FOR CULTURE project will connect new high resolution climate change evolution scenarios with whole building simulation models to identify the most urgent risks for specific regions. The innovation lies in the elaboration of a more systematically and reliable damage/risk assessment which will be deduced by correlating the projected future climate data (with the spatial resolution of up to 10x10 km grid size) with whole building simulation models and new damage assessment functions. Thus not only the impact on historic buildings can be evaluated but also the possible effects on the indoor environment which surrounds the works of art we are keeping inside them. In situ measurements and investigations at cultural heritage sites throughout Europe (Fig. 1) and the Mediterranean will allow a much more precise and integrated assessment of the real damage impact of climate change on cultural heritage at regional scale. Sustainable (energy and resource efficient) and appropriate mitigation/adaptation strategies, also from previous EU projects, are further developed and applied on the basis of these findings simultaneously.

Figure1: Linderhof Castle, Bavaria, is one of the buildings to be examined using hygrothermal building simulation

The CLIMATE FOR CULTURE project will estimate more systematically the damage potential of climate change on European cultural heritage under different climate change scenarios at regional scale. The team consists of 27 multidisciplinary partners from 16 countries all over Europe and Egypt including leading institutes and experts in conservation, climate modeling and whole building simulation. One team partner is a member of the International Panel on Climate Change (IPCC) and four partners are members of the standardization body CEN TC 346 (Conservation of Cultural Property).

To raise the awareness of the decision makers about the costs to take actions and what it costs, if we do not take actions to protect cultural heritage the economic impacts and physical risks to European cultural heritage will be identified.

## 2. The Climate for Culture Project

### Main Objectives and Scientific Methods

To assess the effects of climate change high resolution climate evolution scenarios (based on regional climate model simulations) are connected with whole building simulation models to identify the most urgent risks for the whole of Europe and the Mediterranean. The correlation of the climate data and the whole building simulation models with close up surface monitoring will build the basis for setting up new damage functions. Collections in historic buildings from various European regions as well as UNESCO World Heritage Sites are included as case studies for in situ assessment of existing problems, retrospective investigations on the state of preservation and for the projection of future challenging issues. All results will be incorporated into the report on the assessment of the economic costs and impacts on cultural heritage under two different IPCC climate scenarios on regional scale.

Almost the entire research in the field of microclimate related preventive conservation so far has focused on the climate responses of singular artistic, historic materials which generally has led to a definition of very strict and rather limited climate ranges. However, historic buildings are living places which are frequently inhabited, visited or used for a wide variety of activities. The change in their use and function is often the condition of their survival as a monument. Maintaining these strict microclimate ranges for most historic buildings is not feasible,  in particular with regard to the global warming trend and often unnecessary because many of the movable cultural assets can withstand a wider range of climatic conditions.

The project aims at assessing the influence of climate change and microclimatic functioning of historic buildings with regard to the dangers for the interior equipment or works of art, as well as at new strategies for the improvement of the microclimatic control and the optimization of the buildings. The project will also contribute directly to the standardization process of the CEN TC 346 ”Conservation of cultural property”.

### Climate Change Modeling

A comprehensive description of the climate system components as well as their interaction under different climate change conditions can be achieved by using physically-based climate models /1/. An entirely new high resolution simulation (10x10 km) will be executed over entire Europe for time slices 1960-2000, 2020-2050 and 2070-2100. Two IPCC scenarios will be considered (B1 and A1B). While A1B is the manifestation of “business as usual” with high economic growth the B1 scenario gives a more optimistic vision of a world with lower emissions where resource efficient and sustainable technologies are fast developed and introduced. This allows covering a range of possible climate changes over the selected regions.These two different climate scenarios will

deliver climate indicators for assessment of future changes, including estimation and evaluation of uncertainties in the models.
To assess and simulate the local climate changes according to the different emission scenarios in a high resolution of 10 x 10 km the regional climate model REMO has been developed at the Max-Planck Institute for Meteorology (MPG/MPI-MET) in Hamburg /2, 3/ and has already been applied for several different areas (e.g. within the European CLAVIER, ENSEMBLES and the German KLIWAS, GLOWA-DANUBE projects). The global fields from the coupled general circulation model ECHAM5-MPIOM will be used as driving forces. In addition, the regional coupled model REMO/MPIOM with 25 km resolution in the atmosphere and 11 km in the ocean will be used to estimate both changes in mean sea level as well as changes in positive sea level extremes. The results from the this model will also be used to assess the uncertainty in the high resolution atmosphere-only simulations arising from the use of the coarse resolution sea surface temperature as lower boundary condition.

## Hygrothermal Building Simulation

Historic buildings usually show elevated indoor humidity levels and a high variation of the climatic conditions, which can be dangerous to cultural heritage materials. This requires the detailed consideration of all hygrothermal interactions between the indoor air, the usage, the furnishing and the building envelope. The hygrothermal behaviour of a building component exposed to weather is an important aspect of the overall performance of a building. The calculation of the hygrothermal performance of a part of the envelope is state-of-the-art and a realistic assessment of all relevant effects can be carried out, but until now the total behaviour of the actual whole building is not accounted for.
How much ventilation and additional heat energy is required to ensure safe indoor conditions for cultural heritage when a historic building is exposed to extreme climate conditions or up to 4000 visitor per day? What will happen to the hygrothermal behaviour of walls and ceiling when a historic cellar is changed in its use and is turned for example into a restaurant? How do the indoor air conditions and the envelope of buildings with temporary use react to different heating and ventilation strategies? Can sorptive finish materials improve and stabilise the microclimate in historic buildings?
For risk assessment in cultural heritage buildings the exact indoor humidity fluctuations and the moisture profiles in the building envelope are extremely relevant. Therefore models that combine thermal building simulation with the hygrothermal component simulation have to be applied.
Different thermal and hygrothermal building simulation tools will be evaluated for their applicability to simulate the indoor environment and hygrothermal transport mechanisms in historic building materials. These computational models are usually used for simulating water and temperature distributions in modern building components like insulated walls or roofs. Whole building simulations will also take into account the type of use (e.g. visitors, events) and HVAC climatisation components to assess the indoor environment. Their applicability to existent historic buildings with often unknown constructions and material properties is still limited.

The whole building model WUFI® PLUS /4/ is a combination of thermal building simulation with the hygrothermal envelope calculation model WUFI®. This holistic model takes into account the main hygrothermal effects, like moisture sources and sinks inside a room and the moisture input from the envelope due to capillary action and diffusion as well as vapour ad- and desorption as a response to the exterior and interior climate conditions. Also different heat sources and sinks inside the room, heat input from the envelope, the solar energy input through walls and windows as well as hygrothermal sources and sinks due to natural or mechanical ventilation are considered.
Also other simulation software like Hambase /5/, ESP-r /6/, Energy Plus /7/ or IDA-ICE /8/ will be compared in a Common Exercise between the several research institutes with the aim of testing their applicability for historic buildings. The different tools are expected to have strength and weaknesses for different topics of the assessment, e.g. some simulate the combined heat and moisture transport through porous materials, whereas others only use simplified models for these processes or just simulate the heat transport but have higher possibilities in accurately modelling different HVAC systems.
The most suitable models will then be used to model the predicted impact of the climate change. As probably some features for the appropriate climate change impact modelling on complex historic buildings are missing, missing modules will be assessed, developed and implemented into the software tools. This allows to use the high resolution climate data to predict the future indoor environment of the case study buildings. This indoor climate data will then be assessed with the new damage functions.
In a final step, the effects of active and passive mitigation measures will be evaluated with the building simulation models. The most promising mitigation measures will be implemented in the simulation models. This allows the assessment of the effect of different measures suggested.

## 3. Case Example – The King’s House on the Schachen

The CLIMATE FOR CULTURE project aims at providing a general overview on the difference of the indoor environment in historic buildings all over Europe. Selected and representative buildings will be used as Case Studies for simulation. The best documented and thoroughly known of these buildings will be used for the simulation common exercise. These cases must allow a validation of the software tools on the basis of measured interior climate conditions from the past connected with the documented boundary conditions.

### Building and Works of art

The King’s house on the Schachen is one of five historic buildings in Bavaria (besides Linderhof Palace and St. Renatus Chapel, Lustheim, and two further churches), which are examined in the Climate for Culture project. The King’s house on the Schachen, located in the Wetterstein Mountains in the Alps was built by King Ludwig II of Bavaria from 1869 to 1872 in a wooden post-and-infill construction. On the first floor there is the richly decorated Turkish hall furnished with different materials such as wall paper, textiles, polychromed and gilded wood surfaces, and coloured windows. Due to the exposed location, the building is set out rough atmospheric conditions all year with fast weather changes and long periods of frost during the whole winter. Nevertheless the condition of the house, the interior and especially the Turkish hall is very good (Fig. 2). To find out more about the circumstances for this state of preservation, the Fraunhofer-Institute for Building Physics has started climate measurements in 2006. The first step of examination was the simulation of the indoor climate of the king's house with the whole building simulation software WUFI®+ and the thorough analysis of the condition of the decoration of the Turkish hall by a trained conservator.

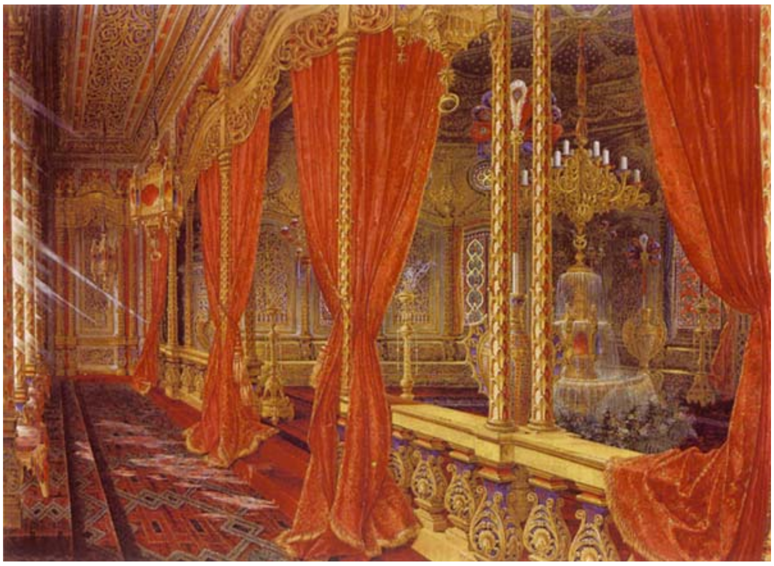

Figure 2: Interieur of the Turkish Hall on a watercolour painting from 1879 by Peter Herwegen. The decoration looks the same today as on the picture, so later changes to the decorative program can be excluded.

As first conclusions it has to be stated that many factors contribute to the good state of preservation: the house is open only in the summer months and due to the location the only access is by a three hour march. For this reason, compared to other Bavarian palaces for example Linderhof Palace, less visitors – who are one cause for indoor climate fluctuations – come to see the king's house on the Schachen. The indoor environment of the Turkish hall is buffered by a house-in-house-construction and stable without any heating or climatisation system. Also the indoor surface materials buffer moisture fluctuations. This helps to preserve the furnishing and works of art inside the building.

## Simulation

The hygrothermal building simulation of the Kings House on the Schachen has been published earlier /9/. Here just exemplary results are shown (Fig. 3 and Fig. 4).
The comparison of the simulations results with the measured data shows quite good fitting for the winter months. During summer in the simulation the temperature is too high in comparison with the measured data due to necessary simplifications in regard to the building construction and uncertainties in regard to the available weather data in the approximation of the model, especially solar radiation and shading from the mountains during winter months.
This will also pose difficulties for modelling local climate change, as also climate change modelling has limitations, e.g. when it comes to simulating mountain regions with very special local microclimates that cannot be modelled in sufficient high resolution up to now.

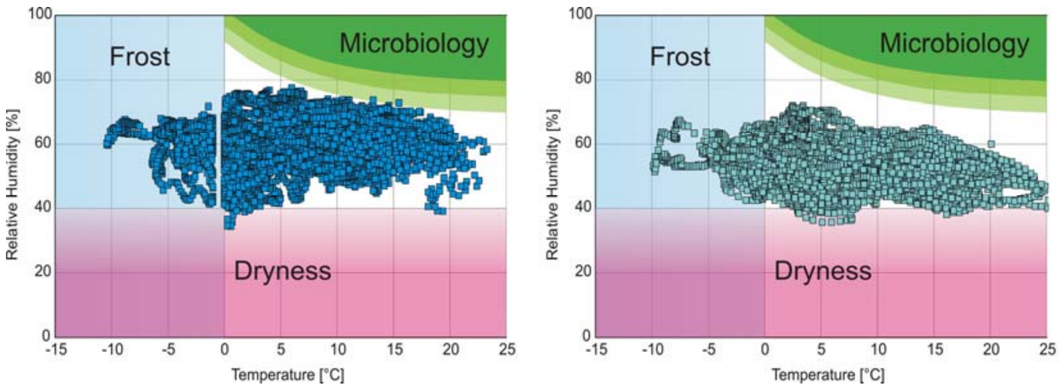


Figure 3: Scatterplots showing the comparison between measurement and simulation for 1 year of data (from October, 1st  2006 to September, 31st 2007). Risk assessment of the measured indoor climate (left) shows that most of the data is in a safe region for the one year monitoring period. The gap in the measured temperature at 0° C is due to a malfunction of the data logger. The simulation provides to high temperature and in turn lower RH for the summer months.

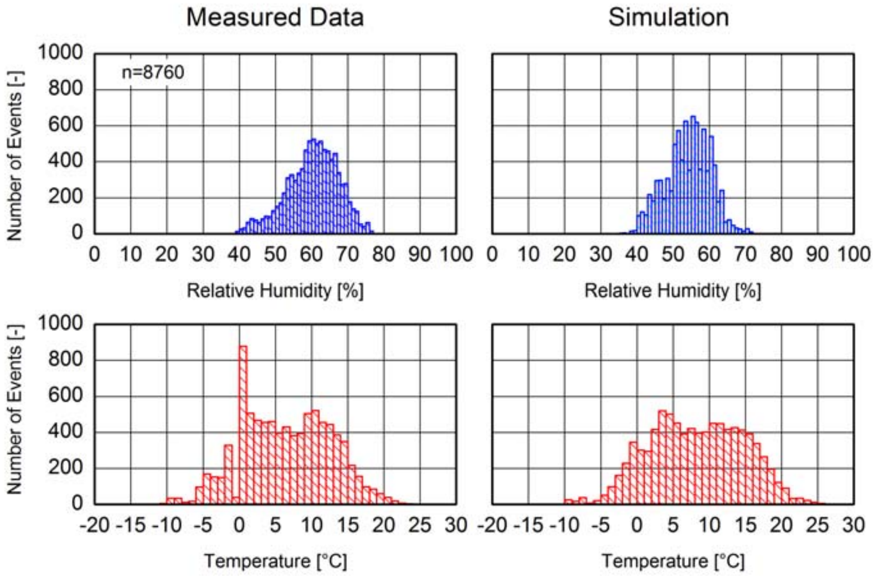


Figure 4: Histograms showing the comparison between measurement and simulation for 1 year of data (2006-2007). The gap in the measured temperature at 0° C is due to a malfunction of the data logger.

## 4. Summary

In general it is difficult to simulate historic buildings, due to multiple materials often unknown or with changed properties from aging and often unknown building constructions. Nevertheless it is possible to obtain approximations that are sufficiently close to reality.

With a good knowledge of the hygrothermal behavior of a historic building today coupled with high resolution climate change simulations it will be possible to assess future impacts of climate change on these buildings and on the works of art that are kept inside them, by looking at a large number of case studies all over Europe. Of course for this task all uncertainties of the climate change prediction models as well of building simulation will have to be taken into account. This will be our project for the next years to come.

## 5. References

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