The Climate for Culture Method for Assessing Future Risks resulting from the Indoor Climate in Historic Buildings

R. Kilian[1], T. Broström[2], J. Ashley-Smith[3], H.L. Schellen[4], M. Martens[4], F. Antretter[1], M. Winkler[1], C. Bertolin[5], D. Camuffo[5], J. Leissner[1]

ABSTRACT

In order to assess the most substantial risks of changing climate conditions for historic artifacts in specific regions, the large-scale integrated EU-Project CLIMATE FOR CULTURE has taken the approach of correlating high resolution regional climate modeling with building simulation tools to produce scenarios of future indoor climates in historic buildings. Risks to the building and to the interiors with valuable artifacts resulting from the indoor environment are assessed by damage functions. A set of generic buildings based on data from existing buildings are used to transfer outdoor climate conditions to indoor conditions using high resolution climate projections for Europe and the Mediterranean. With this method risk maps of future climate induced risks to historic buildings and their interiors can be produced. The results can be used for climate change impact assessments and for planning adaption and mitigation measures of the built cultural heritage. The present paper presents the method and expected results.

Keywords

Climate change, indoor climate, heritage, risk maps

1. Introduction

Climate change, the worldwide energy and resource deficiency problem are serious threats of our time. For a sustainable management of our cultural heritage, it is vital to know how the future changing climate will influence the indoor climates of buildings. 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 (CfC) project is connecting new high resolution climate change evolution scenarios with whole building simulation tools to identify the most urgent risks for specific regions. A further innovation of the project lies in the elaboration of a more systematic and reliable damage/risk assessment which will be deduced by correlating the projected future climate data with whole building simulation models and new damage assessment functions. Thus not only can the impact on historic buildings and future energy demands be evaluated, but also the possible effects on the related indoor climates in which valuable works of art are kept. In situ measurements and investigations at cultural heritage sites throughout Europe (Figure 1) and the Mediterranean allows for a more precise and integrated assessment of the real damage impact of climate change on cultural heritage on a regional scale. Sustainable (energy and resource efficient) and appropriate mitigation/adaptation strategies, are further developed and

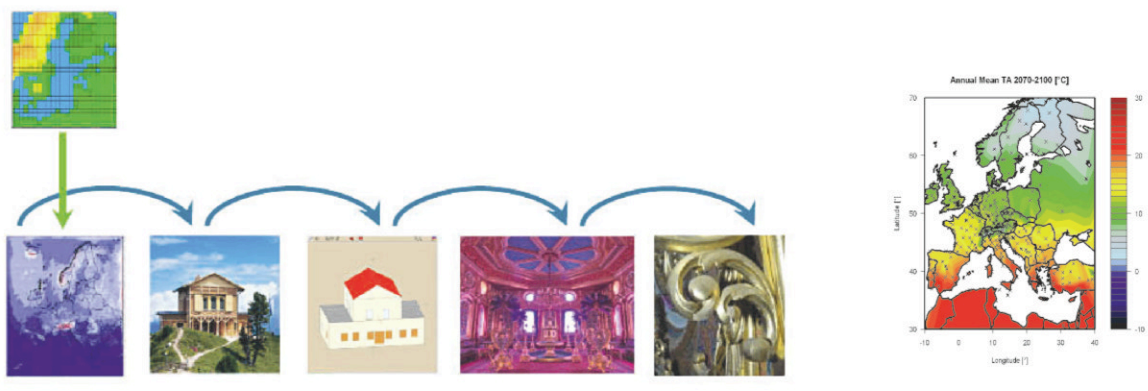

Figure 1 The CfC method for risk assessment from climate change projections to individual risk assessment and risk maps: Global climate simulations provide input to building simulations that predict future indoor climate. Damage functions are used to assess future risks.

1 Fraunhofer Gesellschaft, Germany
2 Uppsala University, Sweden
3 Cambridge, United Kingdom
4 Technical University Eindhoven, The Netherlands
5 CNR-ISAC Padova, Italy

applied on the basis of these findings simultaneously. The paper presents a method to assess future risks resulting from the indoor climate of historic buildings. Furthermore preliminary results are shown to indicate the nature of the final products of the project.

2. Climate change modeling and simulations

According to the World Meteorological Organisation the term CLIMATE can be defined as "the statistical description in terms of the mean and variability of relevant weather quantities over a period of time". Climate covers different weather elements like temperature, air humidity, wind, clouding, precipitation, sushine duration, air pressure, snowfall, radiation and evaporation. All these parameters including their interactions with the atmosphere, the hydrosphere, the cryosphere, the surface lithosphere, the biosphere and the resulting carbon cycles are integrated into global climate models (GCM). Global climate models are based on different future scenarios, for example how the future population will grow or which technologies will be applied to reduce CO2 emissions [4, 5].

For the high resolution climate simulations within the Climate for Culture project two scenarios are investigated, the A1B scenario [7] and the very recent RCP4.5 scenario for the next IPCC assessment report 5 (AR5) due in 2014 [5]. For the mid-line A1B scenario, a CO2 emission increase is assumed until 2050 and a decrease afterwards. The second scenario - the RCP 4.5 - stands for Representative Concentration Pathway (RCP) 4.5 and is a scenario of long-term, global emissions of greenhouse gases, short-lived species, and land-use-land-cover which stabilizes radiative forcing at 4.5 Watts per square meter (W/m2, approximately 650 ppm CO2 equivalent) in the year 2100 without ever exceeding that value.

The climate simulations for the first scenario have been completed and produced data for two future time periods 2020-2050 (near future) and 2070-2100 (far future). As a reference the project has collected data for past weather conditions for 1960-1990. Data is available for more than 900 locations all over Europe, which includes all case study locations, a regular grid over Europe and more than 300 locations (Figure 2) where measured/modeled climate data was available for verification (see table 1). The modeled climate data sets were extensively verified with measured data sets to check their applicability for hygrothermal whole building simulation. Systematic deviations and other issues related to the use of modeled climate data were identified. Publications that address those issues are in preparation.

Table 1 Indices from climate modelling

Value	Unit
Temperature	°C
Relative Humidity	%
Normal Rain	mm
Wind Speed	m/s
Wind Direction	degree
Global Radiation	W/m2
Diffuse Radiation	W/m2
Global Counterradiation	W/m2
Cloud Coverage	%
Ground Temperature	°C
Ground Reflectance	-
Air Pressure	Pa

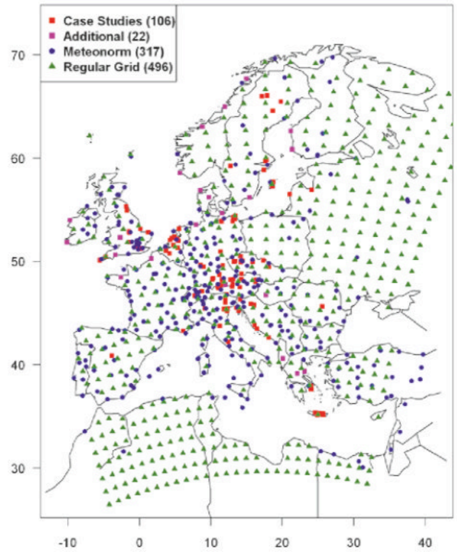

Figure 2 Location of sites for which outdoor climate data are provided.

3. Building simulations

Using the results from the global climate simulations, the future indoor climate can be predicted. For this purpose, the project has developed tools to model and simulate indoor climates of historic buildings through analyzing the buildings, introducing various modeling steps and validating the model using data from measurements. Two approaches are followed: development of a full-scale multizone dynamic hygrothermal whole building simulation and a simplified hygrothermal building model.

For the whole building simulation models that combine thermal building simulation with the hygrothermal component simulation have to be applied. These models take into account the type of use (e.g. visitors, events) and HVAC climatisation to assess the indoor environment. Different software tools have been systematically evaluated and the most useful ones in this context were found to be Hambase [2] and WUFIplus [3]. The full building simulations give a better representation of the hygrothermal performance of the building but this is at a high cost of developing the model and relatively long times for computing.

The simplified hygrothermal building model or the state space model is a simple mathematical function that can be used to calculate the indoor climate from the outdoor climate. The function is derived from a statistical analysis of measurements. The state space model is easier to set up and the computing time is so short that simulations can be made on line. At this point of development, the simplified model is limited to buildings without active climate control.

4. Damage functions

A damage function is an equation or an algorithm that relates quantifiable factors in the environment to quantifiable changes within the object. The link between environment and the change detected in the object may be primarily deterministic, such as the hydrolysis and consequent decrease in degree of polymerisation in paper. Or it may be probabilistic, for instance the mechanical damage in wood as a response to a change in relative humidity. Given the variety of materials and constructions found in heritage objects and the complexity of the processes of change, the two terms probabilistic and deterministic are not mutually exclusive. The predictions can only be interpreted as expected changes in levels of risk.

Within the CfC project the term damage function is used as a broad heading that includes not only dose-response functions but also quantitative information about environmental standards, thresholds and tolerable ranges, which are not usually presented in the form of equations.

The definition of damage function adopted within the project is: "A quantitative expression of cause and effect relationships between environmental factors and material change."

This definition has the advantage of being validated as part of a publicly accessible standard (BSI PAS 198:2012). But it has the disadvantage of emphasising the measurable scientific element and ignoring the intangible consequences. This problem can be overcome by the prior assumption that the functions that are used are those where the consequence of change will be a loss in value or significance, or a reduction in fitness for purpose. The physical or chemical change must be detectable and hopefully measureable, but the change must be considered unwelcome by relevant stakeholders. This assumption ties into the project definition of damage as 'unwanted irreversible change'.

The functions that are used within the project include:

- Mechanical damage to
  - wood
  - painted wood
- Chemical damage to
  - paper
  - textiles
  - photographic material
- Biological damage
  - mould growth
  - insect attack

5. Risk assessment for a particular building

As a next step, the output of the damage functions are used to assess present or future risks for a given building. For this purpose an indoor climate analysis toolbox has been developed. Data, either measured or predicted can be downloaded to a database. The analysis can focus either on specified damage functions or can be presented as a general report.

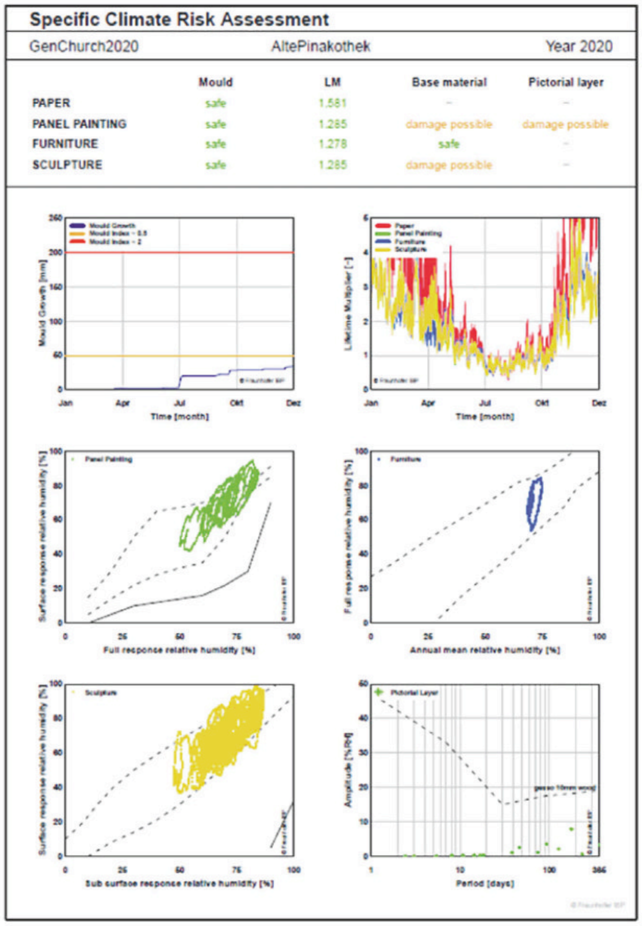

Figure 3 Examples of risk analysis based on measured or predicted data [12].

	Building category			
Type of climate control	Heavy, high moisture buffering capacity (MBP)	Heavy, low MBP	Lightweight, high MBP	Lightweight, low MBP
No climate control (TF)	Risk assessment (RA)	RA	RA	RA
Conservation heating (HAM)	Energy demand (ED) / RA	ED / RA	ED / RA	ED / RA
Intermittent heating	ED / RA	ED / RA	ED / RA	ED / RA
Permanent heating	ED / RA	ED / RA	ED / RA	ED / RA
Cooling	ED / RA	ED / RA	ED / RA	ED / RA
Temperature and humidity control	ED / RA	ED / RA	ED / RA	ED / RA

Table 2 Generic building categories and various climate control systems

6. From Climate Simulation to European Risk Maps

Furthermore, the CfC method is used to produce risk maps illustrating the risks for different kinds of buildings. To produce the risk maps, a limited number of generic buildings with different climate control systems were selected, see table 2. For each combination of building and climate control strategy, the indoor climate will be computed for all locations indicated in fig 2. Unheated buildings are used for assessment of risks from Climate Change all over Europe. The different climate control strategies can also be assessed in regard to applicability in different regions and their energy demand.

MBP refers to moisture buffering capacity of the indoor materials – which is relevant for indoor climate stability. The results are presented as indoor climate risk maps; an example is shown in figure 4.

The predicted indoor climate in combination with damage functions are used to produce risk maps, as shown Figure 1. The basis for the risk maps is formed by hygrothermal building simulations for three time periods: 1960 – 1990 (Recent Past), 2020 – 2050 (Near Future) and 2070 – 2100 (Far Future). External climate data generated with the downscaling method REMO [8] is used to compute the indoor climate conditions in these time periods for different building types and operations.

Martens' specific risk assessment method is used for risk classification. Based on temperature and relative humidity data biological, chemical and mechanical degradation can be evaluated for four objects, which represent typical museum collections: Paper, panel paintings, lacquered furniture and wooden sculptures. By applying permissible limits the results of this method are categorised into a three-step system, representing small, medium or high deterioration-risk [12]. To assess the long-term development of these risks over multiple years, Martens' method was extended. Therefore trend-analyses are performed for each degradation principle. The categorisation-system was also expanded to consider these long-term developments in addition to the permissible limits [14].

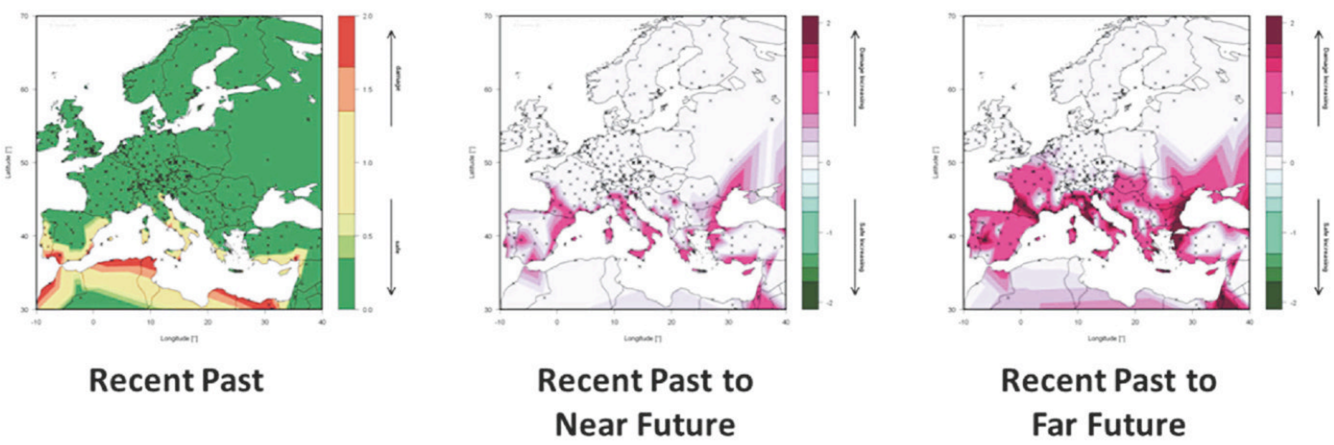

Figure 4 Example of a prototype risk map (left) and resulting maps for the near and far future periods showing the degree of changes according to climate changes. The data are arbitrarily chosen and are not real values.

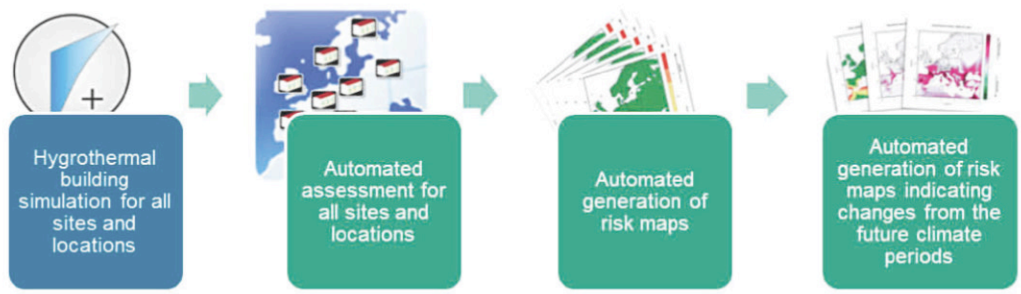

Figure 5 The CfC method for generating European risk maps.

Besides the specific risk assessment, a general evaluation of the indoor climate is performed. Here also trend-analysis is used to quantify the long-term developments of temperature and relative humidity.

Currently, the assessment is being performed for 460 locations which are unequally distributed across Europe and the Mediterranean area. Further locations can be added. The assessment for the long-term damage risks and the indoor climate are applied to every location: Their results are the basis for the pan-European maps, which display the damage risks and their trends as well as the characteristic values of the indoor climate and its further evolution. Changes between the time periods are also analysed and visualised as maps. The recent past serves as baseline for each of the two future periods. Figure 4 displays the prototype for the layout of a risk map (left) and of the maps which show the changes in the risks according to the changing climate periods. The data are chosen arbitrarily and do not represent realistic values.

To perform all these operations two software-tools are used: The hygrothermal building-simulations are performed with the hygrothermal whole building simulation software WUFI® Plus. Starting from the risk assessment to the generation of the risk maps is a completely automated process. This algorithm is programmed in R, a free programming language and software environment for statistical computing and graphics [13]. Figure 5 shows the procedure for producing the risk maps.

7. Uncertainty

A significant amount of uncertainty is generated in the process of combining projections of future climate, building simulations and damage functions. Climate scenarios describing the future climate are associated with uncertainty, rising from inadequate knowledge of the climate system, imperfections in the numerical climate models and inherent variability in the climate system e.g. building simulations and damage functions do not only propagate uncertainties in the climate scenarios but also add new elements of uncertainty. If the propagation of uncertainties is not dealt with, there is a risk that data will be used in ways that cannot be supported. This has been discussed extensively elsewhere [9]. The uncertainty cascade of producing risk maps is shown step-by-step in figure 6. The uncertainty is increasing due to added uncertainties in each step of the projections [9]

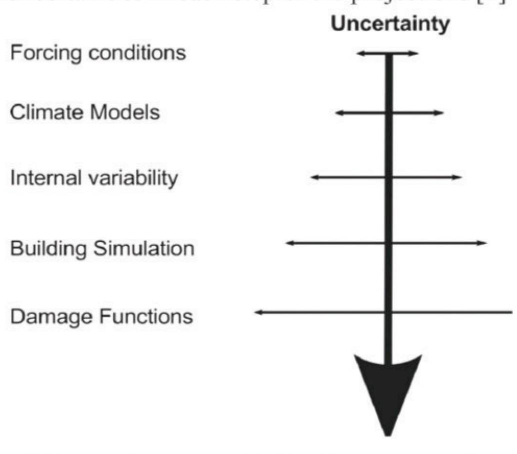

Figure 6 Uncertainty cascade for the process of assessing risks to a singular object

8. Conclusions

A new method has been presented to assess not only outdoor risks to cultural heritage assets, but also risks for indoor collections. The new method can be applied to single buildings as well as on a larger scale in the form of risk maps illustrating the risks for buildings and their collections geographically distributed over the whole of Europe. These maps can be produced using a generic building approach: By using different and exemplary artificial buildings in modelling the climate change impact, a standardised comparison between different regions in Europe becomes possible for the first time. The calculations are performed with two different methods: simplified transfer functions and/or more elaborate whole building simulation models. The final level of uncertainty in the risk maps is high as for most of these simulations regardless of whether a deterministic or a probabilistic approach is used. But these risk maps based on state-of-the-art scientific knowledge are valuable tools to indicate trends of future risks to cultural heritage. The risk maps can play an important role as a decision tool helping to better plan mitigation and adaption measures at various levels and thus using resources more sustainably.

9. Acknowledgement

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