Computational modelling of the impact of climate change on the indoor environment of a historic building in the Netherlands

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KEYWORDS: *Cultural heritage, climate change, building simulation*

SUMMARY:
The damage potential of climate change on the indoor environment of a historic building in the Netherlands has been analysed. An indoor climate simulation model has been created and validated with on-site measurements. In combination with weather data from a future climate scenario, the simulation model is able to generate a prediction of the impact of climate change on the indoor environment. The indoor environment has been assessed based on ASHRAE guidelines for museum collections and the annual energy demand for heating and cooling has been calculated. The results show that from 2000 until 2099, both the indoor air temperature and relative humidity in unheated rooms will increase. The impact of climate change on hourly and daily fluctuations of temperature and relative humidity seems relatively low. In heated rooms, the energy demand for heating systems is considerably reduced, while the energy demand for cooling slightly increases.

1. Introduction

Within the EU project Climate for Culture, the damage potential of climate change on a large selection of representative historic buildings, including UNESCO World Heritage Sites, throughout Europe and North Africa is assessed. For the Netherlands, future outdoor climate scenarios until 2100 have predicted that the temperature will continue to rise, winters will become wetter and the number of rainy days in summer will decrease, although the intensity of extreme rain showers will increase (Van den Hurk et al., 2006). In general, it is expected that the warming climate will increase the overheating risk of buildings, reduce the energy demand for heating and increase the energy demand for cooling (Frank, 2005). However, the impact of climate change on buildings is largely depended on building location and building characteristics. Commonly, the overheating risk for non-insulated buildings is significantly lower than for insulated buildings, because insulation considerably reduces the transmission of internal heat gains through the building envelope (Aebischer et al., 2007). Furthermore, a rising relative humidity, due to higher amounts of precipitation, will increase the risk on unfavourable microclimate conditions that cause damage to historic buildings and their collections. Besides that, the indoor environment in historic buildings is difficult to control because HVAC systems are often limited or outdated.

In this preliminary study, an indoor climate simulation program in combination with one future outdoor climate scenario has been applied to evaluate the impact of climate change on indoor climate variables and energy consumption. A historical building in the Netherlands, which provides accommodation to a collection of valuable furniture and paintings, has been selected as a case study. Based on the ASHRAE guidelines for indoor conditions related to museum collections (ASHRAE 2007), the damage potential of climate change on the indoor environment and the building collection has been assessed and the annual energy demand for heating and cooling has been calculated.

2. Method

2.1 Regional climate model

The regional climate model REMO is based on the Europe model, the former numerical weather prediction model from the German Weather Service (Majewski, 1991). The large-scale initial and boundary conditions in REMO are obtained from the global climate model ECHAM5, while the dynamical core and discretization in time and space are similar to the Europe model (Jacob and Podzun, 1997). REMO can be used for weather forecast and (future) climate simulations on a grid with a minimum horizontal resolution of approximately 10km (Max Planck Institute for Meteorology, 2010). The weather forecast cannot be predicted for individual days, but it is possible to generate an assumption of the average conditions for an area.

With REMO, an outdoor climate scenario from 1950 until 2099 for one central location in The Netherlands (latitude = 52° 10′ N, longitude = 5° 18′ E), based on the IPCC A1B emission scenario (IPPC, 2007), has been produced. Hourly data for air temperature, surface temperature, relative humidity, precipitation, wind direction, wind speed, albedo, cloud cover, global radiation and global count radiation have been provided. From 2000 until 2099, the estimated mean temperature rises by approximately 2.6˚C. The mean absolute humidity is estimated to increase by 2.1 g/kg. Since both temperature and absolute humidity increase, the estimated mean relative humidity rise is relatively small (0.8 %).

2.2 Computational modelling

The indoor climate simulation model HAMBase has been used as method to simulate the indoor environment in a historic monument in The Netherlands. With HAMBase, the thermal and hygric indoor climate and energy use for heating and cooling of multi-zone buildings can be simulated. HAMBase requires hourly values of the exterior air temperature, diffuse solar radiation on the horizontal surface, direct normal solar intensity, relative humidity, wind speed, wind direction and cloud cover (de Wit, 2006). Although the influence of air filtration through cracks and openings is included in HAMBase, data for wind speed and wind direction are not taken into account.

2.3 Case study

The method has been applied in a case study, concerning a castle that was built in the 17^{th} century. The five-storey building has brick walls with a thickness varying between 0.7 and 1.5m. The building is currently under renovation and most existing HVAC systems are not functioning properly. Therefore, indoor climate conditions are mainly determined by the outdoor climate. In the near future, the building will open as a museum.

A HAMBase model of the historic building has been created using recent measured outdoor climate data files from the weather station closest to the building location. Weather data have been provided by the Royal Netherlands Meteorological Institute. Ten rooms, divided over four levels, have been modelled. The simulation model has been validated with on-site measurements that were carried out from January 2009 until January 2010 (Fig. 1).

Two zones have been assumed in the building: the first zone has seven unheated rooms and the second zone has three heated rooms. In each zone, the rooms are connected by internal walls. To prevent the influence of heating and cooling systems on the indoor temperature in unheated rooms, no heat transfer is assumed between the zone with unheated rooms and the zone with heated rooms. The unheated rooms are located at the south and east façade of the building and the heated rooms are located at the south and west façade of the building.

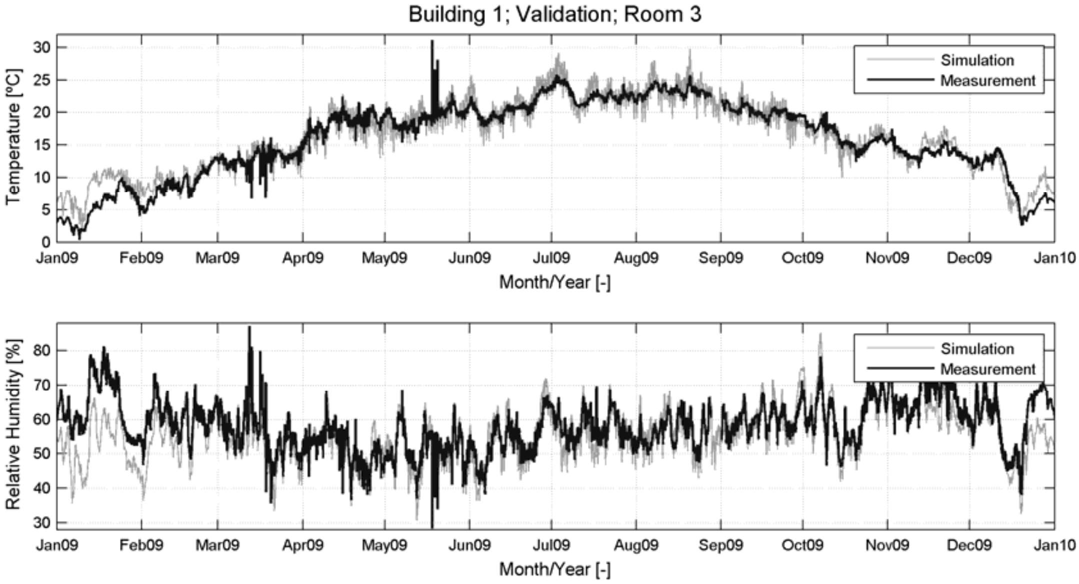

FIG 1. Validation of indoor climate simulation model

3. Results

3.1 Unheated rooms

3.1.1 Indoor temperature and relative humidity

In the calculation of the indoor temperature in the unheated rooms, free-floating conditions have been assumed. No internal heat gains have been modelled inside the rooms and the air change rate, which has been derived from on-site measurements, has been kept constant. Averaged estimated values over periods of 1, 5 and 25 years for indoor temperature and relative humidity per season in one of the unheated rooms are shown in Figs. 2 and 3. The smallest averaged temperature rise over 100 years is found in spring (1.2˚C) and summer (2.4˚C). The warming is largest in winter (2.8˚C) and autumn (3.1˚C). The average relative humidity rise varies from 0.5 % (in winter) to 5.1 % (in spring).

Table 1 contains estimated values for the increase in mean temperature and relative humidity in each unheated room between 2000 and 2099. The estimated mean indoor temperature rises by approximately 2.5˚C and the estimated mean relative humidity is expected to increase by 3.7%.

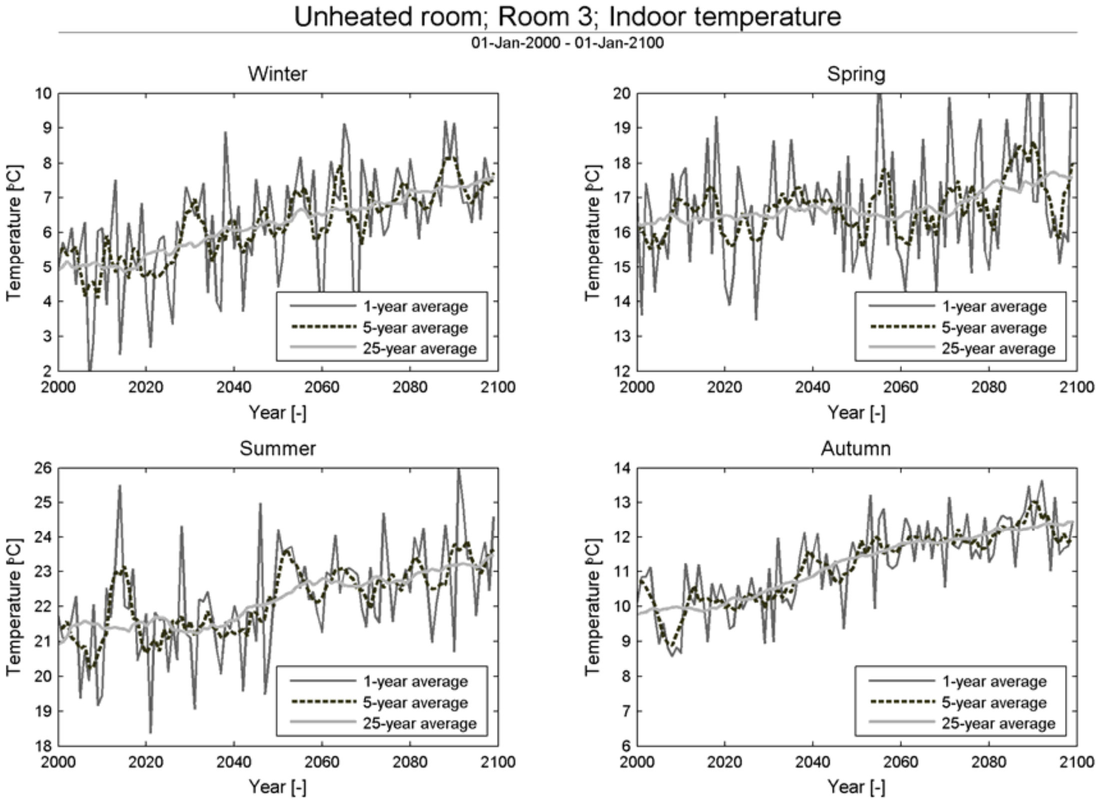

FIG 2. Indoor temperature in an unheated room, values averaged over periods of 1, 5 and 25 years

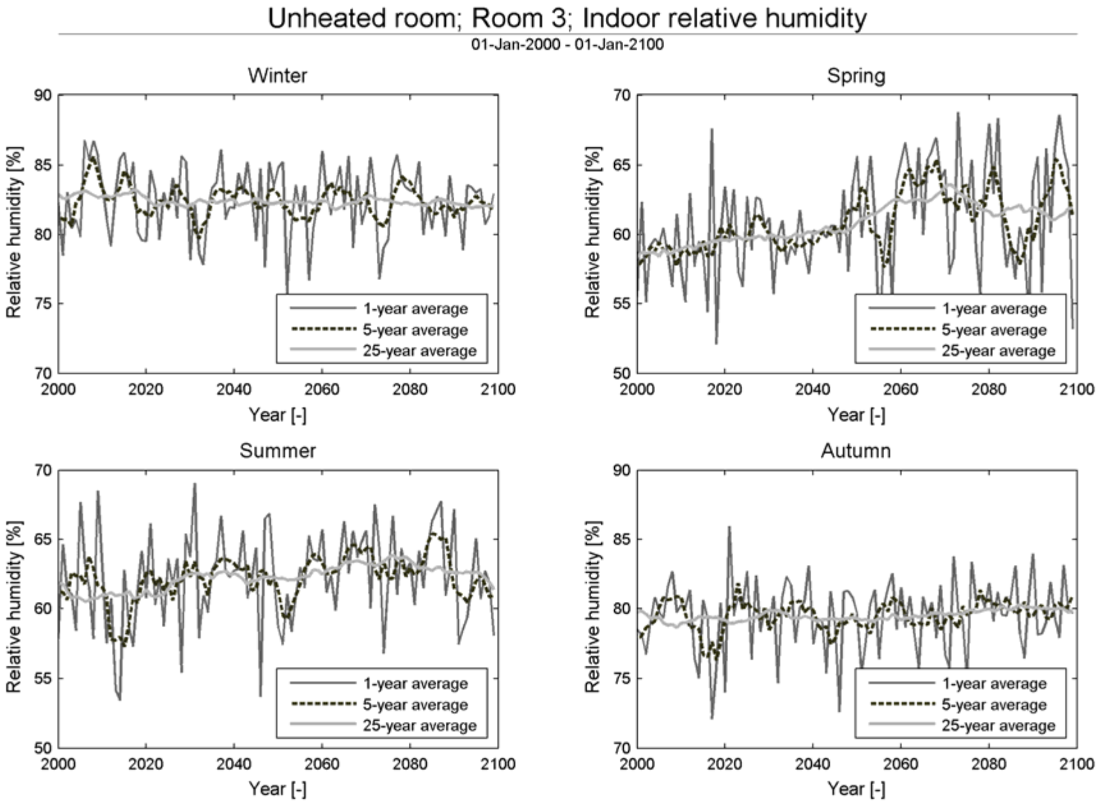

FIG 3. Relative humidity in an unheated room, values averaged over periods of 1, 5 and 25 years

TABLE 1. Differences in indoor temperature and relative humidity in unheated rooms between year 2000 and 2099

Room	Level	Volume	Indoor temperature [˚C]	Relative humidity [%]
1	-1	173	+ 1.7	+ 7.9
2	0	285	+ 2.6	+ 3.0
3	1	259	+ 2.8	+ 2.1
4	-1	83	+ 2.2	+ 5.8
5	0	98	+ 2.6	+ 3.3
6	1	83	+ 2.8	+ 2.3
7	2	388	+ 2.9	+ 1.8

3.1.2 Climate evaluation

The indoor climate in the historic building has been assessed according to the guidelines for museum indoor conditions related to collections developed by ASHRAE (2007). In general, very low or fluctuating temperature and relative humidity values can lead to mechanical damage of artefacts, while high temperature and relative humidity values accelerate damaging chemical processes. For general museums, ASHRAE distinguishes six classes of control, dependent on the damage risk to the collection. When a moderate (class B), small (class A) or no (class AA) damage risk is required, the guidelines provide minimum and maximum values as well as maximum hourly and daily fluctuations for indoor temperature and relative humidity.

One method to assess the indoor climate per room based on the guidelines for one of the ASHRAE classes is the Climate Evaluation Chart that has been developed by Martens et al. (2006). This chart consists of three parts: a psychometric chart containing the hourly climate data divided per season, five 3 x 3 matrices which show the percentage of the data in total and per season that is within and without the limits for minimum and maximum temperature and relative humidity and four histograms presenting the occurrence in percentage of time that the data are outside the recommended limits for hourly and daily fluctuations of temperature and relative humidity. The chart uses a different colour for each season; please note that printing this chart in black and white may negatively affect the visibility of the seasonal differences. Because Climate Evaluation Charts do not represent indoor climate data as a function of time, the use of only one chart is not suitable to analyse the influence of climate change over a certain period. However, by creating a chart for each year, it is possible to compare yearly values of the percentage of time the indoor climate data are within and without the ASHRAE limits.

A Climate Evaluation Chart of the indoor climate in one of the unheated rooms in the year 2000 compared with the criteria of ASHRAE Class B is shown in Fig. 4.The chart shows that particularly in winter and autumn the temperature is too low and that the relative humidity is generally too high. The hourly fluctuations are within the ASHRAE limits, but the daily fluctuations of temperature and relative humidity often exceed the limits. An overview of the annual percentages of data that are within the ASHRAE limits and that exceed the limits for maximum relative humidity and daily fluctuations of temperature and relative humidity between 2000 and 2099 is shown in Fig. 5. The differences in percentages within and outside ASHRAE limits between 2000 and 2099 for all unheated rooms are given in Table 2. Minimum relative humidity values and hourly fluctuations of temperature and relative humidity are in each year mainly within the ASHRAE limits and are therefore not discussed in detail. The percentage of data that is within the limits decreases, which is for the largest part caused by an increasing relative humidity and a larger amount of temperature overheating hours. The impact of climate change on the daily fluctuations of temperature and relative humidity is relatively small. In order to reduce the damage risk to the collection due to climate change, improved systems for cooling, dehumidification and mechanical ventilation are recommended.

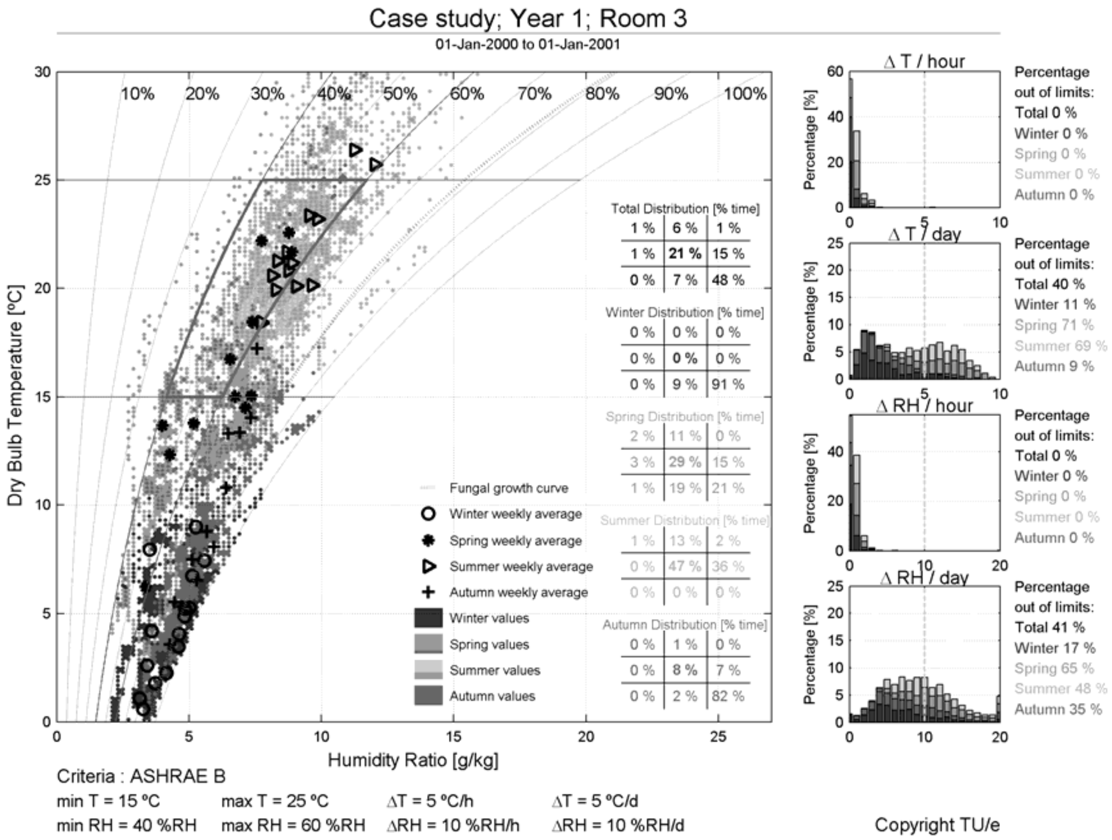

FIG 4.Climate Evaluation Chart of an unheated room

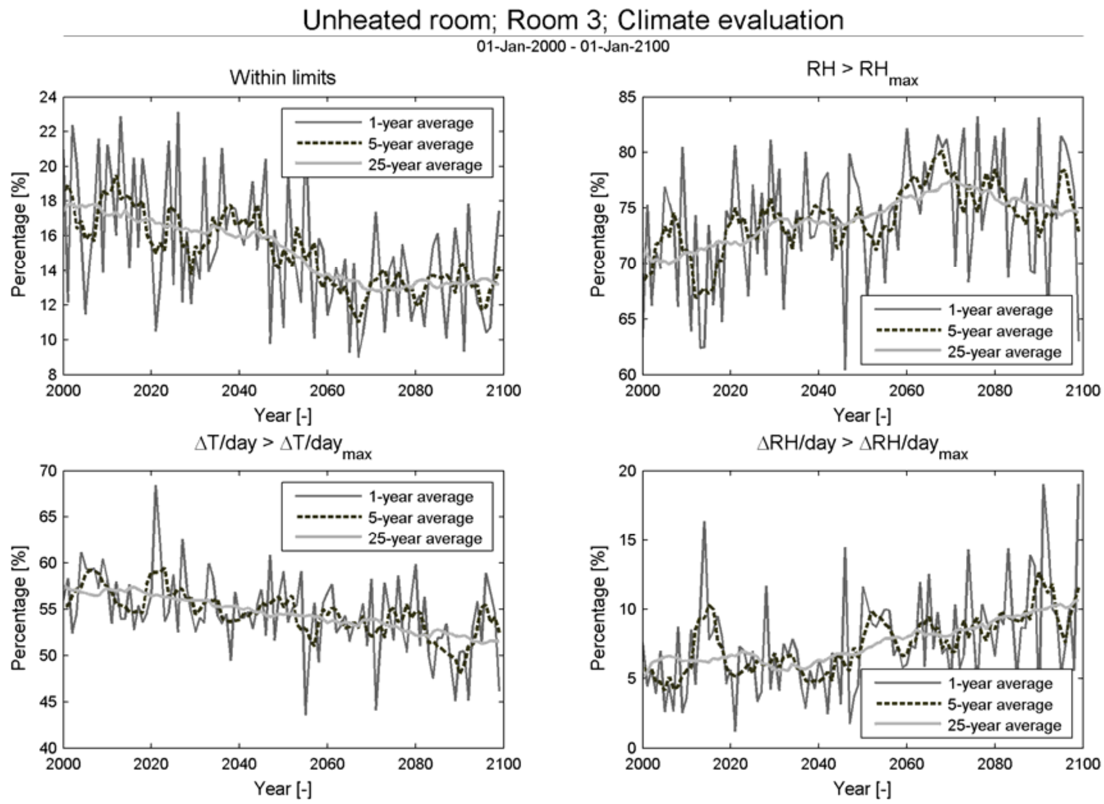

FIG 5. Evaluation of percentages within and without ASHRAE limits in an unheated room

TABLE 2. Differences in percentages within and outside ASHRAE Class B limits in unheated rooms between year 2000 and 2099

Room	Within ASHRAE class B limits [%]	$T < T_{min}$ Percentage out of limits[%]	$T > T_{max}$ Percentage out of limits[%]	$RH > RH_{max}$ Percentage out of limits[%]	$\Delta T/day > \Delta T/day_{max}$ Percentage out of limits[%]	$\Delta RH/day > \Delta RH/day_{max}$ Percentage out of limits[%]
1	- 4	- 6	0	+ 10	0	+ 2
2	- 7	- 5	+ 5	+ 7	- 3	+ 3
3	- 6	- 6	+ 5	+ 6	- 3	0
4	- 5	- 6	+ 2	+ 9	- 1	+ 2
5	- 7	- 5	+ 5	+ 8	- 3	+ 2
6	- 7	- 5	+ 6	+ 6	- 2	+ 2
7	- 5	- 7	+ 5	+ 6	- 3	0

3.2 Heated rooms

3.2.1 HVAC system

In the indoor climate simulation of the heated rooms, the setpoint switches for heating and cooling are set to the minimal and maximum value recommended by ASHRAE Class B, 15˚C and 25˚C, respectively. To guarantee that the temperature will constantly be between these limits, the simulated heating and cooling plant have an infinite capacity.

3.2.2 Annual energy demand

The annual energy demand for heating and cooling for one of the heated rooms is shown in Fig. 6. An overview of the total difference in annual energy demands for heating and cooling of the heated rooms between 2000 and 2099 are shown in Table 3. It can be seen that the total energy demand for heating decreases by 5300 kWh, while the energy demand for cooling increases by 800kWh. Overall, the impact of climate change considerably reduces the annual energy demand of the building.

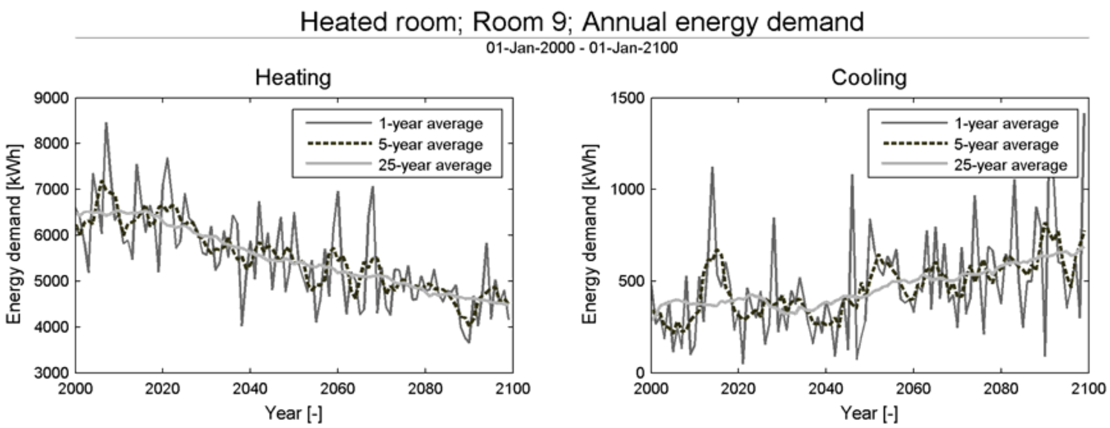

FIG 6. Annual energy demands for heating and cooling in a heated room

TABLE 3. Differences in energy demands for heating and cooling in heated rooms between year 2000 and 2099

Room	Level	Volume [m³]	Annual heating demand [kWh]	Annual cooling demand [kWh]
8	-1	172	- 800	+ 100
9	0	249	- 2400	+ 400
10	1	226	- 2100	+ 300

4. Conclusions

In this preliminary study, the impact of climate change on the indoor environment of a historic building in the Netherlands has been assessed by combining the indoor climate simulation program HAMBase with the future outdoor climate scenario REMO. Based on the results from on-site measurements in the historic building, the indoor temperature is generally between 5 and 25˚C and indoor climate problems in unheated rooms are in particular caused by a high relative humidity and large relative humidity fluctuations per day. The preliminary results of the simulations with REMO data show that the predicted climate change leads to an increasing temperature and relative humidity.

From the preliminary results, it can be concluded that, for the specific case, climate change causes an increasing number of overheating hours and a rise of the indoor relative humidity. Therefore, in order to meet the ASHRAE standards, the need for cooling systems, dehumidification systems and improved mechanical ventilation systems rises. Hourly and daily indoor temperature and relative humidity fluctuations, which present a considerable risk for mechanical damage to museum collections, do not seem to be significantly influenced by climate change. Furthermore, the energy demand of the heating systems considerably reduces, while the energy demand for cooling systems slightly rises.

In the near future, further research will be carried out investigating more case studies and different outdoor climate scenarios. In this way, it is expected that more general results will be achieved.

5. Acknowledgements

This work was supported by European Commission funding through the EU Climate for Culture project 226973 within FP7-ENV-2008-1.

6. References

Aebischer, B., Jakob, M. and Catenazzi, G. 2007. Impact of climate change on thermal comfort, heating and cooling energy demand in Europe. Proceedings ECEEE 2007, Summer Study “Saving energy – Just do it!”. France, 4-9 June, 2007, p. 859-870.

ASHRAE, 2007. ASHRAE handbook: HVAC Applications, Chapter 21, Museums, Galleries, Archives, and Libraries. SI edition, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. p. 21.1-21.23.

Frank, Th. 2005. Climate change impacts on building heating and cooling energy demand in Switzerland. Energy and Buildings 37, p. 1175-1185.

IPCC, 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.). IPCC, Geneva, Switzerland, 104 pp.

Jacob, D. and Podzun, R.1997. Sensitivity studies with the Regional Climate Model REMO. Meteorology and Atmospheric Physics, 63, p. 119-129.

Majewski, D. 1991. The Europa-Modell of the Deutscher Wetterdienst. ECMWF Seminar on Numerical Methods in Atmospheric Models, Vol 2, p. 147-191.

Martens, M.H.J., Schijndel, A.W.M. van, and Schellen, H.L. 2006. Evaluation of indoor climates using the ‘Climate Evaluation Chart’. Proceedings of the Lyon EPIC conference 2006, p. 523-528.

Max Planck Institute for Meteorology. 2010: http://www.mpimet.mpg.de

Wit, M.H. de, 2006. HAMBase, Heat, Air and Moisture Model for Building and System Evaluation, Eindhoven University of Technology, Bouwstenen 100.