APPLICABILITY OF REGIONAL MODEL CLIMATE DATA FOR HYGROTHERMAL BUILDING SIMULATION AND CLIMATE CHANGE IMPACT ON THE INDOOR ENVIRONMENT OF A GENERIC CHURCH IN EUROPE

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ABSTRACT

Climate change effects are supposed to have an impact on cultural heritage. To assess the impact of climate change scenarios on the indoor environment on certain locations it is necessary to apply modeled climate data downscaled by regional models in building simulation models. This allows transferring the expected exterior conditions into temperature and relative humidity conditions indoors. To ensure the applicability of the modeled climate data, all parameters relevant for hygrothermal building simulation need to be verified.

This paper uses the exterior climate data produced with the regional model REMO for more than 300 locations. For all locations the modeled climate data sets for the period 1960-1990 are compared with one year datasets representing an "average climate" for the location. Furthermore a comparison with measured data for ten years for more than ten locations is performed to exclude errors due to only one data source. Systematic deviations for each relevant parameter between measured and modeled weather data can be identified.

After verifying the modeled climate data sets this data is applied in hygrothermal whole building simulation. A generic building is created, representing an average church in Europe, for which the inner temperature and relative humidity is computed. The changes in indoor conditions due to changing climate for various locations in Europe are assessed. Results in indoor conditions for the periods 1960-1990, 2020-2050 and 2070-2100 are compared.

It was found, that the parameters used in hygrothermal whole building simulation were provided by the regional model with different accuracy compared to measured weather data. Deviations in solar radiation caused deviations also in modeled indoor climate.

Keywords

Climate change, modeled climate data, climate data assessment, hygrothermal building simulation, generic building.

1. Introduction

The outdoor climate takes effect on the indoor climate of buildings. The barrier which separates the two is the building envelope. Simplified, the higher the thermal mass or the insulation of the building envelope is, the lower is the influence of the outdoor climate on the indoor conditions. Typically heritage buildings are not well insulated (see Chapter 3) but have high thermal inertia. Churches are often not heated and therefore the inner climate is strongly dependent on the outer climate and changes in the outer climate cause changes inside.

The present paper tries to assess the impact of the modeled climate change in the 21st century on the indoor environment of heritage buildings in Europe. Climate data downscaled by the regional model REMO [1] for the periods 1960-1990, 2020-2050 and 2070-2100 is used for hygrothermal building simulations. So the exterior conditions can be transferred into inner climate.

In a first step the parameters of the exterior climate data produced with the regional model REMO are assessed. This is done by comparing the REMO climate data 1960-1990 for more than 300 locations in Europe with one year datasets representing "average climates". These one year datasets are derived from the Software Meteonorm [2]. Moreover a comparison with measured data for ten years for 18 locations is performed for some parameters to exclude errors due to only one data source. Systematic deviations for each relevant parameter between measured and modeled weather data are identified.

Afterwards a generic building is created, representing an average church in Europe, for which the inner temperature and relative humidity is computed by hyrothermal whole building simulation.

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The advanced hygrothermal whole building simulation tool WUFI®plus is used for simulation [3]. The software calculates the coupled heat and mass transfer for every enclosing assembly and couples heat and moisture fluxes from the inner surfaces with the zone temperature and relative humidity.

After executing simulations with the REMO 1960-1990 climate data and the one year Meteonorm climate data for more than 300 locations in Europe, temperature and relative humidity inside the generic church are compared.

Finally the simulation is run with the future climate datasets REMO 2020-2050 and REMO 2070-2100. The results of these simulations show the impact of future climate change on the inner climate of heritage buildings.

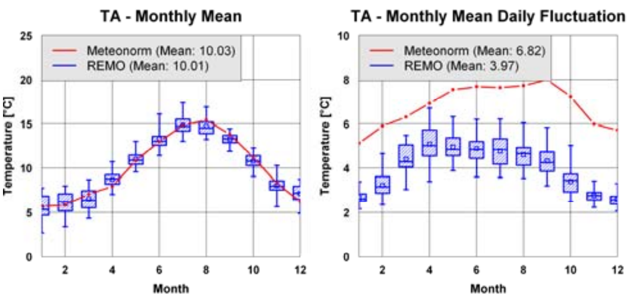
The contribution of this paper is to validate modeled climate data by comparing with average and measured climate data and to show it is possible to derive predictions for changes in the indoor climate of heritage buildings due to climate changes in the 21st century by the use of hygrothermal whole building models.

2. Climate data assessment

To ensure the applicability of the modeled climate data generated with the downscaling simulation REMO, all parameters relevant for hygrothermal building simulation needed to be verified. Therefore air temperature (TA), relative humidity (HREL), wind speed (WS), wind direction (WD), global radiation (ISGH), atmospheric counter radiation (ILAH), rainfall (RN) and cloud index (CI) of the REMO 1960-1990 data are compared with the equivalent parameters of other climate datasets. Thereby this paper focuses on monthly mean values and on monthly mean values of maximum daily fluctuations. Daily fluctuations are computed by subtracting the daily minimum from daily maximum. Radiation and rainfall is always contemplated as monthly sum values.

2.1 Comparison of REMO with Meteonorm

In a first step REMO climate data for Aberporth, as one example location, was compared with weather data derived from the Meteonorm weather database. The monthly values of the 30 year REMO dataset are plotted as box plots in Figure 1.



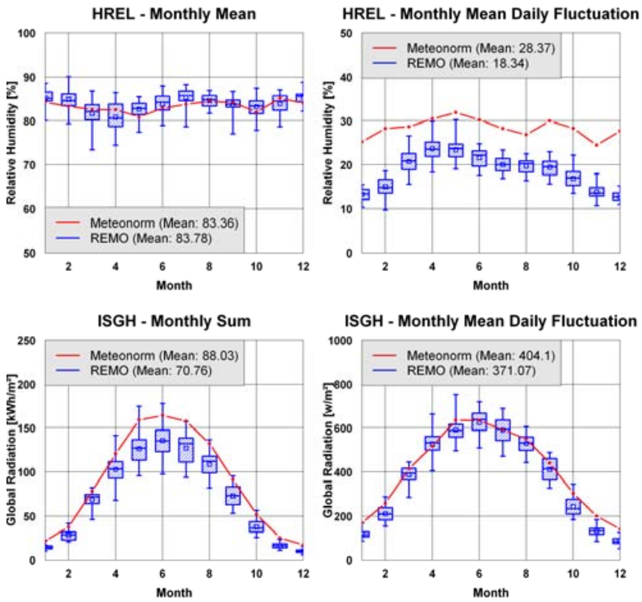
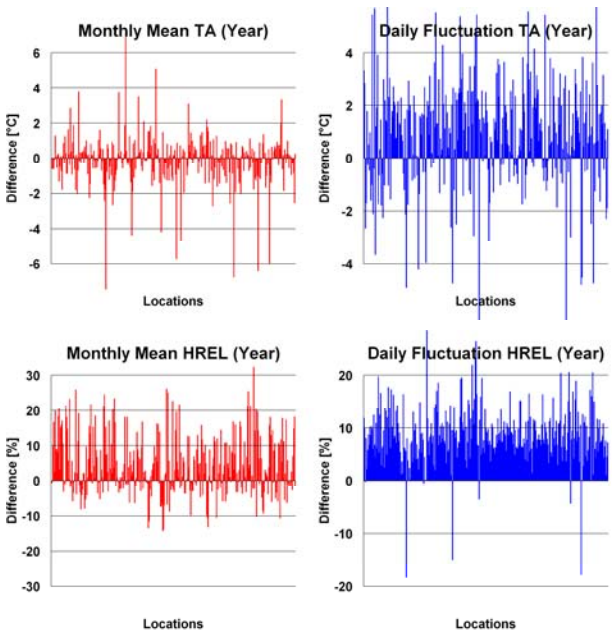


Figure 1 Comparison of REMO and Meteonorm climate data for Aberporth

The box plots show the distribution of the 30 years of the REMO data. For the monthly means of temperature and relative humidity the means and medians of the boxes fit well with the Meteonorm data. Tough the monthly means of daily fluctuation differ. Measured monthly mean global radiation sums are under predicted by almost all thirty year averages for almost all month. Contrary the daily fluctuation is represented quite well in the summer month.

To check if there are general deviations, temperature, relative humidity and global radiation differences of REMO and Meteonorm data for all 300 locations are shown in Figure 2. Differences are represented as measured value from the one year data sets minus mean value of 30 years simulation data.



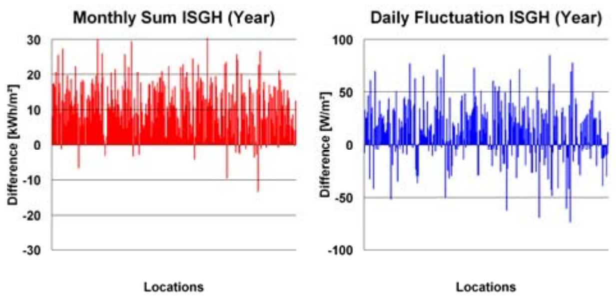


Figure 2 Deviation of REMO data from Meteonorm climate data

The air temperature shows an expected distribution with over- and under predictions uniformly distributed. There is no systematic deviation between the air temperature of the REMO 1960-1990 data and the Meteonorm one year datasets.

Over all locations the average difference of the monthly mean temperature is -0,1°C. The average difference of the daily fluctuations is 0,9°C. In contrast the daily fluctuations of the relative humidity show clear systematic deviations with an under prediction of the modeled mean relative humidity. Only six locations show a negative difference of measurement and simulation. Monthly mean of global radiation shows also significant differences between the REMO and Meteonorm data. Especially the total sum of global radiation is systematically under predicted by the regional downscaling model.

Similarly the other climate parameters were treated. The average values and standard deviations over all locations are listed in Table 1.

Table 1 Average (mean) and standard (sd) deviation of REMO 1960-1990 from Meteonorm climate data

Para-meter	Deviation monthly mean		Deviation daily fluctuation	
	Mean	sd	mean	sd
TA	-0,1°C	1,4°C	0,9°C	2,0°C
HREL	4%	9%	9%	5%
ISGH	11 kWh/m²	7 kWh/m²	13 W/m²	27 W/m²
ILAH	1 kWh/m²	7 kWh/m²	-22 W/m²	6 W/m²
RN	-19 mm/M	41 mm/M	0,3 mm/h	0,3 mm/h
WS	-0,2 m/s	1 m/s	1,9 m/s	0,8 m/s
CI	0,12	0,08	-0,16	0,07

Systematic deviation is assumed where the absolute value of the mean is higher than the standard deviation as is the case for daily relative humidity fluctuation for example.

In general global radiation tends to be modeled too low. This could be linked with the cloud index, which also shows systematic deviation of monthly mean. Apart from that daily fluctuation shows more likely a systematic deviation. To confirm these statements, some climate parameters are compared with measured long time climate data.

2.2 Comparison of REMO with measured long time data

A comparison of measured climate data for 18 locations is performed for some parameters. Thus errors due to only one data source can be excluded. The long term data was downloaded from http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data.cfm [4] and combined to long time data sets to allow the described comparison.

The differences of monthly mean values and monthly mean of daily fluctuation show similar results. Also the temperature suggests having a deviation, thus the model under predicting the real measured mean temperatures. One cause here might already be a climate change effect, as the modeled climate data set is from 1960-1990, the measured data set is from 2002 to 2011.

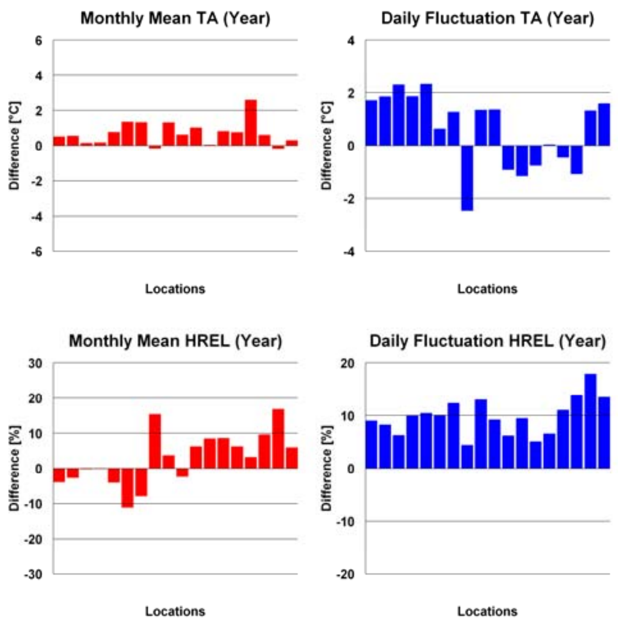


Figure 3 Deviation of REMO data from measured long time climate data for air temperature and relative humidity

The deviation of global radiation could also be confirmed. The only parameters that could not be compared with long time weather data were atmospheric counter radiation (ILAH) and cloud index (CI). Apart from that the statements made in Table 1 could be approved.

3. Generic building

After comparing the modeled climate data with other climate datasets, a generic church (see model in Figure 4) was created, representing an average church in Europe. Therefore 15 churches all over Europe were compared and means of length, width, height, form, material and glazing area etc. were formed.

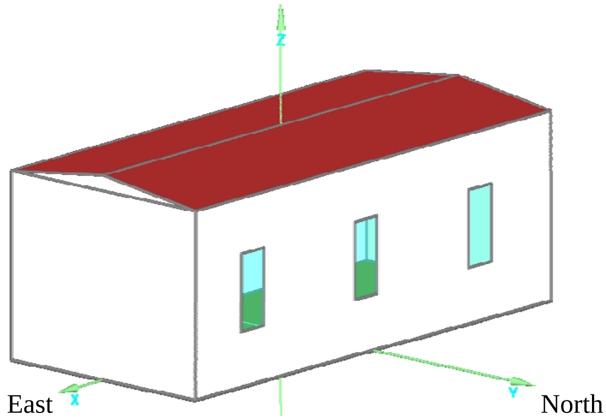


Figure 4 Generic church

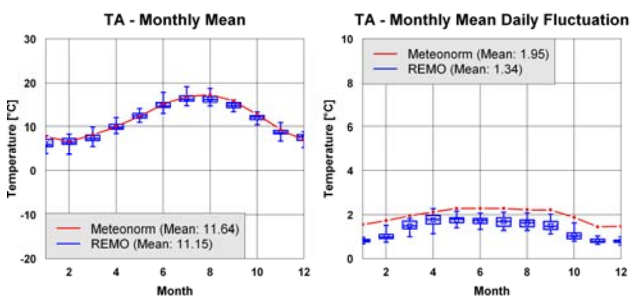
Table 2 Building parameter generic church

Height	18,4 m
Length	46,9 m
Width	21,4 m
Wall material	Stone
Thickness wall	1 m
Roof	Gable roof
Glazing area	126 m²

For this generic church the inner temperature and relative humidity was computed, using the REMO 1960-1990 and the Meteonorm datasets as outdoor climate input parameter. In this manner the influence of the differences of the two datasets on the simulation results could be investigated.

3.1 Comparison of inner climate conditions

As in Figure 1 the results of the determined inner climate conditions were compared. Thereby the focus was also on monthly mean values and on monthly mean of maximum daily fluctuations. In a first step the inner climate of the generic church localized in Aberporth was simulated.



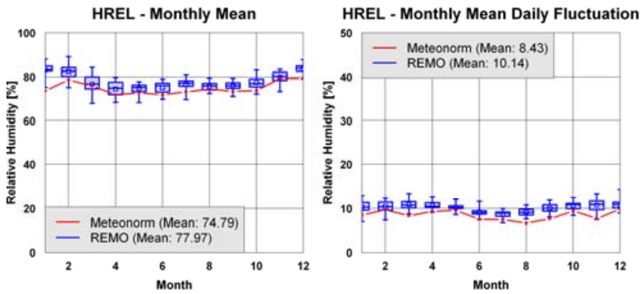


Figure 5 Simulation results calculated with REMO and Meteonorm climate data for Aberporth

Comparing Figure 5 with Figure 1 illustrates the impact of the outer climate on the inner climate conditions for the generic church in Aberporth. Due to heat and moisture buffering effects of the 1 m thick stone wall, the differences of daily fluctuation of inner temperature and relative humidity are diminished. The slightly increased difference of monthly mean temperature may be caused by the lower global radiation of the REMO climate data. In turn the lower temperature affects a higher relative humidity.

As in chapter 2.1 it is checked if these are general statements. Therefore temperature and relative humidity differences of the simulation results for all 300 locations are shown in Figure 6. Additionally the average values and standard deviations over all locations are listed in Table 3.

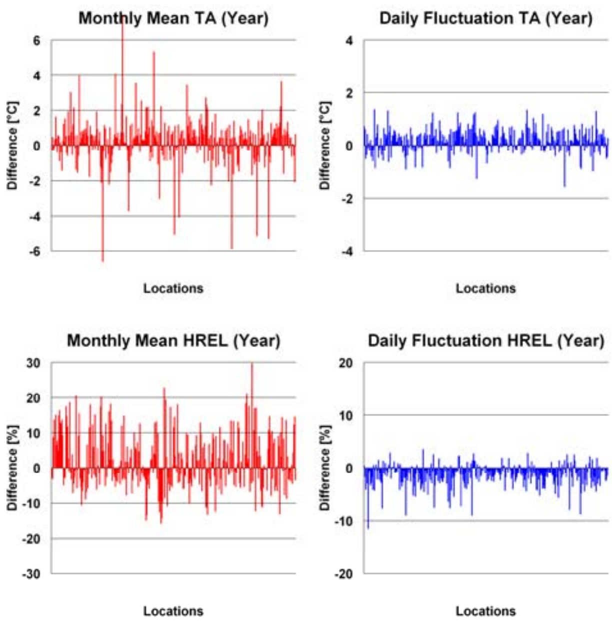


Figure 6 Deviation of simulation results

Table 3 Average (mean) and standard (sd) deviation of simulation results

Para-meter	Deviation monthly mean		Deviation daily fluctuation	
	mean	**sd**	**mean**	**sd**
TA	0,3°C	1,4°C	0,2°C	0,4°C
HREL	1,9%	8,1%	-1,4%	2,1%

It is noticeable that the deviation of monthly mean temperature rises from -0,1°C for the outer climate data (see Table 1) to 0,3°C for the indoor conditions. This phenomenon may be caused by the lower global radiation of the REMO data which induces lower solar gains especially from the windows. The impact of these higher inner temperatures on the relative humidity inside the building is a decrease of the deviation of mean relative humidity from 4% for the outer climate to fewer than 2% for the inner conditions.

The average of daily temperature fluctuations descends from 0,9°C to 0,2°C, the average of relative humidity fluctuations from 9% to -1,4%. The reductions of these deviations are caused by the massive stone walls which balance the daily peak-to-valley value. Interestingly the deviation of the daily relative humidity fluctuation for the inner climate is not systematic.

It can be summarized that the buffering effects of the massive stone wall diminish the differences between the REMO and Meteonorm climate data. Due to the lower global radiation of the REMO data, the mean temperature inside the building is marginally lower.

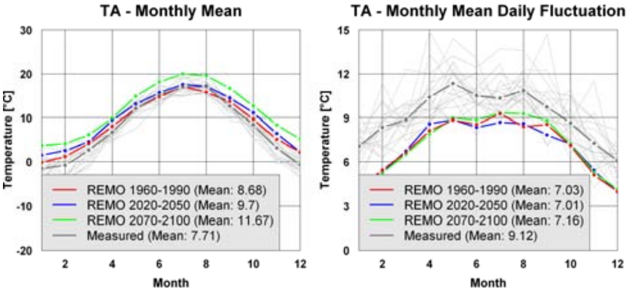
3.2 Future climate changes

To assess the impact of climate changes on the indoor conditions simulation results for the periods 1960-1990, 2020-2050 and 2070-2100 are compared. Thereby the example of the climate location Roggersdorf in Germany is chosen for this paper because there is measured long time weather data available for this location

3.2.1 Outdoor climate

The climate change in the 21st century is modeled by REMO on basis of the IPCC scenario A1B which describes a future world of rapid economic growth, global population that peaks in mid-century and declines thereafter. The group A1B in the storyline A1 is distinguished by its technological emphasis which is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end-use technologies [5].

To show the expected development of climate parameters temperature, relative humidity and global radiation for the periods 1960-1990, 2020-2050 and 2070-2100 are plotted in Figure 7. Additionally the runs of measured long time weather data for the years 1991-2010 are added.



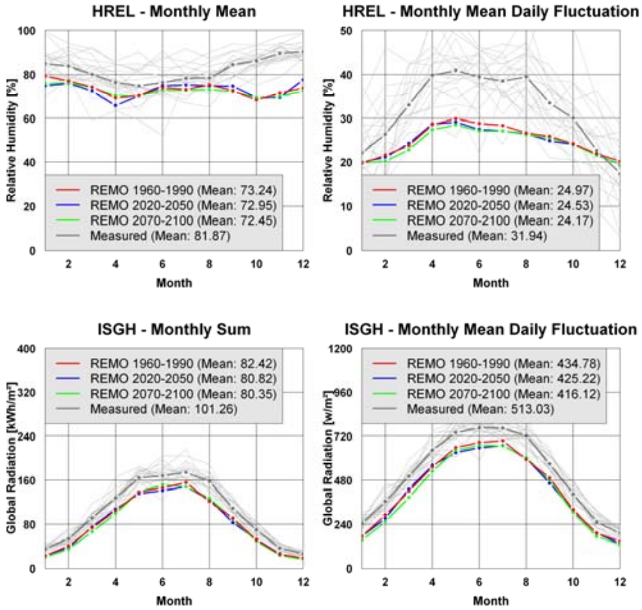


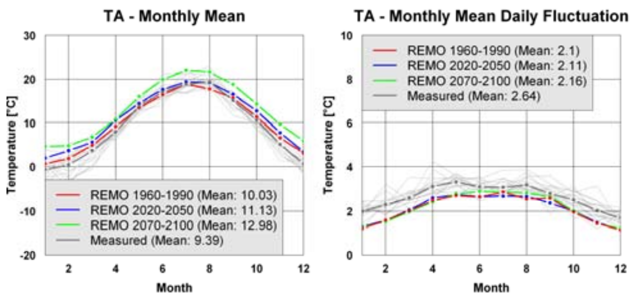
Figure 7 Comparison of REMO 1960-1990, 2020-2050 and 2070-2100 climate data and measured long time weather data for Roggersdorf

Except the temperature, which is predicted to rise around 3°C until end of this century the changes of the other parameters seem to be marginal compared with the differences between REMO and measured data. As shown in Figure 2 and Table 1 the deviations determined for Roggersdorf are not unusual. Only global radiation lies outside the range of mean ± standard deviation.

In the following the impact of the climate change on the inner conditions of a heritage building is investigated.

3.2.2 Inner climate conditions

As in chapter 3.1 the inner conditions are simulated using the defined generic church. Additional to the modeled climate data for the periods 1960-1990, 2020-2050 and 2070-2100 the simulation was carried out with the measured long time weather data for Roggersdorf.



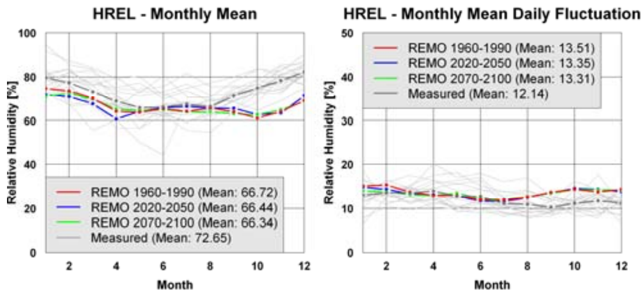


Figure 8 Simulation results calculated with REMO and measured climate data for Roggersdorf

The differences between REMO and the measured climate data are diminished by the buffering effects of the massive building. But there remains an average temperature difference of 0,6°C between the simulation results on basis of the measured weather data and the REMO 1960-1990 data.

Due to the lower global radiation and the lower temperature fluctuation of the REMO data the daily temperature fluctuation inside the generic church is lower than the daily fluctuation calculated on basis of the measured weather data.

The climate change modeled by REMO affects the mean temperature inside the building while the daily temperature fluctuation and the relative humidity nearly stay the same.

4. Conclusion

The contribution of this paper was to validate modeled climate data by comparing with average and measured climate data and to derive predictions for changes in the indoor climate of heritage buildings due to climate changes in the 21st century.

The comparison of the modeled REMO data with measured and average climate data showed a good representation of mean temperatures but systematic deviations for other parameters. Especially the systematic underestimation of global radiation affects the simulation results in hygrothermal whole building simulation. Furthermore short time fluctuations on a daily basis show very often systematic deviations. These fluctuations are often the most critical ones for the assessment of acceptable climate conditions for cultural heritage buildings. Therefore a deeper understanding of the found systematic deviations on the simulation results for the conditions inside buildings is required.

In a first step this was conducted by applying the modeled as well as the measured exterior climate data sets to a generic building. The under prediction of global radiation in the climate model affected the mean temperature inside the simulated generic church lightly. The massive construction of the generic building indeed diminished the impact of differences in climate data.

Generally the simulation results showed a strong dependency on the outer temperature. Therefore differences in mean temperature caused temperature differences inside the building. As the climate change modeled by REMO mainly implies an increase in temperature the effect on the inner climate of the generic church was also an increase in mean temperature.

It is necessary to continue simulating and analyzing the climate change effects of the 300 locations all over Europe. Then detailed statements about the impact of the expected climate change in the 21st century can be made. Furthermore local deviations are to be investigated. Therefore map plots could be an adequate way to show spatial differences between the REMO data and measured or average climate data.

Yet another interesting approach is a more detailed analysis of the simulated inner climate conditions containing overheating frequencies, mass of condensation water or thermal comfort.

The analysis showed, that even with the limitations due to differences between simulation and measurement, it is possible to analyze climate change effects on real buildings. Especially in cases where hygrothermal interaction is one key phenomenon, hygrothermal whole building simulation is required. But also the climate data set needs to be a physically consistent data-set. Therefore it is not recommended to use climate data achieved by statistical down-scaling.

Further work is required on understanding the differences between modeled and simulated exterior climate in detail. The implications these differences have on the analysis of cultural heritage buildings need to be fully understood, before in-depth conclusions can be drawn about measures to prepare cultural heritage buildings for a coming change in climate.

5. Acknowledgements

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6. References

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