Pilot study on indoor climate investigation and computer simulation in historical museum building: Amerongen Castle, the Netherlands

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Abstract

The indoor climate is one of the most important factors contributing to climate-induced damage to the building materials and cultural collections of a monumental building. The Dutch monumental building - Amerongen Castle, and the collections housed in it show severe deterioration caused by inappropriate historical indoor environment. Assessments of the indoor climate, especially on the room temperature and relative humidity, are necessary to analyze the causes and impacts of climate change. As the building was flooded in year 1993 and 1996, extra attention is paid to investigate the effects of flooding to it. This pilot study was aimed to identify the buildup linkages between the known past, historical data on indoor environment and indoor climate performance in the building through simulation based-prediction. This paper focuses on the methodology of indoor climate investigation from the past to the current situation. A hypothesis was developed on backcasting-based prediction simulation which can be used to identify the accepted historical indoor climate where during those times there probably was no damage to the building and the collection. A simulation method based on heat, air and moisture transport is used with the HAMBase program. The computer model representing the Grand Salon of Amerongen Castle was calibrated by comparing real measurements to simulation results. It shows that the differences were only to the minimum of -1.8°C and maximum of 3.2°C. The data for the historical outdoor weather files was obtained by interpolating outdoor ancient climatology constructed by MATLAB. Based on archival research, indoor thermal history was gathered as input for the profiles used in simulation. Further, the calibrated computer model can be used to simulate past indoor climate and investigate the process of the deterioration of the room and the collections mainly due to the fluctuation of indoor temperature and relative humidity. At the end, the climate related damages of the building from the past to current situation can be described and documented.

Keywords: *historical building, backcasting simulation, indoor climate, temperature, relative humidity*

1. Introduction

There will be changes in building demand in the near future as building profession may shift its focus from new construction to maintenance and refurbishment of existing buildings (Kohler and Hassler, 2002) including historic buildings. Furthermore, it has become apparent that since the last decade, research on environmental conditions in historic buildings, mainly in museum and archival buildings, is in great demand (Pavlogeorgatos, 2003). On the other hand, there is an increase of research interest in the climate change effects and its impact on cultural heritage. Some of the successful European researches concerning this area are amongst others Noah's Ark (Sabbioni et al, 2006; Sabbioni, 2009), Engineering Historic Future (Cassar, 2005), Climate Change and the Historic Environment (English Heritage, 2008), and the on-going Climate for Culture (Kilian et al, 2010). These studies were concentrated on the damages of cultural collection and built heritage due to the macro-scale outdoor changes caused by human impact and pressure, pollutant as well as climate of the environment and the micro-scale of indoor changes such as building usage, system use, collection displayed and indoor climate of the building. Therefore, it is important to understand the performance and behaviors of the built heritage during their past indoor conditions, as well as under current climate and future scenarios.

Previous studies have shown that historic buildings may not withstand the rapid changes of outdoor and indoor climate due to the different acceptable level of indoor climate condition either for aging building elements and collections of artifacts or the requirements of people comfort condition. These changes create a risk for the built heritage by increasing or decreasing the occurrence of damage on both a short and a longer timescale. Therefore, historic buildings will need a proper conservation approach to safeguard nation's cultural resources and to preserve cultural heritage. To carry out efficient conservation and preservation activities, it is important to know the risk of deterioration and damages to the building fabric and its materials as well as interior moveable collections. There are a number of factors which caused these deteriorations.

Furthermore, Sabbioni (2009) highlighted in a well known research, the Noah's Ark European project, that there are still gaps to be filled when it comes to safeguarding the built heritage. Those gaps are (i) deterioration of historic buildings and archaeological landscapes studied on past or present term time scales and (ii) the importance of novel climatic factors that affect buildings on a longer timescale.

Therefore, this pilot study was aimed to build up linkages between the known past and historical data on indoor environment and indoor climate performance in historical buildings. An investigation over time and computer simulations are used to achieve this.. This is essential as it is hypothesized that the investigation on past indoor environment can identify the accepted historical indoor climate during which time there was probably no damage to the building and its interior. Further, with the exposure to short and long term environmental changes, indoor climate and building usage, the deterioration process can be studied. At the end, the climate related damages to the built heritage from the past to the current situation can be described and documented for the selected cultural collection and historic building.

In this paper, HAMBASE simulations of heat and moisture on selected rooms of Amerongen Castle (Figure 2) are performed. The rooms were represented in a computer model in which the Grand Salon was the main subject (Figure 3, 4 and 5). This room was chosen because it housed a very important wooden cabinet by Jan van Meekeren (1658 – 1733). Over times, severe deterioration on this wooden cabinet occurred, caused by improper indoor climate. This leads to subsequent phenomena such as mechanical damage due to fluctuating temperature and, more important, resulting relative humidity. Therefore, the Hambase simulations are important to obtain the distribution of indoor temperature and relative humidity. These simulations will then be used in a future investigation to analyse the climate-induced damage of the cabinet. Calibration of the model is performed by simulations and comparisons with real measured data of several years.

In Section 2 of the paper, the description of indoor climate in old buildings and its importance are given. The research methodology, the building and the computer model descriptions are described in Section 3. In Section 4, the interesting part on ancient climatology and past indoor climate data are described. The calibration of the computer model and the validation of the simulations are compared with the measurements in Section 5. This section also contains the results of the simulations exercises. The paper ends with a discussion (Section 6) and the conclusion (section 7).

2. Indoor climate for the historical building and cultural collections

In general, the quantities that are used to describe the indoor climate in buildings are temperature, humidity, lighting, air flow and its quality as well as noise levels in an occupied room. These factors will give effect to people's comfort and the quality of the building. Therefore, a building with a good indoor climate is most important. However, old and historical buildings usually will be facing problems of poor indoor climate. Previous studies have shown that the older buildings may not withstand the rapid changes of outdoor and indoor climate as there is a difference between a person's indoor climate needs and the collections needs. The cultural collection has been in the building since the beginning and should sustain in another hundred years or more, this is not comparable to the thermal comfort of people who live in the building. Therefore, the quality of the indoor climate in old and historical buildings needs to be based on the requirements of the collections rather than the requirements considered important to human thermal comfort.

Having mentioned the overall indoor climate parameters, temperature and relative humidity are the most important in the context of preservation and conservation of cultural collections - as temperatures and relative humidity are the dominant parameters in microclimate. So any incorrect value of them - whether too low or too high - will create a risk for the collections which further be the agents of deterioration for the collections.

Old buildings have survived centuries and within this period, they have been facing a lot of changes. Especially outdoor climate changes such as flooding and higher precipitation. It is often the case that the indoor climate is directly influenced by the outdoor climate. As time flies, these changes and influences are predicted to further worsen the deterioration process to the buildings as well as to the collections. It is hoped that studies using the backcasting approach will lead to an understanding of the likely accepted indoor environment in the past.

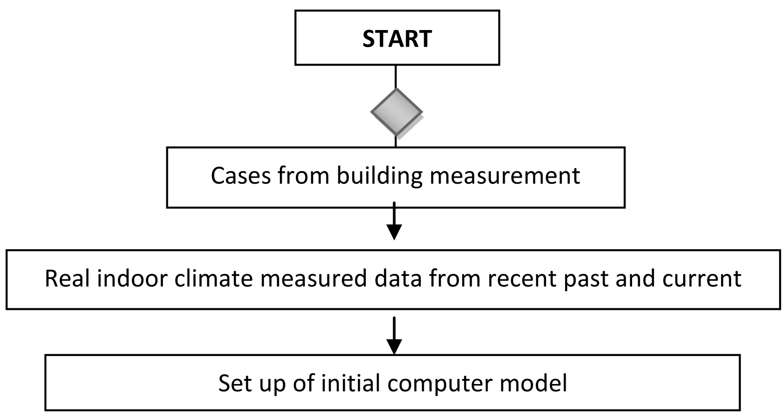
Research and experience have proved that the building envelope, components and interior of the older and historical buildings may not withstand the changes of the indoor environment. Cassar and Taylor (2004) and Taylor et al (2005) did a research on natural ageing of a book/paper based collection due to the effect of indoor environment from past and historical scenarios. Further, from their findings, predictions about future risks to the historical books are identified. The approach of their research was as follows; (1) investigation on the building's past indoor environment through archival research, (2) simulations with Energy Plus software, (3) observation of the indoor environment of the building and, (4) identification of the rate of deterioration based on analytical calculation.

Blades et al (2006) on the other hand examined the hygrothermal conditions of historical building fabrics, mainly masonry walls constructed with stone and bricks. The approach of the research was on heat, air and moisture effects and a thermal and energy model. The effects of flooding these walls were identified by using a wetting and drying projection model as well as simulations with three different baseline periods; 1970 (past), 2020 (near future) and 2080 (far future). The results show that during 1970s to 2020s, there was and will be little effect of moisture on the wall while in 2080, external dry wall starts to appear and reduce the possibilities of mould and algae growth.

Therefore, it is concluded that indoor climate investigation is important for historical buildings so one can understand the exposure of certain indoor environment parameters on objects and building's lifetime, can measure the rate of predicted deterioration from the changing indoor environment, can track the scenarios and situation right back to the accepted indoor environment of the historical building as well as demonstrate the effect of indoor and outdoor changes on heritage items. Computer simulation is one of the methods which can support this comprehensive investigation and the deliverable results can be used to predict what the future risks will be for built heritage and cultural collections.

3. Material and methods

Figure 1 is a flow chart which shows the methodology of the indoor climate investigation and computer simulation. The following information will describe each stage in detail.



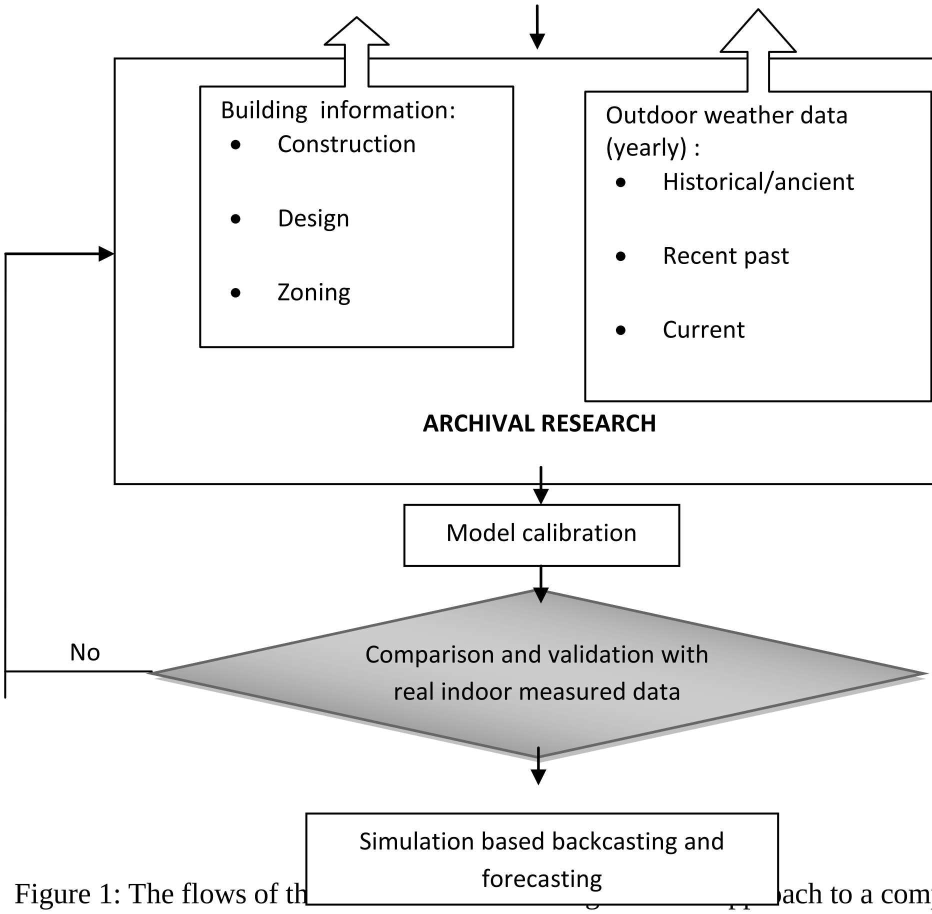


Figure 1: The flows of th… …ach to a computer simulation

The flow starts with the selection of the case study. The selected building must undergo real indoor climate measurements for at least one year. Input such as the external climate data, building size, shape, construction materials, orientation, glazing system, ventilation and heating/cooling system are required to predict the internal indoor climate, especially on temperature and relative humidity. As this research deals with historic buildings, a considerable amount of knowledge of hygrothermal properties of the materials, fabric and content is important. The focus will be the response of the external and internal wall to both external and internal environment in the selected zone.

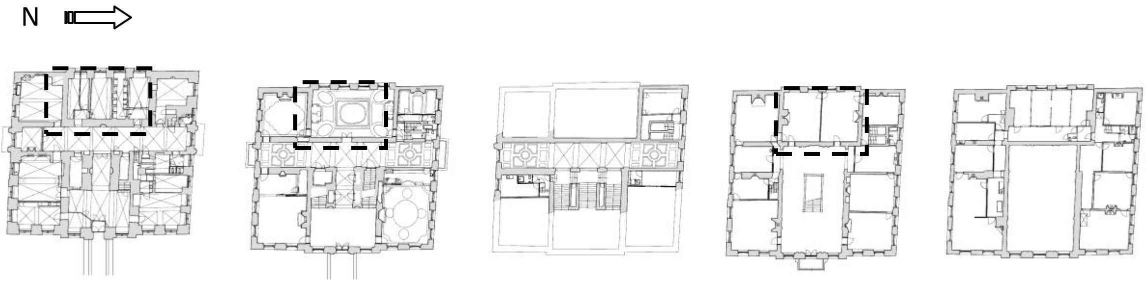
4. Building's description

Museum Amerongen Castle was built in the period of 1674 – 1680. It is located in the southeast of Utrecht province in the Netherlands. Other than the aesthetical and historical value of the building, there are many valuable collections inside it that need to be preserved. However, due to its historical time horizon, it is expected that climate-induced damage will be the main factor of decay not only to the building components and materials but also to the moveable collections inside it. Furthermore, in 1993 and 1996, the entire basement of the castle was flooded by the Lower Rhine river (Figure 2b). The indoor climate of the building was getting worse from these floods which led to an inappropriate museum environment. The building and the collections are subjected to the high risk of rapid deterioration and decay.

The four-storey building was constructed by solid masonry wall with various thicknesses, varying from 1.5m to approximately at 0.7m at the second floor. The shape of the building is rectangular (Figure 33) and it has characteristic various ceiling heights; the basement at 3.963m, the ground floor at 5.384m, the mezzanine at 2.22 m and the first floor at 4.767m (Figure 4).

(a) (b)

Figure 2: (a) Amerongen Castle and (b) the entire basement of the building was flooded twice from the nearby Lower Rhine river in 1993 and 1996



(a) **(b)** **(c)** **(d)** **(e)**

Figure 3: The floor plans of the building; (a) basement (b) ground floor (c) mezzanine floor (d) first floor (e) second floor. The dashed line boxes indicate the selected zones for the simulation exercises and where the red box in (b) shows the Grand Salon, the focus of this pilot study.

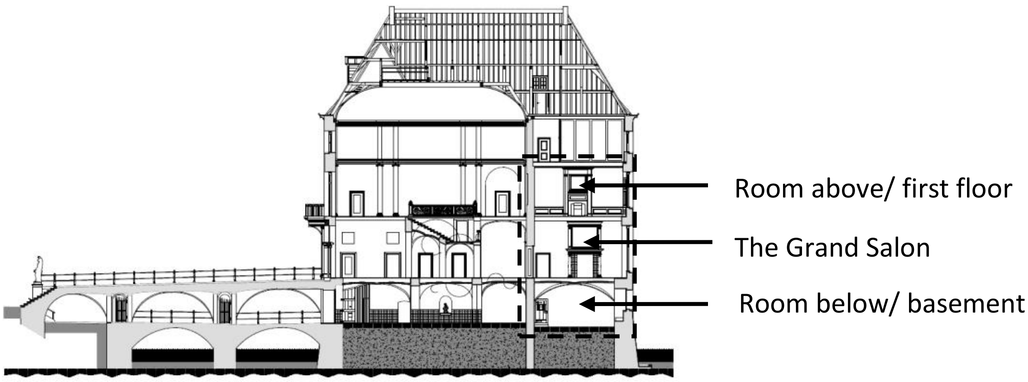
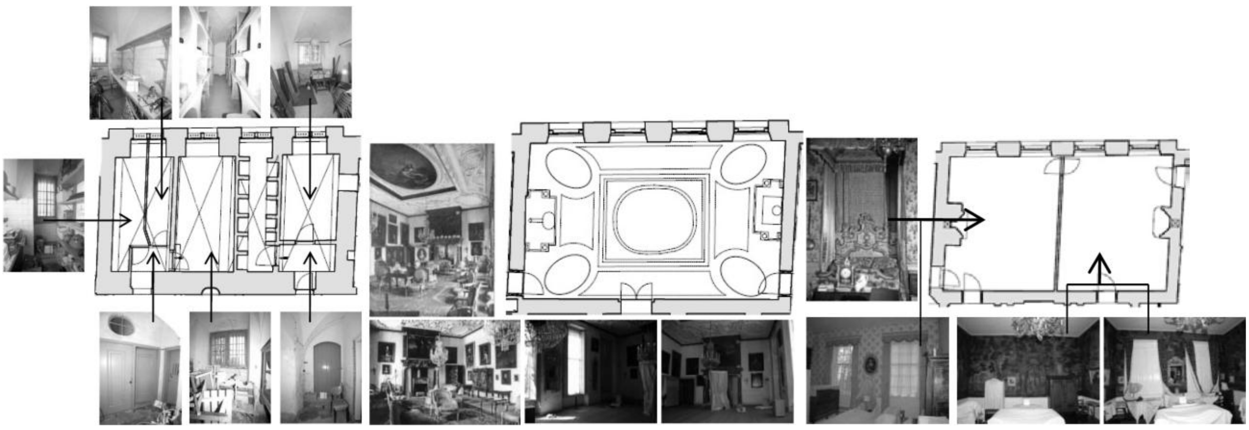


Figure 4: Cross-section of the building showing the location of the rooms constructed in the computer model by the dashed line box.



(a) (b) (c)

Figure 5: The floor plans used in the construction of the initial model; (a) the selected zone in the basement is divided into several rooms; (b) the Grand Salon at ground floor and its environment over time; (c) the selected zone at 1st floor with the Lodewijk room on the left side and the resident room on the right side.

This research was concentrated on the Grand Salon and its environment (Figure 5b). As mentioned previously, the room was constructed in the computer program Hambase to investigate the thermal environment of the room. It was included the inconvenient microclimatic conditions in the Grand Salon such as incorrect indoor temperature and relative humidity and their effects to the building fabric and the valuable objects inside it. System used and activities in the room were also identified. Table 1 shows the description of the Grand Salon and its adjacent room with the same indoor enclosure located at upper floor and the floor below. Information from this table was then used as the input for the Hambase program. Figure 6 indicates how it works.

Table 1: Detailed description of the initial computer model of the selected rooms

Location	**Room identification**	**Installation**	**Function**	**Materials and construction characteristics**
Basement (Zone 1)	S10, S10a, S10b, S11, S12, S13, S13a	-	Resident and staff room	• Consists of 4 small adjacent rooms with a total volume at 396m^3 • External masonry wall with thickness from 3.0m to 1.0m and internal wall of 0.14m • Floor in contact with sandstone h constant ground temperature • Enclosed with internal adiabatic wall and ceiling • Some part of the internal wall finished with hard-baked tiles • Single glazing windows with no internal blinds
Ground floor (Zone 2)	Grand salon (B08)	Originally open fire place and replaced with mobile humidifier and dehumidifier	Museum	• Consist of one big room with volume at 582m^3 • External and internal masonry wall with thickness from 0.85m to 0.70m • Enclosed with internal adiabatic wall, floor and ceiling • Fully height single glazing with internal curtain and wooden shutter • Timber flooring
First floor (Zone 3)	Lodewijk room (107)	Originally open fire place and replaced with mobile dehumidifier	Museum	• Adjacent to Zone 4 but with different profile and usage • Volume at 264m ^{3} • External masonry wall with thickness 0.67m and internal wall from 0.73m to

				0.25m • Enclosed with internal adiabatic wall, floor and ceiling • Fully height single glazing with internal curtain • Timber flooring
First floor (Zone 4)	108	Originally open fire place and replaced with radiator	Resident	• Adjacent to Zone 3 but with different profile and usage • Volume at 236m^3 • External masonry wall with thickness 0.67m and internal wall from 0.73m to 0.35m • Enclosed with internal adiabatic wall, floor and ceiling • Fully height single window glazing with internal curtain • Timber flooring

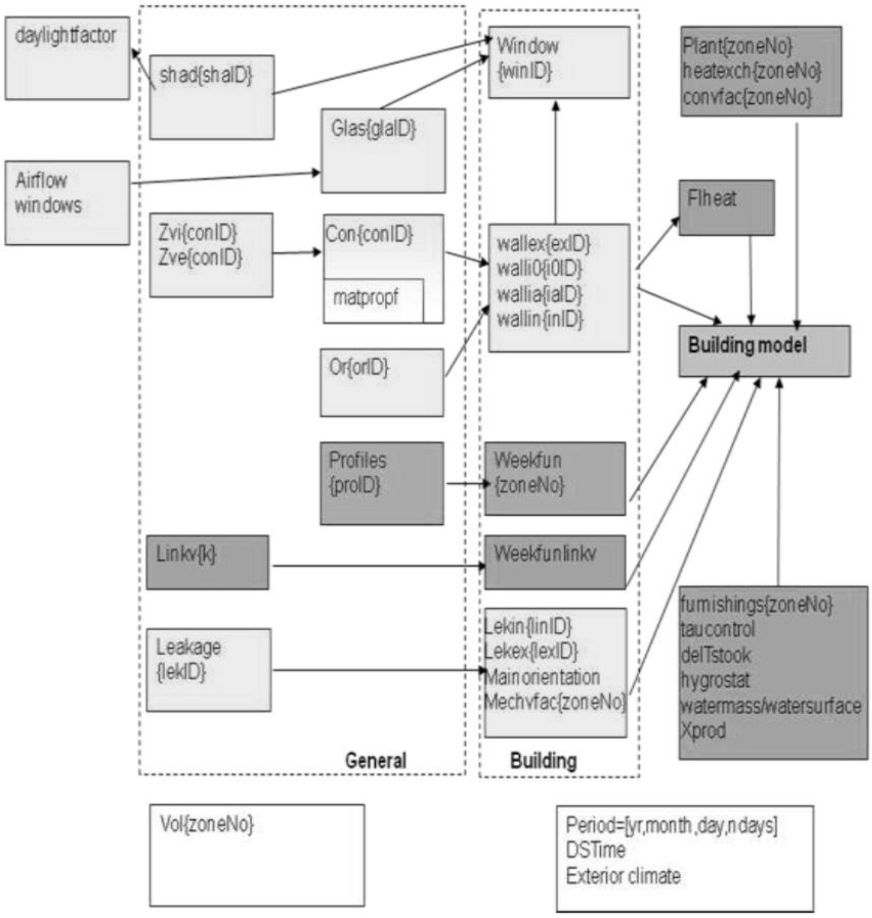


Figure 6: The general structure of input to construct the computer model in Hambase (de Wit, 2009)

5. Historical data on outdoor weather and indoor climate

The lengthy historical record in consistent time period can only be found in the UK in the database of HadCET (Historical Central England Temperature Data). Together with the Hadley Model, the output can be estimated for the period from 1100–2100 CE (Brimblecombe et.al., 2008). So, to conduct a similar research in other parts of Europe would be of interest. So far, apart from the UK, the Netherlands has a similar database called Ancient Climatology Data, thanks to the Royal Netherlands Meteorological Institute (KNMI).

The complete overall ancient climate database which can be found from the official KNMI website is recorded based on a complete integration of the synoptic meteorology after 1847 and climatological networks since the first observation from 1612 to 1615 (Geurts and Engelen, 1983). Then, on June 1981 research on historical instrumental observation of the weather data officially started at the KNMI and consequently the calculation was used to process the historical readings of temperature (Engelen and Geurts, 1983).

At KNMI, the database of the ancient climatology data for Utrecht can be obtained for the years 1881 until 1896. It is acknowledge that this non-instrumental data is not completely recorded or measured. Figures 7a below shows the example of the distribution of outdoor temperature of Utrecht province in January, 1881. During this period, the observation of complete meteorological data was tabulated in 7 different time scales; 200, 600, 800, 1400, 1800, 2200 and 2400s. However, for the correction and conversion of the outdoor temperatures and relative humidity, they were only recorded during 4 time scales at 600, 800, 1400 and 2200s. However, these distribution patterns are only applied for the ancient climatology of Utrecht for the years of 1881 until 1890. For the years 1891 to 1896, the meteorological data were tabulated in 8 different time scales; 200, 500, 800, 1400, 1800, 2200 and 2400s. For the outdoor temperature and relative humidity, the data were recorded only in 3 time scales; 800, 1400, 2200s.

To carry out a simulation over a year, it is normal practice for the climate files to be in hourly values for the whole one year period. Based on the above explanations, it is questionable that the backcasting simulation can be carried out to investigate the indoor climate of the Grand Salon during those periods. Therefore, the ancient climatology data needs to be interpolated to hourly data for each year. Furthermore, to be consistent with the availability of the recorded data, it is necessary to choose the data within the same time scales. So, the interpolations of the ancient climatology data were done based on the same three time scales throughout 1881 to 1896; 800, 1400 and 2200s. The following description will further elaborate on the interpolation and construction of the ancient climatology data.

5.1 *Interpolation and construction of the ancient climatology data*

The interpolation will be calculated based on the hourly data which are available from the existing hourly climate data from the years 1971 to 2005 (recent past files). On the other hand, the available ancient climatology data for the years 1881 to 1896 (ancient files) were formatted in excel files before they were converted into *.dat* files, so they can be used in the MATLAB platform. Please keep in mind that all these ancient files will be saved on a yearly basis. In general, the MATLAB interpolation function will balance the smoothness of the missing data in the ancient files with the recent past files. MATLAB® is a high-level language and interactive environment for algorithm development, data visualization, data analysis, and numerical computation that enables you to perform tasks faster (The Mathwork, 2004). As mentioned earlier, the simulation used in this pilot study was carried out with Hambase program. The MATLAB code was integrated with the Hambase program and that was the main reason why the interpolations of the ancient weather files were constructed with MATLAB.

The data in the ancient files are based on 3 time scales and the interpolation will estimate the values that lie between these known data points and match them with the unknown missing data from the recent past files. Moreover, it is fortunate that the ancient files from KNMI have a meteorological data set that involves wind directions, wind pressure 0.1 kgf/m2, temperature in 0.1 degree Celsius, daily precipitation, surface air pressure in 0.1 mm column of mercury, cloud cover in tenths and relative atmospheric humidity in percents. Therefore, it can be said that these ancient files are good enough to be the basis of the interpolation due to the reasonable data provided.

To start the interpolation, the climate files of the recent past and ancient past files are stored in the structured array BAS. By typing BAS in the MATLAB command window, together with other functions, the input can be checked and changed. For the recent past files, the meteorological data that already stored are; (1) diffuse solar radiation [W/m2], (2) 10 x air temperature outside, (3) direct solar radiation (plane normal to the direction)[W/m2], (4) cloud cover(1...8), (5) 100 x relative humidity outside, (7) 10 x wind velocity and (8) wind direction(degrees north).

For the ancient files, the structure of the data are as tabulated as; (1) year, (2) month, (3) day, (4) hour, (5) temperature in 0.1 degree Celsius, (6) minimum temperature in 0.1 degree Celsius, (7) maximum temperature in 0.1 degree Celsius, (8) cloud cover in tenth and (9) relative humidity in percents. After all initial data have been completed and generalized; the interpolation will be done on a yearly basis.

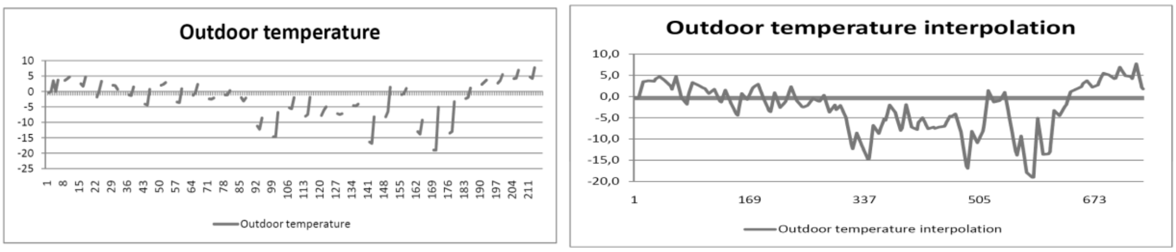
First, load the complete all ancient files (for example here *mt8196* file) and state the selected year that needs to be interpolated, for instance 1897. With the command of *nhours=8760 + 24*leap*, the incomplete climate data in this year will be interpolated into 8760 hours which are the hourly values throughout one year. The *24*leap* is calculated to take into account whether or not the year is in the leap year. A further consideration is the monthly arrangement; *mon=[31, 28+leap, 31, 30, 31, 30, 31, 31, 30, 31, 30, 31],*and the day arrangement; *day = 1 : mon (month).* Further steps will be the instruction of arranging the data yearly, monthly, daily and the climate data.

To make sure that the interpolation for the ancient climate is based on the recent past climate files, with the function of; *m = [0, 1, -1, 2, -2, 3, -3, 4, -4, 5, -5, 6, -6, 7, -7, 8, -8, 9, -9, 10, -10, 11, -11, 12, -12];* the interpolation processes will search the same value at certain time within the same ratio of the given available data in the ancient climate file. For instance, in 1 January 1881, the cloud cover at 800 was 5. So, in the weather file of 1971 to 2005, also at 1 January, the data will look at the same value of cloud cover at 5 at any time which fall in the same value of 5. This can be one hour earlier or later or at any suitable time. The data will be stored as *n* value as; at which year, and at which time. The calculation keeps going on for the next day until 365 days of comparing the ancient climate data with the available data in recent past files.

Then, to interpolate the temperature data for the missing hours, with the function of *interpl (xp, yp, xpi)* where *xp* = the hour, *yp* is the temperature given at those hours and the *xpi* are the interpolated temperatures. The same calculation will be used for the interpolation of relative humidity with references made from the saturated vapour pressure value.

The next step is to interpolate the solar radiation based on the calculated value of the cloud cover in tenth. First, the data will use the given cloud cover value in the selected historical weather data. The cloud cover value must be available for every day at the same frequency. In this calculation, the frequencies were 3 measurements per day. The value will be referred to the hourly cloud cover measurement from the recent past climate files whichever the data was available to fit in between the missing data. For example, on 1 January 1881, the cloud cover was available at 800s and the value was 5. So, in the weather file of 1971 to 2005, also on 1 January, the data will find the same value of the cloud cover at 5 maybe at the same time of 800s, or either earlier or later than that but with the same value of cloud cover as in ancient climate files. From the chosen time, it is assumed that the ratio of the solar radiation will also be the same so this value will be used in the historical weather file. However, if there are two values found in the different years, the solar radiation will be interpolated by using half of the earlier year, the other half from the latter year and the average value of the overlapping period between the two years.

By having interpolated temperature, relative humidity, cloud cover and solar radiation, finally complete hourly ancient climate files for the years1881 to 1896 are successfully calculated (Figure 7).



(a) (b)

Figure 7: The comparison between; (a) incomplete and (b) interpolated outdoor temperature in January 1881

5.2 *Investigation on past indoor climate and environment*

The aim of this ongoing research is to link the historical and known past data on indoor environment and the indoor climate with their likely effects and impacts on the building and the collections inside. In general, the building and the collections would be in an acceptable state with an ideal condition at their initial time until they are exposed to short term and long term of environmental changes. Therefore, by investigating (i) Amerongen Castle's previous usage, (ii) activities and (iii) systems, this may provide brief pictures on how the indoor climate – of the room – would be in the past. (Table 2). Any changes on these 3 factors will further change the indoor climate of the room. For instance in the Grand Salon, historically the indoor climates were different when it was used for normal gathering with people just sat on the chairs with sedentary activities, open windows with natural ventilation during summer than a normal gathering and closed environment, with open fire heating during winter.

Table 2: The investigation on past indoor climate of the Grand Salon mainly based on archival records and oral communication

Date/Year	Description of the castle and cabinet	Heating regimes of the castle / grand saloon
1748	Inventory showed that many furniture and cabinets have been brought into the castle. During the same era, there was Jan van Meekeren who was the leading cabinet maker (1658 – 1733). Therefore, it is assumed that the cabinets were brought into the castle during this period. However, no records were found to support this data.	Fireplace with stove
1795 – 1879/80	Male members of the family left to England followed by the female. It is assumed that one of the cabinets was brought out of the castle to England. The castle was not fully occupied for 85 years by the family and only operated/managed by the workers.	The castle was unheated
1879 – 1880 **(+- after 85 years)**	The castle was again occupied. It is assumed that one of the cabinet was brought to the castle again.	Open fire in the Grand Salon and electrical heating in some parts of the castle.
1884	A series of modernization activities in the castle, especially in water supply, heating , electricity and plumbing.	
Early 20th century	Modernized central heating	Grand salon remained unheated and not really used It was only heated once a year for annual meeting in November
1940 – 1977	The grand saloon was not used anymore from 1940	Grand salon remained unheated
1976/77	The castle was sold to Utrecht Museum Foundation as a mixed household (some parts were converted to museum and some parts still remain as dwelling). Open to public as museum.	Grand salon remained unheated
1982	The foundation changed to the Foundation of Amerongen Castle. Open to public as museum.	Grand salon remained unheated

2003 – 2010	Restoration works	Grand salon remained unheated

The heating system will always create a lower RH and a dry condition. Therefore, if the room frequently used the heating system when it was occupied, and was left unheated during unoccupied times, the fluctuation of the temperature/RH between these two scenarios may have contributed to the climate related damage to the cabinet. But, Table 2 shows that there was no significant usage of heating in the Grand Salon. It can be said that the Grand Salon was in a stable cold and unheated climate.

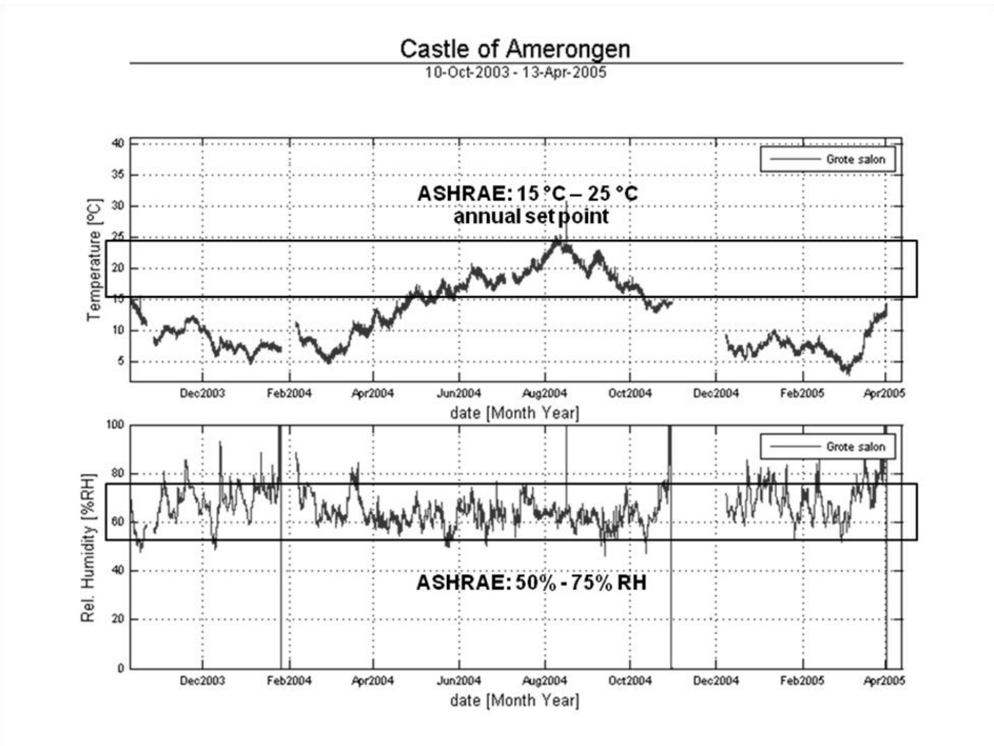


Figure 8: Real data on indoor temperature and relative humidity in the Grand Salon from October 2003 to April 2005. Indication of the ASHRAE requirements for the objects and collection are also shown in this figure.
Source: Smulders and Martens (2008)

Further, Figure 8 above shows the recent past indoor climate of the Grand Salon for the duration of December 2003 to April 2005. It shows that the indoor temperature falls within the acceptable range during summer, but most of the time it falls outside of the accepted range. However, the indoor relative humidity was within the acceptable range, but not during winter. During this time, it was recorded that the coldest outdoor temperature was -9.1 °C in 2005, -7.4 °C in 2004 and -5.3 °C in 2003. What is expected to happen during the ancient time for instance in 1881 where the outdoor temperature was at -19 °C, far below the current past data? Therefore, based on; 1) the construction of the ancient climate data, 2) investigation on past indoor environment of the Grand Salon and, 3) simulation-based-prediction, it is hypothesized that the accepted historical indoor climate can be identified.

6. Calibration of the computer model and results

The results and discussion produced in this paper were based on the simulations done by the initial computer model of the three selected zones in Amerongen Castle. The model calibration is achieved by adjusting the available parameters which will influence the sensitivity of the model to match up with the real data measured in the building. It includes the volumes of each zone, construction types of the building (ie thickness, materials used, glazing types, etc), the orientations, the type of the walls, ceiling and floors and the profiles of the zones/building. The architecture and construction of old buildings are often complicated and thus subject to many simplifications due to computational limitations. The input for the constructions was mainly based on the previous documentation, especially records on the building floor plans and from observation of previous researches and works. Corrections have also been carried out, for instance the U-value of the glazing. This is due to the observation from the photo which shows that there were layers of internal shutters or curtains being used in the building (Figure 9). As historical information were normally not sufficient enough, estimations but with proper argumentation and judgments will always be an option. For an example, the results from this ongoing research are to be used further to predict the climate-induced damage of the historical wooden cabinet. From real photos, archival research and oral investigation, it is concluded that the cabinet was standing in the Grand Salon most of the time. Based on these findings, it is estimated that the long exposure of the wooden cabinet to the indoor climate of the Grand Salon would be the major cause for its damages. Therefore, it is important to carry out this research partly on the backcasting simulation to identify the unknown historical indoor climate in the Grand Salon.

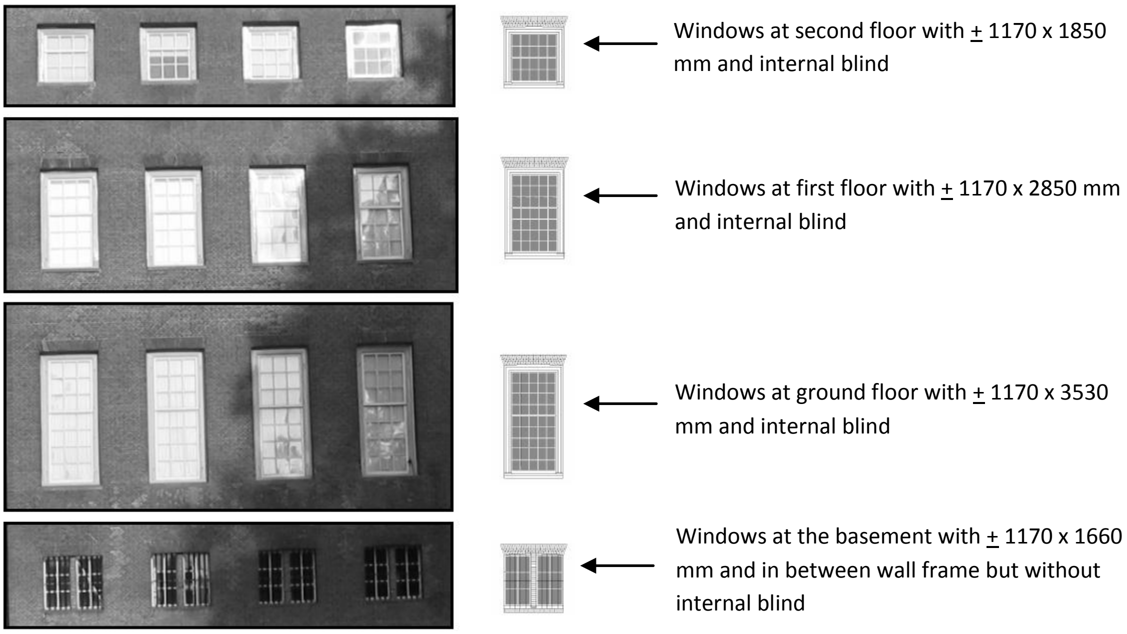


Figure 9: Thermal transmittance of the windows is taking into account the Uv of the glazing, the wooden frame and the correction for the effect of the internal blinds. The surface area of the glazing which excludes the wooden frame area is also identified as part of the sensitivity of the computer model and correction of the Uv have to be carried out based on the data observed from this figure.
Source: Ritmeijer (2007)

6.1 *Comparison of measurement and simulation*

Comparison with real measured data is essential in setting up the initial historical properties of the simulation model. In constructing this initial model, the baseline conditions were taken from the one year measurement done in 2004. The one year measurement and ongoing working model is shown in Figure 10. The comparisons of the indoor temperature from the measured and the simulated data are shown with little disagreement, especially in March but it was still an acceptable pattern of distribution between them especially during spring and summer. As the simulations were done based on synoptic weather file which was also so-called as forecasted climate condition, the disagreement was believed due to different real situation of the weather during that time. For example, the real situation was a sunny, bright day and clear sky during that time but in the synoptic weather file it was recorded as sunny but with higher cloud cover. Often it is the case that the weather files did not really match the real situation of the weather condition. Nevertheless, it is essential that this working model needs a lot more refinement as these are only preliminary results.

Meanwhile, results for the indoor relative humidity as in Figure 11 also show differences, especially on the lowest and highest value of RH level. Based on records and oral evidence, plastering work is covering the original lime plaster ceiling. Wet and humid condition during this work led to a higher indoor RH during January and February and resulted in quite a contradict comparison between the simulated and the real measured data. Other than this, comparison on other months shows also little disagreement but fall within the same pattern and distribution of real measured data except for March. This is the same with the argumentation made on the above discussion as the disagreement of indoor temperature will also give effect to the disagreement of indoor relative humidity.

Having made a comparison between the simulated and the measured data, it shows that this simulation exercise may give promising results, provided that the computer model input will be improved, modified and altered based on better input parameters.

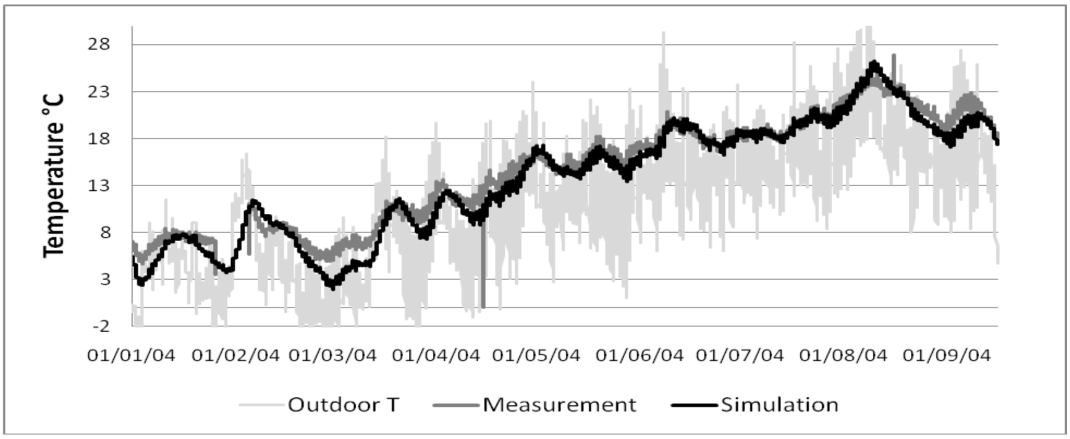


Figure 10: Comparison of measured to simulated temperature values in 2004

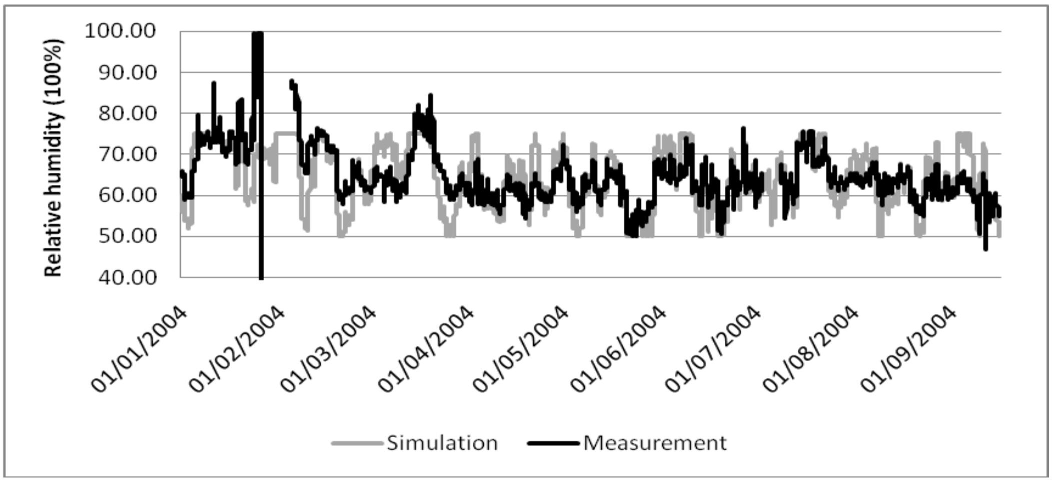


Figure 11: Comparison of measured and simulated relative humidity values in 2004

Research on historical buildings and collection requires all data which are time sensitive presenting historical, present and future time scale with very different time constant. Through simulations different periods can be linked. In order to study the impact of indoor environmental changes on the built heritage, the use of building simulation techniques together with forecast weather data is often necessary. Normally, building performance simulation is a tool which is used to support the designers of modern buildings, newly built or reconstructed, and their building systems. It can be expected that this tool is also capable to predict risks related to changes of the natural indoor environment of historical buildings. This assumption is feasible only if an appropriate methodology would be developed to ensure that modeling and simulation is properly used.

Simulation based prediction will deal with many unknown conditions and only based on estimations and proper corrections which is explained from the above sections. Predictions with proper and concrete evidence are required for the information which is not known precisely but. In combination with complete building information and external historical, recent past, current and future climate data, correct inputs can give good results to predict the historical indoor climate of the building.

7. Conclusions

It can be said that the interpolation of data in MATLAB is a common approach. However, in this research, its usability to construct a complete one year hourly data for historical weather files is exceptional. Researches done by Brimblecombe (2008, 2009) have proven that past weather data can be estimated for the period of 1100 – 2100 CE. However, these data, which are obtained from the Central England Temperature Record (CETR) and the Hadley Model climate data, still remain to be cautious (Brimblecombe, 2008) as estimations were made based on earliest literature with a combination of several corrections for urban heat islands, extraction from the HadCM3 model and calibration against the CETR records. Based on his arguments, it is undeniable that this historical weather data constructed from interpolation in MATLAB is open to discussion. But, yet it still can be a good basis for the preliminary backcasting simulation used in this research.

It is hoped that the computer simulation will lead to an understanding of the likely accepted indoor environment of a historical building. As time flies, changes in outdoor and indoor climate may produce more agents to contribute short and long term risk which further worsen the deterioration process. Therefore, further investigation will be carried out to build up a better methodology to predict the accepted indoor environment. Identification on the most important agent of deterioration due to indoor environmental changes starting from the early stage (which is from the past) can help to mitigate and reduce the risk of predicted damage process in the future. Further the potential adaptation strategies can be proposed for future safeguarding purposes on the selected objects.

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