Chapter 8
Step 7: Defining Climate Specifications

Abstract The starting point when optimizing any indoor climate is knowing what the current indoor climate actually is, understanding how this indoor climate is formed, and if the collection or the building are at risk, and/or if the visitors and staff are (un)comfortable. When it is decided to optimize the indoor climate the first step is to identify what is important to you for the decision at hand.

In this chapter the process of combining collection, building and human needs is described. An optimal climate for collections can be detrimental to the building and/or very uncomfortable to people and vice versa. Examples of new risks resulting from a specific climate control objective are provided.

The process starts by projecting the desired functionality for each room, the climate zones and the current climate in each zone onto a map of the building. Secondly, the collection is divided into collection units, ideally based on objects with similar susceptibility. For each collection unit the relevance of controlling a specific climate parameter is indicated. Then, the values between which the relative humidity and temperature set point and the acceptable relative humidity and temperature fluctuations can be chosen. Examples of an approach for balancing these requirements is given to help explain how this process works in practice.

Keywords Combining collection, building and human needs • Balancing climate specifications • Zoning • Climate specification process

8.1 Introduction

Traditionally climate specifications were provided as a set of six numbers, indicating the set points and acceptable hourly and/or seasonally fluctuations for temperature and relative humidity and the rate of change of the fluctuation in time. These numbers could be found in (inter)national standards, (inter)national loan requirements and easily be copied into the list of requirements made by museum professionals, architects, consultants and engineers. A thorough analysis of the collection's (cultural) values and/or susceptibility was not required. Specifications were based on the best technically achievable climate, on the implementation of climate control systems, and adaptation of the building to the new indoor climate.

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Questions were focused on adjusting the building physics, floor loading issues and hiding possible ducts and pipes from direct sight.

In this publication we work towards affordable, tailor-made, indoor climate conditions for collections and the building. The starting point when optimizing the indoor climate is knowing what the current indoor climate actually is and understand how this indoor climate is formed (Chap. 7: Step 6), and if the collection is at risk (Chap. 4: Step 3); or the building is at risk (Chap. 5: Step 4), or if the visitors and staff are (un)comfortable (Chap. 6: Step 5). The original objectives of the decision (Chap. 2: Step 1) form the foundation for the decision to be made. Within this decision making the cultural values of the building and the collection (Chap. 3: Step 2) form an essential basis. These (cultural) values of the building can be weighed against those of the collection, see Fig. 3.3, which allows a rough analysis of the possibilities for climate control. When the collection is (much) more valuable than the building, the indoor climate can be designed as a preservation environment with an emphasis on relative humidity and/or temperature control. Changes to the building to improve the building physics, or implementation of a climate control strategy, will most likely involve a loss of cultural value. If the building is much more valuable than the collection, then the climate will be aimed at preserving the building values and accepting (some) climate risks to the moveable collection.

Bringing all the arguments into the decision making process and weighing these findings against other ambitions, requirements and boundary conditions is a complex process. In real life the climate specifications depend not only on the cultural values, the susceptibility of the building and the collection, and the comfort requirements, but also on other arguments such as financial and technical feasibility, and the desire to have incoming loans, which often play an important role in defining climate specifications.

Decisions to optimize the indoor climate are regularly based on an individual's intuition: "*I think the climate is fluctuating too much ……. and …… this is not good for the collection……*", a statement that is not very precise and does not really help in guiding a decision. Understanding the indoor climate requires measuring it. The results of these measurements can then be used for an analysis of the climate risks to the collection, the building, or people's discomfort. When climate data is collected digitally, the results can easily be inserted into the risk models for mold, chemical deterioration and mechanical damage (see Fig. 8.5).

Specifying the indoor climate numerically is not easy, but quite necessary. The numbers are essential to design an air-conditioning system and the necessary adaptations to the building's construction. In a museum context, contrary to almost all other indoor environments in public buildings, it is important to control the relative humidity to avoid high or low extremes and too large fluctuations. So (de) humidification capacities need to be calculated. These calculations can also be used to assess the expected energy consumption. After changing the building and/or implementation of a climate control system, the numbers can be used as a reference for climate measurements to analyze the systems' performance.

Fig. 8.1 Low temperatures in this unheated palace in Koeskovo, Moscow during winter time makes the indoor climate uncomfortable to staff and visitors but will help preserving the interiors

8.2 Combining Collection, Building and Human Needs

It is clear that an optimal climate for collections can be uncomfortable to people (see Fig. 8.1) and/or detrimental to the building (see Fig. 8.2). On the other hand climate specifications solely based on human comfort will not always be optimal for the collection's preservation. Some of these negative effects resulting from options to develop single objectives are presented in Table 8.1.

8.3 Zoning

When the building is redeveloped or the museum refurbished the indoor climate often becomes important. To put the theory about the need for a specific indoor climate into practice, it is helpful to see the building's layout as a set of different climate zones. Quite similar to the zoning that many museums have developed to control fire risks or to manage security.

Fig. 8.2 Adding moisture to the indoor climate in winter can result in water running down the glazing and the uninsulated wall

In practice, it is rare that all three climate requirements are equally important for all climate zones in a museum. In Table 8.2 the typical climate zones found in museums are given. Some climate zones, like storage rooms and exhibition spaces are specifically meant to house collections. Offices, are generally designed for human comfort and not for collection preservation. Obviously, in those zones where both staff and visitors are brought together with collections, the indoor climate will most likely be a compromise of an optimum climate for the collection and users.

The zones that are specifically used by people, such as offices, the restaurant etc. require a comfortable climate for people. This means that temperature control is more important than control of the relative humidity. In cold climates this generally means heating of the indoor air, while in warm regions cooling and/or ventilation is required. The relative humidity in these rooms is uncontrolled, free floating and will have large short and long term fluctuations. In collection zones in which human comfort is less important, the control of relative humidity is more relevant. Dry outdoor air will be humidified and humid outdoor air will be dehumidified to maintain a specific indoor relative humidity.

Examples of these special environments are the low temperature storage rooms for highly sensitive materials and conservation heating of storage rooms in humid

Table 8.1 The new climate risks that might result from a specific climate control objective

	Objectives		
Risks to	Collection needs	Building needs	Human needs
Collection		Relative humidity fluctuations increase the risk of mechanical damage to susceptible collections	Heating to increase human comfort in cold climates, increasing the risk of mold and rot
		Allowing low relative humidity in winter will increase the risk of mechanical damage to susceptible collections	Cooling might increase the risk of locally high relative humidity with an increase of biological decay and relative humidity gradients in time and space with an increase of mechanical risks
			High ventilation might cause temperature and relative humidity fluctuations, increasing the mechanical risk to susceptible collections
Building	Control of the moisture balance might cause high relative humidity conditions in cold locations in the building envelope, increasing the risk of mold and rot		Intermittent heating or cooling for human comfort will increase the risk of mechanical damage to susceptible finishes and salt efflorescence due to relative humidity fluctuations
	A continuous lower relative humidity indoors will increase the risk of salt efflorescence, where present		
Human	Low temperatures to reduce the risk of chemical deterioration will make the indoor climate uncomfortable to staff and visitors	High ventilation rates can be uncomfortable to staff and visitors due to draughts	
	Stabilizing the relative humidity by temperature control (i.e. conservation heating) might result in high temperatures and thus discomfort, during warm seasons		

Table 8.2 Typical climate zones found in a museum (These are often similar to the safety zones)

Collection zone	Mixed zone	People zone
Permanent store rooms, typical microclimates such as showcases, cabinets etc.	(Permanent store room), transit store room, exhibition galleries, study rooms, conservation laboratories, photo studio, collection packing area	Foyer, lobby, restaurant, shop, lecture rooms, offices, server room, loading bay

regions (Maekawa and Toledo 2003). Obviously, the requirements for human comfort were insignificant in the decision making for those repositories. It should be noted however that, defining the temperature at which the storage should be kept is a fine tuning process. The objective is to find the optimum temperature balancing the discomfort of staff, researchers and potential visitors. At low temperatures the fine motor skills that are required to handle delicate objects will be reduced, while at elevated temperatures people become physically uncomfortable. To assess the relevance of the need for human comfort it is important to analyze how often staff enter the cold or hot store room(s) and for how much time. Temporary heating/ cooling of the store room can be considered to overcome the discomfort at specific moments when staff will have to work inside the storage room for prolonged times, e.g. to prepare an exhibition.

The biggest challenge is to define the climate specifications of the mixed zones were collection needs are just as important as human comfort. Especially in extreme climates.

In cold climates where the indoor temperature is maintained at comfort levels, the relative humidity will be low and additional humidification is often required for collection preservation. Changing the moisture balance requires careful examination of the building physics. Traditionally the building was fully adapted to this new indoor climate by changing the insulation, infiltration and moisture barrier properties. That these changes resulted in a loss of cultural values to the building seemed to be much less important than the possible deterioration of the movable collection. In cases where the cultural value of the collection is much higher than the cultural value of the building these adaptions can be made without much loss of architectural or historic value. But in cases where the building is of equal value to the collection, finding an optimum for the preservation of cultural values becomes much more difficult.

In hot and humid climates human comfort was traditionally provided by shading and ventilation. This will result in fluctuations of temperature and relative humidity. Reducing infiltration combined with additional cooling will reduce the temperature and often to a certain extent also the relative humidity. But removal of condensate from the cooling unit might require a drain to go through an historic important wall or floor.

8.4 The Process

The process to derive the numerical specifications that describe the future indoor climate, is complicated. It is complicated because the knowledge of different scientific areas needs to be combined without only thinking about solutions to solve the problem. In many discussions about optimizing the indoor climate, the debate narrows down to which option is best. It is important to keep an open mind and to hear all stakeholders involved. Ideally a group of stakeholders comes together to discuss the issues that are involved in finding the optimal climate specifications, based on the balance between preserving cultural values of both building and collection and creating a welcoming atmosphere for visitors and museum staff. Having this discussion in the building that needs to be refurbished, renovated or redesigned will help in having a shared idea of the challenges and possible options. In an open discussion the collection manager(s), the climate engineer, the (conservation) scientist, the building physicist, the contractor, the architect and the climate consultant will have to discuss goals and boundary conditions. In the discussion several themes have to be brought together: cultural values, the collection needs, building needs, human comfort and building physics. Every stakeholder explains what is important to him/her and why, and identifies the boundaries in which the options can be developed (Table 8.3).

Given the level of interests and specific goals of each of the stakeholders the discussion to reach the optimum climate specifications is complex. The conservator and (conservation) scientist will be key in identifying a possible incorrect indoor climate. The curator, director and (restoration) architect will have a view on how the building will be used and designed. The building engineering physicist and the climate consultant engineer will have ideas on control strategies. In the process it is paramount that each of the stakeholders can bring in their expertise. It is advisable to have an independent moderator who can encourage everyone to take part in the discussion and keep focus at the decision to be made. In Fig. 8.3 the complexity of the decision making with this group of stakeholders is depicted schematically. To maintain this focus the discussion leader might ask participants questions that stimulate evaluation, such as:

- Are we focusing on the right issue?
- Do we really understand each other or do we need to backtrack to make sure we are really grounded in what is important?
- What else do we need to consider or investigate to specify the desired indoor climate?

Obviously when thinking about specifications, the options to solve climatic issues will be brought into the discussion too. By talking about options, most likely new risks become relevant which will drive the discussion about the climate specifications. Similarly, when talking about design and use, new options will be developed that in turn will influence the design and/or use of the building or zones. The discussion is not linear and will iterate around these subjects several times before it is clear to all involved what the decision context is.

Table 8.3 The stakeholders with their typical interests and goals

	Function	Typical interests	Goals
Museum	(General) director	Collection/people/budget	Providing a comfortable visit
			Stay within the budget
			Building should look nice
	Conservator	Object/material/ construction	Object(s) preservation
	Curator	Collection unit/object	Object(s) preservation
			Object(s) should be used to tell stories
	Facility manager	Building	Building preservation
			Visitor comfort
			Manageable (climate control) systems
External	Building engineer	Building/zone	Building should be developed to allow a specific environment
	Climate system engineer	Building	Climate control system(s) should be reliable and provide the climate required
	Conservation scientist	Object/building	Finding a balance between object and building preservation
			Providing scientific knowledge and possibly case studies
	(Restoration) Architect	Building/people	Translating the goals from all stakeholders to a realistic plan
Local authorities	Building services	Building	Reviewing the plan (legislation)
	Environmental services	City	Reviewing the plan for environmental impact (legislation)
	(Cultural) heritage	Building/collection	Reviewing the plan for impact on cultural value (legislation)
National authorities	Building services	Building	Reviewing the plan (legislation/ costs/people)
	Cultural heritage	Building/collection	Reviewing the plan (legislation/ cultural value)

To help going through this process it might be practical to critically evaluate floor plans in which the new environmental conditions are projected. On this floor plan the following can be indicated:

- The desired functionality for each room (see Table 8.2).
- The desired climate zones. This can be done by drawing a thick colored line over the floor plan for every zone that is to be separated from the other.
- The current climate in each zone. When measured data is not available the indoor climate can be estimated based on data known for similar spaces or by modeling the outdoor climate coming in.
- The desired indoor climate based on human comfort needs

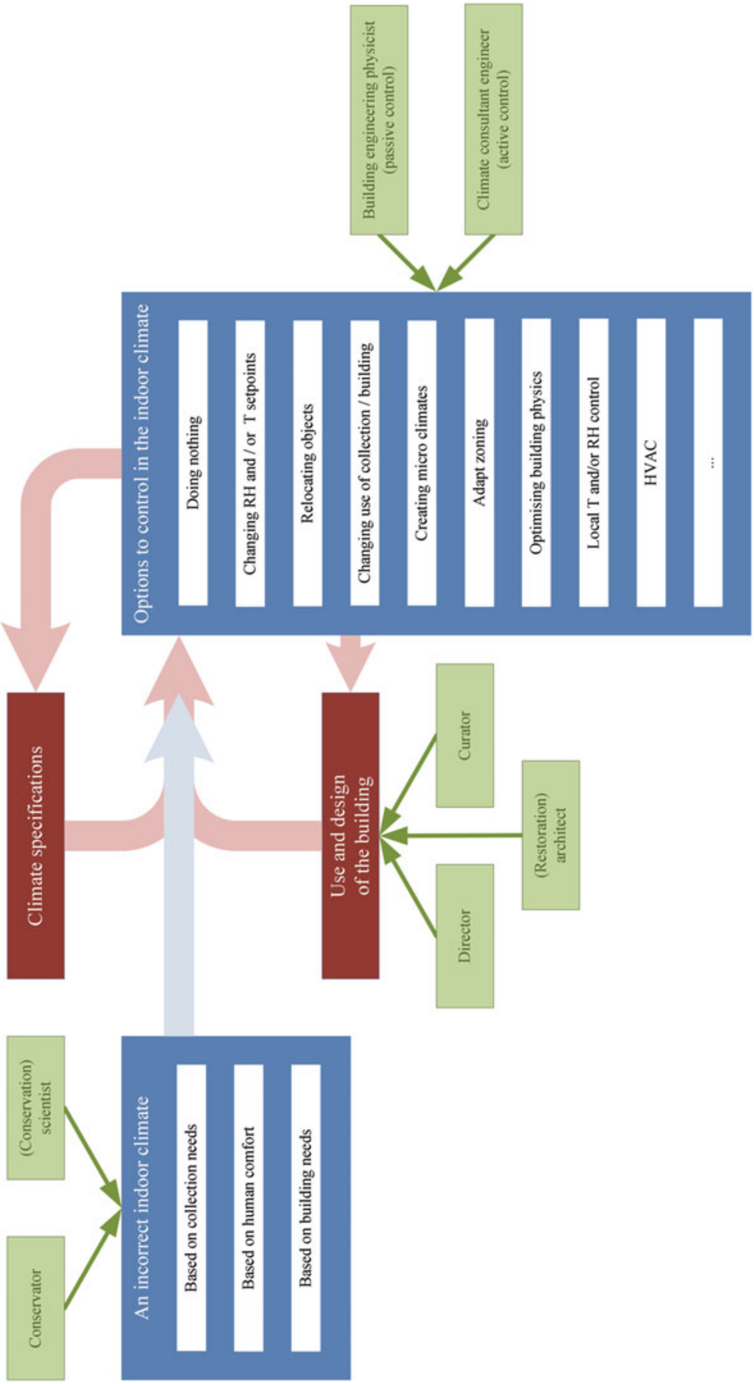

Fig. 8.3 The schematic representation of the discussion and it's stakeholders

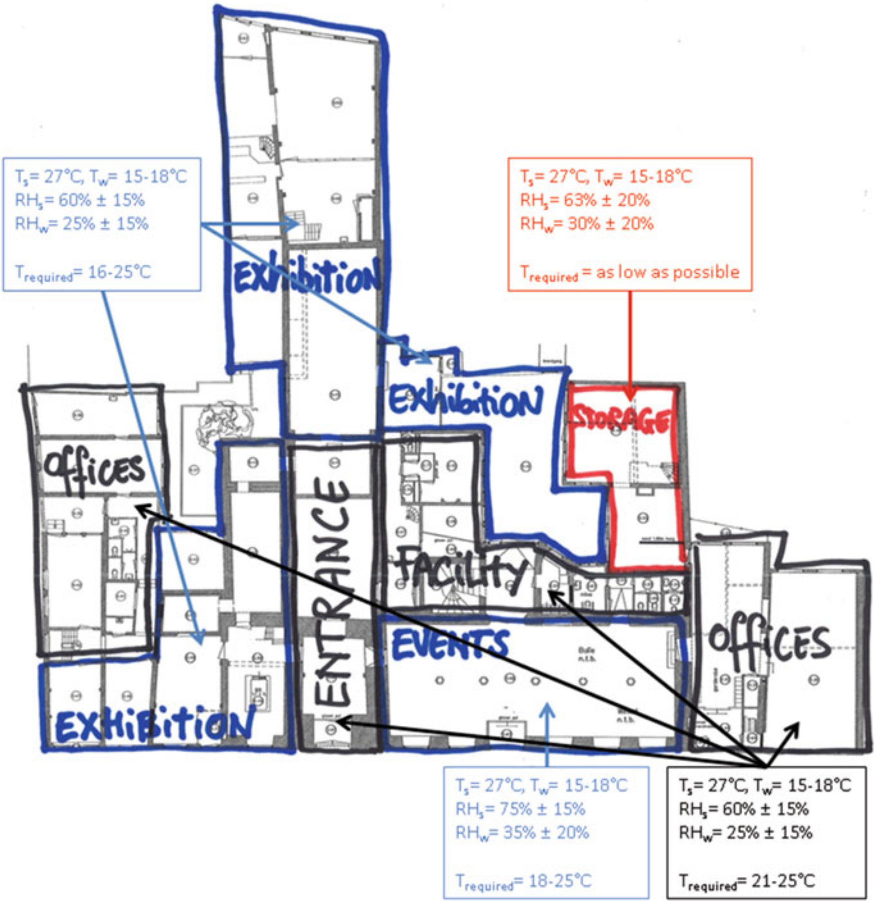

Fig. 8.4 Example of a floor plan indicating different climate zones and the current climate in summer (s) and winter (w) in each zone climate including the desired human comfort specifications

In Fig. 8.4 an imaginary example is provided indicating different climate zones projected on a floor plan of an historic building. The summer climate in the building can reach temperatures of around 27 °C (81 °F), while in winter the temperature indoors depends on the set point of the thermostat. The relative humidity varies greatly indoors due to orientation, isolation and the use of natural ventilation. For the new functions inside the building, exhibition spaces, offices, storage room and event room, the temperature specifications are presented as $T_{required}$. The next step is to define the relative humidity specifications for the zones.

As an example, an imaginary exhibition in one climate zone will be discussed in more detail. Again the process starts with the current climate in the zone. This is ideally known by measurements, but can also be deduced from data in similar buildings or zones with equal physical building qualities. Based on climate data from similar locations, the climate in this zone is expected to be:

	Summer	Winter
Temperature	22–28 °C (72–82 °F)	18–20 °C (64–68 °F)
Relative humidity	55–75 %	35–50 %

For human comfort the desired climate was formulated as:

	Summer	Winter
Temperature	22–25 °C (72–77 °F)	18–21 °C (64–70 °F)
Relative humidity	20–80 %	20–80 %

The imaginary collection that will be present in this zone is: 10 paintings on canvas, 5 wooden statues, 15 works on paper, 2 textiles and 2 bronze statues. The collection is divided into collection units. These units can be based on different aspects. Using type of object, often includes materials and construction results on collection units with similar susceptibility. For each collection unit the relevance of controlling a specific climate parameter can be indicated. In Table 8.4 an example is provided using color codes, in which green indicates not important to control, orange means possibly important to control, while red means important to control.

Based on the specific construction and condition of the most valuable objects in the collection units the desired climate conditions can be given, see Chap. 4, step 3 for more background information. For each collection unit the next step is to numerically define:

- Between which values can the relative humidity set point be chosen?
- Between which values can the temperature set point be chosen?

Table 8.4 The relative importance of controlling a specific climate parameter of the indoor climate for different types of collections

	Temperature*		**Relative Humidity***	
	Set point	**Fluctuations**	**Set point**	**Fluctuations**
10 Paintings on canvas	Small risk of chemical degradation		Small risk of chemical degradation	Risk of mechanical degradation
5 Wooden statues	Small risk of chemical degradation		Small risk of chemical degradation	Risk of mechanical degradation
15 Works on paper	Risk of chemical degradation		Risk of chemical degradation	Small risk of mechanical degradation
2 Textiles	Small risk of chemical degradation		Small risk of chemical degradation	Small risk of mechanical degradation
2 Bronze sculptures			Small risk of chemical degradation	

Green: relatively unimportant to control, *orange*: might be relatively important to control, *red*: is relatively important to control

Table 8.5 The climate specifications for different collection units in an imaginary collection as was specified by an imaginary staff

	Temperature (°C)		Relative humidity (%)	
	Set point	Acceptable fluctuations	Set point	Acceptable Fluctuations
Paintings on canvas	13–25 (55–77 °F)	n.a.	40–55	5–10
Wooden statues	13–25 (55–77 °F)	n.a.	40–55	5–10
Works on paper	Cool	n.a.	45–55	10–20
Textiles	Cool	n.a.	40–55	10–20
Bronze sculptures	n.a.	n.a.	30–60	n.a.

- What are the acceptable relative humidity fluctuations?
- What are the acceptable temperature fluctuations?

In Table 8.5 the climate specifications of this imaginary collection are provided.

The discussion will finally focus on the current climate data that falls outside the desired climate parameters. In this case the temperature in summer can be slightly higher than desired for the collection. So the question will be if some form of cooling is needed, and how is this done within the boundaries of cultural values and finances. Developing options to cool involves thinking about how these options might change the design, the cultural values of the building, or the experience of the visitors. Similarly, if the relative humidity set point should be between 40 and 55 % and fluctuations should be minimized to 5 %, than some humidification is required to prevent the low relative humidity in winter and some dehumidification in summer to reduce the peaks.

Several options should be considered. The first question to be answered is 'how many objects determined the indoor climate specifications?' if this a limited amount than relocation of these objects to a naturally more stable zone can be considered. Often this zone can be found deeper inside the building, because the outside climate generally has less influence on these spaces. Secondly, protection by microclimates might further reduce the need for climate control on a zone level. Changes to the building to reduce the impact of the outdoor climate can also be looked at. In this process it is important to continuously iterate between cultural values and options to optimize the indoor climate. Questions such as, 'what will the climate be if this option is implemented and how will it change the use of the collection, the values of my building, the risks to the building? will help in analyzing the effect of different options.

In this case the three most susceptible paintings can be presented in microclimate boxes, while the others have no risk of mechanical damage due to relative humidity fluctuations of 10 %. The wooden statue that required a maximum 5 % relative humidity fluctuations is presented inside a showcase. The risk of chemical deterioration due to temperature was accepted because the loss of cultural values to the building and the financial implications were unacceptable when cooling of the air is implemented.

So the final climate specification was determined to be:

	Temperature (°C)		Relative humidity (%)	
	Set point	Acceptable fluctuations	Set point	Acceptable fluctuations
Summer	23.5 (74.5 °F)	1.5	55	10
Winter	20 (66 °F)	2	45	10

8.5 A Case Study

Defining the desired indoor climate can take place in two ways. Analysis of the current climate risks can be done by using knowledge about the risks of the past, or by analyzing the material properties of objects. The latter was presented before. In this section the relative humidity specifications are developed based on the historic climate. To define the acceptable relative humidity fluctuations the so-called proofed fluctuation is determined. "The proofed relative humidity or temperature is the largest relative humidity or temperature fluctuation to which the object has been exposed in the past or, alternatively, just the lowest and highest relative humidity and temperature of the past. The risk of further mechanical damage (beyond that already accumulated) from fluctuations smaller than the proofed value is extremely low." (Michalski 2007).

This analysis requires access to climate data over a prolonged time for the location. The grand salon in the Amerongen Castle provides the case study (see Fig. 8.5). In Sect. 10.5 Amerongen Castle is also described.

The grand salon is the most beautifully decorated room of the castle. Here important guests were received, it provides a beautiful view over the floodplains. The room is decorated with a large number of royal portraits, including those of William the Silent, Louise de Coligny, Maurice, Frederick Henry and the King William III. The marble mantelpieces dating from 1684 were made in Dresden. Several beautifully decorated pieces of furniture, among which two cabinets (see Fig. 8.6) were made around 1700 by the Amsterdam cabinetmaker Jan van Meekeren.

Often, the amount of climate data in these kind of locations is limited. Due to the highly valued interiors of the castle, climate measurements were recorded for prolonged periods of time, see Fig. 8.7. Since neither the heating nor the moisture balance were changed in the past decades it is believed that 1 year's data could be used as an indicator for the previous years. Despite the fact that the outdoor climate during this time will have varied to a certain extent.

Analysis of the data indicates that the current indoor climate in the salon could be optimized. A relative humidity distribution of 35–80 %, with an average of

Fig. 8.5 The grand salon of Castle Amerongen with many objects of great national value

Fig. 8.6 The cabinet of Van Meekeren in the grand salon of Castle Amerongen

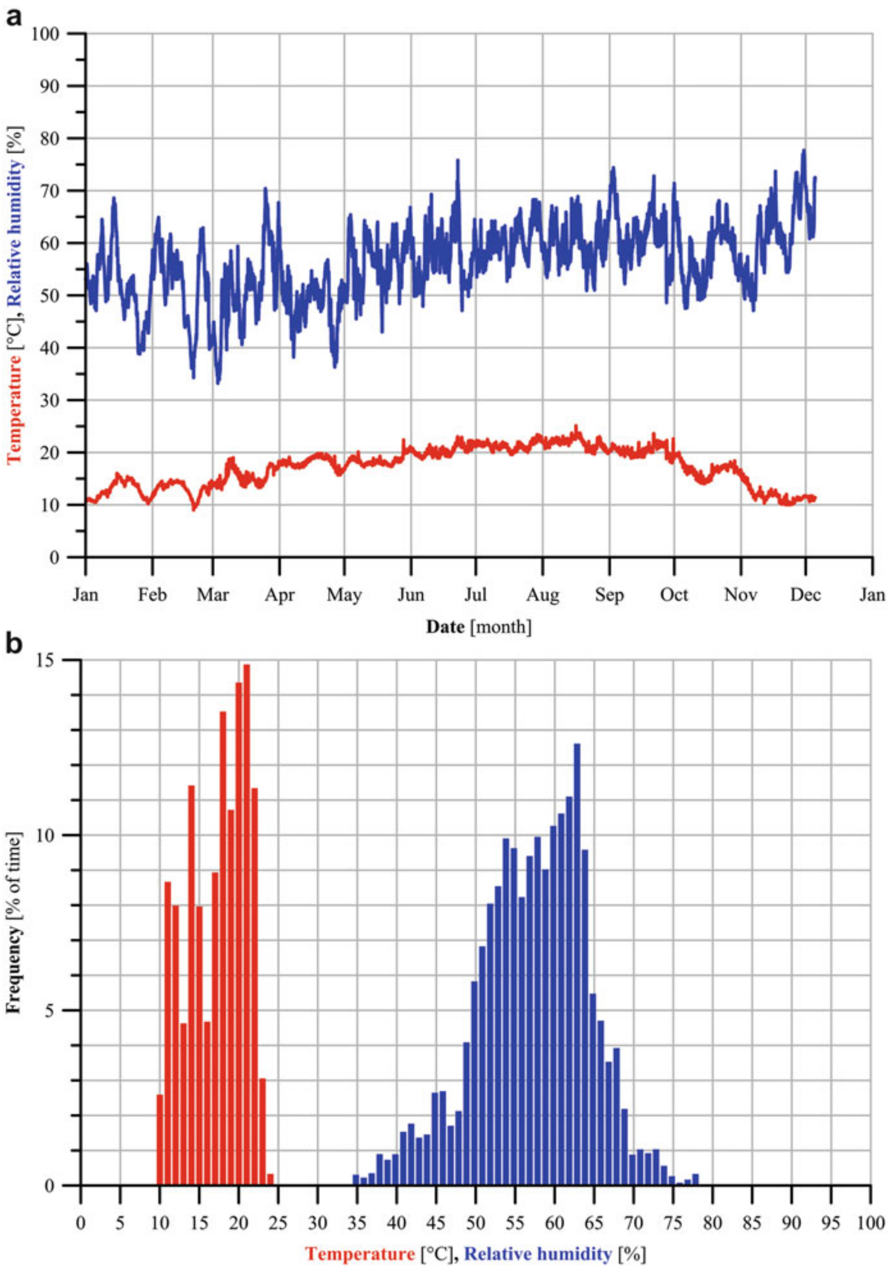

Fig. 8.7 (**a**) Temperature and relative humidity plots for the climate in the salon of Castle Amerongen in 2011. (**b**) the distribution of temperature (*in red*) and relative humidity (*in blue*)

56.4 % and a standard deviation of 7.2 % were calculated. Since climate specifications generally take an overshoot and undershoot of about 8 % of the time into account, to cover for excess climate conditions, relative humidity climate specifications based on this analysis would be: $56 \pm 7\,\%$ without a significant risk of mechanical damage due to relative humidity fluctuations. Similarly the temperature can be specified as $17 \pm 4\,°\mathrm{C}$ ($63 \pm 7\,°\mathrm{F}$). So simply: annual average ± one standard deviation.

Ideally the temperature should be as low as possible to reduce every chemical reaction that takes place within the collection. The Amerongen salon is already quite cold during winter time (~12 °C/54 °F) see the red line in Fig. 8.7a. Chemically unstable materials will degrade significantly faster when temperatures are high during summer times, as can be seen in Fig. 8.8a.

Obviously human comfort in the salon of Castle Amerongen is low. When the climate data for this room is plotted in the Adaptive Thermal Guideline (van der Linden 2006), see Fig. 8.8b, it is clear that it is too cold most of the time. Even though temperatures are too low for optimal visitor comfort, the museum decided that collection needs overrule human needs and the house will not be heated in winter. Similar to most estates managed by the National Trust in England that are either closed in winter or have restricted access (Lloyd 2006).

8.6 Conclusions

Bringing all arguments together and deciding what the indoor climate in a room or of a zone in a museum should be is not easy. The priorities of the institution, values of the building and collection, as well as their needs and those of users, will shape the final specifications and requirements of any climate optimization. Combining technical information about building physics, material science and human behavior with design and cultural experiences requires a process in which very different stakeholders are to be heard. An independent moderator can lead the group of stakeholders through a process in which different types of information is shared, discussed and evaluated, leading finally to a set of 8 numbers that can be used to develop the optimum mitigation strategy.

The result of this step is a table in which for each zone the climate set points and the acceptable fluctuations for relative humidity and temperature are specified for each season.

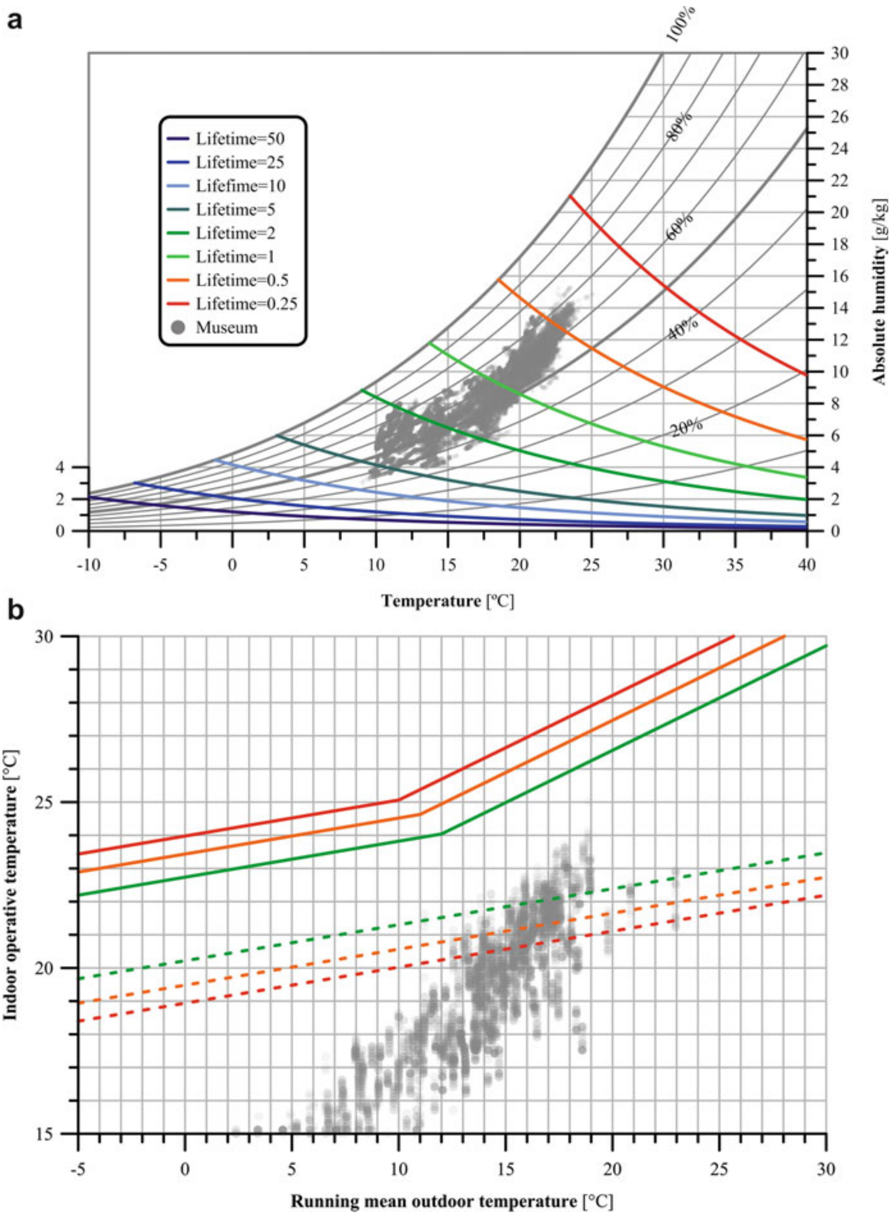

Fig. 8.8 (**a**) The indoor climate for 2011 in the salon of Castle Amerongen plotted in a psychrometric chart showing the *lines* of equal relative lifetimes and (**b**) a thermal comfort assessment of the salon climate during opening hours (09:00–18:00 in 2011)

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