Cultural Heritage Agency
Ministry of Education, Culture and Science

Managing indoor climate risks

Are you facing a project in which the climate will play a role? Are you going to renovate your museum or implement a new climate control system? Then this brochure will be helpful to you.

Introduction

Every museum undergoes small and large changes, often these changes involve the indoor climate. The activities to manage indoor climate risks are often daily museum practise (See Figure 1). In this brochure, 9 steps are introduced to guide you through that process (See Figure 2). These steps are not presented chronologically; instead, they should be integrated into your daily routine and into your decision-making process.

It is essential to utilise the best knowledge and experience available to find the best solution that fits your ambitions, your budget and your organisation. It is a group process, in which stakeholders and external and internal experts should be involved. It requires evaluating and reflecting on the current situation and the possible strategies. The climate needs of the moveable collection are considered, as well as the needs of the building and the people who visit and work inside it. There are no standard solutions; rather, the unique collection and its building direct you to the best, tailor-made, solution for your situation. First it is necessary to formulate the context for this decision-making process: a renovation, an extension or detected deterioration, for example. And also, it is necessary to identify your institute's values and objectives. Especially for larger projects, such as building renovations, it is important to start this process at an early stage.

With limited budgets and the wish to develop sustainable solutions, it is important to focus on more than managing the material aspects of your collection. You can ask yourself how both current visitors and future generations can have as much access as possible to (the value or significance of) the collection. Although following guidelines and standards can give you a sense of security, thinking outside the box and considering your own situation from several perspectives will give you the best possible outcome for your specific situation; from low-tech to high-tech, and with every possible budget.

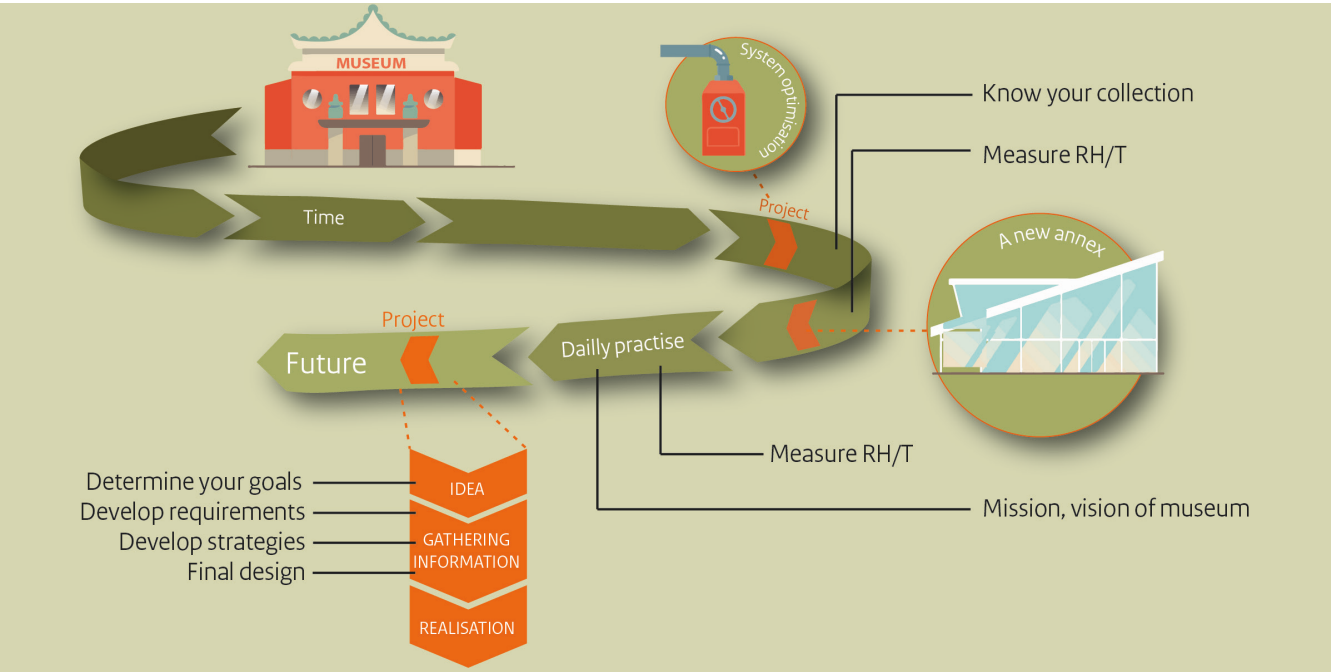


Figure 1: During its lifetime, a museum faces many projects. For each, different types of information are required to make the best decisions. The projects in which the indoor climate plays a key role require information about the institute's goals and possibilities, and these can involve large changes to building, staff and budget.

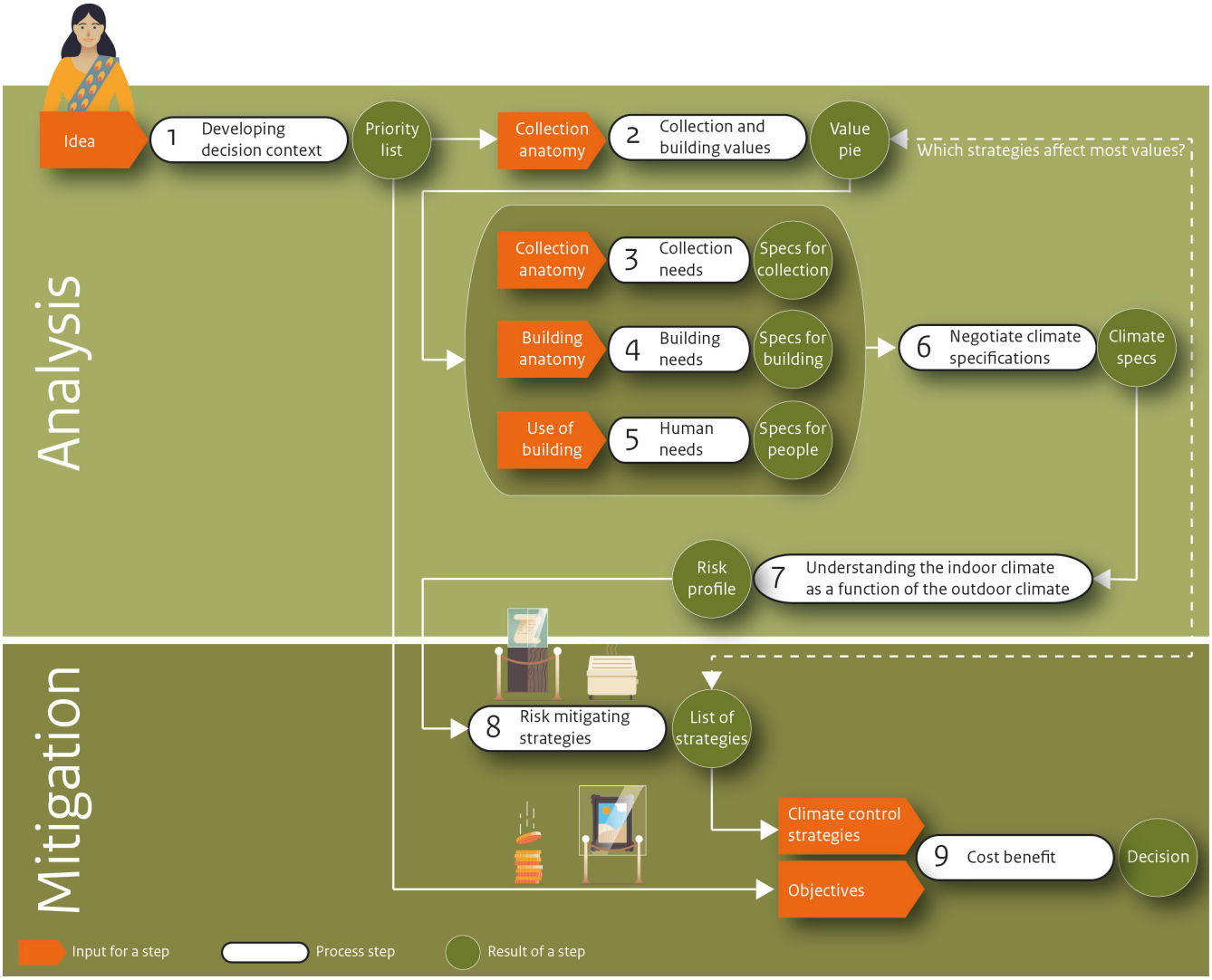


Figure 2: The nine steps of the decision-making process to reach an optimum solution for achieving your goals.

Step 1 – Towards a balanced decision

When you plan to make changes in your museum, the indoor climate might be involved. If that is the case, it is important to look carefully at the decision-making context. Defining the context and the objectives of your museum allows you to lay the foundation on which the next steps will be built.

It can be challenging to realise the ambitions of your heritage institute while taking into account the goals and ambitions of everyone who is connected to the process. It is important to involve stakeholders at an early stage. Managing indoor climate risks is a group process in which preferences, constrains, (cultural) values, policies and regulations should be made explicit by all those involved. The mission statement of the heritage institute is usually a good starting point to define your objectives, although it is often too general. You can ask all stakeholders and experts to contribute with their views. By thinking outside the box at this stage, ambitions become clear without you feeling limited by the options you think you have. General examples of objectives include: to maximise income (or reduce costs); to minimise the rate of deterioration of the collection (preserve collection for future generations); and to give as much access as possible to (the cultural values of) the collection.

Within this context, you can think about what is important for your specific situation and what makes your museum unique. Not only the collection you house, but also the story you want to tell and the building itself, contribute to the sense of place people have when they visit your museum. First consider both the material and immaterial values your museum houses. Then you can prioritise the objectives and you can even think about which objectives might be dealbreakers. In Figure 3 and 4 examples are presented of historic house museums with different mitigation strategies to limit climatic impact on the collection with very different impact on the way the visitor experiences the ‘sense of place’.

At the end of this step, you will have a list of goals that are very important to you and your museum and that somehow will influence the decision or choice that will have to be made.

Figure 3a-b: The Mastboomhuis in Oud-Gastel in the Netherlands is a historic house museum in which the experience value is most important. The interior is frozen in 1995, the year when the last resident died (left). As a result, all preventive measures, like the air handling unit and the air inlets, should be invisible. They are carefully hidden in the chimney (right).
Conservation treatment of objects and materials is aimed at maintaining the condition of the objects in 1995. Flaking paint on walls and ceiling are preserved as a memento of the condition in which the last owner lived.

Figure 4a-b: The Corrie ten Boomhuis in Haarlem in the Netherlands is a historic house museum which tells the story of Jewish people and resistance fighters that hid during the Second World War from the Nazi regime (left). In this museum, the preservation of objects by display cases created in the old wardrobes is seen as more important than preservation of the original sense of place (right). Some aspects of the overall experience, such as the hidden room with a hole in the wall, are recreated.

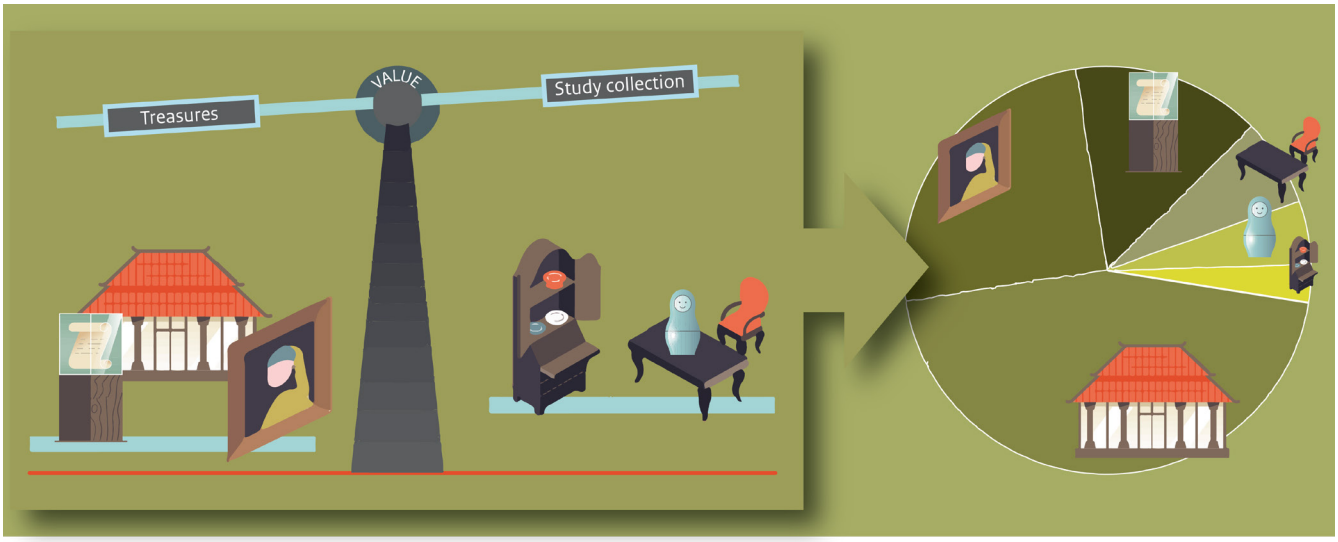


Figure 5: Not all objects have the same value. Making a value pie will help explore relative cultural values of collection units with colleagues and stakeholders.

Figure 6: Each material and construction reacts uniquely to an incorrect indoor climate.

Step 2 – Valuing heritage assets

Museums' primary goal is to enable people to enjoy important cultural objects, in the present and in the far future. Objects are collected because of their cultural significance. An object's significance is based on all the cultural values it embodies (including artistic, aesthetic, historic, informative, emotional/experiential, material, representative, social and spiritual values) and its relation to other objects.

Consider which items within your collection represent most cultural significance. Ask yourself which objects help tell the story you want to bring across to the visitors. Not every part of your collection has the same importance (see Figure 5). For example, a unique piece on permanent display represents a different cultural value than one of a hundred items from a collection that is only taken out of storage for study. When you want to manage cultural significance, you should think about how values change when certain parts of your collection deteriorate.

Sometimes the museum building is your most important asset. If that is the case, you need to handle it accordingly. In other situations, the building is simply a modern shell used to house the collection, and thus can be subject to modification. Measures taken to minimise the climate risks to the collection often involve changing the building. It is therefore important to look at the connection and the relative value of the collection in relation to the building. Examples include:

- A repurposed historic building with a non-related collection
- A historic house with the owner's collection
- A newly built museum for a valuable collection

It can be useful to develop a so-called collection anatomy. This is a list of all the parts of your collection and the building it is housed in that have cultural significance to you. Objects of similar materials, such as paintings, wooden objects, ceilings and doors, are grouped together. Then you can rank these according to their relative (cultural) value.

At a later stage, the climate strategies that are developed to minimise the indoor climate risks can be evaluated by looking at the way each strategy affects the collection. Which cultural values will be lost? Are there any air ducts that will go through a culturally important ceiling? Is it suitable to place all the wooden objects in display cases?

The result of this step will be a list of the parts of the collection and the building itself, which will be influenced by the decision to be made. The relative value of each part of the collection anatomy is made clear. The collection units and/or objects with the highest value are identified.

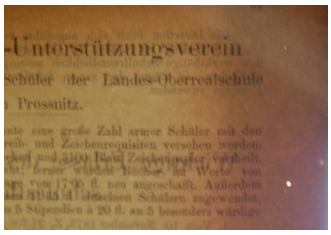
Step 3 – Assessing the climate risks to the moveable collection

Collections consist of different objects that are made of different materials and constructions. All these constructions and materials will respond to a certain indoor climate in their own way (see Figure 6). In this step, you will look at the various deterioration mechanisms that your collection might experience due to its surrounding climate.

The temperature (T) and moisture content of the air are related properties. At a specific temperature and moisture content, the air has a specific relative humidity (RH) between 0% (completely dry) and 100% (condensation). There are three different deterioration processes that are related to an incorrect indoor climate.

	Temperature		Relative Humidity	
	Set point	Fluctuations	Set point	Fluctuations
Paintings on canvas	chemical		chemical	mechanical
Wooden statues	chemical		chemical	mechanical
Works on paper	chemical		chemical	mechanical
Textiles	chemical		chemical	mechanical
Bronze sculptures			chemical	

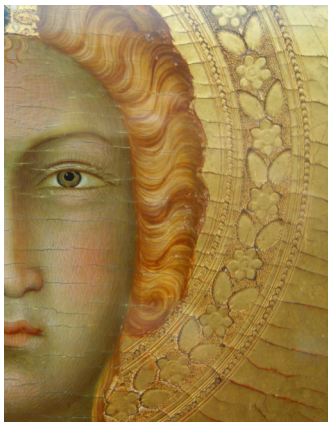
Table 1: For each sensitivity category a colour code is given that shows if the specific climate aspect is potentially high risk (red), medium risk (orange) or low risk (green).



Chemical degradation

The rate of chemical reactions, and thus decay, increases at higher temperatures. Many objects found in museum collections, such as paper after 1850, early photographic materials, rubber, many plastics, analogue tapes and digital discs, chemically decompose within a human lifetime. You can double the lifetime of chemically unstable materials by lowering the temperature with 5°C.

Figure 7: Chemical reactions that take place on paper cause it to yellow.



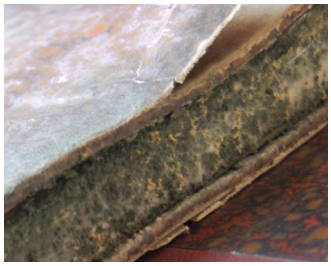
Mechanical degradation

Organic, hygroscopic materials will swell and shrink due to changes in relative humidity. Due to their construction, some objects are restrained in these movements, resulting in a development of stress in the materials. If the stress is too high, very susceptible constructions will deform and sometimes even crack. Examples of very susceptible wooden constructions are: joints where wood grains meet at right angles; inlays of metal, horn, ivory, or shell; thick images on parchment; globes.

The historic indoor climate to which the collection was exposed to in the past years determines the future risk of mechanical damage due to an incorrect RH.

The largest RH fluctuation an object is exposed to in the past is the so-called proofed fluctuation. As long as the RH fluctuations in the future are not larger than those experienced in the past, the risk of mechanical damage is extremely small.

Figure 8: Fluctuations of relative humidity cause cracks in paint and gilding.



Biological degradation

If the relative humidity is too high for too long, mould spores can germinate and moulds can grow. For moulds to germinate and grow not only a high RH is required, but also a high temperature and a surface that acts as nutrient. At 65% RH it takes a couple of months before mould becomes visible. If the collection is exposed to a higher relative humidity and higher temperature, the risk of mould becomes significant. However, if the relative humidty of 70% lasts only for a short period and is followed by a dry period (<50%), the risk of mould growth is negligible.

Figure 9: Very high relative humidity for a prolonged time increases the risk of mould.

There is no single annual average relative humidity set point at which a mixed museum collection can be kept without any risk. Exposure to relative humidities above 75% for extended periods of time is almost always very risky.

The specifications for the indoor climate can be developed by using the collection anatomy and by evaluating for each collection unit to what extent it is susceptible to the set points for RH and T and the allowable seasonal and short-term fluctuations (see Table 1).

The outcome of this step is an overview of the collection anatomy indicating if a collection unit is susceptible to a specific aspect of the indoor climate. Through this table, the overall specifications for the indoor climate can be further developed and specified.

Step 4 – Assessing building needs

Besides providing protection from the outside climate, the building itself can also be exposed to climate risks that might cause a loss of (cultural) values. Architectural details inside the building can deteriorate due to a high relative humidity (e.g. mould) and historic finishes, such as wallpaper and wooden finishes, can be damaged by large relative humidity fluctuations. Therefore, just as with the moveable collection, finding the climate needs of the building requires a similar understanding of the specific climate risks to the building envelope, and its interior finishes.

Just as in step 3, you can also divide the building into sensitivity categories and identify the parts with the highest cultural value. This will help you to take the building into account when considering new climate strategies.

The result will be an overview of the different building parts or materials indicating which of these are susceptible to specific aspects of the indoor climate. See Tabel 1 for a comparable example of the moveable collection assessment. The specific temperature and relative humidity set points and acceptable fluctuations can be developed and specified for different seasons.

Step 5 – Assessing human comfort needs

It is not only the moveable collection and the building that benefit from a certain climate; visitors and staff also require a comfortable climate in which to enjoy their visit or be able to do their work. Human beings prefer relatively high temperatures (between 19-26 °C), while the collection thrives best under lower temperatures. It is useful to divide the building in zones, depending on the different functions and activities. Depending on the zone, the climate can be adapted to its use. For example, storage spaces can be kept relatively cool because the presence of people is limited,

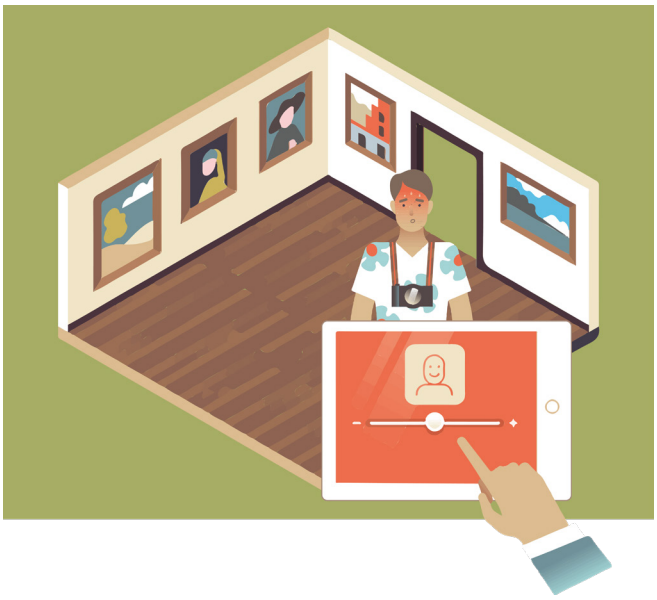


Figure 10: It is not only the collection that requires a specific indoor climate; also the staff and visitors are affected by an incorrect indoor climate.

while foyers and restaurants can be acclimatised just for humans (see Figure 10).

It is important to keep in mind that the experience of temperature is quite complex and is influenced by physical, physiological and psychological processes. This can be used to your advantage, for example, by allowing seasonal changes to occur. Since people are dressed for the season they do not mind if a building is slightly warmer than ideal when it is warm outside too.

Visitors will also not experience at first the set temperature of a space, but rather the difference between where they came from and their current location. It is important not to cool nor heat too much in relation to the outside temperature, because a temperature transition of more than 10 °C is uncomfortable.

The result of this step is a floor plan in which the different climate zones are indicated. For each zone the acceptable temperature ranges are provided, based on human comfort requirements.

Step 6 - Understanding the indoor climate

After assessing the indoor climate needs of the moveable collection (step 3), the building (step 4) and human beings (step 5), it is key to understand what the current indoor climate is. Knowing how the indoor climate is influenced by the outdoor climate is part of that. This will help you to better design new climate strategies in which an optimisation of the building plays an important role. The two important tools at your disposal are climate data collection and assessing the building's physical properties.

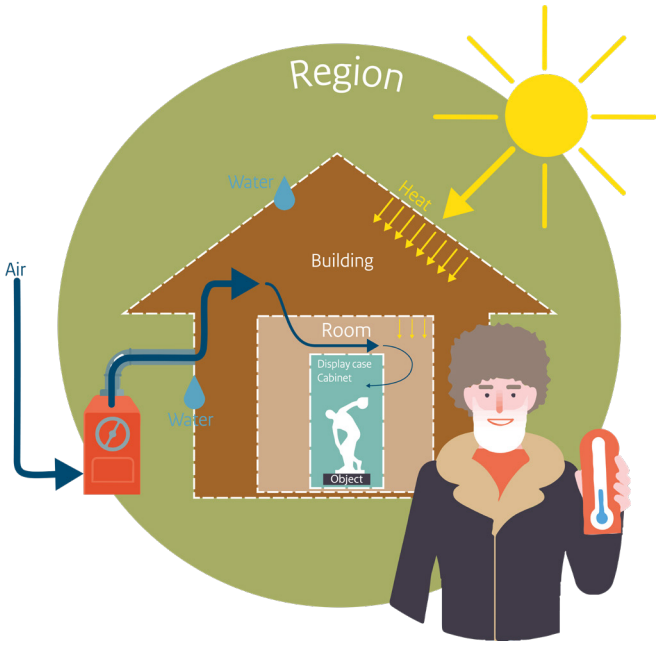


Figure 11: The indoor climate is a result of the outdoor climate, the building performance and possible systems that change the moisture content or temperature of the air inside.

Regarding data collection, you need to ask yourself what you exactly want to know before you start measuring. In order to get representative data, you probably need to measure in more than one location and over a period of time that covers seasonal changes. These climate data are very important, because engineers can derive a lot of information from them that will help develop options to achieve your goals.

You gain knowledge about the building's physical properties by carefully studying the building and its systems which influence either the temperature or the humidity. Building surveys that have been done in the past can help, and climate data and archival information can be key in understanding how the building functions. Questions that help investigate the current quality of the building envelope as a first barrier are:

- What is the resistance to heat (sun) and cold? Can the roof heat up because of the sun? Can the sun penetrate into the building? Which indoor surfaces are heated up by solar radiation?
- Is the water effectively transported away from the building? Are there any moist walls or floors? Does the cellar have that particular moist smell? Can rain penetrate into the building?
- Does the building cool down during the night? Or instead, quickly heat up during the day? Is the building a heavy structure made of bricks?
- Is there an effective airflow of outside air through the building?

Figure 12: With all those involved in the decision-making process, the requirements of collection, building and people are written on a floor plan. Together, the requirements are studied and plans are developed to see how the requirements can be realised by combinations of building adaptations, technical solutions and choices regarding object presentation.

A second climate barrier can consist of a microclimate surrounding an object: for example, a box-inside-a-box principle, a showcase or a microclimate frame.
You can use a floor plan of your museum to indicate the average values for temperature (T) and relative humidity (RH) for the indoor and outdoor climate together with the moisture and temperature sinks and sources. It will become clear where specific parts of the collection fit best: the most sensitive categories of objects are best placed in areas that are more stable.

At the end of this step, climatic data can be presented in figures. There is an understanding of how the building acts as a first barrier to the outside climate. It can be very helpful to use a floor plan in which the climate zones are presented to indicate, for example, moisture and temperature sources and sinks.

Step 7 - Defining climate specifications

In this step, the information of previous steps is combined into a short list of climate requirements per zone. The set points and fluctuations for temperature and relative humidity for each season are specified.

Typically, three different zones are found in museums:

1. Collection zone: This is a zone where the climate conditions are primarily based on the needs of the collection. Examples include storage rooms, display cases and vaults;
2. People zone: This is a zone where the climate conditions are primarily based on human needs. Examples include offices and public spaces;

3. Mixed zone: This is a zone where the climate conditions are based on the needs of the collection and on the needs of the occupants. Examples include exhibition rooms, study rooms and conservation laboratories.

Each zone has a different functionality and thus different climate specifications. These can be indicated on the floor plan (see Figure 12). Note that the desired climate for a given zone does not necessarily need to suit collection, building and people requirements. If very valuable and susceptible objects are to be placed in a mixed zone, the use of microclimates can be considered.

In this step, you do not have to consider the implementation of new indoor climate strategies, but rather the desired outcomes. However, it is still useful to keep in mind that the lesser interventions you have to do, the more sustainable your new strategy will be.

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

Step 8 – Mitigating strategies

In this step, the outcome of step 7 will be the starting point to develop various strategies to manage the indoor climate. A strategy refers to the adaptation of the physical properties of the building (first barrier), the microclimate around an object (second barrier) and/or the implementation of some form of passive or active climate control.

Relying only on technology with active climate control is hardly ever sustainable in terms of energy use nor a durable solution. Keep in mind that you will introduce new risks by introducing high-tech solutions. The reliability of the indoor climate on active climate control results in higher risks for the collection when the system fails. Further more, you should also consider the future costs for maintenance and energy for high-tech solutions.

Within the value framework established in step 2, the options to improve the indoor climate are considered and selected. Possible strategies (or a combination of these) can be considered in order of increasing impact:

1. Take advantage of the physical properties and architectural features of the building. Consider optimising natural ventilation and the use of shutters.
2. Consider applying complementary physical measures to the building. Think about adaptations to windows, insulation, reducing infiltration and the use of buffering materials.
3. Consider a 'box-inside-a-box'. By creating a smaller, better buffered and better air tight construction inside an existing building, the number of barriers between the in- and outdoor climate increases and control over the climate in close proximity to the collection becomes easier.
4. Placing objects inside passive or active controlled showcases or microclimate enclosures. This is the same principle as 'box-inside-a-box' but with a much lower air volume. The disadvantage is the lower accessibility to the object.
5. Consider user dynamics and user behaviour. For example, limiting visitor numbers and cloakrooms for wet coats.
6. Consider climate control systems. In increasing complexity: mobile (de)humidification, conservation heating, cooling, full climate control with the use of HVAC systems.

Figure 13: Changing the moisture content or the temperature of the indoor air can increase the risk on the outside of the building. Ducts will negatively affect the experience of a historic interior, while placing objects inside a display case will affect the way visitors view the objects.

Developing multiple climate control strategies will help you to keep an open mind. In the next step, these scenarios will be evaluated. Note that some measures might be beneficial to one objective but might have a negative impact on other objectives (see Figure 13)

The result of this step is a set of scenarios that will maintain an indoor climate that is specified in step 7. Often, each scenario consists of a combination of building adaptations, together with the use of microclimates and/or some kind of climate control measure.

Step 9 – Weighing alternatives

In step 8, several strategies to manage the indoor climate were developed. In this step, these options are further analysed and evaluated.

There are various methods available to evaluate alternative strategies and to choose the one that helps you achieve most goals. A multi-criteria decision-making analysis can be carried out to evaluate how each mitigating strategy helps to achieve the goals developed in Step 1. It is important to weigh different options and involve all stakeholders since bias can lead to poor choices.

A multi-criteria analysis (see Figure 14) can for example be carried out by answering the following questions:

- What are your objectives? (Established in step 1)
- Which objectives are most important? Include weights to reflect their relative importance and multiply your scores.
- Which of the climate control strategies help you maintain the required indoor climate? (Established in step 8)
- How well does each strategy fulfill the objectives? Use '+/-' or a score from 1-10 to express a relative quality.
- How will the outcome change if the objectives are weighed differently?
- Choose the strategy that helps you achieve most objectives; this is the one with the highest score.

At the end of this step, all stakeholders should feel that their input is taken into consideration and that the best strategy is chosen.

Freely accessible websites with important information on managing the indoor climate risks of museums include:

- https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html
- http://www.conservationphysics.org/
- http://www.conservation-wiki.com/wiki/Environmental_Guidelines
- http://www.icom-cc.org/332/-icom-cc-documents/declaration-on-environmental-guidelines/#.VgnbvM7Bxap
- https://www.iiconservation.org/sites/default/files/dialogues/plus-minus-en.pdf
- http://www.getty.edu/conservation/our_projects/science/climate/climate_experts_roundtable.html

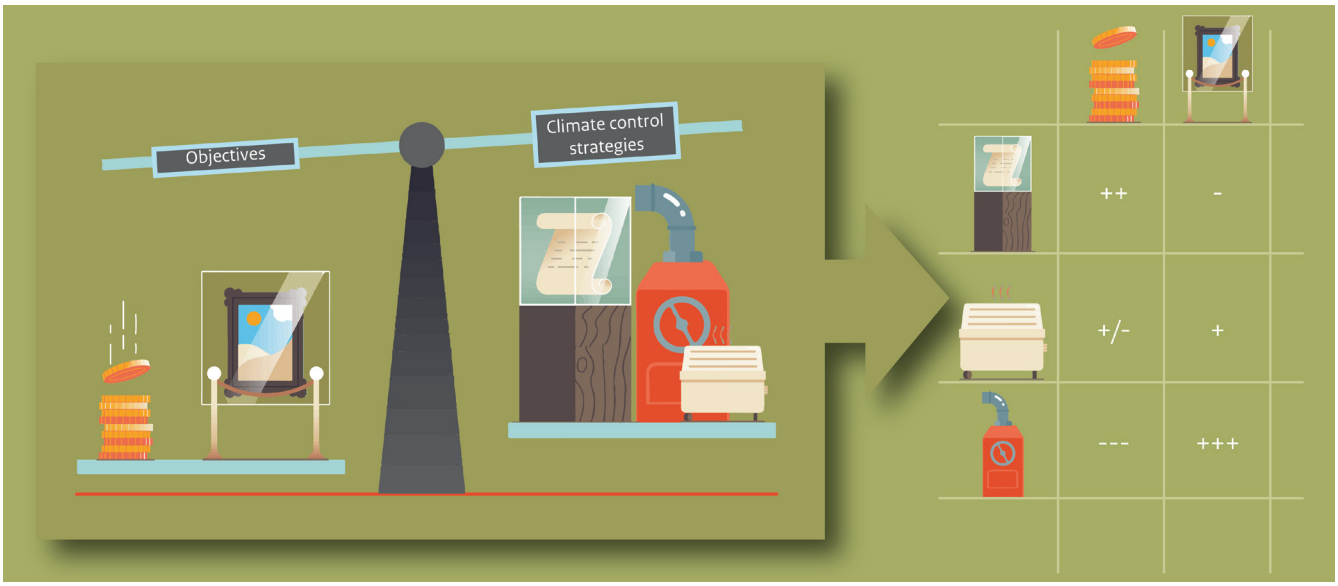


Figure 14: Each climate control strategy is weighed against each objective and is scored.

Colophon

For further questions: info@cultureelerfgoed.nl
www.culturalheritageagency.nl

Text: Lieve d'Hont, Bart Ankersmit (RCE) and Marc Stappers (RCE)

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Cultural Heritage Agency of the Netherlands, Smallepad 5, 3811 MG Amersfoort.
With knowledge and advice the Cultural Heritage Agency of the Netherlands gives the future a past.