Climate for Culture

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 226973

Decision support system for indoor-climate risk assessment and control and its implementation in a newly developed exDSS open source software

TOMÁŠ VYHLÍDAL[1], JIŘÍ ŠOLC[1], GUSTAF LEIJONHUFVUD[2], TOR BROSTRÖM[2]

[1]Department of Instrumentation and Control Engineering, Faculty of Mechanical Engineering, Czech Technical University in Prague, Czech Republic
[2]Campus Gotland, Uppsala University, Sweden

Introduction

One of the key objectives of the Climate for Culture project was to develop decision support tools for best practice advice with regard to maintenance and mitigation strategies for a specific building type in a specific climatic region in Europe and the Mediterranean and implement it in a form of freely available software.

In this report, we address the module for the decision support for indoor-climate risk assessment and control in various types of historical buildings. The objective of this module is to provide the end user help in evaluation of the current state of the indoor-climate in a particular building, to assess potential risks for the collections as well as for the building and to propose best practice mitigation measures taking into consideration the predicted climate change in the particular region. The methodology has been proposed based on the state of the art in the given subject of indoor-climate management, particularly taking into consideration the assessment of existing microclimate control strategies (equal-sorption humidity control, conservation heating, humidistat heating, friendly heating, "Temperierung" (wall heating), controlled air exchange), which have been addressed in the deliverable D 7.1 [1]. Consequently, the expertise of the project team members have been projected to the proposed decision support methodology, focusing particularly on the sustainable and energy efficient solutions addressed in deliverable D 7.2 [2]. For the risk assessment, the research results on various damage functions, described in deliverable reports D 4.1 and D 4.2 [3, 4], and their projections to the risk maps documented in deliverable D5.1 [5], have been widely applied. Finally, the climate prediction maps have been used as the key part of the decision support methodology, presented also in D5.1 and D5.2 [5].

Considering design and qualitative aspects of the indoor-climate control in historical interiors, there are several open questions to be addressed. They are briefly highlighted in Fig. 1 on the closed indoor-climate control loop. First, the desired indoor-climate needs to be specified. The primary objective of the active control is to eliminate RH induced risks for the historical objects. In order to do so, RH is usually kept in a certain range, see [7] for both the overview and the review on their determination based on various standards and guidelines. For a long time, the target range 50 or 55 ±5% determined by Thomson in [8] was considered as the standard for museums and collection halls. However, based on understanding the phenomena of the interactions between the levels and variability of RH and mechanical and biological responses of the material of historical objects, it was shown that these strict ranges can be considerably relaxed, see e.g. [7, 8-11], and still the environment is safe for the historical objects. Consequently, these findings were implemented in standards and guidelines. For example, in ASHRAE standards [12], five categories of indoor-climate are specified depending on the seasonal and short-term fluctuations of temperature and relative humidity with highlighting the potential associated risks for the objects. Recently, following the acclimatisation concept of the objects containing organic hygroscopic material to the indoor-climate conditions of the storing interior, the European standard EN 15757 [13] was proposed to specify the limits on the indoor-climate variability to prevent further damage to the objects.

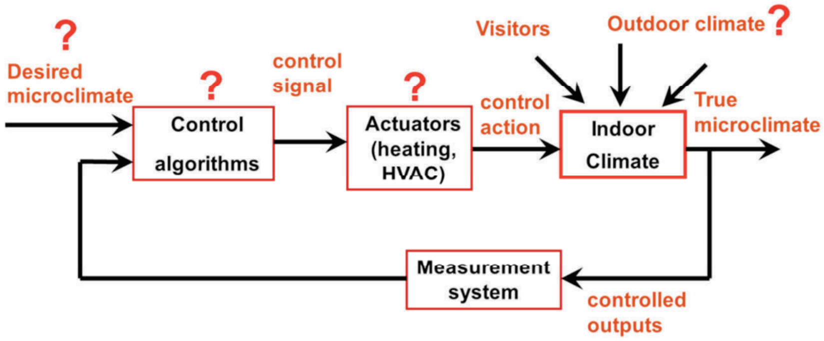


Figure 1 Open questions concerning the indoor-climate control system in historical buildings

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 226973

Another open task to be solved is the selection of the most suitable control method. This includes not only the selection of the actuators (heaters, coolers, humidifiers, dehumidifiers, ventilators, etc.), but also the algorithms which control them following the desired microclimate objectives. Next to the classical methods such as humidity control, humidistat heating, controlled ventilation, temperierung, radiative heating, addressed widely in [1,2, 14] and also in the other reports of this deliverable document, novel control strategies such as equal-sorption humidity control and natural climate fluctuations control have been considered in the project [15, 16, 17]. Next, a proper analysis of the outdoor-climate and its predicted changes in the lifetime period of the technical solutions (20-50 years as a rule) are the critical factors that need to be considered when selecting the most suitable mitigation measure. Finally, the number of visitors and requirements on the comfort aspects needs to be considered too.

However, before looking at the active control strategies mentioned above, applicability of passive strategies should be investigated, i.e. we should always try to minimize the influence from the outdoor climate through the passive function of the building envelope. Passive control is determined by the insulation, air tightness and hygrothermal buffering of the building envelope. Case studies within the project and simulations show how the indoor climate can be stabilised by reducing the air exchange and by reducing solar heat gain from windows. This idea is highlighted in our first general outline of the decision support tool, which is shown in Fig. 2. Thus, after considering all the above mentioned aspects, the possibility to solve the problem by applying the passive solutions should be considered first. The active solutions should come if and only if the passive mitigation measures are not sufficient to achieve safe indoor-climate conditions.

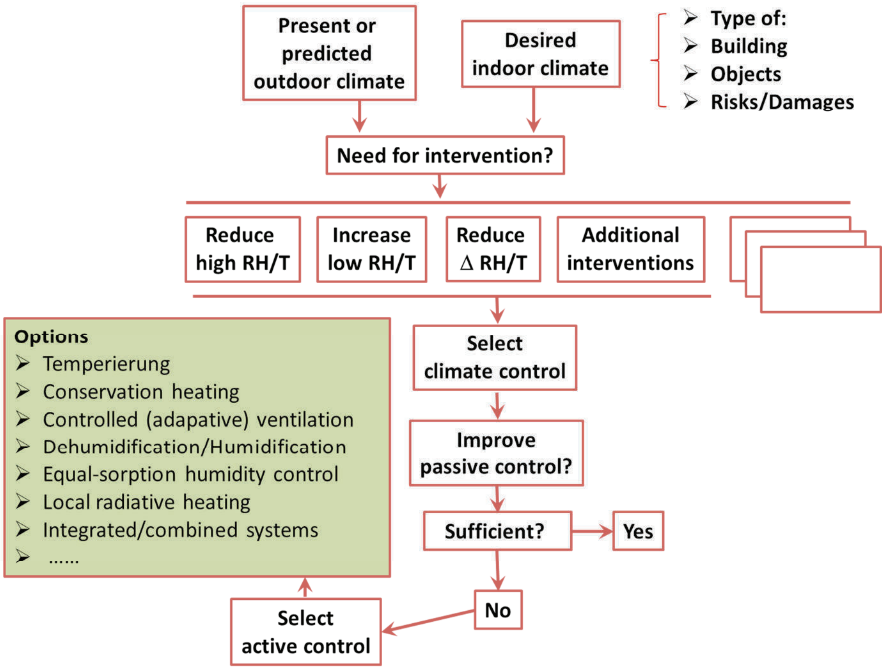


Figure 2 General outline of the decision support system

Expert and decision support systems play an important role in many fields nowadays. Next to the traditional application spheres, such as medicine, engineering and chemistry, recently, various expert system tools and methods have been applied to the field of cultural heritage. For example, in [18] a web information system was described to manage all types of documentary data related to an archaeological site or monument. In [19] the authors proposed a decision support model for determining restoration priorities of cultural heritage under the limited budget. Next, for example, the multi-attribute theory is applied to deal with decision problems in reuse of historical buildings in [20]. In the Climate for Cultural project, various risk assessment tools have been developed concerning the impact of climate change to the indoor-climate of historical buildings [21], see also [22]. These methodologies have been applied to the web-based Case study database at the Technical University of Eindhoven [23], which provides automated data analysis and the risk assessment based on the indoor-climate data provided by the end user. Another very advanced web-based decision support tool – Responsible retrofit guidance wheel [24] - has been developed by the Sustainable Traditional

Buildings Alliance (STBA), UK. The Wheel has been designed to address various aspects of retrofit design for traditional buildings. The Wheel is both an aid to decision making and a way of learning about traditional building retrofit.

In what follows, we first describe the exDSS software tool, which has been developed by the project partner Czech Technical University of Prague for the purposes of the Climate for Culture project. After the software introduction, we focus on and describe the main product – Decision support tool for indoor-climate risk assessment and control in historic buildings.

The exDSS Software – application aspects and a brief introduction

The abbreviation exDSS denotes expert Decision Support System, which, as mentioned above, has been developed for the purposes of Climate for Culture project, particularly to implement the decision support methodologies into web based user friendly applications.

Philosophy and requirements on the software

The requirements on the system have been assessed as follows:

- The application will be web based, easily editable and transparent open source software for both categories of the users:
    - Experts (developers of the tools) - who will include and edit their know-how to the software utilities and thus will form the decision support tools
    - End-users – who will use the decision support tool

In the web based tool, through an interactive questionnaire the end user will gradually provide the information on a particular problem and the decision support tool will select the most applicable solutions and recommendations based on the information provided by the end-user. Both the questions in the questionnaire and the conclusions will need to be generated and tuned in advance, by the experts. Detailed requirements depending on these basic prerequisites are:

- For both the end-users and experts:
    - User friendly - very simple and intuitive interface. Clear and nice look.
    - Portability - Independent on operation system or hardware (this means a SW application which can run in different operating systems and devices – pc, tablet… and is easy to deploy without installing large add-ons to the device)
    - Scalability – Ready for extensions and improvements (the application should be of easy to expand modular design)
    - Open license – Not depending on expensive robust systems and tools. Cheap or free.
    - Today's application – Based on the recent standards (fancy and user friendly design and look)
    - Upgradable and online – system should be online for better distribution of new or upgraded versions of each project (availability to patch projects without difficult distributions)

- Requirements on the functioning from the end-user perspective:
    - The end-user gradually provides the information on current state of situation (for example the building type - dimension characteristics, envelope type, its use - archive, collection hall, museum, on the identified risks - mould growth…)
    - An answer to a given question can be provided in various ways. As a number or a string to be filled in a text box or by ticking radio-buttons or check-boxes corresponding to the most appropriate option(s) offered by the tool.
    - After passing all the questions available for current project (questions are dynamically added and removed from the list depending on the past answers), the tool provides a list of conclusions with comments useful to the end-user for decision making.

- Requirements on the functioning from the expert perspective:
    - Easy to write and test the questions, rules and conclusions, no need of knowledge of a complex programming language.

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 226973

- Rules and logic expressions must be written as easy as possible.
- Possibility to test, debug and easy to deploy new versions of the decision support projects.
- Easy to share and cooperate on projects in small teams of experts.

All the above requirements are typical for experts systems. Before deciding to developed a new, authorized exDSS software, a proper analysis of existing tools that could possibly be used for implementation of the decision support methodology have been performed. However, none applicable non-commercial open source tool have been found to fulfill all the above requirements.

Design of exDSS software

As a platform of exDSS, PHP/MySQL/jQuery environment was selected. This combination is easy to port and easy to expand. All parts of exDSS can be considered as alive projects, i.e. all parts can be continuously developed - various patches according to needed changes can be implemented in real time. Besides, the core of the expert system was designed as widely and easily expandable in future research. In Fig. 3, the exDSS design menu for designing and editing the expert system is shown, where all the entities and functionalities of exDSS are listed.

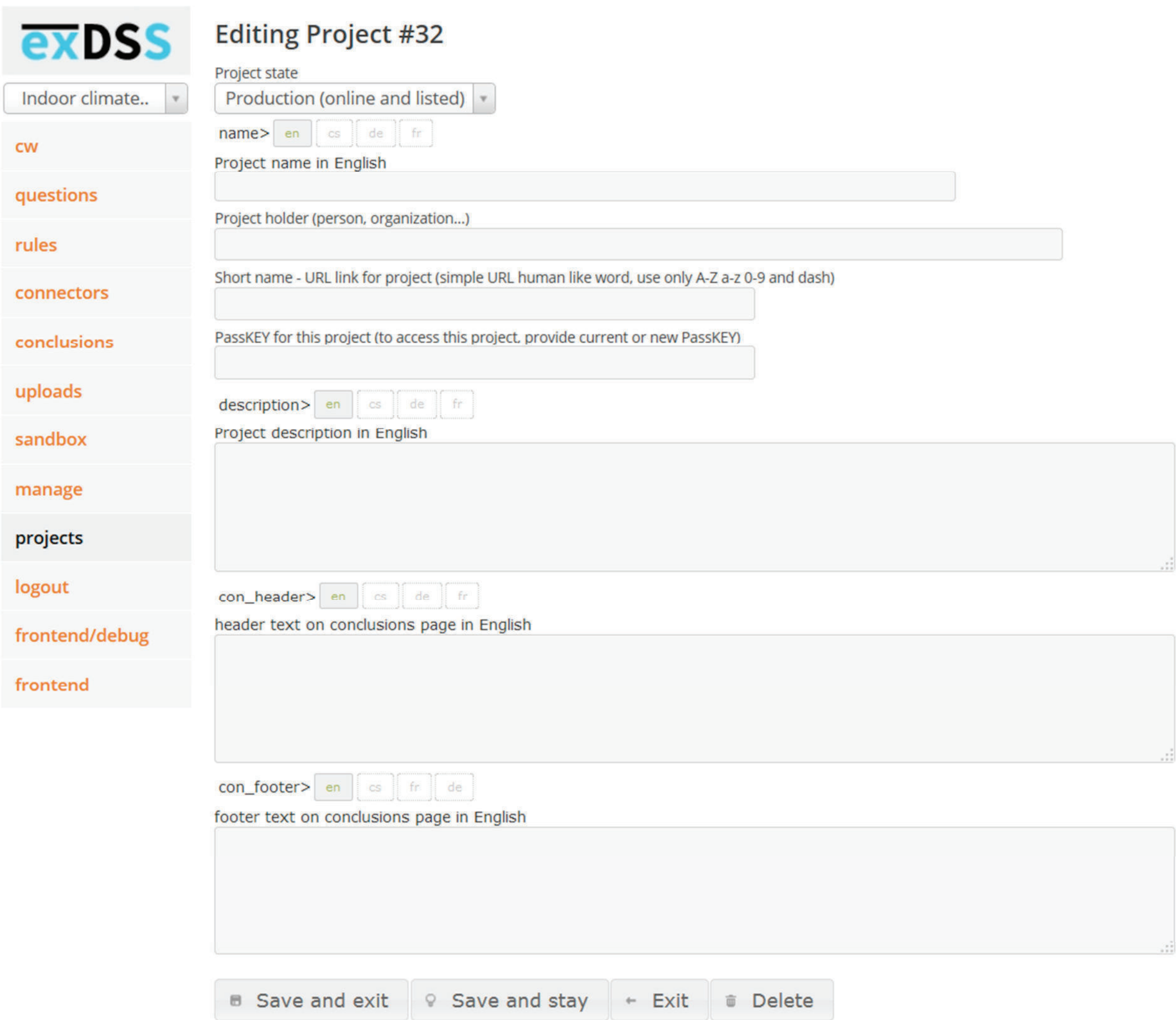


Figure 3 Project design menu of exDSS software and the interface for defining a new project

The first step which needs to be done by the expert is a definition of the decision project, which can be done in the menu shown in **Fig. 3**. Through this interface, project name and holder (person, organization) need to be assigned. A particular important text box is the short-name as it will become a part of the URL link of the project. All the projects can be user protected, via a defined pass key. Then, the expert can provide some

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 226973

introductory text, which will appear as the first screen in the decision support procedure. Finally a header and a footer text can be included.

Brief introduction to exDSS

The key entities of the exDSS application (project), which needs to be defined by the expert, are given as follows (see their list in the side menu in Fig. 3):

- **Control words (CW)** - the main tokens (variables) of the system which store the information provided by the end-user. CWs need to be predefined by the expert, including their type (Boolean, Float, Integer, String). CWs in fact control behaviour of exDSS. *For example CW could be "OBJECT_HAS_WINDOWS" with value "yes"*
  Below, in Fig. 4, we present an environment for defining the CWs. Next to the CW short name, which is then used to represent the CW, a long, descriptive name is to be defined. Next, the type needs to be defined as stated above.

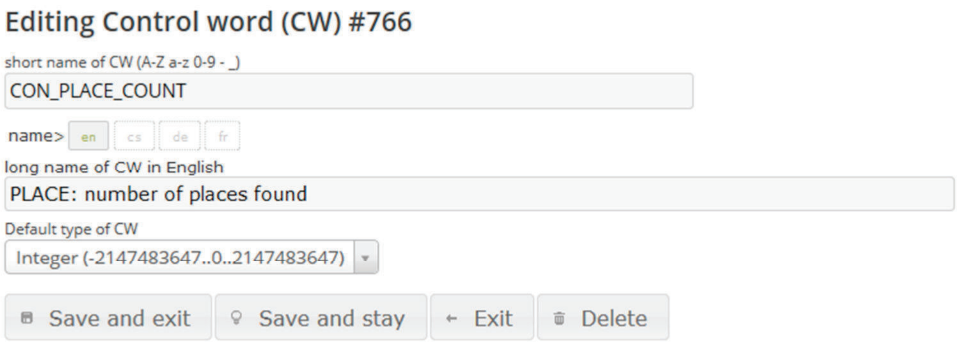
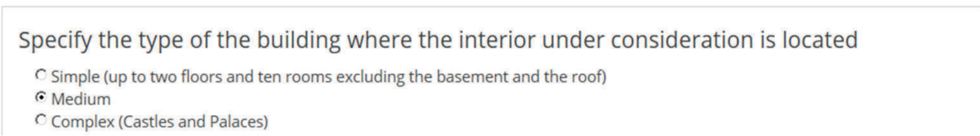


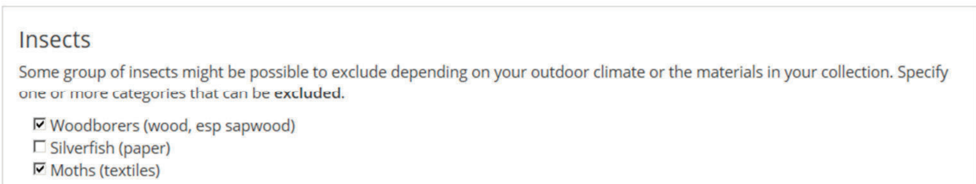
Figure 4 Menu for defining and editing the **control words** (CW)

- **CW pool** – defines a current state of exDSS (current phase in the decision process). Whenever the end-user answers a question, the CW pool is updated, one or more CWs are either included or excluded from the pool. Based on the CW pool, the questions to be given to the end user are selected and at the end, the relevant recommendations are provided.
  For example after answering several questions, CW pool can be like this:
  OBJECT_HAS_WINDOWS=yes (Boolean)
  RISK_OF_MOULD=85 (Integer)
  MAPS_LONGITUDE=20.45 (Float)
  MAPS_LATITUDE=40.1 (Float)
  OBJECT_TYPE=CASTLE (String)

- **Questions** – defined by the experts in one of the following styles
  - Single select - only one answer to the defined question is correct (see an example below)

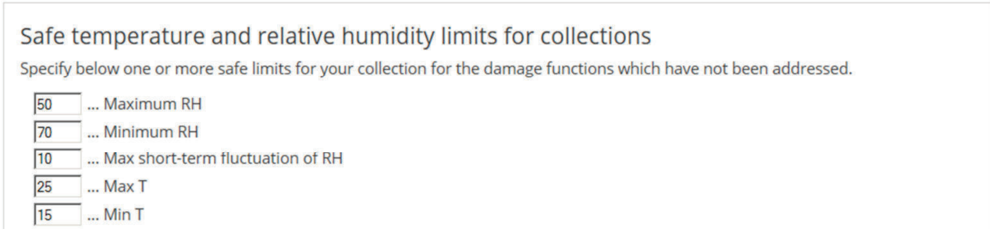


  - Multiple answer - several answers to the defined question are correct (see an example below)



This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 226973

- Numeric Value – answer is a numeric value (see an example below)



- String Value – answer is a string value (see an example below)

Figure 5 Menu for defining and editing the **questions**

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 226973

The answers to the questions are stored in the pool in form of the CWs.
For example, a question could be: "Please select object type" and possible answers are types of objects, this question will add to CW OBJECT_TYPE=CASTLE into CW pool.

In Fig. 5, we present an example of the environment for defining a question in exDSS. Next to the short name (for the internal purposes) and long name to be shown to the end-user, the menu includes text box for putting in the question. Then, type of the question needs to be defined as described above. Consequently, logical operations can be included with the purpose to control when to give a particular question. As can be seen, the question can be blocked or given under defined logics. Let us remark that *block rule* condition has the priority over the *add rule* condition. If none of these items are defined, the question will be given. The question order is defined by the user-defined question sort order number located below the large text boxes. The third large text box then provides a possibility to execute any logic expression after the question has been answered. Finally, possible answers need to be defined that actually assign the CWs to the pool.

- **Rules -** are classical rules as defined in the expert system terminology. Basically, the rule can be activated by a predefined state of the pool. If active, the rule can perform some adjustments of the pool state and thus to control the decision process (e.g. to skip a given set of questions).
  For example a rule could be like this: if OBJECT_TYPE is CASTLE and RISK_OF_MOULD is less than 30 then increase RISK_OF_MOULD about 20 percent.

The menu for defining the rule is shown in Fig. 6. Next to the internal short name and the descriptive name of the rule, analogously to the questions, the boxes for adding and blocking the rule are available. Unlike for the questions, the rule is active if and only if the add rule condition is satisfied. Let us remark that *block rule* condition has also the priority over the *add rule* condition. Next, the conditions for modifying the state of the pool need to be defined in the last text box.

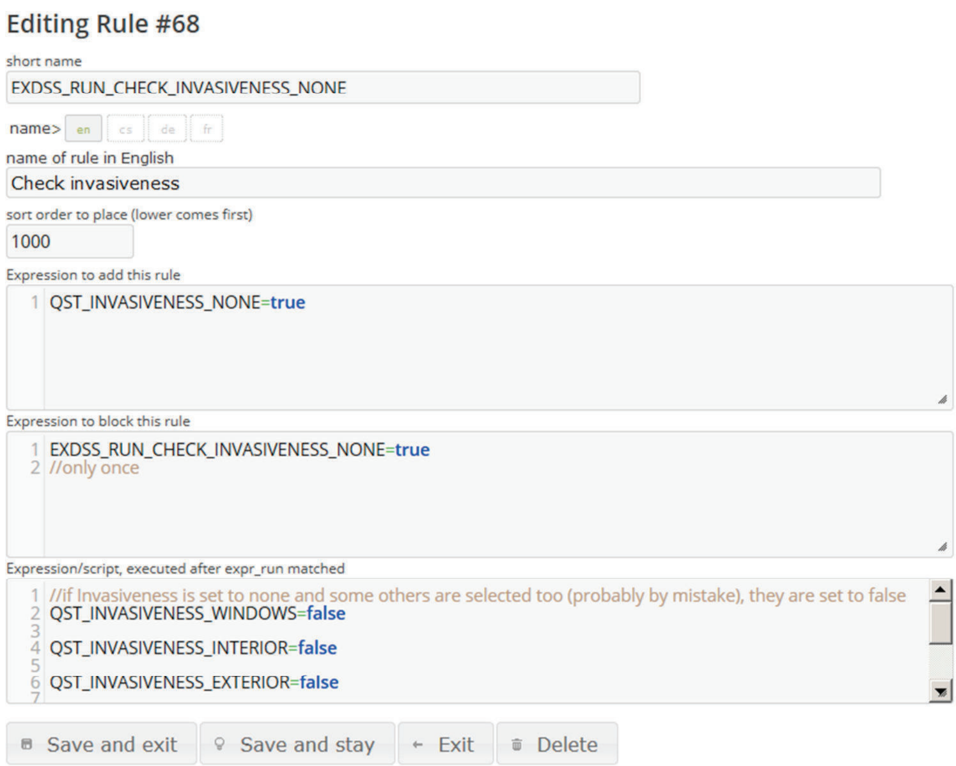


Figure 6 Menu for defining and editing the **rules**

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 226973

- **Connectors** to external applications - predefined system/script calls to external projects and applications. The connectors can be used to exchange the information with the external applications, which needs to be interfaced with the exDSS software.
  For example, the user can provide a name of place in Europe and the external connector will look-up for longitude and latitude of the place at an external web application.

The menu for defining the rule is shown in Fig. 7. Next to the internal short name and the descriptive name of the connector, the boxes for adding and blocking the connector are available. The connector is active if and only if the add rule condition is satisfied. Let us remark that *block rule* condition has the priority over the *add rule* condition. Next, the web link to the external connector, which (at this stage) needs to be prepared by the exDSS administrator.

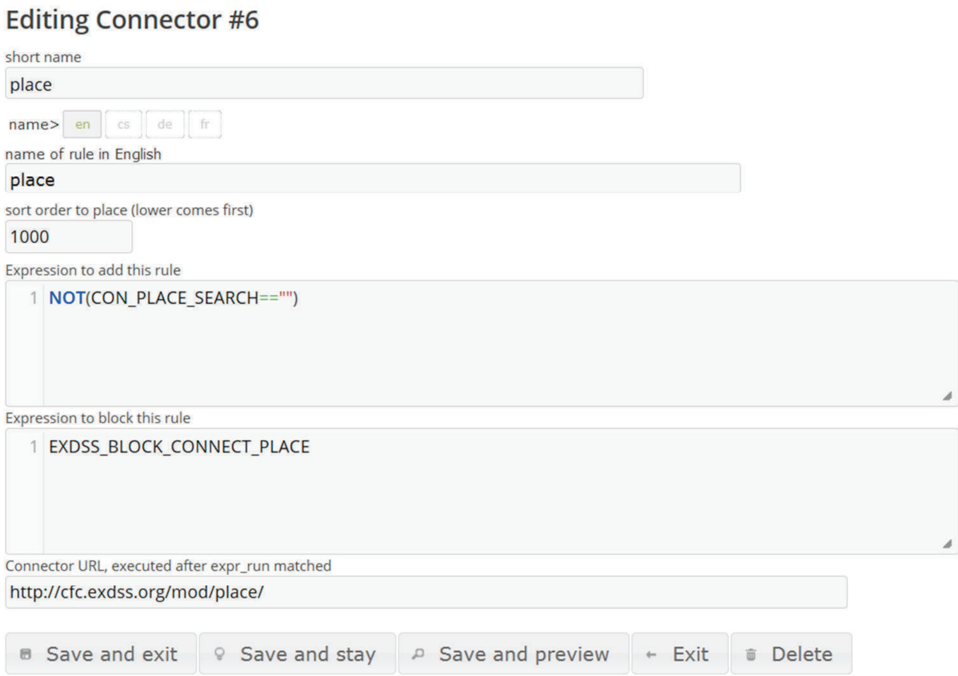


Figure 7 Menu for defining and editing the **connectors**

- **Conclusions** - the most important part of the system, by which the recommendations to the end-users are generated based on the final state of the pool.
  For example, if the end-user specifies the problem with mould or the exDSS comes to the risk of mould depending on the answered questions, the conclusion with the recommendation on how to avoid the risk, which was predefined by the expert, is provided to the end-user.

The menu for defining the conclusions is shown in Fig. 8. Next to the short name (for the internal purposes) and long name to be shown to the end-user, the menu includes text boxes for short conclusion message (or header) and the text box for the main text of the conclusion. The text can be formatted using the html notation – by which the pictures, files or the links to external pages can be included. Then, there are boxes for adding and blocking the conclusion. The conclusion is given if and only if the add rule condition is satisfied. Let us remark that, again, *block rule* condition has the priority over the *add rule* condition.

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 226973

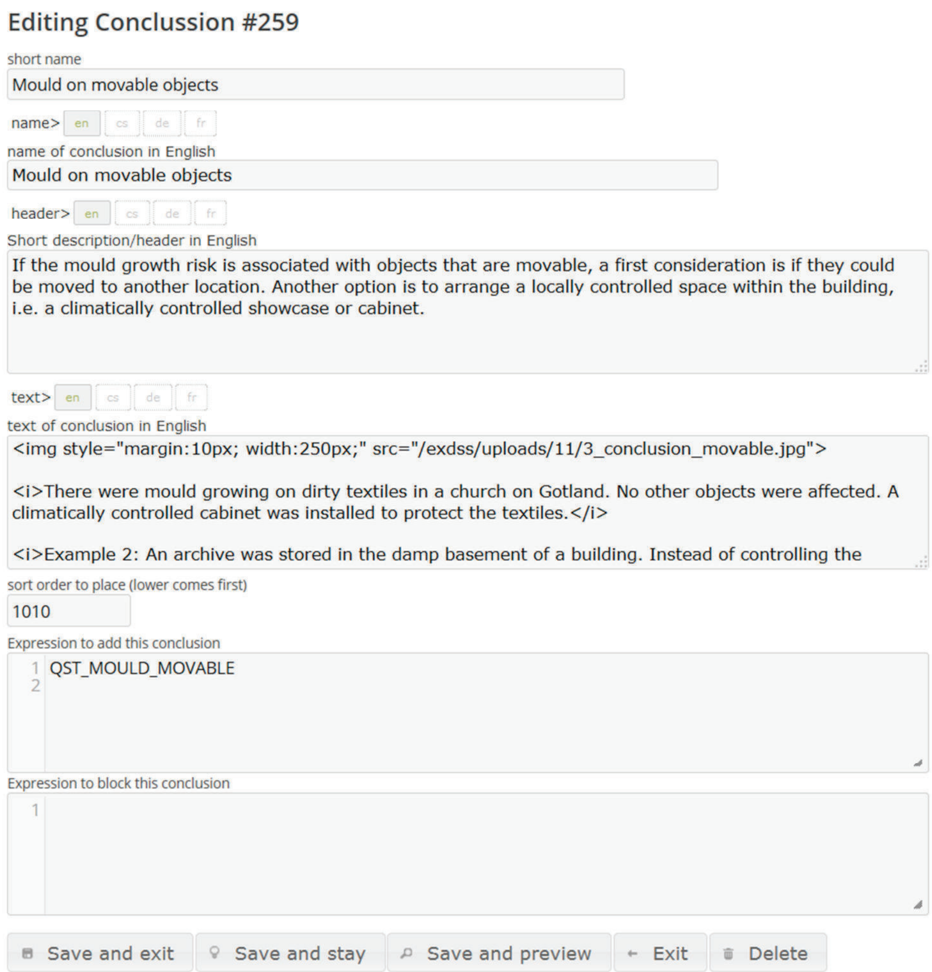


Figure 8 Menu for defining and editing the **conclusion**

As shown in the main menu in Fig. 3, we have there several additional items with the following functions:

- **Uploads** – allows the expert to upload external files to the given project, which can then be included to the questions and conclusions. When a file is uploaded, the exDSS will generate the web URL link.
- **Sandbox** – a utility for checking and tuning the logic operations
- **Manage** – a utility which can be used to import and export the projects. It is used mainly to create the back-up files and clones of existing projects
- **Projects** – allows defining a new decision support project, as shown in right part of Fig. 3 and already discussed above
- **Logout** – logs out the expert
- **Frontend/debug** – shows the actual stage of the defined decision support project in the debugging mode, under which the expert is able to see the current state of the pool and can check the proper functionality of the decision support project
- **Frontend** - shows the actual stage of the defined decision support project in the end-user mode.

Next, the exDSS system has the following **internal parts**, which are not visible to neither the expert nor the end-user:

- **Interaction engine** - generates questions and conclusions depending on current state of CW pool. It is responsible for interacting with the end-user.

- **Inference engine -** is working with the rules, action parts of the questions and initiates external applications. The engine runs after any input comes into the system (after each of the questions is answered or after the external application returns the CWs to the pool). Based on the current state of the pool, it checks whether any of the rules or external connectors should be activated and thus updates the state of the pool.

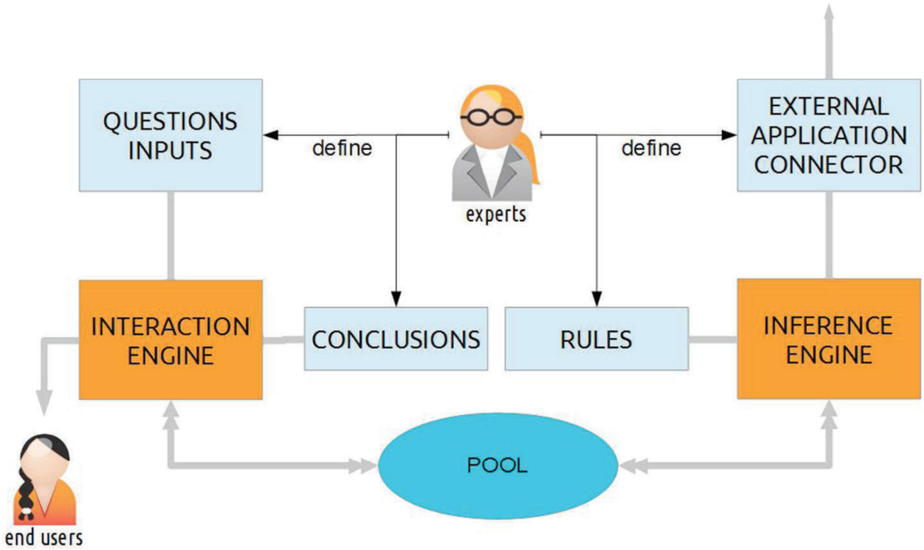


Figure 9 A scheme of the expert system in relation to the roles by the expert and the end-user

The above two parts are typical and basic parts of each expert systems. In Fig. 9, a typical configuration of an expert system is outlined, which is fully applicable for the developed exDSS software. As outlined, the expert is responsible for defining CWs, questions, rules, decisions and configuration of the external connectors. In exDSS, all these parts can be defined in a user friendly environment. A favourable feature of exDSS is that multiple experts can work in one time on the same or different projects. All the rules can be defined just with very basic knowledge of Boolean logics and if-then forms of conditions. Subsequently, with very basic knowledge of html, fairly fancy look can be provided to the questions and conclusions in the web interface. As shown in Fig. 9, the end-user is in a direct connection with the Interaction engine which drives the end-user through whole set of predefined and applicable questions and at the end, provides and visualise the set of applicable conclusions.

exDSS deployment

The current version of exDSS is running on a cloud environment at the web server of Czech Technical University in Prague, Faculty of Mechanical Engineering.

Technical information:

- Operation System: Ubuntu Server LTS
- Virtual environment: Vmware vSphere
- HW: 3x ESX server and virtualised storage

Maintenance of infrastructure is provided by the Faculty Centre of Computer services.

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 226973

Decision support system for Indoor climate risk assessment and control in historic buildings

As a contribution to Climate for Culture decision support functionalities, a module for Indoor-climate risk assessment and control has been proposed and implemented within the above descried exDSS SW application. The decision support module is divided into three parts, which will be described below:

Part 1: Future outlook

This part indicates how the indoor climate and related risks might change in the near and far future for the building of interest, which is defined by key characteristics, such as thermal inertia of the walls, glassing area of windows and buffering capacity of the building interior. The information is derived from the Climate for Culture prediction maps, just based on the given building characteristics and its location. In this part of the module, the end-user needs to provide information on the building by answering the questions outlined below (copied from the web page of exDSS) :

Building structure

Specify the type of the building where the interior under consideration is located

- Simple (up to two floors and ten rooms excluding the basement and the roof)
- Medium
- Complex (Castles and Palaces)

Interior size

Specify the size of the interior room where your collections are located.

- Small (<100 m^3)
- Medium (100-1000 m^3)
- Large (>1000 m^3)

Interior use

Specify the use of the interior under consideration

- Residential/office/shop/restaurant
- Museum/exhibition area/showroom
- Church/synagogue/mosque
- Castle - mansion
- Castle - preserved ruin
- Other

Location

Provide the name of the location where your building is situated

Examples: "Prague, Czech Republic", "Karlstejn", "Technicka 4, Praha", ...

[ ] ... Name of the location

After answering the above questions, the end-user is asked whether he or she wants to continue with the risk assessment:

Continue with risk assessment?

You are now finished with part 1 (future outlook). Would you like to continue with part 2 (risk assessment) and part 3 (indoor climate control methods)?

- yes
- no

If the answer is no, the above information is used to derive the damage function parameters from the risk assessment maps for the given type of building and the given location. The Conclusion screen then looks as shown in Fig. 10. If the answer is yes, the system continues with Part 2 outlined below.

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 226973

Simulated changes of the indoorclimate in the near and the far future

The **Indoor climate and damage function data** specified below have been obtained by coupling the results of the climate model considering the A1B1 IPCC Scenario and the building simulation software. The data corresponds to the hypothetical situation when the *artificial building model*, which is structurally similar to your building, was placed at the location of the building you have specified. Besides, the corresponding data maps are shown for the whole Europe.

Building location: 15: Schloss Neuschwanstein, Deffingen, Günzburg, Landkreis Günzburg, Schwaben, Bayern, 89312, Deutschland
Latitude: 48.4246267
Longitude: 10.301787213623

	Recent Past [1961 - 1990]	Changes from Recent Past [1961 - 1990] to Near Future [2021 - 2050]	Changes from Recent Past [1961 - 1990] to Far Future [2071 - 2100]
Mean Temperature in January [deg. C]	0.6	1.5	3.9
Mean Temperature in July [deg. C]	19.5	0.4	2.9
Mean Relative Humidity in January [%]	80.6	-1.2	-2.3
Mean Relative Humidity in July [%]	64.4	1.9	-0.7
Mould Growth conditions [mm/year]	12	3	11
Salt Crystalization Cycles [no/year]	114	-1	4

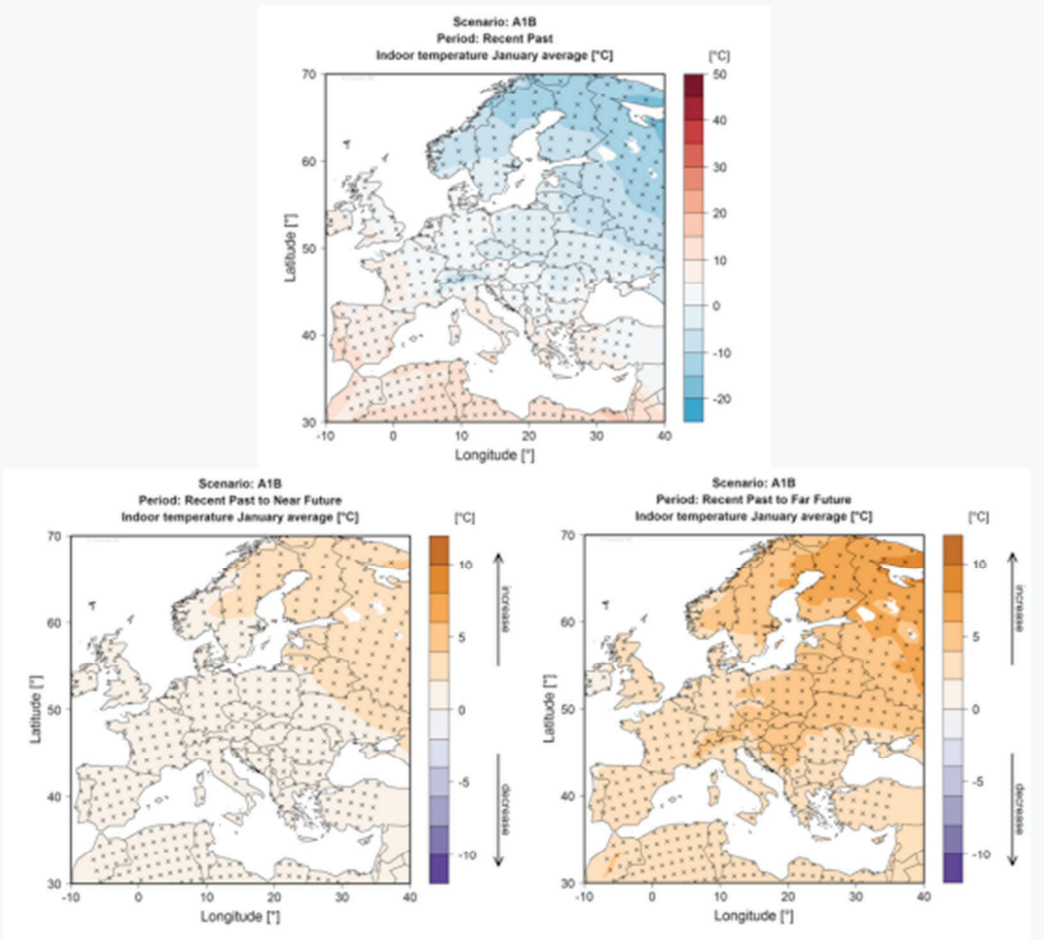


Figure 10 Example of predicted indoor-climate data and selected damage functions values for the given type of the building and the given location derived from the set of climatic and risk-assessment maps (an example of a map set shown in the bottom part of the figure)

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 226973

Part 2: Risk assessment

This part investigates which climate-induced risks are relevant to the defined building and collections stored in its interior. Particularly, risks related to mould growth, mechanical damage and insect are addressed. Bellow, we first provide the whole list of the questions in this part and then a selected questions copies from exDSS are shown (particularly the questions related to the mould growth and mechanical damage).

Overall list of question available in Part 2 – Risk assessment

- Relevant risks - what types of risks do you consider relevant for your interior
- Mould – Local problem? Extremely susceptible materials? Some objects at risk are movable?
- Insects - Woodborers (wood, esp sapwood)?, Silverfish (paper)?, Moths (textiles)?
- Salt damage – define salt
- Salt - Custom equilibrium RH for the salt outside the list
- Salt - Moisture transport reduction by adaptation of the building construction?
- Mechanical damage - proofed fluctuations
- Mechanical damage, vulnerability
- One year data available?
- Historic climate – define by the temperature and relative humidity ranges
- Need for Temperature above zero?
- Handle objects in winter?
- Specify conditions to be kept in your interior?
- Safe temperature and relative humidity limits for collections – specify

Examples of the screenshot copies of selected questions from the exDSS web interface:

Relevant risks

What types of risks do you consider relevant for your interior?

- **Mould**: Mould grows on organic materials. If there are no exceptional circumstances, your building should be susceptible to mould growth.
- **Insects**: Insects and rodents thrive on organic materials such as wood, paper and textiles.
- **Salt damage**: The crystallization of salt within porous materials cause mechanical damage. This is a common problem in buildings with stone or brick walls.
- **Mechanical damage**: Shrinking and swelling of materials due to fluctuations in temperature and humidity can cause cracking, flaking and delamination.
- **Other** risks not included in this system. If you choose this option you will be given the option to indicate levels of RH and T that you consider safe for the type of risk you have in mind.

Note: Interior here refers to the space to be controlled (e.g. a room within a building). Damage refers to ongoing or potential unwanted irreversible change within that space.

☑ Mould
☐ Insect
☐ Salt damage
☑ Mechanical damage
☐ Other

Mould

a) Is the risk for mould connected to a limited area only and not applicable to the whole building? Examples are rooms or enclosures that lack climate control and limited areas with cold bridges in the building envelope.

b) Do you have materials that are extremely susceptible to mould growth? Examples are leather bindings, dirty textiles or objects where mould already has grown.

c) Are the objects most susceptible to mould growth possible to move or to protect with enclosures? Examples: showcases, textile cabinets

☐ a) It is a local problem
☐ b) There are extremely susceptible materials
☐ c) Some objects at risk are movable

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 226973

Mechanical damage - proofed fluctuations

Have the objects susceptible to mechanical damage been exposed for the same climatic conditions for a long time (i.e. many years) without being damaged? In this case, they have adapted to the historic indoor climate and further risk of damages is limited if the fluctuations are kept the same. Existing cracks in paintings, furniture, ivory act as expansion joints, relaxing further stress.

- ○ Yes
- ○ No

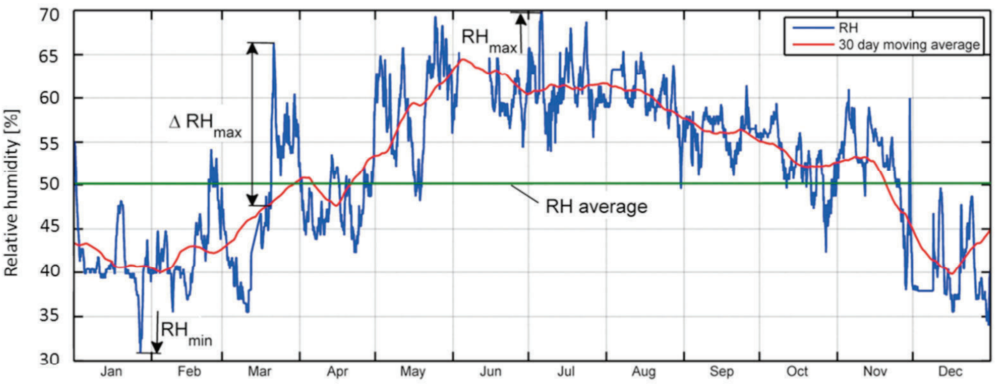
Mechanical damage, vulnerability

How vulnerable do you consider your most fragile object on display in the interior to be regarding mechanical damage? Objects in showcases etc not included.

- ○ Robust
- ○ Normal
- ○ Extremely vulnerable. Examples: chemically and biologically degraded materials, cross-grained veneers that have lost adhesion.

Historic climate

Specify your historic indoor climate by using measured data for the latest year or simulated data for your building. If you do not have all the data available, provide a reasonable guess.



Demonstration of relative humidity characteristics of yearly cycle measurements

- [ ] ... Maximum RH over the year
- [ ] ... Minimum RH over the year
- [ ] ... Maximum short-term fluctuation of RH (+-%). Fluctuations are calculated as deviations from a 30-day moving average
- [ ] ... Maximum T
- [ ] ... Minimum T
- [ ] ... Average RH over the year

Need for Temperature above zero

Is there a need to avoid temperatures below 0 to avoid freezing of free water?

- ○ Yes
- ○ No

After passing this part of the decision tree, the end-user is asked whether he or she wants to continue in the part focused on the Part 3: Indoor-climate control methods:

Continue with indoor climate control methods?

You have now finished part 1 (future outlook) and part 2 (risk assessment). Would you like to continue with part 3 (indoor climate control methods)?

- ○ Yes
- ○ No

If the answer is no, next to the Conclusion on the indoor-climate prediction, shown in Fig. 10, any of the following lists of the conclusions can be provided, depending on the answers by the end-user and depending on

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 226973

the logics which has been defined by the expert. If the answer of the above question is yes, then the system moves to the Part 3, which is outlined in the following subsection.

Overall list of conclusions available in Part 2 – Risk assessment

- Avoid mechanical damage: suggested target levels for different risk levels/proofed
- Avoid mechanical damage: suggested target levels for different risk levels/not proofed
- Prevent mould growth
- Mould on movable objects
- Prevent insects
- Prevent salt damage - general
- Prevent salt damage - salt not known
- Specific salt - calcium nitrate tetrahydrate
- Specific salt - Magnesium Nitrate
- Specific salt - Sodium Chloride
- Specific salt - Mirabilite
- Avoid freezing

Examples of the screenshot copies of selected conclusions from the exDSS web interface:

Avoid mechanical damage: suggested target levels for different risk levels/proofed

The target specifications to avoid mechanical damage are given for three risk levels: minimum, low and medium. The targets are derived from the historical indoor climate and based on the assumption that the objects in the collection has been "proofed" to the fluctuations of the indoor climate where they are located.

Suggested targets for minimum risk:
Max RH: 72
Min RH: 33
Maximum short-term fluctuations of RH: 13

Suggested targets for low risk:
Max RH: 80
Min RH: 30
Maximum short-term fluctuations of RH: 15

Suggested targets for medium risk:
Max RH: 88
Min RH: 27
Maximum short-term fluctuations of RH: 18

Short-term fluctuations are in this case defined as deviations from the 30-day moving average.

The suggestion is to keep the indoor climate parameters within the targets all of the time, i.e. they should never be exceeded. This has to be taken into account when the actual targets of the control system are set.

Remember that the further the indoor climate deviates from the outdoor climate, the higher is the risk of dangerous fluctuations in case of a failure of the climate control system.

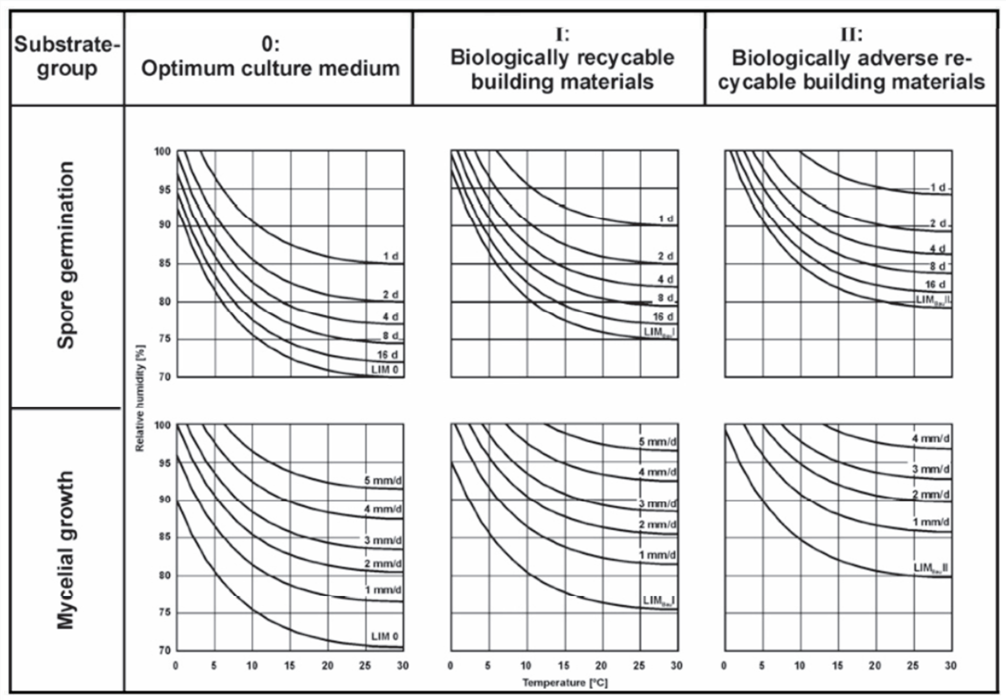
This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 226973

Prevent mould growth

Mould growth can be prevented with a combination of temperature and relative humidity control.

Several factors are known to have an effect on the development of mould fungi on wood: relative humidity, temperature, fluctuation of humidity, exposure time and surface quality. The charts below show conditions that indicate time to germination and rate of growth at different temperatures and humidities on three substrates of decreasing nutritional value (Sedlbauer 2002). These conditions have to be exceeded for a period of time (i.e. days at higher T, weeks or more at lower T) in order for mould to germinate. Have in mind that the microclimate varies within a building and that this has to be taken into account when actual set points are decided.

Below, an example of mould growth isopleth model is presented, which was proposed by (Krus and Sedlbauer) and which can be used for the risk assessment.



Isopleth systems for three categories of substrates, in order to regard the influence of the substrate on the formation of mould fungus

Isopleth LIM 0 - Minimum risk - Optimal culture medium
RH at different T 0°C: 90% 5°C: 80% 10°C: 75% 15°C: 73% 20°C: 72% 25°C: 71% 30°C: 70%

Isopleth LIM 1 - Low risk - bio-utilizable substrates (e.g. wall papers, plaster board)
RH at different T 0°C: 95% 5°C: 85% 10°C: 80% 15°C: 78% 20°C: 76% 25°C: 75% 30°C: 75%

Isopleth LIM 2 - Medium risk - substrates with porous structure (plasters, some woods)
RH at different T 0°C: 99% 5°C: 90% 10°C: 85% 15°C: 83% 20°C: 81% 25°C: 80% 30°C: 80%

NB: The air velocity over a surface will not affect mould growth, hence an increased ventilation is only useful if it lowers temperature and/or relative humidity.

Further reading:
Hukka, A. and Viitanen, H. 1999. A mathematical model of mould growth on wooden material. Wood Science and Technology 33(6)475-485.

Isaksson T, Thelandersson S, Ekstrand-Tobin A, Johansson P. 2010. Critical conditions for onset of mould growth under varying climate conditions. Build Environ 45:1712–21.

Reference

M. Krus, and K. Sedlbauer A new model for prediction and its application in practice. International Network for Information on Ventilation and Energy Performance

Mould on movable objects

If the mould growth risk is associated with objects that are movable, a first consideration is if they could be moved to another location. Another option is to arrange a locally controlled space within the building, i.e. a climatically controlled showcase or cabinet.

There were mould growing on dirty textiles in a church on Gotland. No other objects were affected. A climatically controlled cabinet was installed to protect the textiles.

Example 2: An archive was stored in the damp basement of a building. Instead of controlling the climate in the basement the whole archive was moved to another location, and the basement was kept clean from organic materials.

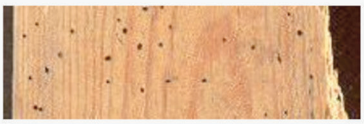
Prevent insects

Insects can be prevented with both temperature and humidity control. There are no universal limits for all insect groups, except that they will not survive in extremely dry, hot or cold environments. Generally a lower temperature will decrease the activity of insects. Some groups, such as woodborers, need a certain level om moisture content in the material to survive while moths thrive in relative humidities as low as 30 %.

Minimum risk
Woodborers: RH below 65%, T below 5°C
Silverfish and booklice: RH below 80%, T below 5°C
Webbing clothes moth: RH below 30%, T below 5°C
General recommendation: RH below 65%, avoid T over 15°C

Low risk
Woodborers: RH below 75%, T below 15°C
General recommendation: RH below 65%, avoid T over 20°C

Medium risk
General recommendation: RH below 80%, avoid T over 25°C



Holes in a wooden floor board made by the common furniture beetle

Further reading

- Brimblecombe, P. and Lankester. P. 2013. Long-term changes in climate and insect damage in historic houses. Studies in Conservation, vol. 58, no. 1, pp. 13-22.
- Child. R. 2012. The influence of the museum environment in controlling insect pests. Climate for Collections: Standards and Uncertainties. Eds. Jonathan Ashley-Smith, Andreas Burmester and Melanie Eibl. Munich. 419-424 Link
- Stengaard Hansen, L., Akerlund, M., Grontoft, T., Rhyl-Svendsen, M., Schmidt, A., Bergh, J. & Vagn Jensen, K. 2012. Future Pest Status of an Insect Pest in Museums, Attagenus smirnovi: Distribution and Food Consumption in Relation to Climate Change. Journal of Cultural Heritage, 13(1): 22–27.

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 226973

Prevent salt damage - general

Salt damage occurs when a salt in solution precipitates (i.e. crystallize/take solid form) within a porous material. This happens when a certain crystallization threshold of relative humidity is passed. Every cycle of RH over this threshold will add to the risk of damage. If the construction part is humid (e.g. a wet wall) there is a risk that the salt crystallization occurs inside the wall if the surface is dried out.

Salt damage is caused by one of two mechanisms. In the first, the salt attracts moisture at high humidities and deliquesces, becomes a liquid solution. When the humidity falls the salt re-crystallizes exerting pressure on surrounding material. This happens at specific relative humidities which, for many salts may be temperature dependent. In the second mechanism the salt transforms (via a liquid phase) from one crystal form to another though a change in the degree of hydration. The change in volume may exert pressure that causes damage. These transitions are both temperature and humidity dependent. Unfortunately it is common for salt problems to be caused by mixtures of salts, in which case it is more difficult to determine an exact critical RH.

Both of these damage mechanisms can be avoided by keeping fluctuations of relative humidity above or below certain thresholds which are specific for the salt mixture. There are however large uncertainties in using the links between environmental fluctuations and damage caused by salts. In the case of crystallization below the surface in the pores of the material the environment is not known and may not resemble that of that measured in the building.

If the moisture transport through the construction part is limited, there will also be a limitation of the salt transport. One should therefore be cautious with decreasing the indoor absolute humidity when there are salt damages, as this can increase the moisture transport.

Further reading

Charola, A. Elena (2000): Salts in the Deterioration of Porous Materials: An Overview. In Journal of the American Institute for Conservation 39 (3), pp. 327–343. Available online at Link

D'Armada, Paul (2005): Prediction and Prevention of Hygroscopic Salt Activity in Historic Buildings. In Journal of Architectural Conservation 11 (1), pp. 28–41. Available online at Link

Doehne, Eric (2002): Salt weathering: a selective review. In Geological Society, London, Special Publications 205 (1), pp. 51–64.

Specific salt - calcium nitrate tetrahydrate

You should try to avoid cycling relative humidity over the following thresholds. To be safe, try to keep RH either above (preferred to decrease moisture transport) or below the threshold with a marginal of at least 5% RH.

Equilibrium relative humidity at different temperature

T [deg. C]	0	5	10	15	20	25	30
RH [%]	90	80	75	73	72	71	70

Source: D'Armada, Paul (2005): Prediction and Prevention of Hygroscopic Salt Activity in Historic Buildings. In Journal of Architectural Conservation 11 (1), pp. 28–41.

Part 3: Indoor climate control methods.

This part of the decision support system investigates which indoor climate control methods are suitable for the defined building interior. For this purpose, the information received in the Parts one and two is also utilized. The overall list of questions in this part is listed as follows:

Overall list of question available in Part 3 – Indoor climate control methods

- Existing climate control?
- Zone heating possible?
- Type of dehumidifier?
- Thermal comfort?
- Heating during summertime?
- Ventilation rate?
- Relative humidity - need to lower during winter?

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 226973

- Relative humidity - need to lower during summer?
- Relative humidity - too dry during winter?
- Natural ventilation?
- Is there a moisture surplus in the building?
- What is the source of the moisture surplus?
- Conservation versus comfort?
- Economic aspects - installation costs?
- Priorities concerning the energy demand of the control system?
- Maintenance?
- Invasiveness?
- How to measure?

Examples of the screenshot copies of selected questions from the exDSS web interface:

Existing climate control

Specify the existing climate control system(s) used in the interior

- ☐ Permanent heating system
- ☐ Portable heaters
- ☐ Dehumidifiers
- ☐ Humidifiers
- ☐ Mechanical ventilation

Type of dehumidifier

Specify a type of the humidifier

- ○ Condensation dehumidifier
- ○ Adsorption dehumidifier
- ○ Do not know

Thermal comfort

Is heating to provide thermal comfort needed?

- ○ Yes, permanent heating
- ○ Yes, intermittent heating
- ○ No

Heating during summertime

In relation to thermal comfort, would it be possible to heat the interior in the summer in order to reduce relative humidity?

- ○ Yes
- ○ No

Ventilation rate

Provide information on ventilation rate when all the windows and doors are closed

- ○ Very high - permanently open/broken windows
- ○ High - leaky windows/doors (you will feel drought close to the window/door)
- ○ Normal (no drought, but windows/doors are not airtight)
- ○ Airtight windows/doors

Relative humidity - need to lower during winter?

Is there a need to lower the relative humidity during the cold part of the year?

- ○ No
- ○ Yes, a small need for a limited period
- ○ Yes, it is very humid

Relative humidity - need to lower during summer?

Is there a need to lower the relative humidity during the warm part of the year?

- ○ No
- ○ Yes, a small need for a limited period
- ○ Yes, it is very humid

Is there a moisture surplus in the building?

In most buildings, there is a surplus of moisture within the building in relation to outdoors. The easiest way to find out if this is the case is to measure the absolute humidity both inside and outside over an extended period (eg. one year) and compare the mean values.

- ○ Yes
- ○ No or very small surplus.

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 226973

What is the source of the moisture surplus?

The moisture surplus can originate from the building envelope (eg. rain penetrating walls, moisture from the ground, leakages) or from activities related to the use of the building (eg. visitors). *Example: moisture from the ground penetrating the walls on a manor house on Gotland*

- ☐ From building envelope
- ☐ Related to use

Balance the importance of keeping indoor climate conditions with respect to object/building conserva

- ○ Conservation is the only priority
- ○ Conservation is the priority, but minimal level of comfort should be guaranteed
- ○ Conservation and comfort are equally important
- ○ Comfort is the priority, but conservation should be improved too, if possible

Economical aspects - installation costs

Assess the priority concerning the costs needed for the installation of the control system

- ○ Low costs is the key requirement
- ○ Low costs is important, but not crucial
- ○ Moderate costs possible, if well justified
- ○ High costs possible, if well justified

Assess the priority concerning the energy demand of the control system

- ○ Low energy consumption is the key requirement
- ○ Low energy consumption is important, but not crucial
- ○ Moderate energy consumption is possible, if well justified

Invasiveness

What type of repair and renovation of the building construction (e.g. walls, windows) can be done ?

Remark:If you tick **None**, all the above options will be considered as not applicable even if they are ticked too.)

- ☐ Window renovation
- ☐ Slight reconstruction of interior walls possible
- ☐ Slight reconstruction of exterior walls, roof possible
- ☐ Passive mitigation measures, such us windows shielding can be introduced
- ☐ None

The overall list of possible additional conclusions corresponding to these parts is given as follows:

Overall list of conclusions available in Part 3 – Indoor climate control methods

- Recommended humidity control: Condensing dehumidifiers during summer
- Recommended humidity control: Condensing dehumidifiers in summer and conservation heating in winter
- Recommended humidity control: Sorption dehumidification during winter
- Recommended humidity control: Sorption dehumidification all year round
- Recommended humidity control: Conservation heating all year round
- Recommended humidity control: Conservation heating during winter
- Adaptive ventilation
- Wall heating, Temperierung
- Passive measures
- Intermittent heating
- Local Radiative heating (Friendly heating)
- Natural ventilation
- How to measure and analyse the indoor-climate

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 226973

- General recommendations - non-invasive approaches

Examples of the screenshot copies of selected conclusions from the exDSS web interface:

Recommended humidity control: Condensing dehumidifiers during summer

If the demand for dehumidification is mainly during the summer and early autumn, condensing humidifiers can be used

More information about dehumidification can be found in this document.

Condensing dehumidifier used during summer in a church on Gotland

Recommended humidity control: Sorption dehumidification during winter

With no problem during summer, the recommendation is to us a sorption dehumidification during winter

More information about dehumidification can be found in this document.

Sorption dehumidifier, temporary installation in a church on Gotland

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 226973

Recommended humidity control: Conservation heating all year round

If there is an existing heating system or a need to achieve thermal comfort, the recommendation is to use conservation heating. This strategy might lead to temperatures above the thermal comfort zone during summer.

Principal function
Conservation heating is the concept of heating a building in order to keep a constant relative humidity. The temperature is continuously adjusted and not controlled to a constant set point. The appropriate temperature is given by the water vapour content of the air. The humidity comes from the outside air by infiltration and in some cases also from rising damp or rain penetrating the walls. Conservation heating is mainly used in historic buildings, which are not used in the winter, so there is usually little humidity generated by human activity. More information can be found in this document.

Applicability
Conservation heating can be implemented in any building with permanent or temporary heating installations. The heat must either be adjusted manually on a daily basis or controlled by a humidistat. Moveable electric heaters are frequently used because they need little installation work. Central heating is more invasive due to the need for piping, but allows for the use of different heat sources.

Present use and experience
Conservation heating has been used for many years to maintain a Medium relative humidity in historic houses in winter. It is a simple and robust climate control strategy, but the stability of RH depends on the air infiltration rate and the temperature control. A leaky house with high thermal stability will experience large variations in RH. Humidistatic control may suffer the problem of positive feedback in the case of evaporation from damp walls or floors.

Performance
As energy conservation becomes more important, conservation heating is less attractive for climate control. The heat loss is much larger from historic buildings is than from modern houses due to poor thermal insulation of walls and ceilings. Leaky doors and window further increase the heat loss even at reduced temperature. It is usually not possible to improve the thermal performance of the building envelope, so the source of energy must be efficient.

Costs
The installation costs depend on the conditions in the building. If an existing heating system can be reused, the cost is limited to a control system. Energy costs are much lower as compared to heating for comfort but generally higher as compared to dehumidification high and there is some need for maintenance. Heat pumps are well suited for conservation heating, this will reduce energy costs, but the investment is high.

Other
A peculiar aspect of conservations heating is that it is sometimes required to heat in summer in order to keep the RH at an acceptable Medium level. This may cause uncomfortably high temperatures.

Results from case studies
The concept of conservation heating is used in Kommandørgården, DK. The traditional farmhouse is located on the island Rømø at the west coast of Jylland, exposed to the strong winds from the North Sea. The building has solid walls of brick masonry with wooden panels or glazed tiles on the inside. The floors and ceilings are wooden planks and the roof is thatched. It is used as an open air museum in summer, and climate control is not possible due to the many visitors during the day. In winter conservation heating is introduced with portable heating fans the three main rooms. Each heater is controlled by a hygrostatic switch placed in some distance from the warm air stream. Climate records for shows that the temperature is raised from 2-3 ˚C to 8-12 ˚C, and the RH is maintained at 60 – 70 %. The heating is stopped again when the museum opens in the spring. In summer the climate is much more unstable due to the large influence of the outside air through open doors.

The traditional farmhouse Kommandørgården is located at the West coast of Jylland. It has conservation heating with moveable electric heaters controlled by hygrostats.

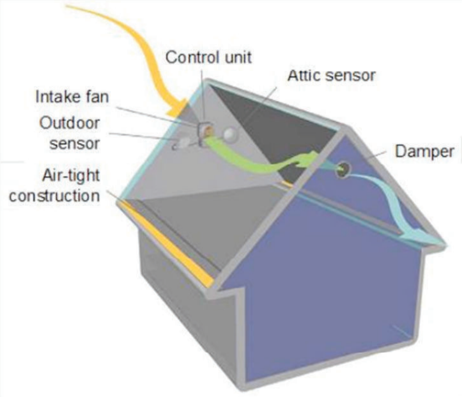
This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 226973

Adaptive ventilation

A surplus of moisture in the building opens up for the possibility to use adaptive ventilation, which is also an easy to apply control method with low installation costs and energy demand.

Principal function
Air exchange in a historic building, through infiltration or ventilation, often has an important effect on the indoor climate in general and humidity in particular. Depending on outdoor and indoor climate conditions, air exchange can either increase or decrease the RH in a building. A classic example is an unheated building where doors and windows are opened in the spring to warm up the building. Once inside the building, the warm outside air is cooled off and RH increases. Hygroscopic materials such as plaster and wood are saturated and condensation may occur on cold surfaces.

Adaptive ventilation (see this document for more information) can be used to reduce RH below risk levels for biodeterioration. The basic control condition is to ventilate when AH inside the building is higher than outside. Equally important is not to ventilate when AH outside is higher. Thus, both air tightness and ventilation must be controlled and adapted through the use of mechanical fans and dampers controlled by indoor and outdoor climate sensors.

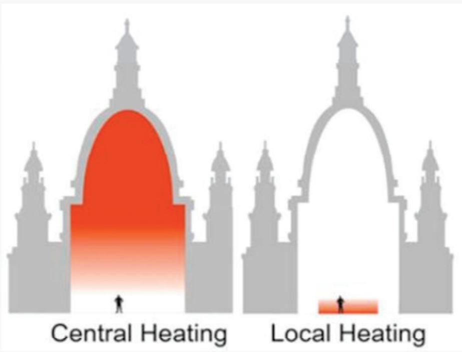


The technical installations for adaptive ventilation

Local Radiative heating (Friendly heating)

If there is no need to heat the whole interior for reasons of comfort, a local radiative heating system can be a good solution. It combines localized comfort, good preservation and low energy use.

Principal function
The objective of local radiative heating is to heat only designated parts of a building or a room in order provide either comfort or better preservation conditions. While achieving the desired heating effect locally, unwanted climatic disturbance in the building or room as a whole can be limited. The basic technical solution is to place a number of low-temperature radiant sources in the room to heat designated zones. The heaters may consist of low temperature radiators, heating foils integrated into structures or electric heating glass. The principal idea is to direct the heat to where it is required and to reduce heat dispersion and to provide as much radiant area as possible as required by the different thermal comfort needs of the various parts of the human body.



General heating as compared to local heating. The picture indicates the difference in temperature distribution.

Applicability
Local radiative heating can be used in building where there is a need to:
• Provide comfort in a limited zone
• Provide better preservation in a limited zone
• To maintain a stable climate with respect to conservation in the rest of the room or building.
Local radiative heating is particularly useful for intermittent heating. The visual and invasive impact depends on the type of installation, but it is generally modest in relation to installations for general heating. Typically this kind of heating system is used in churches, but it can be applied in any kind of building

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 226973

Wall heating, temperierung

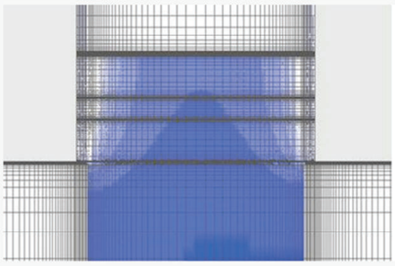
Wall heating can be an option to achieve moderate comfort and a favourable environment for the collection combined with moderate energy consumption. It requires a permanent installation within or close to the outer walls.

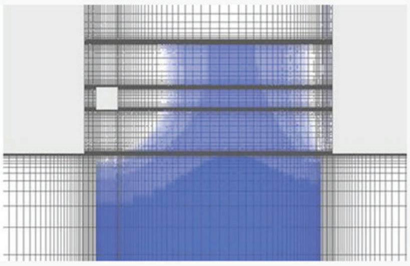
Principal function
The "Temperierung" method is based on providing continuous heating to the building envelope. Normally this is done with heating tubes or electric coils built into the inner side of outer walls, favourably put in newly made slits. The slits with heating pipes are closed with plaster. If slits are not possible painted pipes can be mounted on the surface of the walls instead. The system should heat all critical points in the construction (e.g. base of the walls, corners , beam heads) where otherwise high relative humidity and even condensation may occur. Thereby it helps to prevent mould or algae growth in massive buildings.

Applicability
Temperierung is used mainly for conservation, rather than comfort heating.The advantages of the wall heating of building components lie mainly in its ability to reduce high indoor humidity, to avoid moisture damages and helping to dry out wet building parts. It can help to reduce draughts and dust soiling of the walls.

In case of locally high moisture contents in materials on internal surfaces caused by rising damp, condensation in summer or other effects it is a useful method.This technology allows the reduction of moisture in certain problematic areas and can avoid for example microbial growth due to drying effects. If correctly applied, the wall heating is a reasonable and appropriate measure in many cases to preserve precious cultural heritage. Under this aspect, other topics, e.g. energy saving, may be of secondary importance.
Temperierung should not be applied in the case the installation of the pipes would damage valuable surfaces of the building.

Present use and experience
Temperierung, i.e. wall heating is a commercial, regularly used product. Widest application is in southern and eastern Germany, but also Austria and some applications in other European countries.





Left, typical picture of rising damp in a wall, right, drying out of wall due to wall heating (Temperiering) with heating tubes below the wall surface.

General recommendations - non-invasive approaches

Recommendations for non invasive micro climate approaches and for energy efficiency in historic buildings:

- The envelop of the building should be air tight
- The thermal quality should be – if possible – improved (insulation of the roof, improvements of windows)
- Buffer rooms should be organized
- The windows should be improved, especially the shading
- UV protection is necessary
- Heat should be distributed in the house only by means of radiation, never through convection
- Heat should be distributed in the cold outer walls in order to avoid mould
- Ventilation air should be brought in unheated. Never heat with ventilation (dust and outside drift of inside humidity)
- The air exchange rate should be as low as possible (i.e. thermostat valve)
- The control of heating, ventilation and cooling should be as simple as possible
- Control of ventilation should organized through air quality and through comparison of absolute humidity inside and outside with activation, when there is no danger of outside climate
- Lower room temperature in winter as much as possible
- Humidification always by means of decentralized systems, never through central units in order not to pollute ventilations ducts with dust and mould
- Choosing always housing systems which are very simple and economic in order to keep running costs and maintenance costs lowest possible
- Using alternative sources of energy

Outline of the decision process

In order to complete information on the complexity of the above described decision support module on indoor-climate risk assessment in historical buildings, let us mention that the exDSS project includes 128 control words, eight internal rules and two connectors (one for finding the GPS coordinates for the given location of the building and the other for deriving information from the risk maps which are stored in the format of data matrices).

In each of the three parts, we listed all the questions which are available. However, some of the questions are skipped as a rule in the decision process, depending on the answers by the end-user and depending on the given state of the pool of control words. For example, if the end-user answers that he or she wants to address mould growth risk only, the questions related to the other damage phenomena (salt, insect and mechanical) are skipped.

An example of the whole decision process is outlined in Figs 11-13 in a form of a sequence diagram. As can be seen in Fig. 11, we start with providing information on the building structure and location. Then mould is identified as the relevant risk from the set of available damage risks. Consequently, more data are being collected by the system. It is defined by the end-user that the mould growth problem is local and that the historic data are available. As can be seen, the branches which are not relevant for solving the current problem are skipped. The decision tree then continues in Fig. 12, where the end-user specifies the historic climate conditions and after answering several subsequent questions (some of them are not visualized in the given tree), the information on the risk is processed jointly with the information on the predicted climate obtained from the risk maps for the defined type of building and the location of the building. Then, relevant conclusions on the indoor-climate conditions and the risk assessment are selected by the system. As the end-user chooses to continue with the climate control, the conclusions are not provided yet. After passing a set of the questions in this branch of the decision tree, where the end-users provides information e.g. on the existing technical solution of the indoor-climate control system, information on the comfort requirements, additional properties on the building envelop, such as airtightness, moisture surplus existence, and specifies the economical and energy consumption constraints, the system selects additional relevant conclusions and visualise them together with the conclusions generated in the previous parts of the decision process.

It needs to be emphasised that the recommendations provided by the system cannot be considered as the definite, i.e. the final and perfect solutions. The system just provides a list of solutions and recommendations which can be relevant for the given problem. The purpose of the system is truly to provide supportive information only. The final solution needs to be specified after most advanced and comprehensive analysis that needs to be done by an expert in the field.

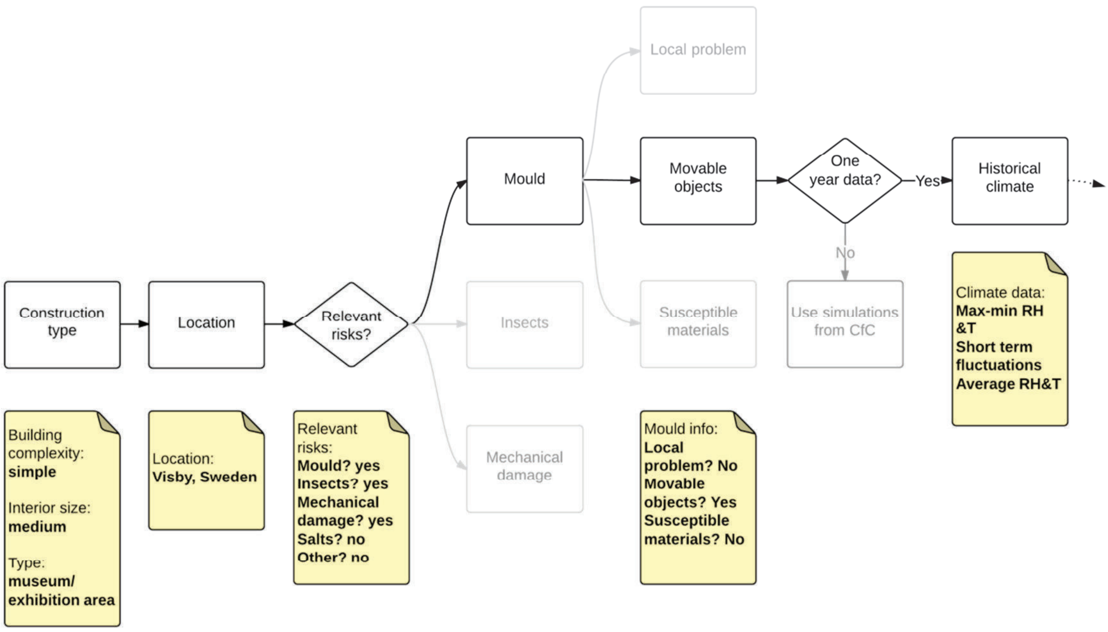


Figure 11 An outline of the decision support process in the Parts 1 and 2 of the module for the indoor-climate risk assessment and control in historical buildings - the first stage

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 226973

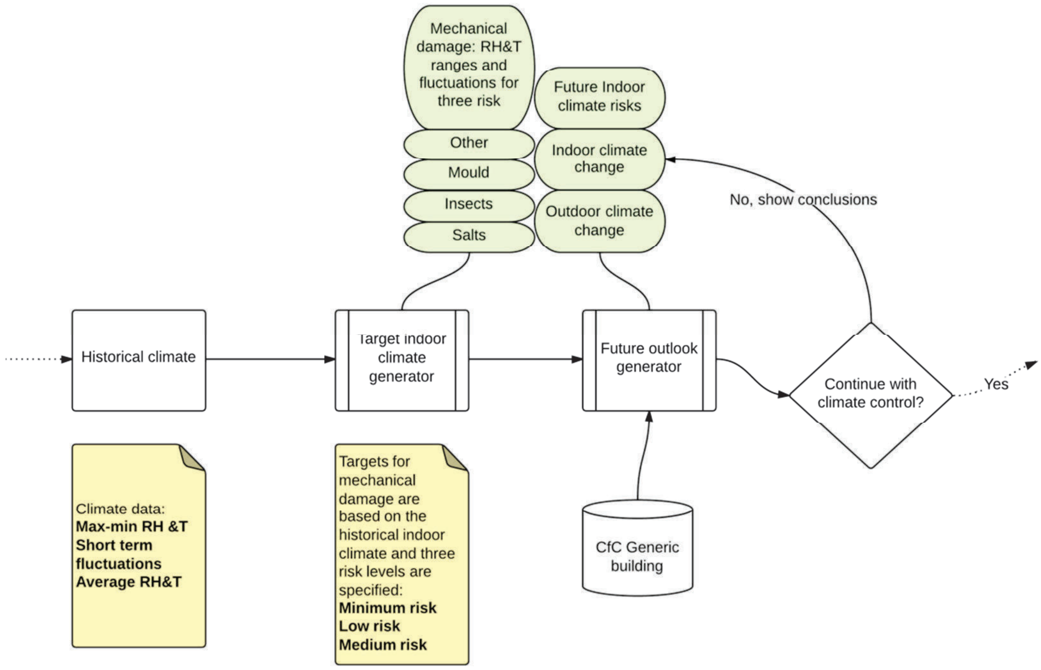


Figure 12 An outline of the decision support process in the Parts 1 and 2 of the module for the indoor-climate risk assessment and control in historical buildings - the second stage

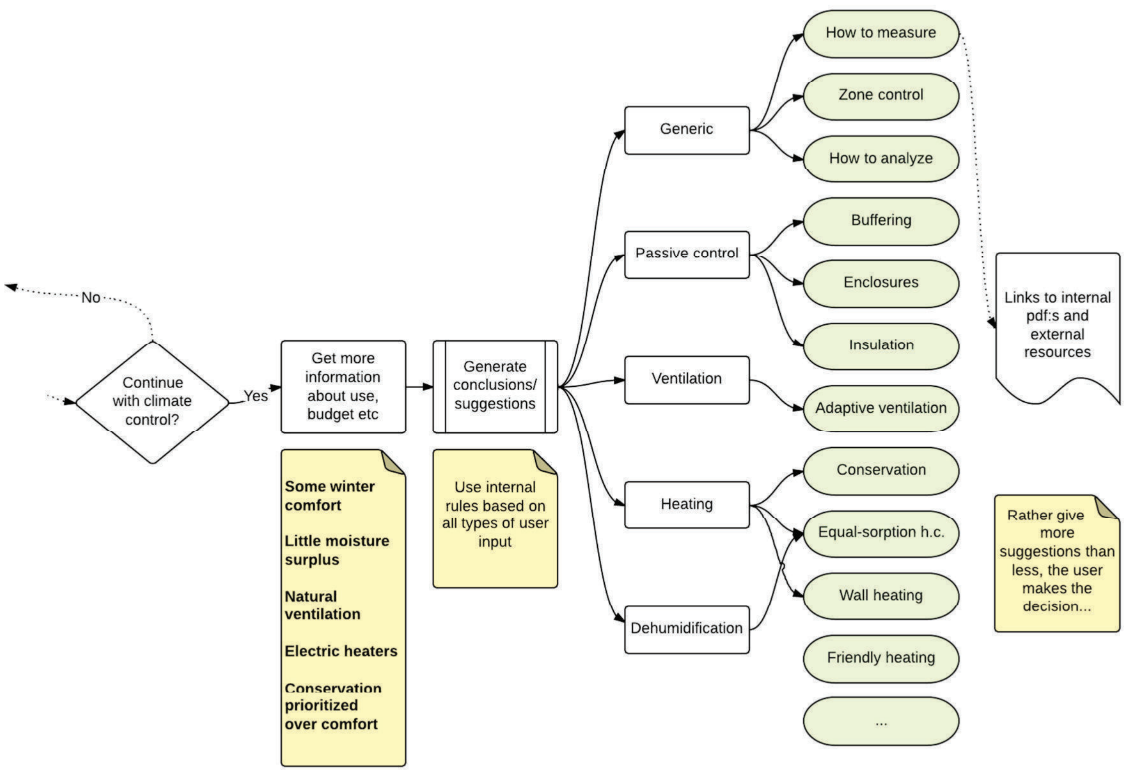


Figure 13 An outline of the decision support process in the Part 3 of the module for the indoor-climate risk assessment and control in historical buildings

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 226973

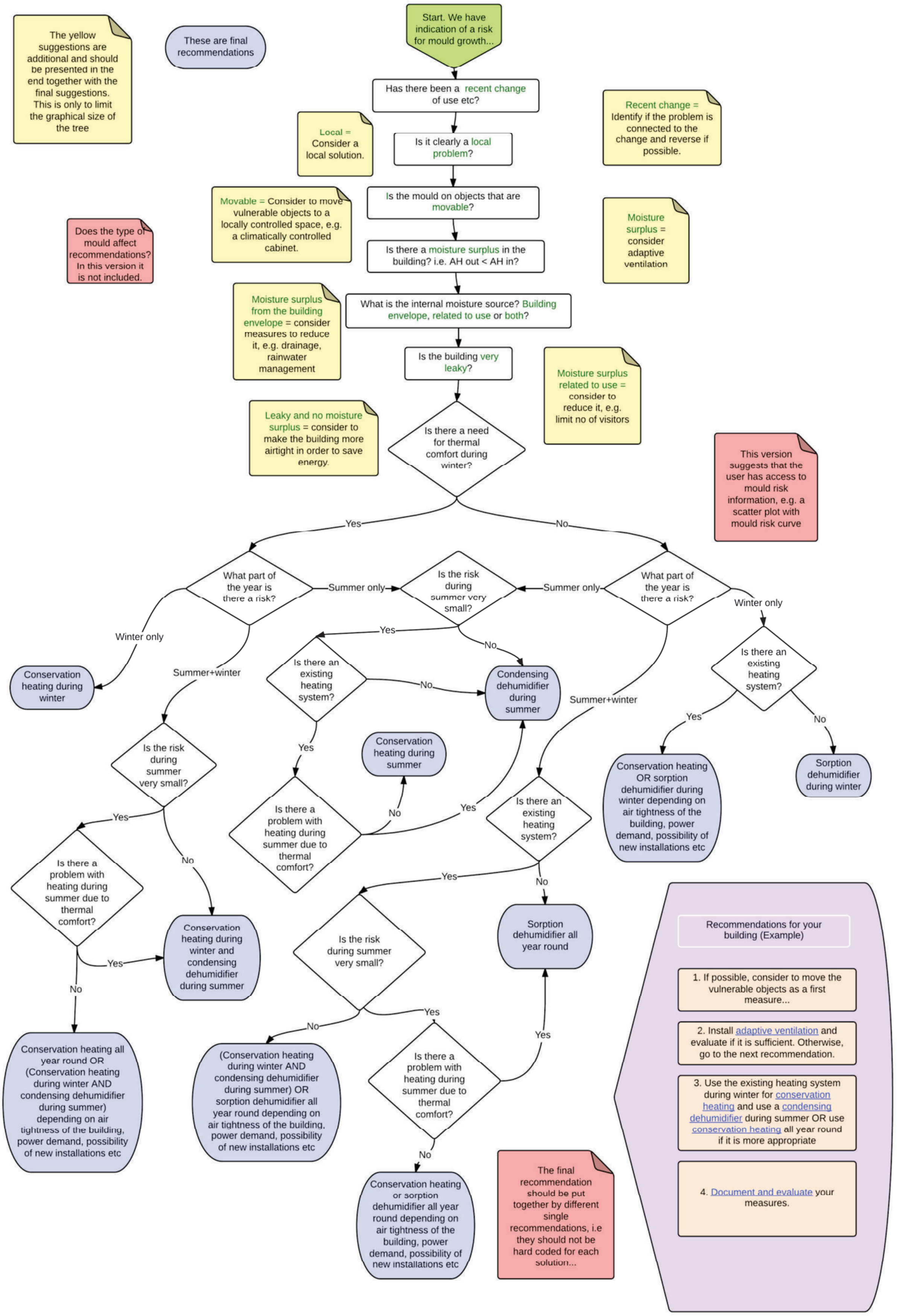


Figure 14 An example of a decision tree used for development of the risk assessment and control under identified damage by mould

In order to provide a deeper look to the process of forming the architecture of the decision tree, we provide more detailed and also complex tree for the problem of mould growth in Fig. 13. As can be seen, many aspects need to be taken into consideration even for this relatively simple decision task. The number of possible combinations of all of the aspects is relatively high and it is not a straightforward task to handle all of them. This is one the reasons why the system needs to be considered as open and all the functionalities need to provide a possibility for the adjustments and extensions.

Summary

The exDSS software, which is described in the first part of the report and which has been developed for the purposes of the Climate for Culture project is fully functional open source software for developing decision support tools. The applicability is not only in the field of cultural heritage, but it can be used anywhere, where the know-how of the experts can be structured into a form of logic decision trees or diagrams. As the architecture of the exDSS software is open, we suppose and plan that its development will continue in the framework of successive projects. Future steps may be focused on including fuzzy logic variables and rules, self-learning utilities, automated integrity checking, etc.

The decision support tool for indoor-climate risk assessment and control, which have been outlined in the second part of the report, is freely available at the following web link:

http://cfc.exdss.org/dss/riskcon

Along with the whole philosophy of the activities in developing the decision support methodologies within the Climate for Culture project, the above described decision support module is open for further adjustments and development either by the project team members (within subsequent PhD activities) or even by a different team under a different project. Due to flexibility of the exDSS software, various clones of the project can be created which are then free for modification. Thus, rather than a final and closed product, we provide a platform for creating the decision support tools. We also see a large potential in the possibility to derive the future indoor-climate risk indices from the wide set of maps, which has been provided as one of the main results of the Climate for Culture project. Let us also remark that the given decision support module has also been used for dissemination of the Climate for Culture project results. Particularly, the Case study reports and various guideline texts are available directly on the web interface of the Conclusions or are web-linked to them as pdf files.

Contact Authors

Tomáš Vyhlídal[1], Jiří Šolc [2],

[1]Contact author for the decision support module: tomas.vyhlidal@fs.cvut.cz
[2]Contact author, developer and administrator of the exDSS software: Jiri.Solc@fs.cvut.cz

References

[1] D 7.1 (2012) New algorithms for optimal control of the relative humidity and temperature using equal-sorption humidity control as well as approaches including combinations of active and passive climatisation, Deliverable report of the Climate for Culture project

[2] D 7.2 (2014) Report on minimizing energy consumption needs of typical historical sites (case studies), revitalization and enhancement of historic climatisation systems, use of the alternative energy sources, Deliverable report of the Climate for Culture project

[3] D 4.1 (2012) Report on newly gathered knowledge about damage functions based on the various climate data interpretations existing throughout Europe, Deliverable report of the Climate for Culture project

[4] D 4.2 (2014) Report on the set up of a range of new damage functions in relation to climate change scenarios and microclimatic responses, Deliverable report of the Climate for Culture project

[5] D 5.1 (2013) Dataset of climate risk maps to be implemented in the Analysis and Decision Support System software, Deliverable report of the Climate for Culture project

[6] D 5.2 (2014) Report on the climate change impact on movable and immovable cultural heritage

throughout Europe as a contribution to future IPCC Reports, Deliverable report of the Climate for Culture project

[7] Bratasz, Ł., Allowable microclimatic variations in museums and historic buildings: reviewing the guidelines, Climate for Collections - Standards and Uncertainties, Jonathan Ashley-Smith, Andreas Burmester, Melanie Eibl (eds), Archetype Publications, London, (2012) 11-19.

[8] Thomson, G., The Museum Environment, 2nd edn, Butterworth-Heinemann, London (1986) 268–269.

[9] Mecklenburg, M.F., Tumosa, C.S., and Erhardt, D., Structural response of painted wood surfaces to changes in ambient relative humidity, in Painted Wood: History and Conservation, ed. V. Dorgeand F.C. Howlett, The Getty Conservation Inst., Los Angeles, (1998) 464–483.

[10] Bratasz Ł, Acceptable and non-acceptable microclimate variability: the case of wood, Chapter 4 in Basic environmental mechanisms affecting cultural heritage, Nardini Editore, Firenze, edited by D. Camuffo, V, Fassina, J. Havermans, (2010).

[11] Camuffo, D., Microclimate for Cultural Heritage. Elsevier Science Ltd., Amsterdam, London, (1998)

[12] ASHRAE Handbook - HVAC Applications, Chapter 21, Museums, libraries, and archives, (2003) 21.1-21.16.

[13] Conservation of Cultural Property - Specifications for temperature and relative humidity to limit climate-induced mechanical damage in organic hygroscopic materials, European Standard EN15757, (2010)

[14] Broström, T., Vyhlídal, T., Simeunovic, G., Larsen, P.-K., and Zítek, P., Evaluation of different approaches of microclimate control in cultural heritage buildings, Climate for Collections - Standards and Uncertainties, Jonathan Ashley-Smith, Andreas Burmester, Melanie Eibl (eds), Archetype Publications, London. (2012), 105-115.

[15] Zítek, P. - Vyhlídal, T. (2009) Model-based moisture sorption stabilization in historical buildings. Building and Environment, vol. 44, no. 6, p. 1181-1187

[16] Zitek P., Vyhlidal T., Sladek O., Sladek A., Simeunovic G. (2011) Equal-sorption microclimate control applied to the Holy Cross Chapel at Karlstejn Castle. In Proc. Developments in Climate Control of Historical Buildings. Edited by Kilian R., Vyhlidal T., Brostrom T., Fraunhofer IRB Verlag, ISBN 978-3-8167-8637-5, p. 57-65.

[17] Vyhlídal, T. - Zítek, P. - Camuffo, D. - Simeunovič, G. - Sládek, O. - et al.: Relative Humidity Control in Historical Buildings Allowing the Safe Natural Indoor-climate Fluctuations. In: Proceedings of the 3rd European Workshop on Cultural Heritage Preservation. Milano: Felix Verlag editrice, 2013, p. 77-84.

[18] É. Meyer, P. Grussenmeyer, J.-P. Perrin, A. Durand, P. Drap, A web information system for the management and the dissemination of Cultural Heritage data, Journal of Cultural Heritage 8 (2007) 396-411

[19] C.-J. Kim, W. Sung Yoo, U.-K. Lee, K.-J. Song, K.-I. Kang, H. Cho, An experience curve-based decision support model for prioritizing restoration needs of cultural heritage, Journal of Cultural Heritage, Volume 11, Issue 4, October–December 2010, Pages 430-437

[20] V. Ferretti, M. Bottero, G. Mondini , Decision making and cultural heritage: An application of the Multi-Attribute Value Theory for the reuse of historical buildings, Journal of Cultural Heritage, 2014, DOI: 10.1016/j.culher.2013.12.007

[21] Z. Huijbregts, R.P. Kramer, M.H.J. Martens, A.W.M. van Schijndel, H.L. Schellen, A proposed method to assess the damage risk of future climate change to museum objects in historic buildings, Building and Environment, Vol. 55, 2012, Pages 43–56

[22] Martens, M.H.J. (2012). Climate risk assessment in museums : degradation risks determined from temperature and relative humidity data. Eindhoven: Technische Universiteit Eindhoven. ((Co-)promot.: prof.dr.ir. M.H. de Wit, dr.ir. H.L. Schellen & H.A. Ankersmit).

[23] Physics of Monuments, http://www.monumenten.bwk.tue.nl, TUE Eindhoven

[24] Sustainable Traditional Buildings Alliance (STBA) (2012), Responsible retrofit guidance wheel, http://responsible-retrofit.org/wheel/