Indoor Climate in Churches

– Problems and Solutions

Seminar in Riga, November 2004

Baltic
Sea
States

Heritage Co-operation

Riksantikvarieämbetet

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Riksantikvarieämbetet

Riksantikvarieämbetet/
National Heritage Board
P.O. Box 5405
SE-114 84 Stockholm, Sweden
Phone +46-8-5191 8000
Fax +46-8-5191 8083

Photos Front page: Above, left: Church in Tervola, Finland. Photo: Sakari Mentu, National Board of Antiquities. Above right: Church of St. Virgin Mary's Visit in Kamalduliai
Convent of Pazaislis, Lithuania. Electrical under-floor heating. Photo: Diana Pikšriene.
Below, left: St. John's church in Cesis, Latvia. Photo: Karna Jönsson. Below, right: Church in Lau, Gotland, Sweden. Photo: Stefan Haase.
Photos inside by the authors if not stated otherwise.

This report is a summary of a seminar in Riga in November 2004. The seminar was arranged within the frame of the Co-operation on Cultural Heritage in the Baltic Sea Region.

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Editor Agnese Rupenheite and Hans Sandström
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Cultural Heritage Co-operation in the Baltic Sea Region

Hans Sandström (Sweden)

This report is a summary of a seminar held in Riga on the 11th of November 2004. Each lecturer has made a short version of his/her lecture and two appendices are added:

1. "Reflections after a seminar on indorr climate", by Ilmars Dirveiks, architect and contact for Latvia in the working group on Building Preservation and Maintenance in Practice.
2. "Preventive Conservation by Climate Control", a paper by Tor Broström from the University of Gotland (Sweden). Tor Broström is responsible for the follow-up of the seminar, by organizing a Baltic Region network.

The seminar is one in a series of seminars and workshops, organized within the Baltic Sea Region. Co-operation on Cultural Heritage in the Baltic Sea Region was initiated by the ministers of culture in 1997. Four working groups, in four different fields, have been active since the year 2000. The working group on Building Preservation and Maintenance in Practice has members from all Baltic Sea countries but Denmark and the Russian Federation; Germany is participating through the State of Mecklenburg-Vorpommern. The group is chaired by Sweden and Latvia.

The long-term objective for the group is to enhance good management of the built heritage in the region. There are three aims for the work programme 2004–2006:

- to compile a Reference Library on Good Practices
- to create Networks for Professional Co-operation
- to establish BSR Guidelines on Sustainable Management

Good management for the built heritage is highly depending on specialized knowledge and on the survival of traditional crafts and building materials. The best way to enhance good management is to demand the genuine knowledge and skills, to work for a sustainable market for the trained masons, carpenters, architects, engineers, historians, restorers etc., for the traditional building materials and the adapted products.

In the period 2001–2004 a series of seminars and workshops has been arranged, documentation has been compiled on traditional building materials and a documentary film has been produced and distributed. Reports can be found on the web-site: http://balticheritage.raa.se/groups/building.htm/

As objects of study and reference for 2004–2006 the working group has selected "church buildings", i.e. not only churches but also synagogues and other "houses of faith". These buildings represent advanced techniques and craftsmanship and structural and maintenance problems are constantly present. Their future function is an urgent question and thus the adoption to new uses and to modern demands like heating.

Recommendations on climate control in historical churches

Juris Dambis (Latvia)

The State Inspection for Heritage Protection would like to draw attention to the problems concerning heating in historical churches. In order to work on the problems, international co-operation has been initiated. The result of the co-operation was international seminar "Indoor Climate in Churches – Problems and Solutions" in 11–12 November, 2004 in Riga. During the seminar recommendations were elaborated in order to facilitate finding professional solutions of the problems.

- The basis of preservation of cultural monuments is information, maintenance, control of changes and professional management.
- Microclimate is essential factor for long term physical preservation of church buildings and interior items.
- The most degrading factors in utilisation of churches are too high or too low humidity and especially rapid changes of humidity level (that can be solved by thoughtful heating and ventilation of the object).
- In order to provide more comfortable conditions in the churches, inappropriate systems are used thus causing severe damage the repair of which is more expensive than establishing appropriate heating system.
- Changing original window and door isles in order to save energy, damages cultural value and authenticity of the objects and only well-advertised companies benefit from it.
- Regular control of microclimate is obligatory in culture historical churches with heating.
- It should be prohibited to use new and untested heating systems in culture historical churches.
- When choosing the heating system it is important to pay attention not only to visual impact, but primarily to the influence of climate to the building and interior on the whole, as well as fire security.
- There are positive practices in experience of heating systems in churches, which are not connected with permanent heating of the whole building, but only with temporary heating during particular period and within particular areas, thus enabling to control the humidity regime within the whole object.

Fundamentals of indoor climate

Tor Broström (Sweden)

Creating an indoor climate, separated from the outdoor climate, is the basic purpose of most buildings. On one hand, the climate is meant to provide comfort for people who live and work in the buildings. On the other hand, climate induced degradation is one of the major hazards to our cultural heritage. The best conservation strategy is to act in order to prevent damages and degradation rather than reacting afterwards. Climate control, when properly used, is an efficient and cost-effective method for preventive conservation. Too often the discussion on climate control is focused on the technical solutions whereas the real difficulty lies in establishing proper climate criteria.

The thermal indoor climate is defined by:

- Air temperature
- Surface temperatures
- Relative humidity
- Air movements

In order to control the indoor climate we need a physical and quantitative understanding of the complex interaction in the building between air, the building structure, objects and interiors and people.

The proper indoor climate is determined with respect to:

- **Comfort** is a subjective parameter that describes to what extent humans find the indoor climate acceptable. People are very sensitive to temperatures, but not so sensitive to relative humidity. The comfort temperature range depends mainly on clothing, activity and duration of stay in the building; a typical range is 18–22ºC. Relative humidity matters to humans only when it is very high; >80% or very low; <30%.
- **Conservation** of materials in the building require an indoor climate that minimises ageing and degradation of the materials that are to be preserved. This depends on the materials and the type of degradation processes that are prevalent in the building. For materials, relative humidity is often the most important climate parameter.
- **Costs** are always a limiting factor and we must consider this from the beginning. A solution that is too expensive is useless.

An improper indoor climate may cause serious damage to the building and its objects. To conserve the building and its objects we need to control both temperature and relative humidity This can be achieved by relatively modest means using a combination of proper technology and training for the people involved.

The issue of preventive conservation and indoor climate control is common to all of Europe. We need to find ways for a systematic exchange of existing knowledge and practical know-how. In addition to this, there are fields where we also need to find new knowledge by research and development.

Heating strategies in Norway

Ulf Christensen (Norway)

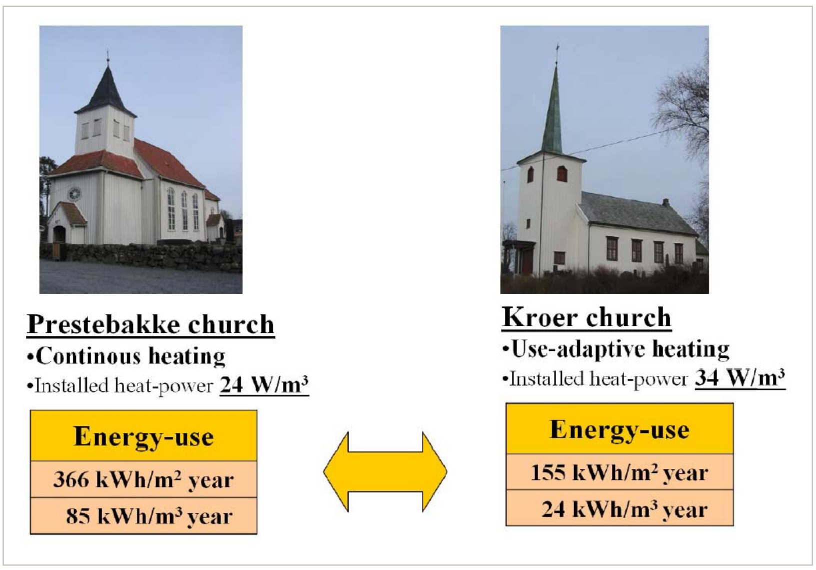
Big effort in the 1980's from the authorities on energy-saving and energy-efficient running in buildings had small effects on the Norwegian churches. First late in the 1990's – through focus on uncritical heating with dry indoor-climate and bad preservation for building, interior and church-arts – authorities of environment and cultural heritage got an interest in energy-efficient running in our churches.

Practical and valuable experiences from the nation-wide project

In the beginning small and single projects were carried out to get necessary knowledge and experiences in the connections between heating and preservation. A nationwide co-operation project called "Environmental and energy-efficient heating of churches" was launched early in the year 2000. The project was carried out by economical support and with skilled resources from responsible authorities for church, energy, environment (cultural heritage) and from the church itself. The project started to investigate (by questionnaires) the condition in 850 churches which gave a good survey over the use, heating, running and maintenance of our churches.

Heating strategies based on our experiences

Further on through continuous measurements and daily registrations of use, indoor-climate and energy-use in 4050 churches are showing that so-called use-adaptive heating is more economical and environmental-friendly. Use-adaptive heating is characterized by heating to a desired temperature, when the church is in use – then the temperature will be held at a low level, when the church is not in use. Churches with relatively little use and so-called low "resting-temperature" are getting low energy-use and acceptable indoor-climate with good preservation of building, interior and church-art.



Comparison of energy-use between similar churches using different heating-strategies.

This is illustrated by an example of a comparison between two similar churches using different heating strategies.

Most of our churches are heated to temperatures often at an unnecessary high level through cold periods at winter. This is caused by a combination of low effect heating and insufficient knowledge about the preservative consequences by the responsible staff for running and heating the churches.

More use-adaptive heating at "low resting" temperature will bring the energy-use down to 40–60 % of its level today in most of our churches. This assumes installation of new heating or additional heating in combination with other possible efforts in the church-building as insulation in walls and roofs and so on.

Barriers that prevent implementation

Executing more use-adaptive heating, together with other efforts to implement the big potential of energy-saving, could be difficult for the following reasons:

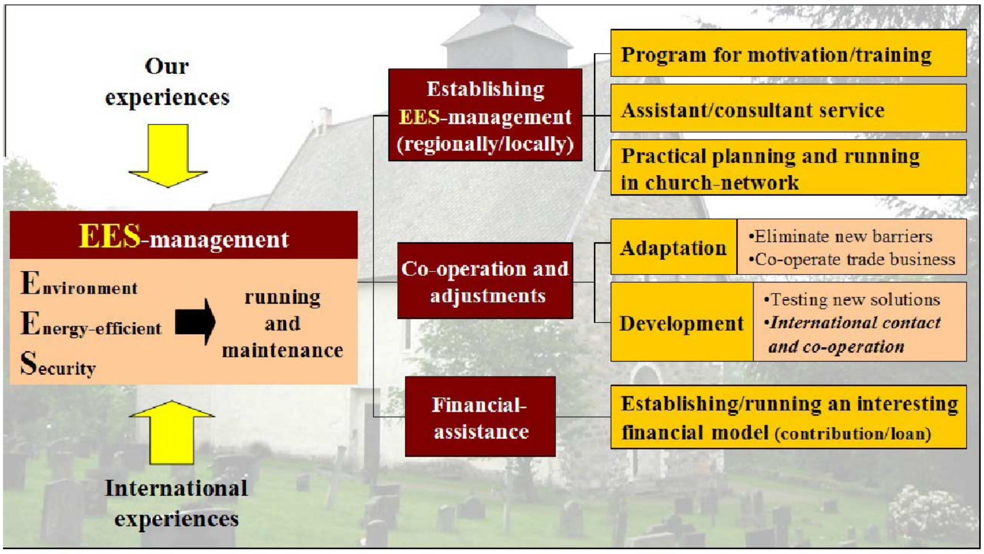
- Practical knowledge and competence about energy-efficient and environmental running are very low among the responsible staff in our churches
- Low effect by heating gives strong limitations to make use-adaptive running possible most of the winter season
- Over 95% of our churches are electrically heated. The often needed increase of "heating-power" will lead to higher energy-costs by legal changes and demands in using more expensive electrical-tariffs
- The good alternatives to electrical heating are limited regarding to aesthetic demands and adequate effect to make more use-adaptive heating in churches
- Flexible, simple and user-friendly automatic control systems for heating are difficult to find in the standard assortment
- Confusion and disagreement about what conditions of indoor climate are good for running and preservation of the organs
- Rather bad economy for investments by the local congregations makes it difficult to effectuate recommended practical efforts as needed

These are the important barriers which make it difficult for a quick implementation of the big potential of energy saving and environmental preservation in our churches and ecclesiastical buildings.

Our strategy for the future

Today technical knowledge and practical experiences exist and should be used for establishing Energy-efficient, Environmental and Secure running of our churches in the near future. A big challenge is to disseminate this knowledge and these experiences to useful actions by the responsible staff both regionally and locally. Through practical actions and tasks both in future planning and in the daily running it is possible to implement the big potential of energy-saving and preservation of building, interior and church-arts.

Church of Norway Employers' Association (CNEA) has sufficient knowledge and direct contact with the regional and local church organisations and is a perfect coordinator for the needed activities further on. The project-oriented activities today should be carried out in a more permanent and entire way. The main goal is to establish Energy-efficient, Environmental and Secure running in our churches – so-called EES-management in the regional and local church communities. This needs effectuation of



The Norwegian preliminary strategy for **E**nergy-efficient, **E**nvironmental and **S**ecure running of our churches.

running information and motivating actions to all the ecclesiastic levels. It will be very important working with a purpose to carry out the following three main activities in attempt to reach the goals above with lasting results:

- Central, regional and local establishment of **EES**-management
- Co-operation and adjustments in reaching necessary quality and lasting good solutions
- Establishment for offering an interesting financial-assistance to get quicker effectuations of the recommended physical efforts and investments

All main activities ought to be carried out at the same time in attempt to get considerable effects with lasting results.

Measuring climate in churches – occasions, demands and results

Andreas Weiss (Mecklenburg-Vorpommern)

The lecturer finished studies at the Academy of Fine Arts in Dresden. As a freelance restorer of panel paintings, polychromic wooden sculptures and murals he has dealt with some 70 monuments, among which such interesting ones as the classicist theatre of Putbus and the romanesque murals of St. Mary´s in Bergen on the isle of Rügen. Since 1992 he has been occupied by climate in churches. At that time still working with thermohygrographs which – apart from problems like the incompatibility with any electronic data-processing – delivered only two data: temperature and the relative humidity in the place where they stood. Statements on mutual climatic effects on the surfaces of building parts or furnishings had to rely on complicated additional calculations and remained empirical all the same. At present his technical equipment enables measuring networks with up to 40 sensors to register the potential of climatic damage e.g. for precious surfaces and furnishings in churches.

In the following is given a very brief overview of this climatic damage potential. High humidity encourages the growth of microorganisms which make use of organic bonds, or hurts by secreting acids. For the prevention of organic infestation a relative humidity below 70%, even 60% would be desirable. Such low humidity may on the contrary lead to even worse damage by the crystallization of salts the walls containing.

Not less problematic, though less paid attention to, are the changes of humidity and temperature. Mural salts react upon these changes not only by solution and recrystallization but also by changing their chemical bond. Both increase degradation due to crystallization of salts. Different materials that at first were solidly attached to each other react upon changes of temperature and humidity with different expansion e.g. for the gesso of chalk on panel up to a proportion of 8:1. Shearing stress generated thereby is one of the main causes for loss of the paint layers.

This small choice of reasons already show why the conservator should be interested in the climatic processes, primarily on the surfaces, and why he should not rely on snapshots.

From the conservator's point of view, relevant mutual climatic effects on surfaces are enrichments of moisture structure (caused by capillary transport from within) or condensation on the surface of the building structure resp. on the surface of its interior pores. The considerable risks also include drying processes on surfaces. They can be caused by an inflow of dry air, or when the surface warms up, effected by radiation or convection, e.g. from a heating.

Beside the analysis of such causes of damages measuring the climate should be aimed towards an improvement of the actual interior climate. To this purpose at first the conditions have to be established that hitherto dominated the climate.

Of course the influences of outdoor climate have to be taken into account with regard to the construction of the church. Short term reactions of the interior upon changes of the outdoor climate depend mainly on solar radiation through the windows and on the wind tightness as well as the buffer capacity of the building. E.g. can the relatively large windows of a gothic city church induce a high air change rate. Outer influences upon the interior climate can in such a case only at a much lesser degree be compensated by the buffer masses that are relatively small in relation to the volume, in comparison to a small village church built of similar materials.

For the sake of completeness must be named not only such comprehensible influences as from heating or the humidity imported by the visitors, but also – as will be shown – the effect of a door left open in a village church.

In comparison to the various existing influences upon the interior climate the possibilities to improve it are limited. In older churches usually cannot be done much more than to reduce the moisture that soaks in from outside, to regulate the air change – in which e.g. the leaks of lead glazing must be submitted to, or to reduce thermal irradiation.

Heating, even tempering usually leads to quite radical changes of an existing climate. Especially if not harmonized with the air change rates, it can induce heavy drying damages.

These considerations result in specific demands for the measuring arrangement, which will be explained at the practical example of climate monitoring in the village church of Mellenthin on the isle of Usedom (fig. 1).

The choir of this church was built during the second half of the 13^{th} century mainly of granite, the nave not before the 15^{th} century of bricks. The church includes a rich furnishing, murals of the 15^{th} century under the choir vaulting as well as two large painted panels of the late 17^{th} century and a richly decorated baroque balustrade on a gallery. Like most rural churches in Mecklenburg-West Pomerania it is unheated.

The monitoring was asked for because of an interior climate that was felt to be very humid and of a microbiological infestation on the murals in the vaults. Means to reduce humidity and thereby to prevent further decay from microorganisms were to be found at one hand, the risks for the paintings on vaults as well as on wooden furnishings on the other hand should be judged.

Fig. 1. Village church of Mellenthin on the isle of Usedom, nave and choir vaulting.

The measures were taken exemplary at one place in the choir vaulting and on one of the large painted panels fixed to the northern wall, the latter because of the problems that were to be expected from the microclimate between panel and wall – rather than at the balustrade standing free.

In order to establish the mutual effects in both places not only the surface of the component was analysed but also the surrounding air at a short distance as it is determined by the component. Moisture set free from the component as well as absorbed by it does not effect the air at a longer distance as it does in proximity. At the balustrade e.g. the panels adjoining the outer walls are much more damaged than those in the middle, obviously under the influence of the air in proximity to the walls. At comparatively thin components like the panel as well as the vault strong climatic tensions between front and rear are to assume. Therefore the rear surface was equally measured. To correlate with the outdoor climate the air outside the northern wall has been measured too. It was necessary further to register the openings of the main door (the southern door) in order to convince the parishioners of the climatic consequences.

These become obvious by comparing the climatic data of two days with similar outer climate, taken at the painted panel (fig. 2). The pointed lines shows the outdoor climate, the bold those inside, near the surface and the small between panel and the northern wall. The black line between relative humidity and temperatures that shows little variation corresponds to the moisture of the wood in the panel. The yellow line indicates the door, low if opened, high if closed. On the 24th of June the door stood open for more than 7 hours. In this period relative humidity near the surface fell about 19% while behind the panel it rose ca. 9%. This led to a difference between front and rear of the panel of 28%. Although the change in wood moisture had not become grave at first, faced with the short reaction interval and the shear tension between wood and gesso it must be regarded though as critical! On the 27th of June similarly many visitors are supposed to have come, but now they respected the newly set up sign saying "shut the door, please!". The decrease of humidity near the surface was therefore reduced to 5%, the difference between front and rear to only 6%.

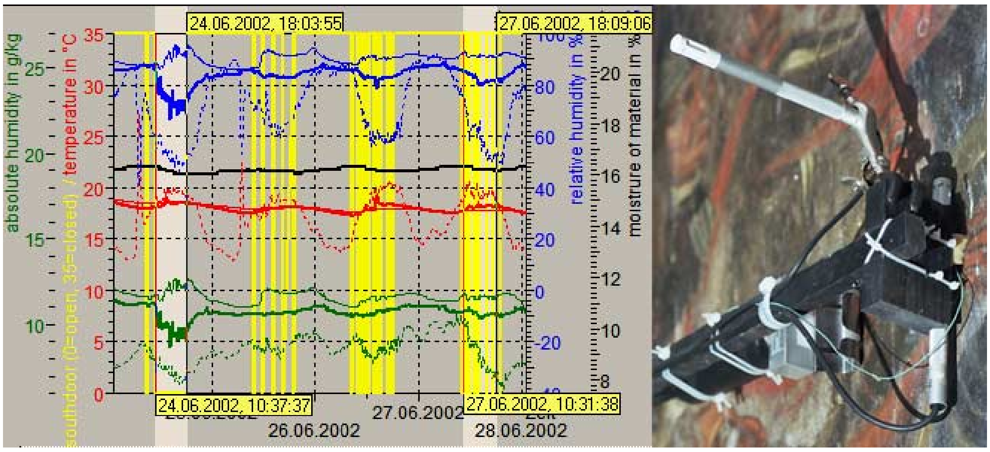


Fig. 2. Climate measuring on a painted panel, data and measuring arrangement (details).

Further important results are shown in figure 3. Apart from the described exceptions near the doorway the relative humidity inside remains all over the year on a constant high level between 80 and 100%. The diagrams show a choice of data concerning the vault in comparison with the outdoor climate. The pointed lines mirrors the outdoor climate, the bold those inside on the surface and the small indicates the surface on top of the vault.

It attracts attention, that the interior data nearly continuously precede those of the outside. Moisture seems to be trapped inside. Looking more closely – here upon an unsmoothed weekly diagram on the right side – the relative humidity at the inner surface seems hardly to react upon changes in temperature. To these however the changes of absolute humidity show a clear correspondence. This indicates a high moisture content and an equally high buffering capacity of the outward shell of the building.

In spite of the very high moisture level there were hardly any climate induced damages to be found in the vault murals – probably due to a continuous gradient of humidity between the interior and exterior all through the year as shown in the monthly averages in the left diagram. Presumably this leads to a continuous flow of moisture from the inside outward, so that periodically condensing water is drained capillary without

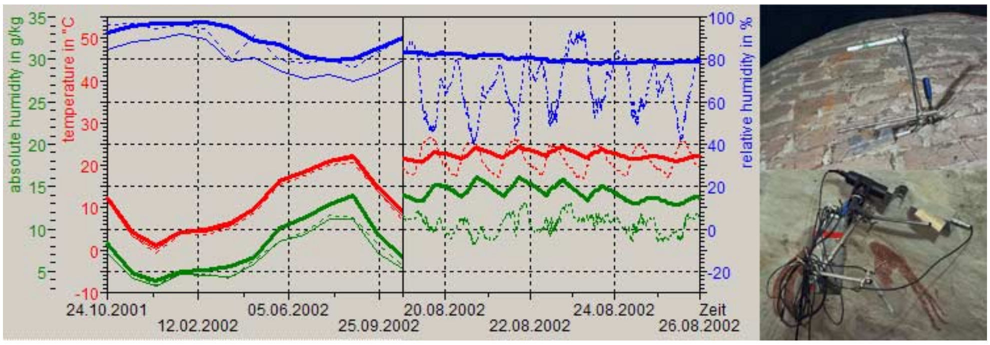


Fig. 2. Climate data from the choir vaulting, monthly averages, unsmoothed details and measuring arrangement.

damage. Presumably this is not at all a rare phenomenon and it should be drawn into account when thinking about insulation of vaults!

Searching the source of the moisture in Mellenthin first the floor could be excluded by measures of the material moisture. For further encircling of the source choir and nave were divided by a foil. In fact the climate in the choir proves to be somewhat more dry in comparison with the nave. The distribution of moisture in the cross section of the brick walls of the nave leads to the conclusion that driving rain transported capillary towards the inside of the walls is the cause of the high average moisture.

As many village churches this one has no guttering. The southern wall, more exposed to rain, consequently shows more moisture. High measures in the upper third presumably correspond with rain water running down from the eaves pressed against the wall by wind, while the equally high measures in the lowest parts reflect splash water.

Moist southern walls in contrary to rather dry northern walls are a paradox to be observed in many churches of our region. Together with rain that is especially frequent with southwesterly winds, this could also be caused by sun irradiation that interrupts the capillary transport to the outer surface and thereby slows down the desiccation of a moist wall.

Rain infusion can be reduced by a guttering at first. Furthermore a shelter from driving rain is to be found. Alternative to hydrophobic coatings that facilitates the growth of algae on the surface and increases the water transport into the walls if they shows cracks above 0.3mm width, plantings could also help to reduce direct solar irradiation and thus improve the desiccation of southern walls. Ivy however will cause damages if cracks above 3mm width exists.

Airing rules constructed in order to reduce the climatic stress stranded immediately after retreat of the conservators, overcome by the ignorance of the users. The only way out seemed an automatic ventilation guided by climate measures. This should work on the lowest possible technical and financial level to be also used by other poor parishes owning similar small churches. Its effectiveness is thought to be secured by excluding manual manipulations. The concept aims at an air change based on natural pressure differences, without any ventilators. The air should flow through the inner space towards the most frequent wind direction, taking advantage of thermal lift. In the case of Mellenthin this means: the air flows through the room from west to east. By pre-buffering in the tower hall extreme variations of the outer climate could already be subdued. Waste air leaves the building near the roof ridge, taking advantage of the suction in lee. The regulation works by electrical valves, steered by a climate measuring unit. The steering can be defined on the basis of the existing climatic conditions and the “conservation related” demands.

Demands on climate according to the Finnish experience

Sakari Mentu (Finland)

The 543 protected churches in Finland are owned by the parishes and regularly used for ceremonies. The protection of churches is based on the Church Code and monitored by The National Board of Antiquities and the Church Council. There are 35 so-called "desolate churches", which are kept open for public, but not actively used. About 60 % of Finnish churches are built of wood.

Unheated churches

Churches without heating systems have few problems caused directly by interior climate. Decay and insect damage in timber do occur, but mostly as a result of other structural failures, e.g. a leaking roof. Ground moisture seems to affect the interior climate; experiments with a short temporary blocking have strongly reduced relative humidity indoors. The base floor should thus be properly ventilated and inspected at regular intervals if there is any doubt of water in the ground soil.

A short heating period in spring is considered as a possible means to reduce condensation indoors; nevertheless, the negative effects of a faulty heating procedure (shrinkage and cracking) are a threat big enough to discourage unconsidered action. A constant high relative humidity (up to 80–90%) is less harmful than a strong fluctuation of the temperature and humidity. There is an obvious upper limit of 92% rH (wood cells completely filled with water), after which the timber will shrink during the drying period.

In stone churches there is a greater risk for condensation in springtime, since the temperature of massive walls does not rise immediately. In order to reduce this it is recommended to keep the church doors closed most of the time until the walls have reached the outdoor temperature (in Finland until mid-July).

Furniture, paintings and other valuable items are more sensitive to climate than the building itself, and lack of heating is not always the optimum. Low indoor temperature increases corrosion of metal objects. Tinware must always be removed from unheated churches in autumn.

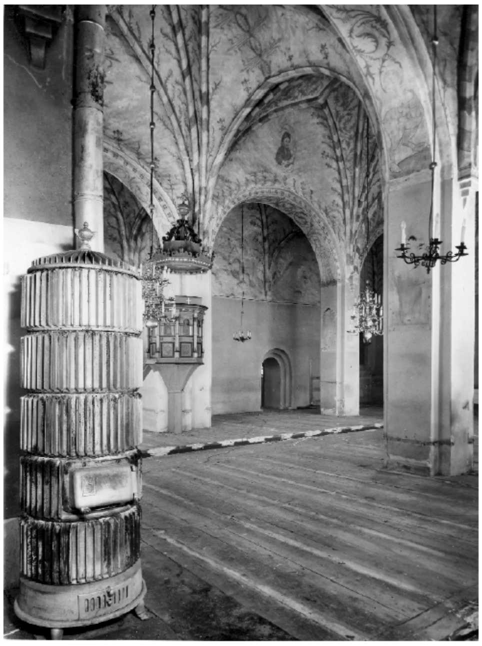
Churches with heating systems

The earliest heating facilities in Finnish churches (tiled stoves) were installed in sacristies by the end of the 18th century. A more extensive phase in this development took place from the 1880s onwards; most of the churches were equipped with cast-iron stoves, normally 2–5 in the nave and one in sacristy. Heating with stoves did not damage the construction or surface treatments; however, a lot of soot was produced and periodical cleaning became necessary. This repeated process faded the painted decoration on walls and vaults. Calorifiers were introduced in 1860s and steam heating in 1890s; both were gradually replaced by other systems due to their apparent technical shortcomings. According to a survey carried out in 1956 there were still 270 churches heated with stoves and 14 heated with calorifiers. None of these early heating systems are used in churches anymore.

Recent changes in religious ceremonies and multi-functional use of churches (concerts, performing arts etc.) have created a demand for warmer church interiors; overcoats are left in coat-racks and a temperature of a normal living room would be optimal. The heating systems used today are central heating, electrical radiators and warm-air blowers. All the systems have disadvantages, but the damaging effects can be reduced by careful planning and measuring. Placing the radiators under the benches is a good way to reach a compromise between preservation and comfort.

Optimal climate conditions for heated churches would be a temperature less than 18 degrees and a relative humidity of 50±5% rH (furniture and artefacts) or 60%rH (structures). Rising the temperature above 20 degrees is a considerable risk, since the humidity can no longer be kept at a tolerable level. Going under 30% rH has proved to be fatal for painted or gilded wooden sculptures and thick layers of distemper paint on wall surfaces. The first item to suffer from dry interior climate is the organ. Sensitive and therefore easily going out of tune, organs have often been equipped with a humidifier. In one case this has led to mould growth and damaged paint on the façade.

Last Judgement by Mikael Toppelius, 1779, in Haukipudas church, distemper paint damaged by dry interior climate.



Stove in Laitila church (1483), picture from 1967 (National Board of Antiquities, Finland).

Heating devices and their influence on the interiors of old churches

Diana Pikšriene (Lithuania)

Modern technologies have enabled to install new *heating-ventilation* systems in churches, and their interiors have been supplemented not only by hot prayers but by warm air as well. The *heating-ventilation process* in churches is a topical subject in respect of both people's comfort and proper maintenance of a building. The reasonable choice of *heating-ventilation* system and its installation guarantee proper maintenance of art objects in a church. *Heating-ventilation* systems and their operation should not damage:

- Authenticity of church interiors
- Existing ventilation systems. In case of damage to the existing one, the alternative should be found that could ensure appropriate ventilation of the building
- Material of the building, and proper maintenance of the organ and items of art (paintings, etc.)
- The rites or other events that take place in a church (in respect of noise or any other negative impact)

The peculiarities of *heating-ventilation* systems installed in four Lithuanian churches are presented below alongside with their impact on the interiors of the churches.

The principle of *blowing out warm air* with gas heat has been applied for *heating-ventilation* process at Šiauliai *Cathedral of Sts. Apostles Peter and Paul*. A gas boiler-room, ventilation pipes and other equipment for air intake, warming and warm air sending have been installed in the unemployed space of the cathedral's attic. The automatic control of the system allows to warm up the Cathedral premises objectively to the temperature desired before the service or other ceremony, and later to keep it to a minimum and to maintain the standard relative air humidity as well. Thus the economical effect has been achieved. The *heating-ventilation* system in this church has damaged the interior minimally: the special muzzles for blowing out warm air have been mounted in the existing holes in the curve of arch of the central nave and ventilation grates have been installed in the existing holes in the walls.

Electrical under-floor heating has been installed at the church of *St. Virgin Mary's Visit* in Kamalduliai Convent of Pazaislis. The maintenance of this heating system is extremely expensive and has not been used for several years. However, having found the sponsors, they intend to use the heating system the following winter adjusting the intensity of heating accordingly to the rites and ordinary periods of time.

Electrical under-floor heating has been installed at the church of St. Trinity in Liškiava. The church was heated during the cold season continuously. The economical effectiveness has been achieved controlling heating intensity during events and by heating separate floor areas according to the demand.

The electrical under-floor heating system has not damaged the space of interiors of the churches.

Radiant heating using gas has been installed at the church of *St. Virgin Mary Rosary* in Balbieriškis. The glass pipe of the heating device, which has been fitted in a pad of curve of arch in central nave gives warmth while the gas is burning.

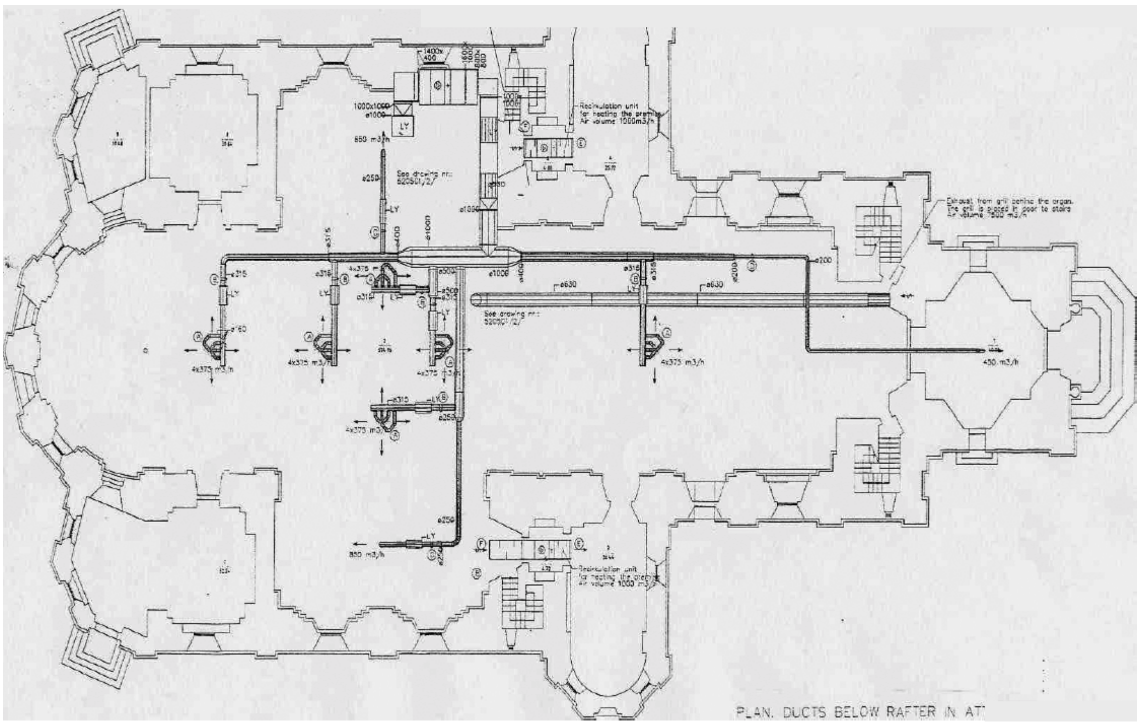
This heating system has damaged the space of the interior of the church and did not produce the desired thermal effect in local places of people's presence. For these reasons this heating system has not been used in the church.

Conclusion

It is purposeful to install in churches a proper *heating-ventilation* system that should not have a negative effect on the interior from an aesthetic-visual point of view in respect of people's demand and protection of art valuables present in the church spaces.

Church of St. Virgin Mary's Visit in Kamalduliai Convent of Pazaislis. Electrical under-floor heating.

Cathedral of St. Apostles Peter and Paul in Šiauliai. Attic plan showing gas-boiler room and ducts for warm air heating.



Creating heating system solutions for ancient churches in Denmark

Kurt Jacobsen (Denmark)

1) We have 2400 medieval churches in Denmark, of which we have been working with approximately 600, to solve climate and construction problems.
2) Earlier co-operation on a Scandinavian level, to exchange experience regarding new heating systems, and the negative effects of climate on historical inventory, e.g. altar, pulpit, pews.
3) The Danish guidelines for dimensioning, specification and use of heating installations:

   A: Circular letter from the Ministry of Ecclesiastical Affairs dated 10th august 1993.

   B: Professor Vagn Korsgaard's experiment with different heating-systems in Saint Jørgensbjerg Church in 1986.
4) A typical project process

   A: Conduct interior climate measurements for 1 year for both temperature and relative humidity with a data logger.

   B: Calculate heat requirements based on the established extended formula.

   C: Take and record detailed measurements within the church.

   D: Develop the heating system solution: e.g. zone-heating pews, radiators under windows, convection heaters under floor grids, thermal balance between the individual areas within the building.

   E: Implement the project; carry out supervision and quality control of the work.

   F: Conduct final heating test.
5) 3 examples of new heating installations:

   A: The system most commonly used in Denmark's medieval village churches.

   B: The Church at Christiansborg Castle.

   C: Heating system solutions for:

   The Cathedral of Roskilde (with humidity regulated heating) and the Cathedral of Copenhagen (with humidity regulation).
6) Summary and conclusions.

The Cathedral of Roskilde, Denmark.

Learning from experience in Norway

Ulf Christensen (Norway)

In the nation-wide project we get practical experiences by follow up and measuring indoor-climate and energy-use in many of the pilot-churches.

Practical experiences from different types of heating

Through this work we have got some experiences with the following types of heating systems and products:

- Direct electrical heating with traditional pipe-heaters under benches, low temperature electrical sheets or cables built in ceilings and floors and panel-heaters at walls or newer types of bench-heaters and mobile radiant heaters
- Gas radiant heating in older and in newer churches
- Water-based heating with some different types of heating centrals and distributions

In these days the project is in the finishing stage. We are now studying and evaluating the documented data and the attained results from the pilot-churches. Soon this work will be presented in the finishing report of the project early next year.

The main and preliminary results can briefly be presented in following items:

- *In churches and in using-areas with big volumes and heights* high temperature radiant heating either by gas or by electricity are the most efficient heating, but the location of the relative ugly radiant heaters in the church space must be carded out with caution
- *In churches and in the using-areas with normal height* (in our churches) combination of direct electrical heating by newer types of bench-heaters (with 400 W/m or higher) in fixed bench-areas and with mobile radiant heaters in the more open using-areas are sufficient to get rapid warm-up from low resting-temperature also in cold winter-periods
- *Electrical mobile radiant heaters right located* have made acceptable thermal comfort and working environment for organists, especially under practices the organ in empty church

Newer electrical heaters

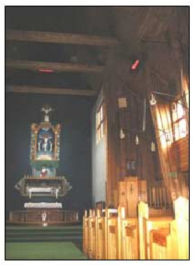

Bench-heater


Radiant heating in seat and back


Mobile radiant-heater

Gas-radiant heaters


In older churches


In newer churches

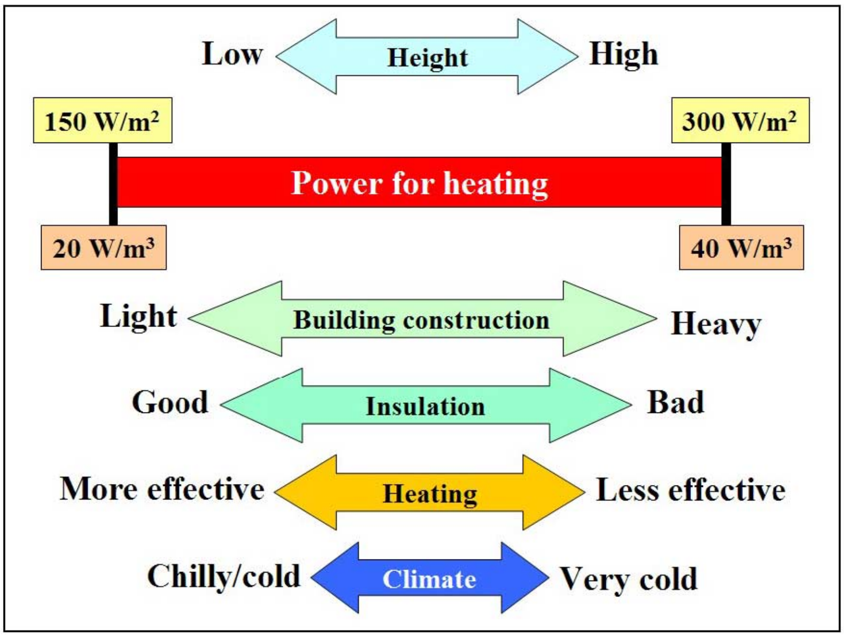
Some of the different types of heaters which were tested out with interesting and useful experiences.

- *Possibility for flexible heating more adapted to the use of the church* by making different and suitable heatingzones between and in the main using-areas
- *Obtain thermal comfort in the using areas near the entrances* by preventing cold air to trickle in by several types of heaters and air-fans products. The location and running of these equipments must be handled with caution in an aesthetic and a user-friendly way

These are the preliminary results and experiences from our work in the pilot-churches which have given valuable contribution to our practical knowledge in how to run our churches in a more environmental and energy-efficient way. Our efforts to carry out more use-adaptive heating are almost based on the above mentioned experiences.

Use-adaptive heating needs sufficient power installed (our preliminary experiences)

One of the important activities in the pilot-churches was the testing of the warming-up capacity and speed in several types of heating and different building constructions under cold climate condition.



Preliminary view of sufficient power needed for use-adaptive heating.

Preliminary our testing is showing that sufficient power between 150–300 W/m^2 to carry out use-adaptive heating in cold winter-periods. The actual need of power will depend on the

- building construction – light or heavy
- insulation – good or bad or anything at all
- system of heating – the warm-up capacity and speed and also the efficient way of heating distribution
- outdoor climate – chilly or very cold

Another important parameter is the building volume of the church and the heights between floor and ceiling in different using-areas. In this occasion we have found out that the needed power of use-adaptive heating is more convenient and suitable stated per volume-unit. Our experiences are showing that the needed power of use-adaptive heating will be at the level between *20–40 W*/m^3. Soon we are hoping to work out several key-numbers depending on the above conditions. This will give us a practical tool in the near future.

Tools for total analyzes and planning

In our work we have carried out active follows up and measured important parameters for in-door climate and energy-input. This claims resources and time, but it is necessary and important in the first stages to get the right survey and knowledge. Now we are going into a new stage in developing and adapting practical tools and routines which can be used in planning and executing of physical efforts to get our churches in a more environmental and energy-efficient running. We are now testing several data-programs for simulation of in-door climate and energy-use. Soon we hope and believe to work out a practical and efficient tool which can be used in this important field.

Practices and problems in Sweden

Tor Broström (Sweden)

This presentation deals with the problems of rural historical churches in Sweden. Typically these churches are used intermittently, every other week or so, by very few people. The parishes are generally small and relatively poor. In many parishes, the cost of heating and maintenance is becoming more and more painful. The most common problems are:

- High heating costs
- Bad indoor climate for the visitors
- Material damages due to improper climate control

Intermittent heating is the most common heating strategy. The churches are fully heated for services only, in between the churches are kept at a low temperature or with no heating at all. Intermittent heating provides an acceptable indoor climate for both people and materials at a moderate energy cost. However it requires a high power capacity that gives high fixed costs.

The energy demand can be reduced significantly by simple measures:

- Lower the temperature when the church is not in use
- Lower the temperature when the church is in use
- Use full heating power when the church is heated before use

The proper temperature levels should be determined with respect to the relative humidity. The objective is to keep the relative humidity in a safe interval; not too dry, not too humid. For the future we need to provide these parishes with concepts and solutions for climate control, i.e. heating, ventilation and humidity control, which allows them to use the church and maintain it for future generations.

Humidity control

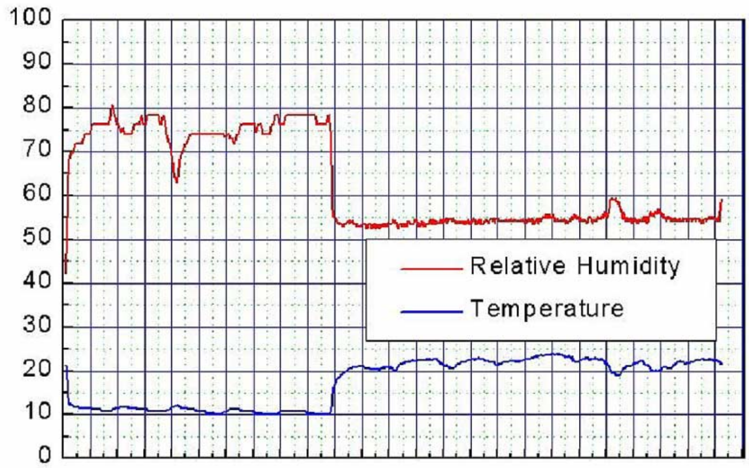
In many churches the relative humidity is allowed to reach dangerous levels. Too low levels will cause drying damages on wooden objects. Too high levels increase the risk for mildew, rot and other fungi.

The relative humidity can be actively controlled through the temperature. This is a relatively simple installation that allows us to avoid extreme values and overheating.

Church in Endre, Gotland, Sweden.

Intelligent ventilation

In most cases ventilation is necessary to control the humidity in churches, However improper ventilation may add to the problems. For example, in springtime, when the church still is cold after the winter, ventilation will bring warm and humid air in to the church causing condensation. The solution is to provide intelligent ventilation, by technical means or by instructions to the people involved.



Climate zoning

One way to reduce both investments and heating costs is to provide heated zones within the church rather than heating the whole building. In principal it is easy, in practice more difficult. Zoning can be applied by making a room within the room or by focusing the heat in certain areas.

Radiative heating

High temperature radiators allow us to project heat directly to a limited area without having to heat the air first. The picture shows 12 kW of radiators placed in chandeliers above the benches. In the benches there is low temperature floor heating. Acceptable comfort is provided even at very low air temperatures. The heating costs, including investments are 1/3 of the cost for a conventional heating system.

Church in Lau,
Gotland, Sweden.
Photo: Stefan Haase.

Continued co-operation

We need to share knowledge and know-how in this field in order to develop, evaluate and implement cost-effective solutions for climate control in churches. This can be done by interdisciplinary research projects, pilot installations and systematic evaluation.

One important venue for European cooperation in this field is the project *European Standards for Conservation of Cultural Property.* For more information contact your national standards organisation or Mr Erling Trudso (ert@ds.dk).

Agenda

"Indoor Climate in Churches – Problems and Solutions"

Riga, the 11th of November 2004
M.Pils iela 4

9.00–9.30	Registration
9.30	Introduction, Ilmars Dirveiks (Latvia)
9.35	Welcome, opening of seminar and address to participants, Juris Dambis (Latvia)
9.45	Heritage co-operation in the Baltic Sea Region, Hans Sandström (Sweden)

Indoor climate in historical buildings

10.00	Fundamentals of indoor climate, Tor Broström (Sweden)
10.30	Heating strategies in Norway, Ulf Christensen (Norway)
11.00	Maintenance of church buildings. The experience of Latvia, Artis Eglitis (Latvia)
11.30–12.00	Coffee break. Discussion

Demands of the user, the building and the interiors

12.00	Demands and results of climate measuring, Andreas Weiss (Mecklenburg-Vorpommern)
12.30	Demands of climate according to the Finnish experience, Sakari Mentu (Finland)
13.00–14.00	Lunch

Good practices, experiences from different countries

14.00	Heating devices and their influence on interiors of old churches, Diana Pikšriene (Lithuania)
14.30	Creating heating systems solutions for ancient churches, Kurt Jacobsen (Denmark)
15.00	Learning from experience in Norway, Ulf Christensen (Norway)
15.20	Practices and problems in Sweden, Tor Broström (Sweden)
15.40	Discussion – with coffee
16.30	End of seminar

Lecturers

Tor Broström, Ph D and Assistant Professor at the University of Gotland (Sweden), Department for Building Preservation.

Ulf Christensen, civil engineer, consultant, expert in the KME-project (research on heating systems for the church buildings in Norway), final report published February 2005 by the Church of Norway Employers' Association.

Juris Dambis, architect, head of the State Inspection for Heritage Protection in Latvia.

Ilmars Dirveiks, architect, consultant and teacher at the Riga Technical University, contact for Latvia and member of the working group on Building Preservation and Maintenance in Practice.

Artis Eglitis, head of the finance commission of the Evangelical Lutheran Church of Latvia.

Kurt Jacobsen, civil engineer, expert on indoor climate, Eduard Troelsgaard Engineers A/S, Denmark.

Sakari Mentu, architect, National Board of Antiquities (Finland), contact for Finland and member of the working group on Building Preservation and Maintenance in Practice.

Diana Pikšriene, architect, Department for Heritage Protection, Vilnius, Lithuania.

Hans Sandström, architect, National Heritage Board (Sweden), contact for Sweden and chairman of the working group on Building Preservation and Maintenance in Practice.

Andreas Weiss, restorer, with his own practice in Mecklenburg-Vorpommern, Germany.

Appendix 1

Reflections after a seminar on indoor climate

Ilmars Dirveiks (Latvia)

There is increase of demands of church visitors for favourable conditions. At the same time the economical capacity of the possessors and managers of the objects have increased as well. The market offers a variety of materials for climate regulation, nevertheless there is not enough sufficient information on their appropriatness for solving particular problems. The chosen solutions do not always correspond the conditions of maintenance of historic buildings. The church buildings and their interior demand special attention in climate maintenance and control. Therefore when planning climate changes in churches, there should be thorough preplanning in order to find the best solution.

Activities can be divided in the following stages
- analysis and evaluation of existing situation
- planning of changes and evaluation
- implementation of the project
- regular control

Analysis and evaluation of existing situation

- Is there originally intended any heating system in the building?
- Has the building been heated during the last 100 years and by what means?
- The technical condition of foundations and external walls (does the rain water flow away from the building and does it create wash-outs? Does the water come on the walls regularly? Is the water drainage system arranged properly?)
- Are there humidity caused processes creating damages in the external walls? (Spots and mould detected in the interior)
- What is the floor covering in the building? Is it too dense to allow vapouration of ground humidity?
- What is the regime of humidity and temperature in the building? How does it influence the structure of the building and valuable interior elements (church equipment, organ, furniture, sculptures and paintings)

Planning of changes

- What is the intended utilisation of the building (frequency, services, length, number of people and their location)
- Does the project solve all the problems in complex (comfort for the visitors, does not harm the constructions of the building and valuable details)
- How will the new climatical conditions influence the structure of the building (walls, vaults etc.), interior and furniture, pieces of art (sculptures and paintings) and organ?
- Is the particular solution the most economical and efficient of all considered versions?
- Choosing heating elements, one should evaluate their conformity with the interior (benches, floor etc.) architectonically artistic importance and constructive features.

- Is it possible to perform works beneath the floor level?
- Will the new conditions be influenced by actvities performed before (such as isolation on the vaults, pannels on the walls etc.)

Implementation and regular control

- Inform the local authority in charge of heritage protection on the planned activities in due time.
- Select experienced designers and consultants. Make sure that he, as a professional, is aware of the principles of the current document.
- Demand clear argumentation for the chosen solution.
- One must take into account not only instant financial investment, but also planned expenses in future.
- The project should have effect on all aspects, taking into account the overall technical condition of the building,
- The change of windows and doors is not the main and most important activity for facilitating the comfort level in the church.
- Evaluate natural ventilation systems.
- It is not acceptable to build in a separate heating device, relying only on recommendations of consulting seller.
- Before the project, during its implementation, as well as after it, regular consultations with experts on heritage preservation should be held (organ experts, restorers of art items, experts on management of historic buildings as well as learn from the experience of other churches).
- After the implementation of the project, regular measurements of humidity and temperature should be performed and in case of unplanned results immediately inform respective experts.
- Remember internationally adopted principles in heating historical churches: “heating for the people, not for the building”, as well as avoid rapid and big temperature oscillations.

Appendix 2

Preventive conservation by climate control

Tor Broström (Sweden)

Introduction

Creating an indoor climate, separated from the outdoor climate, is the basic purpose of most buildings. On one hand, the climate is meant to provide comfort for people who live and work in the buildings. On the other hand, climate induced degradation is one of the major hazards to our cultural heritage

The best conservation strategy is to act in order to prevent damages and degradation rather than reacting afterwards. Climate control, when properly used, is an efficient and cost-effective method for preventive conservation. Too often the discussion on climate control is focused on the technical solutions whereas the real difficulty lies in establishing proper climate criteria.

In the first part of the paper, climate and climate induced degradation are introduced briefly. In the second part, climate criteria and solutions for preventive climate control are presented. The third and final part is a case study, dealing with climate and climate control in old Scandinavian stone churches.

The literature in this field is quite extensive, a short bibliography is given with a number of selected references and bibliographies in the field.

Fig 1. The basic purpose of most buildings is to provide a certain indoor climate. Climate induced degradation is a common danger to our cultural heritage.

Climate

Climate is a term meant to describe the physical environment in The factors that generally define the indoor climate in a building are:

- Air temperature
- Surface temperatures
- Relative humidity
- Air movements
- Air Pollution
- Light
- Sound

The present paper deals mainly with degradation and conservation in relation to temperature and humidity. The other factors are not dealt with primarily. Climate control implicitly refers to indoor climate, however in the field of cultural heritage it is not unusual to create controllable climate zones outside. The principles involved are much the same in both cases.

In order to be able to control the indoor climate in a sensible way, we need to understand how the climate is governed by a number of internal and external factors such as:

- The outdoor climate that sets the basic conditions for the indoor climate.
- The building construction as a shield that controls the transfer of heat, moisture, and air in and out of the building.
- Humans in the building will add heat, moisture and polluting agents.
- Activities in the building, such as cooking, washing etc will influence the indoor climate.
- Active climate control such as heating, ventilation and cooling.

Climate induced degradation

Temperature and relative humidity have a profound effect on degradation due to physical, chemical and biological causes. The following is a qualitative overview of some common processes.

Physical degradation

Dimensional changes are due to variations in temperature and/or relative humidity. Most materials will shrink and swell when exposed to varying temperatures and humidity. This may lead to cracks and permanent deformation of materials. In the long term, small dimensional variations may give failure due to fatigue.

Salt crystallisation is due to variations in humidity; when the relative humidity is sufficiently high, salts in or on materials will be solved in water. As the relative humidity decreases salt will crystallise at a certain level. This will cause damage to the material, particularly if the salt crystallises within the material. Salt crystals on the surface have also been reported to cause damages. If the relative humidity varies in periodical cycles, the salt will solve and recrystallise in each cycle, adding to the damage.

Brittleness may occur due to low relative humidity. Many organic materials will become brittle at low humidity, thus making them more vulnerable to physical damages.

Blackening of walls is due a combination of warm air and cold surfaces. A phenomenon known as thermal diffusion will give a higher concentration of particles near the cold surfaces thus increasing the amount of particles that stick to the surface. Slow as this process may be, it can in the long run turn a white surface into black.

Freezing is a common cause of damages in the northern climate zone. Porous materials saturated by water will be exposed to very high stresses if the water freezes, as water expands by 10% when it turns into ice.

Biological degradation

Biological degradation is very much dependent on the climate. In buildings, biological degradation is due to different organisms such as:

- Mildew
- Rot
- Algae
- Insects

For the all the above-mentioned organisms, one can define a range of relative humidity and temperature, which is safe and one which promotes biological activity. In general, biological activity requires high relative humidity and a medium range of temperature. In many cases toxins are used to suppress biological growth. One should keep in mind that eliminating the basic conditions, i.e. providing the right climate is the only long-term solution to fight biological degradation.

Chemical degradation

Chemical degradation may be due to natural processing such as oxidation or be due to pollution in the air, e.g. corrosion from acidic pollutants. Most chemical processes are temperature dependent. In many cases humidity will influence the chemical degradation processes.

Climate criteria for preventive conservation

The purpose of climate control for preventive conservation is simple and obvious; we want to maintain a climate that minimises ageing and degradation of the materials that are to be preserved. In practice it is not so simple, the difficult part is not the technical systems, but rather to establish what range of temperature and humidity one should use with respect to conservation. This, of course, depends on the materials and the type of degradation processes that are prevalent in the building. Even though the previous section in no way describes the full complexity of climate induced degradation it can be seen that we in most cases have to deal with a number of materials subjected to a number of potential threats, all which require their own climate. The ideal climate has to be a compromise that must be determined in each case.

This issue of climatic influence on degradation of materials has been addressed in numerous scientific publications, yet one often finds that there is not enough knowledge available when it comes implementations in the buildings. The first reason is that much of the research is strictly disciplinary, i.e. in narrow fields of physics, biology, chemistry etc, making it difficult for a building conservator to find and apply it. A second reason is that much practice and know-how in the field rest on an empirical basis, often unpublished, seldom evaluated by scientific standards. Finally there is a lack of applied interdisciplinary research and development.

Climate criteria for comfort

The previous section dealt with climate criteria for materials in the building. Of course the climate in the building must be suited to the people who visit and work there. Comfort, in it's technical meaning, is a subjective parameter which describes to what extent humans, individuals or groups, find the indoor climate acceptable. People are very sensitive to temperatures, but not so sensitive to relative humidity. The comfort temperature range depends mainly on clothing, activity and duration of stay in the building; a typical range is 18–22ºC. Relative humidity matters to humans only when it is very high; >80% or very low; <30%,

In the case of protecting monuments and conserving valuable objects one must consider lowering the thermal comfort for people in order to get a more favourable climate for the materials. For example, in a place where people visit briefly, less than one hour, one can tolerate a much wider range of temperatures, especially when properly clothed.

Technical solutions for climate control

The technical solutions are tools to establish the required climatic conditions, A discussion of technical solutions is meaningless if the climatic criteria are not established to begin with. Generally there is no lack of technology, technical devices or technical know-how. The problem is to apply existing technology under unusual conditions. This requires a thorough understanding of the problem, interdisciplinary co-operation and innovative thinking.

The basic tools of active climate control are

Heating
Ventilation
Cooling
Humidification / Dehumidification
Control systems

The simplest way to control relative humidity is by changing the temperature, since the relative humidity will decrease with rising temperatures and vice versa. In some case humidification or dehumidification may be needed.

Ventilation is often used with the intended purpose of controlling humidity. Under some conditions, for example in the spring when it is be warmer outside than inside, ventilation will add humidity to the building.

Modern control systems are computerised. Even if modern information technology gives us great flexibility one should keep in mind that sometimes more is less; i.e. simpler systems may work just as well or better at a lower cost.

In both modern and traditional architecture massive buildings structures are used to store heat and moisture in order to moderate the indoor climate. This can be very effective, but generally it is difficult to design these structures in order to obtain the effect required.

Economics

Preventive conservation by climate control is an investment in our cultural heritage. When compared to the long-term costs of reactive conservation, proactive measures, such as climate control, are generally much more cost-efficient. The problem is that economic time scales are so different; investments in a building are expected to pay off in 10 to 20 years, whereas the pay off time for investments in conservation is an order of magnitude greater.

Case study

The following case study refers to heating of churches in Scandinavia. Even though the climate may be very different as compared to the Mediterranean area, the approach should be useful under different circumstances.

Historically the medieval churches of Scandinavia have not been heated, even during the winters. As church visitors came to expect a higher degree of comfort, different means of heating were installed. First stoves and then central heating was installed during the 20th Century. During the 1960's and 1970's heating oil was so cheap that one began to heat the churches permanently. In many cases this lead to severe damages. During the winters the indoor climate got extremely dry, causing wooden objects to shrink, thus cracking and peeling paint. Blackening due to thermal diffusion increased dramatically.

During the early years of church heating, intermittent heating i.e. the churches were heated for mass only, was a practical and economic solution. In the 1970's one had to go back to intermittent heating for reasons of conservation.

The churches dealt with in the present study are built in heavy limestone walls with lime plaster on both sides. In most churches one will find valuable wooden objects as well as wall paintings. There is no ventilation, except for infiltration. The typical rural church is used only a few hours every other week.

The general method is:

a) Describe and analyse the problems from a physical point of view
b) Establish the climate criteria
c) Determine the financial means available
d) Choose a strategy; an overall solution
e) Determine the technical solution
f) Evaluation and feed back

Problem

The general problem is how to heat the churches without damaging the buildings or objects stored there. More specifically we have a number of common problems presented in table 1.

Material	Type of damage	Cause
Wood and paint on wood	Cracking and peeling	Large and long term variations in relative humidity
Walls	Blackening	High air temperature Air movements Particles in the air
Walls and surfaces	Algae and mildew	High relative humidity, >80% Moderate temperatures
Walls	Salt crystallisation	Low / Varying relative humidity
Wood	Insects	High relative humidity Moderate temperature
Iron	Oxidation	High relative humidity High temperature

Table 1. Common problems of climate induced degradation in Scandinavian churches.

Climate criteria

The materials and degradation processes all require their own optimal climate. In many cases the literature provides sufficient information determine the proper climatic criteria. The layman, however, may need to consult experts in the field.

Research and practical experience has established the following general rules for conservation in these churches:

- Minimise large and long variations in temperature and humidity.
- Avoid high relative humidity, more than 80%.
- Minimise particles in the air

The next consideration is the people in the building. The primary human comfort criterion is temperature; 16–22ºC depending on clothing, activity and duration of stay, In the cold season in Scandinavia, these indoor temperatures are inevitably associated with very low relative humidity. In the summer, on the other hand, the relative humidity is often much too high.

Now, the problem has been specified; how can we provide thermal comfort for people while controlling the relative humidity.

Economy

The churches involved belong to very small parishes, typically 200–300 members, and the financial means are limited. For investments in the buildings, there are federal subsidies which allows for long term planning and investments. For the parishes, the most important is to keep the running costs low. This should be considered when choosing the heating strategy.

Strategy and solutions

The strategy should simultaneously take into account aspects of conservation, comfort and costs in order to come up with the best possible compromise.

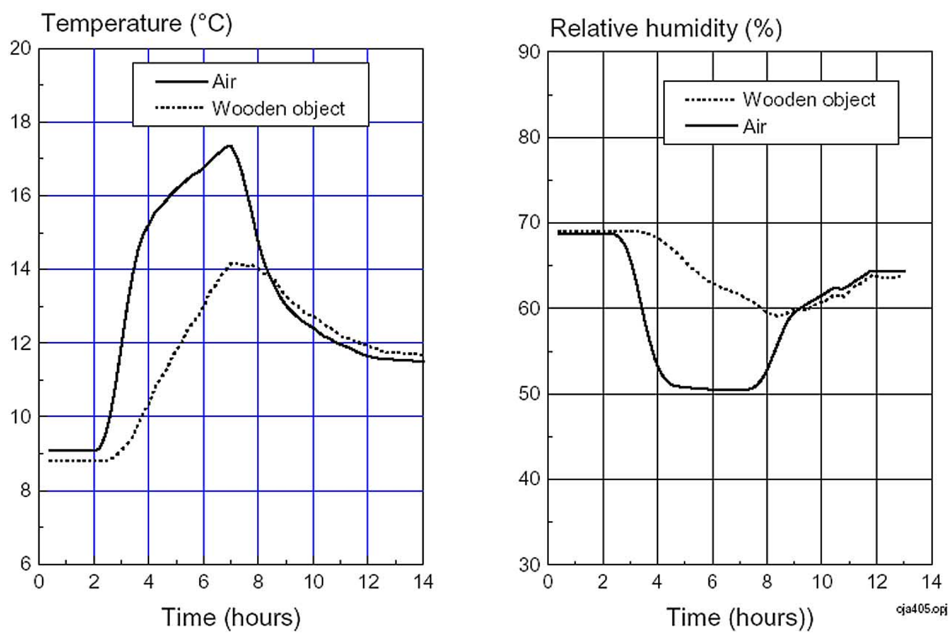


Fig. 2. The graphs show how temperature and relative humidity vary during intermittent heating.

In this case, the main strategy is intermittent heating. This means that the church is heated only when it is being used. In between sessions, the church is kept at the lowest possible temperature. In fig. 2 a temperature and relative humidity during a heating session are shown.

The idea is to heat the air so quickly that there is little effect on the materials. In this way, there will be a moderate change of relative humidity on the surface of the materials, even though there is significant temperature increase in the air, se fig 2. The faster the heating rate, the less effect on the materials.

The second pad of the strategy is set up climate zones, allowing us provide comfort in certain areas without having to heat the whole building. For this purpose one can use using heaters attached under the church benches and/or radiative heating. Using bench heaters one can achieve zones with 2–4°C higher temperature than in the rest of the building. This has a significant effect, both in terms of energy savings and energy economy. By using high temperature radiators in combination with floor heaters, it is possible to reduce the air temperature by 8–10°C as compared to normal heating practice. Lowering the required air temperature has a dramatic effect on the energy consumption since the heating increases with the square of the temperature rise.

The third pad of the strategy is to actively monitor and control relative humidity. Traditionally all heating is governed by temperature. When conservation is an objective, it is often necessary to control and regulate the relative humidity. In modern control systems one can easily include control by relative humidity and the relative humidity is regulated by changing the temperature. In churches, this can be used in two purposes:

a) To avoid too low values when heating the church in the winter
b) To maintain a stable relative humidity over the year.

In extreme cases, moisture control can be accomplished by humidification or dehumidification, but this is a more complicated and expensive solution. Ventilation as a general means of climate control is not recommended unless the humidity outside is monitored in order to avoid adding moisture to the building.

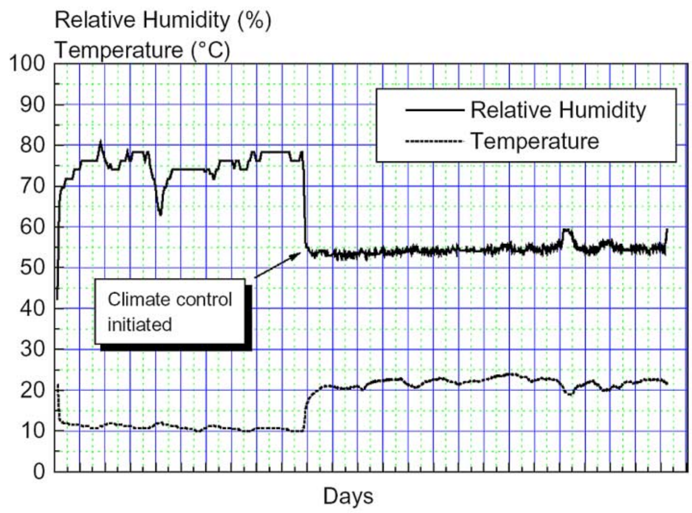


Fig 3. The graph shows how the relative humidity can be controlled by regulating the temperature.

Fig 3 shows results from a field test in a Swedish church. As can be seen, the relative humidity decreases with increasing temperature. In order to avoid extremely low relative humidity when the church is heated, one can set threshold values for the control systems at which the heat supply is reduced.

Evaluation and feed back

Climate control in historic buildings is a combination of systematic engineering on one hand and trial and error on the other hand. It is necessary the monitor the indoor climate and make adjustments. Monitoring temperature and relative humidity can be done by using small data loggers that store data at a given interval. Data is transferred to a computer for display and analysis.

Systematic measurements in a number of churches where the above mentioned solutions have been implemented show that the climatic conditions, from a conservation point of view, are improved significantly. At the same time, heating costs are reduced.

Monitoring the indoor climate is relatively simple and can be done by custodians. However more qualified personnel is needed to make the adjustments.

Conclusion

The present paper has tried to provide a fundamental method to come up with solutions and systems for climate control in historic buildings. The main steps of the method are:

a. Describe and analyse the problems from a physical point of view
b. Establish the climate criteria
c. Determine the financial means available
d. Choose a strategy; an overall solution
e. Determine the technical solution
f. Evaluation and feed back

Results from the case study shows that climate control gives significant improvement in the indoor climate with respect to conservation. As compared to costs for reactive measures climate control a very cost-effective method.

In order to refine the knowledge base of climate control in historic building, we need more research and development. Knowledge management is also a limiting factor, we have to gather, evaluate and disseminate existing data on climate criteria for conservation.

In the implementation phase there is generally no lack of technology, technical devices or technical know-how. The problem is to apply existing technology under unusual conditions. This requires an interdisciplinary understanding, co-operation and innovative thinking.

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