

BS EN 15759-1:2011



BSI Standards Publication

Conservation of cultural property — Indoor climate

Part 1: Guidelines for heating churches, chapels and other places of worship

NO COPYING WITHOUT BSI PERMISSION EXCEPT AS PERMITTED BY COPYRIGHT LAW

raising standards worldwide™



National foreword

This British Standard is the UK implementation of EN 15759-1:2011.

The UK participation in its preparation was entrusted to Technical Committee B/560, Conservation of tangible cultural heritage.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

© BSI 2011

ISBN 978 0 580 60908 4

ICS 91.040.10; 97.195

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 December 2011.

Amendments issued since publication

Date	Text affected
------	---------------

EUROPEAN STANDARD

EN 15759-1

NORME EUROPÉENNE

EUROPÄISCHE NORM

November 2011

ICS 97.195

English Version

Conservation of cultural property - Indoor climate - Part 1: Guidelines for heating churches, chapels and other places of worship

Conservation des biens culturels - Environnement intérieur
- Partie 1 : Recommandations pour le chauffage des
églises, chapelles et autres édifices cultuels

Erhaltung des kulturellen Erbes - Raumklima - Teil 1:
Leitfäden für die Beheizung von Andachtsstätten

This European Standard was approved by CEN on 8 October 2011.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.



EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: Avenue Marnix 17, B-1000 Brussels

Contents

Page

Foreword.....	4
Introduction	5
1 Scope	6
2 Normative references	6
3 Terms and definitions	6
4 General aspects to be considered before and during the application of the standard.....	8
4.1 Overall objective of any intervention.....	8
4.2 The individual character of the building	8
4.3 Professional support.....	8
4.4 The effect of installations	8
4.5 Sustainability and energy efficiency	8
5 Assessment of building, interiors and contents	8
5.1 Building structure and its condition	8
5.2 Building interiors and contents.....	9
5.3 Use of the building.....	9
5.4 Air exchange	9
6 Specification for indoor climate	9
6.1 Determine the appropriate indoor climate	9
6.2 Establish the historic indoor climate.....	10
6.3 Indoor climate specification for conservation.....	10
6.3.1 General.....	10
6.3.2 Relative humidity	10
6.3.3 Temperature	10
6.3.4 Air movement.....	11
6.4 Indoor climate specification for thermal comfort.....	11
6.4.1 General.....	11
6.4.2 Relative humidity	11
6.4.3 Temperature	11
6.4.4 Air movement.....	11
6.5 Compromise between thermal comfort and conservation.....	11
7 Heating strategies.....	12
7.1 Choice of heating strategy.....	12
7.2 Basic strategies	12
7.2.1 No heating	12
7.2.2 Conservation heating	13
7.2.3 Heating for thermal comfort	13
7.3 Distribution in space	13
7.3.1 General heating.....	13
7.3.2 Local heating.....	13
7.4 Distribution in time	13
7.4.1 Continuous heating	13
7.4.2 Intermittent heating	14
7.4.3 Mixed mode heating	14
8 Heating systems and their application.....	14
8.1 Warm-air heating.....	14
8.1.1 General.....	14
8.1.2 Centralised warm-air heating system.....	14
8.1.3 Decentralised warm-air heating system.....	14
8.1.4 Application	15

8.1.5	Thermal comfort	15
8.1.6	Conservation.....	15
8.2	Infrared heating	15
8.2.1	General	15
8.2.2	IR heating from gas combustion	15
8.2.3	IR heating from electric tubular and halogen quartz heaters	16
8.2.4	Thermal comfort	16
8.2.5	Conservation.....	16
8.2.6	Application	16
8.3	Radiators	16
8.3.1	General	16
8.3.2	Thermal comfort	16
8.3.3	Conservation.....	16
8.3.4	Application	16
8.4	Wall heating through pipes mounted in or on the inside of the walls	17
8.4.1	General	17
8.4.2	Thermal comfort	17
8.4.3	Conservation.....	17
8.4.4	Application	17
8.5	Under floor heating	17
8.5.1	General	17
8.5.2	Thermal comfort	17
8.5.3	Conservation.....	17
8.5.4	Application	18
8.6	Pew heating.....	18
8.6.1	General	18
8.6.2	Thermal comfort	18
8.6.3	Conservation.....	18
8.6.4	Application	18
8.6.5	Pew heating systems	18
9	Implementation	19
10	Evaluation.....	20
11	Comments on the application of this standard	20
Annex A (informative) Flow chart giving an overview of the standard		21
Bibliography.....		22

Foreword

This document (EN 15759-1:2011) has been prepared by Technical Committee CEN/TC 346 "Conservation of cultural property", the secretariat of which is held by UNI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by May 2012, and conflicting national standards shall be withdrawn at the latest by May 2012.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

Introduction

Churches, chapels and other places of worship such as mosques and synagogues (referred to collectively in the text of this standard as “places of worship”) are an important part of European cultural heritage. The buildings and their interiors, containing cultural heritage objects, are documents of our heritage that society agrees need to be preserved for present and future generations. The indoor climate is a critical factor in conserving the fabric of buildings and the objects they house.

This European Standard is motivated by the need to reflect the special characteristics of places of worship, conditions which are not addressed in standards for the heating of other kinds of buildings. The defining characteristics of these buildings are their construction (often early building techniques); the fact that they were not designed as living or working spaces; their intermittent use; and the vulnerability of their surface decoration and contents. Originally, most historic places of worship had little or no heating. Nowadays, buildings in cold climate regions may be heated in order to:

- a) provide thermal comfort for worshippers, staff and visitors (referred collectively in this text as “users”);
- b) improve the indoor climate conditions for the conservation of the building and its contents;
- c) achieve a combination of (a) and (b) in buildings where both conservation and thermal comfort have to be considered.

The conventional climate requirements for thermal comfort can sometimes be in conflict with the requirements for conservation and may therefore call for compromise.

A decision on changing or replacing the heating system in a place of worship generally depends on a variety of factors: the pattern of use of the building (e.g. frequency, numbers of users, opening hours for visitors), its liturgical uses, the significance, condition, and vulnerability of the building and its often valuable contents, thermal comfort of the users, costs (installation, operation and maintenance), energy efficiency and sustainability, visual and audible impact, aesthetics, impact on the building structure, safety, and national laws and regulations.

This standard provides guidelines in order to facilitate the best possible decision on behalf of the end users. The standard is divided into the following steps:

- a) assessment of the building, its interior and contents;
- b) determine an indoor climate specification with respect to conservation and thermal comfort;
- c) determine an appropriate heating strategy;
- d) select and design an appropriate heating system;
- e) implement the proposed changes;
- f) evaluate the effectiveness of the heating system with respect to the specification.

This is the first standard in a series of standards on indoor climate and climate control in cultural heritage buildings. The air exchange of a building has a fundamental influence on its indoor climate and climate control; general considerations are given in Clause 5. Ventilation will be dealt with fully in the second part of the series of standards on indoor climate in cultural heritage buildings, prEN 15759-2, *Conservation of cultural property — Indoor climate — Part 2: Ventilation*.

1 Scope

This European Standard provides guidelines for the selection of heating strategies and heating systems in churches, chapels and other places of worship such as mosques and synagogues, in order to prevent damage to cultural property while at the same time creating an indoor climate that allows for a sustainable use of these buildings. It applies to most kinds of places of worship regardless of size and construction. This European Standard applies not only to the introduction of new heating systems but also to the replacement of old ones.

This European Standard applies to buildings that are part of cultural heritage or that house cultural heritage objects. This European Standard deals with indoor climate conditions, heating strategies and technical solutions for their implementation but not with the technical equipment itself.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 15757, *Conservation of Cultural Property — Specifications for temperature and relative humidity to limit climate-induced mechanical damage in organic hygroscopic materials*

EN 15758, *Conservation of Cultural Property — Procedures and instruments for measuring temperatures of the air and the surfaces of objects*

prEN 16095¹⁾, *Conservation of cultural property — Condition report of movable heritage — Visual inspection and description of the condition of movable heritage*

prEN 16096¹⁾, *Conservation of cultural property — Condition survey of immovable heritage*

prEN 16242¹⁾, *Conservation of cultural property — Procedures and instruments for measuring humidity in the air and moisture exchanges between air and cultural property*

EN ISO 7730, *Ergonomics of the thermal environment — Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria (ISO 7730:2005)*

EN ISO 11079:2007, *Ergonomics of the thermal environment — Determination and interpretation of cold stress when using required clothing insulation (IREQ) and local cooling effects (ISO 11079:2007)*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1 climate

statistics of temperature, humidity, atmospheric pressure, wind, rainfall, and other meteorological elements in a given location over a long period of time

3.2 preservation heating

heating used to improve the indoor climate for conservation purposes

1) Under publication.

3.3

continuous heating

permanent heating of a building throughout the cold period of the year

3.4

cultural heritage

tangible and intangible entities of significance to present and future generations

3.5

dew point

temperature to which humid air must be cooled for water vapour to condense into liquid water

3.6

general heating

heating of the whole building volume

3.7

historic climate

description of the climate over a representative period of time

3.8

indoor climate

climate inside a room or a building

3.9

intermittent heating

heating of a building operated for limited periods of time

3.10

local heating

heating a limited space in the building

3.11

microclimate

climate in part of a building or a room where the climate differs from the surrounding climate

3.12

mixed mode heating

combination of continuous and intermittent heating, where the building is continually kept at a low temperature and heated to a higher temperature only when it is used

3.13

natural indoor climate

indoor climate of a building without heating, forced ventilation or any other kind of active climate control

3.14

outdoor climate

climate outside of a building

3.15

target range of RH variations

range of RH variations that must be maintained to avoid climate induced damages

3.16

thermal comfort

state of mind that expresses satisfaction with the surrounding environment

3.17

thermal stratification

vertical layering of air temperatures in a building

4 General aspects to be considered before and during the application of the standard

4.1 Overall objective of any intervention

The reason for a proposed intervention shall be clearly defined with respect to the conservation and use of the building. As long as the historic indoor climate is not causing any damage, it need not necessarily be altered unless change in use or other requirements make it necessary. Heating is not an objective in itself.

4.2 The individual character of the building

This European Standard is based on the notion that places of worship in general share enough common characteristics for a standard to be meaningful. On the other hand, it recognizes that the control of the indoor climate of each building is a complex task which requires taking into account many factors particular to the individual building, its contents, its use and its context. Therefore, this European Standard shall be applied with understanding and respect for the individual character of each building.

4.3 Professional support

The process of designing a new or altering an existing heating system shall be carried out by a multidisciplinary team in close consultation with the users of the building. The team shall include all relevant expertise, including specialists professionally qualified in the conservation of structures and heritage items, and in all other relevant technical aspects involved.

4.4 The effect of installations

For all installations related to changes in the heating system, the following factors shall be considered:

- structural alterations to the building related to ducting, pipe work, cabling etc shall be avoided unless absolutely necessary. The need for equipment rooms shall be considered at an early stage;
- installations involving damage to walls or the excavation of floors shall be subject to prior inspection comment and agreement by the relevant experts and authorities. Special attention must be paid to hidden paint layers and to the under floor archaeology of the building, including tombs and earlier construction phases;
- reduction of additional damaging interventions, the lifespan of the proposed installations shall be given greater priority than is generally the case for modern buildings;
- installations chosen shall be as visually unobtrusive as possible;
- account shall be taken of any light and sound emitted by heating installations which may be disturbing to the users.

4.5 Sustainability and energy efficiency

Sustainability in general and energy efficiency in particular should be considered at each step in the application of this standard. Given the specification for indoor climate based on conservation aspects and the use of the building, heating strategies and systems shall be chosen in order to minimise the use of energy and the environmental impact.

5 Assessment of building, interiors and contents

5.1 Building structure and its condition

Before deciding on a new or modified heating system, it is important to establish whether:

- the perceived need for intervention is related to the climate envelope of the building itself rather than the need for a new or improved the heating system;
- parts of the building would be at risk if the heating strategy or heating system was altered.

For these purposes, a condition survey of the building is required. The European Standard prEN 16096 provides guidelines for condition survey of immovable cultural heritage objects. In the survey, special attention shall be paid to the building envelope: moisture transport, air tightness and thermal insulation. The survey shall also include the condition and functionality of existing heating installations.

5.2 Building interiors and contents

The condition of the surface decoration and significant contents shall be surveyed. The European Standard prEN 16095 provides guidelines on condition report, visual inspection and description of movable cultural heritage. In the survey, special attention shall be paid to the condition of wall paintings, some of which may be hidden under layers of plaster or paint, and to that of stone monuments, stained glass, painted and unpainted woodwork, canvas paintings, textiles (e.g. banners), metalwork (e.g. lecterns and brasses) and objects of mixed materials such as organs.

5.3 Use of the building

The initial assessment shall include a description of the heating demand in relation to the present and planned use of the building, and is to take into account patterns of worship and visiting; liturgical arrangements, performances and secular activities.

5.4 Air exchange

The air exchange of a building, whether it is due to mechanical ventilation, natural ventilation or infiltration, (leakage) can have a significant influence on the indoor climate and hence on climate control decision-making. Although this standard is limited to heating, it is essential to consider the two in tandem. When choosing a heating strategy and designing a heating system, the following aspects of air exchange shall be taken into account:

- unnecessary air exchange will increase both energy and power demand in order to counteract its effects on temperature and/or humidity;
- depending on outdoor climate conditions in relation to indoor conditions, air exchange can sometimes reduce humidity levels, sometimes having the reverse effect; therefore it has to be considered in parallel with heating strategies designed to control internal humidity;
- controlled ventilation can be an alternative to heating when high humidity is a problem;
- air exchange creates air motions that may affect conditions both for thermal comfort and for conservation.

6 Specification for indoor climate

6.1 Determine the appropriate indoor climate

In order to determine the appropriate indoor climate with respect to conservation and thermal comfort, the following steps shall be taken:

- a) establish the historic indoor climate;
- b) determine an indoor climate specification for conservation;
- c) determine an indoor climate specification for thermal comfort;

- d) find a compromise between b) and c) if needed.

It is generally necessary to consult an interdisciplinary team of specialists for the full range of this task to be covered. It must be fully understood that, without a proper analysis of past conditions or careful determination of the proposed indoor climate specification, it is not safe to proceed to the next steps of the overall process: heating strategy and heating systems.

6.2 Establish the historic indoor climate

In order to establish the historic indoor climate inside the building, measurements of temperature and relative humidity (RH), according to EN 15758 and prEN 16242, are to be taken over a period of at least a year, and any records consulted for earlier years. For reference, similar measurements shall be made for external conditions over the same period and/or meteorological records consulted.

6.3 Indoor climate specification for conservation

6.3.1 General

This clause describes a process of determining an indoor climate specification for conservation. Based on the survey, the specification for each building has to take into consideration a wide range of materials and combinations of materials, both in the building itself and its interiors, for which specialists will often have to be consulted.

6.3.2 Relative humidity

Relative humidity (RH) is generally the most critical parameter from a conservation point of view and shall therefore be kept at a defined level and as stable as possible. RH depends on both the temperature and the moisture content of the air. Attention shall be paid to the fact that in the immediate vicinity of surfaces RH is determined by the surface temperature which may be significantly different from the ambient room temperature. Determining a target range for the building means taking into consideration the steps and issues listed below and adjusting a number of ranges into a common range. Experts shall be consulted when defining the final target range.

- a) Determine a target range for the RH variations to limit climate-induced mechanical damage in organic hygroscopic materials according to EN 15757.
- b) For materials other than those covered in EN 15757 such as metals and glass and in the event of salt crystallisation, an expert shall be consulted to adjust the target range.
- c) The allowable rate of change in RH shall be determined by an expert. Rapid changes in RH lead to gradients of moisture contents across materials and corresponding differential dimensional response resulting in stress. Slow changes in RH bring about a more uniform moisture distribution within the materials but still cause an overall dimensional response which may lead to stress development in objects and design layers restrained in their movement.
- d) Determine an upper limit for RH to avoid biodeterioration: mould, rot, insects, etc. It should be borne in mind that biodeterioration depends on a combination of RH, temperature and other factors.
- e) Determine a lower limit for RH as some materials become brittle at low RH. The lower limit is to be defined with respect to the most fragile material or combination of materials in the building.
- f) The rate of degradation from chemical processes such as corrosion, oxidation and hydrolysis will increase with RH. Given that the previous steps leave room for choice, a drier indoor climate is to be preferred.

6.3.3 Temperature

Temperature in itself may have a direct effect on the condition of cultural heritage items and will have an indirect effect on RH.

- a) Temperatures may have to be adjusted to meet the RH requirements.
- b) Temperatures of vulnerable surfaces shall be kept above the dew point in order to avoid condensation. The presence of hygroscopic salts, mainly in walls, may increase the moisture content of materials irrespective of the dew point.
- c) If there is a risk of frozen water pipes or if non frost-resistant elements of the building are exposed to moisture, a minimum temperature for the endangered area shall be set. The minimum temperature has to be determined in each case in order to maintain a proper safety margin.
- d) The rate of degradation due to chemical processes generally increases with temperature. Given that the previous steps leave room for choice, a cooler indoor climate is to be preferred.

6.3.4 Air movement

Air movement is caused by heating systems or air exchange (see 5.4). All heating systems cause a degree of air movement, directly through convection from the heat sources and, indirectly through temperature differences between the air and the surfaces of the building envelope. Air movement shall be kept to a minimum because it may increase the rate of deposition of particles and the risk of damage due to salt crystallisation on surfaces in the building.

6.4 Indoor climate specification for thermal comfort

6.4.1 General

In everyday life, people will accept varying degrees of thermal comfort. Air temperature, radiant temperature, humidity, air movement, activity, clothing and personal preference are all factors that affect human thermal comfort. Requirements for thermal comfort in general are given in EN ISO 7730. However, there are no standards that apply specifically to comfort in places of worship. Since the comfort criteria may be in conflict with the criteria for conservation, the general standards on thermal comfort are not automatically applicable in places of worship.

The specification for thermal comfort in a place of worship has to be determined on a case-by-case basis with respect to RH, temperature, and air movement.

6.4.2 Relative humidity

Considering thermal comfort only, RH is to be kept within the 30-80 % range.

6.4.3 Temperature

Thermal comfort is affected by air temperature, radiant heat exchange with surrounding cold or warm surfaces, and convective exchange with the surrounding air. Warm clothing as well as the presence of other users reduces body cooling and thus less heating is needed. A person may feel thermally comfortable with regard to the whole body, but would be uncomfortable if one part of the body is warm and another cold. It is preferable to have one's feet, legs and hands neutral or warm and face neutral or cool rather than vice versa.

6.4.4 Air movement

Air movement, when the air is cool or cold may have a negative effect on thermal comfort, consequently air movement shall be kept to a minimum.

6.5 Compromise between thermal comfort and conservation

In some places of worship, where either conservation or thermal comfort alone is the main priority, the indoor climate specification will be determined in accordance with either 6.3 or 6.4. In most places of worship, both conservation and comfort needs have to be considered together since a comfortable temperature level may

be in conflict with conservation needs. A compromise is often necessary, in which case conservation needs shall have priority. The following steps shall be taken:

- a) compare the specifications for thermal comfort and conservation and identify areas of conflict. For example, heating for comfort in the winter may result in an RH that is too low with respect to conservation;
- b) identify possible solutions;
- c) evaluate the different solutions with respect to the effects on conservation and thermal comfort.

The temperature required for services is the key parameter in finding a compromise. A lower temperature will generally improve conservation conditions. With appropriate clothing and limited length of stay, there is no definite lower limit for temperature with respect to thermal comfort. If it can be assumed that users will wear clothing suitable for the current outdoor conditions, the heating can be reduced and conservation conditions improved. This standard proposes a limitation of the thermal comfort range from a “neutral” sensation to “slightly cool” which corresponds to an average skin temperature in the 30 °C-33 °C range (EN ISO 11079:2007).

7 Heating strategies

7.1 Choice of heating strategy

The choice of heating strategy will be determined mainly by the need to balance climate requirements for conservation and comfort, the pattern of use of the building, and energy efficiency. The most common strategies for heating buildings of worship are presented in Table 1.

Table 1 — Heating strategies

Basic strategy	Distribution in space	Distribution in time
No heating		
Conservation heating	General heating	Continuous heating
	Local heating	Intermittent heating
Heating for comfort	General heating	Continuous heating
	Local heating	Intermittent heating
		Mixed mode heating

These strategies may be complementary, which means, for instance, that intermittent and local heating can be combined. The following is a description of the heating strategies in relation to the indoor climate requirements.

7.2 Basic strategies

7.2.1 No heating

The building has no heating at all. The indoor climate is governed only by the outdoor climate, the building envelope, air exchange and activities in the building. Generally, the average RH level is higher and the amplitude of variations in RH is smaller than in heated buildings.

In buildings where there is a problem with salt crystallisation, and/or soiling of walls and other surfaces, heating may increase the risk.

7.2.2 Conservation heating

Conservation heating uses heat to improve the indoor climate for conservation. The primary aim is to keep RH at a stable and appropriate level throughout the year in order to minimize damage due to RH variations and to prevent dampness and biodeterioration. Conservation heating may be needed even in the summer to keep RH below thresholds for mould growth. The secondary aim of conservation heating is to keep the inside of the building envelope warm enough to avoid moisture condensation or frost. Conservation heating can only reduce RH, if the indoor climate is too dry other measures will be needed.

Conservation heating can be controlled in two ways, with different degrees of precision. The most precise control method is heat input based on RH (humidistatic heating). Given sufficient heating power, this will always keep RH below a specified level. In contrast, a constant heating power, if properly selected, will reduce RH, although with less stability and precision than humidistatic heating.

When condensation or frost on internal surfaces is a major consideration, the control system shall also take into account the dew point at the surfaces. In the winter, a minimum temperature can be set in order to prevent freezing.

If conservation heating is used in the summer to reduce RH, a maximum temperature can be set to prevent excessively high temperatures causing discomfort to users.

7.2.3 Heating for thermal comfort

Heating for thermal comfort is aimed at providing acceptable comfort for the users. In winter, heating for comfort may result in a lower RH than is preferable from a conservation point of view.

Heating for comfort is primarily controlled with respect to temperature. Care shall be taken that thermostats or temperature sensors are placed in such way that they best represent the temperature around the people in the building.

7.3 Distribution in space

7.3.1 General heating

The objective is to heat the whole building. General heating can be intermittent or continuous. The whole volume of the building is heated with no discrimination between people and cultural heritage objects.

7.3.2 Local heating

The objective is to heat only designated parts of the building. The temperature increase in the general space shall be as small as possible in relation to the temperature increase in the heated zone. The advantage of this is that unwanted climatic disturbance in the building as a whole can be reduced.

A potential problem associated with local heating is that some surfaces of the building envelope will remain cold, causing condensation due to moisture added when large numbers of users are present. Another potential problem is convective air movement (see 6.3.4). In the case of low background temperatures in the building, acceptable thermal comfort in the heated zone may be difficult to reach with local heating alone. Reduced comfort outside of the heated zones may also be a problem.

7.4 Distribution in time

7.4.1 Continuous heating

Continuous heating is the permanent heating of a building throughout the cold period of the year. The objective is to provide a specified indoor climate at all times. This can be heating either for comfort or for conservation. Particle deposition and thermal stratification are unwanted effects of continuous heating.

7.4.2 Intermittent heating

The objective of intermittent heating is to provide a specified indoor climate for a limited period of time. Most commonly this is heating for comfort, but it can also be used for conservation heating.

Intermittent heating causes, by definition, a temporary disturbance to the indoor climate, but if properly designed and managed, it can reduce unwanted disturbance to the basic indoor climate in the long term and promote good conservation conditions.

Intermittent heating can cause damaging cycles of salt re-crystallisation in porous structures, such as masonry, stone, plaster, or wall paintings. Intermittent heating may also result in walls that are colder than the air, which may cause increased particle deposition, cold draughts and condensation.

The control conditions for intermittent heating are:

- a set point for temperature during service;
- a lower limit for RH during service;
- duration of heating;
- rate of change of temperature during the heating period.

7.4.3 Mixed mode heating

Mixed mode heating is a combination of continuous and intermittent heating, where the building is continually kept at a low temperature and heated to a comfort temperature only when it is used.

Mixed mode heating can be combined with conservation heating in between services and will reduce the amplitude of variations in temperature and RH during the heating episodes compared with intermittent heating alone.

The control conditions for mixed mode heating are the same as for intermittent heating with the addition of a set point for temperature or RH between services.

8 Heating systems and their application

8.1 Warm-air heating

8.1.1 General

In a warm-air heating system, air heated to a pre-selected temperature is circulated in the building. A warm-air system can be either centralised or decentralised. This clause deals with warm-air heating systems for general heating.

8.1.2 Centralised warm-air heating system

Air from the building is filtered, heated and fed back into the building through a warm-air duct system. Generally, the air inlet vents are fitted in the floor.

Outside air can also be added to the circulating air to improve air quality. The warm air can be generated by any kind of conventional heat source,

8.1.3 Decentralised warm-air heating system

To minimise the impact of installing air duct systems, places of worship often use decentralised warm-air heating systems. The convective heaters can be placed under and above the floor, on the walls and in the

pews and are heated by hot water, electricity, or gas. They can also be made portable to facilitate seasonal use.

8.1.4 Application

Warm-air heating is suited for general heating in medium-size and large buildings. It can be used for all heating strategies.

By definition, warm-air systems cause air movements. The systems shall be properly designed and tuned in order to minimise air movement in the building and to provide an even temperature distribution throughout the space. The distribution of heat depends to a large extent on the arrangement and number of warm-air vents/convectors, on the air outlet temperature and speed and on the internal topography of the building.

8.1.5 Thermal comfort

General and continuous warm-air heating provides thermal comfort in the whole building. Care shall be taken in order to avoid air movements that will reduce comfort.

Convective heaters may be used as a complement to counteract cold down draughts from windows and walls.

8.1.6 Conservation

Warm-air heating systems shall be properly designed to:

- minimise deposition of particles on surfaces;
- ensure that the flow of warm air is unobstructed and not directed onto walls or cultural heritage objects;
- minimise thermal stratification;
- avoid excessive fluctuations of temperature and consequently of RH.

Floor vents shall not be installed in areas frequently walked on in order to prevent the airborne circulation of dust and dirt particles from shoes.

Warm-air heating systems shall be equipped with filters to clean the circulated air. Filters shall be maintained and changed according to specification.

In buildings with no air duct system, installation of a new central warm-air heating system can be highly invasive. However, if there is an existing duct system, it may be possible to upgrade it with an acceptable intervention.

8.2 Infrared heating

8.2.1 General

Infrared heaters (IR) transfer heat directly to a recipient body without heating the air in between. The radiation intensity increases rapidly with the temperature of the radiator. Common power sources are electricity and gas for high-temperature radiators and hot water or electricity for low-temperature radiators.

8.2.2 IR heating from gas combustion

The fuel is gas or liquid (e.g. methane, propane, LPG) and the combustion generates CO₂, water vapour and other exhaust products that may cause problems, such as condensation and high CO₂ levels, unless there is sufficient ventilation. Chimneys or exhaust pipes for flue gases need to be considered. The gas burners cause audible noise and a red glare. Fuel storage and distribution bring the risk of fire and explosions.

8.2.3 IR heating from electric tubular and halogen quartz heaters

Tubular heaters are electrically heated to high temperatures emitting visible light in a spectrum from red to white. Electric halogen quartz lamps emit partially visible radiation of a pink colour which can be disturbing and lessens IR efficiency. Their installation is less invasive and hazardous than gas heaters.

8.2.4 Thermal comfort

An IR system, well balanced in terms of direction and intensity, can provide thermal comfort even at low air temperatures. However, to be thermally comfortable, the IR contribution to the globe-thermometer temperature or black strip temperature (EN 15758) shall not exceed 10°C. Overhead IR systems used alone provide limited comfort since users' heads are warmed more than their feet and blind areas where the heat is obstructed remain uncomfortable.

8.2.5 Conservation

IR heating can be used in a limited area with minor influence on the general indoor climate in the rest of the building. Care shall be taken to ensure that sensitive objects and surfaces are not heated by misdirected radiation. The IR heaters shall be installed with respect to heritage values and aesthetics. Particle deposition due to the convective rise of the air may develop above the high-temperature heaters.

8.2.6 Application

IR heating is specially suited for intermittent and local heating since the warm-up time is short and the heat can be directed.

8.3 Radiators

8.3.1 General

A radiator is a heating element that transmits heat to the surroundings primarily through radiation. Radiators are heated with hot water or electricity. They have lower surface temperatures than IR heaters and generally require larger heat emitting surface areas. Radiators can be wall- or floor mounted.

8.3.2 Thermal comfort

In addition to raising the general temperature of a room, radiators are used to counteract the cold sensation from windows and walls. The level of thermal comfort depends on the location, number, surface temperature and area of the radiators and on how long the system is kept in operation before the building is used.

8.3.3 Conservation

Most radiators will cause convective movement of warm air and possibly particle deposition on walls and ceiling. Radiators should not be placed near sensitive surfaces or objects in order not to cause damaging microclimates.

8.3.4 Application

Water or oil filled radiators of high thermal inertia, filled with water or oil, need to be turned on well in advance of use.

Radiators are usually mounted on the walls or floor and their overall visual impact is strong, since the total radiator area required is generally large in relation to the size of the building. Pipes and electric cables generally require passage through walls and floors which may cause considerable damage.

8.4 Wall heating through pipes mounted in or on the inside of the walls

8.4.1 General

This method is based on providing continuous heating to the building envelope in masonry structures, normally through heating tubes installed in the plaster on the inside of outer walls. There are systems with one or few pipes to heat critical parts of the building construction ²⁾ for conservation but also systems that heat the whole wall for comfort. A less intrusive measure, which works on the same principle, is to install pipes on the surface of the walls.

8.4.2 Thermal comfort

This method may provide limited thermal comfort depending on the amount of heat provided. Heating the inner surfaces of the room will lead to better comfort than that provided by convective heating at the same air temperature.

8.4.3 Conservation

The invasive impact is considerable if the heating elements are installed inside the wall and special care has to be taken with interior surfaces. This system shall not be installed into walls of historic or artistic value.

This system heats the most critical points of the construction (corners) where condensation may otherwise occur and thus helps to prevent mould or algae growth. In the event of rising damp, the system may cause damage due to salt efflorescence. In comparison with convective heating, the wall heating method will generally reduce draughts and particle deposition.

8.4.4 Application

The method is used primarily for conservation heating and it is not well suited for intermittent heating due to the high thermal inertia of the system.

8.5 Under floor heating

8.5.1 General

Under floor heating uses heating elements embedded in the floor. Heat can be provided by hot water pipes, warm air or electrically heated cables and foils.

8.5.2 Thermal comfort

The heated floor provides a comfortable feeling of warmth from below but the warm floor in combination with the cold walls and ceiling may cause air movement that reduces comfort. The floor surface temperature shall be limited to a maximum of 25 °C-29 °C in order to prevent the overheating of users' feet and to limit air movements.

8.5.3 Conservation

Particle deposition on surfaces is generally increased by air movement. A floor heating system may be inconspicuous, but the invasive impact on the floor is considerable. This system shall not be installed in floors of historic or artistic value, or in the presence of buried tombs or archaeological remains.

2) In German, this method is referred to as "Temperierung".

8.5.4 Application

Under floor heating is generally not well suited for intermittent heating due to the thermal inertia of the system. Wooden pews or other objects covering the floor may also reduce the heating effect.

8.6 Pew heating

8.6.1 General

The objective of pew heating is to provide an acceptable thermal comfort for the seated users while minimizing the adverse effects on the indoor climate in general. The design of the pew-heating system will determine its effect in terms of thermal comfort and conservation. In enclosed (box) pews, it is easier to achieve a localised microclimate that does not disturb the general indoor climate. In 8.6.5 a number of different solutions for pew heating are presented.

8.6.2 Thermal comfort

In cold regions, pew heating alone may not be sufficient. It can however be used as a complement to other heating systems or to reduce discomfort when no other heating is available. In cold climates, the users' heads may remain insufficiently heated and an extra overhead IR source or general preheating may be necessary. For users who are outside of the pews, local solutions are recommended such as heating carpets and additional local IR heaters.

8.6.3 Conservation

Installation is generally not very invasive. It depends on the design of the heaters and the permitted level of visual impact: low visibility may require invasive measures. In the case of pews of historic value, the heating elements shall be installed on an independent frame to minimise the physical impact.

Pew heating, being local and often intermittent, will increase the risk of condensation on cold surfaces caused by the water vapour emitted by users.

8.6.4 Application

Pew heating is well suited for local, intermittent and mixed mode heating. The pews can be divided into individually controlled sections, but moving pews with fixed heating installations is difficult.

8.6.5 Pew heating systems

8.6.5.1 Pew heating: Single high-temperature electric heaters

Single high temperature electric heaters placed in the pews emit infrared radiation that heats the user's feet and legs. This type of system often provides limited thermal comfort due to the insufficient heating of the upper part of the body or overheating of the legs. The combination of a high-temperature source and relatively cold walls may generate strong convective air movements causing poor thermal comfort and enhancing particle deposition and condensation on walls.

The visual and physical impact depends on the type of installation and the power needed. If a heater is not adequately insulated, shielded or regulated, it may damage the pews.

8.6.5.2 Pew heating: Single low-temperature heaters

Single heaters, such as hot water pipes or electric elements, are placed under the pews. They are often turned on beforehand to heat the room first and then the users.

This type of system generates less convective motion compared to high-temperature sources, resulting in a lower rate of particle deposition on walls and ceilings. It may be difficult to reach a satisfactory degree of thermal comfort with just one low-temperature source.

8.6.5.3 Pew heating: warm air

The air is transported through ducts inserted under the floor or in a footboard. The warm air is injected at floor level or below the seats and rises in the pews to heat people.

Although users' feet and legs are heated, unpleasant air currents may be formed in the pews. Warm, dry up draughts above the pews are followed by cold downdraughts along walls and windows.

Convective air movements will enhance particle deposition and condensation on walls and ceiling. In the case of under floor ducts, the installation is invasive, less so if the ducts are inserted within a footboard.

8.6.5.4 Pew heating: Jet of warm air grazing the floor

At floor level, a fan convector, comprising a heating coil and a fan, blows out warm air that grazes the floor at a high velocity from a slot outlet. Due to a phenomenon known as the Coanda effect, the warm airflow stays close to the floor as long as it is unobstructed; however, when it hits an obstacle, such as pews or feet, it is dissipated to form a convective upward airflow that heats the users. Although users' feet and legs are heated, there is a risk of unpleasant draughts.

The floor-based jet carries dust, spores and other particles from the floor and shoes, increasing depositions on walls and ceilings. The noise from the fans and outlets may be disturbing.

This technique can only be applied when fixed pews are open at the back and below. The fan casings behind each group of pews are visible, but otherwise the installation is generally not very invasive.

8.6.5.5 Pew heating: Integrated local heating

Local heating is provided by heating elements integrated into seat cushions and heating carpets. This kind of heating is not sufficient in cold regions, but it can be used as a complement to other heating systems and to reduce discomfort when no other heating is available.

8.6.5.6 Pew heating: Ergonomically distributed low-temperature radiative heating

A number of low-temperature radiant sources are ergonomically placed in the pews to heat various parts of the body, e.g. below the kneeling pads to heat feet, below seats to heat legs, on the back of seats to heat users' backs and hands, on the floor, etc. The heaters may consist of heating foils or electric heating glass. The principal idea is to reduce heat dispersion and to provide as much radiant area as possible in the pews as required by the different thermal comfort needs of the various parts of the human body [18].

This method provides acceptable thermal comfort in mild climates when the indoor temperature in the building does not fall too much in winter. Thermal comfort is generally better than with other pew heating but remains difficult to achieve in very cold indoor environments.

Properly designed pew heating systems can reduce convective air-movements and thus improve thermal comfort and reduce the rate of particle deposition on walls. Away from pews, the influence on temperature and RH is not greater than that of the natural indoor climate fluctuations. The visual and invasive impact depends on the construction of the pews, but it is generally modest.

9 Implementation

Implementation comprises installation and bringing the new heating system into operation. The installation shall comply with national procedures and regulations. Care should be taken that the indoor climate is kept within the specification even during installation. When the system is brought into operation, its technical function must be controlled to prevent damaging effects during test runs. Written information on the operation of the system shall be given to all parties concerned.

10 Evaluation

Any changes regarding indoor climate, heating strategy or heating systems shall be evaluated to ensure that the objectives, with respect to conservation and comfort, have been met. Such evaluation will include determining whether the desired climate conditions have been achieved, and whether the heating system has caused any damage to cultural heritage objects. The extent and depth of the evaluation shall be determined in each case by an independent group of qualified experts. Normally, an evaluation shall include indoor climate measurements and the response of objects and building over a period of at least one year, preferably more. It shall also include a users' survey and an inspection of the fabric and the contents to determine any response to the changes.

The first evaluation shall take place early on after installation, a second evaluation within one to three years thereafter.

11 Comments on the application of this standard

There is no single heating solution that is optimal for all places of worship. By following the guidelines provided in this standard, a team of qualified professionals can identify solutions that match the requirements for thermal comfort and conservation. The heating strategy is chosen with respect to the climate specification, also taking the use of the building into account. Suitable heating systems that fit the indoor climate specification and the chosen strategy are then identified whereas the systems unsuitable for the purpose are eliminated. The proposed heating system(s) shall be evaluated also from a technical, practical, economic and aesthetic standpoint. It shall comply with relevant national rules for public assembly buildings. In some cases, it may be necessary to reconsider some of the decisions made in the first steps and to reiterate the process.

A flow chart describing the process is given in Annex A.

Annex A (informative)

Flow chart giving an overview of the standard

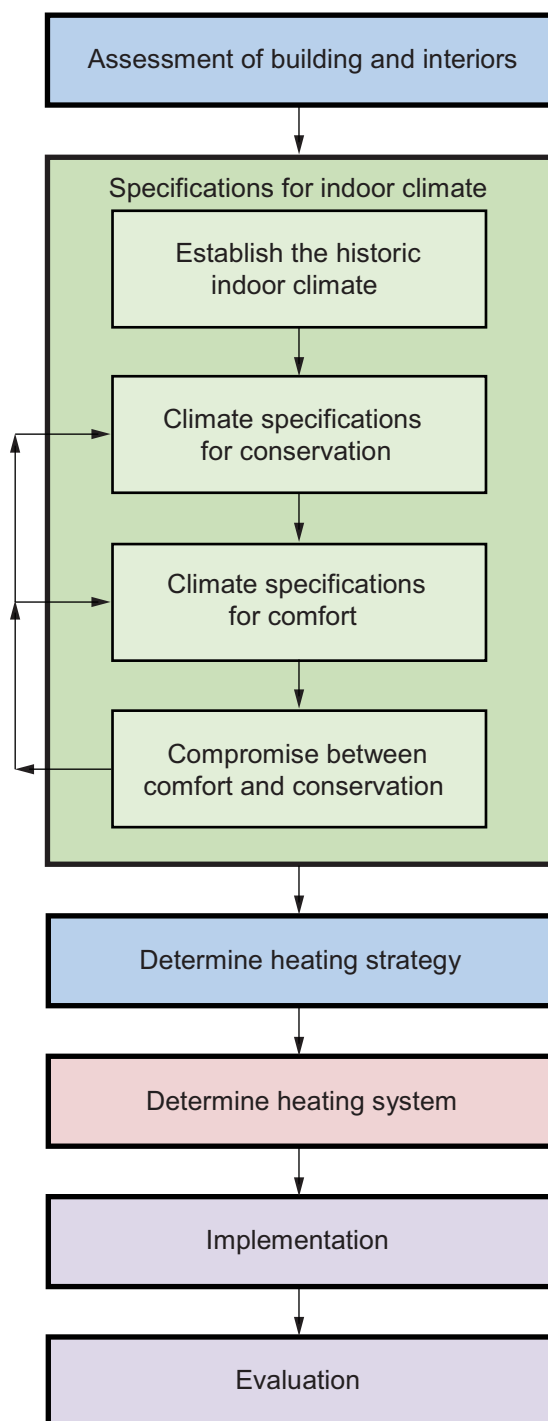


Figure A.1 — Flow chart giving an overview of the standard

Bibliography

- [1] EN 15251, *Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics*
- [2] prEN 15759-2, *Conservation of cultural property — Indoor climate — Part 2: Ventilation*
- [3] EN 15898, *Conservation of cultural property — Main general terms and definitions concerning conservation of cultural property*
- [4] EN ISO 7726, *Ergonomics of the thermal environment — Instruments for measuring physical quantities (ISO 7726:1998)*
- [5] EN ISO 8996, *Ergonomics of the thermal environment — Determination of metabolic rate (ISO 8996:2004)*
- [6] EN ISO 9920, *Ergonomics of the thermal environment — Estimation of thermal insulation and water vapour resistance of a clothing ensemble (ISO 9920:2007, Corrected version 2008-11-01)*
- [7] EN ISO 10551, *Ergonomics of the thermal environment — Assessment of the influence of the thermal environment using subjective judgment scales (ISO 10551:1995)*
- [8] BS 7913:1998, *Guide to the principles of the conservation of historic buildings*
- [9] ASHRAE 55, *Standard 55: Thermal Environment Conditions for Human Occupancy, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2004*
- [10] BEMROSE, C and BORDASS, W. *Heating your Church. Council for the Care of Churches*. London: Church House Publishing, 1996. 106 p.
- [11] BULLOCK, L; HAYES, B and STANIFORTH, S. *Appropriate Technologies for Relative Humidity Control for Museum Collections Housed in Historic Buildings*. In Roy, Ashok, Perry and Smith. *Preventive Conservation Practice, Theory and Research*. London: Preprints of the Contributions to the Ottawa Congress, 12–16 September 1994, 1994. p. 123–128
- [12] CAMUFFO et al. *Church Heating and the Preservation of the Cultural Heritage - Guide to the Analysis of the Pros and Cons of Various Heating Systems*. Milan: Electa, 2007. 240 p.
- [13] CAMUFFO, D. *Microclimate for Cultural Heritage*. Amsterdam: Elsevier, 1998. 415 p.
- [14] CAMUFFO, D., PAGAN, E., RISSANEN, S., BRATASZ, Ł., KOZŁOWSKI, R., CAMUFFO, M., DELLA VALLE, A. 2010: *An advanced church heating system favourable to artworks: a contribution to European standardisation*. *Journal of Cultural Heritage* 11, 205-219
- [15] KÜNZEL, H. *Verbesserung der Raumklima- und Feuchteverhältnisse in historischen Gebäuden durch gesteuertes Heizen und Lüften*. In *Raumklima in Museen und historischen Gebäuden*. Bietigheim-Bissingen, 2000
- [16] KÜNZEL, H. *Bauphysik und Denkmalpflege*. Stuttgart: Fraunhofer IRB Verlag, 2007
- [17] LIMPENS-NEILEN, D. *Bench Heating in Monumental Churches – Thermal Performance of a Prototype*. Eindhoven (NL): Technische Universiteit Eindhoven, 2006. 137 p.
- [18] SCHELLEN, H.L. *Heating Monumental Churches – Indoor Climate and Preservation of Cultural Heritage*. Eindhoven (NL): Technische Universiteit Eindhoven, 2002. 228 p
- [19] WTA Guidelines E 6-12. *Climate and climate stability in historical buildings*

British Standards Institution (BSI)

BSI is the independent national body responsible for preparing British Standards and other standards-related publications, information and services.

It presents the UK view on standards in Europe and at the international level.

It is incorporated by Royal Charter.

Revisions

British Standards are updated by amendment or revision. Users of British Standards should make sure that they possess the latest amendments or editions.

It is the constant aim of BSI to improve the quality of our products and services. We would be grateful if anyone finding an inaccuracy or ambiguity while using this British Standard would inform the Secretary of the technical committee responsible, the identity of which can be found on the inside front cover.

Tel: +44 (0)20 8996 9001 Fax: +44 (0)20 8996 7001

BSI offers Members an individual updating service called PLUS which ensures that subscribers automatically receive the latest editions of standards.

Tel: +44 (0)20 8996 7669 Fax: +44 (0)20 8996 7001

Email: plus@bsigroup.com

Buying standards

You may buy PDF and hard copy versions of standards directly using a credit card from the BSI Shop on the website www.bsigroup.com/shop. In addition all orders for BSI, international and foreign standards publications can be addressed to BSI Customer Services.

Tel: +44 (0)20 8996 9001 Fax: +44 (0)20 8996 7001

Email: orders@bsigroup.com

In response to orders for international standards, it is BSI policy to supply the BSI implementation of those that have been published as British Standards, unless otherwise requested.

Information on standards

BSI provides a wide range of information on national, European and international standards through its Knowledge Centre.

Tel: +44 (0)20 8996 7004 Fax: +44 (0)20 8996 7005

Email: knowledgecentre@bsigroup.com

Various BSI electronic information services are also available which give details on all its products and services.

Tel: +44 (0)20 8996 7111 Fax: +44 (0)20 8996 7048

Email: info@bsigroup.com

BSI Subscribing Members are kept up to date with standards developments and receive substantial discounts on the purchase price of standards. For details of these and other benefits contact Membership Administration.

Tel: +44 (0)20 8996 7002 Fax: +44 (0)20 8996 7001

Email: membership@bsigroup.com

Information regarding online access to British Standards via British Standards Online can be found at www.bsigroup.com/BSOL

Further information about BSI is available on the BSI website at www.bsigroup.com/standards

Copyright

Copyright subsists in all BSI publications. BSI also holds the copyright, in the UK, of the publications of the international standardization bodies. Except as permitted under the Copyright, Designs and Patents Act 1988 no extract may be reproduced, stored in a retrieval system or transmitted in any form or by any means – electronic, photocopying, recording or otherwise – without prior written permission from BSI. This does not preclude the free use, in the course of implementing the standard of necessary details such as symbols, and size, type or grade designations. If these details are to be used for any other purpose than implementation then the prior written permission of BSI must be obtained. Details and advice can be obtained from the Copyright & Licensing Manager.

Tel: +44 (0)20 8996 7070

Email: copyright@bsigroup.com

BSI Group Headquarters

389 Chiswick High Road London W4 4AL UK

Tel +44 (0)20 8996 9001

Fax +44 (0)20 8996 7001

www.bsigroup.com/standards