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Review

Historic Churches and Their Hygrothermal Environment: A Review of Criteria Related to Building Fabric, Artefacts, Artwork and Occupants

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Abstract: Regarded as important cultural heritage, historic churches have been utilised over hundreds of years for worship and community benefit. Simple on/off space heating systems are installed in many churches to increase human comfort. However, the conservation of the important historic artefacts and artwork contained within may not have been fully considered. This review attempts to appraise the standards in place for artefacts and artwork. A consensus of 15–25 °C and 40–65% relative humidity is established as safe from the standards reviewed. Consideration is given to the environment within the church to understand if such exacting conditions can be met. The review finds that the conservation and preservation of artefacts and buildings are aligned goals, although striving to meet specified target ranges for artefact types is not fully compatible with historic churches. The stability of the internal environment is clearly an important factor in conservation and benefits human comfort expectations. Churches may contain microclimates throughout the building, complicating the use of target ranges for artefacts, artwork and comfort. The findings of this study can assist historic churches in managing the change, alteration or installation of heating systems.

Keywords: heating; conservation; church; non-domestic; historic; comfort

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1. Introduction

Historic churches are a class of building which embody significant cultural heritage; as a result, they are historically listed in recognition of the contribution they make to the built environment [1]. Frequently composed of different building materials and techniques, these have been adapted over hundreds of years to fit stylistic changes alongside congregational and maintenance requirements. Churches are often home to important artefacts and design features that require consideration in terms of conservation, yet historic churches seldom possess heating and ventilation systems (HVAC) which effectively monitor and control temperature and humidity to preserve artefacts' life and condition.

Where space heating is used in historic churches, it often focuses on human thermal comfort rather than the building and artefact requirements, inducing large fluctuations in temperature and relative humidity [2]. Space heating systems attempt to condition large volumes of air in the church in an often futile effort to meet modern comfort expectations [3]. Despite construction utilising high thermal mass materials, the sporadic nature of church services results in an environment which is often below human comfort levels [4]. The repeated heating of such high thermal mass buildings often introduces degrading processes in high value artefacts such as paintings, fabric, artwork and musical instruments like the organ [5].

In order to protect and preserve historic buildings for the future, major alterations to their fabric and character are usually prohibited. Historic buildings such as churches have been exempted from energy efficiency targets because they are constructed using methods which do not meet energy performance benchmarks [6]. In addition, undertaking any retrofitting of energy saving measures may result in damage to the historic fabric and artefacts contained within [7,8]. Historic building fabric is porous, requiring a careful management of ventilation to prevent excessive moisture accumulating in the fabric and internal space [9,10]. British Standard EN 15759-1: *Heating churches, chapels and other places of worship* suggests that the ideal solution is to maintain suitable environmental conditions over a constant period, although it does not specify temperature and relative humidity ranges, rather focusing on the type of systems available and their general effect upon the conservation of the building and its contents [11].

One heating option discussed in EN 15759-1 is conservation heating. This is a strategy some historic properties implement to focus on the preservation of fabric and artefacts through controlling relative humidity. The control of moisture condensation and frost is deemed more important in conservation than human comfort levels [11]. Conservation heating aims to meet the standard for environmental control set out by the National Trust but results in a wide range of room temperatures [12]. The operation of heating solely to preserve church artefacts risks degrading human comfort and limiting the use of the space at a time when churches are looking to utilise buildings for the wider community [13]. If churches are to be heated regularly in response to increased usage patterns, research is required to understand if the internal environment of historic churches is suitable to meet the needs of conservation, while attempting to meet human comfort demands.

Guidelines and standards exist for museums and art galleries to maintain good conservation standards through the operation of HVAC systems. The British Standards Institution BS EN 15759-1:2011 [11] establishes that 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. While not every museum and art gallery have sophisticated HVAC and/or building management control systems installed, they are, at an institutional level, focused on best practice in managing conservation and maintaining collections in good order. Therefore, the option to consider if the specific temperature and relative humidity ranges outlined in the standards applicable to the museum and conservation sector are relevant when historic churches look towards the increased operation of less sophisticated retrofitted HVAC systems to meet increased usage patterns.

2. Methodology

The study aims to appraise conservation standards and guidelines for the preservation of artefacts, artwork and when applied to historic churches striving to meet occupant comfort. This research contains source material composed of case studies, conference proceedings, scientific journal papers, defined standards and techniques for cultural heritage preservation. A number of scientific studies from churches across Europe feature in the available literature. Three sections have been created in this paper to review the building fabric, artefacts and occupants, with the aim to appraise a number of standards accepted in the conservation and building services engineering industries for maintaining environments suitable for the preservation of art and artefacts. These standards and guidelines are considered alongside the unique environment presented by historic churches, where expensive monitoring and HVAC systems are unlikely, and limited resources inevitably lead to compromise. These factors are considered, with conclusions drawn on whether the standards and guidelines are suitable for the historic church setting, which will help prepare this sector for future use of the church building and meeting the needs of the community.

3. Overview of Standards and Guidelines

3.1. Building Fabric

Historic churches are monuments to traditional building practices and skills. Often composed of different materials, building techniques and styles, many church buildings have been in regular use for hundreds of years. Alterations and repairs have taken place during the lifetime of the building in response to changing needs and the degradation of fabric components. Hoping to remedy the problems inherent to the traditional construction, modern building technologies and materials have been applied to traditional buildings, resulting in new and more complex problems. In many cases, a lack of knowledge related to the function of traditional buildings and their materials has played a part in creating problems for building operators [14]. In some cases, these individual interventions do not appear to singularly cause a problem, but in combination, they are damaging to the building [15,16]. It should be recognised that historic buildings possess more complex interactive bioclimatic properties when compared to modern equivalents [7].

Christian church design and layout generally conform to the established parameters inherent to the faith. The majority of Christian churches were built with the nave oriented west to east, typically having the main entrance at the west end of the church. Site restrictions and peculiarities result in some churches which do not conform to these design principles [17]. Cathedrals also adhere to the same principles of orientation, but with somewhat grander designs: walls are thick masonry with deep window and door reveals.

The availability of quality building materials on a local level has resulted in varying construction techniques across Europe. Flint construction and infill feature heavily in Dorset, Wiltshire, Hampshire, Sussex, Kent, Surrey, Berkshire, Suffolk and Norfolk (UK) and have been used in many of those region's churches [18]. Examples of typical construction materials can be seen in Figure 1.

Figure 1. Brick and sandstone construction exhibiting weathering (**left**) and two examples of masonry wall with flint construction (**right**). Photographs R. Talbot.

Historic churches are constructed without insulation in the walls or roof structures. Retrofitting insulation is possible to reduce thermal transmittance. However, not all church buildings are suitable for such insulation due to solid floors or ornate/decorated ceilings. Depending upon the ceiling design and construction, insulation may be possible but is likely to be impractical elsewhere, as well as potentially damaging to fabric. Haupl et al. [19] suggest that calcium silicate possesses the necessary capillary action required to allow moisture, which may condense on the cold side of the insulation, to diffuse on the warm side. Failing to account for the possibility of interstitial condensation may allow moisture to become trapped and lead to damage risk. Uniformly applying insulation across the whole wall may not account for the local microclimates associated with different fabric components and construction [20]. Despite the ability to respond to the local climatic conditions, over time, human thermal comfort requirements have resulted in the installation of space heating systems. Although the system is specified to heat the building fabric and the volume of air, the design of historic churches often leads to human discomfort, as large vertical temperature gradients exist, and inadequate mean radiant and operative temperatures are experienced [21].

Wall thickness and material choice dictate the thermal performance of a major part of the church building. A list of construction materials and wall thicknesses in historic European churches and religious buildings identified during the literature review can be found in Table 1. Correctly establishing the thermal properties of locally sourced materials, given the shortage of thermal conductivity data in the UK, thickness of the walls and accounting for voids in the construction, contribute to reduced confidence when attempting to understanding the overall thermal performance. It is suggested that standard calculations for U-values underestimate the thermal performance of traditionally built buildings [22,23].

Table 1. Wall thickness of six historic European religious buildings—sourced from listed authors.

Country	Church	Constructed	Material	Wall Thickness	Ref.
Sweden	Hamrånge	1850	Stone	1.3 m	[24]
Denmark	Gundsømagle	12th Century	Calcareous tufa (Limestone)	0.8 m	[25]
Italy	The Matera Cathedral	1270	Sandstone calcarenite (Limestone)	0.8 m	[26]
Italy	Basilica di Collemaggio	14th Century	Limestone	1–2.6 m	[2]
Italy	Chiesa di San Francesco	14th Century	Limestone	0.8 m	[23]
Portugal	Monastery of Jeronimos	16th Century	Limestone	1.9–2.65 m	[27]
Portugal	Bernardas' Convent	18th Century reconstruction	Limestone	1 m	[28]
Romania	Saint Michael Archangel	1894	Sand limestone	0.8 m	[29]

3.2. Artefacts

Historic churches represent a rich legacy of liturgical development covering hundreds of years. With changing fashions, the interior decoration of the buildings and the artefacts were adjusted or obscured. In some cases, church ownership passed to different denominations with their own stylistic view point. In addition to the usual artefacts present within UK churches, there are some remarkable survivors, despite the changing views on religious art and decoration, representing rare examples of Christian artwork [30,31]. To maintain conservation standards, the selection of the guidelines reviewed here set out the tolerance to fluctuating relative humidity. By setting limits on changes to the RH in a 24 h period, damage to artefacts can be avoided, especially those which undergo mechanical changes, such as wood. Laboratory tests on wood samples have shown that wood takes one day or more to adapt to new environmental conditions [32]. Schito et al. [33] attributed deterioration of a painting on the Scrovegni Chapel walls and wooden objects in the Roslyn Chapel to high values of relative humidity. Therefore, the duration of the fluctuation is important in the preservation of wooden artefacts. The high moisture content in wood also has the potential to foster development of rot fungi and wood borers [34].

The desire to control relative humidity and the resulting damage to artefacts and building fabrics prompted the concept and application of conservation heating in National Trust properties. Historic properties normally experience relative humidity levels between 60–80% [35], which is above the maximum that many artefacts can tolerate for long periods without experiencing degradation. Over time, the tolerance and range has been adjusted due to the financial implications of providing heating to larger properties and a greater understanding of the behaviour of artefacts with the duration and range of fluctuations in relative humidity. Human comfort is considered secondary to control of relative humidity in National Trust properties; therefore, comfort boost heating has been established during visiting times to maintain an environment conducive to visitors and staff. The drawback of such humidistat controlled heating systems is the increased temperatures required in summer months to keep relative humidity within acceptable ranges. At a time when humidity is highest in the outdoor environment, and often coinciding with higher air temperatures, heating a property up to 30 °C to maintain 58% RH is difficult to justify. Therefore, the proposal to limit room temperature to 22 °C in summer and allow the RH to increase has been the National Trust policy since 1994. However, with climate change, the percentage of time that RH control is lost in a calendar year has increased [35].

Most historic churches were built without heating systems; therefore, artefacts may have resided within the natural indoor environment for many generations. With the advent and installation of space heating systems, the historic environment has been changed to one that favours human comfort. Legner and Geijer [36] highlighted the increasing frequency of the conservation required for wooden artefacts when space heating was installed in old Swedish churches. The most common damages reported were the cracking of paint and desiccation cracks. The desire to achieve human comfort may cause degradation of heritage items [2], although materials respond differently to changes in temperature and relative humidity. Items made of wood, for example, take longer to respond to changes than other artefact types. A comparison of the recommended temperatures and relative humidity ranges for artwork, displays and internal spaces are detailed in Figure 2. The data are sourced from four separate studies encompassing microclimate, thermal comfort, hygrometric and climate control research in historic buildings.

Artefact sensitivity to changing humidity levels ranges from extreme (inlaid furniture, wooden musical instruments, wooden sculptures and paintings on panels) to low (metals, glass and stone) [37]. Figure 2 demonstrates the wide-ranging minimum temperatures that separate items can tolerate, some as low as −20 °C, according to Larsen and Brostrom [38]. While temperature fluctuations themselves may not induce damage, the resultant change in relative humidity dictates the safe range for room and building temperatures. Other authors and sources providing figures for safe temperature ranges tend towards the general accepted ranges for museum class items on display, namely the 15–25 °C range, which is the temperature acceptable for human occupation.

Figure 2 allows the individual bands to be seen in comparison to others of the same or different category. It is clear that an area for temperature and relative humidity exists where most artefact types will be safe, although short term fluctuations outside these bands are allowable in many standards and guidelines.

Table 2 is taken from six separate guidelines and standards available for the display and preservation of museum quality artefacts. These standards are also displayed in Figure 2 for ease of comparison. The tolerance for temperature fluctuation in the National Trust conservation heating guidelines and UK Government Indemnity Scheme is an allowance of ±4 °C in a 24 h period. the guidance indicates that rapid, large fluctuations should be minimised, favouring instead slow changes over longer periods of time. By adhering to these parameters, the damage to artefacts on loan can be limited, or at least managed, in line with conservation policies. Providing a tight control of temperature is possible through the appropriate control of HVAC systems and can be facilitated by high thermal inertia buildings.

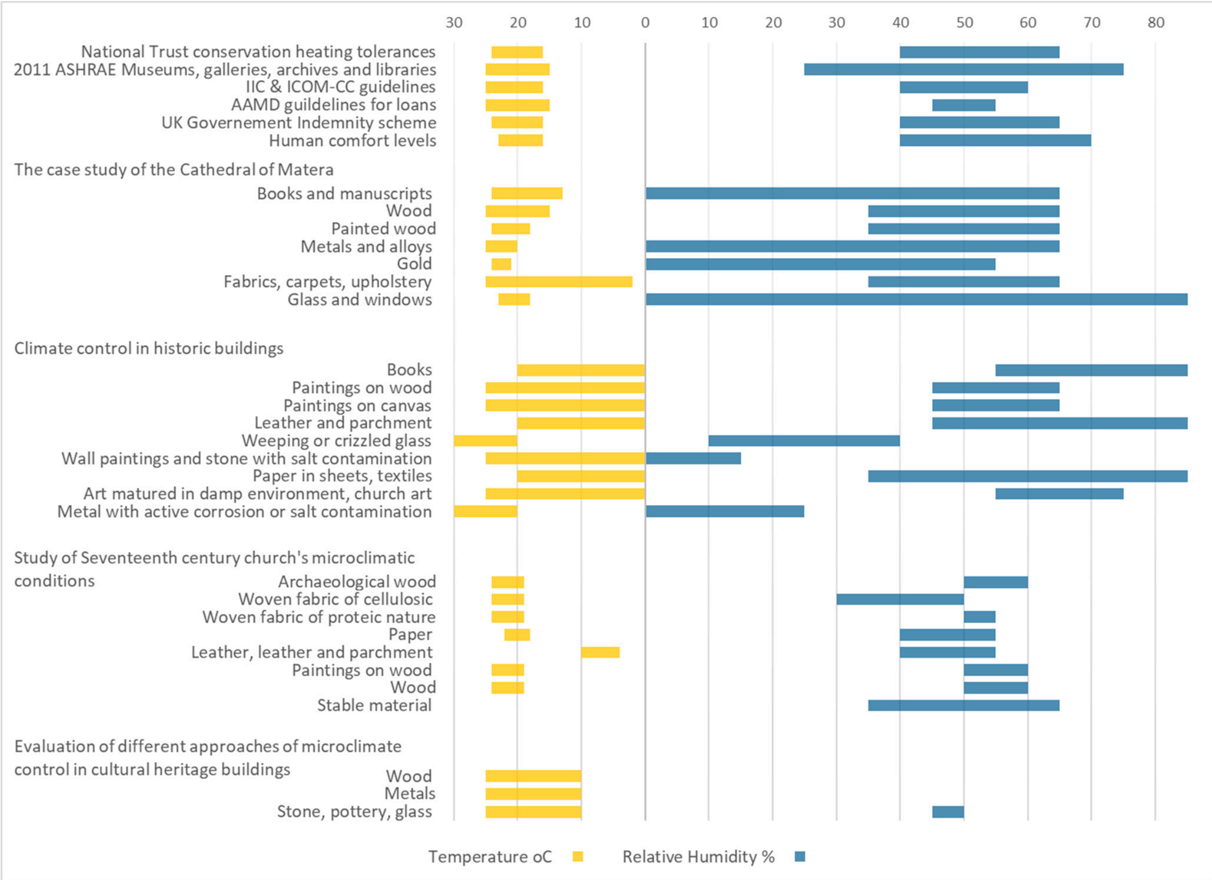

Figure 2. Sensitivity ranges for individual items and material types. The case study of the Cathedral of Matera [26], Climate control in historic buildings [38], Study of Seventeenth century church's microclimatic conditions [37], Evaluation of different approaches of microclimate control in cultural heritage buildings [39].

The ASHRAE 2011 handbook provides the widest range of relative humidity, but must be used with regard to object class and not applied broadly across all collections. Bencs et al. [5] draw particular attention to the concentration and distribution of water vapour within the church, with its effect on hygroscopic material. Water can react with acid-forming gases, producing strong acids that can trigger the deterioration of artworks. Tabunschikov et al. [40] also highlight that artefacts are capillary-porous physical bodies with pores partially filled by moisture, including dissolved salts. If the humidity increases, frescos, icons and wood absorb the water from the air. The effect of varying RH in the cycles associated with heating can be mechanical damage to hygroscopic materials through swelling and desiccation. Metal objects begin to oxidise at high increasing humidity [41].

Table 2. Comparison of standards for heritage buildings, museums and internal spaces. Sources cited in each section.

Guidelines for Display of Artefacts				
National Trust Conservation Heating Tolerances [42]	**$T_{(Min)}$ °C**	**$T_{(max)}$ °C**	**$RH_{(Min)}$%**	**$RH_{(Max)}$%**
Ranges	16	24	40	65
Tolerance within 24 h period	±4		±10%	
Aim to keep RH in range for 90% of calendar year. Important to match climate which the collection has already acclimatised to. Temperature min often sacrificed to control RH between 40–65%, leading to human comfort issue. Max temp exceeded in summer if RH too high for extended periods (collection dependant).				

Table 2. *Cont.*

Guidelines for Display of Artefacts				
2011 ASHRAE Museums, Galleries, Archives and Libraries Handbook—HVAC Applications [43]	**$T_{(Min)}$ °C**	**$T_{(max)}$ °C**	**$RH_{(Min)}$%**	**$RH_{(Max)}$%**
Ranges	15	25	25	75
Tolerance	None defined		Object class dependant (5 classes). Aim for long-term average of 50% with ±5–10% short term fluctuations.	
IIC and ICOM-CC Declaration on Environmental Guidelines [44]	**$T_{(Min)}$ °C**	**$T_{(max)}$ °C**	**$RH_{(Min)}$%**	**$RH_{(Max)}$%**
Ranges	16	25	40	60
Tolerance	None defined		Fluctuations no more than 10% in 24 h. More sensitive items, such as panel paintings, require specific and tight RH control.	
Association of Art Museum Directors (AAMD) Guidelines for Loan Items [45]	**$T_{(Min)}$ °C**	**$T_{(max)}$ °C**	**$RH_{(Min)}$%**	**$RH_{(Max)}$%**
Ranges	15	25	45	55
Tolerance	None defined		±5%	
UK Government Indemnity Scheme, Non-National Institutions. Climate on Display [42]	**$T_{(Min)}$ °C**	**$T_{(max)}$ °C**	**$RH_{(Min)}$%**	**$RH_{(Max)}$%**
Ranges	16	24	40	65
Tolerance	Maximum cycle of 4 °C within 24 h.		Maximum cycle of 10% within 24 h.	
BSi 15757:2010 [39]	**$T_{(Min)}$ °C**	**$T_{(max)}$ °C**	**$RH_{(Min)}$%**	**$RH_{(Max)}$%**
Ranges	-	-	-	-
Tolerance	No specification		Use historic data to determine thresholds, tolerance and allowances.	

Historic churches are capable of providing the necessary thermal inertia to minimise rapid fluctuations in temperature. The ability to control relative humidity is less precise in historic churches, which are constructed without vapour barriers and can suffer from water ingress after hundreds of years of use, even with regular maintenance regimes in place. The problem of water ingress and the transport of moisture into the internal church environment via people make the church a less-than-ideal space for the display of certain types of sensitive artefacts due to limited or non-existent HVAC control. However, it is accepted that artefacts may have already resided in that environment for a long period of time, and therefore are acclimatised to the variations in temperature and humidity that regularly take place. Bratasz [46] discussed the uniqueness of each sensitive object, its conservation history and the resultant specific ranges of temperature and relative humidity that it has endured. As a result, the moderate variation of ±15% from 50% RH is within safe levels. Bratasz further commented that broadening the allowable variation may result in objects enduring far-from-ideal conditions.

Hnilica et al. [47] proposed establishing the historic indoor climate as a suitable method of assessing historic buildings. Understanding the historic climate within the church is a method for understanding the climatic variations the artefact has endured over its lifetime in that space. British Standard EN 15757:2010 also follows this procedure by avoiding the definition of min and max ranges for RH, encouraging the use of historic data instead. Cannistraro et al. [37] and D'Agostino and Congedo [23] state that it is appropriate to maintain the current indoor climate rather than attempt to create a new ideal climate for the item after many years of exposure within the church. The only reason to instigate change is in response to the degradation of artefacts, fabric and/or in response to human thermal comfort demands. Historic climate data can be obtained through the analysis of artefact conditions and any records of building services work or maintenance. Installed monitoring systems may be able to provide long term data in detail [46].

An alternative method of establishing a suitable indoor climate for artefacts is to use the target range method described by Hnilica et al. [47]. Through the identification of the artefacts present within the historic church environment, the temperature and relative humidity range can be established using tables of data, such as those presented in Figure 2. Aiming to limit temperatures to 25 °$C_{(max)}$ within the building or room will meet the requirements of the majority of artefacts present within the church. The present difficulty when heating a church is the high ceiling heights and lack of insulation, resulting in space heating events which are often longer in duration and occur sporadically during each week, with associated heating and cooling of the building fabric perhaps below and beyond the limits established within the target data.

3.3. Occupants

With the widespread installation of central heating in homes across the developed world, individuals routinely expect to find optimal thermal comfort widespread in public buildings. It is estimated that 80–90% of people spend their time indoors [48]. Thermal comfort is a subjective measure based on several criteria: temperature, thermal radiation, humidity, activity, clothing and air speed [48–50]. Ethnicity, health, body type, fitness and acclimatisation all further contribute to the complex nature of thermal comfort. Personal adaptations such as clothing, duration of stay and activity can overcome temperatures outside individual comfort ranges [41]. Different denominations require varied levels of activity from occupants. Orthodox services usually require the congregation to stand throughout [40], while Catholic and high Anglican services may involve frequent changes between seated, standing, kneeling and walking to the alter. Presbyterian services call on the participant to be seated the majority of the service. When higher levels of activity are undertaken, sensitivity is decreased, and the risk of thermal discomfort is lowered [51]. Elderly or sick persons may need a higher room temperature to feel the same comfort as other younger and healthier occupants [52].

It is evident that temperature is of chief concern to occupants, while relative humidity matters only when very low (<30%) or very high (>80%). Occupants typically expect temperatures in the range of 18–22 °C [50]. When human comfort expectations are examined in the context of this study, we find that only a minor conflict arises between the demands of the occupants and those of the artefacts and artworks. The difficulty is that artefacts are susceptible to relative humidity changes in a way humans are not [50]. Andersen et al. [53] observed, in a study of 48 young males, that participants did not perceive changes in relative humidity when it was altered from 70% down to 10% in controlled clean air at 23 °C. However, the altered RH% did cause a change in the perceived temperature, despite being 23 °C throughout.

The location of the church may also lead to exposure to wind and moisture. In the case of Kilmelford Parish Church, a church located 700 metres from the sea, the prevailing south west wind brings in damp air due to the entrance on the west gable. The positioning of the door leads to significant draughts and heat loss as occupants enter or leave the building [16]. With the alter typically being placed at the east end of the church, the entrance to the building is often exposed to the UK's prevailing south westerly wind.

A room with many cold surfaces is inherently uncomfortable for human occupation. The amount of heat transferred to the surface is dependent on the temperature difference and the duration of occupation [52]. ISO 7730 [28] advises that vertical surfaces' radiant asymmetry should be kept to less than 10 °C from air temperature. In winter those sitting near cold windows and surfaces may feel uncomfortable. It is common to feel a downdraught from a cold window, therefore radiators are often fitted on the wall below the window to counteract these draughts, providing they cover the entire width of the window [52]. Historic churches unfortunately meet all the criteria for thermal discomfort: insufficient local thermal control, poor insulation, large vertical temperature gradients and inadequate mean radiant and operative temperatures. Where heating systems are installed, they are unable to guarantee thermal comfort due to intermittent usage, large heat loss through the building fabric, significant room height, single glazed windows and infiltration loses [21]. Heat is often concentrated in the upper areas of the church, while cold air is retained at pew height [54].

Although thermal comfort is a subjective quality expressing satisfaction with the thermal environment [51], standards do exist to measure human comfort and meet those demands. ASHRAE Standard 55, EN15251 and ISO 7730 all use the same method of Predictive Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) to determine human comfort levels. The PMV predicts the mean value in votes from a large group of people on a seven-point thermal sensation scale. The seven points are: +3 Hot, +2 Warm, +1 Slightly warm, 0 Neutral, −1 Slightly cool, −2 Cool, −3 Cold. PPD is derived from PMV and predicts the percentage of people who are likely to feel too warm or too cold in the given environment [51]. ASHRAE Standard 55 specifies the thermal conditions in which 80% or more of the occupants within a space will find the environment thermally acceptable based on the heat balance model of the human body. This model is influenced by measurable factors: humidity, air speed, air temperature, radiant temperature, metabolic rate and clothing insulation. It does not account for subjective measures like those mentioned previously [48–50,55].

In cold seasons, churches are often heated very quickly before services in order to achieve a comfortable environment for all. However, this produces a highly variable temperature throughout the church [41,56]. Short rapid heating events are unable to heat the fabric of the building; thus, the cold radiant temperatures from the surfaces of the church remain a risk to those nearby. High temperatures in summer are often associated with high relative humidity inside historic buildings. Despite the interior being at a comfortable temperature for occupation, in the summer, users may still find the church uncomfortable. This aspect of thermal comfort was reported by Martinez-Molina et al. [57] when assessing visitors' thermal comfort at a museum based in a historic building. The hotter the temperature outdoors the colder visitors felt inside.

3.4. Hygrothermal and Microclimates

Many historic churches are now heated on a regular cycle during the winter season. However, it is worth noting that space heating was not a feature when they were designed and built. Therefore, it is safe to assume that a lack of heating will not have a detrimental effect upon their condition, given the hundreds of years many have survived without being heated [58]. Due to the design features inherent in most Christian church buildings, Curteis [3] reports broadly similar internal environmental microclimates existing in historic cathedrals of different size and location. Conditions at the west end of the nave are more unstable, and artefacts located in that area of the building are at greater stress due to this being the main door of the church. Smaller churches experience greater instability when large groups of people occupy the space due to a smaller internal volume and complete exchange of air from the entrance door [3]. Historic England also highlights the existence of various microclimates in historic buildings. This is due, in part, to older buildings often having walls composed of more than one material, resulting in different performance characteristics [59].

The UK climate is challenging for historic buildings. With an annual average relative humidity of 80%, the UK is dominated by moisture-laden maritime depressions: rapidly changing conditions interspersed with high-pressure stable situations [60]. Problems related to moisture within building fabrics are a common theme for historic building stock. The masonry walls of historical buildings lack damp insulation and were designed to allow the absorption and evaporation of moisture. As a result they exhibit high humidity associated with outside conditions, rising damp or rain penetration [9,10]. In San Jan Bautista Church, Talamanca de Jarama, Spain, the indoor relative humidity (RH) rises from around 45% to about 70–75% on rainy days, where it remains for around 48 h. During rainy periods the area experiences over 90% relative humidity, with a yearly average of 57.1% [61]. When studying the cathedrals of England, Curteis [3] stated that typical churches have 85% RH at 10 °C. Furthermore, winter typically sees lower RH during the period the heating system is operative. With high relative humidity comes the potential for mechanical stress, mould growth and degradation in susceptible items. Conservation heating is one strategy to control relative humidity in historic buildings. It is used by the National Trust to reduce the risk to collections and building fabrics. The main function of conservation heating is to keep the building envelope at a suitable temperature to avoid moisture condensation or frost, which is a frequent problem in buildings with high thermal inertia [11].

4. Results

Comparing the standards and guidelines for individual artefact types and suitable conservation environments reveals areas of overlap where the various demands do correspond well. Using the reviewed data, a small sample of artefact tolerances has been plotted in Figure 3. ASHRAE, ICOM, AAMD, UK Indemnity Scheme and National Trust standards have been plotted in Figure 4. Typical human comfort levels have been added to the graph using data available in the literature. The two sets of data have been combined in Figure 5. The lower RH range for church art falls within the standards reviewed here. A preference for the long-term stability of the indoor climate is affirmed by the majority of standards reviewed in this paper. Attempting to minimise short-term fluctuations in temperature and RH is key to artefact conservation. When RH drops during comfort boost heating events, hygroscopic materials begin to give up moisture in response to the lowered RH [35].

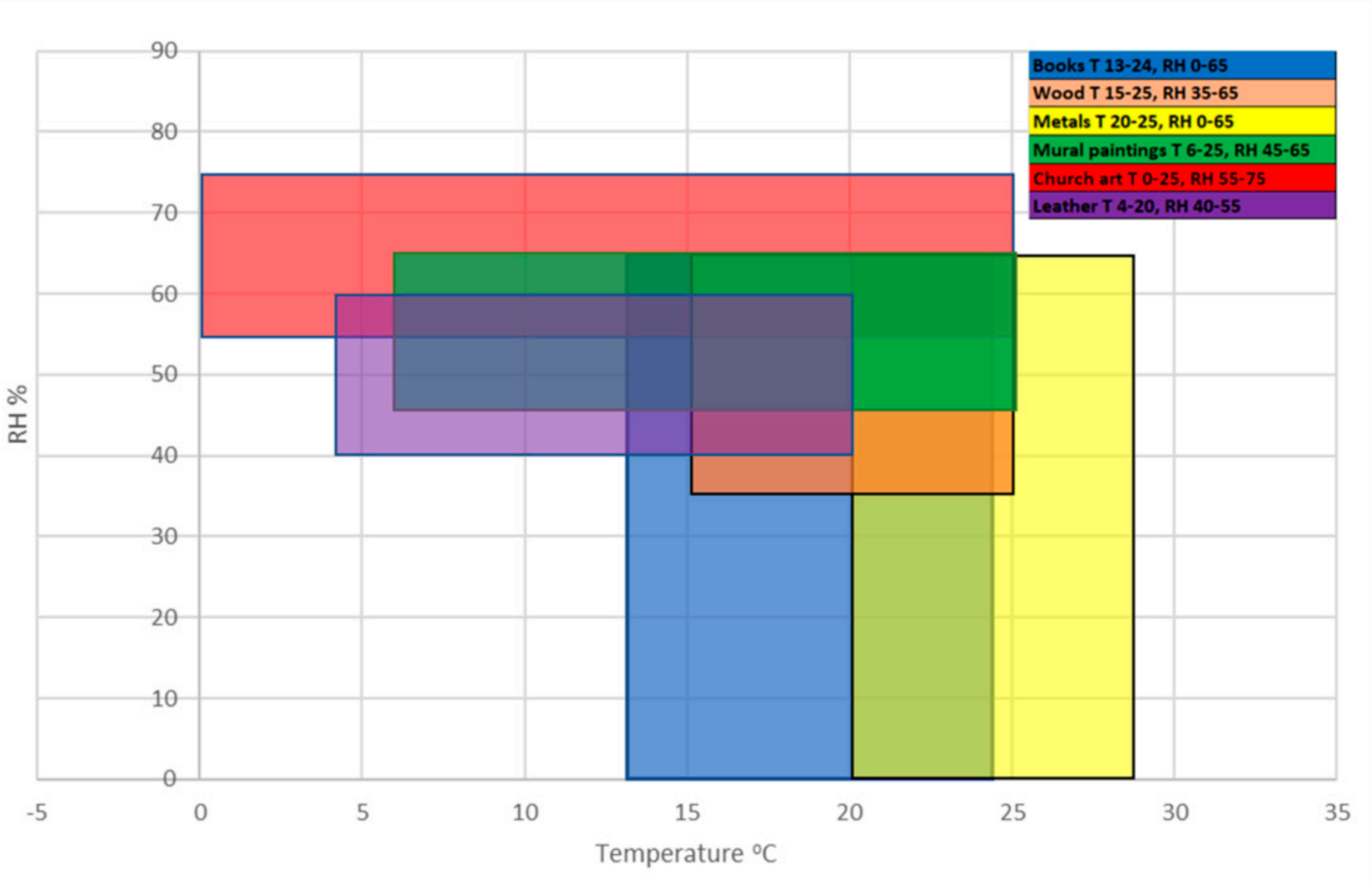

Figure 3. Plot of temperature and relative humidity tolerances for selected artefacts.

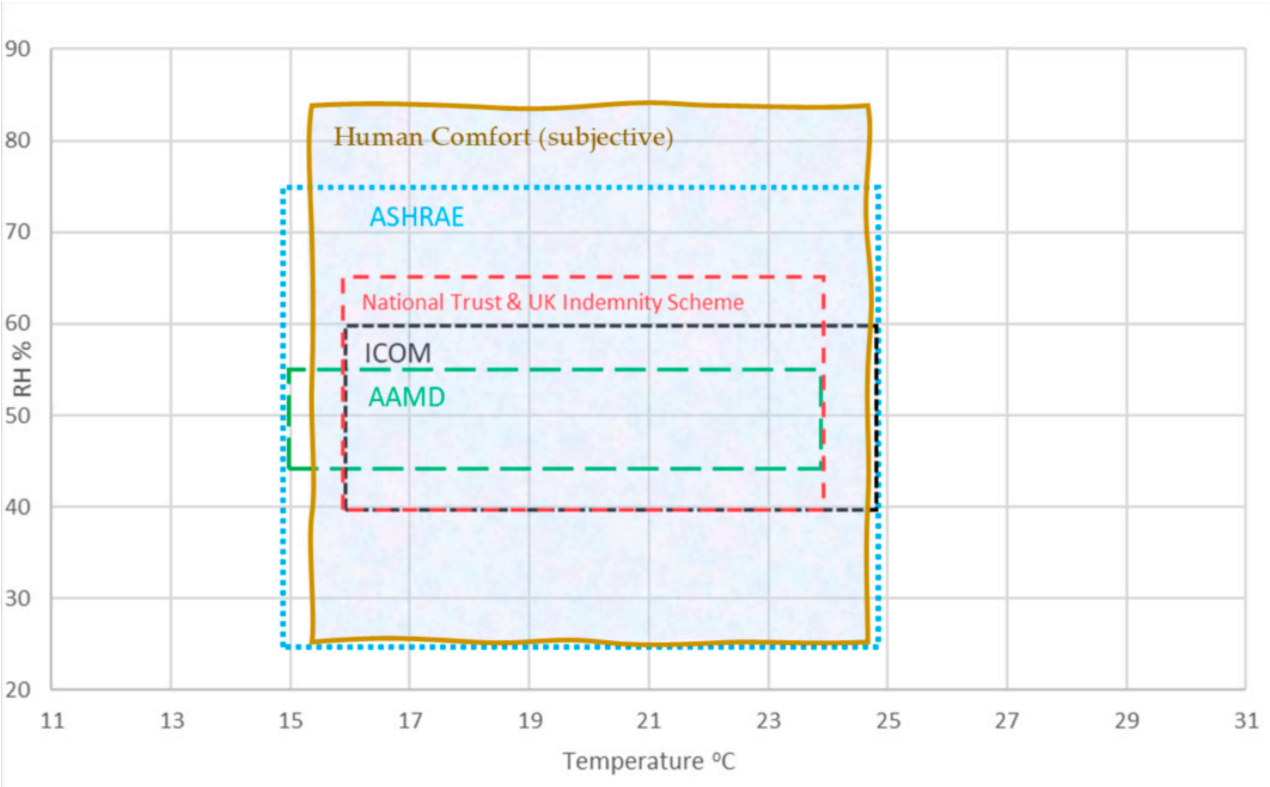

Figure 4. Standards and human comfort plot of temperature and relative humidity.

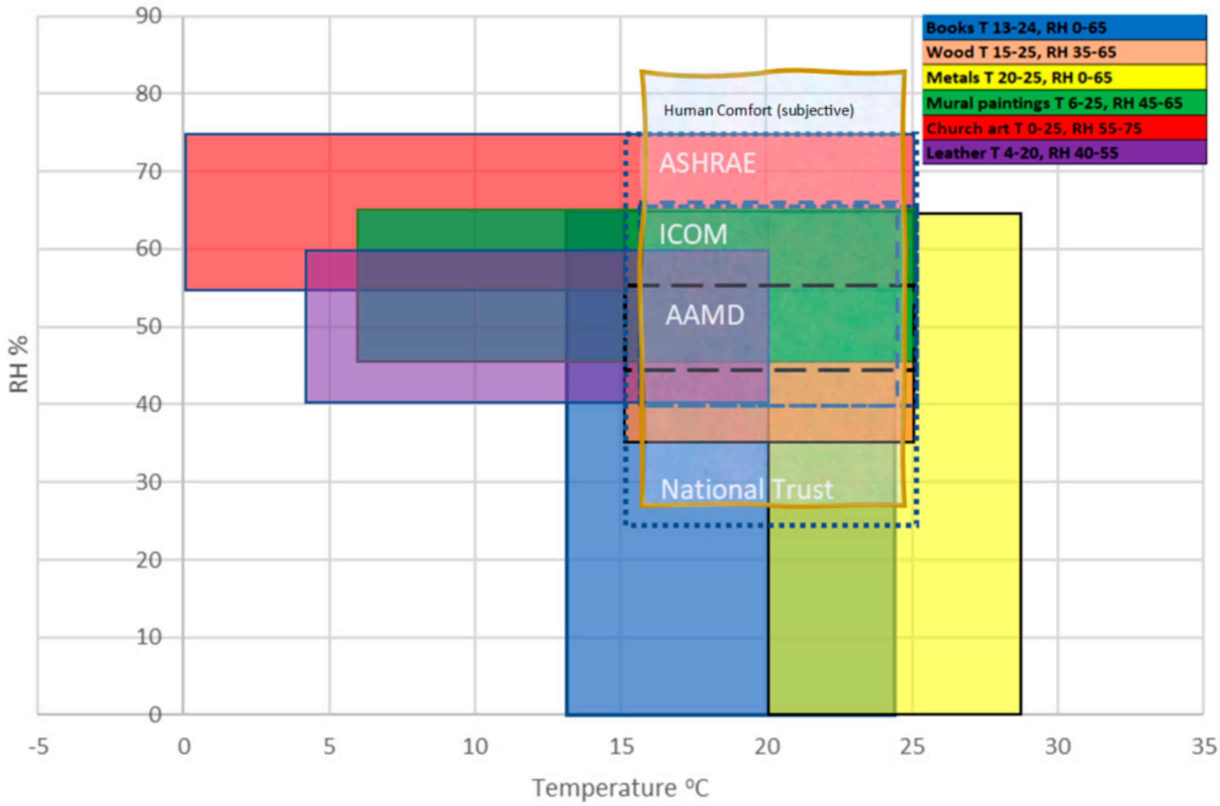

Figure 5. Combined plot of standards, artefact tolerance and human comfort.

The reviewed standards advise that small deviations over 24 h periods are acceptable, but fast changing conditions should always be avoided. This statement contradicts the concept of the rapid heating of churches mentioned as typical earlier in the text. This appears to be the area where churches represent a significantly different scenario from other managed internal environments. As a result, it could be concluded that rapid heating systems and events should be avoided, but the literature does not fully support this approach for churches, since artefacts and materials have already adjusted to the operation of the heating system. It appears that both heating strategies apply to the church scenario, and operators must choose which is more appropriate for their occupancy patterns and system choice. However, the stability of the internal environment does appear to achieve better results when matching human comfort levels to those conditions demanded by the artefacts and materials. A heating system able to maintain stable conditions without excessive cost would be advantageous for a historic church. Those aiming to adhere to the standards should have the climate in the ideal range for a high percentage of the calendar year. There is a clear area between 15–25 °C and 40–65% RH where the standards and artefact tolerances merge favourably with human comfort demands.

5. Discussion

Historic churches present a unique environment for conservation, distinctly different to conditioned museum spaces and art galleries. The fact that objects of value, both culturally and monetary, exist in historic churches does not automatically dictate the creation of museum-grade environmental conditions. Due to the occupancy patterns of many churches, they are not heated every day. Rather it is common practice to turn the heating system to its highest output prior to services in an effort to rapidly heat the space for occupant comfort. Once the air temperature is acceptable to the occupants, the heating will be turned off and remain off until the next scheduled service. The duration of the heating event is kept to a minimum, reducing the impact upon sensitive artefacts and fixtures which have acclimatised to such fluctuations since installation of the heating system. This intermittent pattern of rapid heating has been suggested as beneficial for both the occupant and those artefacts within the building [41]. The additional benefit is that sufficient energy is retained within the building to prevent very low temperatures occurring during periods the building is not in use.

Human comfort is less dependent on relative humidity, and therefore most heating systems are temperature governed, unlike other historic properties which focus on managing humidity changes, putting human thermal comfort as a secondary requirement. The National Trust, which uses conservation heating extensively across its portfolio of properties, has focused attention on training house staff and conservators on the operation of conservation heating strategies. Humidistat-governed heating systems are only effective if staff understand the principles and techniques required to operate them [35]. One of the major drawbacks when trying to apply the principles of conservation heating to historic churches is the lack of thermal comfort that could result during high and low temperatures in summer and winter, respectively. High relative humidity is experienced in historic churches during the summer months, often beyond the 65% published safe upper limit from the reviewed standards. Controlling humidity beyond this ideal upper limit would require the heating to be turned on in order to reduce RH. This would result in very high indoor temperatures for occupants, beyond the comfort range of most individuals and the ranges highlighted in the reviewed literature. There are also risks to the fabrics and certain materials in maintaining temperatures beyond 25 °C.

The ASHRAE standards offer the widest range of acceptable relative humidity; however, it should be noted that object classes are employed to further refine the limits of RH. Other standards prove to be much tighter on acceptable RH fluctuations. The AAMD has the smallest range of only 15–25 °C and 45–55% RH. In terms of artefacts, church art was specifically highlighted by one author, and when plotted alongside the other artefacts, it is evident the church presents a different range of temperatures and relative humidity than other managed environments.

In sourcing data on artefact sensitivity from various authors and research, there appeared to be some disparity in quoted figures. Similar items were given very broad ranges of tolerance by some authors, while others attributed much narrower ranges. (These sensitivity ranges were plotted in Figure 2). Citing several authors is helpful in establishing a broad range of data for each artefact and material type; however, it limits confidence in the actual quoted figures. It perhaps strengthens the argument against the target method of assessment, rather favouring the historic climate approach for churches. Striving to alter the climate to meet the target range of several important or valuable items overlooks the fact that all have been present within the prevailing indoor climate for many years. Damage that could take place, due to varying temperature and RH, will most likely have already happened; therefore, it is desirable to maintain the current climate where possible. Items of significance, such as the organ, may not easily fall into the same category as other artefacts given an organ's complex structure and use of many materials. Organs can be locally humidified or de-humidified, if necessary, rather than attempting to condition the whole building for an instrument which only ever occupies one specific area of the building [62].

While human comfort level is subjective, it generally falls within the limits outlined in Figure 4. People expect thermal comfort rather than conditions which are designed to benefit artefacts and facilitate conservation strategies. Rupenheite and Sandström [41] suggest that once relative humidity ranges are identified in the church, attention can then be focused on addressing the thermal comfort of people in conjunction with RH control. Lawson-Smith [60] commented that long periods of low heating are beneficial for historic buildings. Unfortunately, the Fanger model, used to establish human thermal comfort in the reviewed comfort standards, relies on steady-state conditions and provides better results in mechanically ventilated buildings. Therefore, it is perhaps less suited when applied to natural ventilated building like churches [63].

Leijonhufvud and Brostrom [64] suggest that modification of the standards is necessary when sophisticated control systems are not possible in the church. The authors suggest using standards which account for individual circumstances and develop recommendations based upon each church. It is also suggested by Kramer et al. [65] that most research on human thermal comfort relates to office environments. Therefore, applying the usual group of comfort standards may fall short in the church environment. Additional research has focused on individual climate adaptations rather than applying defined standards used in other industries and building types. Adaptive theories argue that people have the ability to adapt themselves more broadly than the thermal comfort standards allow. While such theories may facilitate improved comfort in other buildings, the church presents an environment where individuals cannot control the heating system output.

Past research has focused on improving the comfort experience of the occupant without compromising the natural environment of the church. The 2002 EU Friendly Heating programme established that greater occupant comfort could be found using radiant heating systems which focus on the areas where occupants sit. The building is then left as free-running in response to the outside climate and activities taking place within. By avoiding the installation of traditional space heating systems, authors have suggested that the building lifespan will be preserved, as no attempt has been made to modify the thermal balance of the historic structure [7]. Larsen and Brostrom pointed to gaining an understanding and utilisation of the passive function of the building, then basing active climate control solutions upon these parameters [38]. Rupenheite and Sandström [55] discussed the damage inflicted upon churches by inappropriate systems when striving to provide increased comfort for occupants. In some cases, the repair is more expensive than establishing appropriate heating systems. Although radiant systems have the potential to increase localised comfort while reducing the impact upon the building as a whole, it may result in a building which is cold and unwelcoming upon entry; a situation many churches are keen to avoid. In a study in Balbieriškis, Lithuania, a gas-fired radiant heating system fell short of providing comfort for those in the church [41].

6. Conclusions

Difficulties arise when attempting to match human comfort expectation with the aim of conservation, partly due to the need to control relative humidity rather than temperature. Human comfort is less dependent upon relative humidity, unlike many materials which are primarily affected by changing moisture levels. However, there is a clear indication from the available evidence that church-based artefacts and artwork have already adapted to the prevailing climate within the building over many years. Applying museum standards of climate control is an inappropriate strategy for many historic churches to follow, primarily because the church and its relatively simple HVAC system cannot achieve the outlined standards. Radically overhauling the temperature and relative humidity within the church in an effort to establish more suitable conditions is not necessary for church artwork and artefacts.

The stability of the internal environment is clearly an important factor in conservation, and there is some scope for historic churches to create more stable conditions that would have benefits for conservation and human comfort. Unfortunately, many different microclimates may exist in the church at the same time, limiting the efficacy of this approach. Adapting the heating strategy to heat the occupants rather than the building fabric may allow churches to limit the impact of increased usage patterns upon conservation aims.

The findings of this study can assist historic churches in managing the change, alteration or installation of heating systems. Where increased usage of the church is proposed, this research assists in managing conservation priorities alongside human comfort requirements.

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References

1. Smith, B.; Gomez-Heras, M.; McCabe, S. Understanding the decay of stone-built cultural heritage. *Prog. Phys. Geogr. Earth Environ.* **2008**, *32*, 439–461. [CrossRef]
2. Aste, N.; Della Torre, S.; Adhikari, R.; Buzzetti, M.; Del Pero, C.; Leonforte, F.; Manfren, M. Sustainable church heating: The Basilica di Collemaggio case-study. *Energy Build.* **2016**, *116*, 218–231. [CrossRef]
3. Curteis, T. The Cathedrals of England: Environmental Performance, Conservation and Exhibitions. *Stud. Conserv.* **2018**, *63*, 70–75. [CrossRef]
4. D'Ayala, D.; Aktas, Y.D. Moisture dynamics in the masonry fabric of historic buildings subjected to wind-driven rain and flooding. *Build. Environ.* **2016**, *104*, 208–220. [CrossRef]
5. Bencs, L.; Spolnik, Z.; Limpens-Neilen, D.; Schellen, H.L.; Jutte, B.A.H.G.; Van Grieken, R. Comparison of hot-air and low-radiant pew heating systems on the distribution and transport of gaseous air pollutants in the mountain church of Rocca Pietore from artwork conservation points of view. *J. Cult. Herit.* **2007**, *8*, 264–271. [CrossRef]
6. UK Government. *A Guide to Energy Performance Certificates for the Construction, Sale and Let of Non Dwellings. Improving the Energy Efficiency of Our Buildings*; Department for Communities and Local Government: London, UK, 2017.
7. Cantin, R.; Burgholzer, J.; Guarracino, G.; Moujalled, B.; Tamelikecht, S.; Royet, B.G. Field assessment of thermal behaviour of historical dwellings in France. *Build. Environ.* **2010**, *45*, 473–484. [CrossRef]
8. Biseniece, E.; Žogla, G.; Kamenders, A.; Purviņš, R.; Kašs, K.; Vanaga, R.; Blumberga, A. Thermal performance of internally insulated historic brick building in cold climate: A long term case study. *Energy Build.* **2017**, *152*, 577–586. [CrossRef]
9. Webb, A.L. Energy retrofits in historic and traditional buildings: A review of problems and methods. *Renew. Sustain. Energy Rev.* **2017**, *77*, 748–759. [CrossRef]
10. Larsen, P.K.; Broström, T. *Climate Control in Historic Buildings in Denmark, in World Renewable Energy Congress*; Low Energy Architecture: Linkoping, Sweden, 2011.
11. British Standards Institution. *BS EN 15759-1:2011 Conservation of Cultural Property-Indoor Climate. Part 1: Guildelines for Heating Churches. Chapels and Other Places of Worship*; British Standards Institution: London, UK, 2011.

12. Blades, N.; Jessep, H.; Lithgow, K. The role of historic house heating systems in collections climate control at the National Trust. In Proceedings of the Climate for Collections-Standards and Uncertainties, Postprints of the Munich Climate Conference, Munich, Germany, 7–9 November 2012; pp. 127–140.
13. UK Government. *The Taylor Review: Sustainability of English Churches and Cathedrals*; Department for Culture Media & Sport: London, UK, 2017.
14. Cramer, J.; Breitling, S. *Architecture in Existing Fabric: Planning, Design and Building*; Birkhäuser: Basel, Switzerland, 2007.
15. British Standards Institution. *BS 7913: 2013 Guide to the Principles of the Conservation of Historic Buildings*; British Standards Institution: London, UK, 2013.
16. Historic Scotland. *Refurbishment Case Study 19. Trial Church Heating: Radiant Panels and Air Source Heat Pump at Kilmelford Church*; Historic Scotland: Edinburgh, UK, 2015.
17. Cave, C.J.P. The Orientation of Churches. *Antiqu. J.* **1950**, *30*, 47–51. [CrossRef]
18. Ashurst, J.; Williams, G. Flint and the Conservation of Flint Buildings. 2005. Available online: http://www.buildingconservation.com/articles/flint/flint.htm (accessed on 22 June 2018).
19. Haupl, P.; Fechner, H.; Grunewald, J.; Petzold, H. The quantification of the moisture distribution in renovated historical wall structures and exposed monuments. *WIT Trans. Built Environ.* **2001**, *55*, 3.
20. Historic England. *Energy Efficiency and Historic Buildings*; Historic England: Swindon, UK, 2016.
21. Lodi, C.; Magli, S.; Contini, F.M.; Muscio, A.; Tartarini, P. Improvement of thermal comfort and energy efficiency in historical and monumental buildings by means of localized heating based on non-invasive electric radiant panels. *Appl. Therm. Eng.* **2017**, *126*, 276–289. [CrossRef]
22. Rye, C.; Scott, C. *The SPAB Research Report 1. U-Value Report*; Society for the Protection of Ancient Buildings: London, UK, 2012.
23. Lucchi, E. Thermal transmittance of historical stone masonries: A comparison among standard, calculated and measured data. *Energy Build.* **2017**, *151*, 393–405. [CrossRef]
24. Sandberg, M.; Mattsson, M.; Wigö, H.; Hayati, A.; Claesson, L.; Linden, E.; Khan, M.A. Viewpoints on wind and air infiltration phenomena at buildings illustrated by field and model studies. *Build. Environ.* **2015**, *92*, 504–517. [CrossRef]
25. Eshoj, B.; Padfield, T. The Use of Porous Building Materials to Provide a Stable Relative Humidity. In *Preprints of the ICOM-CC Conference, Washington DC*; ICOM Committee for Conservation: Paris, France, 1993.
26. Cardinale, T.; Rospi, G.; Cardinale, N. The Influence of Indoor Microclimate on Thermal Comfort and Conservation of Artworks: The Case Study of the Cathedral of Matera (South Italy). *Energy Procedia* **2014**, *59*, 425–432. [CrossRef]
27. Masciotta, M.-G.; Roque, J.C.; Ramos, L.F.; Lourenco, P. A multidisciplinary approach to assess the health state of heritage structures: The case study of the Church of Monastery of Jerónimos in Lisbon. *Constr. Build. Mater.* **2016**, *116*, 169–187. [CrossRef]
28. Martins, A.M.; Carlos, J.S. The retrofitting of the Bernardas' Convent in Lisbon. *Energy Build.* **2014**, *68*, 396–402. [CrossRef]
29. Turcanu, F.-E.; Verdes, M.; Serbanoiu, I.; Ciocan, V.; Balan, M.-C. Assessment of Indoor Climate Environment Via Hygrothermal Simulation in Historical Churches. *Procedia Eng.* **2017**, *181*, 412–417. [CrossRef]
30. Luxford, J. The Sparham Corpse Panels: Unique Revelations of Death from Late Fifteenth-Century England. *Antiq. J.* **2010**, *90*, 299–340. [CrossRef]
31. Luxford, J. Catfield Church, Norfolk: A Lost Rectorial Brass and an Early Case of Brass-Preservation. *J. Br. Archaeol. Assoc.* **2014**, *167*, 205–212. [CrossRef]
32. Camuffo, D.; Sturaro, G.; Valentino, A.; Camuffo, M. The conservation of artworks and hot air heating systems in churches: Are they compatible? The case of Rocca Pietore, Italian Alps. *Stud. Conserv.* **1999**, *44*, 209–216.
33. Schito, E.; Testi, D.; Grassi, W. A Proposal for New Microclimate Indexes for the Evaluation of Indoor Air Quality in Museums. *Buildings* **2016**, *6*, 41. [CrossRef]
34. Kozlov, V.; Kisternaya, M. Sorption properties of historic and recent pine wood. *Int. Biodeterior. Biodegrad.* **2014**, *86*, 153–157. [CrossRef]
35. Blades, N.; Lithgow, K.; Staniforth, S.; Hayes, B. Conservation Heating 24 Years On. *Stud. Conserv.* **2018**, *63*, 15–21. [CrossRef]
36. Legner, M.; Geijer, M. Heating regimes in old Swedish churches, c. 1880-1980. In *2nd European Workshop on Cultural Heritage Preservation*; Norwegian Institute for Air Research: Kjeller, Norway, 2012.
37. Larsen, P.K.; Broström, T. *Climate Control in Historic Buildings*; Uppsala University, National Museum of Denmark: København, Denmark, 2015.
38. Cannistraro, G.; Cannistraro, M.; Restivo, R. Thermo hygrometric monitoring using wireless sensors: Study of seventeenth century church's microclimatic conditions and enclosed reliquary. *Sci. Ser. Data Rep.* **2012**, *4*, 101–123.
39. Broström, T.; Vyhlídal, T.; Simeunovic, G.; Klenz Larsen, P.; Zítek, P. Evaluation of different approaches of microclimate control in cultural heritage buildings. *Clim. Collect.-Stand. Uncertain.* **2013**, *7*, 105–106.
40. Tabunschikov, Y.; Brodatch, M. Indoor air climate requirements for Russian churches and cathedrals. *Indoor Air* **2004**, *14*, 168–174. [CrossRef]
41. Rupenheite, A.; Sandström, H. *Indoor Climate in Churches–Problems and Solutions: Seminar in Riga, November 2004*; Riksantikvarieämbetet: Stockholm, Sweden, 2005.
42. UK Government. *Government Indemnity Scheme: Guidelines for Non-National Institutions*; Department for Culture, Media and Sport: London, UK, 2016.

43. American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE). *HVAC Applications-SI Edition*; American Society of Heating Refrigerating and Air-Conditioning Engineers, Inc.: Atlanta, GA, USA, 2011.
44. Bickersteth, J. IIC and ICOM-CC 2014 Declaration on environmental guidelines. *Stud. Conserv.* **2016**, *61*, 12–17. [CrossRef]
45. Atkinson, J.K. Environmental conditions for the safeguarding of collections: A background to the current debate on the control of relative humidity and temperature. *Stud. Conserv.* **2014**, *59*, 205–212. [CrossRef]
46. Bratasz, Ł. *Allowable Microclimatic Variations in Museums and Historic Buildings: Reviewing the Guidelines*; Climate for Collections: Standards and Uncertainties; Archetype Publications Ltd.: London, UK, 2013; pp. 11–19.
47. Hnilica, O.; Bichlmair, S.; Plášek, J. *Indoor Climate in Jesuit Church of Holy Name of Jesus in Telc, In CLIMA 2019*; EDP Sciences: Paris, France, 2019.
48. Rabanillo-Herrero, M.; Padilla-Marcos, M.Á.; Feijó-Muñoz, J.; Meiss, A. Effects of the radiant heating system location on both the airflow and ventilation efficiency in a room. *Indoor Built Environ.* **2019**, *28*, 372–383. [CrossRef]
49. Salcido, J.C.; Raheem, A.A.; Issa, R.R. From simulation to monitoring: Evaluating the potential of mixed-mode ventilation (MMV) systems for integrating natural ventilation in office buildings through a comprehensive literature review. *Energy Build.* **2016**, *127*, 1008–1018. [CrossRef]
50. Pretlove, S.E.C. An Evaluation of Heating Strategy, Thermal Environment, and Carbon Emissions in Three UK Churches. *Int. J. Archit. Herit.* **2017**, *11*, 913–932.
51. *BS EN 7730:2005*; 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. British Standards Institute: London, UK, 2006.
52. Danfoss. The Heating Book. 8 Steps to Control of Heating Systems. Available online: https://electrical-engineering-portal.com/download-center/books-and-guides/danfoss-the-heating-book (accessed on 11 December 2018).
53. Andersen, I.; Lundqvist, G.R.; Proctor, D.F. Human Perception, of Humidity Under Four Controlled Conditions. *Arch. Environ. Health Int. J.* **1973**, *26*, 22–27. [CrossRef]
54. Varas-Muriel, M.; Garrido, M.I.M.; Fort, R. Monitoring the thermal–hygrometric conditions induced by traditional heating systems in a historic Spanish church (12th–16th C). *Energy Build.* **2014**, *75*, 119–132. [CrossRef]
55. Vella, R.C.; Martinez, F.J.R.; Yousif, C.; Gatt, D. A study of thermal comfort in naturally ventilated churches in a Mediterranean climate. *Energy Build.* **2020**, *213*, 109843. [CrossRef]
56. Pitsch, S.; Holmberg, S.; Angster, J. Ventilation system design for a church pipe organ using numerical simulation and on-site measurement. *Build. Environ.* **2010**, *45*, 2629–2643. [CrossRef]
57. Martinez-Molina, A.; Boarin, P.; Tort-Ausina, I.; Vivancos, J.-L. Assessing visitors' thermal comfort in historic museum buildings: Results from a Post-Occupancy Evaluation on a case study. *Build. Environ.* **2018**, *132*, 291–302. [CrossRef]
58. Silva, H.E.; Henriques, F. Preventive conservation of historic buildings in temperate climates. The importance of a risk-based analysis on the decision-making process. *Energy Build.* **2015**, *107*, 26–36. [CrossRef]
59. Historic England. *Energy Efficiency and Historic Buildings*; Energy Performance Certificates; Historic England: Swindon, UK, 2015.
60. Lawson-Smith, P. Environmental Control in Historic Buildings. *J. Arch. Conserv.* **1998**, *4*, 42–55. [CrossRef]
61. Garrido, M.I.M.; Aparicio, S.; Fort, R.; Anaya, J.; Izquierdo, M. Effect of solar radiation and humidity on the inner core of walls in historic buildings. *Constr. Build. Mater.* **2014**, *51*, 383–394. [CrossRef]
62. The Institute of British Organ Building. *Church Heating and the Organ*; The Insitute of Bitish Organ Building: Bury St. Edmonds, UK, 2016.
63. Bughrara, K.S.; Arsan, Z.D.; Akkurt, G.G. Applying underfloor heating system for improvement of thermal comfort in historic mosques: The case study of Salepcioglu Mosque, Izmir, Turkey. In Proceedings of the Climamed 2017-Mediterranean Conference of Hvac Historical Buildings Retrofit in the Mediterranean Area, Matera, Italy, 12–13 May 2017; pp. 290–299.
64. Leijonhufvud, G.; Broström, T. Standardizing the indoor climate in historic buildings: Opportunities, challenges and ways forward. *J. Arch. Conserv.* **2018**, *24*, 3–18. [CrossRef]
65. Kramer, R.; van Schijndel, J.; Schellen, H. Dynamic setpoint control for museum indoor climate conditioning integrating collection and comfort requirements: Development and energy impact for Europe. *Build. Environ.* **2017**, *118*, 14–31. [CrossRef]