Church Heating: A Balance between Conservation and Thermal Comfort

By Dario Camuffo and Antonio della Valle

Introduction

Churches constitute an inestimable wealth, consisting of sacred and liturgical items as well as the patrimony preserved in museums and historical buildings.

Cold churches have been used for centuries. Yet now, the increasing demand for thermal comfort has made heating systems quite common, and they often cause more or less evident damage. In dry, cold climates, heating generates a climatic condition totally different from the natural, unheated climate to which artworks have become acclimatized, and in most cases, this large difference in levels of climatic factors and in their variability is not tolerable. Except in a few instances, cultural heritage items that for centuries have been kept in naturally cold churches are in good condition—even at times in optimal condition. Then, after the installation of one or more of the various heating systems, signs of rapid degradation have been found immediately.

Churches preserve many kinds of valuable artworks, each of them with a specific vulnerability: paintings on canvas and wooden panels are subject to cracking, swelling, blistering, and soiling; frescoes mostly to efflorescence and blackening; wooden artifacts to cracking; metals to corrosion; textiles to fading and soiling. A special problem derives from complex artifacts made of different materials. Organs are one of the most vulnerable artworks (Schellen et al. 2003; Clarke 2004), because, in addition to aesthetic appearance, they should preserve their use—namely, the production of sound. The characteristic voice of each organ can be severely affected by deformation and cracks in the wooden parts, deposition of suspended particles, and corrosion of the pipes. Corrosion of pipes is especially caused by the release of formic and acetic acid from the wooden parts, a process that is strongly dependent on microclimatic conditions (Tétreault and Stamatopoulou 1997; Dupont and Tétreault 2000). The problem of organs, generally placed in the upper parts of churches, is especially serious in the case of warm air heating, which overheats the organ and creates an exceedingly low relative humidity (RH).

In most cases, heating is derived from two major needs: economy (installation, use, and maintenance) and thermal comfort; conservation requirements are only rarely considered. Two heating methodologies are possible: *central heating*—heating the whole room and then allowing people to enter, and *local heating*—keeping the room cool and warming people with a localized heating source.

Each heating system has its pros and cons. In this article, we have limited the discussion to the primary negative problems; a complete discussion of advantages and disadvantages, as well as a summing up, can be found elsewhere (Danish Ministry for Ecclesiastical Affairs [1993]; Bordass and Bemrose 1996; Camuffo, Sturaro, and Valentino 1999; Schellen 2002; Della Torre and Pracchi 2003; Camuffo et al. 2004; Camuffo et al. 2006). There is an extensive literature on specific heating systems (Camuffo et al. 1999; Bratasz and Kozłowski 2005; Bratasz, Jakieła, and Kozłowski 2005) and on deterioration mechanisms (Camuffo and Schenal 1982; Landi 1992; Olstad 1994; Camuffo and Bernardi 1995; Mecklenburg, Tumosa, and Wyplosz 1995; Siau 1995; Larsen 1996; Dardes and Rothe 1998; Camuffo 1998; Kozłowski 2000; Kozłowski, Wittenburg, and Zeunert 2000; Olstad, Haugen, and Nilsen 2001; Brimblecombe and Camuffo 2003).

Problems with Central Heating

Central heating has the advantage of utilizing well-known, traditional techniques. The whole church volume is heated and, at least in theory, is everywhere thermally comfortable, although at different levels. The most popular types are warm air heating, convective and fan-assisted heating, underfloor heating, and footboard heating.

Heat tends to rise, and in the case of warm air heating or convective or fan-assisted heating, the upper part of the church, which is devoid of people and contains most of the artworks, is heated too much. With intermittent or mixed operation, in the ceiling and in the upper parts of walls, where heating-cooling cycles are at the highest intensity, masonry may be affected by dissolution-recrystallization cycles of soluble salts (Arnold and Zehnder 1991; Bläuer-Böhm et al. 2001).

A supply of moisture for humidification to mitigate drops in RH may prove effective for air, but condensation and damage may occur on cold surfaces (e.g., windows, ceilings, walls). And, when the air is warmer than the ceiling and walls, an endless convective motion of the air is generated, with heavy deposition of candle smoke and other pollutants (Huynh et al. 1991). Cold downdrafts increase blackening and cause human discomfort.

An example of how the microclimate in a heated church departs from natural conditions helps to focus the problem. The example is taken from a church with warm air heating that is used intermittently. Figure 1 shows the peak in temperature (T) and the drop in RH when heating is operated. It is evident that the sharp change may affect artworks with low thermal inertia that are able to follow the fast atmospheric forcing (e.g., paintings on canvas, tapestries, organ pipes). Artworks that react more slowly are especially affected in the surface layer: the color coatings on wooden paintings, gilding, and so on. In the long run, the surface layer of such works is damaged with cracking, flaking, and blistering.

Figure 2 shows the daily range in T versus the daily average T level; figure 3 shows the daily range in RH versus the daily average RH level. It is evident that the daily ranges of T and RH depart very much from the natural cycling to which artworks have been acclimatized. Huge departures cause exceedingly large strain-stress cycles to vulnerable materials that may undergo irreversible damage. Both figures show white dots, representing the natural church climate, which are well separated from black dots, representing the situation after a sharp occasional heating system is operated. Such a heating situation is risky for artwork preservation, as the exceedingly high changes in T and RH exceed the levels and the natural variability to which artworks are acclimatized. The unaffected natural condition is indicated as "historical climate." For this reason it should be recommended that extreme departures from the historical climate be avoided. An extreme departure can be defined as a departure that exceeds by one standard deviation the most frequent values. For a symmetrical or almost symmetrical distribution, this limit coincides with the 84th percentile of the observed values.

With underfloor heating the situation is better balanced; heat is more uniformly distributed, and the environment becomes thermally comfortable. However, in cold regions, and in the case of continuous use, the RH may drop below the threshold of tolerability for wood and other organic materials, causing severe damage such as breaks. In the floor and the lower parts of the walls, heating cycles may cause damage, as mentioned above. The warm floor generates convective air motions and surface blackening.

Both warm air and underfloor heating are very invasive systems. Warm air heating requires piping and ducting, which severely mutilate historical walls. Underfloor heating causes irreversible damage to the floor, tombs, and archaeological remains. With an undisturbed underlying archaeological archive, installation of an underfloor heating system should be forbidden.

Floor damage can be avoided with a variant consisting of a heated footboard placed below the pews. However, this is scarcely efficient for several reasons. First, the radiant area is too small, and most of the emitted infrared (IR) radiation is absorbed by the pews or intercepted by churchgoers. Second, the footboard temperature cannot be set too high, because it will cause the feet of churchgoers to perspire. And third, the amount of IR radiation emitted from the footboard that actually reaches people is extremely limited.

In central heating, the operation methodology is extremely important. Continuous heating—i.e., uninterrupted use during the cold season—avoids heating-cooling and related cycles, such as RH cycles and salt crystallization cycles. However, in cold climates the RH drops too low, damaging organic materials, and surface blackening proceeds at an accelerated rate for the whole cold season. Intermittent heating—i.e., operation only at weekly religious services—causes strong T and RH cycles that may damage artworks that have a rapid response to environmental changes, such as organs, paintings on canvas, wooden statues, and furniture. Strong T and RH cycles also encourage surface and subsurface crystallization cycles in masonry and lead to other damage as well. Mixed-mode operation—i.e. low-power, continuous heating for the whole week and full-power operation at church services—in theory might reduce some problems but will not mitigate all problems, and in some cases, it might in fact worsen the situation. For one thing, in mixed mode, surface blackening occurs during the whole week, while in the case of intermittent use, it is active for only a few hours a week. In practice, each method of heating is better or worse depending on the type of damage mechanism it causes—e.g., surface blackening, mechanical damage and cracks, soluble salt crystallization, condensation, and oxidation or biological decay.

In general, central heating provides the same thermal comfort level throughout the whole church, and the comfort is improved with continuous operation. Cost considerations constitute the main limit to this use. A further argument against continuous use, and against central heating in general, is that churches provide a huge volume to heat, and the fabric has thick walls and leakage. The result is a very large consumption of energy.

Over the course of years, other types of local heating have been introduced, to limit the area warmed and therefore the expense.

Problems with Local Heating

Historically speaking, local heating has been introduced in order to abate operating costs—not in response to specific studies that demonstrate benefits for artwork conservation. Fortunately, both goals are served. Local heating makes better use of heat and reduces dissipation. Most important, it promotes conservation, since artworks remain in the natural environmental conditions. However, local heating is a less common methodology than central heating, and human thermal comfort is generally lower.

The most popular heating types can be grouped into two categories: IR heating from high-temperature emitters (fed either by electric power or gas combustion) and pew heating. IR heating involves high-temperature sources that emit IR radiation, and all the people hit by IR are immediately heated. Thus it is possible to operate the heating system only when it is needed or, perhaps, just a short time in advance. Pew heating adds mild heat to the pew area, which may warm the feet or legs of churchgoers.

Quartz tube heaters and quartz halogen radiant heaters are electric radiant heaters. Both reach a high temperature, but quartz halogen heaters exceed the glare threshold, emitting visible and ultraviolet (UV) radiation. This is not only a matter of aesthetics; the UV emission, which is not negligible, poses a risk for people and artworks. Radiant heaters below the glare threshold supply only IR radiation; thus, they do not have this drawback. In any case, care should be taken to see that direct or diffuse IR reaches artworks, in order to avoid rapid overheating of certain parts. An example of a badly installed emitter that poses a risk for conservation is shown in figure 4.

Radiant emitters are placed aloft, hanging from the ceiling or mounted on the walls. This placement is effective for warming the heads and shoulders of churchgoers, but there is almost no warming of the legs and feet. In addition, for thermal comfort, IR radiation should be symmetrically distributed around the body, which does not occur with this type of heating. Figure 5 shows the results of a case study that delineates the profile of heating for a person standing in the pew area of a church heated with quartz halogen emitters. It is evident that the head and shoulder are well heated, but the lower part of the body is not.

Notwithstanding all of these problems, this kind of heating constitutes a practical solution for churches in which pew heating is not possible or for cases in which general heating is excluded.

While emitters directly heated by gas combustion have the same advantages and disadvantages of the electric radiant heaters, they have a further problem—namely, that the combustion of gas or liquefied petroleum gas (LPG) emits water vapor and other pollutants. Water vapor increases the risk for condensation in the cold areas, and pollutants may be noxious to people and artworks, especially in cases where there is no exhaust removal. When there are only a few services per week, pollution may not reach dangerous concentrations. However, the presence of a highly inflammable fuel in the church might lead to the risk of fire or explosion in case of leakage, and many authorities prefer to prohibit the use of this system and especially to prohibit the storage of liquid fuel in cylinders.

Pew heating is popular in small churches that are used only occasionally. This system has the advantage of a greatly reduced dispersion of heat into the environment. Artworks remain in an almost unaltered climate and do not suffer damage from sudden or persistent changes in temperature and humidity. With pew heating, the thermal comfort of people is not optimal, as only feet and legs are heated; the face remains cold and is exposed to annoying drafts. In fact, in cold conditions, skin is more sensitive to even slight air motions.

Briefly, high-temperature radiant emitters warm the upper part of the body, pew heaters the lower. With both methods, thermal comfort is not fully satisfactory, but pew heating has the advantage of being less harmful—at least if the heaters are properly installed and the most risky types are avoided.

Solution to Local Heating Problems: The European Friendly Heating Project

A European initiative, the Friendly Heating Project, was designed to seek a solution that would satisfy the two aims of thermal comfort and artwork conservation—goals that are generally conflicting (Camuffo et al. 2006; Limpens-Neilen 2006). This project analyzed various heating methods, assessing the problems encountered and the efficiency of each system. For instance, while pew heating has interesting advantages, the thermal comfort it provides is just fair, because only a single low-temperature source is insufficient to provide comfort.

To keep heat localized, low-temperature radiant heaters (emitting IR long-wave radiation) are more efficient than convective air movements. To heat the congregation, a number of radiant heaters set at a low emission temperature are strategically placed in every pew to satisfy the different physiological needs for heat of the various parts of the body. Heaters for feet, legs, and hands incorporate heating foils of different sizes set at temperatures especially designed for each limb. Heating foils are constituted of an electrically heated layer of graphite granules deposited on fiberglass and sealed between two plastic foils. When the electric power is switched on, the graphite warms up, and the resistance offered by the granules increases with T. For this property, the increasing value of the resistance reached by the granules reduces the intensity of the current. Consequently, the maximum temperature is self-regulated. This mechanism prevents ignition or the burning of skin.

Another solution involves the heating of glass panes, made conductive with internally sputtered metal oxides, which provide electrical resistance. A comfortable solution is to use them as back heaters. When the regional climate is not too cold, this system provides a pleasant level of thermal comfort. However, in the case of severe cold inside the church, the problems described for pew heating—that is, cold face and the sensation of draft—may emerge. In such conditions, the best solution is a soft IR integration from above—say, for example, with quartz tube heaters—or preheating of the area. For the priest or other officiant and the choir members, different solutions are used. These include the heating of carpets and small additional IR integration from remote quartz tube emitters.

The European Friendly Heating Project was aimed not only to design an improved heating system but also to verify its potential impact on artworks, especially in comparison with other systems. All the possible impacts, on the microclimate and on artworks, have been thoroughly studied in terms of cause-effect relationships.

Figure 6, which compares the daily ranges of RH and T when the Friendly Heating system and a warm air system are operated in a church, shows that the former has a negligible impact and the latter a substantial one. Figures 7a and 7b illustrate two heating strategies—heating the whole church with warm air (fig. 7a) and local heating (fig. 7b). Figures 8a and 8b compare the efficiency—the ratio between the enjoyable heat and the total heat supplied—of a warm air system (fig. 8a) and the Friendly Heating system (fig. 8b). With Friendly Heating, most of the heat remains in the inhabited area and is enjoyed by people. The warm air system has very low efficiency: most of the heat escapes upward, damaging artworks and leaving people in the cold.

Conclusion

General heating may provide some advantages, especially in terms of thermal comfort, but it dissipates a great deal of energy that can damage artworks. Preferably, artworks should be kept in the historical climate to which they have been acclimatized over many decades or even centuries. A possible criterion for tolerable variability after the installation and use of a heating system is to avoid exceeding one standard deviation above the typical values of the historical climate.

Local heating is potentially more convenient for conservation because little heat is dispersed in the church. However, this method requires improvement, because the thermal comfort supplied is only fair. The European Friendly Heating Project was conducted especially for its value to conservation; the aim was to warm people while allowing the church and its artworks to remain almost undisturbed in their natural microclimate. After comparisons were made with the other heating systems, this strategy was preferred, and the project sought to optimize the advantages and reduce the disadvantages of local heating.

The Friendly Heating system is particularly advantageous when priority or special attention is being given to artwork conservation. With the use of low-temperature elements, the system presents fewer risks than do other types of heating. The system is flexible, and the use of local heaters reduces heat dispersion and increases thermal comfort above the level of other pew heating systems. While the system is comfortable in mild and chilly climates, it is less so in cold climates. It is highly efficient: electric power can be supplied to a selected number of pews, depending on need. The visual and invasive impacts are very low. The Friendly Heating system is particularly convenient when (1) priority is given to conservation needs; (2) the heating is intermittent; (3) the church is small, and (4) the pews are fixed, such as to a footboard. Even when the heating is not intermittent—such as for chapels that are in daily use—the Friendly Heating system is suitable for smaller structures.

Whatever the heating system, thermal comfort may be reached easily in mild climates. In cold climates, however, thermal comfort and conservation necessarily involve conflicting needs. In the service of sustainable conservation, churchgoers may be required to make some sacrifices, such as bearing with a low-temperature environment and wearing heavy clothing. Church use might also have to be reduced during the coldest period.

Acknowledgments

The Friendly Heating Project, with its aim of making artwork conservation and human comfort compatible in historical buildings, is carried out with the support of the European Commission (contract EVK4-2001-00007). A study of organ preservation in churches—the European Commission project Sensorgan (contract no. 022695)—is also under way.

Author Biographies

Dario Camuffo received his doctorate in physics in 1966, and since 1968, he has worked at the National Research Council of Italy. In 1991 he was appointed research director at the council's Institute of Atmospheric Sciences and Climate, Padua. He is a lecturer of atmospheric physics at the University of Padua and a lecturer of physics for conservation at the Cignaroli Academy, Verona. His research activity includes the study of climate and natural hazards over the last millennium, as observed through instrumental observations and documentary data, and microclimate and atmospheric physics for the preservation of cultural heritage.

Antonio della Valle received his master's degree in 2001 and his doctorate in astronomy in 2005. In 2003 he was appointed resident astronomer at the Asiago Astronomical Observatory in Padua, part of the National Institute for Astrophysics. At present he is a Fellow at the Institute of Atmospheric Sciences and Climate of the Italian National Research Council, working on the European Community project Sensorgan. He works with Dario Camuffo on microclimate and atmospheric physics for the preservation of cultural heritage.

Figures

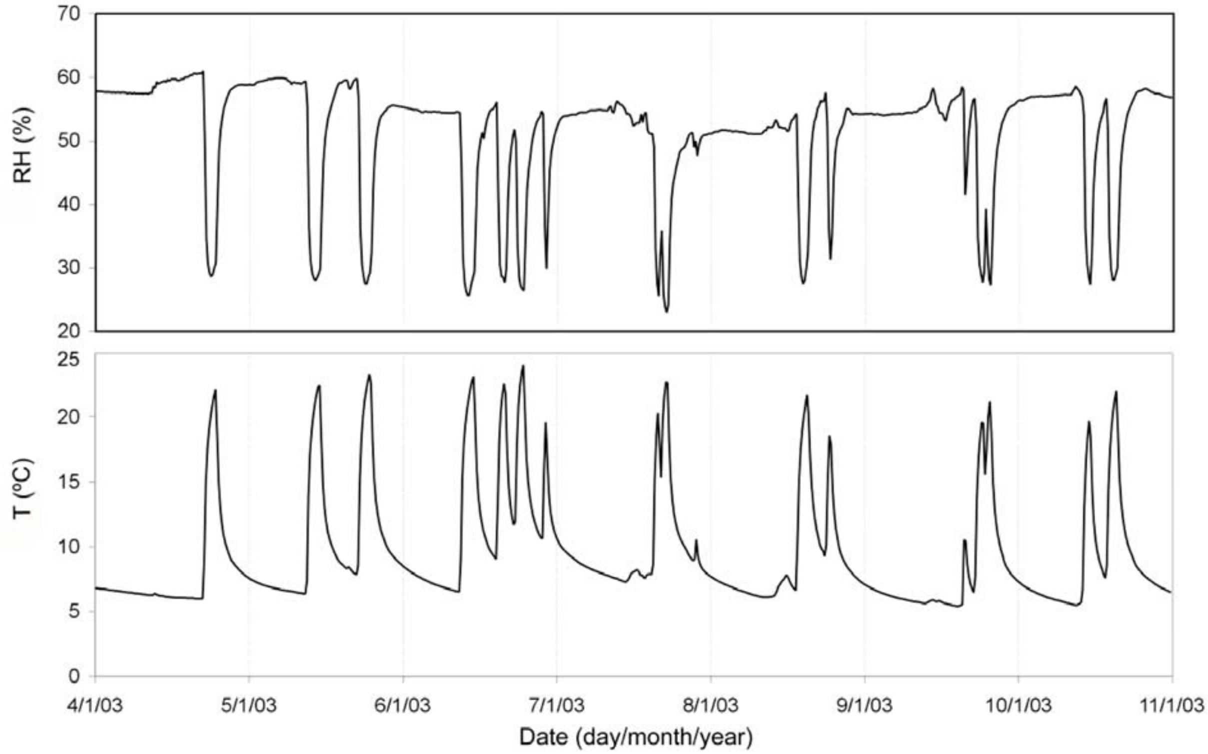


Figure 1

Temperature (T) and relative humidity (RH) profiles sampled 4.5 m above the altar of the church of Rocca Pietore, Italy, in 2003. Peaks in T, drops in RH, and sharp profile changes are caused by intermittent operation of a warm air heating system for daily services.

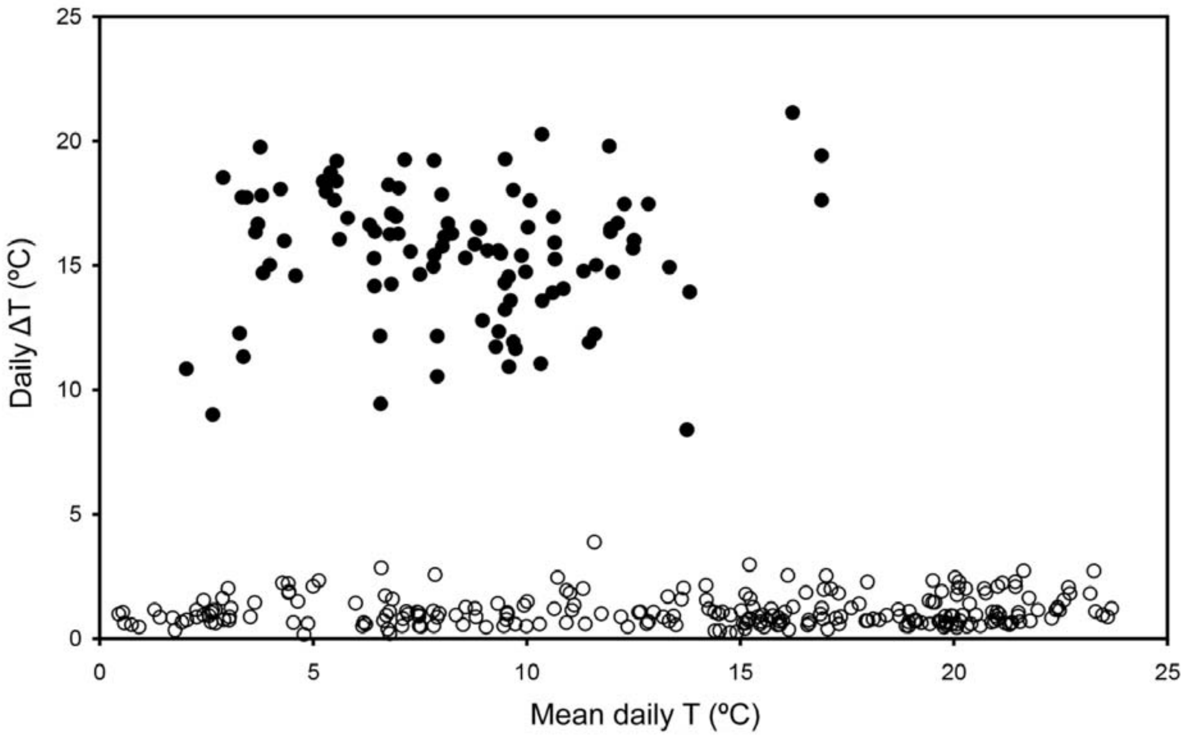


Figure 2

Daily range in temperature (ΔT) versus the daily average T level in the church of Rocca Pietore, Italy, in 2003. White dots represent the natural church climate; black dots represent the situation after a "strong" heating system is operated.

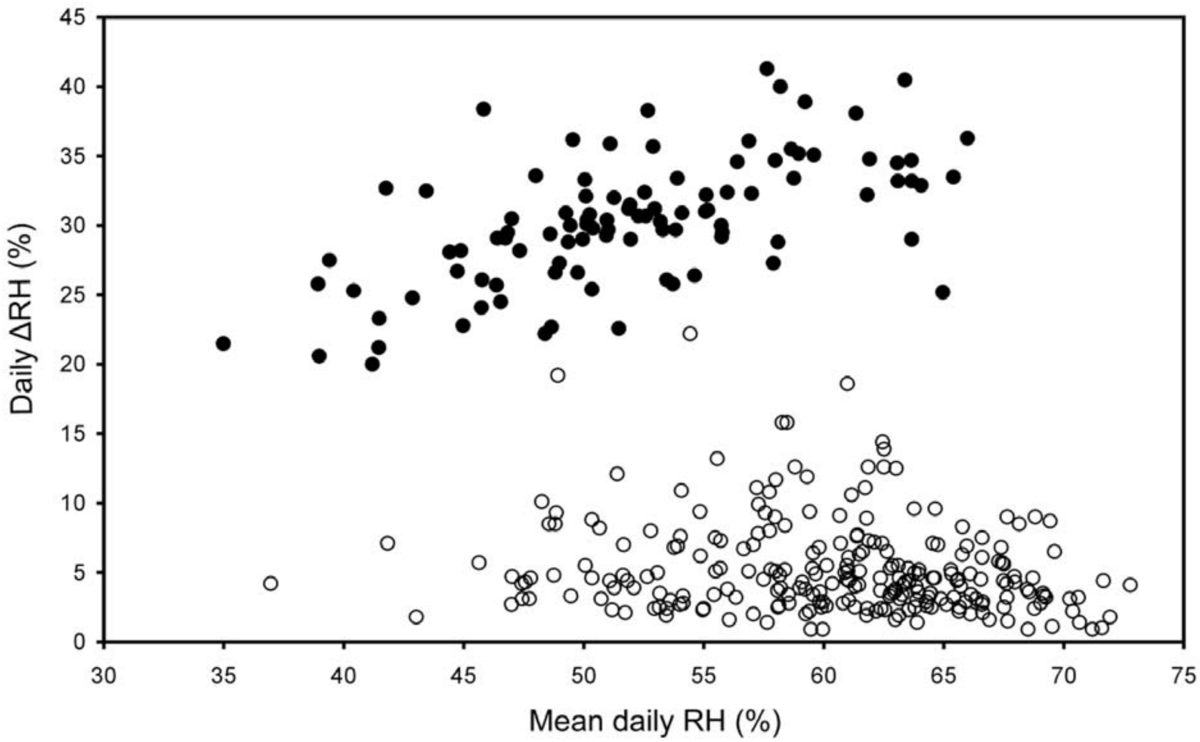


Figure 3

Daily range in relative humidity (ΔRH) versus the daily average RH level in the church of Rocca Pietore, Italy, in 2003. White dots represent the natural church climate; black dots represent the situation after a “strong” heating system is operated.

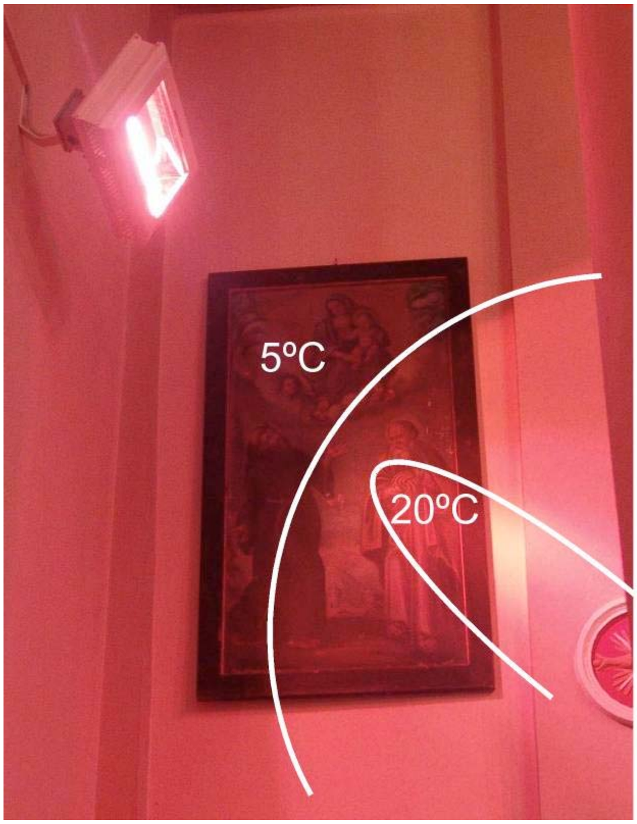


Figure 4

This quartz halogen radiant heater warms the congregation, but there is a risk of damage to the painting. In fact, the temperature of the corner exhibits a sharp rise (20°C) in just a few minutes. Photo: Institute of Atmospheric Sciences and Climate.

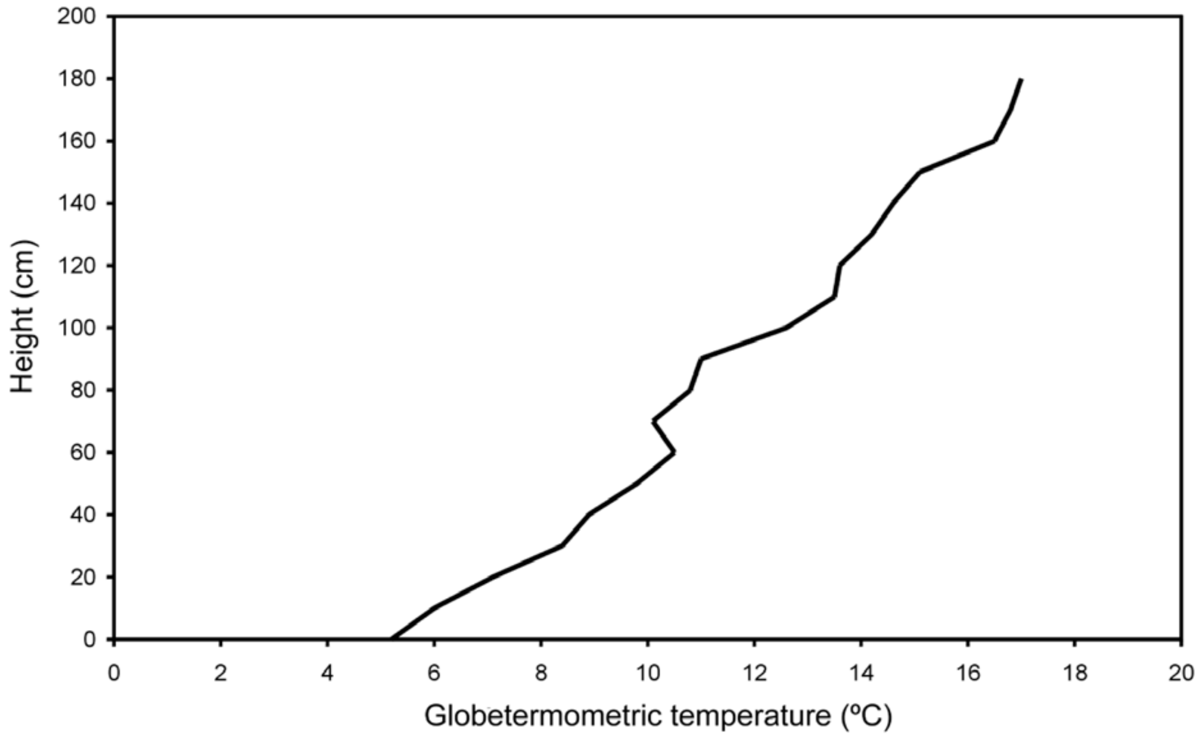


Figure 5

Profile of heating for a person standing in the pew area in a church heated with quartz halogen emitters. While the head and shoulder are well heated, the lower part of the body is not.

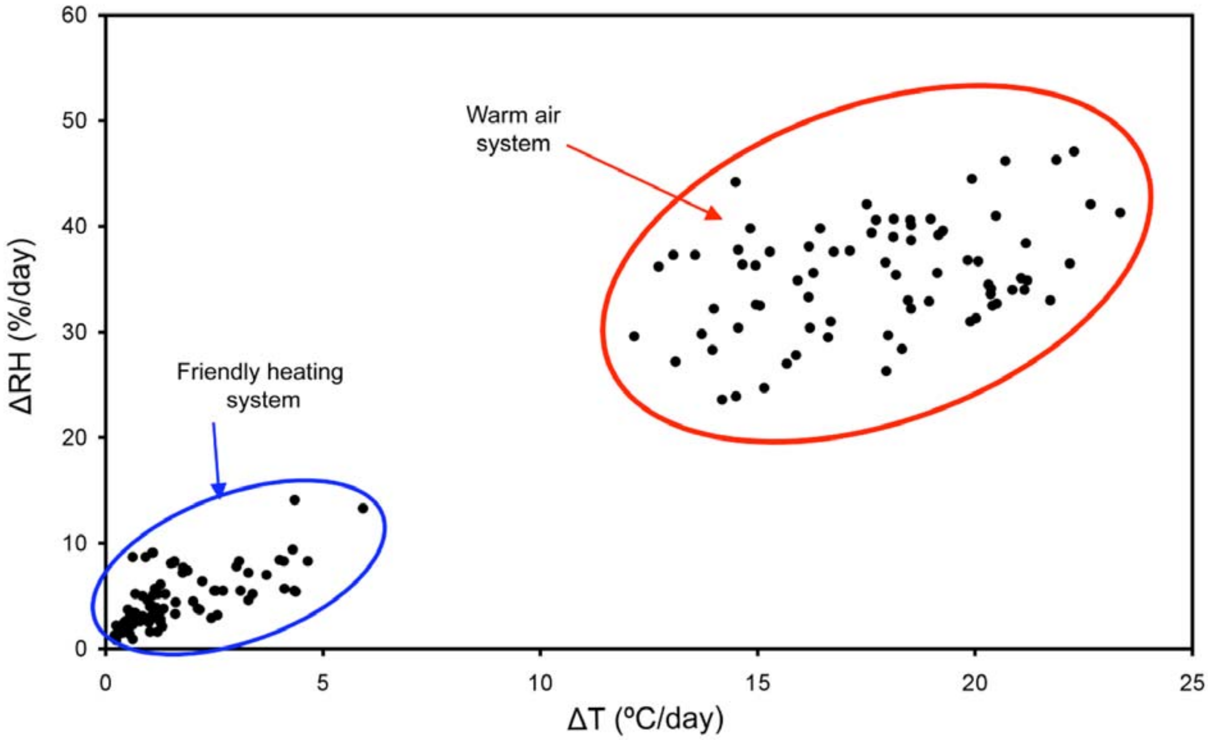
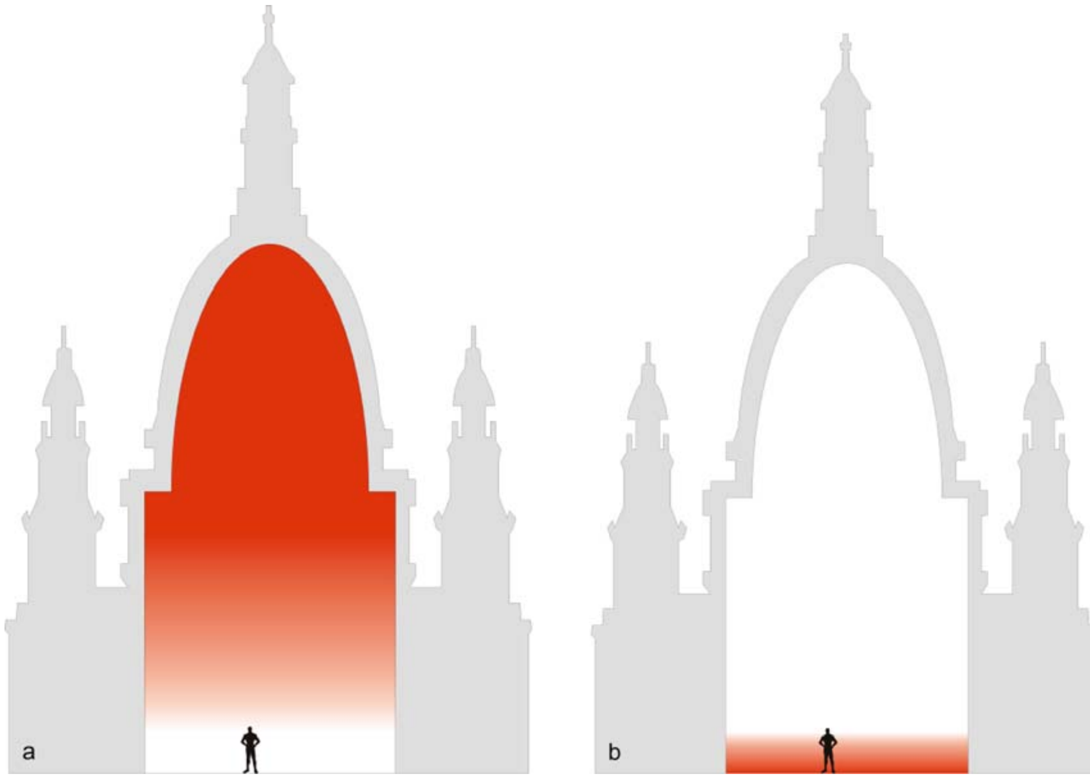


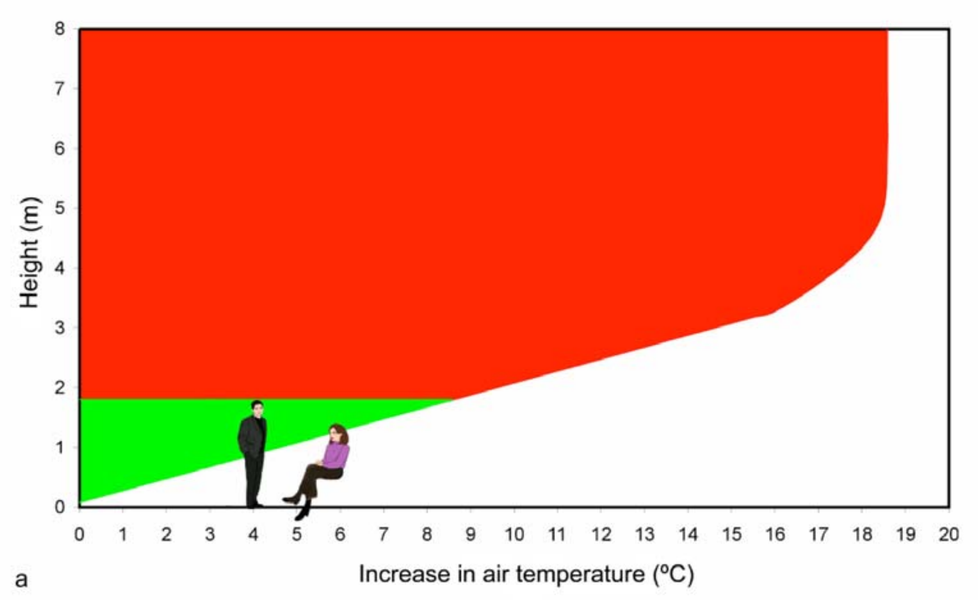
Figure 6

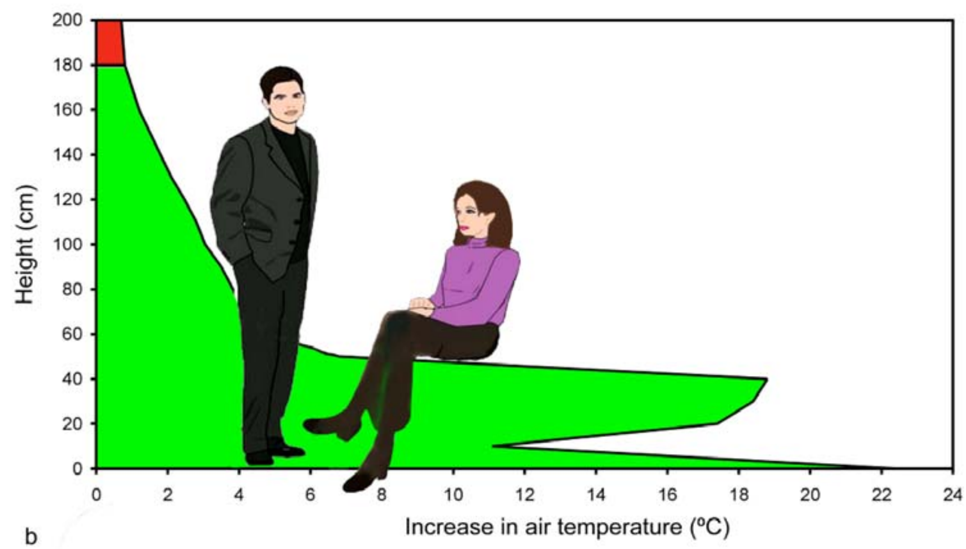
Comparison between the daily ranges of relative (RH) and temperature (T) when the Friendly Heating system and a warm air system are operated on different days in the same church. It is evident that the former has a negligible impact and the latter a substantial one.



Figures 7a and 7b

Two heating strategies: heating the whole church with warm air (a) and heating only people with local heating (b).





Figures 8a and 8b

Efficiency of a warm-air system (a) and the Friendly Heating system (b). The efficiency is defined as the ratio between the enjoyable heat (green) and the total heat supplied, including the part escaping aloft (red). With Friendly Heating, most of the heat remains in the occupied area and is enjoyed by people. The efficiency of the warm air system is very low: most of the heat escapes upward, damaging artworks and leaving people in the cold.

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