Efficiency of an organ heater and its potential impact on the organ in a church

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ABSTRACT

Among the works of art that can be found in churches are organs. They belong to the core of European culture, reflecting a diverse history of traditions and stylistic periods and they themselves represent an example of cultural heritage that requires conservation for use during religious celebrations. Harmful indoor environmental conditions pose a major threat to organs as the demand for thermal comfort during services grows.

The risk derived from the adverse microclimate created by various kinds of church heating systems leads to dryness from continuous heating or occasional overheating, especially with warm air systems. In order to minimize the dispersion of heat within the church and the consequent temperature and relative humidity imbalances, local heating systems have proved to be less damaging to artwork preservation than central heating, as recommended by the EU standard EN15759-1:2011. This paper presents the case study of a radiant organist heater studied to evaluate its heating efficiency, its performance in terms of organist thermal comfort, and the potential risk to the organ console directly reached by IR radiation. Preliminary tests were performed in the laboratory with a blackbody strip as recommended by EN15758:2010 and then in the field, once the twin system was located in the Church of the Eremitani, in Padua, Italy. tTwo heaters were located on either side of the organist to provide symmetrical radiant heating. The experimental results show that these heaters do not guarantee safety against skin burning or accidental ignition of paper, cloth, tapestry or wood due to the large emitter mesh and the excessively high emission temperature of the front and upper part. The laboratory and in field experiments identified a threshold for the use of the radiant heating within which the risk of damage to the console is very low. The recommended distance of placement of the emitters was evaluated on the basis of this threshold.

Keywords

radiant heater, organist, organ , local heating

1. Introduction

Organs belong to the European cultural heritage, reflecting history and traditions of different countries and cultures. A major threat to these vulnerable historical instruments, regarding both the deformation of the structure as well as the loss of sound quality, is a harmful indoor environment. Organs in fact are composed of a number of materials which are sensitive to temperature and humidity changes. To be able to best preserve these ancient instruments, particular attention must be paid to the microclimate and the demand of comfort by churchgoers or final users. Conservation and comfort often have conflictual needs, and the European Standard EN 15757: 2010, "*Conservation of cultural property - Specifications for temperature and relative humidity to limit climate-induced mechanical damage in organic hygroscopic materials*" [1] recommends priority be given to the conservation of cultural heritage items, avoiding departures from the historic climate, to which the work of art has been adapted and acclimatized. In particular, the EN 15759-1: 2011 "*Conservation of cultural property — Indoor climate – Part 1: Guidelines for heating churches, chapels and other places of worship*" [2] specifies that the historic climate should be kept unchanged, referring to to EN 15757: 2010.

How can churghgoers need for warmer churches be met without posing a threat to the most vulnerable works of art, such as historical wooden organs? From the point of view of cultural property preservation, local heating has proved to be the safest way of heating churches ([3], [4], [5] , [6], [7] and [8]).

The organist, however, remains in the cold. The same is obvious for unheated churches. In both cases, the organist may need some heat to reach an acceptable level of comfort to play without damaging the organ itself. A frequent solution is the use of electric infrared (IR) heaters. Electric heaters radiate up to 86% of their input power as radiant energy [9].

The remaining energy is lost due to conduction or convection. Nearly all the electrical power is converted into IR radiant heat by the filament and directed onto the organist by reflectors. Consequently the IR radiation impinging on the organist is virtually doubled. The impinging IR may cause indirect thermal burns when the skin is exposed for too long or the organist is located too close to the heaters. Some radiant heat may reach the organ console, especially manual keyboards made of wood and ivory. Investigations are needed to establish how radiant energy is distributed in space and the impact it may have on man and vulnerable keyboards.

The questions investigated in this paper are: are infrared (IR) heaters safe for both the organist and the organ? What is the distribution of IR radiation, both in vertical and horizontal planes? At what distance from the organist should the emitters be located? How could existing commercial products be improved for human comfort and artwork preservation?

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2. Testing an Organist Heater

The study focuses on a typical heating system (Figure 1), which is commercially available in Scandinavian countries with persistent extreme climate conditions during wintertime. The test heater was provided by a producer through the Norwegian Embassy in Italy.

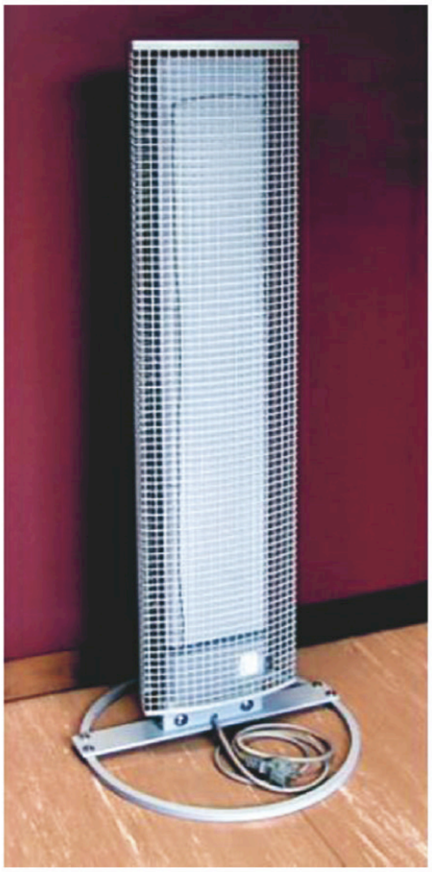


Figure 1 The organist heater.

This system is used in churches to heat the organist during weekly religious services. The organist is heated on either side by two standing heating units located at a certain distance. The height of each standing unit is 100 cm. Each unit consumes 500, 1000 and 1500 watts. An internal capillary thermostat controls the unit against overheating. The hot surface covering the filament is protected with a 10 mm mesh grille,.

The heater was first tested in the laboratory, to check its performance, and to find the best use and thermal comfort it gave to the organist; then it was tested in the field to evaluate its possible impact on the organ console. The field tests were carried out in Italy, inside a 13th century brick church, where the heating system was operated for the length of a typical church service, i.e. 45 min.

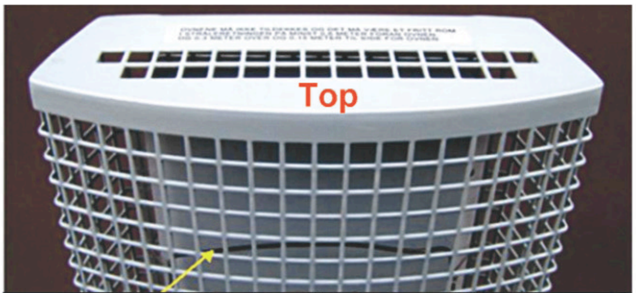
The temperature of the heater surface was measured by a Raytek MX Infrared Thermometer with special compensation for temperature errors and calibration within ±0.1°C in the range -20° to 200°C and slightly larger uncertainty from -30 to -20°C and from 200° to 900°C. The heating caused by the IR radiation was measured with the above instrument and the blackbody strip target method as described in [7] and recommended by EN 15758: 2010 "*Conservation of Cultural Property - Procedures and instruments for measuring temperatures of the air and the surfaces of objects*" [10]. This method measured the temperature reached by a blackbody strip target placed at various heights and distances from the heat source.

All the laboratory tests were performed with the unit operating at maximum power, i.e. 1500 Watts, keeping the room temperatures at two reference conditions, at 0°C and 20°C, respectively with and without ventilation.

2.1 Surface temperature of the heater

For safety reasons, the maker suggests keeping a free area, 60 cm in front of the heater and 30 cm above the top. However, we cannot exclude accidental contact with the unit, or sharp objects penetrating through the wide mesh, and it is necessary to establish the possible risk when this happens.

The observed surface temperature (T_{Surf}) in reported in a chart in Figure 2 (a) and graphically in Figure 2 (b).



		Ventilation 0°C Room Temperature	No Ventilation 20°C Room Temperature
Superficial Temperature	Back	100°C at the Top	140°C at the Top
250 °C	Front	350°C	390°C

Figure 2 (a) Detail of the upper part of the heater and the observed TSurf behind the grille, on the grille and on the top.

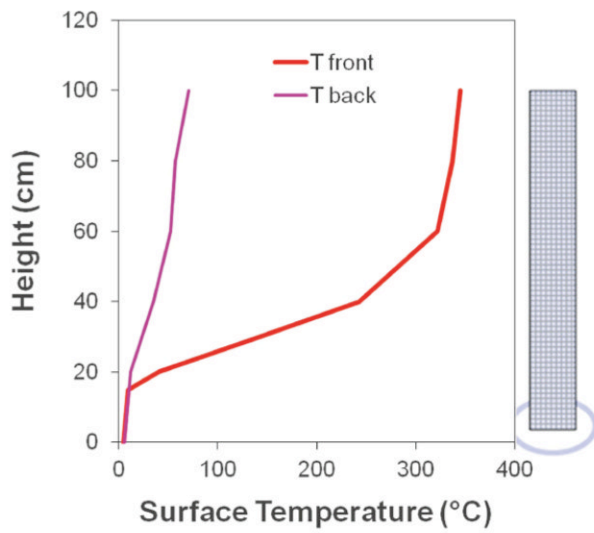


Figure 2 (b) Vertical profiles of the TSurf of the front (red) and the back (magenta) of the standing unit.

The front temperature (red in Figure 2b) increases with height for the convective contribution of air overheated after contact with the hot surface and slips along the surface for buoyancy and the Coanda effect. The back temperature (pink in Figure 2b) is lower for the internal insulation of the unit.

In the frontal part of the emitter, below the protective grille, at a room temperature of 0°C in a well ventilated environment, the surface temperature reaches 350°C. In absence of ventilation and at 20°C room temperature, the surface can reach 390°C.

This surface temperature of the heater's front is higher than the ignition temperature of many organic materials commonly found in churches, such as paper (230°C), wood, silk, cotton and linen (ranging from 230 to 250°C) [11] and could trigger fires on cloths, tapestry, paper or other burning materials placed close to it or it may burn skin.

The heater's back surface temperature is acceptable, although the top reaches 100°C in a ventilated environment at 0°C room temperature. In the absence of ventilation and at 20°C room temperature, the top temperature reaches 140°C.

2.2. Heating efficiency

The heating efficiency was determined by measuring the temperature vertical profiles on a blackbody strip target placed in position at distances further away from the emitter. The used blackbody target was a 180 cm long strip, and the profiles covered measure from 0 cm to 160 cm above the floor, 130 cm being the average height of a sitting person.

The first test was performed on the vertical plane passing across the heater and checking the decrease in heat at increasing distances from the emitting source. To this aim, we monitored how the blackbody strip surface temperature decreased by moving it horizontally at various distances (spaced by steps of 10 cm). The blackbody surface temperature was measured at fixed vertical levels (spaced by steps of 10 cm). A matrix with 10 cm grid was obtained, and the observations graphically reconstructed from the horizontal and the vertical point of view.

Starting with the observations made at the same horizontal level, i.e. temperature versus distance from the emitter, the attenuation of heat with distance follows a third-degree polynomial attenuation as reported in Table 1.

Making a comparison between runs at various levels, the highest temperature is reached around 80 cm, which is more or less the height at which the hands of the organist move across the keyboard.

Other tests were performed to study how the heat emitted in front of the unit is vertically distributed, and how this distribution changes with increasing distances from the source. This means that each run gives the distribution of the temperature along the blackbody strip kept vertically in front of the heat source, and each run is obtained moving the blackbody strip at various distances, 10 cm spaced between them.

The vertical distribution of heat at various distances is reported in Figure 3 and the polynomial fit of the heating efficiency is summarized in Table 2.

In this representation, the level of maximum heating is once again evident at 80 cm above the floor, as in the previous plot.

Distance	Third-Degree Polynomial	Determination Coefficient	Distance	Third-Degree Polynomial	Coef. of Determination
80 cm	y = -3E-05x3 + 0,0108x2 - 1,5486x + 85,392	R^2 = 0,9942	80 cm	$y = -3E-05x^3 + 0.0108x^2 - 1.5486x + 85.392$	R^2 = 0.9942
70 cm	y = -3E-05x3 + 0,0107x2 - 1,5233x + 84,087	R^2 = 0,9939	90 cm	$y = -3E-05x^3 + 0.0106x^2 - 1.4765x + 79.311$	R^2 = 0.993
60 cm	$y = -2E-05x^3 + 0.0081x^2 - 1.2133x + 71.207$	R^2 = 0.9946	100 cm	$y = -2E-05x^3 + 0.0094x^2 - 1.2765x + 68.367$	R^2 = 0.9918
50 cm	$y = -1E-05x^3 + 0.0053x^2 - 0.8784x + 57.125$	R^2 = 0.9965	110 cm	$y = -1E-05x^3 + 0.0048x^2 - 0.7241x + 46.084$	R^2 = 0.9966
40 cm	$y = -9E-06x^3 + 0.004x^2 - 0.6712x + 45.914$	R^2 = 0.9951	120 cm	$y = -5E-06x^3 + 0.0023x^2 - 0.4056x + 31.56$	R^2 = 0.9989
30 cm	$y = 3E-07x^3 + 0.0005x^2 - 0.2263x + 25.684$	R^2 = 0.9975	130 cm	$y = 2E-06x^3 - 0.0006x^2 - 0.0127x + 13.441$	R^2 = 0.9988
20 cm	$y = 2E-06x^3 - 0.0004x^2 - 0.0352x + 13.351$	R^2 = 0.9979	140 cm	$y = 3E-06x^3 - 0.0011x^2 + 0.0841x + 6.4929$	R^2 = 0.9948
10 cm	$y = 2E-06x^3 - 0.0009x^2 + 0.0667x + 5.7121$	R^2 = 0.9945	150 cm	$y = 4E-06x^3 - 0.0014x^2 + 0.1499x + 1.7214$	R^2 = 0.9864
0 cm	$y = 4E-06x^3 - 0.0014x^2 + 0.1339x + 1.7857$	R^2 = 0.9881	160 cm	$y = 2E-06x^3 - 0.0009x^2 + 0.1173x + 0.7357$	R^2 = 0.9643

Table 1 Third-Degree polynomial heat attenuation with distance

Distance	Heating Efficiency Polynomial fit	Determination Coeff
40 cm	$y = -6E-11x^6 + 3E-08x^5 - 3E-06x^4 - 1E-05x^3 + 0.0156x^2 + 0.027x + 5.1791$	R^2 = 0.9981
60 cm	$y = -8E-12x^6 + 1E-09x^5 + 7E-07x^4 - 0.0002x^3 + 0.0142x^2 - 0.0011x + 5.7081$	R^2 = 0.9981
100 cm	$y = 6E-08x^4 - 2E-05x^3 + 0.0001x^2 + 0.1559x + 4.5409$	R^2 = 0.9863
120 cm	$y = 4E-08x^4 - 1E-05x^3 + 0.0004x^2 + 0.078x + 3.8311$	R^2 = 0.9912
160 cm	$y = 2E-08x^4 - 7E-06x^3 + 0.0004x^2 + 0.0316x + 2.4976$	R^2 = 0.9956

Table 2 Polynomial fit of the heating efficiency at various distance from the heater as referred in Figure 3

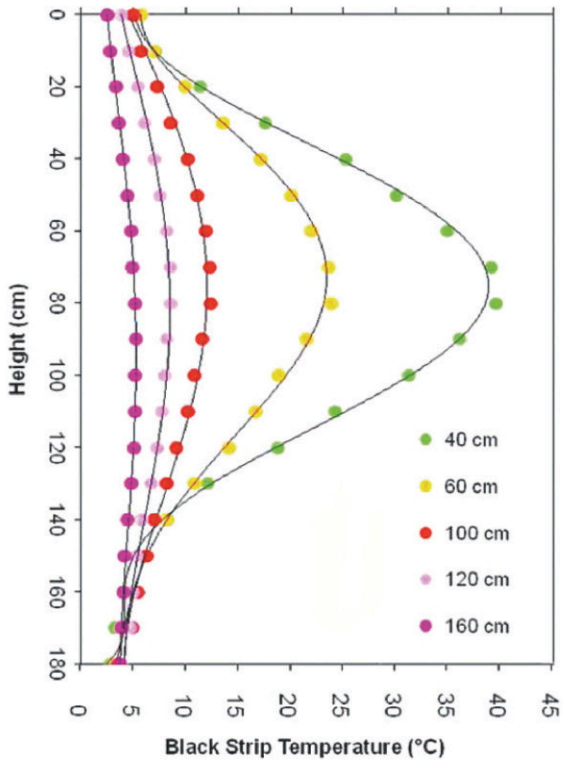


Figure 3 Heating efficiency (vertical profiles) at various distances from the heater.

In order to reach comfort, the IR contribution that determines the difference between the mean radiant temperature and the actual air temperature should not exceed 10°C [3] and should be symmetrically distributed. On average, this situation is obtained at some 80 cm from the heater.

It is also useful to know how heat is horizontally distributed at the level of maximum intensity and highest comfort. Observations were taken on a horizontal blackbody strip, located at a distance of 80 cm from the emitter at different heights above the floor (Figure 4). The heater provides a comfortable area for 60 cm width (± 30 cm) from the center (i.e 0 cm in the x-axis of Figure 4), then warming drops.

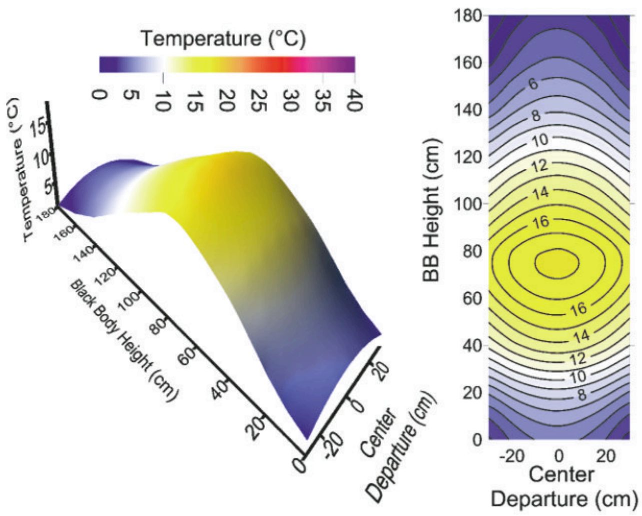


Figure 4 Horizontal distribution of heat at level of maximum intensity and highest comfort, i.e. 80 cm distance from the emitter (3-D and 2-D views).

3. Impact on the organ console and the seat

The field experiment to test the organist heater was performed in the Eremitani Church in Padua where the heaters were then left for the organist's comfort.

The organ console was located at the back of the altar, and the organist sat with his back facing a cold stone wall with a recess. Two heaters A and B were symmetrically installed on both sides of the organist's seat at a distance of 1 m but 20 degrees back to optimize the position in the existing space of the recess (Figure 5).

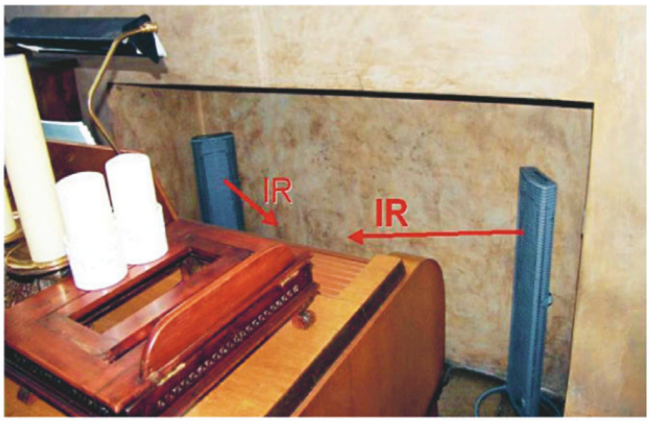


Figure 5 The two heaters symmetrically positioned in the recess behind the organist during the field monitoring campaign.

To test for impact, three contact temperature sensors were located on the keyboard, one in the seat and two on the altar; in addition, the air temperature and relative humidity were also monitored.

On the console, when the heaters have been on for 45 minutes and the organist is not sitting, the total overheating generally reaches 9-10°C, i.e. on the left side as a contribution of 7°C from A and 2°C from B; in the middle 5°C fed from A and the same from B; on the right side 2°C fed form A and 7°C from B. However, when the organist is seated, his shadow protects the organ in the middle and the side so that overheating is less than 7°C. The back of the seat is overheated by some 22°C, half of them due to A and half to B. The altar stone is heated by some 10°C. Air heating is detectable only in close proximity to heaters and heated surfaces.

The contribution of each single heater A, B is shown in Figure 6.

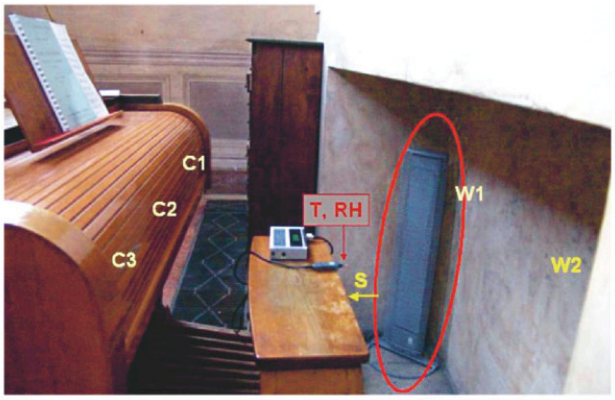


Figure 6 (a) The measuring points and the tested infrared emitter.

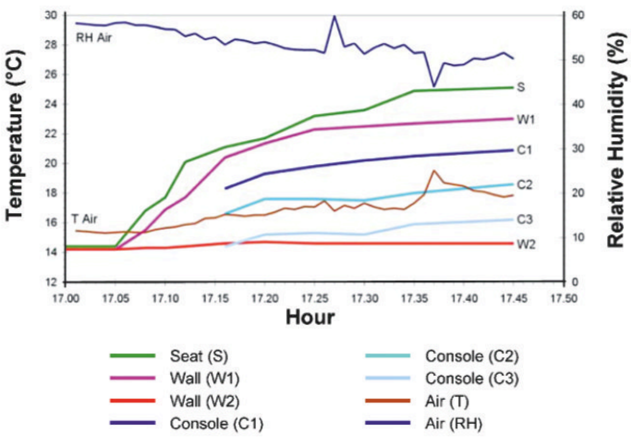


Figure 6 (b) The results of measurements.

4 Discussions and conclusions

The two heaters should be used symmetrically, one on the right and the other on the left of the organist. For physiological reasons concerning thermal comfort, it is preferable not to exceed 10°C radiant heating. This implies that each emitter should be placed 1m from each of the organist shoulders in order to avoid exceedingly high IR contribution, i.e. >10°C. Some free space on both sides of the organist is required for heaters (Figure 7). In the best solution, for a church at around 0°C, two heaters, symmetrically located at 1 m distance from the organist, require at least 3m of free space.

As regards the organist's thermal comfort, while his arms and trunk are quite well heated, his feet remain cold. This is unpleasant, but not critical because his feet are continually moving on the pedals when playing, which reduces the need for heating. As for the impact on the console, when the heaters are operating in the absence of the organist, the IR radiation to the organ may be relevant, causing the surface temperature to increase by 5°C and the RH at the interface to decrease by 10%. The EN 15757:2010 standard considers acceptable RH changes no greater than 10%. In contrast, the impact on the seat causes T to increase by 10°C and the RH to decrease by 22%. This should be considered in the case of particularly vulnerable seating, but this impact should be compared with the disturbance caused by the body temperature. When the organist is sitting, the central part of the keyboard is in the shade, and only the keyboard sides are heated.

The main problem concerns safety, in particular the size of the grid mesh and the excessive surface temperature. The holes of the mesh are too large because a child could insert a finger or a sharp object. The heater could be improved with a thinner mesh (e.g. 1 mm). The exceedingly high surface temperature remains the key problem, because it could cause skin burning or accidental ignition of paper, cloth, tapestry or wood. This problem might be partially solved with better insulation, especially on the upper part of the emitter. However, the front part remains too hot. For this reason, the emission temperature should be reduced. As a consequence, the effective emitter surface should be increased to compensate for the lower IR emission power density.

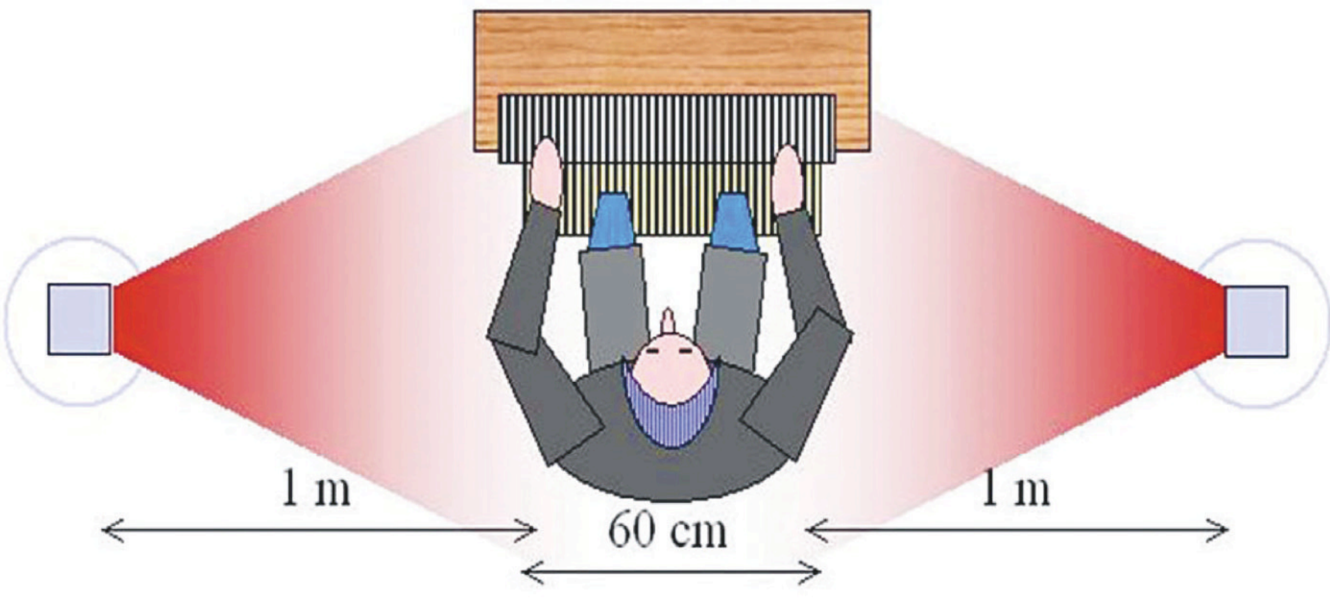


Figure 7: Free space required for heaters when the church is cold (i.e. around 0°C) and the heaters operate at maximum power (1500W).

5. Acknowledgements

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6. References

[1] EN 15757. 2010 *Conservation of cultural property - Specifications for temperature and relative humidity to limit climate-induced mechanical damage in organic hygroscopic materials.* European Committee for Standardization, Brussels, Belgium.

[2] EN 15759-1. 2011 *Conservation of cultural property — Indoor climate – Part 1: Guidelines for heating churches, chapels and other places of worship.* European Committee for Standardization, Brussels, Belgium.

[3] Bemrose, C., Bordass, W. 1996. Heating your Church. Council for the Care of Churches. London: Church House Publishing 106.

[4] Schellen, H.L. 2002. Heating Monumental Churches – Indoor Climate and Preservation of Cultural Heritage. Technische Universiteit Eindhoven, Netherlands 228.

[5] Limpens-Neilen, D. 2006. Bench Heating in Monumental Churches – Thermal Performance of a Prototype. Technische Universiteit Eindhoven 137.

[6] Camuffo D. 2007. Church Heating and the Preservation of the Cultural Heritage - Guide to the Analysis of the Pros and Cons of Various Heating Systems. Milan, Electa, 240 p.

[7] 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, pp. 205-219

[8] Camuffo, D. 2013: Microclimate for Cultural Heritage. Second Edition. Amsterdam: Elsevier.

[9] ASHRAE 2008: ASHRAE Handbook - Heating, Ventilating, and Air-Conditioning Systems and Equipment (I-P Edition), American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., table 2 15.3

[10] EN 15758. 2010 *Conservation of cultural property -– Procedures and instruments for measuring temperatures of the air and the surfaces of objects.* European Committee for Standardization, Brussels, Belgium.

[11] Graf, S.H. 1949. Ignition temperatures of various papers, woods and fabrics. Bulletin No. 26, Engineering Experiment Station, Oregon State System of Higher Education, Oregon State College, Corvallis, USA