Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 59 (2014) 425 – 432

Energy Procedia

European Geosciences Union General Assembly 2014, EGU 2014

The influence of indoor microclimate on thermal comfort and conservation of artworks: the case study of the Cathedral of Matera (South Italy)

Tiziana Cardinale*, Gianluca Rospi, Nicola Cardinale

Dipartimento delle Culture Europee e del Mediterraneo, Università degli Studi della Basilicata, Via Lazazzera, 75100 Matera, Italy

Abstract

The Matera Cathedral was built in Apulian-Romanesque style in the thirteenth century on the highest spur of the "Civita" that divides "Sassi" district in two parts. The constructive material is the calcareous stone of the Vaglia, extracted from quarries in the area of Matera. The interior is Baroque and presents several artworks.

The research had to evaluate the indoor microclimate during and after the restoration works, that also concern the installation of floor heating system to heat the indoor environments. Specifically, we have analyzed the thermal comfort and the effect that the artwork and construction materials inside the Cathedral of Matera have undergone.

© 2014 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/3.0/).
Peer-review under responsibility of the Austrian Academy of Sciences

Keywords: religious architecture; environmental monitoring; energy rehabilitation; radiant floor system.

1. Introduction

The churches are an invaluable heritage of sacred objects, artworks, organs, monumental buildings, furnishings and decorations that must be preserved and defended by constant environmental attacks that affect their health and conservation. These assets are sensitive to certain environmental factors, defined as "limiting", and among all the

* Corresponding author. Tel.: +39 347 1182729
E-mail address: tizcardina@hotmail.it

1876-6102 © 2014 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/3.0/).
Peer-review under responsibility of the Austrian Academy of Sciences
doi:10.1016/j.egypro.2014.10.398

fundamentals are: temperature, relative humidity, light, air and physical agents. These factors are nothing more that the components of what is called "micro-climate" and, for this reason, their balance is crucial in order to guarantee the maintenance and protection of artworks. It has been found that many churches, not artificially heated for a long time in the past, have kept in good condition their interior artistic heritage: this almost until the start of the use of heating, that has deeply influenced their state of preservation. So, the choice of a heating system installed in order to ensure the thermal comfort of the faithful, is a matter to be dealt with the greatest care.

Many papers were published on the performance of heating systems installed in the context of artistic and architectural heritage, but relatively to the historic churches, the number of analyzed case studies was quite low. In particular in [1] the authors analysed the parish church at Talamanca de Jarama (Spain) where the forced hot-air system installed induces wide fluctuations in indoor thermal–hygrometric (*T/RH*) conditions, producing a temporal and horizontal stratification of temperature and relative humidity. As a result, the thermal comfort sought for the faithful is not reached, but also the conservation of Church artworks is compromised. In [2], [3], [4] the performance of a conventional, hot-air heating system and a novel design for heating a church in a cold climate, consisting of low-temperature heating elements, such as electrically heated pews and carpets, were compared. The hot-air heating system has been proved to present a potential deterioration risk to artworks, as it increases the supply, transport and deposition probability of air pollutants. The new heating system eliminates these undesirable effects, but also provided a desirable distribution of heat to the feet, legs and hands of people occupying it. In [5] the authors investigated the impact of electric overhead radiant heaters on the microclimate, air flows, transport and deposition of suspended particulate matter. The radiant heaters proved to generate little convectional flow of the air and didn't increase the concentration of SPM indoors and in particular, no re-suspension of particles already present in the church was observed. Studies in previous papers clearly show the shortcomings of air systems that you should not use in the presence of artworks in churches. Our analysis was therefore focused on the performance of a heating system typology at low temperature, which is the radiant floor system, in a church of historical importance. The plant in question was installed in the Cathedral of the city of Matera, located in the Basilicata region situated in southern Italy. It is important to highlight that the Matera Cathedral is inserted in the settlement of the *Sassi* and Park of Rupestrian Churches of Matera which is an UNESCO World Heritage Site since 1993.

2. Cathedral, thermal properties of materials, climatic parameters.

The construction of the cathedral was started in 1230 under the Bishop Andrew's administration (archdeacon of Acerenza and Matera), and was completed in 1270 in the presence of Monsignor Lorenzo [6]. It was built in the "Civita" the highest point of the Sassi districts, on the site of a Benedictine monastery dedicated to St. Eustace.

The original dedication was to Santa Maria de Episcopio, later (in the late fourteenth and early fifteenth) was dedicated to Our Lady of Bruna and then probably in the seventeenth century, even to St. Eustace. Actually, it is the main place of Catholic religion in Matera, the Mother Church of the Archdiocese of Matera-Irsina.

The architect is unknown, but the church is characterized by a "salient façade" typical of Apulian Romanesque style. The main facade is directed to the west towards the valley of the *Sasso Barisano* and presents the main door surrounded by delicate floral decoration and a magnificent rose window with sixteen rays consisting of 16 columns in the middle and small arches, with a circumference surrounded by two ornate frames (Fig.1).

Entering the Cathedral of Matera there is an evident contrast with the exterior styling and the interior one, composed by three naves, typical of a Latin cross church (Fig.2). In the 17th century were added anywhere stucco decorations which were then covered with a golden patina in the 18th century. The original ceiling was covered in 1719 with a wooden false ceiling, on which in the 19th century were inserted three paintings by Battista Santoro, important for the culture of Matera: St. John of Matera and S. Eustace in the medallions and "The Visitation of the Virgin" at the centre. Inside the cathedral we find several frescoes and paintings by Anselm Palmieri, Domitius Persius, Carlo Rosa and Antonio Conversi, representing life and stories of Saints painting between 1500 and 1650. Of great importance is the high altar, coming from Montescaglioso Abbey, made of fine white marble and dominated by the "Big Cona", made by Fabrizio Santafede and purchased in Naples in 1580. It represents, in the central part, the Virgin surrounded by Saints John the Baptist, John the Evangelist, Biagio, Donato, Peter and Paul, and in the oval at the top, the Holy Trinity. Below, in the boxes, scenes from the Gospel. Behind the high altar a Wooden Choir is situated. The cathedral consists of 3 other altars, one dedicated to Saint Anna, with a beautiful painting of 1632 by Francesco Martina, one dedicated to St. Michael, and the other one dedicated to the Saint Patron of the city, used until 1776 as an altar.

Fig. 1. The Matera Cathedral (exterior)

Fig. 2. The Matera Cathedral (interior)

From the point of view of materials, the cathedral is basically formed by the Vaglia Stone (sandstone calcarenite) (for walls), glass (for windows), marble (for the floor) and wood (for the ceiling). The thermal transmittance of building components are shown in Table 1, indicating that those regarding the sandstone calcarenite are obtained from the conductivity tests reported in [7].

The latitude of Matera is 40° 39’, Longitude 16° 36’ and height above sea level is 401 m. The climate is Mediterranean, characterized by very low summer rainfall and mild winters. The average winter temperature is 4°C-

10°C , the Average summer temperature 15°C-32°C and the wind Speed 2.9 m/s. We have a high relative humidity in the summer (values around at 80 percent).

Table 1. Thermal transmittance of building components.

Structure	Material	Thickness [m]	Thermal trasmittance U [W/m² K]
Wall	*Stone of Vaglia (calcarenite sandstone)*	0.80	0.900
Window	*Glass*	0.04	2.700
Floor	*Marble*	0.16	2.814
Ceiling	*Wood*	0,17	0.916

3. The heating system

One of the reasons that led to the choice of the radiant floor heating system in the Matera Cathedral is that in the general project was already provided the replacement of the existing floor. So no architectural impact and no problem of invasiveness for the intervention to be carried out. Similar plants has already been used in numerous buildings protected by the Italian Ministry of Cultural Heritage, among which we can include the examples of some Churches of Matera: St. Francis of Paola, Purgatory and St. Augustine.

The heating system (Fig. 3) made here is represented by a radiant floor system consists of 6 stations collectors from which the various heating circuits depart; the whole system is controlled by the boiler placed in the north and outside the structure. The radiant panels are formed from tubes of 4135 m with a water content of 550 liters and placed at 10 cm between them (pitch). The operating temperature is 40 °C obtained in 2.5 hours by switching on the system, creating a floor temperature of 29 °C. The heat remains predominantly confined near the area useful for the thermal comfort (up to a height of about 3 meters) and only a small part of it is dispersed into the environment via convection. In the area outside of that occupied by the faithful, the perturbation T-RH (temperature-relative humidity) does not exceed the natural fluctuations. So artworks do not undergo sharp fluctuations in temperature and humidity, harmful to conservation.

The tuning of the system occurs in a short time because the circuits made with opposed spiral are placed only a few centimeters below the floor and the distance between the tubes (10 cm) is low, thus obtaining a high temperature uniformity and a high thermal output per square meter.

In addition, it has been developed a system of regulation, to avoid dangerous overheating for artworks, which is activated to reduce the temperature of the output water in the system to about 30-35 ℃, as soon as the floor begins to reach its operating temperature.

Fig.3. Floor heating system

4. Results of the experimental measurement of climatic parameters.

The experimental campaign consisted of the experimental measurement of temperature and relative humidity at a height of 1.5 m in 5 points, shown in the Fig.4, by a multi-channel control unit for measuring microclimate.

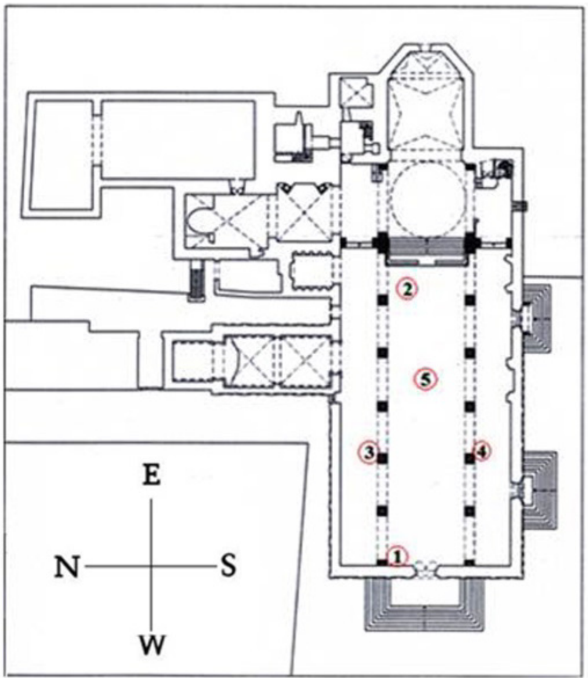

Fig.4. Points of measurement for temperature and relative humidity.

Table 2. Measures before the plant installation.

Point	Indoor TEMPERATURE (°C)	Indoor relative HUMIDITY (%)
1	12	64
2	11	59
3	11	58
4	11	58
5	11	59

Measures were made before the plant installation in period 20-30 January 2013 with a mean outdoor temperature of 9 °C and a mean outdoor relative humidity of 80% (Table 2) and after plant installation in period 13 to 23 April 2013 with a mean outdoor temperature of 14 °C and a mean outdoor relative humidity of 58% (Table 3).

Table 3. Measures made after the plant installation.

	Indoor TEMPERATURE (°C)	Indoor relative HUMIDITY (%)
WALL	17	54
FLOOR	19	55
LEFT COLUMN	17	54
RIGHT COLUMN	18	53
CENTRAL ZONE	18	54

Note that before switching on the plant, temperature is low and the relative humidity is high. The average temperature of 18°C and the relative humidity of 54% after switching on the system can be considered as acceptable values for thermal comfort. But for a more accurate assessment, we used the Fanger's method which evaluated two indices for moderate thermal environments the PMV (Predicted Mean Vote) in the range of -3 (very cold) +3 (very hot) and the PPD (Predicted Percentage of Dissatisfied) in the range 5-95% [8]. The values obtained, with T=18°C, UR=54%,Vair=1 m/s and people with sedentary activity and with high thermal resistance of clothing, are PMV=0.25 and PPD=5.3%, values very close to those ideals of PMV= 0 and PPD=5%, which correspond to thermal neutrality.

The most controversial issue in the field of the monitoring of historical buildings is which way define the "optimal" environmental conditions that should be guaranteed in environments dedicated to the conservation of works of art. The result is that in the literature there are many "tables" which advise optimal values, often very different, and there are no objective criteria to determine which are the most correct. In general we can say that the temperature range 16-22 °C and humidity range 45-55% must be complied with in order not to degrade the artwork. A detailed critical analysis on the recommended values of T (°C) and RH (%) was carried out in [9], from which we derived the table 4 where we have the data recommended by several authors. The thermo-hygrometric parameters observed (T= 18 °C, RH=54%) confirm the suitability of radiant floor heating with respect to the maintenance of artworks of the Cathedral in a good state of conservation, with only a slightly lower temperature for metals. This plant has some others advantages as the lack of production of pollutants and visual impact and the reduced cost of energy compared to other low temperature systems, such as electrical ones.

Table 4. Recommended T (°C) and UR (%) for artworks.

Classes	Recommended T (°C)		Recommended UR (%)			
	(t)sup, max	*(t)inf, min*	*(UR)sup, max*	*(UR)sup, med*	*(UR)inf, min*	*(UR)inf, med*
Wood	25	15	65	60	35	46
Painted Wood and sculpture	24	18	65	59	35	45
Books and manuscripts	24	12,8	65	58	0	44
Metals and alloys: brass, silver, pewter, lead, copper	25	20	65	45	0	17
Gold	23,5	21	55	51	0	19
Mural paintings	25	6	65	49	45	49
Canvas paintings	24	0	65	59	35	46
Fabrics, carpets and upholstery	25	2	65	58	35	44
Stable Glass and windows	23,3	18	60	53	0	34

5. Conclusions

The experimental measurements carried out show that the floor radiant heating system meets the need to ensure thermal comfort for people who attend the church and the optimal preservation of artistic heritage from the point of view of thermo hygrometric. It is also considered essential to highlight that this type of system at low temperature allows high energy savings as it enables the use of combustion systems with high-efficiency (condensing boilers) and/or renewable energy installations (heat pumps, solar thermal collectors).

References

[1] Varas-Muriel MJ, Martínez-Garrido MI, Fort R Monitoring the thermal–hygrometric conditions induced by traditional heating systems in a historic Spanish church (12th–16th C). Energy Buildings 2014; 75:119.

[2] Spolnik Z, Worobiec A, Samek L, Bencs L, Belikov K, Van Grieken R. Influence of different types of heating systems on particulate air pollutant deposition: The case of churches situated in a cold climate. J Cult Heritage 2007; 8(1): 7-12.

[3] Bencs L, Spolnik Z, Limpens-Neilen D, Schellen HL, Jütte BAHG, 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 Heritage 2007; 8(3): 264-271.

[4] Camuffo D, Pagan E, Rissanen S, Bratasz L, Kozłowski R, Camuffo M, Della Valle A. An advanced church heating system favourable to artworks: A contribution to European standardisation. J Cult Heritage 2010; 11(2): 205-219.

[5] Samek L, De Maeyer-Worobiec A, Spolnik Z, Bencs L, Kontozova V, Bratasz L, Kozłowski R, Van Grieken R. The impact of electric overhead radiant heating on the indoor environment of historic churches. J Cult Heritage 2007; 8(4): 361-369.

[6] Rota L. Matera: storia di una città. Matera: Giannatelli; 2011.

[7] Cardinale N, Rospi G, Stefanizzi P, Augenti V. Thermal properties of the vernacular buildings envelopes: the case of the "Sassi di Matera" and "Trulli di Alberobello. Int J Energy Env 2011; 2 (4): 605-614.

[8] Fanger PO. Thermal Comfort. Copenhagen: Danish Technical Press; 1970.
[9] D’Agostino V. Condizioni microclimatiche e di qualità ambientali negli ambienti museali. Naples: PhD.Thesis, Università degli Studi Federico II; 2005.