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Reuse of an ancient church: thermal aspect for integrated solutions

Giovanni Semprini[a,*], Claudio Galli[b], Silvia Farina[c]

[a]*Department of Industrial Engineering - University of Bologna, Viale Risorgimento 2, Bologna 40136, Italy*
[b]*Department of Architecture - University of Bologna, Viale Risorgimento 2, Bologna 40136, Italy*
[c]*Free-lance Professional, Via L.C.Farini, Cesena 47522, Italy*

Abstract

The definition of intervention strategies for the restoration and the functional actualization of historic and high artistic quality artifacts, postulates a systemic approach for the different variables that contribute to the definition of the project. This paper presents an emblematic case study of an historic building, the church of St. Francis in San Giovanni in Persiceto near Bologna, one of the most representative of the architectural construction of Bolognese Baroque, built by Alfonso Torreggiani. The expected new functions as exhibition hall and/or concert activities, requires a search for integrated strategies to ensure indoor comfort requirements (thermo-hygrometric, acoustics) and to define HVAC plant equipment for the reduction of energy consumption without affecting the historic values and artistic perception of the building.
Therefore, the analysis of the church in the survey phase, besides the usual historical and architectural investigations, should investigate the potential issues and the critical aspects of structures, like the multilayered floor and refined decorations that lines the walls of the nave. Understanding the intimate rationality of the building (presence of any shafts, steps etc .) is a prerequisite for the inclusion of plant components without altering the visual perception and to optimize the acoustic and the climatization plant systems.
Although the use of renewable energy are required today for all new plant systems, in this case it was decided to exclude invasive elements that could have altered the image of the entire monumental complex of which the church belongs. The proposed HVAC plant, after an analysis of dynamic thermal behaviour of the building, is an air-conditioning system coupled to radiant heating system to ensure, in a climate context with high humidity levels, the optimal temperature and humidity not only for comfort conditions but also for preservation of the building itself and of artistic works.

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* Corresponding author. Tel.: +39-051-2093286; fax: +39-051-2093296.
E-mail address: giovanni.semprini@unibo.it

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1. Introduction

The need to protect the urban environment and to restore its historical heritage to the collective use, requires that individual cultural goods have a highly compatible feature. This need is already sanctioned with the concept of 'integrated conservation' in the Amsterdam Declaration [1] in which the monument is designed as an integrated element in its urban context, assigning a function so as to ensure its use.

The "function" is not the main objective, but simply the means of achieving the goal of conservation according to the criteria of good restoration, conceived as an act of culture as well as technical competence. The reuse, then, allows the artifact to maintain historical memory and to perform those maintenance actions which are the true guarantors of its preservation. All works related to functional recovery must also be designed according to good restoration guidelines; therefore, consolidation, regulatory compliance, environmental comfort, energy saving, plant installations, acoustic quality, should not be dealt as a separate variables, but as members of a one system closely integrated.

The restoration project must be developed by pursuing the prudential criteria of the discipline: minimal intervention, distinctness and expressive authenticity, reversibility, without inserting improper and impacting installations, but at the same time combining historical sensitivity with technical skills enabling targeted solutions for each individual case [2].

The design process, shared by different designers, must provide a depth knowledge of goods through the extension of the classic investigation of the restoration to new themes in order to identify the values, limits of intervention and transformation. In particular the inclusion of new technological systems requires more investigation aimed at determining the parts of the building, less connoted form historical and architectural point of view, that are more adapted for new plant components. Different methodological approach can be used to define action strategies, all based on multidisciplinary analysis. A general deductive-experimental approach based on different cases studies can be used: from a critical reading of spaces and of its characteristic elements (decorative elements, non-replaceable floors, pipes, chimneys etc.), a "reversibility matrix" is defined [3] in order to identify the degrees of freedom and the different levels of compatibility with the introduction of additional measures for the improvement comfort and the energy performance.

The design of all plant systems aimed at controlling the indoor environmental quality (thermal, acoustics, lighting) requires in general, and in particular in this specific case, a peculiar caution and accuracy, due to the complexity of the functions and intended uses, avoiding forcing on the nature of the historical artifact, but at the same time ensuring all the necessary performances.

In particular the system design approach for the restoration and reutilization of a historical and monumental building requires special caution and accuracy, due to the complexity of the functions and of the uses required, avoiding forcing the nature of architecture but, at the same time, combining the architectural language with that of modern plants, through the implementation of an integrated project.

2. The case study

The case study is the church of St. Francis in San Giovanni in Persiceto, placed inside a convent complex and founded in the thirteenth century by the Franciscan order; over the centuries it has undergone transformations such as the fifteenth-century expansion, damage during wartimes and decay due to improper use after Napoleonic disposals. Although the planimetric structure is still that of 15th century with a single nave, the building was radically changed in 18th century, according to the project of the famous architect Alfonso Torreggiani, where the walls were raised to emphasize the height in relation to the planimetric length and a new system of vaulted roofing was creates. The new building developed in the Baroque style, according to a widespread typology in the Bologna area, is enriched with elegant decorations consisting of stucco and paintings on the lateral walls of the church, whose the entablature evolves like a decorated ribbon. The terminal part of the church maintained the existing rectangular apse, while in the project should be circular.

The monumental church, outside, appears sober for the lack of decorative elements, with the exception of a frame located under the roof (Fig. 1). The single-spired façade has a rectangular central window, very simple, as well as the underlying portal, since the building was originally to enjoy great brightness, while today almost all the windows have been blocked. The overall length is about 44 m, with an internal height between 18 m and 21 m at the dome, and a total volume of about 10.400 m^3.

The preliminary survey has provided important information on future plant system choices. The flooring is composed of layers of different ages so, for his historical and archaeological interest, a floor heating system cannot be done. Also many decorations and frescoes are present on the walls, requiring a temperature and humidity control. The raised portico with its rooms adjacent to the nave church provides potential spaces for plant and equipment installation, also the altars on the two sides give opportunity for the insertion of ventilation channels.

The reuse of this church is addressed to an auditorium, concert hall and/or exhibition hall. Among the different destinations, the following considerations will be referred to the more onerous project scenario, namely that of an auditorium, designed to accommodate up to 140 people.

Fig. 1. San Francesco Church in San Giovanni in Persiceto.

3. Energy analysis

3.1. Modeling criteria

The energy model of the church has been created with a dynamic simulation software (Design Builder+Energy Plus). Due to great internal volume of the church, it has been divided into 15 thermal zones (each of these at uniform temperature) as a compromise between a good reliability of the model (for taking in account thermal gradient and internal airflows) and lower computational times. The subdivision of the volume has been realized by inserting vertical virtual partitions (enabling radiative energy exchanges between sub-zones) and horizontal partition (Fig. 2): then holes are generated on both kind of partitions covering all the surfaces extension, enabling the calculation of air flows between sub-zones as a result of the internal temperature gradients and infiltrations from external doors and windows. The Airflow Network model used by Energy Plus, is based on empirical power-law relationship between the air flow and the pressure difference across opening, using a discharge coefficient according to IEA Annex 20 [4]. External airflows are also calculated considering climatic data of the nearby city of Bologna.

All thermo-physical characteristics and parameters of building components have been defined, based on historical documents and some in situ survey. External walls are brick made with an average thickness of 60 cm, roof is a wooden plank and brick tales, while the base floor present different layers, generally made of brick elements and stone.

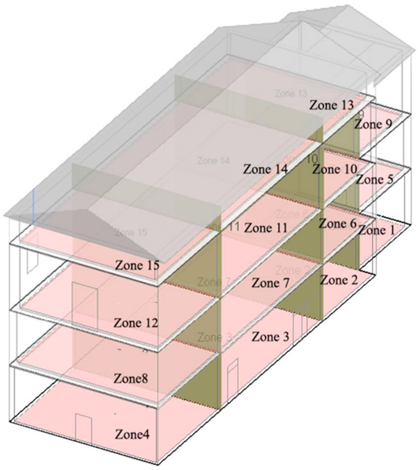

Fig. 2. Schematic representation of virtual partitions into 15 thermal zones of the energy calculation model.

3.2. Calibration of the energy model

The first step was the calibration of the thermal model of the building. It was decided to compare the calculated values of internal temperature and humidity with in situ measurements.

The survey was made in September 2016 during two days with big night-day thermal change (Tmin-max= 21-29 °C and URmin-max=45-75%). Five temperature/humidity sensors have been placed inside the nave church of which three placed at different height: 2, 5 and 8 m respectively, in order to directly measure the internal vertical gradient of temperature. No internal load was present during measurements.

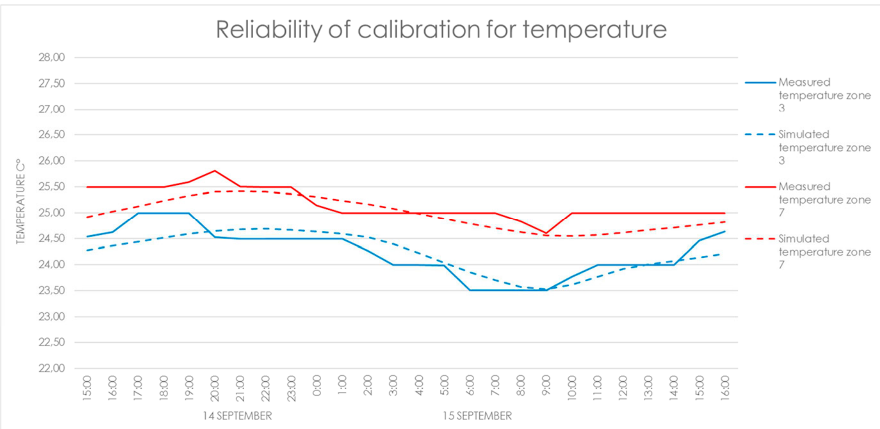

Fig. 3. Comparison between measured and simulated values respectively of temperature and relative humidity.

After making the climatic file with external measured data, the model was calibrated adjusting windows/door infiltration (the main variable that could affect local variation of temperature) since the difference between simulated and measured temperature does not exceed half a degree, as the accuracy of the sensors used. For internal humidity differences exceeding 5% has been accepted, since the rising moisture present inside the walls affects the internal humidity, while the software does not consider the presence of water inside the wall.

In Fig. 3 a comparison between the measured values (solid lines) and simulated ones (dashed lines) are shown. In a same plan position, respectively at height of 2 and 8 m, a temperature difference of about 1°C is present, both in measured values and simulated ones

3.3. Results in actual situation

The analysis of internal microclimatic conditions in the actual situation, without any HVAC plant, was carried out at different periods of the year: winter, spring and summer. In Fig. 4 a comparison between the coldest winter week and the warmest summer one is shown; spring results present similar trend to those of summer, but with less accentuated temperatures.

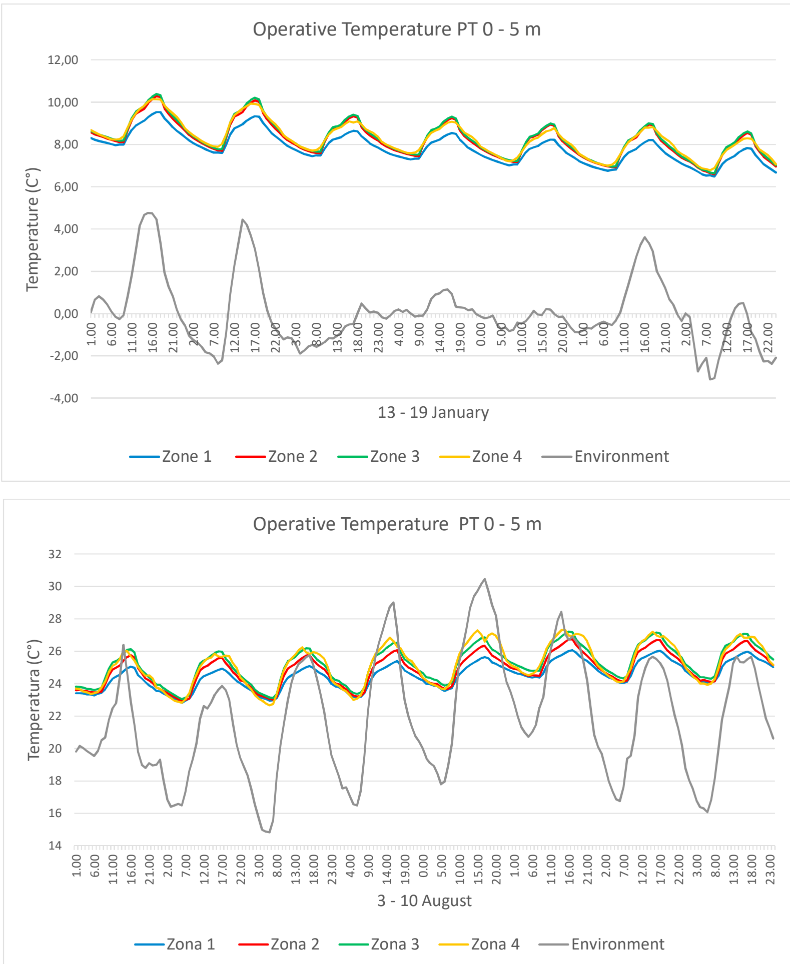

Fig. 4. Actual situation: comparison of simulated internal operating temperatures during the coldest winter week (above) and the warmest summer week (under).

The internal operating temperature in the winter period is at 7-8°C, very far from the required 20°C for thermal comfort, underlining the need to install an heating system, while in summer period the operating temperature is optimal, about 24 -26°C.

The relative humidity in winter conditions is high in relation to the very low internal temperature, but it is high in the summer too, highlighting the need for an air conditioning system for humidity control to ensure not only the occupant comfort during temporary exhibitions or concert, but also for preservation of decorations and frescoes.

4. Design choices for the HVAC system

In case of large volumes with considerable heights, traditional air systems are not effective, in winter period, as the warm air tends to rise upwards, leaving the occupied zone cold, and the floor frosty; so radiant heating solutions are preferred, because they act directly on people and surfaces. These solutions may provide the inclusion of radiant floor systems, (which are not applicable in this case study, because of the historical and archaeological interest of different layers which make up the flooring), or the installation of radiant devices on wall or ceiling.

An effective solution is to use gas emitters at high temperature [5] placed above the cornice, at height of about 11 m, on both sides of the church, provided with a movable bracket, assuming two different configurations: a retracted one, not visible to visitors, in the off condition; a second configuration, when light up, stretch out over the cornice.

Near the stage, where the cornice is not present, the positioning of those devices could have a strong visual impact, so, in place of the gas-emitting ones, electrical radiant panels could be installed, hung to the same reticular structure of the acoustic reflectors (Fig. 5). This electrical system provide lower thermal power and lower installation height.

To improve the acoustics conditions, acoustic reflectors were assumed corresponding to area below the dome, and they have the function to spread and strengthen the sound coming from the sound source for selectively localized points depending on the position in which they will be installed.

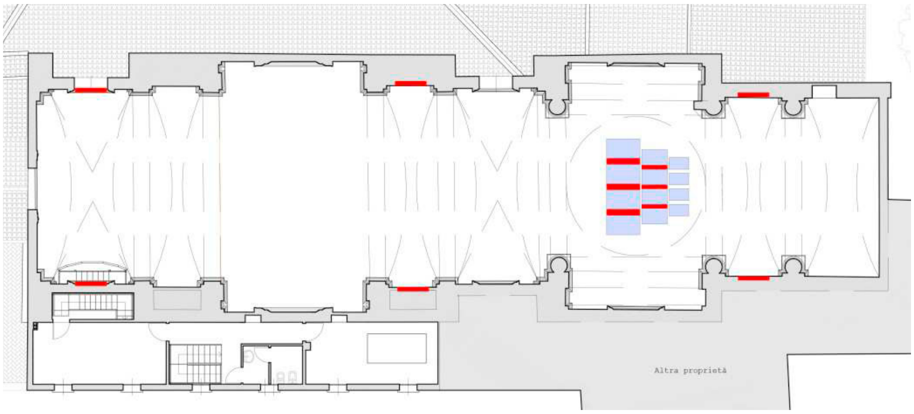

Fig. 5. Position of radiating emitters (red) on the cornice along lateral sides of the former church and radiant stripes integrated with acoustic reflectors (blue) at the dome.

The need to control the relative humidity, especially during exhibitions, and to ensure an adequate air change in the presence of a large number of occupants, led to the design of a mechanical ventilation system. An Air Handling Unit is then planned, located in a technical room on the second floor of the offices built on the eastern side of the Church, above the colonnade. Air ducts can be inserted inside vertical and empty spaces, near the recesses, avoiding further destructive actions on the walls and minimizing the visual impact. To ensure adequate microclimatic conditions in the apse, a second AHU has been placed outside, in the North-west side, above facilities, visible only from the courtyard behind the convent, so it can be inserted without creating any aesthetic and architectural damage to the complex, or altering its perception.

The air extraction is located on the eastern side at the floor level, in correspondence of inlet vents, so that with air recirculation or with an heat exchanger, a reduction of energy consumption is possible. Similar solution for extraction on Northwest side.

Air vents should be placed on the external edge of the recess, in order to ensure a correct launch. The lining wall in plasterboard, to cover air ducts within the recesses, is moved back as possible so as to preserve the perception of depth and shading of the recess (Figg. 6-7).

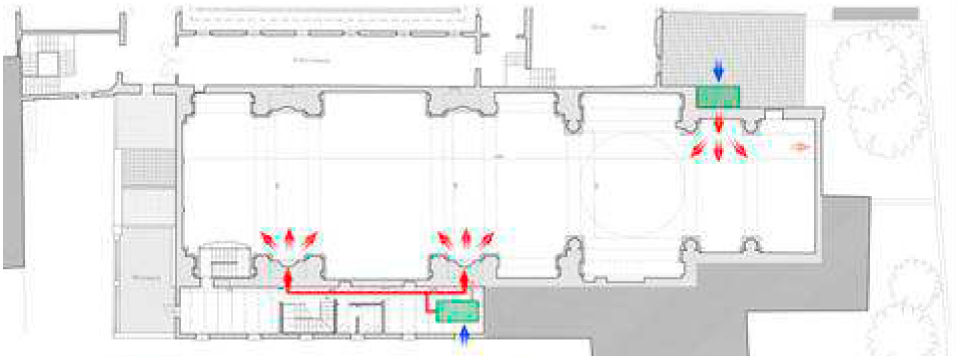

Fig. 6. Schematic representation of the air treatment system using two AHUs (green).

Fig. 7. Design view of the atrium. On the right side, multidirectional nozzles are visible, installed in the recess with a plasterboard wall to hide the presence of the air channel.

5. Energy analysis with proposed HVAC system

The proposed solutions has been modelled and simulated according to the limitations and assumptions of the software, among which the inability to manage the position of terminals within the thermal zone. At the computational level the effect on the treated volume is a uniform temperature, while in real case, the height and launch of terminals is of great importance and needs to be studied by CFD models.

In order to analyze only comfort aspects and the internal temperature distribution at floor level, the radiant devices are modelled as simple electric radiators with a specific radiant power. After a preliminary analysis of view factors, the incident radiant energy fraction from radiating devices to occupants (considering a full occupation) is assumed to be 60% while the remainder is considered equally distributed on all surfaces of the considered sub-zone.

In Fig. 8 results of energy simulations are shown. We can see how internal microclimatic conditions have changed in the same winter week compared to actual situation.

The operative temperatures calculated in the coldest winter week vary between 20 and 22° C during the opening hours, complying with regulatory values even on the coldest days. The floor temperature varies between zones, in particular it is higher at the stage (zone 2) as a result of the intense lighting, and lower in the atrium area (zone 4) due to greater thermal dispersion of the floor; but uniformly reaches acceptable values between 20 and 25 °C during daytime period.

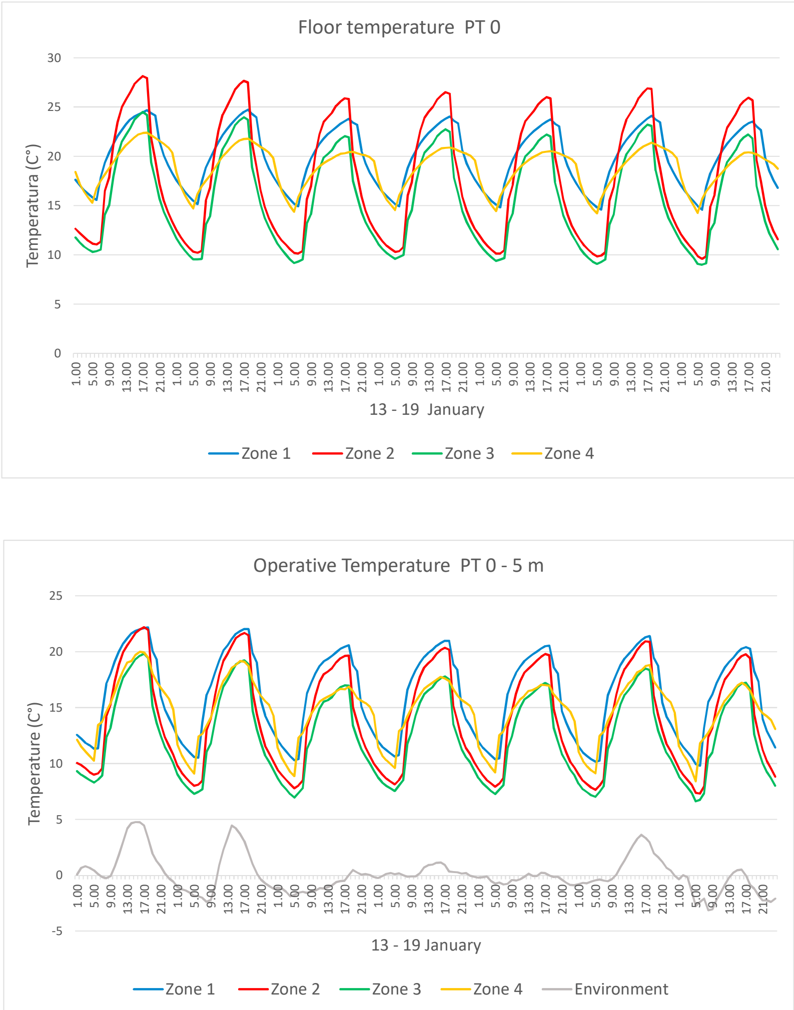

Fig. 8. Operative temperature and floor temperature for all the thermal zones of the ground floor in coldest winter week condition. Simulations considering electric radiators and occupancy for auditorium.

6. Conclusion

The proposed HVAC plant solution allows a good microclimatic control, well-being of the visitors is achieved without detriment of architectural and artistic perception of space and its decorations, nor disregarding the principles of restoration of minimum intervention, reversibility and distinctness.

Simulation results are presented only for a typical winter week condition, being the most critical one, instead of longer periods because occasional performances for the former church are planned. In winter conditions, the air treatment system and the heating system act combined, to ensure the conditions of comfort and conservation required by the legislation, while, in other periods, the air system works alone to humidify or dehumidify depending on the need, both for the well-being of visitors and to preserve the frescoes found and any exhibit.

Acknowledgements

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