Energy in cultural heritage: the case study of Monasterio de Santa Maria de Monfero in Galicia

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ENERGY IN CULTURAL HERITAGE: THE CASE STUDY OF MONASTERIO DE SANTA MARIA DE MONFERO IN GALICIA

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ABSTRACT

Facing a project aimed at the energy refurbishment in historical buildings means – first of all – to declare which are, for the designer, the priorities to respect. Every intervention on cultural heritage, actually, especially when the focus is pointed to the goal of improving energy and sustainability related aspects, assumes a strong cultural relevance.
The case study of the Monastery of *Santa Maria de Monfero* in Galicia, Spain, is an interesting example to explore the range between a general “adaptive reuse” project and the “energy refurbishment” good practice according to the conservation guidelines for historical buildings. The research is targeted at this monumental complex, which has been in state of abandonment for more than two hundred years, with a large part that is now in ruin.
The project that has been used for the research analysis is the result of the first prize in an international ideas competition aimed at giving a new cultural and touristic vocation to the monastery. The competition was won by the Spanish architects Patricia Sabin Diaz and Enrique M. Blanco, co-authors of the paper.
A focus of the study here presented was to investigate the actual performance of different building envelope retrofit solutions, in terms of thermohygrometric compatibility between existent wall and new internal insulation layers, thermal comfort provided and energy demand reduction. Results confirmed the importance of evaluating the proper retrofit strategy by coupling heat and moisture simulations and pointed out that guidelines, which can be applied on a "case by case" basis, are needed, since the retrofit of historical buildings represents an important part of conservation and protection actions and not a mere intervention aimed at reducing the energy consumption.

1. INTRODUCTION

Energy refurbishment in historical buildings implies for a designer a clear frame of the priorities he/she intends to follow. Every intervention on cultural heritage, especially when the focus is energy and sustainability related aspects holds at the same time a strong cultural relevance.
It’s well known, indeed, that each project and, consequently, every restoration work is to be considered as the last “transformation” of the building itself. So, if also a project inspired by the principles of conservation is something dispatched to modify the tangible form – and very often also the intangible one – how can we reconcile the double outcome of preservation and energy refurbishment? In accordance with the basic principles of the conservation theories the purpose must

be to preserve and not to compromise the historical and aesthetic value of the building, in order to ensure that it pass on to the future generations.
As far as the energy aspects are concerned historical buildings constitute a large proportion of the existing building stock of most European cities. In Europe, about 38% of existing buildings was built before 1960, the 45% was built from 1961 to 1990 and only the 17% from 1991 to 2010 [1]. This building stock represents an important cultural and material resource constituting a "public goods" [2] and the local historical memory [3].
Furthermore, since existing buildings have a huge potential for energy savings, their retrofitting can play a key role in addressing the requirements of the reduction of 40% of the greenhouse gas emissions until 2030 [4]. Several studies show that the energy saving potential in existing building is higher than 60% [5]. For this reasons energy retrofitting of the building envelope was identified as the most efficient solution [4], as it can function as a dual tool that can improve the energy efficiency and the conservation of an existing building.
The benefits of the preservation of this type of buildings are many, first of all promoting respect for the future generations and promoting the culture and the history of a city and secondly acting as an incentive for heritage tourism and related economy.
One of the possible way to provide the preservation of an ancient building is to adapt the historical to the modern necessity, through an "adaptive reuse". The process of retrofitting could brought the historical building back to life, but is not easy and requires a specific know-how [6]. Retrofitting assumes a higher level of complexity with buildings that have historical and cultural value since it is essential that any thermal upgrading does not undermine these figures. In most cases a balance can be found between protecting the heritage value of the building and appropriate energy saving interventions able to lessen their adverse impact on the environment, to reduce operational energy costs and to improve occupant comfort, thus ensuring the long-term viability of these buildings typology [7]. In addition to this, retrofit actions can effectively counteract the onset of typical building pathologies pertaining to historical buildings.
One of the main constraint of the retrofit interventions is that the external envelope cannot be modified due to its architectural value. Internal insulation strategies are considered a more viable alternative although they can still be quite invasive: introducing new materials, replacing historical linings, disturbing internal features such as joinery and distorting the original room proportions could be appropriate only for certain buildings. A further concern with internal insulation is its physical compatibility with traditional construction. Changing the balance between heat, air and moisture in a wall can noticeably affect the building's integrity itself [8]. The application of internal insulation on the interior side of a traditional wall can result in moisture storage and in potential interstitial condensation, frost damage, timber decay and mould growth.
In this framework the aim of a retrofit project in historical buildings is thus to prioritize energy improvement and internal comfort, respecting their aesthetics and morphology.
The case study of the Monastery of *Santa Maria de Monfero* in Galicia, Spain, is an interesting example to test the range between a general "adaptive reuse" project and the good practice of "energy refurbishment" according to the conservation guidelines for historical buildings. The research is targeted at this monumental complex, which has been in state of abandonment for more than two hundred years, with a large part that is now in ruin.
The project that has been used for the research analysis is the result of the first prize in an international ideas competition aimed at providing a new cultural and touristic function to the monastery. It was won by the Spanish architects Patricia Sabin Diaz and Enrique M. Blanco, co-authors of the paper.
The focus of the study here presented is the investigation carried out on the building envelope of this historical building, aimed at assessing different internal retrofit interventions in terms of energy demand reduction, thermal comfort enhancement and hygrothermal compatibility between the existent wall and new materials used for insulation purposes. After extensive analyses on the climate, history, materials and features characterising the building, a set of simulations was performed using the tools Wufi Pro [9] and Wufi Plus [10] [11].

2. THE CASE STUDY: EL MONASTERIO DE SANTA MARIA DE MONFERO, SPAIN

The monastery of Santa María de Monfero is located in the north-west of Spain, in Galicia, Autonomous Community in the municipal district of Monfero. The building is surrounded by a natural and rural environment and is one of the point of access to the natural park “Fragas do Eume”, the European best preserved Atlantic coastal forest.

There is no certainty on the historical origin of the Monastery. Apparently the Monastery was built over the ruins of the ancient Saint Marc’s hermitage in the XII century. During the Middle Ages the Monastery was facing a crisis, which lasted until the XVI century under the government of the Catholics rulers who invested in policy of restoration and expansion of the building. The independence war, in 1820, caused another period of crisis, and because of the robberies the nuns abandoned the Monastery [12]. From this period the building is uninhabited and is currently in the state of ruins. The building consists of three cloisters and a church. The first cloister, called “claustro de las procesiones”, was built approximately in the XVI century. The ground floor present a gothic style with a porch decorated by a ribbed vault, the first floor apparently is characterized by a renaissance style ornamented with tuscan columns. The second cloister was built by stonemasons across the XVIII century and is characterized by an austere and raw design. The construction of the church began in 1620. The internal layout forms a Latin cross with one single nave, a transept covered by a dome and the presbytery. The church is the only part of the building that is currently available, the other parts are impracticable: the wall are covered of plants, and the majority of the roofs are missing. The last cloister was built above the ancient renaissance cloister in the early years of XIX century and it was never finished because of the independence war.

On July 2004 the “Consellería de Cultura, Comunicación Social e Turismo” announced the contest of ideas for the rehabilitation of the monastery in hotel-spa. Enrique Blanco and Patricia Sabín Diaz were the winner of the first prize. Among others, competitors were Labics from Rome, Francisco Mangado from Navarra or Estudio Cano Lasso from Madrid [13].   The main ideas of the designers was to maintain the original aesthetics of the Monastery, without altering the perception and feeling that the building provided to the visitors. The first actions were cleaning and securing the unstable parts of the building. The project provide minimum interventions respecting as much as possible the existing masonry: new holes for the windows and doors were open only where essential, covering were provided where missing.

The aims of the project was to making the most of this heritage, exploiting its surroundings and using it as a starting point for the development of quality and sustainable tourism [14].

Monfero is situated in the north-west of Spain, has an oceanic climate characterized by frequent rains and strong winds. This type of climate are characterized by a slight thermal excursion and rainfalls are frequent at any time of the year. Monfero have an highest exposure to driving rain, the annual estimate value of rain fall is 1118.9 mm and the number of day with a driving rain are 131. This means that the driving rain is of great importance for the hygrothermal performance and cause of high damage risk for the stones constituting the construction materials in this city.

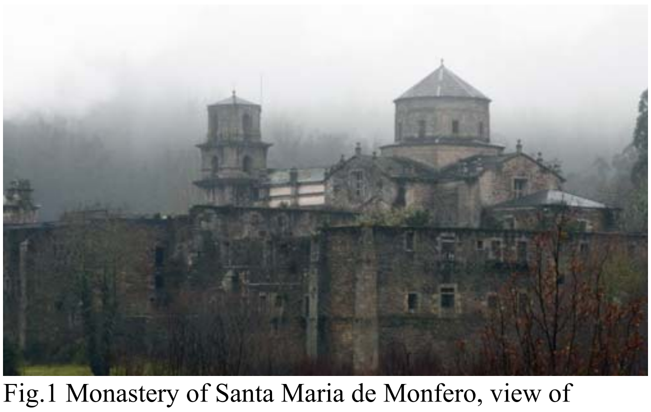

Fig.1 Monastery of Santa Maria de Monfero, view of the complex

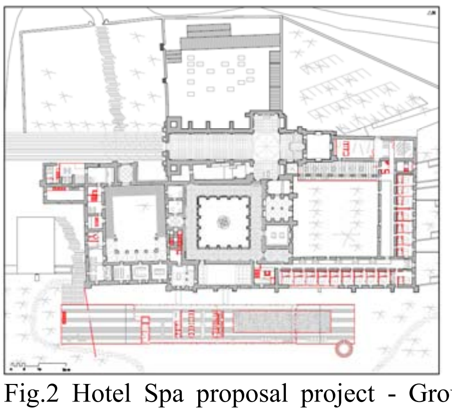

Fig.2 Hotel Spa proposal project - Ground Floor plan

3. METHODOLOGY

The main focus of the study was to investigate the impact of new materials used for insulation purposes on the hygrothermal behaviour of the existing envelope, contemporarily assessing the effect on energy demand and thermal comfort.

Two different internal wall retrofit solutions were compared: thermal insulating plasters and counter-wall insulation. The former was used in this context since thermal insulating plasters represent an attractive solution, showing high versatility and higher thermohygrometric performance as far as thermal bridge reduction and moisture balance are concerned [15]. The latter was investigated since the counter walls represent the current practice during the restoration of old buildings; furthermore the elements which compose the counter-walls are often easily removable.

It is moreover necessary to consider that due to the not coplanar surface of the historic wall, the use of a levelling layer of plaster is needed before insert any other insulation layer and that, often, the existing damaged plastering layer should be replaced. An integrated vision and a holistic approach, geared towards optimisation and taking into account the various aspects that are involved, represent the best practice to develop the appropriate solution for each intervention. This vision takes into account boundary conditions, climate, dampness behaviour, interaction and compatibility between materials.

The analyses were developed at two different level: at the component level the analysis was focused on the thermal performance and on the moisture storage, while at the building level, energy demand reduction and thermal comfort aspects were considered. The results allow to compare and to identify among different solutions, the ones that show the best performance in the different period of the year and related to the different aspects.

Each retrofit scenario was modelled using a Heat and Moisture Transfer tools (HMT) that allow estimating the hygrothermal behaviour of the retrofitted walls and the effects on the indoor environment:

- At component scale six different solutions were analysed using WUFI®pro software;
- At building scale, heating and cooling energy needs and summer comfort conditions were investigated by using WUFI®plus software.

3.1. Analysis at component level

The reference wall is a typical external masonry wall. The perimeter walls of the Monastery of Santa Maria de Monfero are irregular and with an average thickness of 90cm. Nevertheless, it was chosen to carry out studies on the most critical points of the fabric composed by only 31 cm of granite. In order to provide an interior insulation intervention, two different types of interior insulation systems were evaluated: thermal plasters (*P*) and counter wall systems (*C*). All configurations (summarised in table 1) were designed with a thickness of 6 cm, with the aim of comparing solutions that can be applied with reduced thicknesses (indoor space-saving constraints).

- For the thermal plasters (*P*), in this study were analysed formulations presenting different lightweight aggregates to enhance the thermal properties: Expanded Polystyrene (EPS), expanded perlite, granulated cork from bottle cup and aerogel granulates;
- For the counter wall systems (*C*), mineral wool and gypsum board were considered being widely used as interior insulation technique and the effect of the application of a vapour barrier was also analysed. In addition a capillary-active, polyurethane PUR rigid foam panel was investigated.

The analysis carried out with WUFI®pro, evaluated the moisture content in each layer and the thermal conductivity variation. The wind-driven rain on the hygrothermal behaviour of the wall components was considered according to ASHRAE 160P standard (sheltered wall below a steep-sloped roof).

Fig.3a shows the moisture content mc (kg/m^3) of the insulating layers: mineral wool and PUR (counter wall) and thermal plasters. Simulations were performed for 3 years, but the results refer to the last year of simulations since it is not influenced by the initial conditions. The box-plots summarise all the hourly moisture content results, and the maximum and minimum value are indicated for all the design alternatives. The bottom and top of the box represent the first and the third quartile, and the band inside the box is the median of the data (second quartile).

code	layers
S (bare wall)	G. Stone (31cm)
C1 (counter wall)	G. Stone (31cm); Mineral Wool (5cm); Interior Gypsum Board (1cm)
$C1_B$ (counter wall)	G. Stone (31cm); Mineral Wool (5cm); PE-Membrane; Interior Gypsum Board (1cm)
C2 (counter wall)	G. Stone (31cm); Mortars; Capillary-active, PUR panel (5cm); finishing plaster (1 cm)
P1 (Plaster)	G. Stone (31cm); Perlite based plaster (5.7cm); Mineral Finishing Coat (0.3 cm)
P2 (Plaster)	G. Stone (31cm); Cork based plaster (5.7cm); Mineral Finishing Coat (0.3 cm)
P3 (Plaster)	G. Stone (31cm); Aerogel based plaster (5.7cm); Mineral Finishing Coat (0.3 cm)

Table 1: Analysed wall configurations

The results shows higher water content on the thermal plaster configuration due to the higher capability of plasters to absorb and store moisture if compared to mineral wool and PUR. The results show *mc* values of plaster (P1, P2, P3) from 5 to 10 times higher if compared to the counter wall configuration. The data concerning the thermo-hygrometric behaviour of the various solutions allow to make further discussion on the use of vapour barriers. The result reveals that in C1 the addition of a vapour barrier ($C1_b$) between the gypsum board and the mineral wool layer determine an increase of the moisture content. Although the current practice suggests to add the vapour barrier on the warm side of the insulation, in this particular case (unprotected external walls exposed to driving rain) the presence of water vapour does not allow the re-evaporation of moisture on the interior side resulting in a non-negligible moisture storage inside the insulation layer. For this specific case the result is not effective and should be avoided, the values of *mc* for C1 reach a maximum of about 4 kg/m^3 compared to 8 kg/m^3 with a vapour barrier ($C1_b$).

The variation of the thermal transmittance (first-third quartile and median value) during the winter period are illustrated in Fig.3b. Results demonstrate how much the environmental conditions affect the performance of the insulation layer, even if it is placed on the inner side. Indeed an important factor that affects the thermal performance is represented by the water content in the insulating layer.

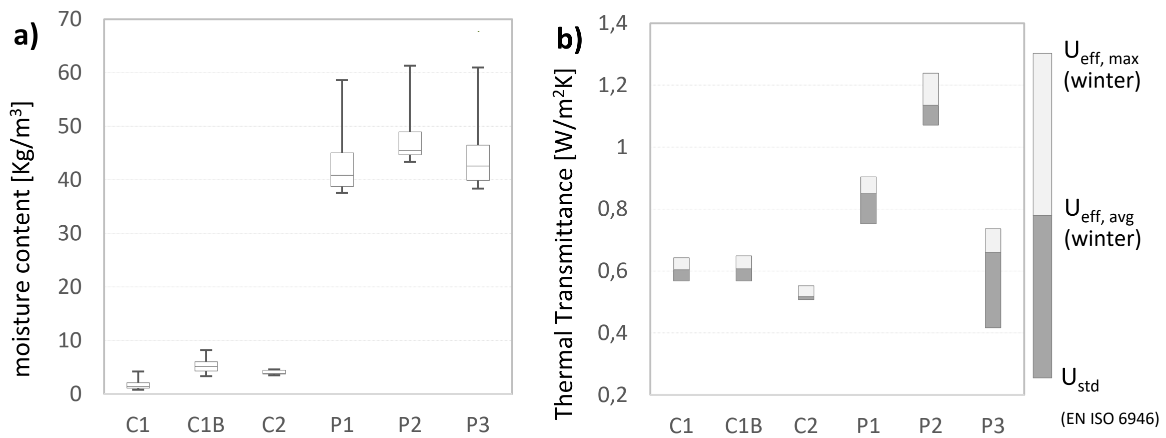

Fig.3 a) Box-plot analysis: moisture content in the insulation layer *mc* [kg/m^3],
b) Wall thermal transmittance *U* [W/m^{2}K] calculated for winter period (October – April)

A clear difference between the value of U_{std} (thermal transmittance) calculated according to EN ISO 6946:2007 (considering dry materials) and the U_{eff} calculated taking into account the moisture dependency of the thermal conductivity was observed, in particular:

- A higher difference between U_{std} and $U_{eff,avg}$ was observed in plasters due to the presence of high moisture content;
- All the retrofit configurations show a reduction of the U_{std} from the initial value of the bare wall (~2.8 W/m^{2}K), between 62% (P2) and 83% (P3);

- Counter wall configurations presents lower $U_{eff,avg}$ (between 0.52 and 0.61 W/m^2K). Nevertheless, plaster P3 (aerogel based) shows slighter higher $U_{eff,avg}$ results, even though in line with the counter wall systems (0.66 W/m^2K).

As the bar graph shows, always result in $U_{eff,max}$> U_{dry}, due to the presence of moisture on the configuration. In general, it appears how this phenomenon is more impacting on thermal plaster than on the counter wall. Actually the $U_{eff,avg}$ value for the plaster configurations results almost 17% higher than U_{std}, while the $U_{eff,avg}$ value of the counter wall grow from 12% to 33%.

3.2. Analysis at building level

Following extensive hygrothermal simulations on a building component, the dynamic energy simulations were then extended to an indoor environment. The indoor environment examined was a standard hotel room, as defined in the winner project and shown in Fig. 4.

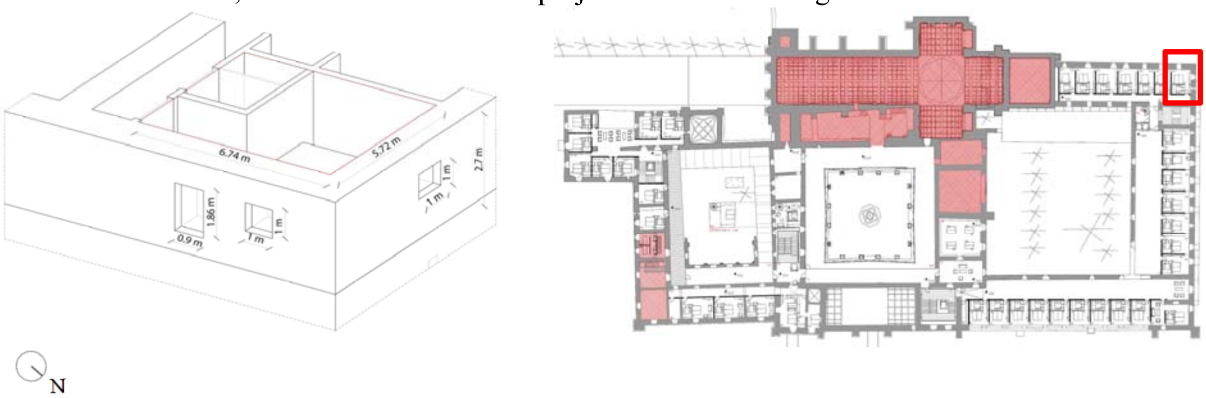

Fig. 4 Axonometric view of the room and floor plan

The study compare the different insulating solutions presented in section (2.4).
The aim of the analysis at building scale was to investigate the thermal performance of the retrofitted case study, considering:

- the indoor comfort conditions without the presence of cooling system (free running), and adopting a night ventilation;
- the heating and cooling energy need for the different solutions considering the presence of an IDEAL HVAC system that mantains the temperature at 20°C in winter and 26°C in summer.

The assessment of thermal comfort was carried out using the PMV (predicted mean vote) index, according to UNI EN ISO 7730 and following the four PMV categories of building established by UNI EN ISO 15251 (from the less to the most severe condition). The analysis in this case was done by referring to a *clo* of 0.5 (i.e. panties, T-shirt, shorts) air velocity of 0.1 m/s and metabolic activity of 58 W/m^2, corresponding to 1 met (seated, relaxed).
The summer period considered for the analyses was from the 1^{st} of June to the 30^{th} of September.
Analysing the operative temperature, the chart in fig. 5 shows that plasters solutions for most of the hours of the summer period achieve the class I and II, which correspond respectively at $0 < PMV < +0.2$ and $+0.2 < PMV < +0.5$, meaning high level and normal level of comfort expectation. The number of hours in which plaster achieves these classes is significantly lower if compared to counter-walls, since the indoor environment presents mainly negative PMV values (cold thermal sensation), but this drawback could be easily overtaken with higher clothes resistances. The other classes III and IV are reached for a limited number of hours which means that by adopting these plasters solutions during the summer period it is possible to obtain acceptable levels of indoor temperature avoiding the use of cooling systems. The counter-walls achieve the class I and II for a longer period of hours but contemporarily the number of hours with temperatures providing a PMV> 0.5 is 3 times greater than the plasters solutions.

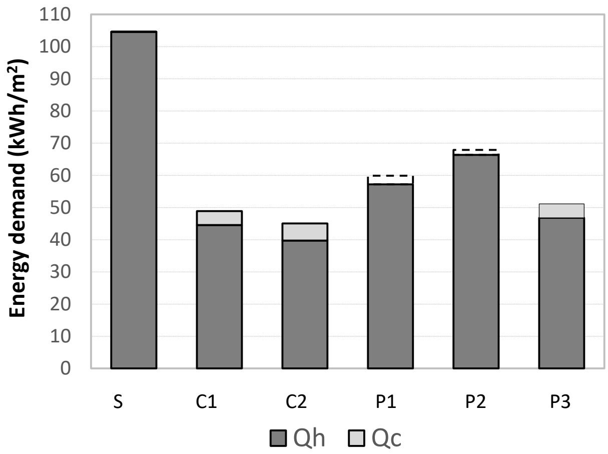

Fig. 5 Annual net energy demand for heating (Q_h) and cooling (Q_c).

For the evaluation of the right strategy to be adopted, another crucial aspect is related to the energy saving potential of the intervention in term of heating and cooling energy demand reduction. The bar chart in fig.6, shows that counter-walls have lower consumption than the thermal plaster, but is also clear that the energy consumption for cooling, using thermal plaster, is near to zero. Moreover considering that, from the comfort point of view, only few hours per year presents a PMV higher than +0.7, evidence the possibility to avoid the installation of cooling systems with some advantages in particular for historic buildings in term of space saving issues, HVAC elements integration and as far as economic aspects are concerned.

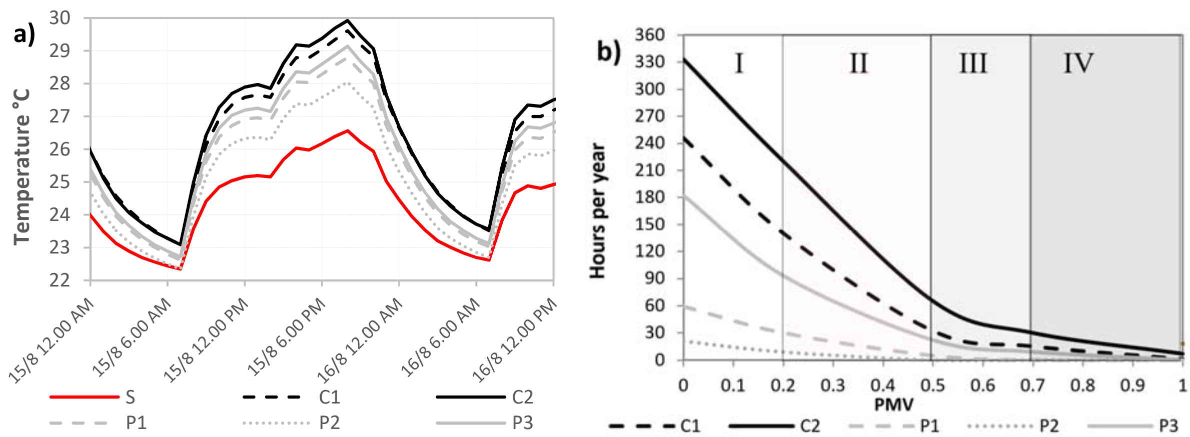

Fig. 6 a) Indoor temperature on August 15th b) Number of hours per year within a certain thermal comfort category.

4. CONCLUSIONS

This work investigates a suite of technologies and step-by-step approaches for "hard-to-treat" retrofit upgrades of historical buildings, in order to evaluate the proper solution taking into account issues related to feasibility, compatibility, hygrothermal behaviour, operational energy demand and indoor thermal comfort. The case study adopted for the analyses at component and building scale is the Monastery of *Santa Maria de Monfero* in Galicia, Spain, which is an interesting example to explore the range between a general "adaptive reuse" project and an energy retrofit good practice.

The study points out that for the selection of the proper retrofit strategy related to the building envelope, an important support could be given by performing dynamic heat and moisture transfer simulations at component level considering the hygrothermal behaviour of the wall structure and at building level evaluating the energy saving potential and the thermal comfort conditions provided.

Comparing two internal insulation intervention strategy based on thermal plasters, on one side and counter-walls on the other side, the study highlights that:

- thermal plasters always present higher level of moisture content in the winter period which implies on one hand higher thermal transmittances and thus higher heating energy demand but on the other a better regulation of the indoor air humidity;
- the counter-wall provides worst thermal comfort conditions and higher energy needs for cooling in the summer periods.

The methodology here proposed can provide a support tool in order to identify a set of guidelines, according to a "case by case" criterion, through a collaborative approach where experts in the fields of building physics and cultural heritage conservation work together since the earlier stages. Energy refurbishment interventions, even if apparently minimal, can be highly impacting on the fabric and should be accurately evaluated and seen as part of a more general conservation and protection process.

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