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Local energy efficiency interventions by the prioritization of thermal zones in an historical university building

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Abstract

Architectural constraints are a crucial aspect in energy retrofitting of historic buildings. Usual global interventions are often not allowed since preserving historical values of the building stock is mandatory. In this paper, the authors provide an alternative procedure by identifying the most profitable local interventions in order to maintain the architectural values during the restoration and energy retrofitting operations. So, thermal zones prioritization is the key element considered in this study. Its aim is to analyse which energy efficiency measures could be applied to a listed building, but at certain technological elements rather than a unique choice for the entire building envelope. Thus it will prove that you can work with individual elements of the building without compromising the protection of architectural good. The attention was placed in promoting single measures and improving the quality of the built environment. The case study is an historical building in Rome, currently used for university purposes. The analysis was carried out through a building simulation model so that to assess the building energy performance before and after the selected interventions. The chosen software is TRNSYS. This approach shows how interventions, usually not applicable at the building scale, would be beneficial if applied at local scale such as a single thermal zone or a single technological unit. The authors built a reference scenario and, for each identified thermal zone, tested the energy efficiency improvement in terms of heating demand reduction coming from the hypothesized local intervention.

Keywords: Building energy performances; costs benefits analysis; energy efficiency.

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1. Introduction

In order to reduce the environmental impact of buildings, a greater sensitivity is spreading slowly towards energy saving issues accounting for the decarbonization of building energy systems [1]. The European Directive 2002/91/EC on the energy performance drove the revision of the law in force. It has produced in Italy, at a national and a local level, a number of regulations aimed at reducing consumption and energy certification as well as a specific focus on cultural heritage [2]. Its goal is to promote the reduction and the rational use of energy, to manage the consumption of non-renewable resources and to mitigate the environmental impact of energy systems and building services [3,4]. To achieve these objectives two aspects are crucial: the building system and the plant system. The use of an efficient energy system is necessary, therefore, to maximize the natural energy inputs and to minimize internal heat loss. Then, it must be an envelope that reacts flexibly to external inputs, in order to minimize thermal losses during the winter season and to limit the overheating phenomenon during the summer. Both the effects on cultural heritage and the goods they preserve, when used as museum facility, belong to a new research line [5,6].

Energy efficiency in existing buildings has to be considered much more demanding than in new constructions. According to the research conducted by the Italian National Energy Council, Enea, most of the buildings in Italy, about 50%, were built previously to the Italian Law 373/76. That law aimed at containing the energy consumption for heating purposes in buildings. Among those constructions, only 2% satisfy the requirement to be classified as class C in the Energy Performance Certificate.

The current issue in the requalification of the existing building stock is to adapt to the demands of the new regulations, but at the same time preserving the value and essence of the architectural element. Very often, when the architectural debate is about historical buildings, those actions are in conflict with restoration principles. Indeed, other researchers focused on the change in energy supply rather than the MEP facilities [7,8]. These interventions, however, are required to reduce the costs related to the consumption and to contribute to European emission targets.

In this paper, a case study is analyzed and discussed to measure the limitations that often discourage an efficiency intervention. The case study is the Physics building of the Rome University “La Sapienza”, as shown in Figure 1, which was built in 1932 by Giuseppe Pagano. As well as many of the historical artistic value inside the university campus, the building case study was commissioned by Marcello Piacentini for the creation of the new University of Rome facility. In this case, the energy requalification interventions can meet the needs imposed by the restoration canons and the respect of the architectural artifact. This strategy within the framework of urban energy planning focused on identifying a viable and immediate solution without creating further environmental impact or fragmentations in protected areas [9,10] such as historical centers and peri-urban areas [11,12].

The long road towards implementation of new smart energy systems provides demanding issues where renewable integration threatens cultural heritage preservation [13].

The authors analyzed three thermal zones belonging to the building with a common single variable, the same intended use. Then, the results will be evaluated, following the requalification interventions allowed for this building, accounting for the achievable efficiency target. This approach shows how interventions not effective for the whole building would be useful if applied to specific parts, as well as the benefits in terms of energy improvement they will provide.

Fig. 1. Views of the case study.

2. Methods

The analysis of this historical building belonging to the University of Rome campus was conducted by means of the TRNSYS software, which allowed performing a dynamic simulation. For a thorough study a hypothesis of a subdivision of the building in thermal zones was made, taking into account the destination of use, along with the calculation of associated parameters, such as occupancy, required air exchange rate and orientation, which influence the areas in terms of energy losses and gains depending on the season.

Having carried out this first step of investigation, the energy analysis was done by the abovementioned software. TRNSYS allows, through a dynamic simulation by one-hour steps, to quantify the annual energy needs in each thermal zone. Therefore, it can be stated that the real dynamic thermal behavior of the building is strictly dependent on the fluctuations of the internal conditions defined by the appliances, occupancy and management modality. Furthermore, the study analyzed three homogeneous thermal zones for the intended use, but with different orientations.

In this way, the analysis will provide a preliminary measure of the orientation factor on the energy consumption. This is made because getting familiar with design thinking of past time is crucial to understand the possible variations on the architectural features due to orientation. Finally, a preliminary suggestion rather than usual techno-economic optimization will be given, since this latter is quite demanding in complex building [14].

A university building requires also management of outdoor spaces in terms of facilities as well as the relative comfort and wellbeing. Therefore, a specific attention should be paid to outdoor conditions [15-17]. To do so, a project like the analyzed case study must preserve the original features and could be improved by analyzing the adjacent surfaces rather than the listed building envelope [18].

The chosen thermal zones (TZs) are located on the second floor and their destination is intended for classrooms as depicted in Figure 2. Currently, the building is mostly composed by classrooms, about 80%. The details of the chosen TZs are reported in Table 1.

Table 1. Thermal zones features.

Thermal Zones	TZ1	TZ2	TZ3
Exposure	SE	NW	NE
Surface area (m^2)	128	75	58
Height (m)	3,30	3,30	3,30
Volume (m^3)	425,43	249,87	192,35
Occupants	23	14	10

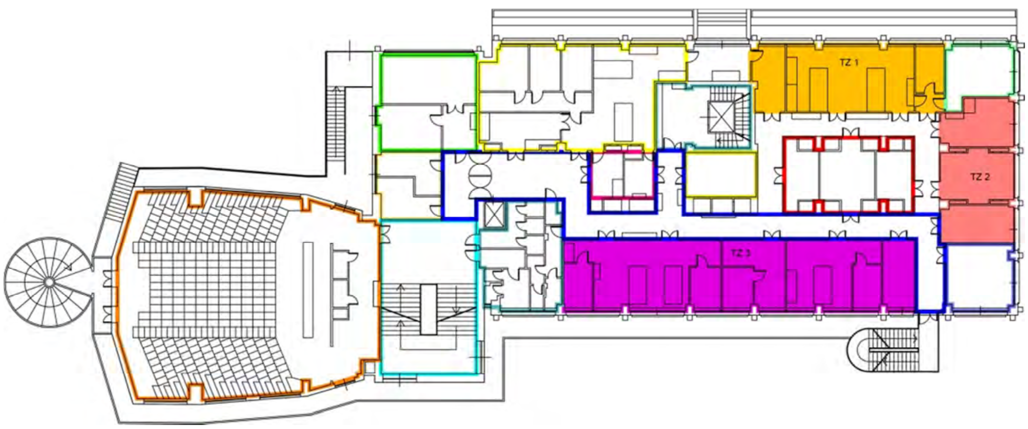

Fig. 2. Thermal zones division of the second floor.

2.1. The case study

A simulation has been performed by TRNSYS: the pre-construction phase. The geometry features of the building model are quite near the real one, since the case study belongs to the Rationalism architecture, free of any ornaments. The outer covering of the building is identical to the other adjacent ones. The plinth is made of Roman travertine slabs almost square, while all the rest is bound by yellow-orange Ceramic stone blocks. The windows are made of aluminum without thermal break frames with single glass. Then, a second simulation was launched having entered data related to the adopted interventions for this building as in Figure 3. Being a historical and listed building, the authors had to maintain unchanged the outer casing; thermal insulation is applied from the inside and windows are replaced. Once the simulations were launched, the results were analyzed in terms of thermal comfort of the human body by the following parameters: operating temperatures and air relative humidity as well as their impact on the consumption of the building, in other words the sensible heating load.

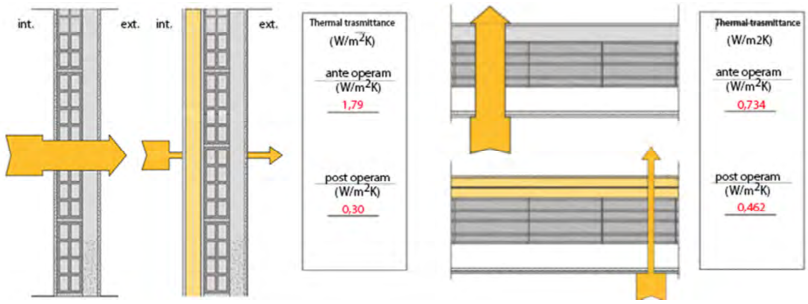

Fig. 3. (a) Wall stratigraphy before and after insulation addition; (b) Roof stratigraphy before and after insulation addition.

An intervention on the heating plant is usually suggested. A recent research line promotes the energy supply greening by means of renewable H_2 enhancement. So doing, this measure allows leaving the same heating terminals, already part of the historical interiors [19,20]. Hence, in Tables 2 and 3, the wall and roof stratigraphy with their physical properties are reported.

Table 2. Wall stratigraphy and its thermal characteristics.

Building material	Thickness [m]	L [W/mK]	R [m^2K/W]
Plaster	0,015	0,7	0,021
Polyurethane foam	0,110	0,04	2,77
Hollow brick	0,080	0,27	0,23
Hal-full block of concrete	0,12	1,01	0,119
Plaster	0,015	0,90	0,017

Table 3. Roof stratigraphy and its thermal characteristics.

Building material	Thickness [m]	L [W/mK]	R [m^2K/W]
Plasterboard	0,015	0,58	0,026
Glass fiber	0,03	0,053	0,56
Air gap	0,3	-	0,16
Concreting foundation	0,3	-	0,37
Concrete	0,05	1,16	0,026
Acoustic insulation	0,005	0,035	0,15
Mortar	0,04	1,4	0,029

3. Results

The dynamic simulation allows an hourly analysis of the building evaluated parameters for a whole year. In particular, the selected parameters, i.e. operative air temperature, relative humidity and sensible heating load, have been evaluated in three thermal zones with the same intended use and different exposition. It must be remarked that this orientation factor could be crucial in wind energy integration in the built environment, but further devices such as stators are required to improve their behavior in Mediterranean cities [21]. Considering that the new components are in contrast with restoration, the authors highlighted the needs of minimum intervention to preserve the historic building, in accordance with the Venice Charter [22]. Looking at the obtained results ante and post operam, Figure 4 shows a clear improvement of operative air temperature in all the analyzed thermal zones, reaching optimal thermal comfort ranges in ZT2, with a North-West exposition. Also relative humidity ranges improved after the interventions in each thermal zone, reaching thermal comfort ranges; in this case the best results have been obtained in the zone facing South-East. Moreover, concerning required sensible heat for each zone, in order to avoid an inaccurate analysis, the comparison has been made for energy demand per square meter of floor area (Figure 5). In this way it is possible to pinpoint the thermal zone with the best post operam results in terms of energy saving, i.e. the one exposed to NW.

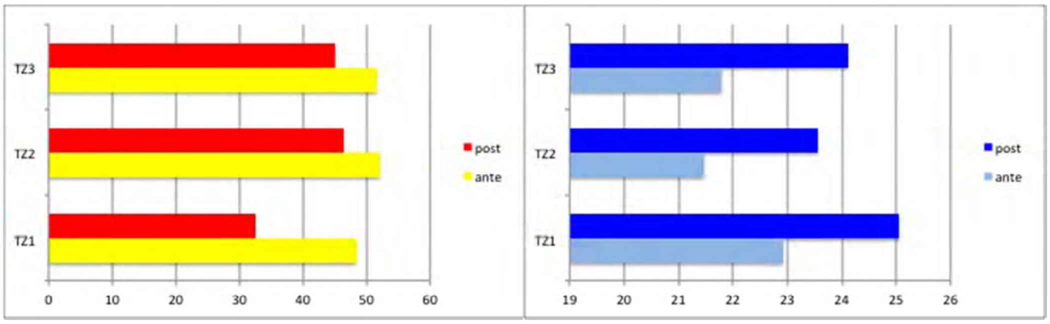

Fig. 4. (a) Relative humidity; (b) Operative air temperature for each zone (ante-post operam).

Using a simplified methodology elaborated by the Sapienza CITERA (interdepartmental research center building territory environment restoration) during an international research project on energy management of urban areas [23,24], these results obtained in a single pilot building of an university campus should be integrated with others coming from surrounding buildings of the same Sapienza Campus. Indeed, this area can be considered like an urban cell for an overall improvement of energy sustainability taking into account territorial, environmental, social and economic aspects at local scale [25-27]. Additionally, a preliminary assessment of local availabilities of renewable energy sources could be done for optimizing energy production efficiency [28,29] and its economic viability [30].

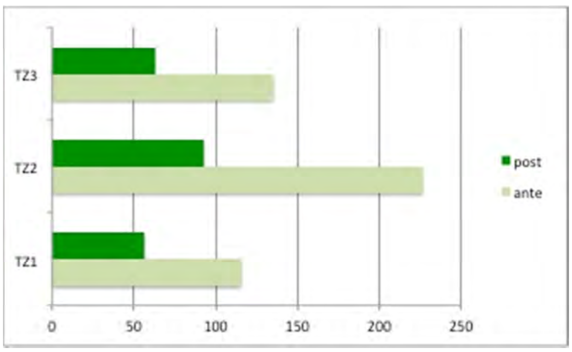

Fig. 5. Sensible heat for each zone (ante-post operam).

4. Conclusions

Given the current situation, where funds for the energy improvements of the public buildings are not addressed to listed buildings due to the absence of any constraint, accurate decisions about retrofitting them have to be taken. With this paper, the authors wanted to demonstrate, firstly, how a correct simulation-analysis of the actions is necessary by evaluating the building structural components, the same intended use, classrooms, the utilization during the day and last, but far from least, the orientation of the areas where actions are taken.

In this way, it is possible to complete the operation in the areas on which it will have the greatest impact on energy saving by avoiding wastage on other areas with less effective interventions or where the impact would be minimal, leading to a wasteful use of the financial resources .

Certainly, in this case, it is better to work on the NW exposed facade where, in term of dispersion, we obtained the best result and, instead, to leave the other two as secondary. In a larger context, everything should be related to the use of the spaces examined, overlooking under-utilized areas that probably would have less benefit.

In an economic situation where there are limited funds, it is convenient to take actions with the minimum efforts where it is possible to have the maximum effects.

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