Journal of Physics: Conference Series

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To cite this article: Fabrizio Pini *et al* 2019 *J. Phys.: Conf. Ser.* **1351** 012080

Energy Refurbishment of the General Physiology Institute at Sapienza University Campus

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Abstract. The energy requalification of the existing building heritage is one of the pillars European Union energy policy. A large part of the building heritage was built without taking into consideration the problem of energy consumption. With the aim of energy efficiency and energy savings in electrical uses, there are wide and diversified possibilities for improvement, including interventions on the building envelope and on the systems, with the introduction, where possible, of renewable energy sources. In this context, the redevelopment of historic buildings constitutes an important challenge, which involves both historical-artistic aspects and technological aspects relating to the improvement of energy efficiency and comfort. A critical analysis of every possibility is essential to preserve the balance between efficiency and architecture. The purpose of the study is the energy retrofitting of the Institute of General Physiology located within the "Sapienza" University campus. The proposed interventions include the renovation of the whole building envelope, investigated by thermographic surveys, and the installation of new heating and cooling systems. The results were analysed to identify the best intervention for a sustainable energy renovation of the historic building, taking into account the preservation of its architectural values and making it suitable for modern use.

1. Introduction

Energy consumption in the building sector represents around 40% of total energy consumption in the European Union [1] emitting particulates talking the citizens health [2]. In this context, the effects of the energy retrofitting of the Institute of General Physiology located within the "Sapienza" University campus is analysed following previous planned interventions [3,4]. Particular attention is paid to the fact that the case study is a building subject to historical-architectural protection [5]. This makes the choice of redevelopment interventions and the integration of renewable energy sources more complex facing limitations often criticalities to be overcome [6,7]. Because of its inclusion in the group of protected buildings, a design proposal must be based on minimal interventions and reversibility to preserve architectural values. For this reason, on-site investigations [8] and bibliographic researches are crucial to calibrate the forecast of energy performance during the life of the building [9,10]. Furthermore, the installation of cutting-edge technologies in the building [11], such as renewable when available in the surrounding areas [12], even if they are protected areas [13], becomes feasible after a detailed analysis of the status quo [14] to link data with real predictable performance [15].

The driver of this energy redevelopment strategy is to show that improving the energy performance of buildings is feasible without affecting architectural and landscape values, as recently demonstrated in this growing research field [16,17] able to involve detailed solutions of energy engineering such as storage [18] or modification of the fuel supply, as well as the new meaning of the restoration discipline [19]. Furthermore, comfort for occupants [20] or masterpieces are protected must be guaranteed [21].

2. Description of the building and analysis of the state of affairs

The "La Sapienza" University is located in the II District of Rome. In 1930-1931, the area between Via Regina Elena, Via del Policlinico and Via dei Peligni was assigned to the University by Mussolini to have the new campus built. Construction work began in 1933 and ended in 1935. The general urban layout of the entire university city was designed by Marcello Piacentini (Figure 1), together with the most representative building (Dean's building); in the period between 1933 and 1935 Giovanni Michelucci designed the Institute of General Physiology and Anthropology (Figure 2), located just behind the Dean's building.

Figure 1. Plan of the University City.

Figure 2. View of the Institute of General Physiology.

For the energy analysis, the collection of all the data concerning the building envelope and the systems was preliminarily carried out (Table 1). Data were got through on-site investigations, thermographic surveys and bibliographic researches, using the documents available at the historical archive, the Sapienza technical office and the university's energy service [22,23]. The foundations of the buildings of the University City were built with different technologies, depending on the different characteristics of the land, using piles or a well system. The latter is the solution used for the Institute of General Physiology. As for the building envelope, the perimeter walls consist of mixed loadbearing masonry [24]. As it can be observed in the other buildings of the University City, the perimeter walls have no thermal insulation [25]. The exterior finishes are made of travertine and plaster slabs. The floors are made of masonry, with reinforced concrete elements used together with perforated tiles with iron reinforcement embedded in the cement conglomerate; the finish is variable, mostly in linoleum or marble grit.

Referring to windows, original solutions are still there. They are made by pitch-pine, a kind of larch from United States solid and very resinous. While, the largest openings are characterized by iron structure located in the assembly hall and in the ground floor. Moreover, the smallest windows were replaced by modern PVC or aluminum-based ones [26]. All those kinds are summarized in figure 3.

Table 1. U-value of building components.

Description	U [W/m^{2}K]
Vertical building envelope	0.41÷0.83
Ground floor	1.25÷1.29
Roof	0.7÷1.51
Original windows	5.05÷5.53
Substituted windows	3.01÷ 3.12

It is important to focus attention on summer behavior of the windows because they have no high protection for solar radiation. Certainly, high solar gain factor of glasses (g = 0.82) is mitigated by the presence of external ledges. If no constraints occur, new small wind energy devices [27,28] could be installed as well building integrated PV could be adopted [29].

Figure 3. (a) Original wooden window; (b) original iron window; (c) modern PVC window; (d) modern aluminium window.

As aforementioned, a thermographic survey was carried out to identify linkage or interruptions in the facade solutions. It was also useful to check the heat transfer where the radiators are usually located, i.e. under the windows, as in figure 4. This is typical also for contemporary housing [30].

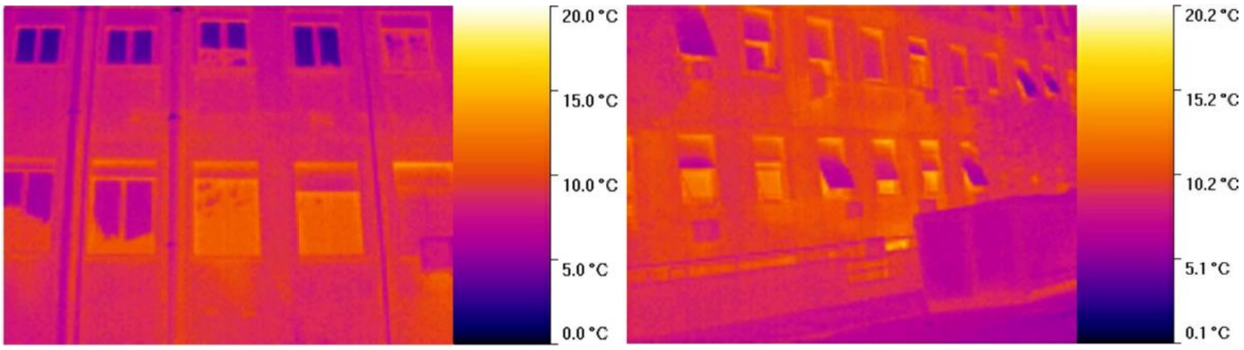

Figure 4. Thermographic pictures.

The University City is served by a district heating network, powered by the new thermal power station, located in the former Regina Elena complex; the thermal power system has a power of 15 MW and it is used for the production of superheated water at 130 °C. As planned, this is clear opportunity to integrate at district level different kind of renewables such as wind [31], biomass [32] or solar [33] without affecting the buildings but even including the surroundings in the supply [34,35]. The building is connected to the district heating network via a sub-station equipped with two plate heat exchangers each of 390 kW; the distribution is of the constant flow type; the terminals inside the rooms are radiators and fan coils and they do not have any room temperature regulators. In some rooms, direct expansion systems of the mono-split type were installed for summer cooling. In toilets, the preparation of domestic hot water is carried out by electric boilers. The lighting system includes fluorescent lamps everywhere. Based on this set of information, a building model was built using Stima10-TFM software, which implements the procedures of the UNI 7357/74 for the calculation of winter thermal loads, the Transfer Function Method (TFM) ASHRAE for the calculation of summer thermal loads and procedures of UNI/TS 11300 (UNI EN ISO 13790 national adoption) for the calculation of energy needs [36,37]. The building model was validated by comparison with the data from energy bills.

According to energy labelling, the building belongs to category E because its fossil primary energy consumption is 118.3 kWh/m^{2}y. The renewable fraction is limited to 9.5%, coming from the connection to the National Power Grid. Those quantities are described in table 2. The primary energy needed for heating goals is 29.4 kWh/m^{2}y while, the one for cooling goals is 61.9 kWh/m^{2}y. Moreover, the average seasonal efficiency of heating system is 44.1%.

Table 2. Primary energy consumptions.

		Heating	Cooling	Hot water	Lighting	Total
Renewable	[kWh/y]	0	17,332	563	46,372	64,267
Fossil	[kWh/y]	344,520	71,959	2,335	192,525	611,339
Total	[kWh/y]	344,520	89,291	2,898	238,898	675,606
Renewable fraction	%	0.0%	19.4%	19.4%	19.4%	9.5%

A comparison between the results of the above model and the actual consumption of the building was made, taking into account the approximation on the calculation of real thermal consumption due to the fact that there are no specific data for the building but only aggregated data for the entire University City (Table 3). As regards the primary energy consumption connected to the heating of the building, what results from the model is higher than the real figure, with a difference of over 78%. With regard to electricity consumption related to lighting, the forecast of the model is in line with real consumption data, obtained assuming a percentage of electrical consumption due to lighting equal to 28.3%, in accordance with what reported in the literature [38].

Table 3. Comparison between estimated consumption and actual consumption in terms of primary energy.

	Real [kWh/m^{2}y]	Estimated [kWh/m^{2}y]	Difference [%]
Heating	33,08	58,94	+78,2%
Lighting	46,61	46,24	-1,0%

3. Intervention strategies

Starting from the analysis, a series of energy redevelopment interventions were hypothesized, compatible with the architectural features of the building, aimed essentially at reducing heating energy consumption [39]. The interventions of thermal insulation for the opaque vertical walls foresee the arrangement of an insulating layer inside, to avoid changes to the aesthetic appearance of the facades; the insulating layer consists of an aerogel panel 3 cm thick. Similarly, for the insulation of the roof slab and of the floor slab, it was assumed the installation of insulating material from the inside; in this case it was assumed a 6 cm thick glass wool panel, as in Table 4.

Table 4. U-value of building components.

Description	U [W/m^{2}K]
Vertical building envelope	0.32÷0.41
Ground floor	0.39
Roof	0.31
Original windows	1.91 ÷ 3.22
Substituted windows	1.95 ÷ 2.15

With reference to the windows, the original frames were retained, but changes in the type of glass and their connection to the fixtures were hypothesized. It was also decided to replace the few non-original windows with wooden or iron windows conforming to the originals. Passive behavior of the building improved largely, reducing the heating demand from 29.4 to 10.1 kWh/m^{2}y, and slightly affecting also the cooling one from 61.9 to 51.0 kWh/m^{2}y.

In addition to interventions on the building envelope, interventions on systems were simulated, trying to correct, where possible, the defects of the current system. In details:

- with reference to the heating system, a low efficiency of the regulation system was observed, without room temperature regulation. It was therefore assumed that the valves on the radiators would be replaced with thermostatic valves, also intervening on the distribution system with variable flow circulation pumps [40].
- with reference to the lighting system, it was assumed to replace the existing lamps, with the introduction of LED lamps and with an automation system equipped with presence sensors, useful for deactivating neglected users [41].

In order to increase the renewable share, an integrated PV array was designed with a rated power of 31.1 kWp to be located on the roof and terraces, as in figure 5. Accounting for a slope of 30°, the annual production is about 36,000 kWh.

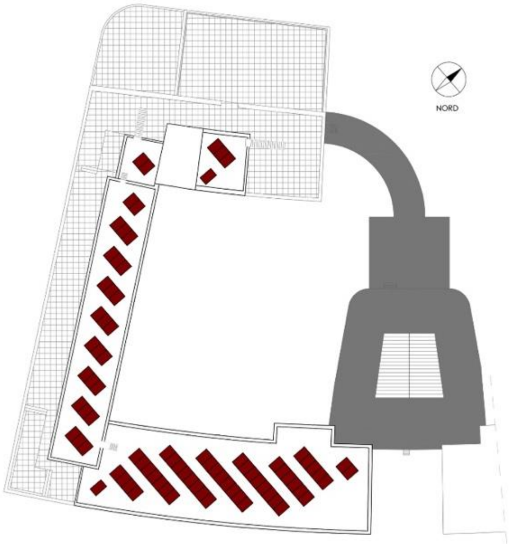

Figure 5. PV array allocation.

Considering all the proposed interventions, the building energy label can achieve letter B, with a fossil primary energy equal to 60.1 kWh/m^{2}y, i.e. -50%, and with a renewable fraction of 20.4% deriving from the PV array and the National Grid contribution, as shown in table 5. This favorably impacts on environment quality directly for the occupants and consequently for ecosystem status [42]

Table 5. Primary energy consumptions.

		Heating	Cooling	Hot water	Lighting	Total
Renewable	[kWh/y]	0	22,313	563	56,474	79,350
Fossil	[kWh/y]	140,853	45,468	2,335	121,884	310,541
Total	[kWh/y]	140,853	67,782	2,898	178,359	389,891
Renewable fraction	%	0.0%	32.9%	19.4%	31.7%	20.4%

The set of all these interventions was analysed in economic terms to evaluate the expenditure for the energy requalification of the Institute of Physiology. The unit costs of energy carriers (gas and electricity) were taken up by the Energy Plan of Sapienza even where non-conventional solutions are included [43]. The economic analysis was developed using the SEAS software made available by ENEA, considering an inflation rate of 2%, stable costs of gas and electricity and a loan interest rate of 1.479%, in line with that granted by the BEI to "Sapienza" University.

Table 6. Expected cost for the realisation of interventions in the Institute of Physiology.

Intervention	Unit Cost		Intervention area		Intervention Cost	
Windows replacement	450	[€/m^2]	680	[m^2]	306,000	[€]
Opaque Vertical walls insulation	100	[€/m^2]	2,500	[m^2]	250,000	[€]
Horizontal slabs insulation	60	[€/m^2]	2,600	[m^2]	156,000	[€]
Regulation and distribution system	5	[€/m^2]	6,800	[m^2]	34,000	[€]
LED lighting	0.5	[€/W]	68,000	[W]	34,000	[€]
PV system	1,800	[€/kW]	12.96	[kW]	23,328	[€]
TOTAL					803,328	[€]

The economic analysis of the different interventions shows different return times and profitability, resulting in shorter payback times and greater profitability for interventions on systems. Interventions on the building envelope, also due to the high specific costs due to the desire to preserve the historic features of the building, are over 50 years. The interventions on the systems, acting on elements not subjected to any type of constraint, have lesser return times, close to 10 years as usual carbon emission balance measures [44,45]. Overall, considering all the interventions there are return times of over 20 years. However, what was said must be reconsidered focusing on the comparison between the real consumption data and the data resulting from the model. In details, it is recalled that the comparison showed that the proposed energy model strongly tends to overestimate thermal consumption, while it is rather reliable in forecasting electricity consumption related to lighting. Re-elaborating the data, in light of the relationship between the real consumption and the consumption of the model, there are longer return times, which, considering all the interventions, can exceed 45 years.

4. Conclusions

In this work, the effects of some energy upgrading interventions on a protected building of Sapienza University campus of Rome were analysed, respecting its historical value. The study highlighted the possibility of functional improvements that can be combined with the recovery of some of the original features of the building. It is clear that great improvements are possible like the introduction of a greater share of renewable energy through the installation of a photovoltaic system on the roof, in order not to disturb the architectural values of the building. The result achieved is the compromise between the architectural value to be protected, preserved, recovered and energy efficiency which, in the case of protected buildings, could be considered a protection tool, allowing the building to be maintained in more efficient and effective use. However, a specific request for economic incentives appears to be necessary because the costs for the renovation of these buildings are generally higher and the design is much more complex and expensive.

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