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Improving the energy performance of healthcare buildings: a case study

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Improving the energy performance of healthcare buildings: a case study

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Abstract. The energy issue due to dependence on fossil fuels, pollution, and problems due to climate change are closely related issues. To address them, in recent years, solutions are being studied that provide for different methodologies that exploit alternative sources and technologies capable of reducing the environmental impact. One of the sectors most affected by the problem linked to environmental sustainability is the building sector, as can be read in the European Union directive 91 of 2002: "the energy used in the residential, healthcare and service sectors, made up for the most part of buildings, represents more than 40% of the total energy consumption". To reduce the environmental load due to construction, it is necessary to study the energy performance of buildings, understand their critical issues and improve their efficiency using systems that exploit renewable energy sources and new construction techniques. In this study, a methodology will be developed to analyse the plant and energy characteristics of healthcare facilities, referring to the "target" buildings of a healthcare complex of Central Italy that will be used as a case study, highlighting all the problems and critical issues. Solutions will be proposed to improve the energy performance of the healthcare buildings, indicating the interventions to be implemented.

Keywords: energy efficiency, renewable energy, healthcare building, Building Information Modelling.

1. Introduction

Healthcare is provided in complex and energy-intensive facilities that range from critical care hospitals to medical office buildings. In general, they account for a remarkable fraction of the energy consumption in the utility buildings sector, due in large part to the very high energy intensity levels of hospitals and other inpatient care facilities. Particularly in hospitals, high energy consumptions are mostly due to their continuous usage patterns and operation which require substantially variable energy demands depending on the specialized services provided.

Figure 1. Healthcare complex case study.

The healthcare complex, located in Central Italy and case study (Figure 1), is made up of activities all accredited to the Regional Healthcare Service:

- 103 post-acute care rehabilitation beds.
- 31 long-term care beds.
- 90 beds in nursing home.

Furthermore, the District is a Rehabilitation Centre for:

- 20 Extensive Rehabilitation beds.
- 150 outpatient services per day.
- 50 Semi-residential services per day.
- 70 daily home services.

The structure is divided into three main buildings:

Building A, built in the second half of the 1950s, consisting of 5 floors above ground and a basement intended for:

- Basement floor: pantry, technical rooms, deposits.
- Ground floor: changing rooms, laundry, kitchen, heating plant, clinics, gyms, radiology, pharmacy, darkroom, mortuary, electrical substation, toilets.
- First floor: general hospital stays, rooms serving employees, toilets.
- Second floor: total of 42 patients, of which 36 in long-term stays, dressing room, rooms for employees, toilets.
- Third floor: total of 61 patients, of which 41 in post-acute rehabilitation and 20 in extensive rehabilitation, toilets, rooms for employees.
- Fourth floor: a total of 62 patients in post-acute rehabilitation, toilets, rooms for employees.
- Fifth floor: 20 patients in long-term care, toilets, rooms for employees.
- Rooftop: technical rooms and a part of the technological systems serving the building.

Building A hosts about 230 patients/day.

Building E, built in the early 1970s, consists of an above-ground floor intended for outpatient rehabilitation, home rehabilitation, semi-residential rehabilitation for a total of about 270 daily services. There is also a church, built in 1990, located on the ground floor and university classrooms (physiotherapists degree), built in 1995.
Building C or "Management Office Building", where the administrative and managerial offices are located.

Table 1 shows the values of the surfaces of the buildings:

Table 1. Building surfaces.

Building	Surface (m^2)
Building A	7625
Building E	5071
Church	700
University	700
Building C	320

As regards the technological systems, the Healthcare District is equipped with:

- electrical substation with two 1600 kVA transformers each.
- thermal power plant serving building A with three steam boilers of 580 kW each.
- thermal power plant serving building E with six boilers of 315 kW each.
- 20 VRV (Variant Refrigerant Volume) heat pumps for a total cooling capacity of 800 kW.
- 55 split air conditioners for a total cooling capacity of 135 kW.

2. Energy study of building

2.1. Energy BIM Model

Based on the geoclimatic characteristics, the intended use of the buildings, the construction characteristics, and the plant equipment, it was possible to reconstruct a 3D model using B.I.M. (Building Information Modelling) energy modelling software (Figure 2).

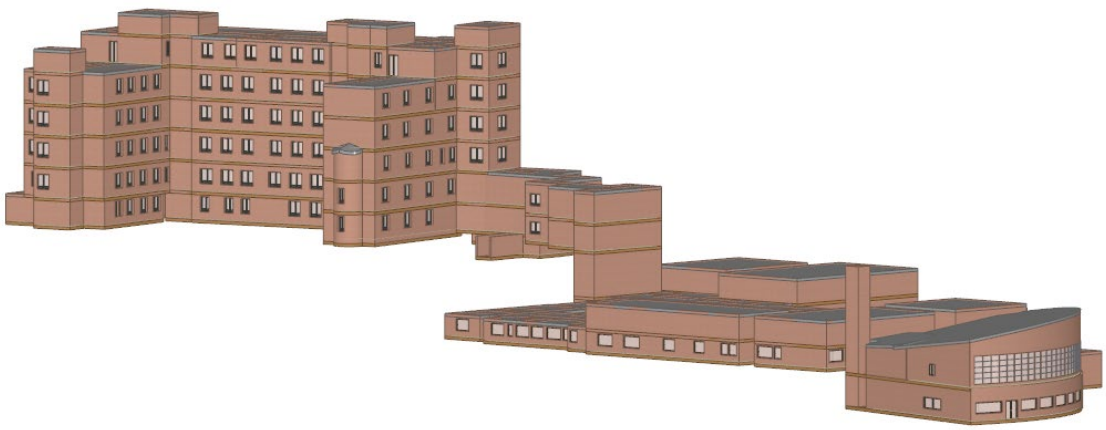


Figure 2. B.I.M. Model.

In the model, the following were entered as input data for all buildings:

- Geoclimatic data.
- The characteristics of the building envelope, i.e. the stratigraphy of dispersing structures (walls, floors, glass surfaces, thermal bridges).

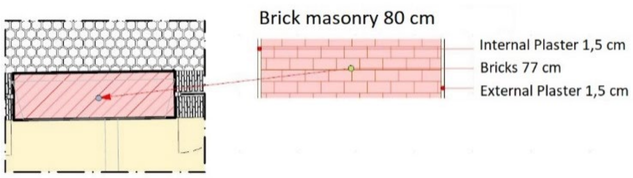
- The characteristics of existing technological systems (winter and summer air conditioning system, mechanical ventilation system and domestic hot water production system).

The use of a B.I.M. software makes it completely easy to reconstruct buildings in their shape and size starting from two-dimensional survey plans.

2.1.1. Building construction characteristics

Through the aid of in situ surveys it was possible to reconstruct the characteristics of the dispersing envelope of the buildings in question.

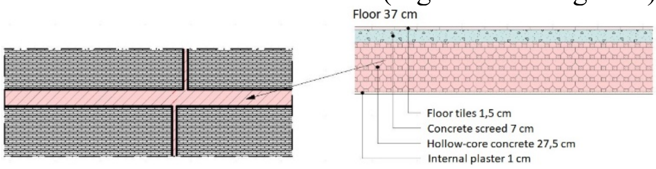
All buildings have a reinforced concrete supporting structure and brick walls with thicknesses ranging from 80 to 30 cm. Figure 3 shows the stratigraphy of an 80 cm masonry and its thermophysical characteristics.



- Total thickness = 800 [mm]
- Global thermal transmittance = 0,6847 [W/m^{2}K]
- Global thermal resistance = 1,4605 [m^{2}K/W]
- Total surface mass = 1540.00 [kg/m^2]
- Heat capacity = 61,158[kJ/m^{2}K]

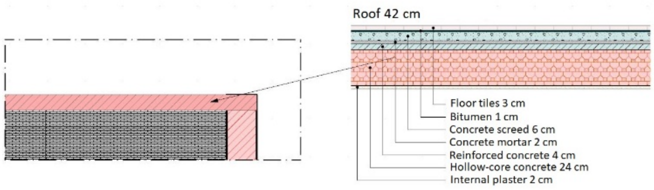
Figure 3. Masonry stratigraphy and thermophysical characteristics.

Floors and roofs are built with hollow-core concrete (Figure 4 and Figure 5)



- Total thickness = 370 [mm]
- Global thermal transmittance = 0,8541 [W/m^{2}K]
- Global thermal resistance = 1,1708 [m^{2}K/W]
- Total surface mass = 574,50 [kg/m^2]
- Heat capacity = 60,886 [kJ/m2K]

Figure 4. Stratigraphy of the floor and thermophysical characteristics.



- Total thickness = 420 [mm]
- Global thermal transmittance = 1,4966 [W/m^{2}K]
- Global thermal resistance = 0,6682 [m^{2}K/W]
- Total surface mass = 529,00 [kg/m^2]
- Heat capacity = 68,692 [kJ/m^{2}K]

Figure 5. Stratigraphy of the roofs and thermophysical characteristics.

The characteristics of the windows are shown below (Table 2 and Table 3):

Table 2. Characteristics of glass and frame.

Glass	Frame
Glass type = Double Area = 3,07 m² Perimeter = 10,41 m Transmittance = 3,30 W/m²K Solar factor = 0,75	Frame type = Aluminum without thermal break Area = 1,42 m² Transmittance = 7,00 W/m²K
Total window area = 4,84 m	

Table 3. Characteristics of windows.

Internal surface resistance	0,13 m^2K/W
External surface resistance	0,04 m^2K/W
Frame area reduction coefficient	0,37
Total transmittance frame - U_w	4,26 W/m^2K
Total window resistance - R_w	0,23 m^2K/W

It should be noted that the walls and roof floors are not insulated and that the windows, even if of the "double glazing" type, have very high transmittance values in relation to the fact that the frames are not "thermal break".

All this contributes to having very high thermal dispersion values amplified moreover by the presence of significant thermal bridges.

2.1.2. . Characteristics of technological systems

Buildings are equipped with:

- electrical cabin with two transformers with apparent electrical power of 1600 kVA each.
- thermal power plant serving Building A with three steam boilers with a thermal input of 765 kW each.
- thermal power plant serving Building E with six boilers with a thermal power of 315 kW each.
- 20 VRV (Variable Refrigerant Flow) for a total cooling capacity of 800 kW currently only used for summer cooling of Building A.
- 55 split air conditioners operating with heat pump for a total cooling capacity of 135 kW.
- mechanical ventilation system (primary air) serving building A with air handling unit with a flow rate of 36000 m^3/h.
- mechanical ventilation system (primary air) serving the University building with air handling unit with a capacity of 20000 m^3/h.
- mechanical ventilation system (all air system with recirculation) serving the Church building with air handling unit with a capacity of 20000 m^3/h.

All buildings are equipped with lighting fixtures with fluorescent lamps of different power.

2.2. Energy analysis of the state-of-the-art

Once the characteristics of the dispersing envelope and the technological systems have been defined, the energy model can be built, and the results obtained can be quantified (from Figure 6 to Figure 10).

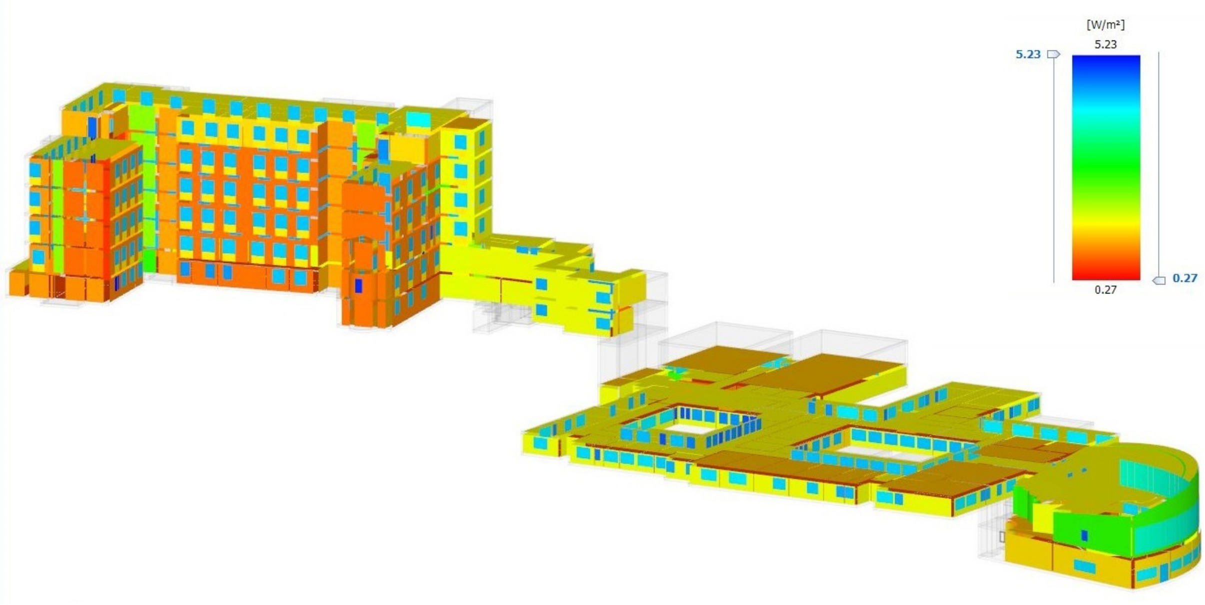


Figure 6. Dispersions by transmission.

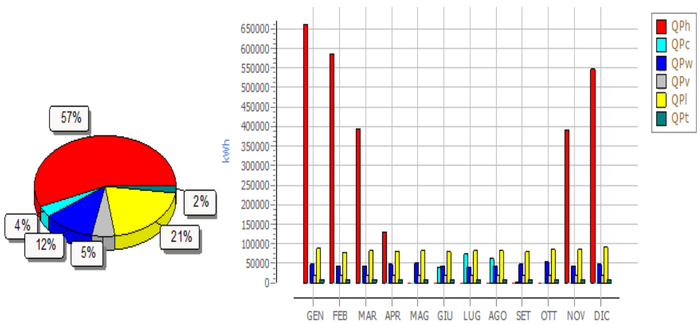


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Figure 7. Primary energy requirements for heating services (QP_h), cooling (QP_c), domestic hot water (QP_w), mechanical ventilation (QP_v), lighting (QP_l), transport of goods and people (QP_t) [kWh].

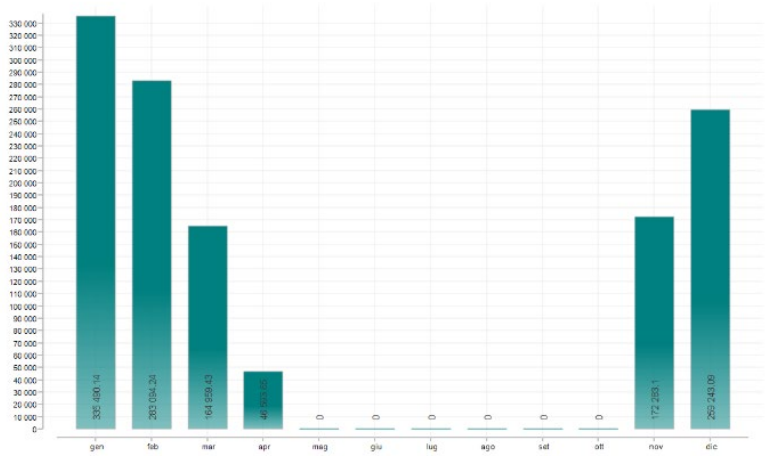

Figure 8. Q_h [kWh] - Heat energy requirement for heating.

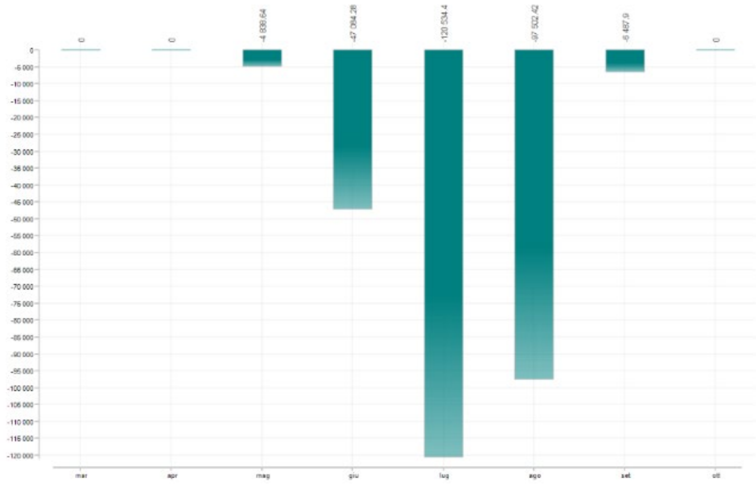

Figure 9. Q_c [kWh] - Heat energy requirement for cooling.

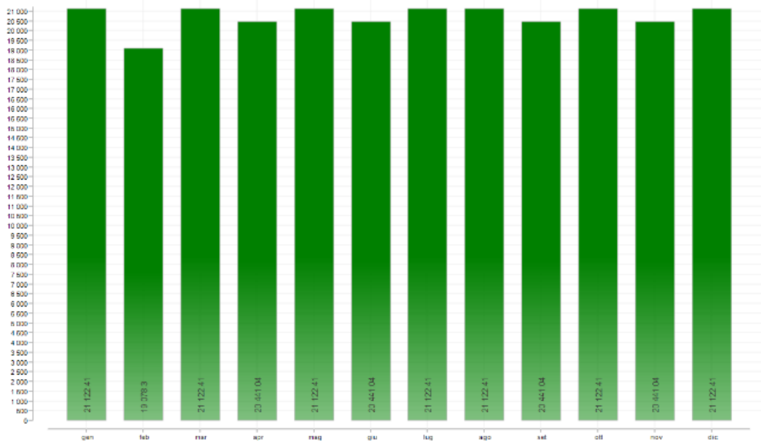

Figure 10. Q_w [kWh] - Thermal energy requirements for domestic hot water.

It's possible to obtain the overall energy performance and energy classification (Figure 11).

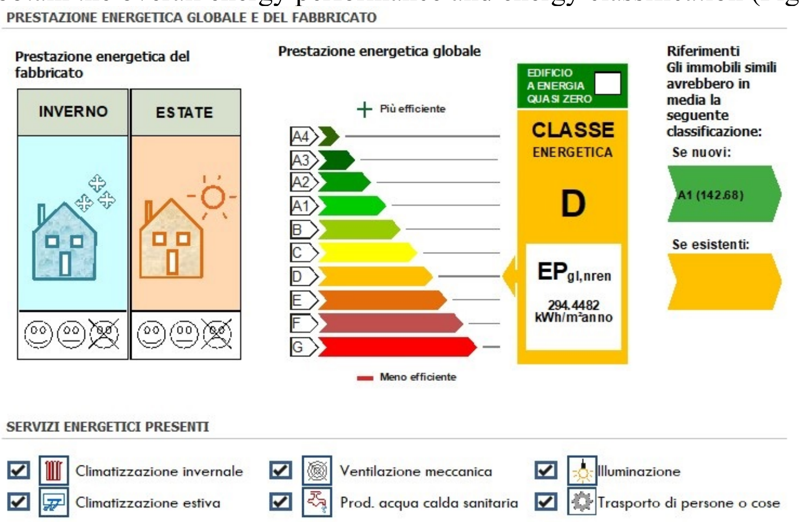

Figure 11. Energy (Italian) Classification.

The energy classification obtained shows that the energy consumption of the buildings is considerable and the overall energy performance completely inefficient.

3. Energy requalification interventions

3.1. Summary of interventions
The energy requalification interventions carried out or proposed can be summarized below:
- Replacing all fluorescent lamps with LED lamps
- Elimination of the steam thermal power plant and connection of Building A to the thermal power plant that served only Building E.
- Deactivation of 203 radiators out of a total of 263 (77%) of Building A, heating the same with the use of heat pumps installed on the roof, much more performing from an energy point of view.
- Replacement of the University's AHU (Air Handling Unit) with one of lower capacity and therefore less energy intensive.
- Modification to the AHU of the Church, with the elimination of the external air intake, which now heats only recirculating air that is at 20°C, rather than outside air that is at a much lower temperature.
- Deactivation the AHU of the Building A.
- Replacement in the kitchen of 200-liter steam kettles with gas kettles.
- Deactivation of one of the two 1500-liter DHW storage tanks serving Building E.
- Installation of a 234-kW photovoltaic system on the roof of Building E.
- Installation of three small boilers for the "summer" operation (6 months a year) of the DHW boilers of Building A and Building E.
- Installation of an Enerkeeper system in the electrical substation to improve the quality of the electricity used and thus reduce its consumption by 10%.

3.2. The new energy model

3.2.1. Introduction
Considering the interventions mentioned above, it was possible to reconstruct the 3D model in the same way as the state made considering that:
- no changes have been made to the building envelope,
- the interventions were all purely of a plant nature.

3.2.2. Modelling results
Once the characteristics of the dispersing envelope and the plants have been defined, the energy model can be built, and the results obtained can be quantified (from Figure 12 to Figure 18).

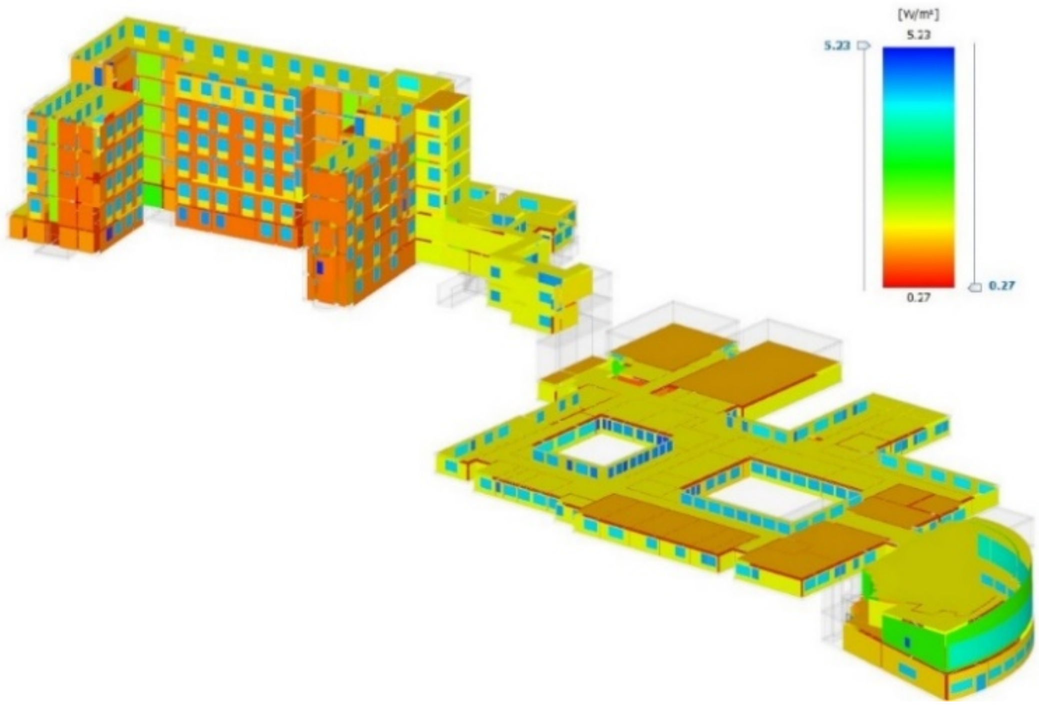

Figure 12. Dispersions by transmission.

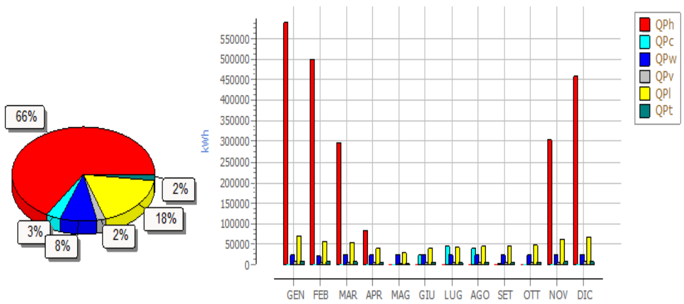

Figure 13. Primary energy requirements for heating services (QP_h), cooling (QP_c), domestic hot water (QP_w), mechanical ventilation (QP_v), lighting (QP_l), transport of goods and people (QP_t) [kWh].

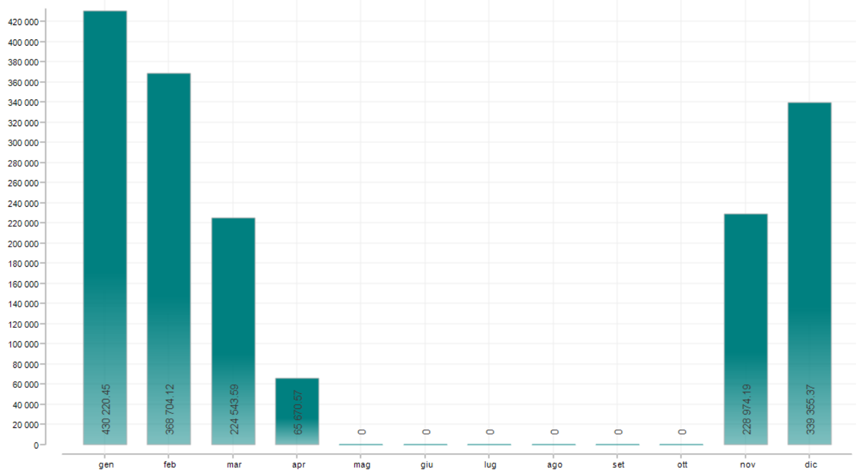

Figure 14. Q_h [kWh] - Heat energy requirement for heating.

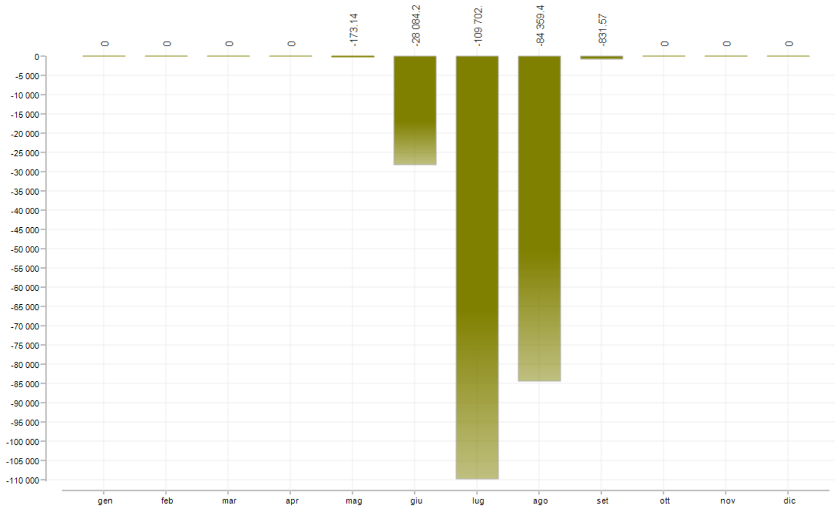

Figure 15. Q_c [kWh] - Heat energy requirement for cooling.

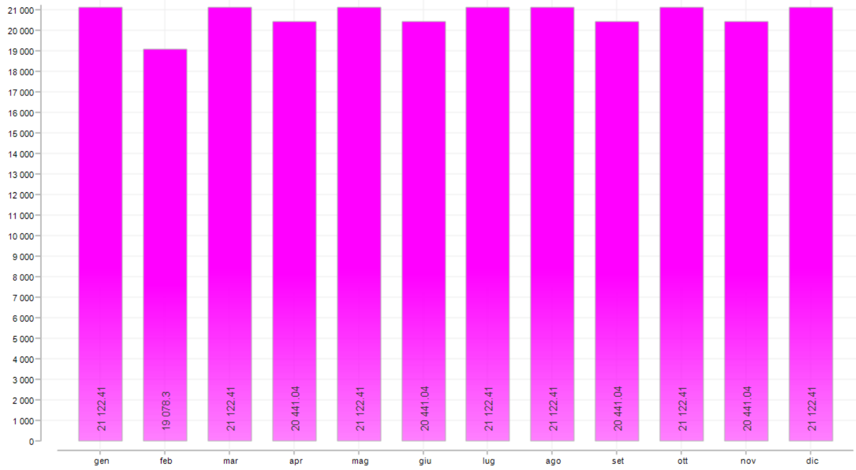

Figure 16. Q_w [kWh] - Thermal energy requirements for domestic hot water.

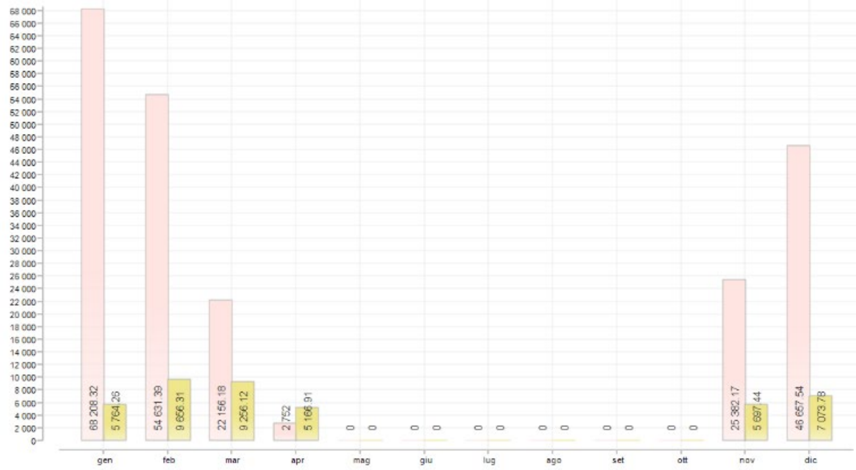

Figure 17. Q_{h_grid} (pink histogram) [kWh] - Electricity demand taken from the grid for heating and Q_{xhPV} (yellow histogram) [kWh] - Electricity produced and used for heating.

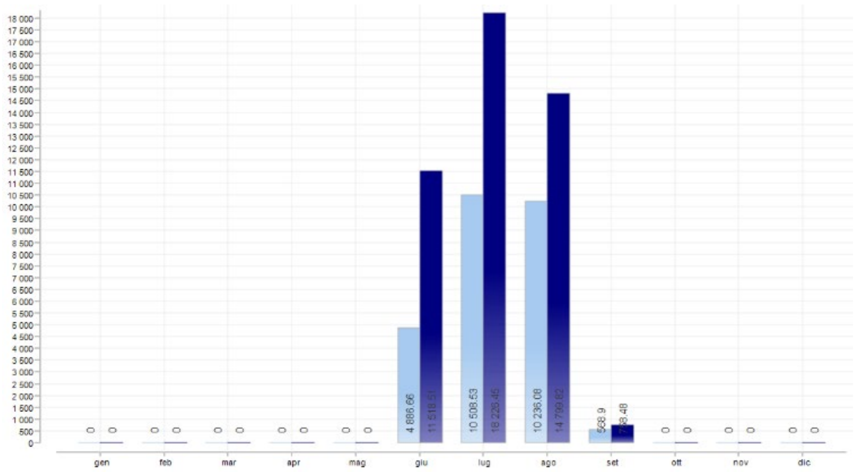

Figure 18. Q_{c_grid} (blue histogram) [kWh] - Electricity demand taken from the grid for cooling and Q_{cPV} (violet histogram) [kWh] - Electricity produced and used for cooling.

It's possible to obtain the overall energy performance and energy classification (Figure 19).

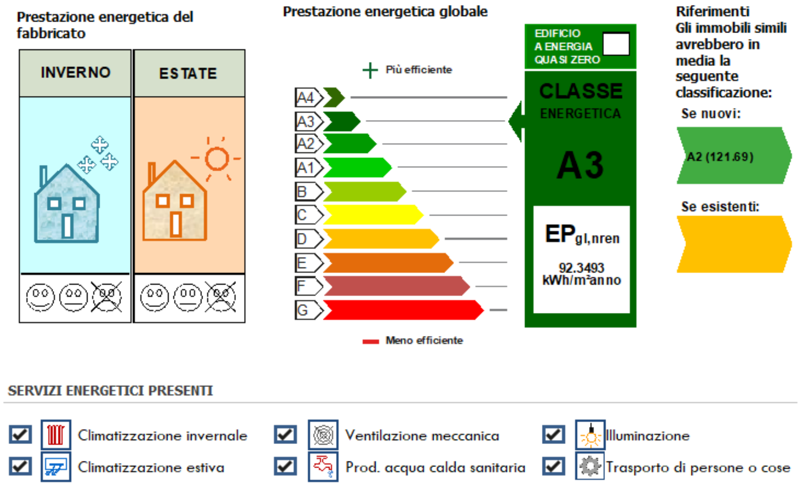

Figure 19. Energy (Italian) Classification after interventions.

4. Discussion of the results

This paper showed that it is necessary to approach the issue of energy efficiency without relying on pre-established solutions.

In other words, it is known that it is necessary to intervene on the building-plant system, according to the case study, analyzing if it is appropriate to intervene: on the envelope (for example with an external insulation); on the windows; on the plants; or a combination of them.

The criticism that we want to make is the thought that "energy efficiency" automatically means " external insulation".

In fact, in the case study, the envelope, although not compliant with current legislation, has discrete energy performance (good transmittance and good surface mass), as well as the windows, ("double glazing" type with "no thermal break"frames), although not compliant with current legislation, have discrete energy performance.

The demonstration of the effectiveness of the energy efficiency approach "without pre-established solutions", is demonstrated by the "jump" of 5 energy classes, obtained in the case study, only by intervening on plant engineering aspects.
We reiterate once again the need to investigate the effectiveness of intervening on the casing (external insulation) on a case-by-case basis; on the windows; on the plants; or a combination of them.
To demonstrate the above, the replacement of all the existing windows with high-performance ones, was also assumed. By making a new simulation with this further improvement, it can be seen that the annual energy consumption decreases by about 6 kWh/m^2 (6.5%) but the energy class obtained does not change (Figure 20). However, the reader must not misunderstand all of this, because a weak and energy consuming envelope remains a weak and energy consuming envelope, but it is also true that an expensive investment must be supported by a proper pay back time.
Therefore, the concept of "only plant intervention" is not an extreme, but it will still be necessary to evaluate how to intervene on a case-by-case basis.

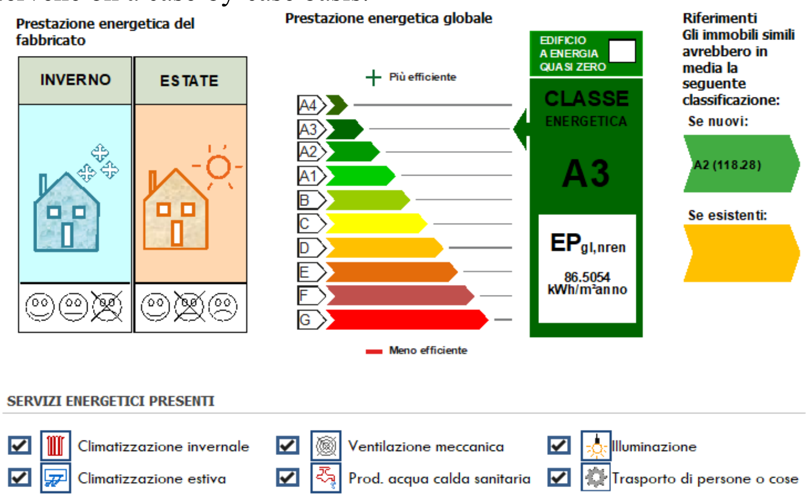

Figure 20. Energy (Italian) Classification with the hypothetical replacement of the windows.

However, the results obtained demonstrate that the plant engineering interventions have significantly improved the overall energy performance. The choice of using heat pump technology for heating and cooling services allows for significantly more efficient system performance that involves simultaneous savings on the consumption of electricity and natural gas given the total disposal of obsolete and highly energy-intensive boilers; moreover, a high degree of electricity savings occurs from the replacement of fluorescent lamps with LED lamps that provide similar lighting performance with half the electric power involved. At the same time, the installation of a photovoltaic system of medium power allows to cover completely (in summer) and partly (in winter) the need for electricity for cooling and heating.

It is also important to note the reduction in fuel consumption obtained with the decision to use a VRV system for the heating service and to use smaller boilers for the domestic hot water production service (Figure 21, 22, 23, 24).

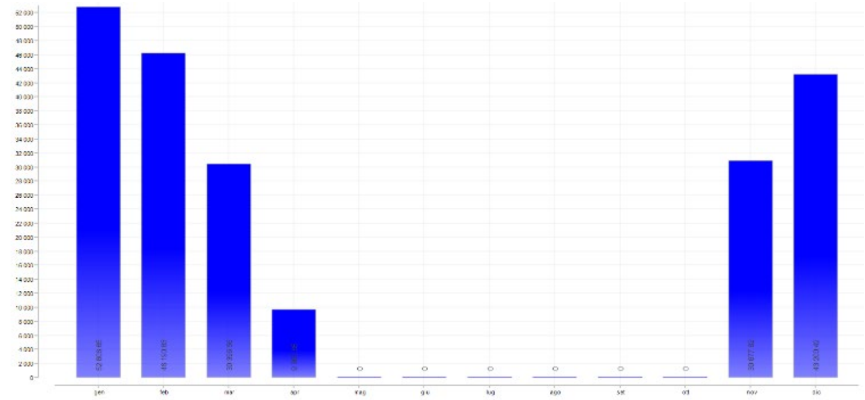

Figure 21. Fuel consumption for heating before interventions.

Figure 22. Fuel consumption for DHW before interventions.

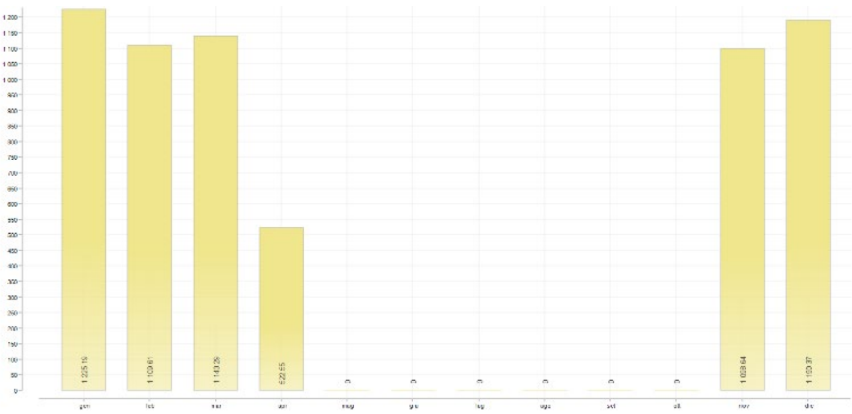

Figure 23. Fuel consumption for heating after interventions.

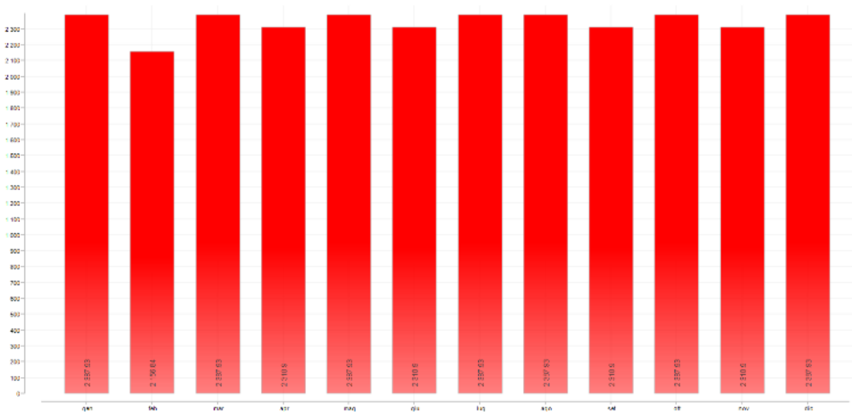

Figure 24. Fuel consumption for DHW before interventions.

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