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Energy and Environmental Refurbishment of the Hygiene Institute within the Sapienza University of Rome campus

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Abstract. Starting from the definition of sustainable development introduced by the 2030 Agenda, and the most recent European implementation tools such as above all the New Green Deal, three goals have been highlighted as pilot objectives of this research: Goal 13 “Climate Action” to strengthen the resilience and adaptability of our building stock to climate-related risks, Goal 7 “Affordable and Clean Energy” by increasing the share of renewable energy and improving the energy efficiency of the existing building stock and Goal 6 “Clean Water and Sanitation”, aimed, in this specific case, at a sustainable management of water resources and technologies for recycling and reuse. In particular, the research work focused on the energy and environmental redevelopment, from a green perspective, of the “Sanarelli” Institute of Hygiene within the “Sapienza” University of Rome campus. The building was built in 1935 and, following a series of changes over the years, currently has a total volume of 37,700 m^3 and an area of 9,475 m^2. After an in-depth study of the status quo thanks to inspections, surveys, non-invasive investigations and environmental analyses, the work has focused on the definition of specific objectives with the ultimate aim of the energy and environmental refurbishment intervention by tracing 7 strategies thanks to which it has been possible to identify 9 technical solutions to be applied to the Institute. The design choices highlight a close synergy between active and passive devices which together contribute to achieving a circular use of water resources on site, with systems for capturing and collecting rainwater and treating wastewater, as well as achieving a significant improvement in the energy behaviour of the building. This improvement has been possible not only thanks to the updating, with respect to nowadays uses and standards, of the characteristics of the building envelope and of the active systems, but also thanks to the close collaboration between the active and passive technological solutions that have led to satisfactory results with a view to reducing CO_2 emissions.

1. Introduction

Achieving climate neutrality is currently one of the priority objectives that Europe has set and reducing greenhouse gas emissions by at least 55% by 2030 [1] to zero by 2050 [2], increasing energy efficiency [3-4] and improving the processes of circularity of resources [5] are among the key strategies that emerge from the European directives with this aim. Over the next three decades, the world’s population living in urban areas is projected to increase to nearly 7 billion people [6], which will be more than two-thirds of all humanity, yet in this same period cities will be less and less liveable at due to climate change, unstable weather conditions and extreme weather events [7] and in part they already are: for this reason Italy is currently pushing hard on the need for green and low carbon criteria [8] by focusing, among others, to encourage broad-spectrum strategies aimed at improving the building stock to jointly address the climate crisis and the relaunch of the sustainable development of the country [9] based on the principles of the green economy [10-11]. To reach these ambitious goals, actions are needed on all sectors of our economy, for this reason the “Fit for 55” package of proposals for the implementation of the climate law proposes to gradually eliminate free emission quotas in the sector of heating and cooling of buildings [12]: energy production and use account for over 75% of the EU’s greenhouse gas emissions and 40% of our energy consumption is for buildings [13]. A refurbished and upgraded building stock in the EU will help pave the way for a decarbonised and clean system, but only 1% of buildings undergo

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energy-efficient redevelopment annually, so effective action is key to making Europe climate neutral by 2050 [14]. It is therefore urgent that we focus on how to make our buildings more efficient in terms of energy, exploitation and careful circularity of all resources, both natural and man-made, with less carbon intensity throughout their life cycle and more sustainable. Although the containment measures to fight the COVID-19 pandemic have drastically reduced pollution levels and slowed economic activities, this is not the way the EU envisions its path and that of the world towards the goal “zero pollution”. On the contrary, the EU is potentially able to sustain prosperity by transforming production and consumption patterns, directing investments towards the “zero pollution” goal [15] and moving towards a more efficient and “circular” system, where waste energy is captured and reused, as well as a cleaner electrical system, with more direct electrification of end-use sectors such as industry, building heating and transportation [16-17].
The Energy and Environmental Refurbishment of the Hygiene Institute within the Sapienza University of Rome campus fits into this framework of international and national references, with a close relationship with the current European directives and the sustainable objectives proposed by the 2030 Agenda [18] : particular attention, in determining the thematic area of research, has been given to the objectives SDG 6 “Clean water and sanitation”, SDG 7 “Affordable and clean energy”, SDG 13 “Climate Action” and SDG 15 “Life on Land”. Deepening these issues, the definition of the macro-objectives of improving the users’ quality of life and the reduction of the environmental impact have been included in the research as improvement of internal microclimatic comfort, reduction of atmospheric and water pollution, promotion of the circular economy and optimization of building management. These objectives have been then achieved through the strategies of: reduction of energy needs, taking into account the changed climatic needs in line with what is described in [19], water needs and sustainable management of rainwater, following the [20]; control and improvement of passive bioclimatic systems and introduction of active devices for the improvement of indoor air quality, following the procedures and methodologies proposed in [21]; enhancement of natural capital for the seizure and storage of pollutants, given the multiple benefits associated with the increase in green surfaces in the urban context explained in [22]; use of recycled materials to ensure the circularity of products as well as resources and reduction of maintenance and management costs of the building; introduction of centralized management systems and control devices according to the Life Cycle Approach and Resilient Design [23]. The choice of the Hygiene building within the Sapienza university city fits into the framework of short and medium-term interventions aimed at increasing energy efficiency, increasing the use of renewable sources, reducing pollution and cost reduction [24] through different proposals for energy and environmental refurbishment, already advanced also for other buildings of the University of Rome [25-26-27]. The ultimate aim is to obtain an increasingly complete, updated and exhaustive frame of the possible solutions to redevelop the existing building stock, taking into account the intended use from time to time, through the use of active and passive systems, in a green and low carbon perspective.

2. Building features and status quo

The building that houses the Institute of Hygiene is one of the 40 Institutes included in the University Campus of La Sapienza, designed by the architect Arnaldo Foschini and built between 1932-1935 under the supervision of the rationalist Marcello Piacentini who oversaw the design of the entire City. The building has undergone various internal changes and external additions (stairwells and lift) over the course of these ninety years. Currently it can accommodate just over a thousand people including students, professors and administrative staff. The Institute covers an area of approximately 2,000 m^2, rising over six levels, one of which is a basement, reaching a total height of 26 m. It has a “U” shape within which we find a courtyard bordered on the north-west side by an open passage that connects the two wings (on the first floor). In addition, we find an appendage volume of the main body consisting of the main hall and below it by technical rooms and storage; this volume has an area of 200 m^2 and a height of 12 m. The main functions of the Institute are dissemination of knowledge transmitted not only in the classroom with theoretical lessons, but also in laboratories with practical lessons. The building has 13 classrooms that extend over an area of 690 m^2 in the basement and ground floor. The laboratories are 56 and extend over all floors of the Institute, covering an area of 1827 m^2. A classroom corresponds to 2.6 laboratories, as the latter occupy 19% of the total area of the Institute (equal to 9476 m^2) with an addition of a 130 m^2 library with its own service rooms and administrative offices (1082 m^2) (Figure 1).

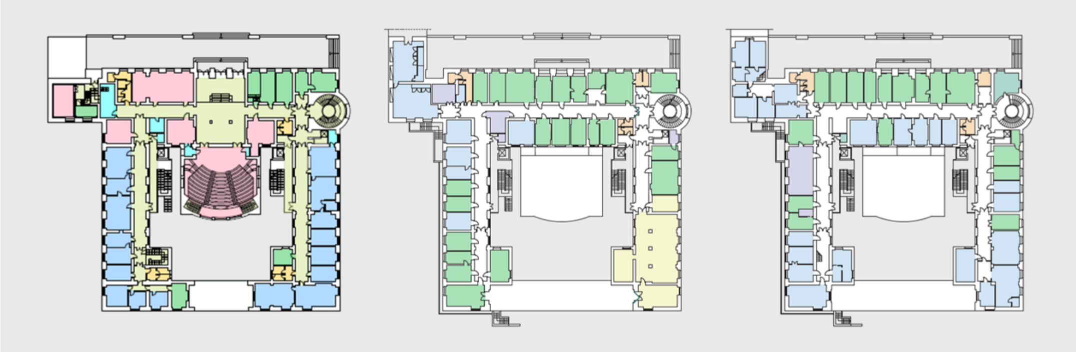


Figure 1. Functional schemes of the basement (a), the ground floor (b) and the second floor (c).

3. Materials and Methods

Proceeding with the consultation of the specifications, the progress of the works and the original drawings kept in the Sapienza Historical Archive, as well as the article entirely dedicated to the realization of the project of the University of the "*Regia Università di Roma*" [29] it has been possible to reconstruct the historicity of the building, its historical and architectural value and understanding design solutions, construction and structural typology, thus appreciating the potential to emerge and problematic sides to be solved in the design phase. A non-invasive approach for in situ surveys has been adopted for the study of the walls while for the study of the solar path (shading) and the solar radiation incident on the surfaces of the envelope, important for the calculation of thermal loads due to solar radiation, the Autodesk Ecotect Analysis software has been used in particular on the enclosures overlooking the internal courtyard. Fundamental for understanding the behaviour of the building, has been the interaction with those who live in the Institute every day, such as professors and students, in order to understand, according to their point of view, the criticalities and the potential of the structure in the field of spaces and in that of thermo-hygrometric comfort; an opinion based not on numbers or mathematical formulas but on feelings of comfort or discomfort that one feels constantly living in an place. This has made it possible to lay the foundations for setting up the project work.

3.1 Current condition of the building envelope

The building has foundations on simplex poles cast on site and an elevated structure made of bearing masonry in tuff bricks with variable sections between 120-30cm. The masonry can be divided into two categories: straight (made with only tuff bricks) and arched (tuff bricks with matrix in tuff stone and lime and pozzolana mortar) [31]. The opaque surfaces show two external finishes: nitrocellulose plaster for the walls that overlook the internal courtyard and exposed brick (stone ceramic, 23x11x6 cm) for the envelope presented at the University Campus.

The variability in the thickness of the opaque closures (Figure 2) has led to different U-values which worsen with the increase in the floors of the building (decrease in the thickness of the perimeter walls), 0.64-1.76 W/m^{2}K, far from the values currently required by the relevant regulations [33].

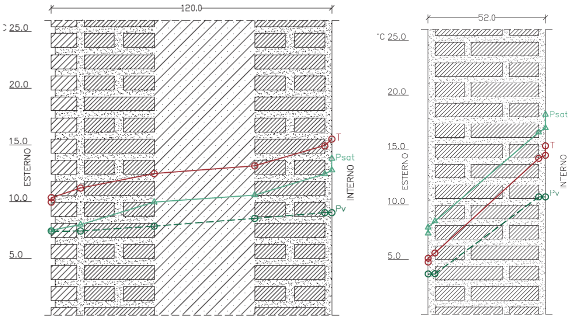


Figure 2. Masonry details (*ante operam*).

The windows are another technical element that strongly affects the energy performance of the building and the thermo-hygrometric comfort conditions of the users. In most cases, the windows are original from 1932 and about ten have been replaced in recent years with double-glazed windows and a PVC frame. There are two types of original fixtures different in shape and material of the frame (wood and iron). The wooden ones have for the most part the same technical characteristics, that is a 60 mm thickness of the wooden frame for a standard size of 148x248 cm, a tilt turn opening with a single 6 mm glass and a U-value between 1.85 and 2.86 W/m^{2}K with an area of approximately 3.7 m^2. As for the ferrofinetra fixtures, they are present on the internal stairwell and in the main hall, they consist of a 20 mm thick frame and a 6 mm thick single frosted glass; the openings are hinged for the window frames on the staircase while for the others they are protruding, with U-values of 5.30 W/m^{2}K for an area of just under 10 m^2.

The roof slab is made of a masonry structure and despite a 5 cm thick layer of cellulite insulation, it has a U-value of 1.44 W/m^{2}K. It has an external finish with terrazzo flooring. In Figure 3 it can be seen from the Glaser diagram how the intersection between the Pv and the Psat curves generate the phenomenon of interstitial condensation to a lesser extent than 500 g/m^2.

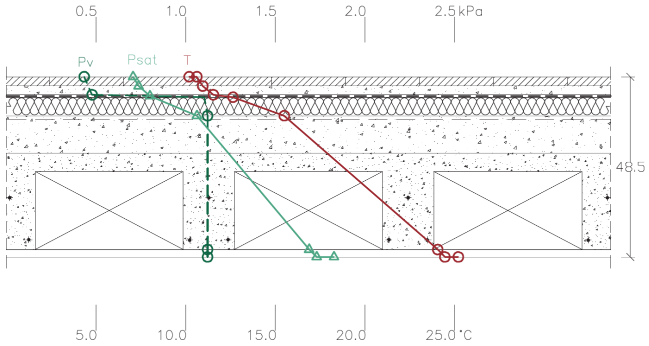


Figure 3. Roof slab detail (*ante operam*).

3.2 Current condition of the systems

The University Campus as well as being a set of Institutes is also an integrated system from the plant engineering point of view: within the campus the type of district heating is active, a technology already used by design in 1932 and improved over the years by introducing a new 20MW thermal power plant in 2014 and a two-pipe network (flow-return) consisting of two circuits, primary and secondary. The primary circuit connects the thermal plant located outside the perimeter of the city with the 15 thermal secondary stations located in the buildings, which the Institute of Hygiene is equipped with [30]. The secondary station in question is a 700 kW heat exchanger that allows you to relate the large system with the heating system of the Hygiene building. The terminals consist of 194 radiators which are made of cast iron (present in greater numbers), steel and aluminium. Over the years, other types of terminals have been introduced such as fan coils, as well as autonomous cooling systems such as 163 split systems present with an average of one system per room, disfiguring the facades placed under Monumental restriction by Cultural and Environmental Heritage since 1989 (Figure 4).

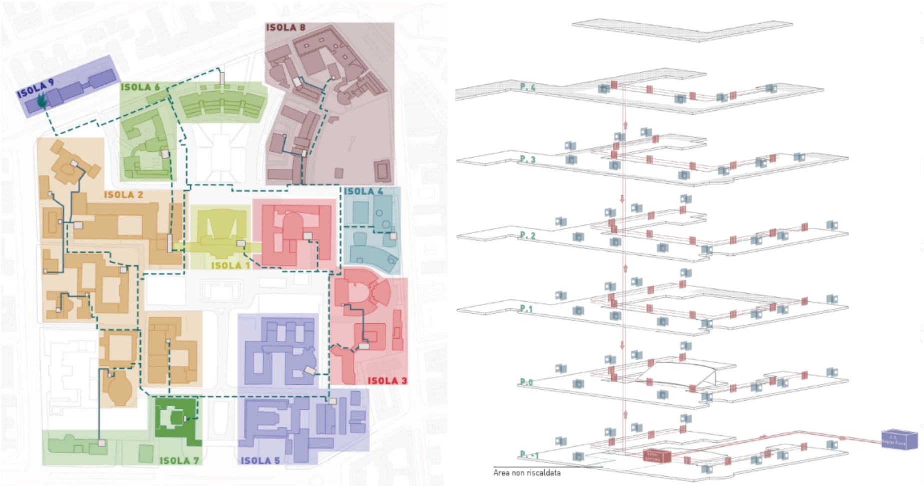


Figure 4. a) district heating scheme; b) distribution scheme of the Institute of Hygiene systems

The University Campus is also interconnected in the energy aspect, which is increasingly becoming reality, thanks to the instrument of the PES, Sapienza Energy Plan [24], which provides for the installation of 14 photovoltaic systems on as many roofs of buildings (some, such as that of the Rectorate, are already operational) by 2030. The coverage of the Hygiene building will be used with a 17.3 kWp plant consisting of amorphous panels, contributing to the production of 19 MWh per year of zero-emission energy [24]. With the application of the UNI 10339 standard it has been possible to calculate the external intake air and the recommended crowding in the various rooms. The analysis of the air intake is an important factor to be able to determine the amount of air necessary for the rooms to have a correct exchange, allowing the extraction of pollutants. The current state value is 10 times lower than that of the UNI 10339 standard, according to which each person needs 25m^3/h of air. Surely the large windows with tilt turn opening inhibit proper air exchange and, at the same time, fail to guarantee (even if only slightly) an average natural lighting level in the rooms. The Institute of Hygiene which differs from other university buildings as it has chemical laboratories and numerous refrigeration machines for the storage of material to be analysed, which must remain constantly at certain temperatures. These machines are in operation all day with a constant and continuous energy consumption, burden some for the University's coffers, as they are dated.

From the study carried out and reported in the Sapienza Energy Plan [24] conducted in the period prior to COVID-19 pandemic, it is clear that the greater consumption of electricity is relating to lighting (Table 1) and above all as in the F3 time slot (during the night on weekdays) this value is significant enough (Figure 5). This is supported by the fact that the lighting system has 1,361 low efficiency light sources, of which 1,059 fluorescents and 302 halogens.

Table 1. Primary energy consumption.

Description	Primary energy consumption		Cost
	[kWh]	[%]	[€]
Heating	21,821,028	21.8	1,770,257
Cooling	6,223,263	6.2	520,666
Hot Water	4,664,778	4.7	390,276
Equipment	19,737,243	19.7	1,651,306

Lighting	30,243,698	30.2	2,533,669
Other	17,442,889	17.4	1,460,187
Total	100,182,898	100.0	8,326,361

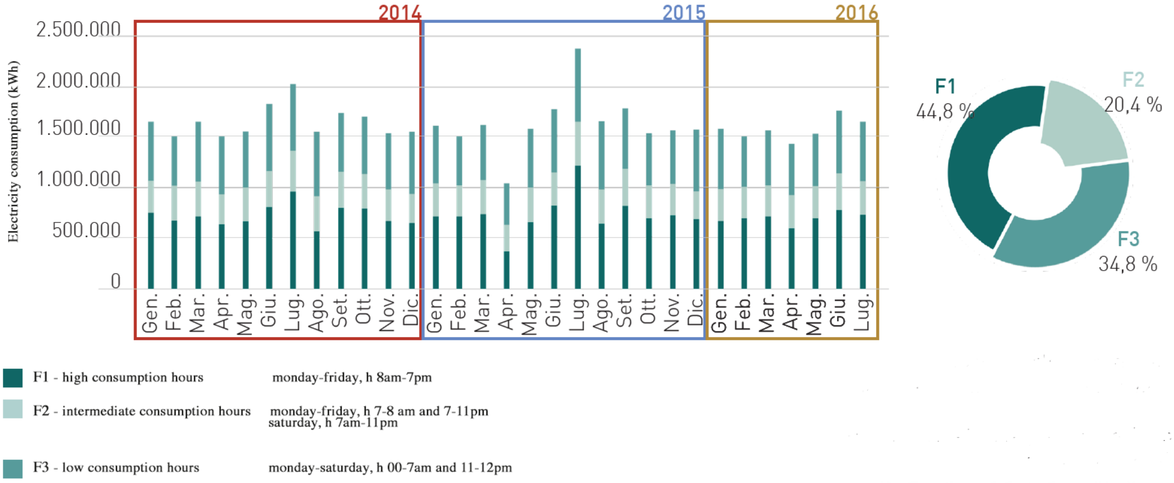


Figure 5. Hourly breakdown of electricity consumption.

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. 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 127.3 kWh/m^{2}y.

3.3 Current condition of the water resource management system

Energy sustainability is followed by water sustainability: water is a fundamental resource for the survival of all species living on Earth. The Hygiene building has not undergone any changes compared to 1935 (the year in which construction was completed) since the only rainwater collection system is linked to collection through rain pipes and disposal in the sewer system. During rainfall, the water that falls on the horizontal roofing surface is conveyed, thanks to a very steep slope, directly into the downspouts incorporated within the thick load-bearing masonry, and then is directed into a system of drainage shafts and collectors, ending so in the city sewer system. The passage of the downspouts within the wall thickness did not allow for a non-invasive investigation to assess the status quo, which would have given information on a possible need for preventive replacement to reduce possible water infiltration into the wall thickness. The building is currently not equipped with systems that allow the reuse or recirculation of the water used within the Institute.

From the meteorological study done through the data published by SIARL [34], it can be deduced that rainfall is becoming less and less frequent but with a greater intensity.

4. Intervention strategies and results

With reference to the 2030 Agenda, the objectives of the research have been set, concerning: the improvement of internal microclimatic comfort, the reduction of atmospheric and water pollution as well as CO_2 emissions, the encouragement of circular economy and the optimization of building management. At these four objectives, fifteen strategies correspond, in turn declined in the various technical solutions and listed according to three different areas: 5 strategies aimed at the building envelope, 5 strategies aimed at technical systems and 5 strategies aimed at the sustainable management of water resources.

4.1 Intervention strategies and technical solutions for the building envelope

The five strategies aimed at the building envelope are:

- Redevelopment of roofs, open spaces, external stairwells and indoor spaces;
- Natural lighting control;
- Control and mitigation of acoustics, temperature, humidity, ventilation, radiation and shading;
- Reduction of maintenance and management costs;
- Use of eco-sustainable, recycled or recyclable materials;

Introduce a layer of insulation placed inside the masonry consisting of pre-coupled panels in recycled wood fibre and rock wool with a thermal coefficient of 0.039 W/mK and with thicknesses ranging between 7.5 - 10.0 - 12.5 cm made it possible to fall within the D.M. June 26, 2015 with U-values of the masonry between 0.27-0.29 W/m^{2}K (Figure 6).

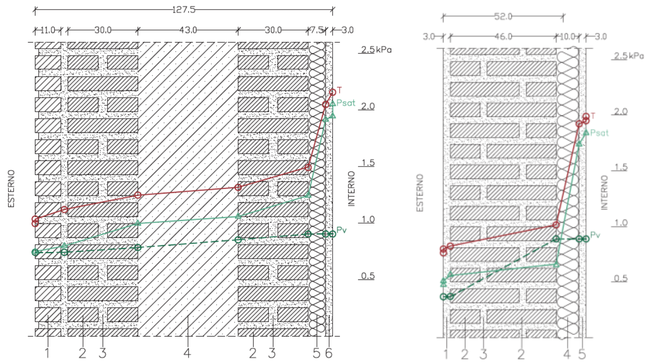


Figure 6. Masonry details (*post operam*).

The replaced frames, in full compliance with the preservation of the shape and colour of the original frames, have a U-value of 1.59-1.77 W/m^{2}K with 4–18–4 mm double glazing with 90% argon and selective treatment in position 3 for the South-East and South-West exposures, while for the others a low-emission treatment in position 2.

As regards the roof slab, the interventions led to the replacement of the existing insulation layer with a 12 cm fiberglass layer, obtaining a U-value of 0.26 W/m^{2}K equal to the maximum limit imposed by the relevant regulations. Two types of roofing have been developed, one practicable and the other, covering the auditorium, with a vegetal layer, in sedum, to increase the green share and all the related benefits.

Table 2 below shows the comparison between the U-values of the currently existing building envelope components and those chosen for the proposed solutions.

Table 2. U-value of building components.

	U [W/m^{2}K]	
Description	Status quo	Proposed solutions
Vertical building envelope	0.64 – 1.76	0.27 - 0.29
Ground floor	1.11	0.39
Roof	1.44	0.26
Original windows	1.85 – 2.86	1.59 – 1.77

4.2 Intervention strategies and technical solutions for the HVAC and electrical systems

The five strategies aimed at technical systems are:

- Reduction of energy requirements;
- Production of electricity from RES;
- Introduction of active devices for improving the indoor air quality;
- Renovation of the electrical system and introduction of LED light sources;
- Introduction of a centralised management system interconnected with various devices and utilities and of control devices for the HVAC systems in the rooms;

As regards the technical systems, it has been decided to keep the district heating solution currently in use within the University Campus in place and exploit the existing plant by replacing the terminals and the internal distribution network of the Institute of Hygiene. The old radiators have been replaced by canalised fan coils embedded in the false ceiling, and with cabinet (where the inter-floor does not allow the introduction of the canalised false ceiling) in equal number of existing radiators (110 for the ground floor, 54 for the first floor, 101 for the second floor, 97 for the third floor, 46 for the fourth floor and 32 for the top floor). The choice of fan coils has been made because it guarantees an autonomous system for switching on and off as well as for regulating the temperature and, moreover, it is a valid machine for both summer and winter air conditioning. The heating and cooling system (Figure 7) serves the entire building excluding the storage areas and/or technical rooms and the auditorium, equipped with an autonomous system. Both plants have in common the terminals and the distribution network of the heat transfer fluid; the cooling system is equipped with a 500 kW air-water heat pump placed on the roof that will be used only during the summer.

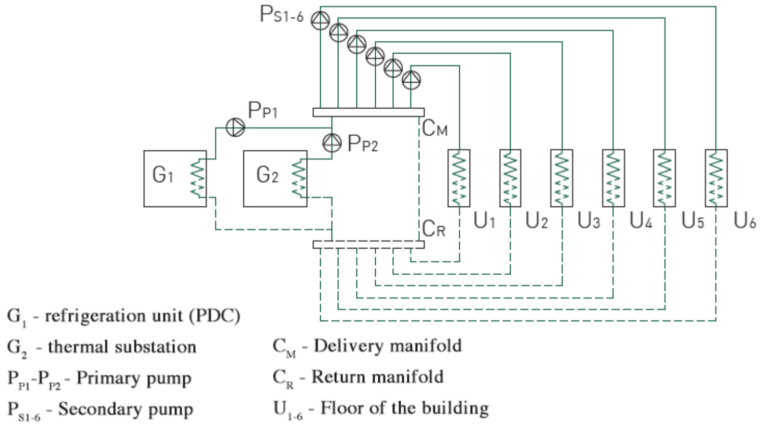
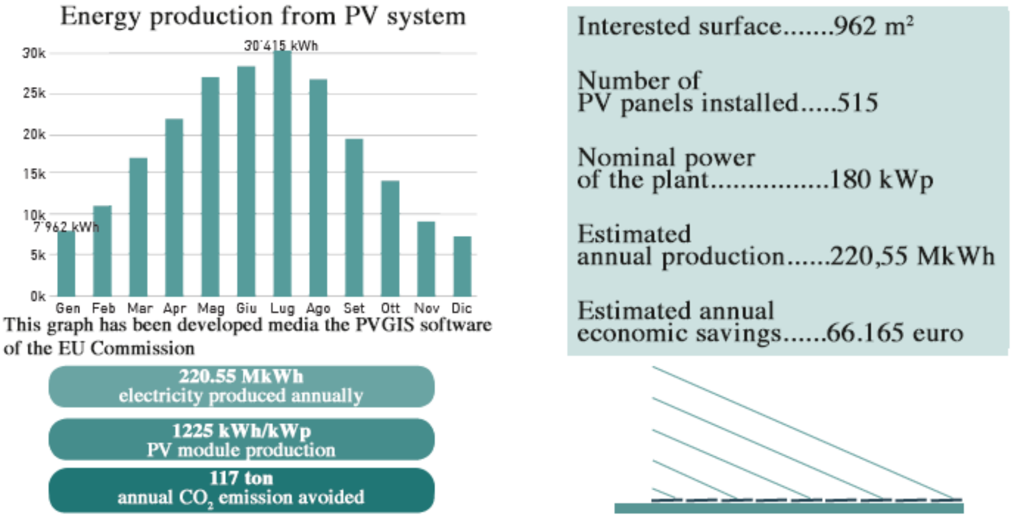


Figure 7. Diagram of the heating and cooling system Institute of Hygiene.

The auditorium is an appendage volume of the main part of the whole building, with a maximum crowding of 282 people and occasional and infrequent use. For this reason, it has been necessary to have an independent air conditioning and ventilation system with all external air with recirculation with an AHU located in the technical rooms under the main hall. The air handling unit will have a 20 kW post-heating battery and a 50 kW cooling battery connected to a dedicated 52 kW heat pump for both summer and winter operation placed on the roof of the building. The air introduced into the indoor space suitably filtered by flat and pocket filters will have a natural pre-filtering. The air is taken from an area that has a vegetated surface of 180 m^2 with a climbing plant (Canadian vine) which is made up of thick foliage for nine months a year. This large green surface allows, through chlorophyll photosynthesis, a decrease in the presence of carbon dioxide and an increase in oxygen in the air taken from the AHU fan.

Continuing with what is reported in the Sapienza Energy Plan, it has been decided to use the entire useful surface of the building roofs with a PV system connected to the Sapienza Smart-grid system, thus obtaining a grid-connected system. The surface used is equal to 1000 m^2, about half of the entire coverage area which, due to shading reasons, it has not been possible to use in full. The solution of panels parallel to the floor has been opted for in order to obtain a larger PV collection surface, given the high energy needs of the University Campus. So that the system has 515 PV modules with a nominal power of 180 kWp, guaranteeing an estimated economic saving of about € 66,000/year (Figure 8).



This graph has been developed media the PVGIS software of the EU Commission

Interested surface.......962 m^2

Number of PV panels installed.....515

Nominal power of the plant................180 kWp

Estimated annual production......220,55 MkWh

Estimated annual economic savings......66.165 euro

220.55 MkWh electricity produced annually

1225 kWh/kWp PV module production

117 ton annual CO_2 emission avoided

Figure 8. Calculation of the energy produced by the PV system.

All the technical systems present in the building, starting from the video surveillance system up to the air conditioning system, passing through the lighting, will be interconnected through the BEMS (Building Energy Management System), an automation system to optimize the energy efficiency of the entire institute guaranteeing the highest levels of comfort, quality and safety. The system is made up of sensors (BAC) through which it is possible to determine the real conditions of each space at that particular time and to supply the actual necessary energy requirements. In addition, the maintenance and management of the entire building-plant system (TBM) is simplified and facilitated (Figure 9).

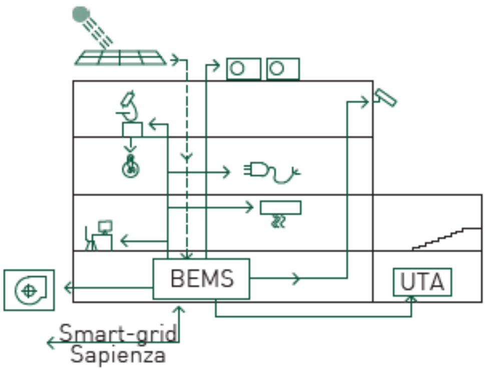


Figure 9. BEMS interconnection diagram.

4.3 Intervention strategies and technical solutions for the water resource management system

The five strategies aimed at the water resources management are:

- Increase in the permeability of soils and roofs;
- Strengthening of natural capital for seizure and storage of pollutants;
- Reduction of water requirements and management of rainwater in situ;

- Introduction of a system for the collection, treatment and reuse of rainwater;
- Introduction of a grey water recovery system;

Through the technical solutions it has been tried to intervene on the management of rainwater through their collection and storage in situ (Figure 10) and on the waste water treatment. Having a coverage area of approximately 1,800 m^2 available, the Hygiene building is able to capture approximately 630,000 l/year, almost two and a half times greater than the estimated requirement. Waste water treatment contributes to increasing the water resource. In summer periods when rainfall is almost zero, having a properly stored supply, preventing the formation of micro bacteria in storage tanks, is a strong and important resource. The two systems will have two different filtering procedures and uses. With adequate filtering, the recovered water can be used for irrigation of the green spaces inside and outside the Institute, as a heat transfer fluid for the air conditioning systems of the building and for cleaning the indoor and outdoor spaces.

Capture surface	1,796 m^2
Estimated need	264,000 l/year
Estimated water captured	620,000 l/year > than needed
Water tank capacity	17,550 l
Number of water tank	2 (7,830 l + 9,720 l)
Economic saving	340 euro/year

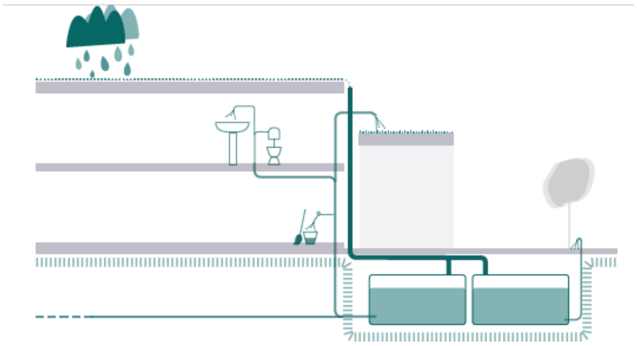


Figure 10. Rainwater capture and storage system.

The management, treatment and reuse of rainwater contributes to not overloading the sewerage system in the period of severe disasters, and it is also part of the measures necessary to eliminate waste and reduce consumption and increase recycling and reuse of natural resources. In order to be reusable for uses other than human consumption, rainwater, which is not drinkable, must come from the roofs of the buildings, through the adoption of collection, filter and accumulation systems.

5. Conclusions

Considering all the active and passive proposed interventions, the building energy label can achieve letter B, with a fossil primary energy equal to 67.1 kWh/m^{2}y with a halving in terms of energy consumption and a net increase in the renewable share. The intent of this project has been to highlight how much the actions on existing buildings can be decisive for the achievement of the increasingly urgent and community-relevant objectives of increasing the energy efficiency of building-plant systems through a coherent introduction of conversion systems. " energy from renewable sources, actions for a green and low carbon transition towards the virtuous closure of the product cycle and the computerization of the management processes of the various life stages of buildings, as well as the increase in benefits and the reduction of maintenance and management costs.

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