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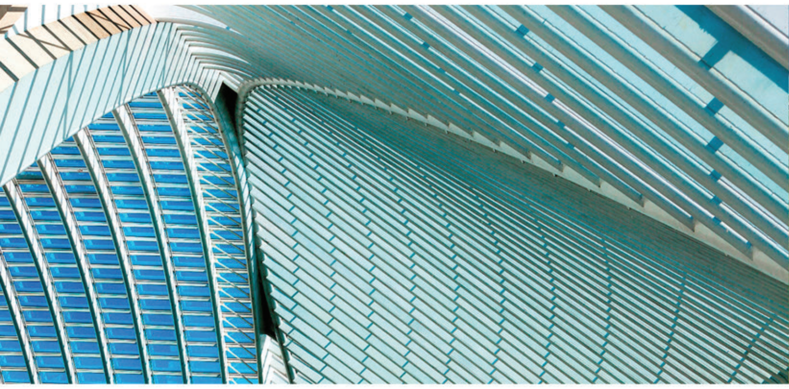

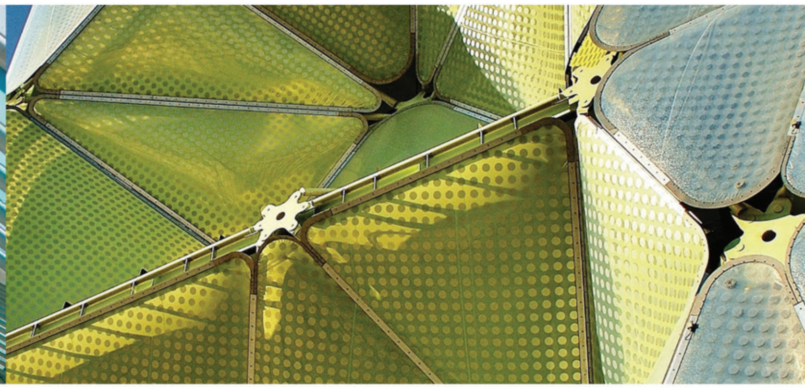

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Bioclimatic design and energetic requalification of existing buildings. An integrated approach.

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Abstract

The contribution is aimed to address the issue of sustainable energy requalification of public buildings, according to a technological and bioclimatic design approach, aimed to reducing air-conditioning needs even before increasing the efficiency of plants.

The main objective was to carry out a deep analysis of the buildings and of their relationship with the surrounding micro climate, in order to determine critical issues, limits and potentiality of individual building elements compared to the maintenance of the wellbeing indoor conditions.

The secondary objective was to pay special attention to energetical and economical sustainability of the intervention hypothesis. To this end, we proceeded by adopting an evaluation costs and benefits model, of the specific intervention categories, extended to the whole conditioning cycle (summer and winter) and over the entire life cycle of the buildings.

The work has highlighted the benefits achievable through the adoption of bioclimatic solutions aimed at optimizing the use of solar technologies. That under condition that is made a careful and constant evaluation of the design solutions.

Keywords: Bioclimatic design, sustainable requalification, dynamic simulation, solar technologies, indoor wellbeing, Solar shadings integration.

1. Introduction

In the field of requalification and improvement of energy performance of the existing building heritage, the most recent guidelines established by Directive 2012/27/EU of the European Parliament and of the Council on energy efficiency give the public sector a leading role to play. This is because the public goods represent a considerable - often under-used or un-used - share of the total housing stock and because the public sector has remarkable visibility and can therefore become a potential driver of dissemination of the energy efficiency culture among citizens. The same directive, when re-affirming the energy-saving objectives set by the European Commission’s communication "Energy 2020: A strategy for competitive, sustainable and secure energy" (COM (2010) 639), identifies the priority intervention objective of energy requalification of public real estate used for administrative and service activities (e.g. offices, schools, universities), which can be described as non-residential buildings (commercial and office buildings). It also introduces the additional objective of verification (and potential recovery) of a sustainable public finance, to be pursued through a careful analysis and assessment of the cost-effectiveness of individual interventions. This aspect was already introduced by Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings, where it suggested to take account, for the purposes of the identification of energy performance-improving measures, of various conditioning elements such as local climate conditions, the architectural and construction characteristics, the quality of air and indoor thermal environment, natural lighting, the use of passive elements of heating/cooling and shading and, last but not least, the cost effectiveness, in order to accomplish an optimal balance between the necessary investment and the savings accomplished during the building life cycle.

Recent studies conducted at a European level on energy consumption in the non-residential sector highlight its extreme variability, with values ranging between 100 and 1000 kWh/m2a per air-conditioned surface unit, based on the location, modes of use, construction techniques, types of air-conditioning and lighting installations and office equipment in use [1, 2] (see figure 1). They also show a constant increase in electricity consumption both due to the intensive use of HVAC to heat and cool rooms and to the use of artificial lighting and electrical equipment, such as to predict an increase in total weight from 42% in 2005 to 50% in 2030 compared to total energy consumption [3, 4]. In particular, the simple change of local climate conditions may produce, in a typical office building made with standard construction techniques and without prejudice to all the other factors, an oscillation of annual energy requirements ranging from approximately 73 KWh/m2a of London (medium climate zone), to approximately 79 KWh/m2a of Madrid (warm climate zone), to approximately 107 KWh/m2a of Tallinn (cold climate zone), as proven by Boyano et al. [5].

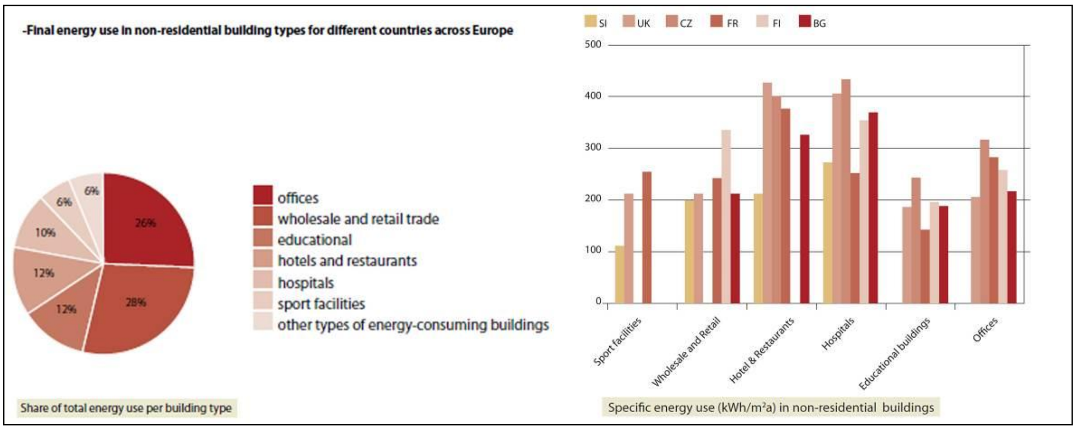


Figure 1: Percentage impact of energy consumption in the non-residential sector in Europe, broken down by uses and by country (source [2]).

Again at a European level research and applications are under way, in order to define and experiment the more appropriate technological solutions to accomplish the objectives of energy consumption reduction in the public building heritage, in order to pursue cost-effectiveness and efficiency of interventions. An example are projects RESSEEPE [6] and BRICKER [7], part of the 7th FP. The former, oriented to the demonstrative application of design and construction technologies for the improvement of energy performance of existing public buildings, sets a consumption reduction objective ranging between 50 and 65% with a limit spending equal to approximately 20% of the cost of construction from scratch of the same building, acting on the choice of the best technologies depending on individual contexts and buildings under review. The latter on the other hand aims at accomplishing and monitoring demonstrative applications of energy requalification of various types of public buildings: an administrative centre, a university building and a hospital. The project's objective is to demonstrate a 50% reduction in energy requirement by intervening via facade systems and innovative insulating materials, together with the use of high-performance fixtures. Outcomes of the project are two new prototypes: a ventilated covering system with insulating panels made by recycling fly ash from thermal power plants and a ventilated heat-recovery glazing unit (see figure 2).

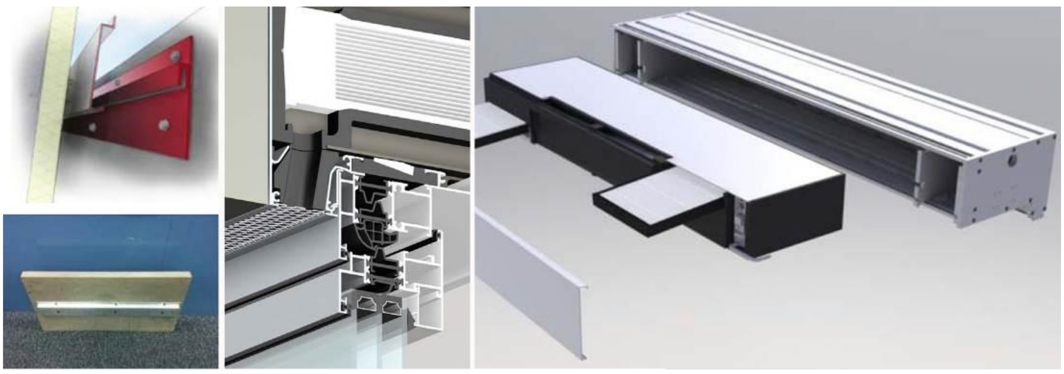


Figure 2: Some images of the prototypes developed as part of the project BRICKER: ventilated facade system and ventilated heat-recovery glazing unit (source: www.bricker-project.com/Technologies)

With reference to the Italian context, recent studies conducted on the energy behaviour of the non-residential building heritage highlight annual average energy consumption equal to approximately 147 KWh/m2a, 54% of which represented by winter heating, 29% by artificial lighting and the use of electrical equipment and 17% by summer heating [8]. On the latter point it should be noted that, given their very old age, these buildings are often not equipped with cooling systems, hence the impact of summer consumption may likely be subject to significant increments following the need to install new systems, also due to the recent increase in monthly average temperatures related to the of climate change phenomenon [9, 10]. This phenomenon is already present on the Italian territory because of its different climate conditions, so much so that, going from north to south, the above-mentioned requirements tend to shift from heating to cooling, despite not changing in absoute terms (see figure 3).

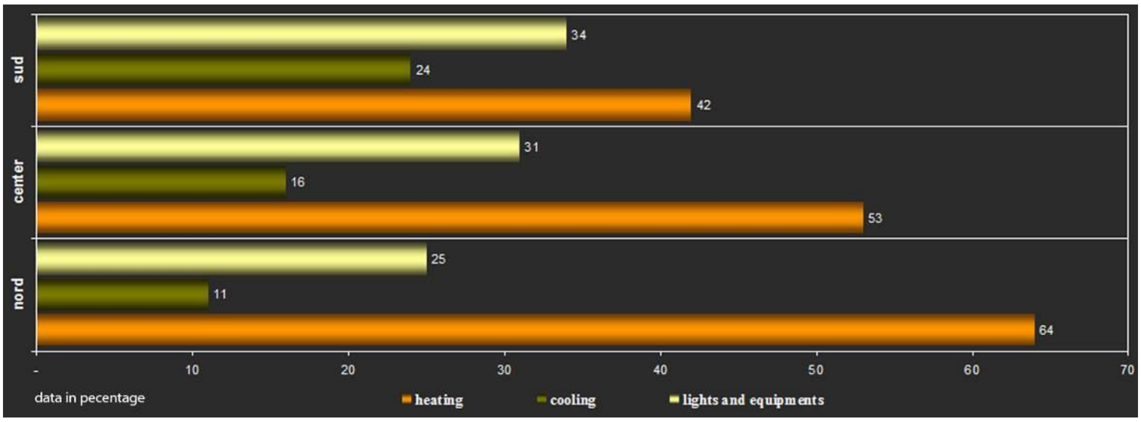


Figure 3: Break-down of the annual energy requirement of office buildings in Italy at the changing of the climate zone (data source [8])

The same studies also show that out of the most recurrent types of intervention for energy requalification, the least burdensome in terms of costs are, in the following order: the replacement of artificial lighting systems (8% of the total), the thermal insulation of enclosures (10% of the total), the installation of sun screens (14% of the total) and last but not least the replacement of glazing units (48% of the total). They eventually stress that in terms of achievable benefits following requalification interventions, direct interventions related to economic savings on the energy bill would amount to approximately 8% p.a., while indirect interventions resulting from the improvement of the environmental quality of office rooms would be more significant, with a resulting increase in productivity and reduction in sick leaves caused by the “sick building syndrome” [11]. Said benefits would appear to be quantifiable in a total reduction in staff costs of approximately 80%.

2. Objectives and subject of the study

In the light of the above, the study conducted intended to verify the possibility to apply the knowledge so far acquired to the energy requalification of the building heritage of the University d'Annunzio of Chieti-Pescara (IT), subject to a specific efficiency programme. More in particular, it intended to assess the cost-effectiveness of the specific intervention strategies, focusing on identifying some technological solutions that could improve its energy behaviour and in particular the indoor environmental quality (e.g. natural lighting, operating temperature).

As concerns the choice of the subject of study, within the broader building heritage of the University that is especially well-structured both in terms of building ages and construction techniques, the study focused on two buildings, one located in the Chieti campus and one in the Pescara campus. An in-depth analysis revealed that these two buildings were older and presumably less efficient from an energy perspective. In particular the Chieti building, former seat of the Rectorate, was built around 1970 on a design of the architecture firm BBPR (Banfi, Belgioioso, Peresutti, Rogers) that provided for the construction of a building compound made up of a series of block buildings of which the current one was the central core. The Pescara building, by contrast, was completed in 1990 following a complex reconversion work of three distinct commercial buildings into university campus. The reconversion project, made by arch. F. Donato, integrated said volumetric articulation and included two additional intermediate buildings joined by a gallery on the ground floor (see figure 4).

Figure 4: Views of the buildings under review: former Rectorate of Chieti (left) and Polo Pindaro in Pescara (right)

2.1 Typological and construction aspects

From an architectural point of view the Chieti building presents a symmetrical plane-volumetric articulation on square section, against which the extrados volume - housing the main entrance and the stairway-lifts block on the south side and the emergency stairways block on the E, W and N sides - leans. This gives access to the corridors connecting the main facade rooms (offices) and to the central core bordered by the corridors (classrooms, conference room). The facades are equally symmetrical and articulated by vertical bands, according to an alternation of fullness and void marked by fixtures and opaque closures. From a construction point of view the building's horizontal and vertical bearing structures are made of concrete (visible), the opaque vertical closures of brick masonry with airspace, the fixtures of iron and glass.

The Pescara building by contrast features an elongated plane-volumetric articulation, in which the three pre-existing square blocks (classrooms and offices) alternate with two stepped volumes housing the conference rooms. The ground-floor gallery connects the various volumes and accommodates the stairways connecting the upper floors. In terms of the energy behaviour, the glass-covered courtyards of the three main blocks are interesting, visually and spatially connecting the first two levels (ground and first floor). In this case the facades are also symmetrical in the three square blocks, divided by horizontal bands with a clear predominance of glazed surfaces and a significant projection of the first-floor volume. The two stepped volumes by contrast are mainly opaque, consistently with the indoor lighting requirements. From a construction point of view the building's horizontal and vertical bearing structures are made of concrete (visible in stepped volumes), the opaque vertical closures of brick masonry with weakly insulated airspace, the double glazing fixtures of aluminium (see figure 5).

Figure 5: Construction and termografic details of the buildings under study: former Rectorate in Chieti (left) and Polo Pindaro in Pescara (right)

2.2 Energy and bio-climate aspects

Both located at a north latitude of approximately 42° and at a longitude of 14°, one of the buildings is at approximately 150 m above sea level (Chieti) and the other at 0 m above sea level (Pescara). The reference climate zone according to the Köppen climate classification is Mediterranean (Csa), marked by a dry summer and a cold winter. This determines the need to alternately meet the heating and cooling requirements of the housing environments. For this purpose it is important to take into the right account the summer and winter solarisation of the rooms, for the resulting heating and lighting contribution to energy management and keeping of the comfort conditions inside the building [12]. From this point of view both buildings benefit from a good sun exposure, free from obstructions of both geomorphological and building type. An exception, for the Chieti building, is made by the shades carried by a embankment located along the NE facade and the own shades generated by the presence of the stairway blocks that, in particular in the main building (south), tend to partially reduce the winter solar gains by the SE and SW facades (see figure 6). As concerns orientation and solar exposure, the Chieti building presents itself with the diagonal line arranged along the N-S axis and the facades respectively pointed towards NE, SE, SW and NW. The Pescara building presents itself with the longitudinal axis (coinciding with the gallery) arranged along the E-SE/W-NW axis as well as the corresponding facades of the head building blocks, while the others are respectively exposed to N-NE (street side) and S-SW.

In order to identify the subsequent design solutions what is especially interesting, in addition to the predictable inadequate heat resistance characteristics of the opaque and transparent shells due to their old age, is the significant absence of sun protection systems on the more exposed glass fixtures (SE and SW in the case of Chieti, E-SE, S-SW and W-NW in the case of Pescara) and, vice-versa, the redundant presence of glass fixtures on the little sunlit facades (NE and NW in the case of Chieti, N-NE in the case of Pescara). These characteristics are typical of the buildings made during that and the following period, and at these latitudes they tend to cause over-heating conditions and summer thermal discomfort (the former) and excessive thermal dispersions that cannot be offset in winter, because of the exposure, by possible solar gains (the latter). Solar glare phenomena caused by excess solarisation add up to said phenomena, especially in the summer and especially in the exposures near the west (see figures 7 and 8).

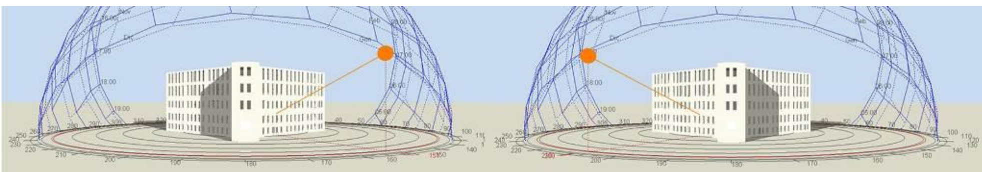
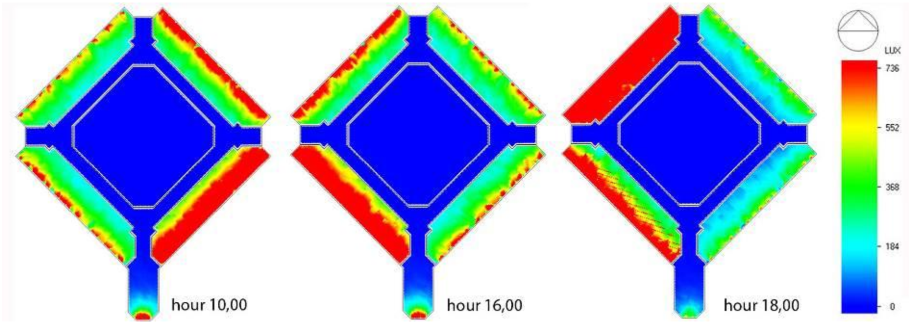
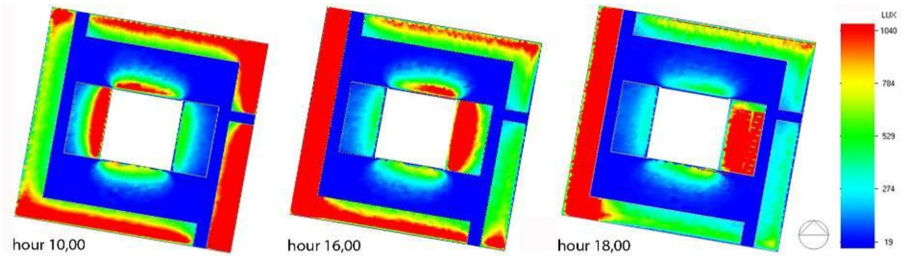


Figure 6: Shades projected at winter solstice by the main stairway block on the SE and SW facades, seat of the former Rectorate, Chieti.





Figures 7 and 8: Lighting maps of the indoor rooms at summer solstice, flat tipe, seat of the former Rectorate, Chieti (top) and building Polo Pindaro, block A, Pescara (below).

3. Methods and instruments

In the wake of the reflections and analyses above, we decided to develop the study through interventions on the enclosure which took account of the special climate conditions (Mediterranean zone), assessing its impact in terms of electrical-environmental improvement, starting from the implementation of more cost-effective construction solutions (see par. 1). For this purpose we used a dynamic-energy modelling of the two buildings in order to simulate subsequent changes in consumption and heat and light input, at the change of individual configurations. In terms of design strategies, we decided to start the thermal upgrading of the walls and outer shells, favouring the use of insulating materials with enough thermal inertia and vapour permeability, useful characteristics to favour displacement and mitigation of the summer heat load as well as the indoor-outdoor vapour exchange across the enclosure. An additional criterion for the selection of insulating materials was the content of enclosed energy (EE) used as an indicator of the eco-profile of the material [13, 14] and its environmental impact on the life cycle. A second element to focus on was whether or not external fixtures should be replaced, considering the high cost-effectiveness of the type of work. In this case the two case studies show different situations. In the case of the former Rectorate of Chieti the old age of the elements (more than 45 years) together with the low performance standards and lasting absence of any supplementary maintenance work and/or technological upgrading did not leave room for any possible alternatives. In the case of the Pescara Polo on the other hand, the younger age (25 years) and the better construction and performance standards (existing double glazing) suggested to consider two possibilities: replacing either the one frame or the entire fixture. In the light of the reflections made on the heat and light load caused by direct exposure to solar radiation in housing environments, a third element we focused on was the configuration of the glazed surfaces in order to improve their capacity to control solar inputs.

More in general the analysis covered how to exploit the free winter input avoiding summer overheating, without compromising the natural lighting of the rooms.

4. Results of the analysis

The set of technological and bio-climate considerations and assessments described above, led to develop a number of design hypotheses which concerned both the functional and distributional aspects and the construction aspects.

In the case of the Chieti building the favourable exposure to the sun of the SE and SW facades suggested to change the indoor layout introducing a buffering gap next to the facades which would act as thermal buffer.

Said gap would create a greenhouse room, with direct gain, multiple effects (see figure 9). In winter it stabilizes the temperatures of the background housing environments, since it naturally develops an intermediate temperature between indoors and outdoors thanks to the solar heating. The introduction of a second fixture next to the external one improves the thermal behaviour of the enclosure since the window-gap-window system tends to behave as a double-skin facade. In summer the recession of the housing environments from the external surface reduces its overexposure to direct solar radiation improving the heat and light comfort. In order to reduce the incoming radiation load, the external fixtures were provided with horizontal cantilevers. These were appropriately lowered from the upper edge of the fixture and extended above the corridors, to act as light shelves. Made of high-reflective material (e.g. Radiant Mirror Fillm® by 3M, Spectralight® Infinity by Infinity Motion SRL), they allow to carry the incident light to the work environments improving their natural lighting [15]. In the NE and NW facades, little sunlit, we decided to reduce clear surfaces, in order to curb the indoor-outdoor heat exchange. In terms of heat performances, but also costs, the clear surfaces yield less thermal resistance (ca. 1/5) and greater cost per unit of surface than matt ones (ca. 5 times), with reference to standard technological solutions. The solution was also effective in order to reduce energy consumption with a specific contribution of ca. 3%. The NW facade, subject to excess summer radiation, was however provided with external vertical screens in order to reflect the summer radiation without compromising access to winter radiation, albeit minimal. The natural lighting of the environments was still ensured by the introduction of light shelves.

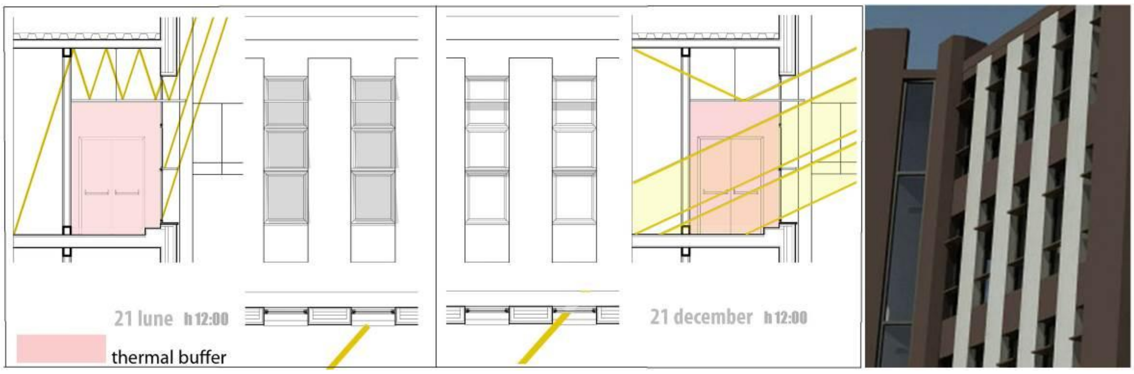


Figure 9: Design solution of the SE and SW facades, seat of the former Rectorate, Chieti.

In the case of the Pescara building the different characteristics of planimetric organization and solar exposure of the facades suggested to pay attention to the control of summer sun inputs through the fixtures, especially in environments overlooking S-SW (mid-day hours) and W-NW (afternoon hours). In the first case, given the significant solar altitude, it was enough to add one horizontal cantilever built in the fixture and placed in order to also act like light shelf, in the same way as the previous case study. The ground-floor classrooms are an exception, because they are already protected by the first-floor cantilever. The presence on the second floor of a level roofing, generated by the volumetric extension of the first floor, then suggested to experiment the introduction of a solar greenhouse, approved by the local building regulations, and to test its potential energy and functional advantages (increase in housing space). In the second case, in addition to the horizontal cantilever, it was also necessary to introduce vertical screens, in the form of deciduous vegetable elements (hedges and green walls) in compliance with the thermal improvement system adopted with the covers (walkable green roof). The same solution of introduction of the horizontal cantilever was adopted for E-NE facades, to protect from late-morning radiation. Lastly, an extrados cover was introduced next to the inner courtyards to protect them from the summer zenith radiation.

For the purposes of improving the thermal performance of matt enclosures, the fact that just slightly changing the openings and vertical connections would make available easily accessible covers at various floors, suggested to build open green roofs so as to obtain a significant increase in usable surfaces and capture and control storm water, in addition to achieving insulation and thermal inertia objectives (see figures 10 and 11).

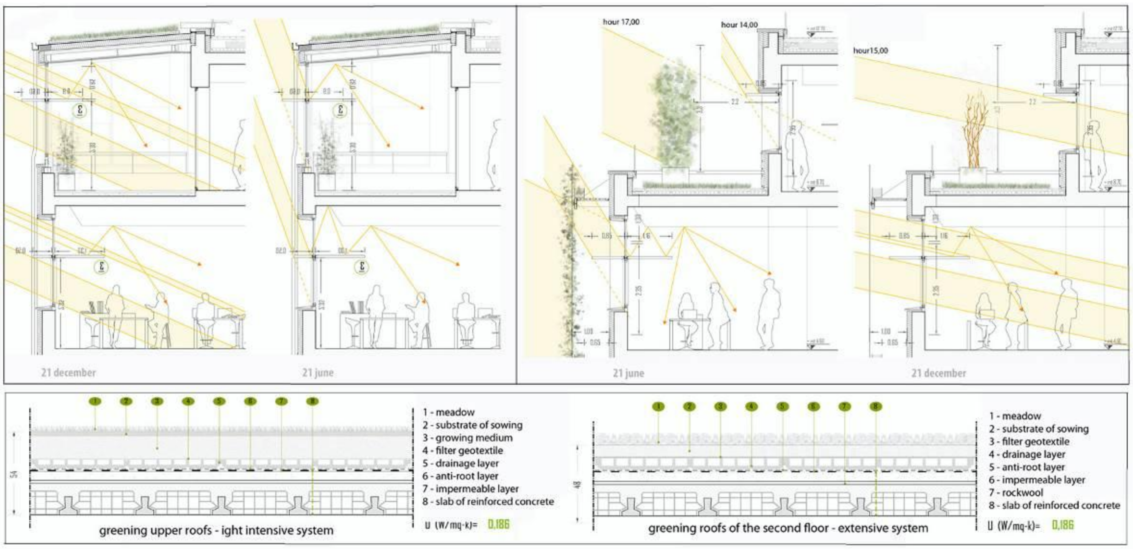


Figure 10: Design solution of the S-SW (left) and W-NW facades (right) and constructive details of green roofs, building Polo Pindaro, Pescara

Figure 11: General view of the new configuration of the facades and roofs, building Polo Pindaro, Pescara

5. Final consideration

From the energetic point of view, all the identified interventions were subjected to a numerical simulation, made through the elaboration of specific processing, conducted with the aid of modelling tools based on dynamic regime, and by relating the summary data to the air-conditioned surfaces. The results of analytical assessments helped to confirm the initial hypothesis, especially as regards the savings achievable through the improvement of bioclimatic envelopes. In the case of the building of Chieti, the potential reduction scenario It would stand at around 40%, allowing to switch from the current 134 kWh/m2a to about 81 kWh/m2a. Differently, In the case of the building in Pescara, the potential reduction scenario It would stand around 32%, allowing to switch from the current 110 kWh/m2a to about 75 kWh/m2a. In this case appears limited, as assumed, the contribution due to the replacement of the entire fixtures (scenario 3) respect to the replacement of only aluminium frames (scenario 2), which would produce a contribution of approximately 1%, in front of an significant increase of costs. Conversely, appears rather important the contribution due to the introduction of solar screens (scenario 4), which could provide a specific reduction of energetic requirements by about 9% (see figure 12).

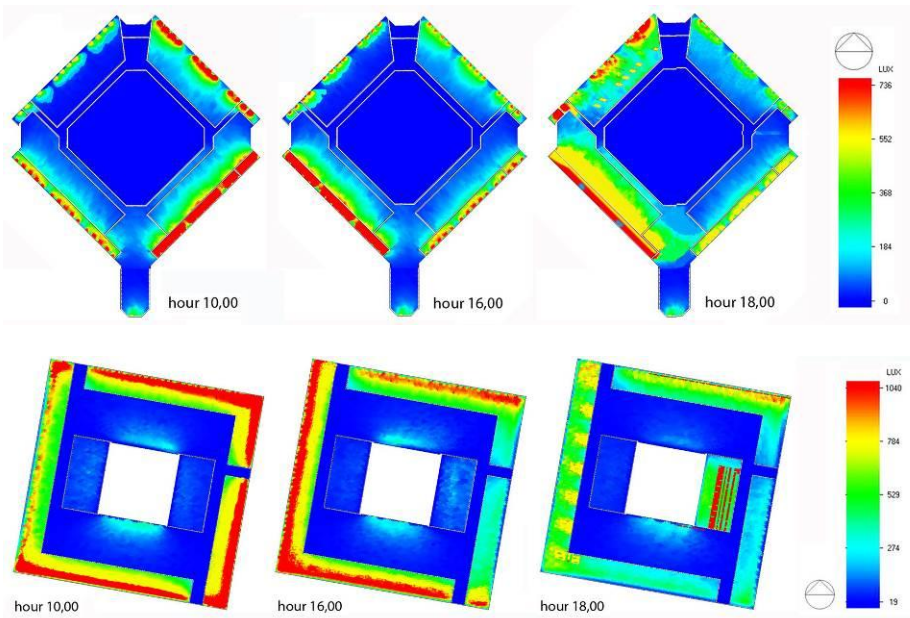
building	current total energy needs	conditioned surfaces	current needs for sq.m.	future needs for sq.m.	potential reduction
	KWh/a	sq.m.	KWh/sq.m.-a	KWh/sq.m.-a	%
Chieti	658.778	4.900	134,44	80,61	-40%
Pescara	1.619.651	14.748	109,82	74,68	-32%

building	current needs	future needs							
		scenario 1		*scenario 2*		*scenario 3*		*scenario 4*	
	KWh/sq.m.-a	KWh/sq.m.-a	%	KWh/sq.m.-a	%	KWh/sq.m.-a	%	KWh/sq.m.-a	%
Pescara	109,82	85,66	-22%	84,26	-23%	84,00	-24%	74,68	-32%

Figure 12: Results of the energy simulation of the different scenarios of intervention hypothesized (Design Builder data)

More generally, from the point of view of the visual wellbeing, the introduction of solar screens joined to the light shelves it would seem to produce in both buildings a better control of the radiation and illumination conditions of the internal environments, and thus a mitigation of the dazzle and dis-comfort situations found in the analysis. This without significantly reducing the amount of natural light and the visual quality (see figures 13 and 14).

In conclusion, the next goal of the study will be to refine the conducted analysis with the integration of additional aspects concerning the durability, the serviceability and the cost-benefit analysis of the specific technologies. The future realization of the intervents, planned as part of the energy improvement program of the University's buildings, will provide the opportunity for a monitoring of the achievable performance and to check the reliability of simulations conducted.



Figures 13 and 14: Lighting maps of the indoor rooms at summer solstice after the application of the design strategies, flat tipe, seat of the former Rectorate, Chieti (top) and building Polo Pindaro, block A, Pescara (below)

6. References

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