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Sustainable Requalification: Hemp, Raw Earth, Sun, and Wind for Energy Strategies in a Case Study in Naples, Italy

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Received: 16 October 2019; Accepted: 26 October 2019; Published: 4 November 2019

Abstract: This paper highlights the development of strategies using a green approach that can be adopted to manage interventions to promote energy efficiency. It focuses on the result of a case study carried out on an existing residential building located in Naples, Italy. The green methodology adopted in this study met the needs and requests of the building owner, who asked for natural materials. We assessed the possibility of maximizing achievable thermal energy savings and hygrometric behavior, starting from the climatic characteristics. The first step was to evaluate the aspects related to sunshine, thermal inputs, natural lighting, and natural ventilation, and prevailing winds. Subsequently, the casing was redesigned with the aim of minimizing energy consumption by using natural materials. Such materials added value to the project by combining high performance and considerations of the residents' health. The objective here was to identify strategies for the well-being of residents both in winter and summer, by reducing energy consumption and installation management costs as well as increasing livability.

Keywords: energy requalification strategies; hemp and raw earth; green methodology; passive air-conditioning; reusable materials

1. Introduction

Today, there is a growing awareness of the multitude of ways by which building designers can exploit natural resources and renewable energy to create sustainable buildings [1]. At the same time, household residents are increasingly determined to enhance their quality of life, and natural solutions often offer the best way of achieving this goal [2]. For these reasons, an accurately designed bioclimatic approach, using natural sources for construction elements and energy, is worth considering, and it would also have methodological value for existing buildings, such as in the case study presented in this paper.

The United Nations Environment Program, according to the U.S. Department of Energy and the European Commission, estimates that buildings consume about 40% of global energy, 25% of global water, and 40% of global resources. Buildings are also responsible for about one-third of global greenhouse gas emissions [3].

In 1976 in Italy (the country of the case study), the first law regarding energy savings was issued (Law 373/1976). As reported in the Italian Census of 2011 (ISTAT data, 2011), about 63% of all houses were built before 1971 and were thus done so without considering any energy design criteria. This fact highlights the need for remediating measures to be taken on existing buildings in Italy to increase their sustainable performance. "Sustainability refers to the concept of coexistent of man and nature in harmony. Sustainable Architecture has become a philosophy for many generations, as the survival and well-being of mankind depend on nature, its elements, and resources" [3]. Therefore, interaction with the external context must be considered when attempting to achieve a balance between people and their inhabited space.

Bioclimatic behavior, more than being an added value to a project, is a founding requirement that belongs to the tradition of some historical buildings, which has been lost in the modern age when new technologies have changed structural solutions. "Environmental issues became relevant in modern architecture around the middle of the 20th century when the public became increasingly aware of the adverse effects of technological innovations of the industrial era on the environment" [4].

The interactive mechanisms between a living space and the external environment can be designed in a scientific way, by which natural materials are added for comfort and thermo–hygrometric well-being [5].

The case study presented in this paper exemplifies how designers and residents can work toward a common goal. We focused on an existing apartment located in a multistory building in the Capodimonte district of Naples. The Mediterranean climate of the city makes the sun a no-cost resource that is available for use in winter but which must be counteracted during summer.

Energy requalification was the object of the intervention. We proposed to transform the existing apartment into a bioclimatically passive unit with an active energy balance. To govern the energy transformation, climate resources and biomaterials were used.

A redesign of the building's plant system was necessary and was developed sustainably through natural materials and solutions. Natural materials for construction, in fact, are increasingly used due to their potential to regenerate internal spatiality with a high technical level of consistency that is a profound innovation [1].

This project proposal should be pursued for entire buildings. However, even if such measures only begin to be taken at the level of individual apartments, it will at least mark the beginning of sustainable project practices.

Sustainable building design must consider the choice of construction materials [6]. The sustainability of a building, in fact, is not only achieved through an energy-efficient design, but, above all, through the appropriate choice of materials which, in addition to possessing characteristics of high thermophysical performance, have a life cycle with little impact on the environment, from the time of their production up to their disposal [1,3,7,8].

As an intervention project, this case study has the methodological value of pursuing tangible energy requalification that is also a sustainable and innovative green approach.

2. Bioclimatic Approach Between Natural Resources and Green Materials

The industrialization of productive processes made in the previous century involved all sectors of industry, including building design and construction. In fact, it is very easy to find buildings with the same structural, architectural, and material characteristics in extremely distant climatic and cultural contexts. The immense amount of construction activity that continued until the late 1970s of the 20th century resulted in buildings in Naples, as well as throughout Italy, with very energy-consuming technological systems because of light perimetric walls and reinforced concrete structures. Real estate parks built between 1946 and 1971 represents 32% of all buildings in Italy (ISTAT data 2001) [1].

Today few examples are exceptions to the many that were constructed during that period, for which little attention was paid to energy-efficient design. In addition, buildings constructed between 1972 and 1991 constitute 30%, and those built after 1991 make up 19% of all buildings in Italy (ISTAT data, 2001). During these periods, the problem of energy savings started to be taken more seriously, and the first technological solutions were developed by making outer walls substantially thicker. In addition, the problem of thermal bridges corresponding to wall-structure nodes began to be solved.

The present case study was done on a building constructed during the 1970s, which belongs to the first temporal range, and like many buildings of this period, it is unsustainable from an energy point of view. The building was designed in the Neapolitan context of the post-World-War-II years and, thus, without any energy design criteria for the Mediterranean climate in which it is located. Today, the importance of a bioclimatic approach for building design has been rediscovered, not only to passively contain thermal dispersions but above all, to exploit the energy resources of the surrounding environment [9]. The Mediterranean climate is typical of all the areas of the western coastal part of Italy (including Naples) and is characterized by long periods of heat and drought during the summer and rainy winters with mild temperatures. The Mediterranean region lies in a transition zone between the arid climate of North Africa and the temperate and rainy climate of Central Europe, and it is affected by the interactions between mid-latitude and tropical processes [10]. In general, the presence of the sea contributes to reducing the daily and annual temperature ranges below 20 °C. For this case study, in addition to the usual analysis of the actual situation based on measurements and construction information of the building, preliminary evaluations were made on the climatic and geographical factors that characterize the place of intervention to verify the possibility of passively exploiting the available environmental resources. This bioclimatic approach characterized the project and intervention method. The sun and wind are two natural resources available as free energy supplies.

The bioclimatic approach is an aspect of green building, which considers the health of the inhabited space.

The use of green materials, some of which have been used in construction for millennia, allows for achieving high thermal performance while respecting ecological considerations, which is a necessary step towards sustainability. So, it is possible to have comfortable passive air-conditioning while also responding to people's increasingly felt need to live in a healthy environment.

Raw earth, hemp, and wood represent traditional, natural, non-toxic, and reusable materials, from which products can be obtained made using modern methods, which are an innovation in traditional methods. They are raw materials that are available in nature, are easy to find, and have minimal impact on the environment.

Little energy is used to produce bricks made of raw earth; the material is air-dried in the sun. In fact, "raw" production chains reduce energy consumption, and climate-altering CO_2 emissions are reduced to about half compared with production methods that involve high-temperature thermal transformations [11]. Moreover, raw earth is a material that can be recovered and repeatedly reused. Since it is an eternally reusable resource, it will never become a waste. [12].

Hemp, according to many researchers [13–16], represents the most valuable and versatile natural resource in the world. It is characterized by very high productivity in terms of both growth speed and biomass, especially when compared with other species used in construction that are cultivated in temperate zones, such as spruce or cork oak. Its cultivation does not require considerable water consumption or the use of pesticides and herbicides, thanks to its antibacterial and antifungal properties. It is among the most powerful and effective phytopediatric plants. Further, it captures four times the average amount of CO_2 stored by trees, and, if used in construction, it retains this property. In terms of waste reduction and maintenance, hemp is known for its high durability. Some examples of hemp's durability include its use for military sheets, mummification, canvases for artists, and cordage, due to it being impervious to insects and rodents without the use of any pesticide treatments.

These are not the only interesting properties of these materials. Compared with artificial construction materials, the natural ones used for the intervention in this case study have very little environmental impact considering their life cycle assessment (LCA). LCA is a methodology to evaluate the impacts of products and services on the environment and human health during their entire life; this is also called a cradle-to-grave approach since the evaluation is performed from the extraction of raw materials to product disposal [1].

Since that they are 100% recyclable, natural materials respond perfectly to the increasingly urgent demand for a circular economy. The choice of these materials is also linked to their ability to interact with the thermo–hygrometric conditions of indoor environments, as they are characterized by their high capacity to absorb or release humidity and heat [12]. This function eliminates the need to compensate for thermo–hygrometric variations with humidification, dehumidification, and controlled mechanical ventilation systems, which increase construction and energy costs related to their operation and necessary periodic maintenance. Thanks to its high thermal inertia, clay reduces temperature fluctuations. It absorbs excess heat generated from windows, appliances, and people, and then releases it when necessary [13]. In this way, it is possible to achieve comfortable passive air-conditioning with considerable energy savings in winter and, especially, summer. Raw earth is able to keep the indoor air humidity constantly around 50%, which is the ideal condition for humans. In fact, 1 m^3 of raw earth could accumulate up to 1 m^3 of water vapor while maintaining its dimensional and resistance characteristics [17]. When the air becomes too dry, clay transfers its stored humidity to the environment with a capacity over 50 times that of common cooked brick. This feature, combined with high breathability, prevents the formation of condensation on internal surfaces and facilitates the release of excess moisture compared with other "inert" materials, such as plasterboard, wood, and many other insulators that do not have these capabilities. The materials chosen for this project respond to the demand for healthy living spaces. In particular, raw earth, thanks to its antistatic properties, does not retain dust, thus reducing the development of mites and, therefore, the various health problems related to their presence. Raw earth can absorb high amounts of moisture, preventing the formation of mold, and thanks to its alkaline pH, it limits the onset of respiratory diseases such as asthma and allergies. According to a study by Prof. Schneider of Munich, raw earth eliminates bad odors that are transported by water vapor and reduces 98% high-frequency electromagnetic radiation. Furthermore, buildings equipped with controlled mechanical ventilation systems and global air-conditioning can cause diseases that fall within the description of the so-called sick building syndrome (SBS), a symptom that has been recognized by the World Health Organization (WHO) since 1986.

In summary, the components chosen for the project were:

- Raw earth blocks, composed of 90% clay and natural fibers (hemp, barley straw, rice straw, rice husk, and wood shavings), to improve properties related to mechanical strength, water, and frost (Figure 1);
- Insulating panels made of Italian hemp fiber, thermo-fixed with corn starch (Figure 2);
- Panels and slabs of raw earth pressed and reinforced with natural wood fibers and jute, for the dry construction of partitioning walls, counter-walls, and false ceilings;
- Thermal break profiles in wood–cork–wood layers, for drywall frames;
- Clay background plaster, river sand, and straw fibers;
- Finishing plaster of clay and colored natural aggregates.

Figure 1. Raw earth block used in the case study.

Figure 2. Reinforced hemp insulation panel used in the project.

3. Case Study

The case study took place on the last level of a three-story building in a residential area of Naples (Capodimonte district) that is not densely urbanized. The structure has a reinforced concrete frame. The infills on the perimeter, of variable thickness, are made of a double-wall, each 8 cm thick. The outer line is made of perforated brick, while the inner line is made of lapillus blocks. The internal and external finishes are with civil-type plaster. When the audit inspection was performed, the lapillus lining and the original fixtures had already been removed, leaving the external anodized aluminum cover as a temporary closure. The heating system consists of a standard gas generator with radiator terminals. There is also an air conditioning unit.

A preliminary energy evaluation was necessary to more precisely understand the starting condition of the building. From this analysis, it was possible to prioritize the most energy-intensive elements of the envelope, limiting the use of the installations. Furthermore, after the identification of the technically and economically possible interventions, the energy analysis of the current condition allowed for a cost/benefit evaluation of the proposed intervention. The energy evaluation was performed by calculating the asset rating conditions, thereby considering the current technical regulations for the calculation of the energy needs of the dwelling. The evaluation was carried out with PAN 7.0 software.

The graphs below (Figure 3) clearly indicate the dispersion percentages of each element of the envelope and the energy consumption requirements for the various services: heating (red), cooling (blue), and Domestic Hot Water DHW (green). It was clear that heating was the most important factor to consider.

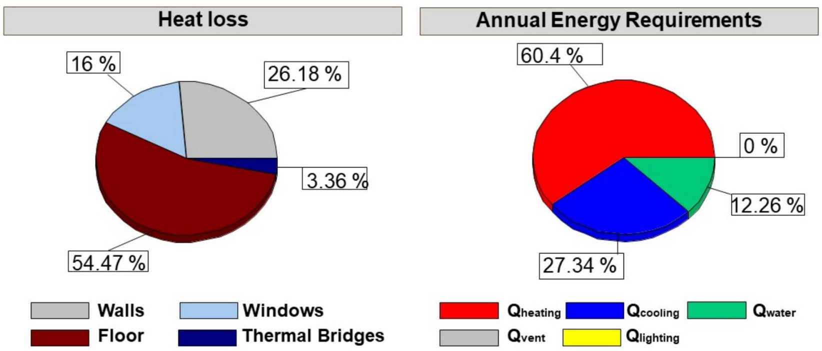


Figure 3. Indication of the dispersion percentages of each element of the envelope and energy consumption requirements for the various services.

An evaluation of the building's environmental context was carried out. In particular, we focused on sun positions and winds during the year.

3.1. Sun Study

Knowledge of the apparent path of the sun in the sky is very important to verify the real conditions of illuminance and shading of a building, as well as any systems necessary to exploit winter inputs while avoiding overheating in the summer.

Figure 4 shows the solar diagram for the reference latitude, enlarged to a wider area, so that the orientations and obstructions on an urban scale are clear "SunEarthTools", a free online program, was used for the simulation. The building, which has an almost rectangular shape, is roughly oriented with the longer side in the direction of S/SE-N/NW. This position is not optimal because it tends to not take full advantage of the sun during the winter period while being subjected to strong summer radiation, especially on the lateral fronts (Figure 5).

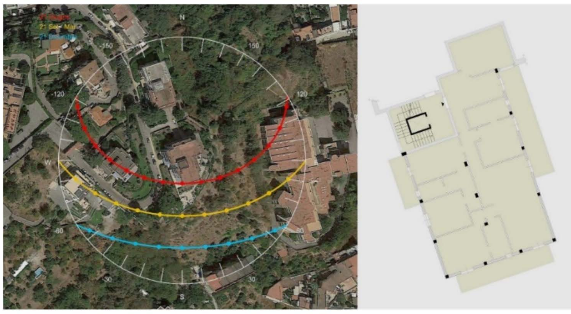


Figure 4. Sun chart, building position with respect to the urban context, and building plan.

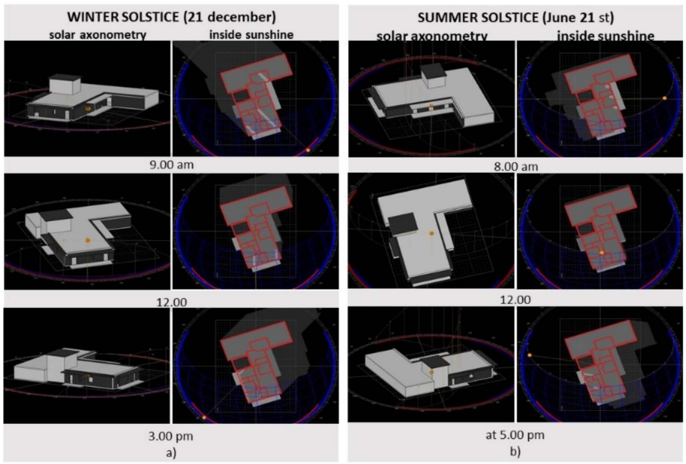


Figure 5. Solar axonometry and inside sunshine for winter and summer solstices. (**a**) Rooms facing east and west are not very sunny. The south-facing rooms are satisfactorily sunny. Existing overhangs do not limit the entry of solar radiation. (**b**)The south-facing rooms are optimally shielded by direct radiation, while those in the east-facing rooms receive solar radiation only in the very early hours of the morning (with medium-low inputs). Rooms in the west may have overheating problems.

The rooms on the side front, due to the specific position of the openings, are scarcely sunny in winter. This is evident in the spaces facing the east front. Further, rooms located on the west front in summer receive a very high amount of radiation, causing overheating. Even the flat rooftop contributes to increasing both dispersions and overheating (Figure 6).

The previously conducted analysis clearly showed how the present shading structures (gutters and projections) are not sufficient to guarantee adequate shading for the various conditions. For this reason, it is advisable to use mobile screening systems, such as sunshades or fabric curtains, that can cope with radiation in the hottest periods so as not to limit the entry of radiation during periods of greatest need.

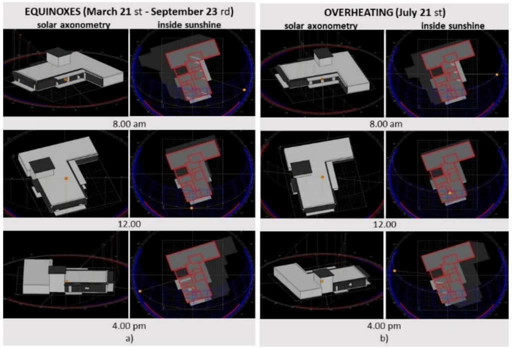


Figure 6. Solar axonometry and inside sunshine for equinoxes and overheating time. (**a**) Rooms facing east and west have a fair amount of sunshine. South-facing rooms have a fair amount of sunshine only in the morning because the roof overhang limits the entry of the sun in the central hours of the day. This limitation of free solar energy is more restricted in March. (**b**) Rooms with the greatest overheating risk are those to the west, as they are completely exposed to solar radiation and without protection.

3.2. Natural Lighting

The evaluation of the quality and quantity of natural light available in an environment is of fundamental importance, not only from an energy point of view but also from a psycho–physical wellness perspective. In practice, the presence of a good amount of natural light leads to both a reduction in electricity consumption and improvement in the quality and livability of interior spaces.

The calculations carried out to correctly assess the lighting primarily related to the quantification of the average daylight factor, that is, the minimum amount of daylight required in each indoor environment and, subsequently, the verification of the illuminance, or the maximum amount of internal lighting, so as to verify the possible presence of glare phenomena. The graph with the isolines made with VELUX Daylight Visualizer software shows how many rooms present very low daylight factors, even in those spaces characterized by a fair level of the daylight factor (DF), as there are pockets completely lacking adequate lighting (Figure 7).

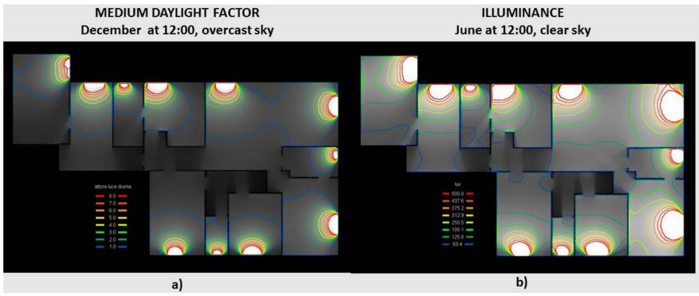


Figure 7. Graphs of medium daylight factor and illuminance in winter and summer. (**a**) Many rooms have very low daylight factors, and in some areas, they completely lack adequate lighting. Therefore, it is advisable to use light colors for the interior finishes to increase the reflected light. (**b**) In some rooms, glare phenomena occur (white areas). It is advisable to use light-colored internal curtains to mitigate the light contributions when necessary, without preventing solar radiation from entering.

It is impossible to correct this fault because of the requirement of respecting the position and the size of the existing openings. This is why it was decided to use light colors for the interior finishes to increase the reflected light and, even if only by a little, the value of the DF (daylight factor).

3.3. Natural Ventilation

The analysis focused on determining the dominant winds, both in winter and summer, by identifying and classifying them through directions and corresponding intensities (Figure 8). The evaluation was based on data collected from various weather stations in the area.

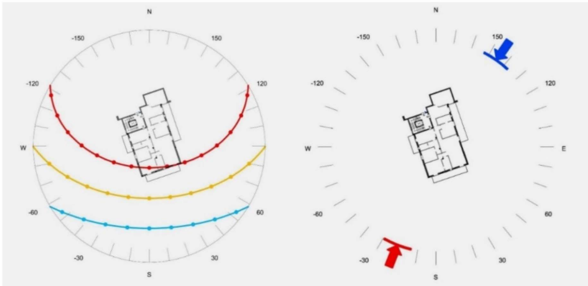


Figure 8. Graphs of the sun and wind charts for building.

The case study focused on summer ventilation only as a function of the natural cooling of the interior spaces. For this, it is necessary that the openings are positioned on opposite sides of the structure and that there are few possible obstructions between them, which could slow down the flow of air coming from the outside.

Natural ventilation also has a significant role in the case of insulation from the inside because it allows the wall structures, which have accumulated heat during the hours of the day, to discharge it during the night hours, always maintaining a high storage capacity. This is fundamental because, vice versa, this capacity would be lost, and overheating phenomena could be triggered.

Because of the position of the windows and the principal direction of winds, the rooms facing the south side and the living area enjoy good air circulation. The others, both due to distribution choices that tend to create a closure between the east and west fronts and to single facing configurations, are more critical. A new design for the openings in the central partition could improve internal air circulation.

4. The Objective of the Intervention, Results, and Comparisons

The intervention aimed to assess the behavior of both the opaque and transparent components of the vertical envelope and the roof to define the energy needs for heating and cooling the building and to integrate them with the help of renewable energy sources.

The thermal insulation intervention was carried out completely from the inside due to the impossibility of working on the facades and the extrados of the flat roof.

Insulating an air-conditioned space from the inside poses a series of problems in relation to three fundamental aspects. The first one is optimal insulation from both heat and cold. Moreover, regarding the summer scenario, it is necessary to avoid heat being produced inside the house, which could lead to situations of thermo–hygrometric discomfort. The second aspect is correct humidity management both in winter and summer, using systems that manage the disposal of excess water vapor. The last one is the very high internal surface capacity of indoor surfaces, which can mitigate internal overheating phenomena.

The proposed thermal improvement intervention, in addition to the use of insulators with excellent winter and summer performance, used clay finishes that can increase the internal periodic capacity (in some cases, it can exceed 45 kJ/m^{2}K) and naturally regulate the internal humidity levels with an antibacterial action. The internal periodic water capacity is an index of the inertial behavior of a wall relative to the thermal stresses coming from inside and outside the building. In a Mediterranean climate, it is essential to keep these parameters under control when working from the inside. The Italian Minimum Environmental Criteria (Criteri Ambientali Minimi CAM) have introduced this parameter, quantifying a minimum threshold of 40 kJ/m^{2}K.

Regarding the transmittance values of the opaque vertical envelope, since the internal lining of the existing infill had been eliminated, it was possible to proceed so as not to create unnecessary and harmful thermal micro-bridges.

The project hypothesis foresaw internal insulation that can be synthesized in the following manner:

- Insulation of the perimeter walls with insulating panels (thickness of 8 cm, density of 100 kg/m^3, and thermal conductivity of 0.039 W/mK) anchored to the existing external cover and a new internal lining of raw clay bricks (12 cm thick). The interior finishes were accomplished using plaster and smoothing in clay.
- Insulation of the structure with reinforced concrete that had panels (thickness of 2 cm, density of 100 kg/m^3, and thermal conductivity of 0.039 W/mK) glued to the underlying surface.
- Wall insulation towards the stairwell (thickness of 2 or 4 cm, density of 100 kg/m^3, and thermal conductivity of 0.039 W/mK) fixed to the wall behind.
- Insulation of the roof slab (thickness of 8 cm, density of 40 kg/m^3, and thermal conductivity of 0.039 W/mK), laid inside a frame with a thermal break plywood cork–wood structure.
- Dry partitions consisting of a thermal break frame and pressed earth panels. Inside, insulating panels were inserted (thickness of 5 cm, density of 40 kg/m^3, and thermal conductivity of 0.039 W/mK) and outside shaving with clay plaster on both sides (Figure 9).
- Aluminum frames with a thermal break, with Uf = 2.22 W/m^{2}K, and Uw = 1.10 W/W/m^{2}K.

Figure 9. Supporting substructures for the internal walls.

For the different layer distributions, the thermo–hygrometric verifications required for the national regulations were carried out along with the evaluation of the thermal bridges between the various structures and sections (Figures 10 and 11).

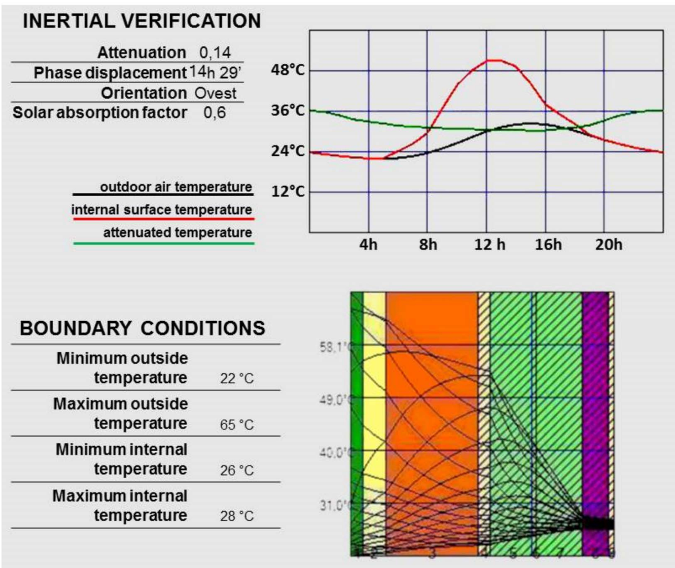
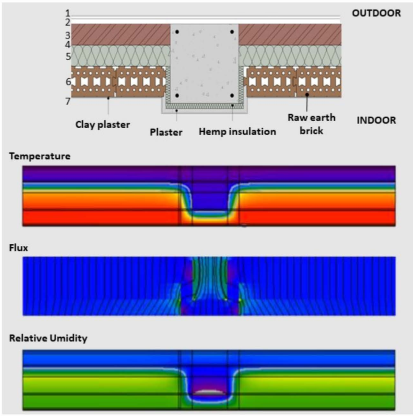


Figure 10. Wall inertial verification and boundary conditions.



	S [m]	r [kg/m³]	l [W/mK]	C [J/kgK]	m [-]	Ms [kg/m²]	R [m²K/W]	SD [m]	a [m²/Ms]
External laminar layer							0,04		
1. External clinker flooring	0,01	1500	0,7	1000	1	15	0,01	0,01	0,467
2. External plaster	0,02	1800	0,9	1000	1	36	0,02	0,02	0,5
3. Perforated bricks th.8cm	0,08	775	0,4	836,8	5	62	0,2	0,4	0,617
4. Smoothing mortar	0,1	1390	0,4	1000	10	13,9	0,03	0,1	0,288
5. Hemp insulation	0,08	100	0,039	2300	3,9	8	2,05	0,31	0,17
6. Raw earth bricks	0,12	1450	0,25	1100	10	174	0,48	1,2	0,157
7. Interior finishing plaster	0,003	2000	1,1	1000	7,5	6	0	0,02	0,55
Internal laminar layer							0,13		

Figure 11. Wall stratigraphy and thermal properties: infill pillar thermal bridge correction with hemp insulation.

In the project hypothesis, the envelope gains transmittance values well below the relative legal limits for 2015. It also passes from the E energy class to the A4 class (according to the Italian Law D.M. 26/06/2015).

In particular, the heating requirement was reduced by 66.8%, and the cooling requirement was reduced by 63.4%, while the energy performance index (Heating +Cooling + DHW) was reduced by 62.7%.

The savings estimate was made considering the economic recovery time of the intervention (less than 10 years), as well as the consumption relative to the calculated energy demand and the pre-existing plant system. In this case, it consisted of a standard gas generator with radiator terminals and an air-conditioning unit. Therefore, the average costs of gas and electricity were considered.

The project plant system, on the other hand, was sized for each environment and based on global thermal loads. It is a hydronic-type heating and cooling system that has a heat pump generator with an 8 kW single-phase outdoor unit and a 40 °C delivery temperature.

For the DHW, a second heat pump with a 260 L water heater and coil was considered for possible integration with a solar thermal panel.

The solution was clearly improved for three principal reasons:

- Greater phase shift of the envelope in intensive heat periods, as in summertime.
- Lower thermal transmittance in intensive cold periods, such as wintertime.
- Greater thermal resistance of the insulating layer.

The use of artificial air-conditioning systems is predicted to be limited to a minimum because of the ability of the chosen materials to interact with the thermo–hygrometric conditions of the indoor environments.

In fact, only the use of raw earth radiant panels with a multilayered pipe coil was envisaged, thus creating a hydronic type heating and cooling system with a low delivery temperature (40 °C).

The evaluation also took into account a web-based home automation system for the entire plant, with probes and centralized control and programming.

Limiting the plant system, therefore, avoided an increase in construction and energy costs related to its operation and the necessary periodic maintenance.

5. Conclusions

For a brief evaluation, a comparison table showing both the initial condition before the intervention and the final condition after the intervention is presented below. It shows drastic energy savings for both winter and summer air-conditioning (Tables 1 and 2).

Table 1. Comparison before and after the intervention.

Symbol	Description	Measurement	State of Fact	Intervention Solution
RSC Period	Heating period		Nov 15 to March 31	Nov 15 to March 31
RFS Period	Cooling period		May 17 to Sept 25	May 16 to Sept 27
Qp	Design thermal load (transmission + ventilation + recovery factor) POWER	kW	11.59	5.07
CO2h	CO_2 emissions for heating	$kgCO_2$	4172.546	186.701
CO2c	CO_2 emissions for cooling	$kgCO_2$	1084.087	446.842
CO2w	CO_2 emissions for Domestic Hot Water (DHW)	$kgCO_2$	842.102	
		ANNUALS		
		Heating and Cooling		
Qh, nd	Thermal energy requirement for heating	kWh	12,738.53	4227.04
Qc, nd	Thermal energy requirement for cooling	kWh	−803,775	−293,963
Qw	Thermal energy requirement for DHW	kWh	2281.84	2281.84
		METRIC DATA		
Class	Global Energy Class of the Building		E	A4
EPh	Energy Performance Index for winter air conditioning	kWh/m^{2}year	1231.064	297.832
EPc	Energy Performance Index for summer air-conditioning	kWh/m^{2}year	334.667	148.035
EPw	Energy Performance Index for DHW	kWh/m^{2}year	248.286	230.254
Epgltot	Total GLOBAL Energy Performance Index	kWh/m^{2}year	1814.016	676.121
Yie	Average Periodic Thermal Transmittance	W/m^{2}K	0.51	0.05
H′T	Global average heat transfer coefficient for transmission	W/m^{2}K	1.49	0.49
AreaH′T	Area for calculating the average thermal exchange coefficient	m^2	335.99	335.99
H′T_lim	Global average heat transfer coefficient for limit transmission	W/m^{2}K	0.60	0.60
Asol′	Summer equivalent solar area		0.0366	0.0062
FEN	Normalized energy requirement	kJ/m^{3}GG	105.785	751.55
VlmL	Gross volume	m^3	729.48	751.55
VlmLc	Gross cooling volume	m^3	729.48	751.55
VlmN	Net volume	m^3	542.87	542.87
Arearfl	Gross dispersant surface	m^2	402.24	408.05
ArearfVT	Gross dispersing surface of the stained glass windows	m^2	24.78	24.55
RpSV	Form S/V ratio	1/m	0.5514	0.5429
RpSvtAn	Glazed surface/useful surface ratio	m^2	0.1370	0.1356
AreaN	Net usable surface	m^2	180.96	180.96
AreaL	Gross surface area	m	210.22	210.22
HigM	Average net height	m	3.00	2.88
Cm	Total thermal capacity	Cm	47,219.80	35,720.69
PrtAir	Outdoor air flow rate for natural ventilation	m^3/h	162.86	162.86

Table 2. Comparative results in terms of energy saving.

Results
Heating Requirement (kWh)
−66.8%
Cooling Requirement (kWh)
−63.4%
Energy Class
E → A4
Energy Performance Index(H+C+DHW) kW/m^2 year
−62.7%

The transition from a highly energy-consuming enclosure from a thermal point of view to a highly efficient one is linked to an economic variation (savings and tax deductions) that can be amortized over the medium term (less than 10 years), while the increase in efficiency toward an envelope that is almost zero energy consuming involves a financial commitment that can be amortized over a period of more than 17 years.

Certainly, the chosen materials have higher costs, but they reduce heating and cooling system use and costs. Further, beyond high energy efficiency, they add comfort. The healthy sense of well-being that comes from such accommodations cannot be fully evaluated economically.

Today, people are beginning to understand that comfort is increasingly a right for everyone, respect for the environment is a duty, and that these two considerations can coexist. Sustainability is no longer an added value, but the very essence of design. Careful planning can deliver, as in the case study, substantial advantages from an energy efficiency point of view. They consequently translate into reductions in environmental pollution and economic savings of residents. All these added values denote high quality as a consequence of the design, and they also consider the sensitivities of the residents. Table 2 is a final report for the case study about the energy savings for heating, cooling, and the change in building energy class and index in accordance with Italian law D.M. 26/06/2015.

Author Contributions: Conceptualization, G.A., L.D.G., and A.M.; Methodology, G.A.; Software, A.M.; Visualization, L.D.G.; Writing—original draft, G.A., L.D.G., and A.M.; Writing—review and editing, G.A. and L.D.G.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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