DECARBONIZING HISTORICAL BUILDINGS: OBJECTIVES AND CONSTRAINTS/

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Abstract. The need to decarbonize the European construction sector clashes with a building stock in many cities dating back a few centuries, with variable energy performance. This raises the question of how much to focus on embodied carbon, the choice of materials, or operational carbon, hence energy efficiency. The Italian National Energy and Climate Change Plan proposes the progressive electrification of the building sector as the primary decarbonization measure, replacing heating systems with heat pumps. This prediction raises several questions. Non-monumental historic buildings are often subjected to landscape restrictions or present typological and decorative characteristics that do not allow insulation interventions, such as reducing energy consumption significantly and, therefore, related CO_2 emissions. Furthermore, the need to replace and centralize the systems raises the problem of positioning the external units and heat distribution. The paper defines issues and opportunities through considerations and graphical schemes.

Introduction. The European Council, in 2020, established an objective for the EU to reduce net emissions by at least 55% by 2030 compared to 1990 levels. Subsequently, in 2021, it entered the European Climate Law (Regulation (EU) 2021/1119). This law harmonizes the EU target for 2030, establishes the binding objective of climate neutrality in the Union by 2050, and establishes a framework for advancing the pursuit of the global adaptation goal. The legislative package, known as Fit for 55, includes a series of proposals to reform directives and regulations relating to ETS (Emission Trading Scheme), ESR (Effort Sharing Regulation), LULUCF (Land Use, Land Use Change and Forestry), energy efficiency, and renewable energy for Member States. In the civil sector, measures have been adopted to accelerate the efficiency of existing buildings to reduce emissions by 2030 compared to 2005 levels and promote an increase in energy savings in final consumption. This process is supported by the diffusion of deep redevelopment interventions and the implementation of high-performance technologies, such as heat pumps and building automation and control systems (BACS Building Automation and Control System). This is leading Member States to define reduction policies, which, for the civil sector, imply the progressive electrification of systems, assuming that electricity production will increase from renewable sources; otherwise, the game will not work.

The reduction of energy consumption in existing buildings involves redevelopment works that modify the transmittance of the opaque walls (thermal insulation) or fixtures (replacement), with the possible adoption of screening systems if not existing (to reduce the load of summer heating), or which see the replacement of the heating system (oil, gas). Decarbonization objectives are associated with energy consumption reduction, mainly from fossil sources, and are connected to the need to implement climate change mitigation strategies. It, therefore, seems that the decarbonization objectives may coincide in the building sector as regards operational energy and, thus, the reduction of CO_2 emissions in the operational phase, with the electrification of the systems aimed at heating, cooling, and dehumidifying homes and offices (and, in some situations, also provide the correct air exchange) with no emissions at a local level.

Issue: abandoning natural gas in end-uses. It should be noted that in many European cities, and in particular in Italy, the existing building stock is vast, and demolition and reconstruction practices are rarely pursued, both for economic-environmental reasons but above all because the majority of this heritage is owned, e.g., by families that own their home. Therefore, issues related to the economic management of the operations come into play, which cannot be medium-long term (payback), as well as psychologically and affective, about one's living space (from the house to the neighborhood, to the city). We face the enormous effort of redeveloping buildings built from the Middle Ages to the 1980s, with different constrictive characteristics and energy performances. The buildings from the 1950s to the 1970s usually present the worst construction characteristics. However, due to their prevalent morphological simplicity, they are well suited to extensive redevelopment works from the outside (thermal insulation, systems). Massive buildings with better behavior, however, often carry constraints linked to belonging to areas of landscape value, or they are characterized by decorative devices that limit their modifiability. Regarding listed buildings, Article 3bis, in Legislative Decree No. 192/2005, establishes that cultural assets are exempt from the obligation of energy certification when compliance with the requirements would lead to an unacceptable alteration of their historical-artistic character. The authority responsible for issuing the authorization evaluates the presence of a "substantial alteration." Therefore, the possibility of installing mechanical, thermal, and electrical systems that help improve the functionality and energy performance of the building during its use is not entirely excluded.

According to Regulation (EU) 2018/1999 on the governance of the Energy Union and Climate Action, Italy has released two key documents: the "National Integrated Plan for Energy and Climate" (PNIEC) in 2020 and the "Italian Long-Term Strategy on Greenhouse Gas Emissions Reduction" in 2021 (MISE, MATTM & MIT, 2020).

The PNIEC outlines binding objectives for 2030 across five intervention areas: decarbonization, efficiency, energy security, development of the internal energy market, research, innovation, and competitiveness. Meanwhile, the long-term strategy extends to 2050, aligning with European targets for climate neutrality. Key goals include:

1.Achieving a 40% reduction in energy demand by 2030, particularly in private mobility and the civil sector.

2.Transitioning towards renewables to cover 85-90% of final consumption and significant electrification (50%) of end uses and hydrogen production.

3.Enhancing CO_2 absorption capacity through sustainable management of green and forested areas, restoration of degraded lands, and reforestation efforts.

Strategies: decarbonization as electrification of thermal plants. The strategies for this purpose can be different, depending on the building's architectural value and the bearable variations without being defined as "impacts." Nesticò et al. [1] highlight the average compatibility of different energy requalification solutions on existing buildings, especially historical ones.

Camieletto et al. [2] illustrate and evaluate some solutions through modeling with Energy Plus for a historic building intended for university use to reduce energy consumption. Contrary to what one might think, some solutions do not involve almost any modification to the building: modification of the on and off points of the heating systems and adoption of programmable intelligent thermostats are low-cost solutions that allow an immediate reduction in energy consumption. The possibility of isolating the opaque parts of the envelope is excluded, and the replacement of only one part of the fixtures is assumed. In any case, a geothermal probe heat pump is considered.

Following the PNIEC, the progressive replacement of heating systems with heat pump systems would lead to better conditions of summer comfort with a consequent increase in electricity consumption since only a part of the population today has cooling systems. In this hypothesis, they could instead benefit from them, in theory, everyone. Leaving aside the question of the availability of electricity in the face of a substantial increase in consumption, it is a question of understanding what the margins of applicability are in existing buildings, for systems that need to be outdoors, if they use the atmosphere to heat exchange or in contact with the ground if the conditions exist for the installation of a geothermal system. Furthermore, perhaps equally complex is the question of understanding how to distribute the heat in systems previously mainly made up of radiators fed by more than 60°C water and, therefore, not always precisely suitable for operation with heat pumps.

We can face different hypotheses. While including a new heat pump system may not be a problem in single- or two-family buildings, we are interested in whether it can happen in urban areas in multi-story buildings. The most frequently used systems use atmosphere air as a source, using air to distribute the heat when air exchange is also requested or fluid to reach radiant plates or fan coils.

The methane gas network has developed in Italy since 1946, starting with predominantly industrial use and becoming the primary source in Italian kitchens for cooking food (https://proxigas.it/chi-siamo/storia/). In the 70s of the twentieth century, gas began to replace diesel for heating buildings. Networks were developed to reduce the use of diesel in heating systems to supply less polluting natural gas in most of the national territory, pushing apartment owners to eliminate centralized systems and replace them with autonomous gas systems. Remember that 80% of the population lives in homes they own in Italy. Therefore, the first solution, represented in 'Figure n. 1', is somewhat dystopian and is already seen in famous images of some eastern cities - see 'Figure n.2' -, in which each owner equips their home with a single air conditioning system. This solution is inapplicable in all areas with a landscape restriction - e.g., in Portofino Park, to give an internationally known example, it is forbidden to install air conditioning systems with exposed external units - and obviously in buildings with a monumental restriction. There is some concession if the external units are hidden, at the risk of reducing their efficiency due to obstacles in the thermal exchange.

The second hypothesis is the creation of a centralized system. Again, this requires ventilated spaces for the external exchange unit, usually the roof (Figure n.3), a space on the ground open to the outside (Figure n.4), or even an intermediate floor open to the outside. Once again, problems of landscape and architectural constraints make these hypotheses complex.

Reasoning away from usual solutions, the constraints that allow us to use heating systems in all situations in which we are limited by architectural characteristics or unknown constraints of landscape and monumental interest must be identified: they must be systems powered by electricity, they must not be visible to the external, possibly they must be centralized systems. There are cases of building redevelopment with the replacement of systems in which heat pump systems with geothermal probes have been used (Figure n.5).

In [3], Cabeza et al. make a long list of cases of historic buildings, even prestigious ones, that have been energetically requalified; rarely does the main work consist of the insulation of the walls, and only in some cases is it limited to working on the intrados roofing and the floor at ground level if the flooring can be modified or removed and reassembled. Among these, whenever possible, an air-to-air heat pump system was adopted more frequently because it had less impact than air-to-water with radiators, radiant floors, or radiant plates. Emmi et al. [4] compare different approaches to replacing heating systems for two historic museum buildings in Venice and Florence through simulations with the TRSYS software. They vary the hours of operation (only during use or throughout the day) using geothermal heat pump systems, compared to a heat pump that uses the atmosphere for heat exchange and to the gas heating and chiller cooling system. Beyond the consumption related to the number of hours, it is clear that the geothermal heat pump is much more efficient, even considering the possible cooling of the ground in 10 years due to a very low cooling requirement compared to the heating requirement.

Some see a solution for the reduction of operational carbon emissions in the activation of smart communities. This solution involves installing thermal systems (heat pumps) and renewable energy production systems (solar thermal, solar photovoltaic) not on all buildings but only on those that can absorb the visual impact, functioning as service providers. Suppose this hypothesis solves problems related to the lack of space, in the case of activation in historical centers or their proximity, the question changes. If the recognized value is linked to a set of elements (landscape constraints "overall beauty" as defined in Italy), for the value to be preserved, the energy community (de São José 2021) [5] should be expanded to incorporate small parts of the historic center and large parts of the adjacent fabric, thus creating a functional tessellation that does not compromise the view of the center itself. Speaking of visual impact—a cultural concept, therefore subjective and changeable—it is necessary to decide whether it is the vision of the systems that create it—and for this purpose, the possible points of view are studied—or whether even the mere presence can define it (Figure n.6). Given that we are in the era of aerial photos, a point of view no longer exists because everything is always visible.

The above considerations raise the question of whether, in addition to heat pump systems, other electricity-powered systems can be a solution easier to apply in historic buildings. The solution obviously cannot be electric resistance plates (radiant) that were used and are still used, because they are inefficient. The new generations of far infrared radiant plates seem a possible alternative, although not as efficient as a heat pump. However, these systems have a very variable efficiency. Bédard [6] tested numerous systems, both gas and electricity sources, and verified a variation from 39% to 85% depending on the type of system.

Since these systems heat objects (and people) and not the air (which is consequently heated by the objects), they determine immediate comfort conditions when facing them at close range. At the same time, they require time to have uniform comfort if you want to reduce the maximum absorption of the panels to adapt to domestic systems and non-excessive power supplies. It is, therefore, a question of changing the approach to heating the home, taking advantage of programmability and differentiated temperatures during the day. If the comparison with heat pump systems is a losing one - also because the latter can also be used for cooling - the comparison with gas systems widely used today places them as a more than valid alternative and consistent with decarbonization objectives.

Conclusion. The objectives of carbonization of the building sector are closely linked to reducing energy consumption from non-renewable sources. The electrification of air conditioning systems and the consequent abandonment of gas systems seems to be a solution since electricity can be produced from renewable sources. Specific energy performance improvements should be studied in historic buildings, protected or otherwise characterized by identifying elements. Alternatives to adopting air heat pumps, such as geothermal heat pumps or far infrared radiant panels, should be evaluated. Finally, the possibility of activating energy communities should be evaluated to avoid intervening directly on the buildings of interest, installing the systems on neighboring buildings that can receive such technical elements without excessive visual impacts.

Acknowledgments

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References

1. A. Nesticò, M. Macchiaroli and O. Pipolo, "Historic Buildings and Energetic Requalification A Model for the Selection of Technologically Advanced Interventions" In: Gervasi, O., et al. Computational Science and Its Applications -- ICCSA 2015. ICCSA 2015. Lecture Notes in Computer Science(), vol 9157. Springer, Cham. https://doi.org/10.1007/978-3-319-21470-2_5

2. L. Carnieletto, G. Emmi, M. Artuzzi, M. C.e Piazza, A. Zarrella and M. De Carli, "Retrofit solutions for an historic building integrated with geothermal heat pumps". E3S Web Conf., 111 (2019) 03055 Published online: 2019-08-13 DOI: https://doi.org/10.1051/e3sconf/201911103055

3. L. F. Cabeza, A. de Gracia and A. L. Pisello, "Integration of renewable technologies in historical and heritage buildings: A review", Energy and Buildings, Volume 177, 2018, Pages 96-111, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2018.07.058.

4. G. Emmi, A. Zarrella, M. De Carli, S. Moretto, A. Galgaro, M. Cultrera, M. Di Tuccio and A. Bernardi, "Ground source heat pump systems in historical buildings: two Italian case studies", Energy Procedia, Volume 133, 2017, Pages 183-194, ISSN 1876-6102, https://doi.org/10.1016/j.egypro.2017.09.383.

5. D. de São José, P. Faria and Z. Vale, "Smart energy community: A systematic review with metanalysis", Energy Strategy Reviews, Volume 36, 2021, 100678, ISSN 2211-467X, https://doi.org/10.1016/j.esr.2021.100678.

6. N. Bédard,. "Laboratory testing of radiant gas burners and electric infrared emitters". Experimental Heat Transfer, 11(3), 255–279. (1998) https://doi.org/10.1080/08916159808946565.

Figures.

FIGURE 1 – Building with individual external air conditioning units for each apartment. Image by P. Sabbion.

FIGURE 2 – Dense urban residential buildings in Hong Kong. Photo by Brian Sugden.

FIGURE 3 – Air Conditioning units on the ground. Photo by P. Sabbion.

FIGURE 4 – Scheme of heat pump systems. Image reworked from the University of Leeds, Leeds.ac.uk/policy-Leeds.

FIGURE 5: Air Conditioning units on the roof of a historical building in Genova, 2024. Photo by P. Sabbion.

FIGURE 6 – Single Air Conditioning unit on a historical building, Genova. Photo by P. Sabbion.


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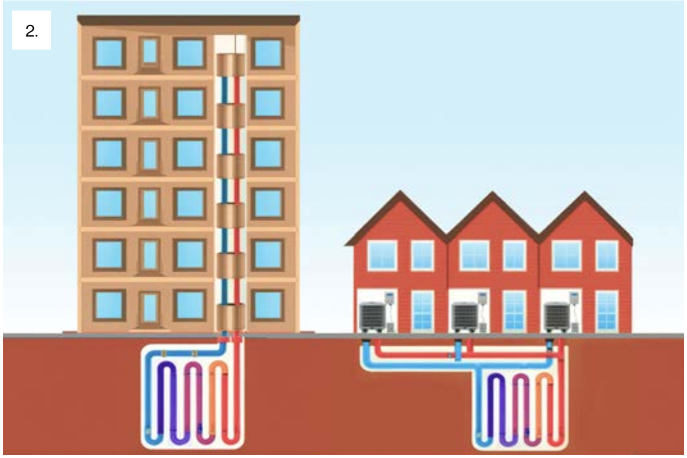
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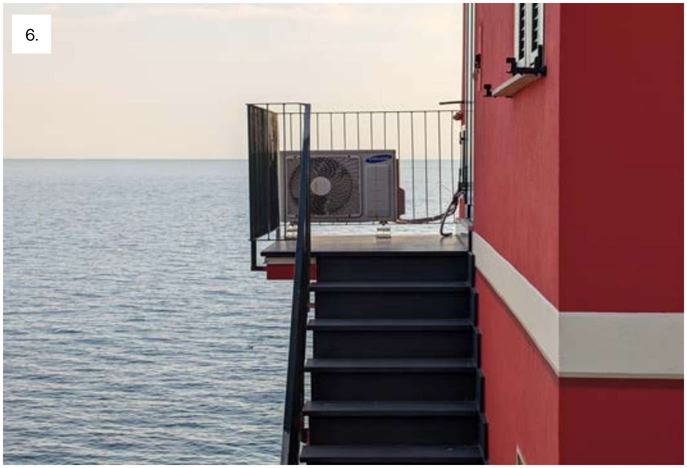
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