IIETA International Information and Engineering Technology Association
Advancing the World of Information and Engineering

International Journal of Sustainable Development and Planning
Vol. 19, No. 10, October, 2024, pp. 3707-3714
Journal homepage: http://iieta.org/journals/ijsdp

Conventional Building Energy Performance and Actual Energy Costs: A Critical Reflection

Chiara Gatti[1,2], Chiara Lodi[1,2], Alberto Muscio[1*]

[1] Department of Engineering "Enzo Ferrari", University of Modena and Reggio Emilia, Modena 41124, Italy
[2] Enerplan S.p.A., 41012 Carpi (MO), Italy

Corresponding Author Email: alberto.muscio@unimore.it

https://doi.org/10.18280/ijsdp.191001

Received: 1 August 2024
Revised: 13 September 2024
Accepted: 1 October 2024
Available online: 30 October 2024

Keywords:
energy costs, energy efficiency, energy performance certification, primary energy

ABSTRACT

Energy Performance Certificates (EPCs) provide information about the energy consumption of the building under conventional climate and use conditions. The calculation method compares the envelope efficiency, energy consumption and carbon emissions of the building with those of a "reference building", of the same location, size, geometry, use and boundary but with thermo-physical characteristics corresponding to the minimum energy requirements in force. Due to its intrinsic definition, the reference building might actually be highly energy-consuming and costly, allowing the actual building to reach a higher energy class thanks e.g., to the use of renewable energies or more performing windows or walls. This study proposes an in-depth analysis of the actual energetic and economic sustainability of buildings on top of the conventional energy classification concept. By exploring variables such as glass surfaces, imported energy consumption and architectural design, the study aims to develop a novel approach to EPCs, based on a novel concept of reference building. The work aims to contribute to the evolution of the EPC definition, providing a more complete overview of the energy and economic performance of buildings. New qualitative indicators are proposed to be included in the EPCs, depicting a more informative picture of the building energy performance. Results show that for the selected case studies, according to the actual EPC methodology, the quality of the envelope would be medium-high, while the novel indicators would present a rather worse envelope performance. The divergence is particularly evident in the case of highly glazed buildings.

1. INTRODUCTION

This study is focused on two crucial challenges of our time: the need to reduce the environmental impact of buildings and the importance of guaranteeing the economic sustainability of our actions.

Buildings play an important role in reducing EU energy consumption as they are responsible for approximately 40% of EU energy consumption and over 1/3 of the energy-related greenhouse gas emissions [1].

In the context of a growing awareness of the urgent need to reduce greenhouse gas emissions and adopt greener building practices, building energy rating is of primary importance. However, while conventional building energy classification focuses primarily on environmental sustainability, often neglecting in-depth analysis of long-term energy and economic costs and benefits, the need for a more holistic approach has emerged.

Li et al. [2] identified several limitations in the current EU building certification system, proposing opportunities for improvement, such as the use of more holistic indexes. Oliveira Panão [3] also proposed alternative indexes to those typical of energy certification, based on the concept of excluding exported renewable energy from the overall fraction of renewable energy generated on site. Several authors [4-7] also underline the importance of the shape of the building in its energy performance. However, in the Italian rating system, comparing the considered building with a reference one having the same geometry does not allow for rewarding relevant aspects such as the shape ratio of the building or the share of glazed surface. This study aims to address these gaps of the rating system and offer a more comprehensive analysis, in which the perspective is widened to include the energy and economic sustainability of the building.

Through a detailed analysis of the multiple factors that influence energy rating such as architectural design, the large use of glazed surfaces and the consumption of imported primary energy, we aim to develop a novel approach that considers both environmental, energetic, and economic aspects. Our objective is to conduct an in-depth study on the current reference building used for the assessment of building energy performance, exploring different building typologies, and developing specific criteria to optimize the existing energy classification method.

More specifically, we propose the definition of an "optimised" reference building, which incorporates relevant variables emerging from the analysis and acts as a model for a more effective assessment of the energy and economic performance. Furthermore, the introduction of two novel qualitative indicators in the energy performance certificate is proposed to provide users with a complete and more detailed picture of the energy performance. This approach aims to improve transparency and understanding of users, allowing them to promote a more sustainable and informed real estate market.

2. METHODS

2.1 Standard calculation of energy performance

Energy certification was first introduced in the EU by the Energy Performance of Buildings Directive (EPBD) in 2002, recast in 2010 and 2021 [8-10]. The EPBD was introduced in Italy with the Legislative Decree 192/2005 [11], followed by a series of other regulatory acts.

An Energy Performance Certificate (EPC) allows to assess and rate the overall building stock and predict energy savings from renovation [12]. However, there are significant variations in the methods used to build the EPC across European countries [13, 14], which is indeed allowed by the EPBD. In Italy, conventional energy classification mainly focuses on the assessment of environmental sustainability. The current method for determining the energy class of a building involves the comparison between the real building and a reference building, identical in terms of geometry, orientation, location and intended use but with thermal and energy parameters predetermined by current legislation. The EPC comprises a label indicating the energy performance level of the building, measured in terms of non-renewable primary energy alone. The level is calculated by comparing the energy performance of the building with predefined levels, in which the reference building represents the limit between classes A1 and B. The energy class is marked by an alphabetical label in which the letter G represents the class characterized by the worst performance index (higher energy consumption), while the letter A4 represents the class with the best performance index (lower energy consumption).

The success in the use of the EPC is very much dependent on the perception, willingness to use, and interest of the end-users [15]. Key aspects to be enhanced are transparency, usability, and reliability of the certificates. Nonetheless, although energy classification is a consolidated method, it can be misleading as it reflects environmental sustainability and neglects overall energy and economic needs. In this study, various factors influencing energy class were examined, including glazing, building shape, imported renewable energy and ventilation. These factors could have a significant impact on both the energy and economic performance of a building.

2.2 Critical issues of the standard calculation

2.2.1 Key factors

In our analysis, several key factors that need to be considered for a comprehensive analysis were examined. Among others, glazed surfaces, imported renewable energy, building ventilation, and building shape were identified.

2.2.2 Glazed surfaces

The evolution of modern architecture has experienced a growing adoption of glazed surfaces in buildings. Transparent surfaces play an important role in defining the architectural quality of a structure, offering a compelling vision of the union between interiority and exteriority. However, the use of these surfaces often does not promote energy efficiency and sustainability of buildings.

Transparent windows significantly influence the control and use of solar radiation, both in terms of natural lighting and overall thermal balance of the building, implying the need of protection from solar radiation to avoid overheating and thermal discomfort. Glazed components indeed play a significant role both during heating and summer periods, influencing the overall energy consumption of buildings.

Concerning the energy performance certificate, the current approach imposes a comparison between the actual building and a reference building with predefined energy parameters but otherwise identical to the real one in terms of intended use, location, orientation, and geometry, of course including windows. This approach, although widely consolidated, may be inadequate in situations where the actual building has a considerable glazed surface. This happens because the reference building, thought being the ideal reference point, itself presents a considerable glazed surface, thus it is inherently expensive from an energy and economic point of view. Therefore, the comparison with a reference building which, in its essence, represents an expensive building, could lead to misleading results. It follows that the actual building may reach a high energy class, which suggests notable environmental sustainability, but energy consumption may turn out to be high, placing the building in a position of inefficiency from the viewpoint of economic and energetic sustainability. To address this issue, a novel "optimised" reference building is introduced in this study.

2.3 Definition of the “optimised” reference building

The "optimised" reference building is still characterized by the same orientation, location, intended use, as well as thermal characteristics and energy parameters predetermined by current legislation. However, it also considers a few requirements prescribed by the construction regulations such as the window-to-floor ratio (WFR).

Concerning WFR, buildings must strictly comply with building and urban planning regulations. An opening towards the outside must be guaranteed such as to have natural lighting and ventilation depending on the internal floor surface. This relationship is conventionally referred to as the window-to-floor ratio (WFR), a value indicating the distribution of room openings depending on the internal floor surface. Ensuring a given WFR and, more generally, offering the right level of air lighting in the building means improving the health conditions of the occupants, maintaining a comfort temperature while allowing an appropriate air renovation and the prevention of humidity issues. In Italy, the legislation that regulates WFR is art. 5 of the Ministerial Decree of 5 July 1975 [16], establishing that the width of the windows must be such as to guarantee daylight greater than 2% and a WFR greater than 1/8. The provisions for private homes require direct natural lighting for all rooms, apart from some type of rooms, like toilets or corridors. The WFR for offices, companies, public places, and schools is always set at a minimum value of 1/8, unless specific changes can be found in municipal building regulations.

Using the definition of optimised reference building, we defined a novel energy performance index. The energy performance index (EP) is a parameter that expresses the total consumption of primary energy for heating (H), ventilation (V), cooling or air conditioning (C), production of domestic hot water (W) and, in the case of the non-residential sector, artificial lighting (L) and the transportation of people or things (T) referring to the unit of building floor, therefore it is calculated in kWh/(m^{2}year). It indicates the amount of consumed energy to maintain comfort conditions. The energy class is determined through the global non-renewable (nren) energy performance index as defined in the technical regulation [17-19]:

$$EP_{gl,\,nren} = EP_{H,\,nren} + EP_{C,nren} + EP_{V,\,nren} + EP_{W,\,nren} + EP_{L,\,nren} + EP_{T,\,nren}$$

By applying increase and reduction coefficients to the $EP_{gl,nren,rif}$, that is $EP_{gl,nren}$ for the reference building, the performance intervals are obtained which identify the energy class of the real building.

2.4 Proposal of new indexes for the certificate

2.4.1 Optimised reference building

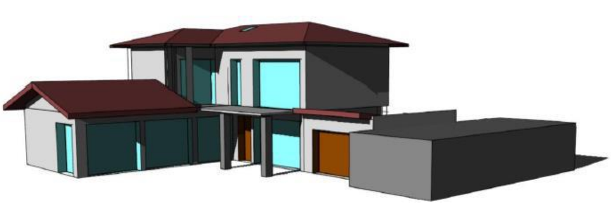
The novel "optimised" reference building has glazed surfaces equal to the legal minimum (Figure 1), moreover it has compact geometry and the whole imported energy is considered and not only its non-renewable fraction. However, this would return a different energy rating than with the approach currently in force and this might create ambiguity on the market. Therefore, sticking to the objective of making the energy certificate more informative, we propose that the energy class is not modified, but two new auxiliary indexes are introduced, the building envelope energy need index and the energy-economic sustainability index, which replace qualitative indexes already present in the certificate.

2.4.2 The building envelope energy need index

A building envelope index is currently expressed in the certificate as a qualitative index ("Smiles"), referring to a small number of parameters. It is proposed to replace the current envelope index with two new, more effective parameters, each one represented by a speedometer, for both winter and summer periods (Figure 2). These indexes indicate the relationship between the thermal energy needs of the actual building and that of the optimised reference building, considering only energy flows entering and exiting the envelope.

2.4.3 Energy-economic sustainability index

The energy-economic sustainability index represents an additional innovation, which consists in introducing two new indexes also expressed through speedometers (Figure 3). These indicate the relationship between the primary energy imported (and paid) in the actual building and the one that the optimised building would import, regardless of the energy source being renewable or not.



(a) Conventional

(b) Optimised

Figure 1. Reference building for case study 1

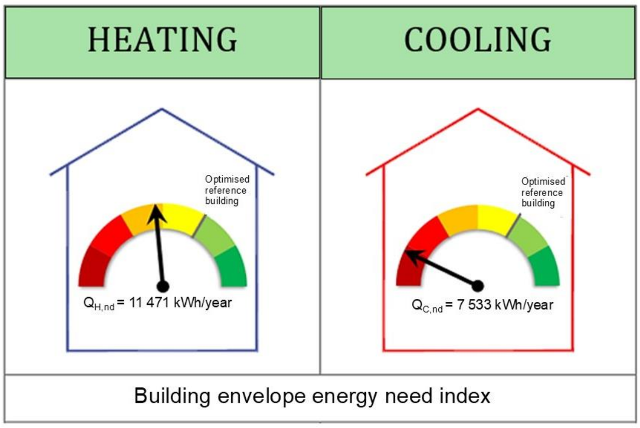


Figure 2. Novel building envelope energy need index

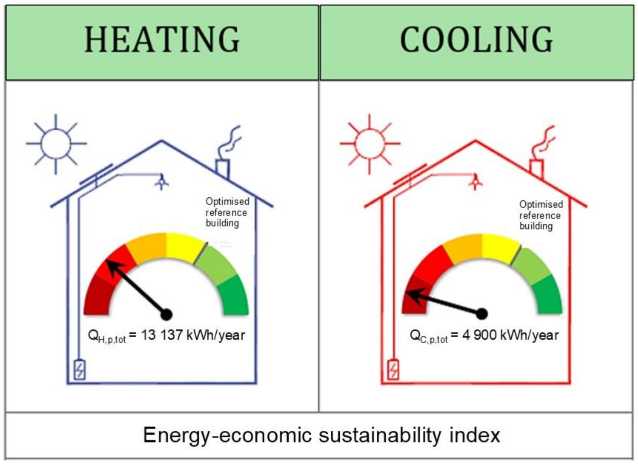


Figure 3. Energy-economic sustainability index

3. CASE STUDIES

The analysis of the energy performance of two case studies is presented here, based on the previously exposed approach. The first case study is a residential building while the second is a commercial building.

3.1 First case study: residential building

The first case study is a residential single house classified in class A1 based on the conventional energy classification. The building is in the province of Reggio Emilia, in northern Italy.

Figure 4 shows that transmission losses through glazed surfaces constitute over 30% of total losses in the rated building, of which the non-optimised reference building is that in Figure 1(a), highlighting the impact of such surfaces on the overall thermal efficiency of the building.

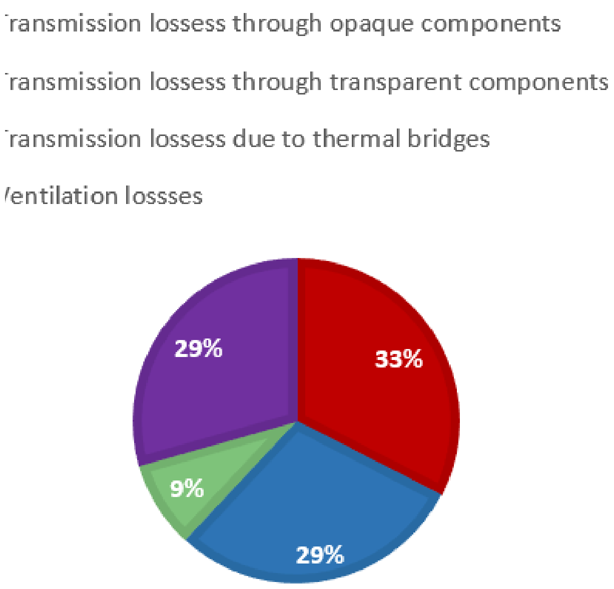


Figure 4. Heat losses for case study 1 (analysed building)

By applying the concept of the optimised reference building, the energy needs of the analysed building will be comparatively assessed. More specifically, given the building plan, the optimised reference building is defined considering the minimum requirements prescribed by current technical standards in terms of WFR. After evaluating the WFR for each room, in the new reference model the glazed elements were located using the same position and orientation as the glazed components present in the actual building, as well as the same characteristics in terms of the thermal transmittance, set to 1.4 W/(m²K), according to Legislative Decree no. 192/2005 for the considered climate zone. In Figure 1 and in Table 1 conventional and optimised reference buildings for case study 1 are compared.

Table 1. Main building parameters for case study 1

Reference Building	% Windows Surface	Windows Surface	Heated Surface
Conventional	11.9%	86.8 m^2	214 m^2
Optimised	4.2%	30.3 m^2	214 m^2

3.2 Second case study: glazed commercial building

The second case study, even more emblematic, is a 15-storey commercial glass tower, classified as A1 by the conventional energy system.

The building is in the province of Modena, in northern Italy.

In this case, a large part of heat losses of the rated building can be attributed to glazed surfaces, given that the structure is composed entirely of glass modules (Figure 5).

As for case study 1, after evaluating the WFR for each room, in the new reference model the glazed elements were in the same position, orientation and with the same characteristics as the glass components present in the actual building. The thermal transmittance was again set to 1.4 W/(m²K), according to the current regulation for the considered climate zone.

In this case, since the building initially had a design entirely based on glass elements, it was necessary to partially substitute transparent surfaces with opaque elements (Figure 6) The transmittance of the introduced opaque elements was set to 0.260 W/m²K, according to the regulation for the selected climate zone.

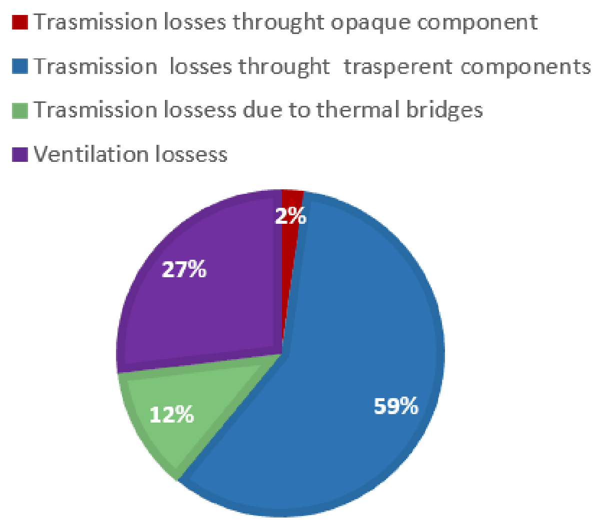
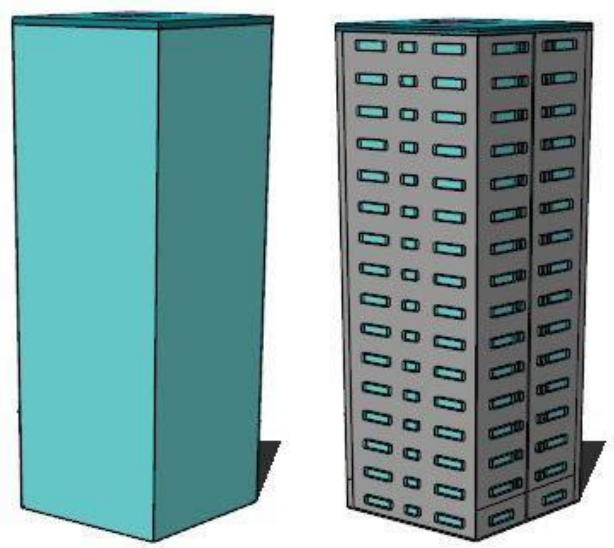


Figure 5. Heat losses for case study 2 (analysed building)

Table 2 conventional and optimised reference buildings for case study 2 are compared.



(a) Conventional (b) Optimised

Figure 6. Reference building for case study 2

Table 2. Main building parameters for case study 2

Reference Building	% Windows Surface	Windows Surface	Heated Surface
Conventional	68.7%	4.467 m^2	4.946 m^2
Optimised	9.8%	636 m^2	4.946 m^2

4. RESULTS

4.1 Primary energy in the analysed case studies

Figure 7 shows the comparison between the energy performance of case study 1 considering the standard and the optimised reference buildings.

The analysis of the energy needs allows to observe that for case study 1 the building has significantly lower consumption than the conventional reference building, while its consumption is higher than the optimised reference building. According to the current energy classification the building would belong to class A1, while considering the optimised reference building it would be in class B.

This is the same situation observed for case study 2 (see Figure 8). For this commercial building, according to the current energy classification the building would belong to class A1, while considering the optimised reference building it would be in class D.

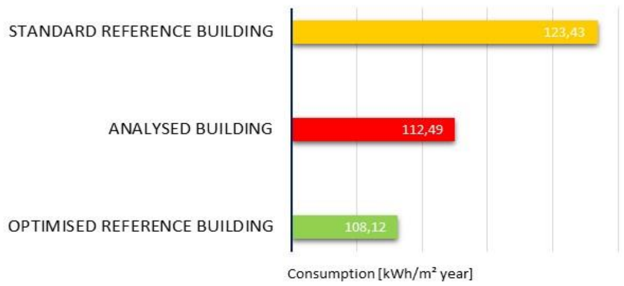


Figure 7. Energy needs for case study 1

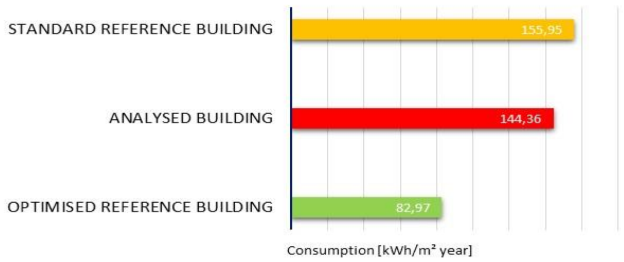


Figure 8. Energy needs for case study 2

4.2 Proposed indexes for the examined case studies

The novel indexes proposed in this study are presented below for the selected case studies.

Considering the residential building (e.g., case study 1), the building envelope energy need index shows the arrow in the red area, in both heating and cooling period (see Figure 9). This indicates a significant energy need to maintain internal thermal comfort, not evident in the current "smile" qualitative indexes (see Figure 10).

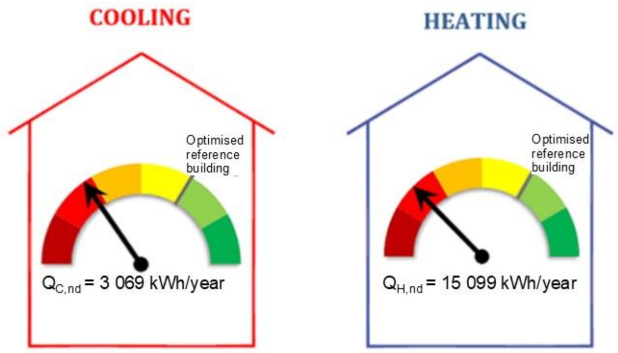


Figure 9. Building envelope energy need index for case study 1

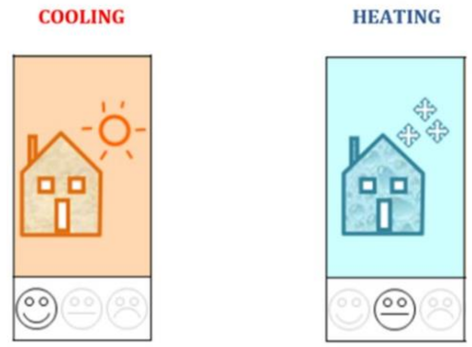


Figure 10. Qualitative "smile" indexes for case study 1

Considering the energy-economic sustainability index for case study 1, the results depict significant costs in the winter period, while lower costs are found in summer (see Figure 11).

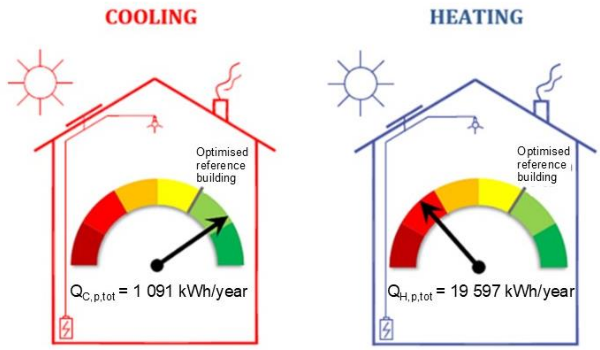


Figure 11. Energy-economic sustainability index for case study 1

Considering the glazed tower (i.e., case study 2), the building envelope energy need index shows the arrow in the yellow area in winter, while the arrow is in the red area in summer (see Figure 12). This indicate significant energy needs to maintain internal thermal comfort in summer, while the situation is less extreme in winter. This would not clearly emerge from the current envelope classification (see Figure 13).

The analysis of the Energy-economic sustainability index for case study 2 shows acceptable behaviour in winter, when solar gains have a positive impact, but highlights critical issues in summer (see Figure 14).

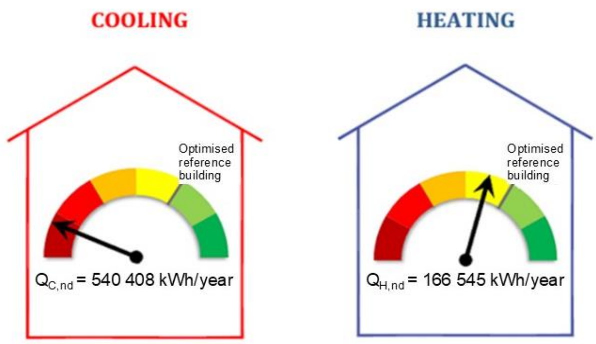


Figure 12. Building envelope energy need index for case study 2

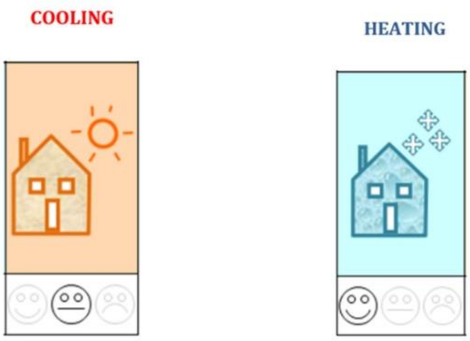


Figure 13. Qualitative "smile" indexes for case study 2

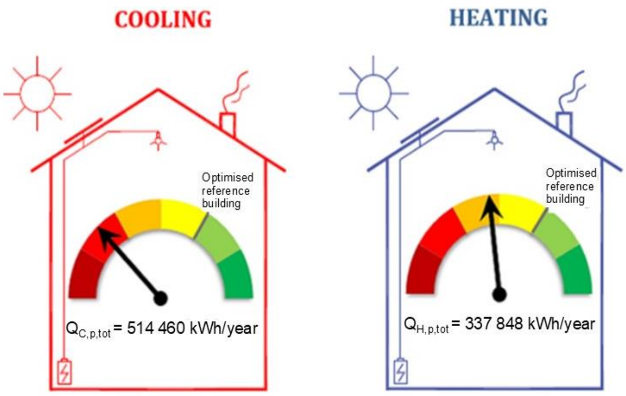


Figure 14. Energy-economic sustainability index for case study 2

4.3 Further thoughts

4.3.1 Imported renewable energy

The current energy rating method focuses exclusively on the non-renewable fraction of consumed energy, but it would be important to expand the analysis.

When renewable energy is produced on site, it is automatically excluded from the calculation. Attention, however, should be paid to imported renewable energy, whether in the form of electricity, biomass, or other fuels. Since the renewable energy is imported, it implies additional costs that should be considered, influencing the overall energy and economic sustainability. Neglecting the origin of the consumed renewable energy, can build the incorrect expectation that a high-class, environmentally sustainable building is also economically sustainable.

As an example, a building would reach A4 class if heated with a pellets boiler instead of a natural gas boiler. Pellets have a non-renewable primary energy conversion factor equal to 0.20 while for natural gas the factor is 1.05 (the additional 0.05 is to consider network losses and pumping). However, it is important to note that pellets must be purchased on the market, similarly to natural gas. Considering the whole imported primary energy is equivalent to increasing the primary energy conversion factor to at least 1, thus reducing the energy class to e.g., A1. This underlines that the class does not fully reflect economic sustainability, given that the use of pellets does not lead to significant economic savings compared to natural gas, but mainly highlights environmental sustainability. If the class cannot be changed, the concept can be included in the energy-economic sustainability index of Figure 11 and Figure 14.

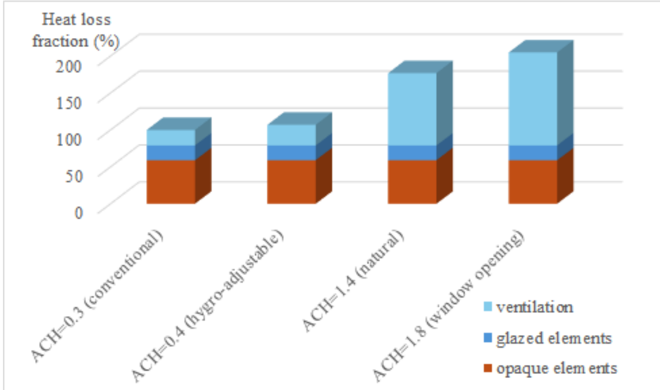


Figure 15. Transmission and ventilation losses with variable air change rate (conventional building is 100%)

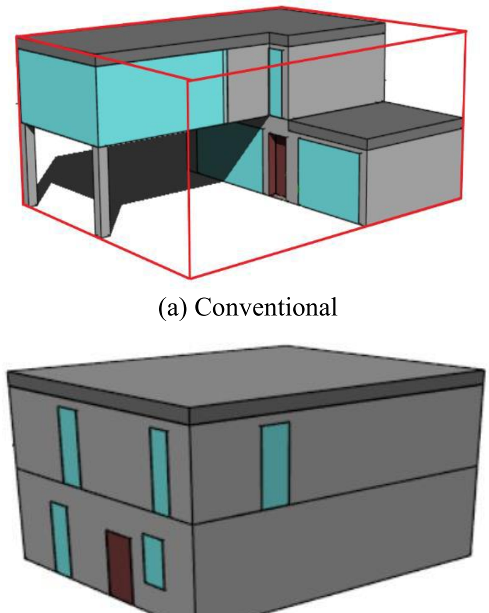
4.3.2 Ventilation

Ventilation, which is essential for comfort and air quality in buildings, can lead to energy losses. Two main approaches can be followed for ventilation in buildings: manual window opening and mechanical ventilation. In the current energy rating approach, ventilation by manual window opening can be evaluated with standard values of air renovation in term of volume air change per hour (ACH). These values may not reflect reality as they do not consider the actual schedule and building use. In contrast, mechanical ventilation systems offer accurate control, improving air quality and optimizing energy consumption. Considering the conventional energy rating approach based on manual window opening, the first column in Figure 15 represents the energy losses with conventional ventilation rate of 0.3 volumes/hour, specified by the Italian regulation. However, there are studies cited in the CEN/TR 14788 report [20] which report that ventilation left to the casual opening of windows can bring the air change rate around 1.8 volumes/hour. In a conventional rating calculation, the distribution of heat losses of the building envelope is like that in the first column of Figure 15, with a ventilation rate of 0.3 volumes/hour. However, ventilation left to the casual opening of windows can bring to a behaviour like that in the last column. The total heat losses of the envelope doubles and the energy class can be modified, for example, from A3 to A1 or even worse. Therefore, it can be concluded that absence of mechanical ventilation systems should be penalized in the energy certification calculation.

4.3.3 Shape factor

Architectural design, including shape factor, can significantly impact the energy efficiency of buildings. Buildings with irregular shapes such as those with pillars or protrusions may result in a greater external surface area for the same internal volume, which increases the areas exposed to heat loss. This can cause higher heat losses and, therefore, an increase in energy consumption for building heating or cooling. Therefore, we propose to include the shape factor in terms of surface to volume (S/V ratio) as an essential parameter in the evaluation of the reference building.

As an example, the building of Case 1 can be considered. In this case, the S/V ratio, which expresses the compactness of the building and is obtained from the ratio between the heated floor surface and the heated volume, is rather high. The optimised reference building could take the S/V ratio into account by inscribing the actual building in a parallelepiped, to which a minimum inter-storey height is assigned that complies with the minimum requirements of the construction standards.



(a) Conventional

(b) Optimised

Figure 16. Example of reference building when S/V ratio is considered

Subsequently, the basis of the parallelepiped is proportionally scaled until the same overall floor area as the original building is reached. The transparent surface would also be reduced according to the window-to-floor ratio of 1/8. The reduced glass components will be positioned in the same place as in the original building, with the same orientation and characteristics, as well as transmittance value complying with Legislative Decree no. 192/2005 depending on the climate zone. The optimised reference building is shown in Figure 16(b). However, it should be noted that a complex shape factor may be due to surrounding conditions: sometimes the building shape is forced by limitations of the building lot such as the shape of the lot area or the regulatory distances from neighbouring buildings.

To take shape factor into account, we also propose the introduction of a specific index, the Geometrical efficiency index of the building. This would express the ratio between the heat loss area of the optimised reference building (Optimised) and that of the building under analysis ($A_{analysed}$).

$$E_f = A_{optimised} / A_{analysed}$$

The introduction of this additional index has the potential to facilitate the assessment of the efficiency of building design, providing the user with more complete information.

5. CONCLUSIONS

Within the framework of the energy certification of buildings, a novel optimised reference building is proposed. The energy performance of such optimised reference buildings complies the minimum requirements of building regulations. Significantly glazed buildings, often aesthetically pleasing and modern, are often celebrated for their appearance. However, in real situations, the widespread use of glazed surfaces makes it necessary to shield them during the day to manage sunlight and prevent overheating and glare. Glazed surface also allows a much larger heat loss than insulated opaque elements. The extensive use of glazed surfaces can challenge economic sustainability of buildings, since maintaining comfort within these spaces can entail significant energetic and economic costs. The presented results could raise awareness among users of the implications and challenges involved in selecting highly glazed buildings. The introduction of an optimised reference building that contemporarily considers aspects such as light control and energy sustainability could serve as an incentive for designers to operate in a more virtuous way.

Furthermore, it is essential to increase transparency in the energy performance certificate. The results of this work could offer a substantial contribution to the promotion of buildings that are contemporarily more environmentally and economically sustainable, laying the foundations for a holistic approach in the field of sustainable design.

ACKNOWLEDGMENT

We gratefully acknowledge Professor Paolo Tartarini of Unimore and Ing. Corrado Faglioni of Enerplan S.p.A.

REFERENCES

[1] European Commission, "Energy, Climate change, Environment - Energy - Energy Performance of Buildings Directive. https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en."

[2] Li, Y., Kubicki, S., Guerriero, A., Rezgui, Y. (2019). Review of building energy performance certification schemes towards future improvement. Renewable and Sustainable Energy Reviews, 113: 109244. https://doi.org/10.1016/j.rser.2019.109244

[3] Oliveira Panão, M.J.N. (2016). The overall renewable energy fraction: An alternative performance indicator for evaluating net zero energy buildings. Energy and Buildings, 127: 736-747. https://doi.org/10.1016/j.enbuild.2016.06.057

[4] Premrov, M., Žegarac Leskovar, V., Mihalič, K. (2016). Influence of the building shape on the energy performance of timber-glass buildings in different climatic conditions. Energy, 108: 201-211. https://doi.org/10.1016/j.energy.2015.05.027

[5] Kheiri, F. (2018). A review on optimization methods applied in energy-efficient building geometry and envelope design. Renewable and Sustainable Energy Reviews, 92: 897-920. https://doi.org/10.1016/j.rser.2018.04.080

[6] Galiano-Garrigós, A., Domenech-Mataix, M., González-Avilés, Á.B., Rizo-Maestre, C. (2021). Evaluation of energy performance and comfort: Case-study of university buildings with design adapted to local climate. Sustainability, 13(13): 7155. https://doi.org/10.3390/su13137155

[7] Foroushani, S., Bernhardt, R., Bernhardt, M. (2022). On the use of the reference building approach in modern building energy codes. Energy and Buildings, 256:

111726. https://doi.org/10.1016/j.enbuild.2021.111726
[8] European Commission. (2002). Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32002L0091.
[9] European Commission, "Directive 2010/31/EU on the energy performance of buildings (recast)." https://eur-lex.europa.eu/eli/dir/2010/31/oj, accessed on Oct. 20, 2024.
[10] European Commission. (2021). Proposal for a Directive of the European Parliament and of the Council on Energy Efficiency (Recast), COM (2021) 558 final. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021PC0558.
[11] Decreto Legislativo 19 agosto 2005, n. 192 Attuazione della direttiva 2002/91/CE relativa al rendimento energetico nell'edilizia. (2005).
[12] Cichowicz, R., Jerominko, T. (2023). Comparison of calculation and consumption methods for determining energy performance certificates (EPC) in the case of multi-family residential buildings in Poland (Central-Eastern Europe). Energy, 282: 128393. https://doi.org/10.1016/j.energy.2023.128393
[13] Semple, S., Jenkins, D. (2020). Variation of energy performance certificate assessments in the European Union. Energy Policy, 137: 111127. https://doi.org/10.1016/j.enpol.2019.111127
[14] Meles, T.H., Farrell, N., Curtis, J. (2023). How well do building energy performance certificates predict heat loss? Energy Efficiency, 16(7): 74. https://doi.org/10.1007/s12053-023-10146-0
[15] Zuhaib, S., Schmatzberger, S., Volt, J., Toth, Z., Kranzl, L., Noronha Maia, I.E., Verheyen, J., Borragán, G., Sousa Monteiro, C., Mateus, N., Fragoso, R., Kwiatkowski, J. (2022). Next-generation energy performance certificates: End-user needs and expectations. Energy Policy, 161: 112723. https://doi.org/10.1016/j.enpol.2021.112723
[16] Italian Health Ministry, "Decreto Ministeriale 5 luglio 1975 - Modificazioni alle istruzioni ministeriali 20 giugno 1896 relativamente all'altezza minima ed ai requisiti igienico sanitari principali dei locali d'abitazione", 1975.
[17] "UNI EN ISO 13790 - Energy performance of buildings Calculation of energy use for space heating and cooling", 2008.
[18] "UNI/TS 11300-1, Prestazioni energetiche degli edifici. Parte 1: Determinazione del fabbisogno di energia termica dell'edificio per la climatizzazione estiva ed invernale", 2014.
[19] "UNI/TS 11300-2, Prestazioni energetiche degli edifici. Parte 2: Determinazione del fabbisogno di energia primaria e dei rendimenti per la climatizzazione estiva e per la produzione di acqua calda sanitaria, per la ventilazione e per l'illuminazione in edifici non residenziali", 2019.
[20] CEN/TR 14788:2006 - Ventilation for buildings - Design and dimensioning of residential ventilation systems. (2006).

NOMENCLATURE

A	Area
C	Cooling
EP	Primary energy, kWh
gl H	Global heating
L	Lighting
nren	Not renewable
T	Transportation
V	Ventilation
W	Water
WFR	Window-to-floor ratio