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Evolution of energy requirements in a green building rating system

Comparison between LEED v4 and LEED v5 addressing ASHRAE 90.1 updates

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ABSTRACT

The main scope of this thesis is to highlight how the variation of one of the most widespread rating systems for evaluating building sustainability (LEED protocol) and the update of the energy standard ASHRAE 90.1 impact on building design.

The analysis, carried out on an existing building located in Turin that recently underwent a major renovation, aims to determine whether a building, previously recognized as performant, sustainable and certified at level "Gold" under LEED v4, can still be considered eligible for certification based on newer and more stringent version (LEED v5).

The investigation focuses on the energy performance of the building and was conducted by means of IESVE. In the first step, the rules and modelling requirements defined by ASHRAE 90.1:2010 were applied and the outcomes were consistent with the previous LEED certification.

Subsequently, the energy model was developed in compliance with ASHRAE 90.1:2019 in order to determine whether the current performance is still representative of an efficient building according to the updated standard and whether it qualifies for LEED v5, at least as regards the energy and atmosphere category.

This approach highlights the need to compare the building "as is", previously recognized as energy efficient, with revised target building and minimum performance threshold defined by the updated energy standard and the rating system.

The outputs of the two models were compared and analysed to define the gap between the different baseline models and their impact on the energy performance assessment of the building according to LEED requirements.

Starting from the awareness of the changed requirements and targets, the analysis continued by first identifying which components of the energy uses and building needs had the greatest impact and why, and, secondly, exploring improvement strategies that could be implemented to increase the achievable LEEDv5 score.

The results of this study highlighted that the building envelope thermal properties were not fully compliant with prescriptions defined by the updated ASHRAE standard, even if the path adopted for the evaluation of its performance was the Performance Rating Method rather than the prescriptive approach. Therefore, the first variation considered was the adaptation of opaque

and transparent envelope properties to those defined in the energy standard. A second strategy involved the adoption of a cool roof strategy and a third consisted in the installation of external shading devices to control solar gains.

It is worth noting that the impact of each solution has been analysed separately to verify the effectiveness of each of them and only after they have been combined together to determine if their overlap resulted in a significant improvement in the performance.

Overall, the analysis, showed that the building remains eligible for LEED v5 certification and that the applied strategies lead to an improvement in energy performance, even if marginal.

It is furthermore clear that the standards require more and more performant building stocks and that the improvement manoeuvre margin is really restricted for buildings that undergone deep renovation according to the current business practise.

LEEDv5 really increases the required sustainability level calling for an integrative design approach since the beginning to optimize and maximize the overall performance of the project.

1. Introduction

The awareness of climate change increased in the past few decades due to the visible natural disasters and intense phenomena taking place all around the world. This ongoing threat, as regards the building sector, presents two sides of the same coin, indeed, the building sector is one of the major responsible for CO_2 emissions highly contributing to the strengthening of these disasters, but, on the other side, the climate change affects the building sectors due to the increased temperatures, heat island effect, increased violent phenomena as droughts, hurricanes, cyclones, wildfires and intense rainfalls.

Based on this, it is highlighted the difficulty to realize buildings able to adapt themselves as resilient structures to the effects of the extreme events, especially when speaking of existing heritage. In addition to adaptation, defined as the capability to reduce vulnerability of the estate when exposed to violent phenomenon, the building should be able to maintain its performance levels and satisfy the needs of its occupants both in terms of well-being and functionality. The capability to do so, it's put in danger by climate change and its impacting effect, indeed, the increased global temperature and the heat island effect lead to a growing necessity to provide efficient and prolonged space cooling to the buildings, and at the same way, the unexpected sink of temperatures in winters leads to an increased demand for space heating. These defence mechanisms against pronounced events, on first impression, seem to guarantee the functionality of the building but the increased energy demand more frequently knocks out the operating systems. They, even indirectly, contribute more and more to the climate change by increasing emissions and by requiring an intensive energy sources' use. For this reason, another strategy to be implemented is related to the mitigation of the building sector with the scope to actively reduce its contribution to climate change by increasing energy efficiency, reducing the use of fossil fuels and substituting them with renewable energy sources.

This has represented the starting point for many sustainability goals all around the world with a strict timeline and defined intermediate steps to reach in order to guarantee a fluid evolution in the sustainability field. All these common objectives have been translated into international standards and regulations, as those defined by the Organization of the United States and European Union, and adopted at national level. One of the most important recognized energy standards is represented by the ASHRAE Energy Standard 90.1; this regulation, indeed, provides tools for the building design, its properties' definition and operational and maintenance plans able to guarantee the sustainability and functionality of the structure itself during its entire lifespan. Even in this case the regulations, all over the years, are updated to be compliant with the timeline's defined steps, with more stringent requirements and as response to varying environmental condition, global benchmarks and needs.

The thesis work well fits into this scenario and highlights the importance of analysing the performance of a building, considered as emblematic of the building typology, by applying updated versions of the energy standards and putting in evidence that the efficiency and performance of the building vary simultaneously with standards variation and global requirements. Furthermore, it provides an analysis of the most affected components of energy efficiency by the energy standard variation and set even possible strategies for further enhancement and alignment with performance requirements.

This objective is pursued by the development of two dynamic energy simulations of the same building where its actual performance, expressed through fixed thermal properties, systems efficiencies and schedules, is compared with two baseline building models realized following the rules of the consecutive versions of the ASHRAE 90.1 standard that provide a different efficiency and performance output. The enhancement strategies are then analysed to determine their impact of the final performance results and accomplishment of target goals.

The first chapter of this thesis is devoted to the analysis of the climate change providing a clear overview of its impact on natural environments, people and infrastructures and it, specifically, focuses on the correlation with the building sector. Starting from the awareness of this evidence and of the need to actively mitigate this phenomenon, the key role of the building sector, as a possible strategic element to contribute to the ecological transition, is shown. Indeed, the commitment of international communities over this topic is clearly emphasised by the issue of international standards subsequently recognized at national level. The attention over these goals and the shared consciousness about the exigency to recreate a green building stock is translated into the launch and spread of the sustainable rating systems that incentivize the development of designs, operational and maintenance able to comply with the three pillars of sustainability: economical sustainability, social sustainability and environmental sustainability. Several rating systems have been developed worldwide promoting the transformation of the existing heritage and orienting the realization of the new one through a new comprehensive vision of the structure both temporally and spatially.

With respect to the second chapter, particular attention is devoted to one of the most diffused building rating systems. LEED, in fact, experienced a rapid development imposing itself as a recognized award for those building respecting its requirements as symbol of sustainability. This recognition is not only representative of the efficiency of the building leading to a reduced consumption, operational costs and improved quality but also increases the market value, the credibility to clients, attracts attention and furthermore enables to access several incentives depending on the nation and region of development. The analysis includes the comparison between version 4 and 5 of the LEED certifications highlighting the main differences and updates due to the main focus areas of the two versions, indeed, the version 5 is more focused on decarbonization, quality of life and ecological conservation and restoration aligning itself to the international sustainability goals. The energy category of this certification is moreover investigated for the two versions through the dynamic energy simulation conducted, even in this case, respectively with two version of the recognized energy standards ASHRAE 90.1. A comparison between these last two is conducted summarizing the main requirements related to envelope, schedules and controls, systems, commissioning and verification and modelling variation.

As regards the third chapter, it is related to the presentation of the case study analysed. It reports the main features of this existing building and provides an overview of the modelling procedure and input data definition according to design choices, respect of minimum requirements and manufacturer's specifications. The building has been chosen as a representative sample of its specific building type for a defined climatic zone allowing a clear path for the performance enhancement and improvement possibilities to be implemented for the portion of the depicted estate. A detailed description of the used methods and of the different phases of the workflow is provided. The modelling analysis even includes the definition of the baseline design building for the two versions of ASHRAE 90.1, respectively 90.1:2010 and 90.1:2019 representative of the standard evolution and used as comparison model for the proposed model's performance delineation.

The fourth chapter concerns the results of the two energy modelling, realized through the IESve software, where the variations are only related to the modelling rules of the baseline building design while the proposed one is maintained unvaried. The comparison even considers the analysis of the main differences in the energy uses and the possible reasons of these variations between the two models. Finally, the results of the energy modelling are used to determine the output in terms of the LEED credit "enhanced energy performance", firstly verifying the respect of requirements to access the credit and successively determining the scoring related to the final performance of the building.

The crucial step of the analysis, exposed in the fifth chapter, is represented by the identification of the possible applicable optimization strategies starting from the analysis of the building needs and the most impacting aspects over the energy demand. Using the results of this assessment, some strategies have been selected and properly modelled to see the variation in the building response and performances and consequently determine the effectiveness of those solutions. Specifically, the adopted strategies are: enhancement of optical and thermal properties of windows, improvement of the thermal properties of the roof, adoption of the cool roof solution and, finally, the integration of automatized external shading devices. Each of these solutions have been implemented separately to verify their impact over the whole building performance and, in a second phase, they were super positioned to verify the presence of some antagonistic effects, the combination's consequences on the several energy uses and on the final performance of the building.

The sixth and the seventh chapters are, finally, devoted to the exposition of conclusions coming from the complete assessment of the building and discussion resulting from the in-depth analysis of the outputs and strategies' implementation. This set the basis for the identification of further possible enhancement and for future adaptation to changing standards and conditions.

The thesis work aims at determining the correlation between the performance of a well-defined building and variable energy standards and sustainability goals. It offers a transparent evaluation of the effectiveness and applicability of the available innovative strategies, improved controls and high-quality materials to guarantee efficiency, functionality and quality of life as required and promoted by the building sustainable certifications. It, furthermore, provides a possible scenario to assist designers and clients relatively to the certification possibilities and to the feasibility of technical solutions.

1.1. Global warning: climate change

Nowadays we are forced to face one of the most challenging ad awful events of the world as a consequence of the unconcerned and short-sighted anthropic activities. The dangerous and huge effects of the climatic change are increasingly visible and impossible to ignore not only from a natural point of view but even social, economic and business ones. Droughts, wildfires, floods, glacier melting, rise of the sea level are just some of the registered phenomena causing in turn several threats as the increase of the mortality due to extreme temperatures, the vulnerability and exposure of people to violent events, reduction of biodiversity, losses in agriculture, pressure on the infrastructures and vulnerability of buildings to just mention some of them. [1] The major and quantifiable result of climate change is represented by the global temperature increase up to 2025 which has been considered as the third hottest year, after 2023 and 2024 which has been recognized as the hottest year reaching an average temperature increase above 1.5 °C with respect to the preindustrial levels.[2]

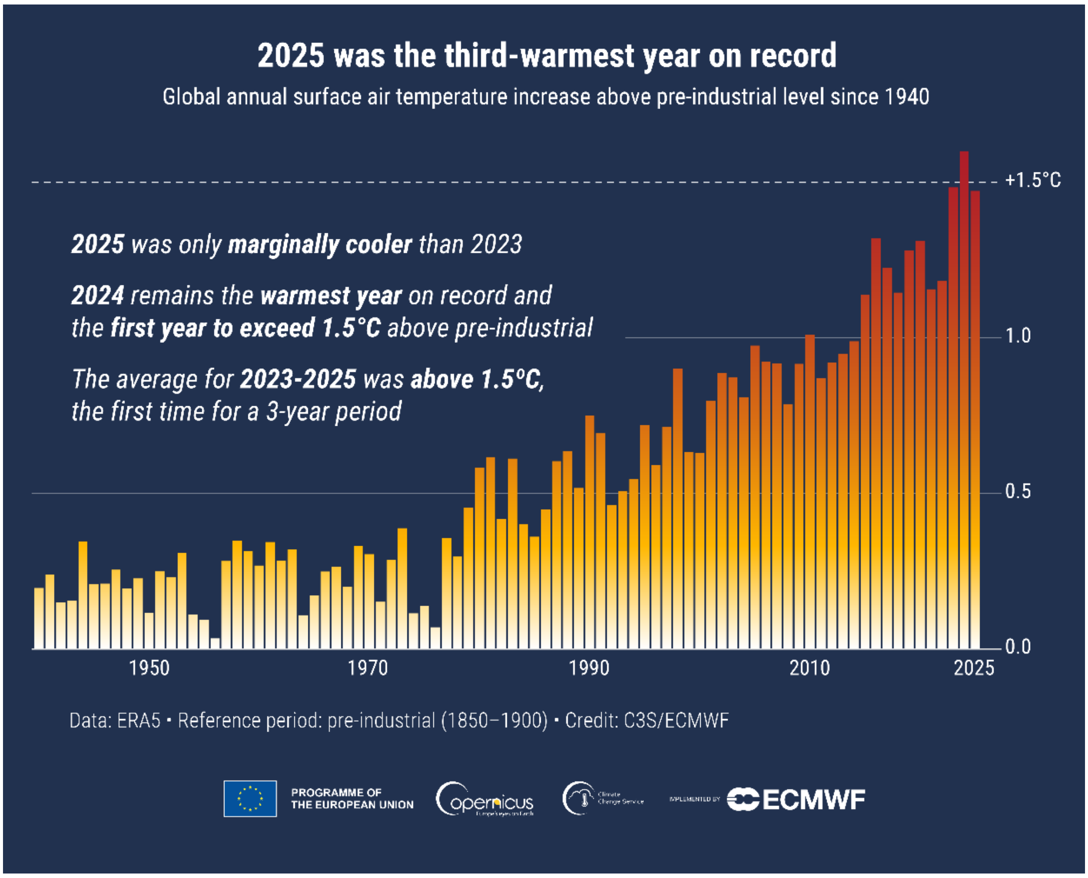

Figure 1- Global temperature trend. https://climate.copernicus.eu/GCH2025-graphics-gallery

Specifically in 2025, the 91% of the globe experienced temperatures higher than the average temperatures signed between 1991-2020 and, with particular attention to poles, 2025 has been recognized as the year with the highest temperature anomaly for Antarctic pole and as the second highest for the Arctic one.[3]

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[1] European Commision , *Consequences of Climate Change* https://climate.ec.europa.eu/climate-change/consequences-climate-change_en (26/01/2026)

[2] Nicolas, J., Vamborg, F., Emerton, R., Simmons,A. & Burgess, S. (January 14th, 2026), *2025 Global Climate Highlights,* ECMWF Communication Section Copernicus Team https://climate.copernicus.eu/global-climate-highlights-2025 (26/01/2026)

[3]Nicolas, J., Vamborg, F., Emerton, R., Simmons,A. & Burgess, S. (January 14th, 2026), *2025 Global Climate Highlights,* ECMWF Communication Section Copernicus Team https://climate.copernicus.eu/global-climate-highlights-2025 (26/01/2026)

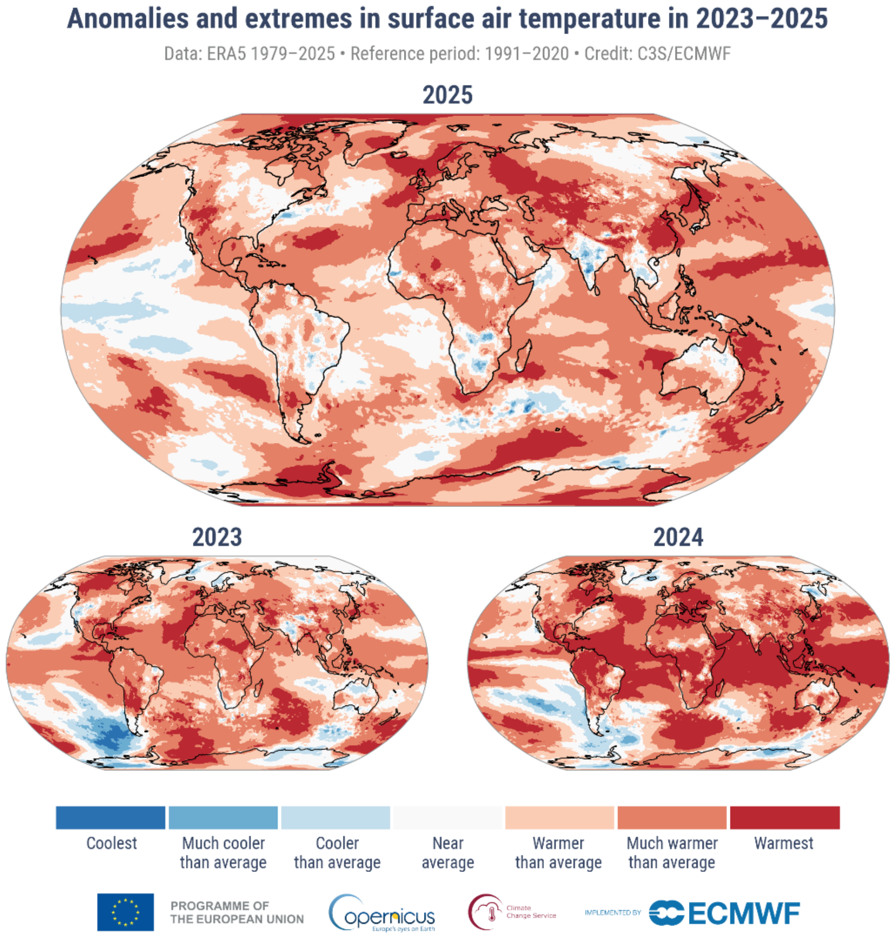

Figure 2- Temperature anomalies maps. The two extremes refer to 1979 and 2025 rankings.
https://climate.copernicus.eu/GCH2025-graphics-gallery

One of the main causes of this temperature rise is represented by the greenhouse effect. Normally, its presence positively impacts life on Earth by making the planet warmer and suitable for human life. Its principle of working is based on the blocked solar radiation that has hit the Earth surface but that is no more able to escape into the space remaining entrapped into the atmosphere; despite this, the increase of GHGs emissions contributes to the greenhouse effect enforcing it and therefore contributing to the global warming. [4] Specifically, carbon dioxide (CO2) in 2023 reached a value equal to 151% of pre-industrial levels showing a rapid increase in its release in atmosphere, methane (CH_4), able to remain in the atmosphere for prolonged period, is responsible for about the 16% of the warming effect and, as regards, nitrous oxide (N_2O) it accounts for the 7% of the warning due to GHGs.[5]

[4] European Parliament (March 23rd, 2023) , *Climate change: the greenhouse gases causing global warming,* https://www.europarl.europa.eu/topics/en/article/20230316STO77629/climate-change-the-greenhouse-gases-causing-global-warming (26/01/2026)
[5] World Metereological Organization (n.d.) , *Greenhouse gases,* https://wmo.int/topics/greenhouse-gases (26/01/2026)

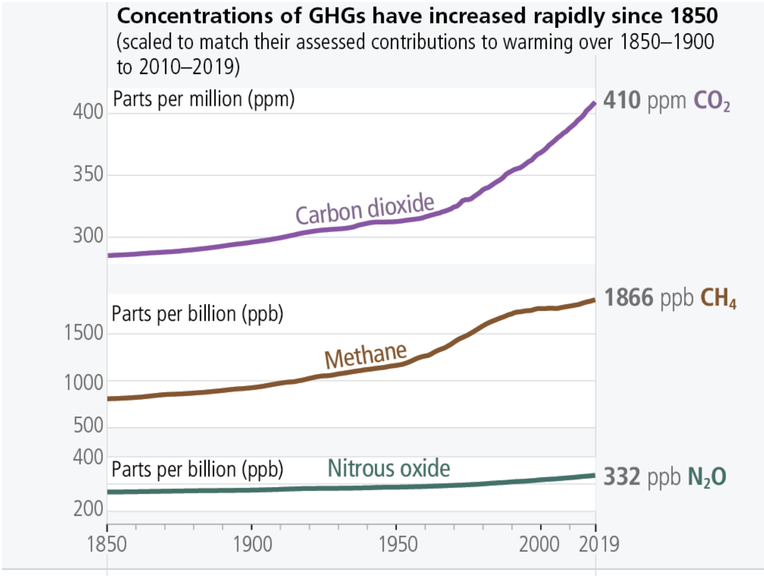

Figure 3- Increase of GHGs concentration up to 2019
IPCC, 2023: Sections. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 35-115, doi: 10.59327/IPCC/AR6-9789291691647

The emission of GHGs as carbon dioxide, methane, nitrus oxide and fluorinated greenhouses gases can be largely attributed to human activities causing an increase in their concentration as demonstrated by the following data:

- the primary cause of CO_2 emissions is represented by fossil fuel combustion and cement production which is responsible for the 9% of the total greenhouse gas emissions[6]
- only the 40% of methane release in atmosphere is due to natural causes, the remaining 60% is due to rice agriculture, fossil fuel and biomass combustion
- fertilizer use and biomass combustion is responsible for the 40% of N_2O emissions.[7]

As above declared, it is recognizable the human contribution to the rise of global warming and climate change, indeed "*the likely range of total human-caused global surface temperature increase from 1850–1900 to 2010–201966 is 0.8°C to 1.3°C, with a best estimate of 1.07°C.*"[8]

[6] Organization for Economic and Co-operation and Development OECD (October, 2018), *Global Material Resources Outlook to 2060: Economic drivers and environmental consequences. Highlights* https://www.oecd.org/environment/waste/highlights-global-material-resources-outlook-to-2060.pdf
[7] World Metereological Organization (n.d.), *Greenhouse gases,* https://wmo.int/topics/greenhouse-gases (26/01/2026)
[8] IPCC, (2023)*: Sections. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate* Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 35-115, doi: 10.59327/IPCC/AR6-9789291691647.001 pag. 42

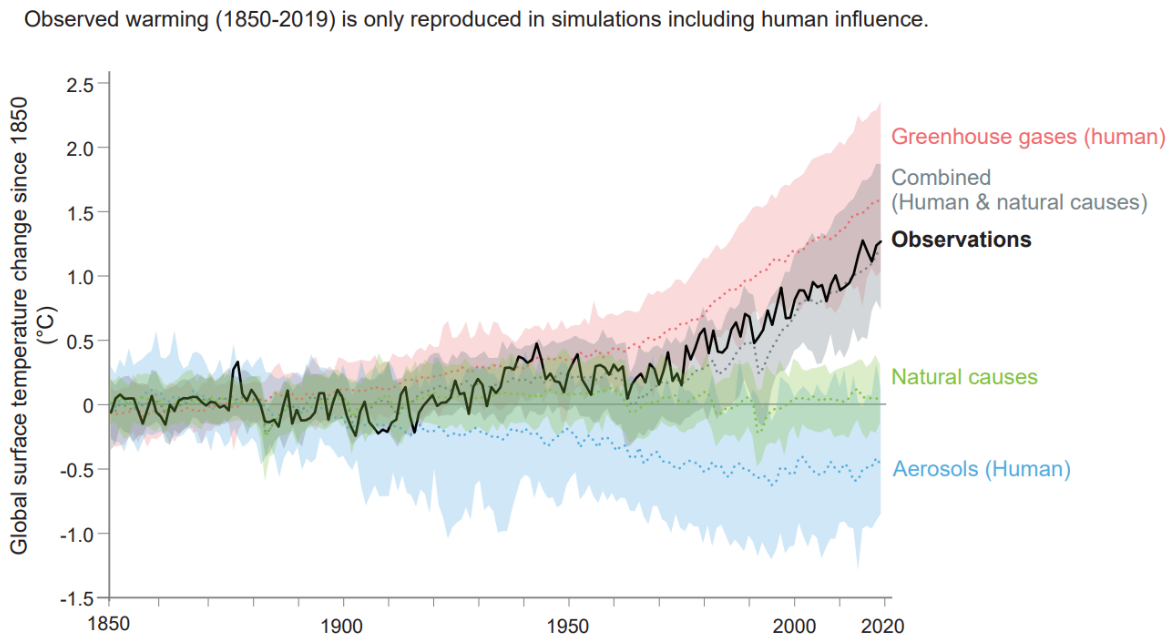

Figure 4- Human activities effects on global warning
https://www.ipcc.ch/report/ar6/wg1/downloads/outreach/IPCC_AR6_WGI_SummaryForAll.pdf

1.2. The role of the building sector in the ecological transition

Starting from the consciousness of humans' responsibility over climate change, it is worth analysing and underling the contribution of the building sector to the global GHGs emissions. Starting from 2019, the building sector emissions were 10 $GtCO_2$ corresponding to the 28% of total global CO_2 emissions without taking into account the contribution of manufacturing, material production and transportation which resulted into CO_2 emissions of about 3.5 $GtCO_2$ equal to the 10% of all energy sector emissions. This led to an overall, direct and indirect, contribution of the building sector of about the 38% of global CO_2 emissions.[9] This data represented a huge reinforcement in the awareness of the major impact caused by the construction sector. By implementing solution to reach the international sustainable goals, the trend, fortunately inverted even if slightly. Indeed, in 2022 the building sector was responsible for the 37% of the global CO_2 emission, only 1% less than in 2019[10]. Moving along the timeline,

[9] United Nations Environment Programme (2020). *2020 Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector*. Nairobi

[10] United Nations Environment Programme (2024). *2023 Global Status Report for Buildings and Construction: Beyond foundations: Mainstreaming sustainable solutions to cut emissions from the buildings sector.* Nairobi. United Nations Environment Programme (UNEP) and Global Alliance for Buildings and Construction (GlobalABC) https://doi.org/10.59117/20.500.11822/45095

2023 was signed by a contribution to the overall CO_2 from this sector of about 34 % with operational emissions equal to 9.8 gigatonnes.[11]

However, the emission gap report of 2024 increased awareness about the challenging objective and purpose represented by the Paris Agreement and its intent to maintain the global temperature increase below the 2°C above the pre-industrial level. The concern about the capacity to reach this objective was justified by the perspective of gap between 2030 and 2035 based on the difference between the full accomplishment of the NDCs and the most efficient trajectory to reach the goal of the Paris Agreement. The NDCs, indeed, represented the enhancement plan and intention of all the involved parties to the Paris Agreement, and according to the NDCs in force, the objective was far from being reached following the above-mentioned trajectory. It was, therefore, advanced a plan filling the gap in the five-years period setting the base for the presentation of the new NDCs required in 2025 able to guarantee the fulfilment of the objective.[12]

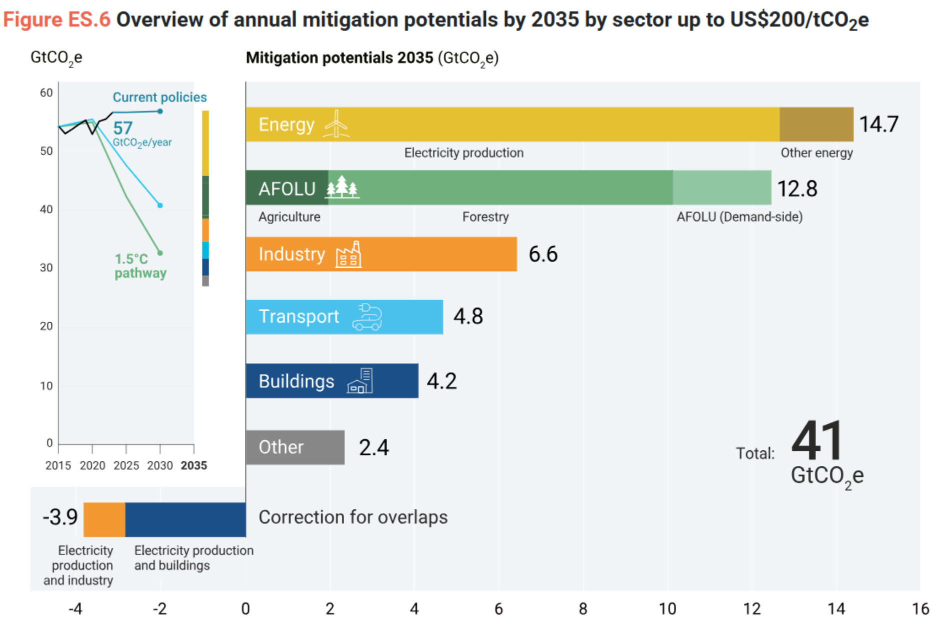

Figure 5- Highlights of mitigation goals United Nations Environment Programme (2024). Emissions Gap Report 2024: No more hot air ... please! With a massive gap between rhetoric and reality, countries draft new climate commitments. Nairobi. *https://doi.org/10.59117/20.500.11822/46404*.

As shown by the above figure, the building sector could have contributed to the mitigation with 4.2 $GtCO_2e$/year potential up to 2035. It was likewise declared that the current speed of

[11] United Nations Environment Programme (2025). *Global Status Report for Buildings and Construction 2024/2025: Not just another brick in the wall – The solutions exist. Scaling them will build on progress and cut emissions fast.* Paris. https://wedocs.unep.org/20.500.11822/47214

[12] United Nations Environment Programme (2024). *Emissions Gap Report 2024: No more hot air ... please! With a massive gap between rhetoric and reality, countries draft new climate commitments.* Nairobi. https://doi.org/10.59117/20.500.11822/46404.

enhancement was far from the aim's achievement, remarking the complexity of the required effort to guarantee retrofitting of existing buildings, the energy efficiency, the respect of zero-carbon standard for the new buildings and decarbonisation.[13] After the release of the new NCDs, the Emission Gap report 2025 still declares the insufficiency of the defined targets to fill the gap between 2030 and 2035 and to limit the temperature increase as defined in the Paris Agreement.[14]

In addition to data mentioned, it is, furthermore, clear that the impact of building sector and its capability to positively contribute or not is dependent on the population growth perspective and on the demand increase in building sector. Indeed, the estimation of population's growth points out an increasing trend up to a value of 10.3 billion by the mid-2080, even if, the trend is different depending on the continent and country considered[15]. Moreover, the growth in population is expected to happen majorly in cities up to 2050 with respect to town growth.[16]

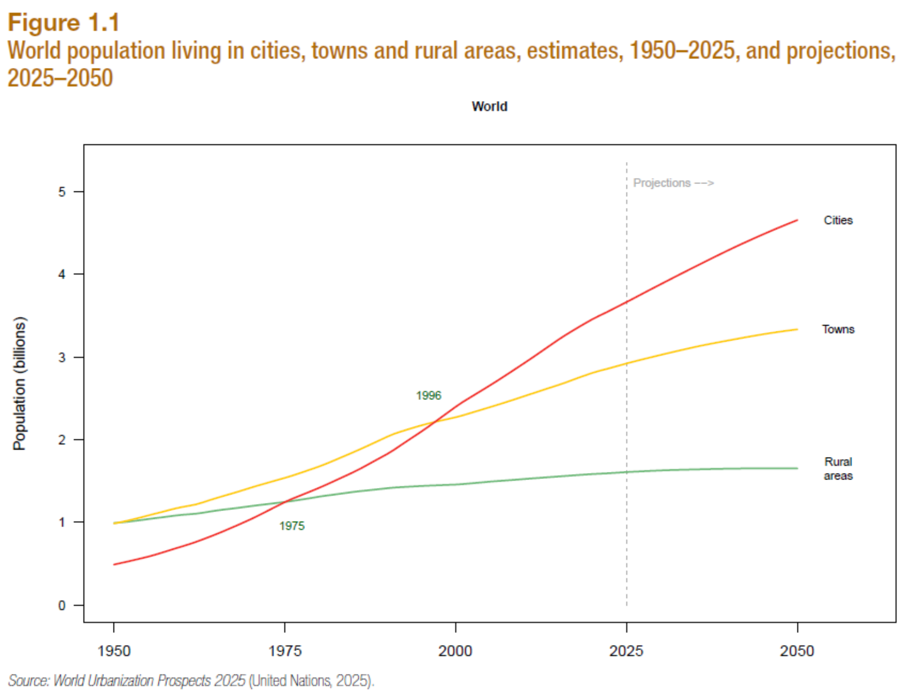

Figure 6- Projection of population growth in cities, towns and rural areas.
United Nations (2025). World Urbanization Prospects 2025: Summary of Results. UN DESA/POP/2025/TR/ NO. 12. New York: United Nations.

[13] United Nations Environment Programme (2024). *Emissions Gap Report 2024: No more hot air ... please! With a massive gap between rhetoric and reality, countries draft new climate commitments.* Nairobi. https://doi.org/10.59117/20.500.11822/46404.

[14] United Nations Environment Programme (2025). *Emissions Gap Report 2025: Off target – Continued collective inaction puts global temperature goal at risk* [Olhoff, A., chief editor; Lamb, W.; Kuramochi, T.; Rogelj, J.; den Elzen, M.; Christensen, J.; Fransen, T.; Pathak, M.; Tong, D. (eds)]. Nairobi. https://doi.org/10.59117/20.500.11822/48854.

[15] United Nations (2024). World Population Prospects 2024: Summary of Results. UN DESA/POP/2024/TR/NO. 9. New York: United Nations.

[16] United Nations (2025). World Urbanization Prospects 2025: Summary of Results. UN DESA/POP/2025/TR/ NO. 12. New York: United Nations.

What above analysed highlights the huge impact of building sector and the threats for its further development in the era of climate change. For this reason, it is equally necessary to underline the exigency for adaption of the building sector to climate change and mitigation over the possible risks and catastrophic phenomena.

Starting from adaptation, the main scope is to provide resilient building stocks, both the existing one and the new one. It is clear that, despite this way of designing and conceived the building is brand new, it is easier to be meant and adopted for new buildings rather than existing ones. Indeed, the existing heritage is often subjected to constraints due to historical value and architectural and structural limitations, making the adaptation to climatic change and the resilience to the risk more challenging. In any case, the first step through the building sector adaptation is the definition and actuation of climatic risk assessment highlighting exposure and vulnerability of the site and, whenever speaking of new buildings, choose a location where there is no risk or lower risk. After that, it is necessary to realize structures or to retrofit the existing ones considering the possible climatic events and conditions based on future previsions and providing resources and maintenance plans.

Actually, some of the resilient strategies coincide with the ones enabling the mitigation. Specifically, nature-based or biophilic solutions can mitigate the impact of building construction over nature and enable to imagine and design the building in deep correlation with the environment. Under this perspective, the building is no more realized as a "per se" entity but as part of an ecosystem that should perfectly integrate and interact with it improving its performances and efficiency.

Mitigation alternatives depend on the considered stage of construction, indeed, in a preliminary stage, representing the ideal condition for the good realization of the construction, it is possible to assess whether the location is suitable for the building construction and to define building characteristics able to withstand eventual damages. Whenever the considered stage is the construction phase the possibilities regard the realization or substitution of designed vulnerable elements with ones for which the risk is reduced and the possibility to implement further measures to reduce risk. Finally, the last and less favourable stage in terms of mitigation occurs when the risk is unavoidable and where the only possible solution is the reactive one. [17]

[17] Mareddy, A. (2017). *Mitigation and impact management: Environmental impact assessment*, 383–419. https://doi.org/10.1016/b978-0-12-811139-0.00011-6

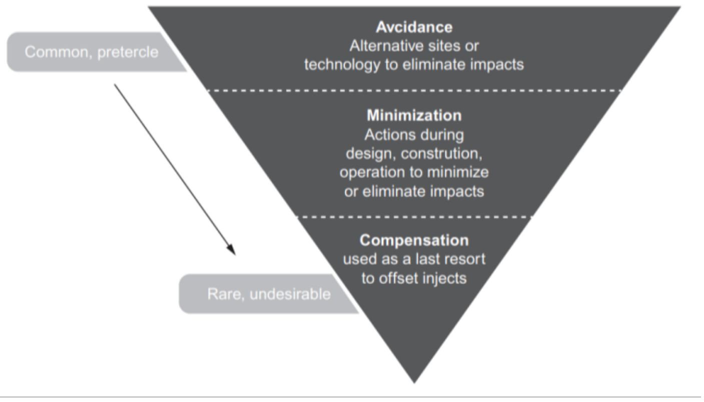

Figure 7- Mitigation stages Mareddy, A. (2017). Mitigation and impact management. Environmental Impact Assessment, 383–419. https://doi.org/10.1016/b978-0-12-811139-0.00011-6

One of the main strategies to enable mitigation is represented by the improvement of the energy efficiency of the building reducing its overall impact, this goal can be achieved through different methodologies from the passive ones to the active and proactive ones. Specifically, one possible solution could be the envelope enhancement by improving the thermal properties of transparent and opaque elements. Other possibilities are the exploitation of natural sources as, for instance, the natural ventilation and the "free cooling" that can reduce the HVAC usage or as the presence of a green roof that can reduce temperatures in summer and the heat island effect and subsequently the energy cooling needs. All these solutions contribute to the realization of buildings which are not designed just as passive and isolated with respect to the environment but able to interact with it trying to respectfully take advantage of it. In addition to the above-mentioned strategies, an improvement in the technologies used, as the daylight control and appliances controls, lead to an enhanced energy efficiency by considering the natural conditions' variation and the variation in occupants' activities. Moreover, the realization of on-site energy production systems based on renewable energy as photovoltaic systems, solar heating systems, geothermal systems, among others, can contribute to the autonomy of the building reducing the non-renewable energy consumption. All these strategies not only enable to make progress towards the decarbonisation of the building sector contributing to its fulfilment by 2050 but leads to the definition, for the first time, of the building as active component able to generate energy to be used on site or to be provided to the grid. These series of interventions set the basis for a future scenario in which the building impact on climate is reduced, its vulnerability against extreme actions is reduced and the quality of life of occupants is improved. Clearly, the adoption of all these strategies is not always effective or possible to be applied, for this reason, it is necessary to determine the most suitable or feasible solution depending on the considered project.

The necessity to carry out this transformation and the relevance of this process is highlighted by a huge number of initiatives, international goals and national regulations which spread out all around the world. As previously mentioned, one of the major and recognized actions was represented by the Paris Agreement subscribed in the Climate Change Conference (COP21) in Paris in December 2015 by 195 parties, even though the current number of involved parties decreased to 194. The main scope of this agreement was the limitation of temperature increase with respect to preindustrial levels below 2°C trying to limit this rise to maximum 1,5°C. The procedure establishes five-year cycles through which all the involved countries should provide a national program to contribute to the common objective; these national milestones are called "Nationally Determined Contributions" (NDCs) and firstly explicated in 2020 as starting point of the five-years cycles. In these NDCs the Nations clarify their effort towards the reduction of GHGs emissions. By the registered output it was assessed that future actions should consider efforts severe enough to guarantee the limitation of the temperature increase to 1,5°C to avoid more impacting and dangerous climatic disasters.[18]

In this scenario, it is equally worth mentioning the Agenda 2030 subscribed in September 2015 by 193 countries of the Organization of the United Nations. The plan is organized according to 17 sustainable objectives which should be reached by the defined deadline and for which the monitoring and verification is on voluntary basis for each country but incentivized to provide annual national reports showing the progress towards the goals. The Agenda is oriented to a sustainable future at global scale providing a holistic vision of sustainability oriented to peace, people, prosperity, partnership and planet leading to an improvement in the quality of life equally for all the involved parties and to environmental preservation.

[18]United Nations Climate Change (n.d.), *The Paris Agreement*, https://unfccc.int/process-and-meetings/the-paris-agreement (02/02/2026)

Figure 8- SDGs of Agenda 2030 https://unric.org/it/agenda-2030/

Despite all these goals are strictly interconnected and dependent on each other creating a cause-effect cascade, for the purpose of the current analysis, only those goals oriented to building sector and energy enhancement are analysed:

- **Affordable and clear energy** (objective 7): the scope of this goal is to guarantee affordable, clear energy by 2030 increasing the rate of renewable energy in the overall energy consumption and doubling the global rate in the energy efficiency enhancement.
- **Sustainable cities and communities** (objective 11): the action plan establishes the realization, by 2030, of adequate dwelling and services in poor areas furthermore providing all the surrounding infrastructure to be safe, accessible and sustainable. The scope is to establish an integrate vision of urbanization with well-functioning services and dwellings able to guarantee quality of life for occupants, mitigation effects on natural environment, foster a conscious use of water and management of waste and to provide resilient structures to natural disasters.
- **Climate action** (objective 13): it aims to implement strategies and action plan able to reduce the climatic risk and disasters' effects. It is underlined the key role of consciousness, education information and sensibilization around climate risk, mitigation and adaptation topics.[19]

[19] ASviS Alleanza Italiana per lo Sviluppo Sostenibile (n.d.), *L'Agenda 2030 dell'Onu per lo sviluppo sostenibile*, https://asvis.it/l-agenda-2030-dell-onu-per-lo-sviluppo-sostenibile/ (01/02/2026)

Just to cite others of them there is the "Building Breakthrough" discussed at COP28 and providing a clear framework for countries[20] part of the "Breakthrough Agenda" launched at COP26. It creates further cooperation between nations through the decarbonisation process with a main focus over seven sectors contributing to the 60% of global emissions which respectively are: steel, road transport, power, cement and concrete, buildings, agriculture and hydrogen. Specifically for buildings, it incentives the realization of Near-Zero Emission and Resilient Buildings in addition to financial support and research.[21] Another quotable event was represented by the "Declaration of Charlotte" in 2024 organized by the French Government in collaboration with UNEP that involved more than 80 ministerial delegation. At that time, it was stressed the concern about the climate risk and the disapproval to still existing investments over source-consuming productivity. The declaration, starting from this premise, remarked the possible strategies towards the sustainability goals including the following possibilities:

- incentives the use of certified or compliant to standards materials guaranteeing cost-effectiveness, durability and reliability
- promote research and innovative technologies and tools
- guarantee fiscal incentives to foster the realization of resilient and carbon-neutral buildings
- update regulations, objectives and building codes up to the carbon-neutrality aim
- analyse mitigation and adaptation strategies for the specific location

This declaration strengthened the commitment of nations over the path and plan specified in the Paris Agreement.[22]

Obviously, the presented scenario is only a concise analysis of the adopted regulations over a so extended and articulated challenge; despite that, one of the main concrete and tangible actions to purse the objective is represented by the stipulation of buildings energy codes. Indeed, 2023 was signed by the adoption of residential and non-residential buildings codes for a total amount of respectively 81 and 77 codes considering that the 80% of them was mandatory.

[20] UNEP UN Environmemntal Program (December 6th, 2023), *The Buildings Breakthrough: Global push for near-zero emission and resilient buildings by 2030 unveiled at COP28*, https://www.unep.org/news-and-stories/press-release/buildings-breakthrough-global-push-near-zero-emission-and-resilient (02/02/2026)
[21] Breakthrough Agenda, *Breakthrough Agenda*, (n.d) https://breakthroughagenda.org/ (02/02/2026)
[22] UNEP UN Environmental Program (March 08th,2024), *Buildings and Climate Global Forum – Declaration de Chaillot*, https://www.unep.org/news-and-stories/press-release/buildings-and-climate-global-forum-declaration-de-chaillot (02/02/2026)

Despite this could represent a good result, the 30% of the above codes was not updated after 2015 drastically reducing their validity, reliability and effectiveness. Their update should follow the requirements of the international goals and Paris agreement purpose, to foster the realization of buildings increasingly performant and efficient thanks to the application of innovative technologies, advanced metering and control systems. Additionally, they promote interaction with the surrounding environment by taking advantage from the cooperation more than from exploitation. [23]

Finally, a major recognized step towards the efficiency of buildings is represented by the rating systems and sustainable certifications, indeed, their role is reinforced and recognized by their inclusion into the evaluation of the "Global Buildings Climate Tracker" (GBCT). The tracker, in line with the global common purpose of decarbonisation, monitors the progresses towards its fulfilment. The monitoring of the CO_2 emissions due to building operation, is provided by a composite index that considers, among others, the adoption of measures towards decarbonisation including green certifications.[24] An in-depth analysis of the rating systems is provided in the following subchapter.

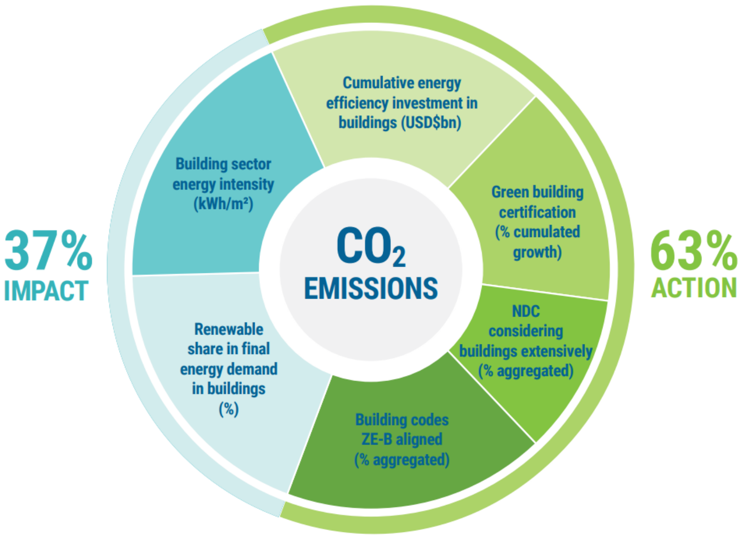

Figure 9- Global Building Climate Tracker's indicators weight United Nations Environment Programme (2024). 2023 Global Status Report for Buildings and Construction: Beyond foundations: Mainstreaming sustainable solutions to cut emissions from the buildings sector. Nairobi. https://doi.org/10.59117/20.500.11822/45095.

[23] United Nations Environment Programme (2024). *2023 Global Status Report for Buildings and Construction: Beyond foundations: Mainstreaming sustainable solutions to cut emissions from the buildings sector*. Nairobi. United Nations Environment Programme (UNEP) and Global Alliance for Buildings and Construction (GlobalABC) https://doi.org/10.59117/20.500.11822/45095

[24] United Nations Environment Programme (2024). *2023 Global Status Report for Buildings and Construction: Beyond foundations: Mainstreaming sustainable solutions to cut emissions from the buildings sector*. Nairobi. United Nations Environment Programme (UNEP) and Global Alliance for Buildings and Construction (GlobalABC) https://doi.org/10.59117/20.500.11822/45095

1.3. The rating systems

The rating systems introduced a solid and recognized way of conceiving the building by imposing their presence in the market as a valid assessment procedure of the building performances to pursue the sustainability in the construction sector. These systems are usually voluntary-based tools oriented to the sustainability of the buildings which provide a clear and measurable output of the multilevel assessment enabling an overall view of the building sector and the comparability of different constructions. Moreover, their validity is not only justified by the mere prestigiousness and marketability of certified buildings, but primarily, it is due to the comprehensive vision of the building. Indeed, the building is analysed in all its phases, not only the operational one but in its entire life-cycle from the site evaluation to the construction material choice based on their production process, from the transportation of materials to passive strategies to be implemented in the design, from the operational schedules to adapt building functioning to occupants habits to the maintenance plan and dismantling impact. This complex and tangled system of evaluation, in its in-depth study of the building, explores all the aspects of sustainability: the social one by considering the effect of the construction over the existing communities, the beneficial effects that the building could provide and well-being, health and comfort of the occupants; the environmental one by appropriately choosing the site, the presence of green services around, the relationship between building and site and the necessity to reclaim the land; the economical one by reducing the energy consumption of the building and the related energy costs, by a controlled use of resources and by financial incentives. Moreover, although the structure of each certification is well-defined according to indicators grouped depending on the influence-area considered, specific variations are presented in each country or region to respond to the specific features and exigencies of the defined site underlining the convince that the concept of sustainability is not only made of defined rules and targets but it is strictly dependent on the considered site.

By the provided scenario their contribution to the international goals and sustainability of the building sector is undeniable and recognizable, in fact, they pursue efficiency, reduction of CO_2 emissions, LCA towards a decarbonized and resilient building stock and enable clear communication between the involved parties, indeed, they provide tools and supports for the designers to realize buildings with the above-mentioned features still respecting functionality and well-being of occupants, provide quantifiable analysis and reports to support the cause and give a clear overview to the politicians and government of the positive impacts of green buildings, promote financial support by assessing the risk reduction and the resulting costs reduction and, finally, encourage clients and occupants towards awareness of climate change, importance of resilience and well-habits. [25]

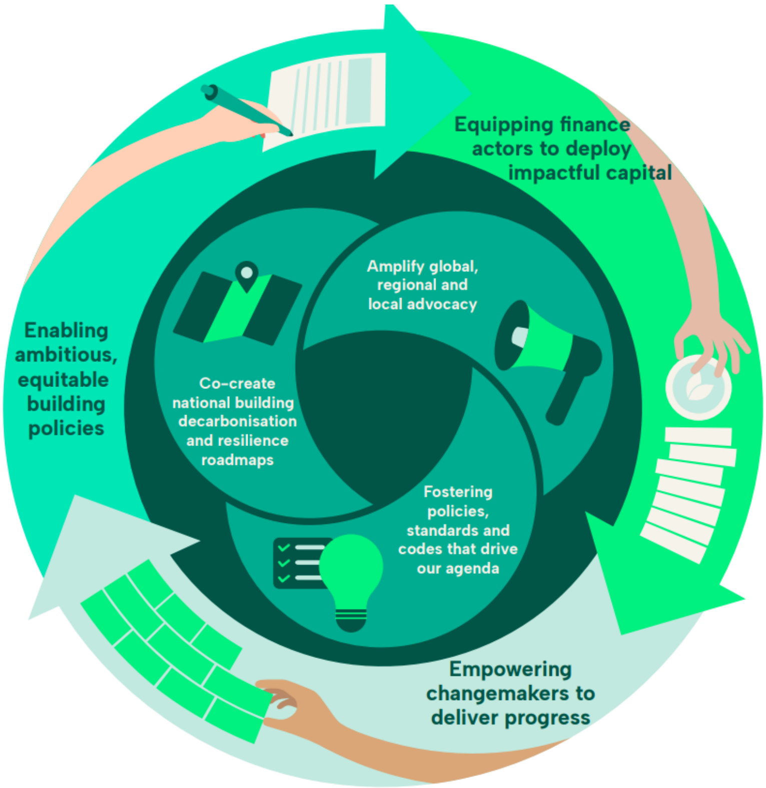

Figure 10- Loop towards building transition World Green Building Council, WorldGBC strategic plan 2025-2027 (n.d.) *https://worldgbc.org/wp-content/uploads/2025/04/WorldGBC-Strategy-2025-2027.pdf*

Specifically, different rating systems are available all around the world, even though only some of them are characterized by clarity, transparency and rigorousness at the point to be considered in the evaluation of the Global Buildings Climate Tracker; just to mention some of them the following list is provided: BREEAM (Building Research Establishment Environmental Assessment Method) realized in 1988 by the Building Research Establishment (BRE), GREEN STAR developed in 2003 by Green Building Council of Australia, LEED (Leadership in Energy and Environmental Design) launched in 1998 by the U.S. Green Building Council (USGBC) and WELL created by The International WELL Building Institute in 2014.[26] Additionally, in this overview, it is worth mentioning the World GBC, created in 1993 with the main scope of promoting cooperation between the different stakeholders in a fluid transition towards green buildings passing from the global scale and objective to the local analysis and operation plan.

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[25] World Green Building Council (n.d.), *WorldGBC strategic plan 2025-2027* https://worldgbc.org/wp-content/uploads/2025/04/WorldGBC-Strategy-2025-2027.pdf (05/02/2026)

[26] United Nations Environment Programme (2024). 2023 *Global Status Report for Buildings and Construction: Beyond foundations: Mainstreaming sustainable solutions to cut emissions from the buildings sector.* Nairobi. https://doi.org/10.59117/20.500.11822/45095.

Starting from US Green Building Council, the interest increased so much all around the world so that a collaboration between different countries was created.[27] Nowadays, it counts more than 75 Green Building Councils with an interconnection grid able to reach the 60% of global building stock, the 65% of global GDP, the 72% of the built environment emissions and, finally, the 60% of global urban population.[28]

As previously reported, the rating systems provide a holistic and comprehensive vision of the building giving the possibility to use this instrument not just as a ranking method but as a basis for the designing of the structure and preliminary analysis of the context, for this reason the rating systems can even be recognized as a guidance tool through ecological and resilient construction. The value of these systems is furthermore increased due to their multicriteria structure able to simplify the complete and deep analysis of buildings providing clear indicators and guidance through quantifiable impacts. Clearly some consistent differences emerged from the comparison of the rating systems but all of them set a series of sustainable achievements and goals that can be properly managed and selected from the designers' team to provide a tailored schedule and subsequent recognition of certification, even though, in some of these systems, some mandatory requirements must be fulfilled to enable access to the certification. The tailored schedule can include more "criteria" belonging to the same "category" (as defined in some systems and referred to as "topic", "evaluation area" or "theme" in others) or includes more widespread credits belonging to different categories, once ascertained the respect of mandatory provisions. Each credit is moreover recognizable with a maximum score; indeed, all the credits and categories are weighted in function of their priority and impact, and the weighting differs between the different rating systems. Finally, the certification procedure can include a different number of phases even though the sequence is more or less identical setting an initial fee payment during registration and successive phases of consulting relative to the documents' presentation and performance assessment and a final verification leading to the score and certification recognition. [29]

For further and deeper information about the rating system differences a comparison between the most common ones is below reported:

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[27] World Green Building Council (n.d.), Our Mission, https://worldgbc.org/about-us/our-mission/ (05/02/2026)

[28] World Green Building Council (n.d.), *WorldGBC strategic plan 2025-2027* https://worldgbc.org/wp-content/uploads/2025/04/WorldGBC-Strategy-2025-2027.pdf (05/02/2026)

[29] Marchi, L., Antonini, E., & Politi, S. (2021). *Green Building Rating Systems (GBRSs).* Encyclopedia, 1(4), 998-1009. https://doi.org/10.3390/encyclopedia1040076 (05/02/2026)

Table 1- Rating systems' comparison

	BREEAM	Green Star	LEED	WELL
Application field	- New construction - Refurbishment and fit-out - In use - Communities	- Green Star Buildings - Green Star Communities - Green Star Performance - Green Star Interiors	- Building Design and Construction - Interior Design and Construction - Building Operation and Maintenance - Neighbourhood Development - Residential - Cities	-Owner-occupied projects - WELL Core Projects
Main principles	- Net zero carbon - Whole life performance - Health and social impact - Circularity and resilience - Biodiversity and nature - Disclosures and reporting	- Climate change's impact reduction - Enhance health and quality of life - Restore and protect biodiversity and ecosystems - Resiliency in buildings, fitouts, and communities - Market transformation and a sustainable economy	v5: -Decarbonization -Quality of life -Ecological conservation and restoration	- Equitable - Global -Evidence-based -Technically robust -Customer-focused -Resilient
Categories	-Management -Water -Energy -Transport -Health & wellbeing -Resources -Resilience -Land use & ecology -Pollution -Materials -Waste -Innovation	-Management - Indoor Environment Quality - Energy - Transport - Water - Materials - Land use and Ecology - Emissions - Innovation	- Integrative Process, Planning and Assessment - Location and Transportation - Sustainable Sites - Water Efficiency - Energy and Atmosphere - Material and Resources - Indoor Environmental Quality - Project priorities	- Air -Water - Nourishment - Light - Movement -Thermal comfort -Sound - Materials -Mind -Community
Rating	- Outstandig: ≥85 % - Excellent: ≥75 % - Very good: ≥ 55% - Pass: ≥30 % - Unclassified: < 30 %	-1 Star: Minimum Practice -2 Star: Average Practise -3 Star: Good Practise -4 Star: Best Practise -5 Star: Australian Excellence -6 Star: World Leadership	-LEED Certified: 40-49 points earned -LEED Silver: 50-59 points earned -LEED Gold: 60-79 points earned -LEED Platinum: 80+ points earned (additional requirements for v5)	-WELL Bronze: 40 points -WELL Silver: 50 points and minimum 1 point per concept -WELL Gold: 60 points and minimum 2 points per concept -WELL Platinum: 80 points and minimum 3 points per concept

30 31 32 33 34

Despite these differences and variations depending on the certification's origin location and some framework and structural organization they are bonded by the final same purpose of sustainability in buildings.

It is even recognized the necessity to foster better-defined financial incentives, assessment of risk and consequent economic losses in function of the local context, identify clear cooperation between governments, alignment between standards, clarity and transparency in framework definition. Furthermore, their structure, assessment method and requirements are always in evolution to adapt themselves and their objectives to the evolving exigencies and defined milestones towards resilience, adaptability and efficiency's enhancement.

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[30] Marchi, L., Antonini, E., & Politi, S. (2021). *Green Building Rating Systems (GBRSs).* Encyclopedia, 1(4), 998-1009. https://doi.org/10.3390/encyclopedia1040076 (05/02/2026)
[31] BREEAM, (n.d.) https://breeam.com/ (05/02/2026)
[32] Green Building Council Australia (n.d.), *Rating System* https://new.gbca.org.au/green-star/rating-system/ (05/02/2026)
[33] USGBC | U.S. Green Building Council (n.d.), *LEED rating system* https://www.usgbc.org/leed (05/02/2026)
[34] International WELL Building Institute (n.d.), *WELL Certification* https://www.wellcertified.com/certification/v2/ (05/02/2026)

2. Evolution of LEED and ASHRAE Standards

2.1. LEED certification: framework and objective

The LEED (Leadership in Energy and Environmental Design) rating system has been realized in 1998 by the U.S. Green Building Council (USGBC), a team who first recognized the impact of the building sector and the need for a more sustainable way of constructing. The main purpose of USGBC is to provide tools and solutions to drive the design, construction and operation of buildings towards a sustainable realization able to fulfil all the requirements necessary for the well-being of occupants and the high-performance of space in the future perspective of a decarbonized building sector. In addition to these main leading principles, the program offers a clear framework able to ease the comparison between several projects.[35]

LEED certification system, specifically, is one of the most important recognized systems for the building rating, providing not only methods to realize an environment able to meet efficiency, high performances and wellness needs but guaranteeing also a cost-effectiveness analysis. [36]

The framework of this certification system presents a holistic evaluation of the building passing from the water efficiency to energy one, from the material selection to the indoor environmental quality in a comprehensive series of credits. The rating system varies according to the typology of building considered, each team, in fact, identifies the rating system which best fits the project. Depending on the chosen category the requirements and frameworks to be fulfilled and adopted vary. Specifically, the categories are those defined as follows:

- LEED BD+C for Building Design and Construction: New Construction and Major Renovation, Core and Shell Development
- LEED ID+C for Interior Design and Construction
- LEED O+M for Operations and Maintenance
- LEED for Residential Design and Construction
- LEED ND for Neighbourhood Development: it overcomes the concept of the building as a per se entity and aims to the realization of a set of buildings conceived as a whole favouring an efficient land use and improving local transportation.

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[35] Ailyn, D., Patel, K., & Thompson, M. (n.d.). *History and Evolution of LEED Certification: Explore the development of LEED standards and their impact on the construction industry*. https://www.researchgate.net/publication/384398865 (27/11/2025)
[36] USGBC | U.S. Green Building Council (n.d.), *LEED rating system* https://www.usgbc.org/leed (28/10/2025)

- LEED for Cities and Communities: it increases the scale to a more comprehensive vision.[37]

Entering in the detail of how the workflow is organized, once the project team has identified the most appropriate rating system, each project should comply firstly with specific minimum program requirements (MPRs), in fact, the buildings which long for LEED certification must be located in a permanent site, with well-defined boundaries and should respect a certain minimum project size. Once these are verified, all the project documentation can be collected and submitted to the GBCI (Green Building Council Inc.) for the purpose of identifying the custom-made scorecard with the specific credits and requirements to pursue according to the specific typology of building, as identified in the above list, and subdivided in different categories. Based on the objective to achieve, the project team carries all the calculations and submit the documentation for the technical review which can be led in a single stage, if there are not missing information required, to certify a certain credit or if the project team is already satisfied of the reached score, otherwise it is still possible to improve the result by providing the missing information and submit the project to a new review.

Finally, when the review procedure is completed, its approval doesn't allow any additional variation and based on the achieved score, the LEED Certification is released.[38] [39]

According to the number of credits satisfied, the project can be awarded with different level of LEED Certification as specified below:

- Certified: if the number of earned point is 40-49 points
- Silver: if the number of earned points is 50-59 points
- Gold: if the number of earned points is 60-79 points
- Platinum: if the number of earned points is 80+ points[40]

[37] USGBC | U.S. Green Building Council, *LEED rating system* https://www.usgbc.org/leed (28/10/2025)
[38] USGBC | U.S. Green Building Council. (n.d.). *LEED v4: Building Design + Construction Guide* https://www.usgbc.org/guide/bdc#lt-overview (30/10/2025)
[39] USGBC | U.S. Green Building Council (n.d.), *Guide to LEED certification: Commercial* https://www.usgbc.org/tools/leed-certification/commercial (28/10/2025)
[40] USGBC | U.S. Green Building Council (n.d.), *LEED rating system* https://www.usgbc.org/leed (28/10/2025)

2.2. LEED v4 vs LEED v5

To better understand this rating system and the procedure to assess the Certification level of building, it is required to make an overview of the evolution and modification across years of the different LEED versions.

LEED v1.0 was officially developed in 1998 with the testing of a restricted number of projects which resulted in the launch of the first version in 2000 with the framework presentation for the sustainability of buildings; based on the results obtained from this initial testing further modifications and improvements were made up to the launch of LEED version 2 in 2001 leading to an increased resonance of the project itself capable to expand its application in new sectors and markets as demonstrated by the visible growth in staff, resources and a more specific and extended rating system conceived in 2003. A more rigorous version has been released in 2009 with a clear identification of the most important credits up to LEED v4. This version apported big modifications to the system introducing a smart grid approach and a major attention to materials and resources. Moving further along the timeline, LEED v4.1 introduced updated requirements and new methodologies to quicken the procedure and encourage the adoption of this rating system.[41] The latest version, LEED v5, is realized to guide the building stock towards a near-zero carbon future where the attention is mainly devoted to the decarbonization and the improved quality of life.[42]

Starting from this overview it is clear how the LEED Certification system had a huge impact on the way of imagining, designing and conceiving the building in all its phases, from the construction to the operation and the maintaining with a special regard to sustainability, resilience and future development. Its increasing rigorousness and validity favoured the widespread use of this rating system all over the world leading to the introduction of local requirements depending on the location of the analysed building emphasizing the concept that sustainability is highly dependent on the characteristics of the site considered.[43]

In the early stages of the LEED Certification's development, there wasn't a predefined weighting system according to which buildings were scored for certain and specific performances following the same rules and specifications, but the scoring and the assignment of credits was at discretion of the qualified specialists depending on what they recognized as more impacting. This method was updated to guarantee a stable and comparable way to certify

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[41] USGBC | U.S. Green Building Council (n.d.), *Mission and Vision* https://www.usgbc.org/about/mission-vision (28/10/2025)
[42] USGBC | U.S. Green Building Council (n.d.), *LEED v5*, https://www.usgbc.org/leed/v5 (28/10/2025)
[43] USGBC | U.S. Green Building Council (n.d.), *LEED rating system* https://www.usgbc.org/leed (28/10/2025)

sustainability of buildings based on categories defined in the Environmental Protection Agency's TRACI categories. Despite this, these categories were not realized ad hoc for the evaluation of the buildings as a whole and, even if their use introduced a framework structure in the rating system, this methodology was overcome and substituted by the LEED version 4 which introduced specific categories fitting the necessity to evaluate the built environment and representing the first individuation, in the field of rating system, of impact categories to clearly and unequivocally define buildings.

Figure 11- Overview of impact categories
https://www.usgbc.org/articles/leed-link-impact-categories

The new version, in addition to the definition of the new impact categories, introduced also a tool, the LEED Weighting Tool, able to associate and cross the adopted strategy with the positive impact produced analysing also which strategies produce more positive effects and which are the categories more influenced by these actions thanks to a statistical analysis. As first step, a ranking of the impact categories depending on their level of influence in the overall sustainability of the project is conducted defining the so-called "Impact Category Weighting Layer".

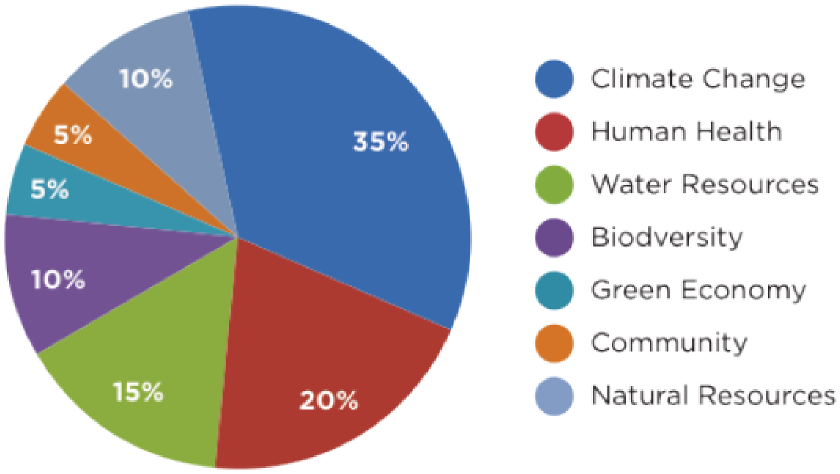


Figure 12- Weighting of the impact categories
Owens B.,Macken C., Rohloff A., Rosenberg H., LEED v4 Impact Category and Point Allocation Process Overview pdf. (2013, August 05)

As highlighted in the figure above, for example, it is clear how the sustainability of the building sector is highly influenced by its impact on climate change depending on the emissions level of the building itself. What defined is the logic at the base of the score associated to each of the credit.

In addition to this, a crossed table is realized between credits and impact categories to better define how impacting each credit is depending on the defined categories and the output is highlighted in the crossed cell. The lower is the value indicated in the cell, the lower is the impact of the credit on the specified category, the higher the value the more influencing effect on the category. Thanks to this crossed combination, a weighting definition of each credit is conducted and defined as the "Credit Outcome Weighting".[44]

The number of points achieved for each credit varies depending on the accomplishment level reached. As previously mentioned, the projects are not required to comply with all the credits presented in the rating system, the structure of the certification, indeed enable to present a flexible and personalized structure creating a tailored rating system which presents only the credits that the project can respect depending on its features and characteristics.

With a specific focus on the rating system for BD+C, LEED v4 is organized according to 8 different categories:

- Location and transportation

[44] Owens B., Macken C., Rohloff A. & Rosenberg H. (August 05th, 2013), *LEED v4 Impact Category and Point Allocation Process Overview pdf*

- Sustainable sites
- Water efficiency
- Energy and Atmosphere
- Material and Resources
- Indoor Environmental Quality
- Innovation
- Regional Priority

And an additional point for the integrative process, reaching maximum achievable score of 110 points.[45]

Location and transportation

This category, previously part of the sustainable site one, has been recognized as a separate category to underline the importance of choosing carefully the location for the project realization and its impact in the overall sustainability of the project. It focuses on the presence of existing amenities and facilities around the site, the transportation network available in terms of public transportation, cyclable paths, pedestrian paths. The availability of these services reduces costs and impacts to realize them to still guarantee the access to facilities for people occupying the building; furthermore, this also increases the value of the building itself and of the overall area. The category aims to reduce also the availability of private parking incentivising people to prefer other means of transportation as bicycles and public mobility.

Sustainable sites

In this section the necessity to realize the building in harmony and respect of the surrounding environment is of primary importance showing as the leak of this evaluation can compromise the well-functioning or the integrity of existing ecosystems leading to the extinction of species, deforestation, interruption of rivers courses and reduction of terrain permeability. The increasing awareness of the negative effects of non-caring construction, led to the adoption of site assessment before the realization of the building to better define the best location to avoid watercourses interruption and impermeabilization among others.

[45] USGBC | U.S. Green Building Council (n.d.) , *Leed Credit Library, Scorecard* https://www.usgbc.org/credits?Rating+System=%22New+Construction%22&Version=%22v4%22 (28/10/2025)

Water efficiency

The main objective of this category is to guarantee an efficient use of potable water in all indoor and outdoor uses. It is highlighted how impacting in terms of energy consumption is the production and transportation of potable water from the origin to the building site and the treatment and disposal of the wastewater. To face this problem, the LEED V4 introduces requirements and credits to encourage the designers to realize project in which an efficient use of water is guaranteed thanks to the use of water-saving fixtures, non-drinkable water and other alternatives sources as rainwater harvesting.

Energy and Atmosphere

Up to now the main energy resource was represented by non-renewable energy sources as coal, natural gas and others whose availability is limited, especially for the quantity required to satisfy the needs and that, moreover, contribute to the greenhouse gases emissions. The presence of credits regarding this field incentivizes, first of all, a reduction of the overall energy needs by adopting passive strategies, natural ventilation and other principles of the bioclimatic architecture. In addition to these measures, it necessary to fulfil the remaining energy requirements exploiting renewable resources which can be also produced on site.

Materials and Resources

Another essential matter is related to the construction's elements considering the overall LCA and the exigency to change the way of constructing starting from a more conscious and reduced use of the resources due to a more efficient treatment and handling of them to drastically reduce the waste disposal. To both fulfil the requirements of a reduced raw material usage and the necessity to produce less waste disposal, the main solution is represented by recycling materials through innovative technologies.

Indoor Environmental Quality

Another rewarded factor is the attention to the realization of a built environment able to guarantee the well-being, health and comfort of the people living the place through the control of indoor environmental quality, the thermal comfort, the acoustic comfort, the lighting one. It is based on an overall analysis of the building spaces that should present all the features and characteristics required to enable people to carry out the activities for which the space is meant.

Innovation

The main objective of this category is to incentivise the actuation of innovative and sustainable solutions.

Regional Priority

One of the most important aspects of the credit assignment refers to this category highlighting how the sustainability of a project is highly dependent on the characteristics of the site in which the building arises and that solutions that could be sustainable in a site don't produce the same effects on another site. For each site, participants identify which are most relevant problems of the region and prioritize them, in this way it is possible to tailor specific strategies and solutions.[46]

An overview of the impacting categories and the credits associated to them is presented in the table below.

Table 2- Impact categories summary in LEED v4

Category	Main Objective	Max. achievable points
Integrative Process (IP)	Improved performances and environmental benefits due to synergic workflow	1
Location and Transportation (LT)	Promote choice of location with existing facilities, services and networks to reduce private transportation	16
Sustainable Sites (SS)	Consider the relationship with surrounding environment reducing impact of construction on site and preserving biodiversity and ecosystems	10
Water Efficiency (WE)	Promote water conservation by efficient and reduced potable water use. Promote use of nonpotable water and alternative sources	11

46 USGBC | U.S. Green Building Council (n.d.), *LEED v4: Building Design + Construction Guide*. https://www.usgbc.org/guide/bdc#lt-overview (30/10/2025)

Energy and Atmosphere (EA)	Promote design with a reduced energy need fulfilled mainly by renewable energy sources	33
Materials and Resources (MR)	Favor the LCA approach using materials with reduced embodied energy	13
Indoor Environmental Quality (EQ)	Generate spaces with good air quality, thermal and acoustic comfort for the wellbeing of occupants	16
Innovation	Reward new innovative technologies which go beyond the credit fulfilment	6
Regional Priority	Recognize sustainability as influenced by the characteristics of the site. Identify sustainable measures depending on the site needs	4

The possibility to submit and register projects under LEED v4 will close in 06/2026[47] and this signs an evolution in the LEED Rating System thanks to the introduction of LEED version 5 launched in April 2025 which represents a huge progress and advancement. In fact, to respond to the increasing awareness about climate change and to main goals defined worldwide to contrast this phenomenon, it is noticeable how LEED v5 overcomes the previous version aligning the requirements and credits towards a decarbonized building sector and a sustainable future.

To just mention some of the worldwide goals showing the importance and validity of LEED v5 application to building site, it is worth noting that according to the Paris Agreement, signed in November 2015 by 195 countries during the Conference of Parties (COP21) on climate changes, the main objective it that of maintaining the global average temperature with respect to the preindustrial level with a maximum surplus of 2 °C, trying to limit it to no more than the 1,5°C. [48]

Due to this international agreement, countries implemented national standards and plan to achieve the main common goal in terms of sustainable actions against climate change. These plans are known as "Nationally Determined Contributions" (NDCs) and they are meant to be updated and overcome by successive more rigid and restrictive versions.

[47] USGBC | U.S. Green Building Council (n.d.), *LEED certification deadlines* https://www.usgbc.org/tools/leed-certification/deadlines (30/10/2025)

[48] United Nations. (n.d.). *The Paris Agreement | United Nations*. https://www.un.org/en/climatechange/paris-agreement (30/10/2025)

As regards Europe, for instance, presents several common guidelines and objectives that subsequently were translated into national standards by European countries. The EU taxonomy, which is a classification system for economic activities depending on their sustainability level, in this context, represents one of the systems adopted to meet the goals of energy targets and climatic neutrality by 2050. This system represents a concrete and significant step towards the sustainability goals[49]. The objectives that taxonomy figured out are specifically: climate change adaptation, sustainable use and protection of water and marine resources, transition to a circular economy, waste prevention and recycling, pollution prevention and control, protection of healthy ecosystems[50] highlighting that one of the most contributing sectors to be considered in the transition and evolution is the building sector. These regulations defined by Europe enabled some of its countries to be part of the Top 10 Countries and Regions for LEED list, especially Italy and Turkey.[51]

In the evolution of LEED, an alignment with EU Taxonomy increased, in fact, already in LEED v4 requirements to be rewarded by the certification were compliant with many of the EU taxonomy criteria as showed by the following table:

[49] European Commission. Finance (n.d.): *EU taxonomy for sustainable activities*. https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en (30/10/2025)
[50] USGBC | U.S. Green Building Council (January, 2022): *LEED and the EU Taxonomy*. https://www.usgbc.org/sites/default/files/2022-01/LEED-Whitepaper-Europe-Jan-2022.pdf (30/10/2025)
[51] USGBC | U.S. Green Building Council. (February 27th, 2025): *GBCI Europe Circle 2025: From innovation to impact* https://www.usgbc.org/articles/gbci-europe-circle-2025-innovation-impact (30/10/2025)

Table 3- LEED certification alignment with EU taxonomy

	EU TAXONOMY – TECHNICAL CRITERIA	APPLICABLE LEED BD+C CREDIT
Technical Screening	Achieve low Primary Energy Demand (10% below NZEB)	Minimum / Optimize Energy Performance Alternative Energy Performance Metric (Pilot Credit v4)
Technical Screening	Quality assurance (testing of air-tightness & thermal integrity)	Enhanced Commissioning
Technical Screening	Calculation of GWP	Building Life-Cycle Impact Reduction (LEED v4- Option 4, LEED v4.1 Option 2)
DNSH	Climate Change adaptation	Pilot Credits: Assessment and Planning for Resilience Passive Survivability and Back-up Power During Disruptions Design for Enhanced Resilience
DNSH	Sustainable use and protection of water and marine resources	Indoor Water Use Reduction
DNSH	Transition to a circular economy	Construction & Demolition Waste Management
DNSH	Pollution prevention and control	Construction activity pollution prevention Low Emitting Materials Material Ingredients (Option 2)
DNSH	Protection and restoration of biodiversity and ecosystems	High Priority Site / Equitable Development

[52]

Moreover, the introduction of the Arc tool by GBCI in 2023 enhanced companies to use this self-assessment tool to demonstrate compliance with the criteria of Eu Taxonomy.[53] The introduction of LEED v5 is another advancement towards the compliance of the certification with European criteria as demonstrated by the introduction, in project priorities, of credits related to EU Taxonomy, in which, all the remaining requirements of Taxonomy not already embedded in previous ones, are included.[54] Furthermore, for those projects which want

[52] USGBC | U.S. Green Building Council (January, 2022): *LEED and the EU Taxonomy*. https://www.usgbc.org/sites/default/files/2022-01/LEED-Whitepaper-Europe-Jan-2022.pdf (30/10/2025)
[53] European Commission, Green Forum (May 12th, 2025) : *LEED certification to deepen alignment with Level(s) and EU Taxonomy in the European market*. https://green-forum.ec.europa.eu/news/leed-certification-deepen-alignment-levels-and-eu-taxonomy-european-market-2025-05-12_en (30/10/2025)
[54] USGBC | U.S. Green Building Council (n.d.): *Project Priorities*. https://www.usgbc.org/project-priorities (30/10/2025)

to demonstrate only compliances with the taxonomy requirements, some specific alternative compliance paths are presented.

As highlighted by this general overview, it is clear how the passage from LEED v4 to LEED v5 defines more detailed requirements and credits, for the buildings to be certified, which better reflect the general common widespread goal to move towards the carbon neutrality.

The new version is focused on 3 main impact areas, as reported below:

- Decarbonization: the building must be analysed in all its phases, from the design by considering the choice of materials to the operation consumptions, the refrigerants used and the transportation of people.
- Ecological conservation and restoration: the way of realizing buildings should consider not only the performances of buildings themselves but all the implications in the surrounding environment and the implications to the ecosystem. Specifically, it is required not only to prevent any damage to the existing ecosystems but also to restore those which have been previously impacted. According to this perspective, the building is not meant as a per se unit but as part of a mechanism which involves also the surrounding environment that must be considered in the design and construction choices.
- Quality of life: the attention is also focused on people living the buildings; the design should not consider only the environmental impact but also the social one assessing the different aspects of sustainability. For this reason, introduces credits about health and accessibility.

It is clear how this version marks a clear advancement in the sustainability goals more than just an adjustment and improvement of the previous versions.

Furthermore, it is important to underline that LEED v5 introduced stricter requirements and credit assessment in order to be scored with a Platinum Certification marking the necessity to be compliant with the main guideline of this version regarding decarbonization and for these reasons introduced rigid requirements in terms of electrification, renewable energy requirements, minimum energy efficiency and reduction of embodied carbon. [55]

[55] USGBC | Green Building Council (n.d): *LEED v5*, https://www.usgbc.org/leed/v5 (28/10/2025)

LEED v5 still maintains the structure articulated according to prerequisites and credits assessing different impact areas which specifically, for v5, are:

- Integrative Process, Planning, and assessment
- Location and Transportation
- Sustainable Sites
- Water efficiency
- Energy and Atmosphere
- Materials and Resources
- Indoor Environmental Quality
- Project Priorities and Innovation

These categories are reorganized and defined with the focus on the three main pillars of LEED v5 approach.

Integrative process, planning and assessment

Differently from LEED v4 in which the integrative and interdisciplinary approach was awarded only by a single credit, in LEED v5 it becomes a whole section and impact category that, specifically for the rating system BD+C, presents 3 different requirements as listed below:

  - climate resilience assessment: the design choices should start always from awareness and knowledge of the site exposure to climatic actions and hazards and to provide resilient strategies and planning.
  - human impact assessment: represent another early-stage analysis to gather information around the community, the infrastructures and facilities around, the land use and other influencing factor of the surrounding area that must be considered in the project.
  - carbon assessment: early evaluation of the carbon emissions and reduction planning.

One these prerequisites are satisfied it is possible to proceed with the evaluation of the aspects related to assignation of the credit itself related to the creation of a multidisciplinary team to share knowledges, strategies, ideas and to improve performances through interconnection.

Location and transportation

Still in the perspective of the 3 main objectives of this version, this category has been modified to incentivize the use of electrical vehicles, public transportation and the social equity. For these reasons, in fact, the structure of the category changed by reorganizing and consolidating the credits contained in it. More than focusing on the density of the site location, the attention has been moved to identify the accessibility to services and infrastructures introducing more rigid rules to get the score. The incentive to the green mobility has been translated into the category by increasing the threshold value of bicycle parking that must be available guaranteeing easy accessibility and identification in addition to reduced car parking area available and increased availability for electric vehicles charging areas. In addition to these modifications and reorganization of topics already presented in LEED v4, new credits regarding the equitable development as benefits to the community have been introduced.

Suitable sites

The prerequisite has been modified and expanded in the perspective of ecological conservation and restoration by preserving and respecting the ecosystem of the site, in addition to the planning to prevent future damages due to the building construction. In the previous version, the assignment of one of the credits considered the possibility to provide a financial donation to support the protection and the restoring of the natural habitat, this possibility has been removed highlighting the importance to directly act on the environmental protection, conservation and also restoration. The focus is also on the well-being of the occupants, incentivizing the realization of spaces to enhance comfort, socialization and contact with the outdoor environment.

Water efficiency

With respect to the previous version, the system requires a more detailed metering and reporting separating data coming from potable water and data related to the alternative water sources guaranteeing a continuous and real-time monitoring. It focuses more on the conservation of potable through a stricter control of water leakages and on the use of alternative sources.

Energy and Atmosphere

LEED v5 refers to a new version of ASHRAE 90.1 which is the ASHRAE 90.1:2019 that can be applied to project submitted before January 1, 2028, while for projects submitted on or after January 1, 2028, the AHSRAE version to be used is the ASHRAE 90.1:2022.

As in the previous version, there is still attention to the energy efficiency but the possible paths to determine if the building is compliant with the minimum energy performance requirements varies from the v4 to the v5. According to the v5, the paths to follow before January 2028 are the energy cost or future source energy. More options are available for projects submitted after January 2028 compliant with ASHRAE 90.1:2022. It is noticeable that the mark is still on the energy efficiency but amplifying the options that can be followed. In addition to this, LEED v5 introduces stricter requirements in terms of commissioning, control and updates requiring a continuous analysis from the very first stages and also during construction and operation, leading to an update of the solutions from the design phase and not only as a corrective action during construction and operational phases improving the efficiency. Another aspect been emphasized in LEED v5 is the decarbonization through different credits identification as: thermal peak load reduction, optimize energy performance and the introduction of a prerequisite which require the simulation of the CO_2 emissions according to operational projection and the presentation of a decarbonization plan. Another big introduction is the credit of electrification, rewarding buildings which are fully electrified and those which don't produce energy from fossil fuels. Finally, the LEED v5 highlights the interaction of the building with the grid recognizing the importance of the demand response program introducing new options with respect to LEED v4 as energy storage and the power resilience for critical systems representing the ability of the building to maintain electricity for critical functions during blackouts.

This impact category is the one object of analysis for this thesis and will be analysed more in detail in next chapters.

Materials and Resources

This category imposes a new requirement related to the assessment of the embodied carbon of all the building's elements obliging designers to assess each component and material chosen. The credits become more rigid regarding the LCA, the EPD, waste management and Health Product Declaration representing an advancement with respect to the mere encouragement of the previous version to select sustainable low-emitting materials. Here the assessment and quantification of the embodied carbon and toxicity of the products is required.

Indoor Environmental Quality

Even if, already in the previous version the Indoor Environmental Quality was not only related to the treatment of internal air, and pollutant concentration presenting several credits and requirements regarding the comfort of people living in it (as, for instance, the definition of minimum threshold values of daylight, interior lighting, acoustic performances and also thermal comfort), the new updated way of looking at the fulfilment of these sustainable goals implemented the IEQ category including also credits as reliant spaces and accessibility and inclusion. It includes more paths and options to be adopted by the designers.

Project Priorities and Innovation

Combines the Innovation and Regional Priority categories emphasising the importance of adopting solutions and strategies which promote the resilience, equity and focuses on relevant features and problems of the specific area. [56]

As indicated in the above overview regarding requirements to be fulfilled in order to achieve the score, the LEED v5 requires several assessments (climatic resilience, carbon, human impact) and commissioning in all the phases to be correlated with documentation, continuous monitoring and access to real time data in each moment. For this reason, the tool Arc becomes essential, and projects are uploaded in the portal in such a way to always have updated data regarding operational performances more than just sporadic or single document related to only a certain phase.[57]

Table 4- General differences between LEED v4 and LEED v5

Generic differences	LEED v4	LEED v5
Reasons for the version launch	1. Improvements of requirements based on previous experiences of experts and specialists 2. Definition of requirements more aligned with updated necessities and priorities in sustainability field	1. Higher focus on objectives to be achieved 2. Alignment with the current standards and international goals 3. Credits definition aligned with EU Taxonomy
Structure	1. Introduction of impact categories according to general sustainability goals 2. Definition of a weighting system based on measurable quantities following specific evaluation method	1. Introduction of 3 main focus areas: decarbonization, ecological conservation and restoration, quality of life 2. Reorganization of impact categories according to the 3 main goals 3. Updated threshold values in many categories according to a more realistic vision 4. More rigid requirements for Platinum certification requiring the fulfilment of decarbonization goals, electrification and renewable energy

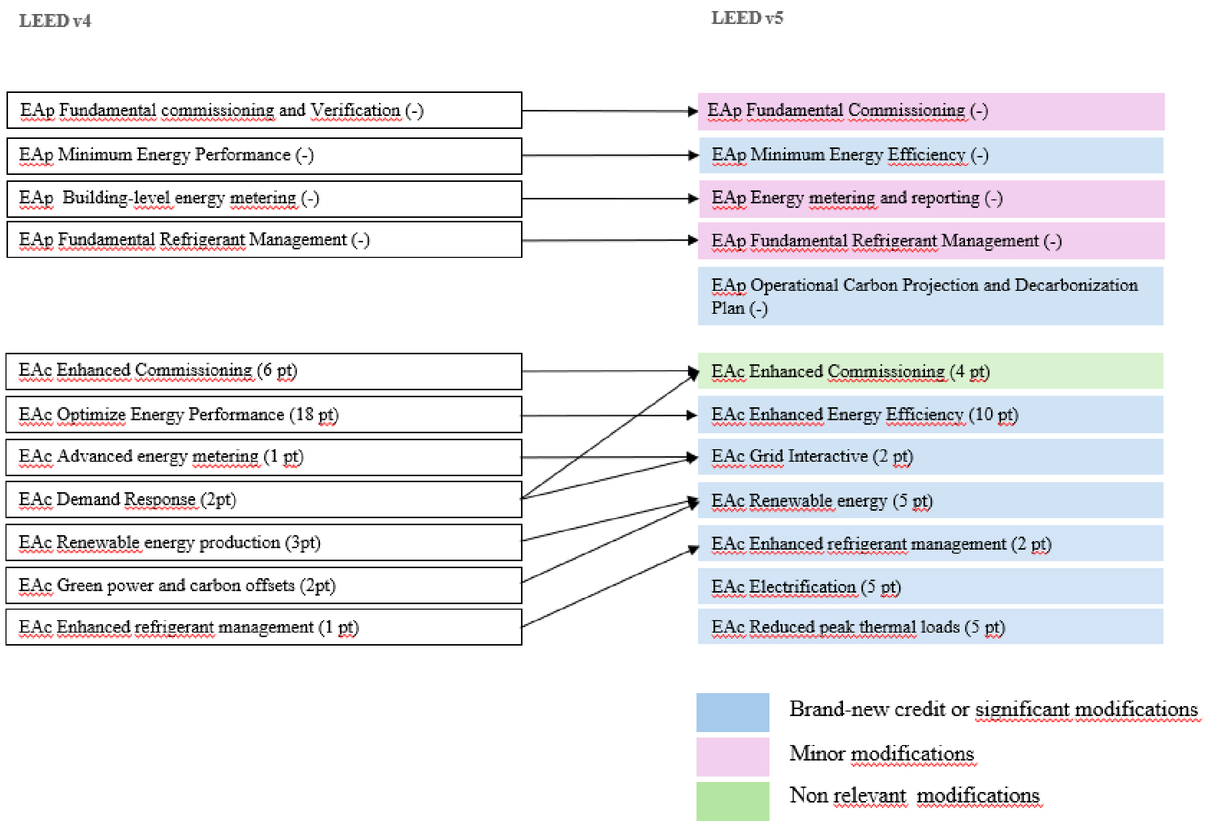
[56] USGBC| U.S. Green Building Council (April 24th, 2025): *LEED BD+C: New Construction and Core + Shell Development from LEED v4 to LEED v5 Summary of changes to LEED v5*.
[57] The American Institute of Architects. (September 29th, 2025): *What you should know about LEED version 5*. https://www.aia.org/aia-architect/article/what-you-should-know-about-leed-version-5

Methodology	1. Rating through simulation, previsions and documents 2. Evaluation according to minimum standard requirements	1. Assessment based on real data performances 2. Evaluation in all phases: design, construction and operational 3. Requirements of previous assessment to reach sufficient knowledge of site conditions 4. Access to real time data 5. Continuous monitoring

2.3 Energy and Atmosphere category in LEED

As mentioned in the previous chapter, the focus of this analysis is related to the energy impact category and its influence on the LEED score assignment. Specifically, with the change of perspective introduced by LEED v5, according to which the reorganization of the scorecard and the impact categories is meant to answer specific widespread needs as decarbonization, electrification, incentive to renewable energy, it is clear how impacting is this category in the rewarding of buildings according to LEED certification and in the overall sustainability of buildings beyond any recognition and award.

Table 5- Credits reorganization from LEED v4 to LEED v5



Despite the scores associated with categories are the same both for LEED v4 and LEED v5 and equal to 33 points, the change of course is recognizable as demonstrated below.

Fundamental commissioning and verification/ Fundamental commissioning- Prerequisite

According to LEED v4, the commissioning process should consider the analysis, testing and verification of mechanical systems, plumping, electrical and renewable energy systems according to ASHRAE Guideline 0-2005 regarding the different phases of the commissioning process itself and ASHRAE Guideline 1.1-2007 specifically addressing the commissioning procedure for HVAC&R systems. The analysis of the building enclosure is only confined to their identification inside the Owner Project's requirements (OPR) and in the Basic of Design (BOD). The Commissioning Authority must be defined by and no later than the end of the design phases and the person identified to cover the role must: present, at least, two previous experiences on two previous projects similar to the one under analysis having followed the procedure from the design phase up to 10 months after the occupancy start; it can be represented by an owner's employee, an independent qualified person, a member of the project's design and construction team only for projects of small entity and specifically with an overall area lower than 1 860 square meters. The commissioning authority oversees several tasks: define a commissioning plan, analyse and review the OPR and BOD, develop a testing procedure, verify tests execution, document all results and recommendations providing them to the owner and draw up a final report among others. Specifically, the plan for the operational and maintenance of building system should be provided with several information regarding the building life as the occupancy schedules, the HVAC functioning schedules, the HVAC setpoints, the minimum outside air requirements, seasonal variations in schedules, a maintenance plan for systems and equipment and periodical testing and verification of the well-functioning according to commissioning plan.[58]

With the introduction of LEED v5, all the previous reference standards have been replaced by the compliance with AHSRAE 90.1 and specifically, projected submitted before January 1, 2028 can use both ASHRAE 90.1:2019 and AHSRAE 90.1:2022, while, projects submitted after January 1, 2028 should be compliant with AHSRAE 90.1:2022. LEED v5 removed even the possibility that, for small projects, a member of the design or construction team can hold the position of Commissioning Authority. Moreover, with respect to previous version the

[58]USGBC| U.S. Green Building Council (n.d.): *LEED Credit Library: LEED BD+C: New Construction v4 - LEED v4: Fundamental commissioning and verification* https://www.usgbc.org/credits/new-construction-commercial-interiors-core-and-shell-schools-new-construction-retail-new-c-6?return=/credits/New%20Construction/v4/Energy%20&%20atmosphere

Commissioning Authority must be active from the very early stages of designing assuming an active role in the development of the OPR and review of the BOD depending on OPRs, attending intermediate milestones regarding the HVAC, envelope and electrical systems and review any modifications of the design choices which could affect the OPR. During construction, this figure is required to attend meeting and reviews at 50% and 100% of completion and finally should provide a commissioning plan for operational and maintenance.[59]

From this analysis is clear that the modifications require the identification of an absolute independent figure covering the role of Commissioning Authority which should be more involved in all the phases of the project to ensure compliance with OPR and well-functioning of all the systems and envelope.[60]

Table 6- Fundamental commissioning prerequisite variation between LEED v4 and LEED v5

LEED v4	LEED v5
Compliance with ASHRAE Guideline 0-2005 and ASHRAE Guideline 1.1-2007	Comply with ANSI/ASHRAE/IES Standard 90.1
Commissioning Authority definition: no later than the end of the design phases.	Commissioning Authority must be active from the very early stages of designing
For small projects the role can be assumed by members of the project team	Option removed
/	CA shall attend intermediate milestones

Minimum Energy Performance/ Minimum Energy Efficiency- Prerequisite

The main objective of this prerequisite is to guarantee a minimum energy efficiency level. According to LEED v4, the compliance to this requirement can be demonstrated according to the following options:

- Option 1 (updated) -whole building energy simulation: the project is compared to a reference baseline model realized in accordance with ASHRAE 90.1:2010, appendix G and it must be demonstrated that the proposed building guarantees an improvement of the energy performance, for new buildings or major renovation of about the 10% with

[59]USGBC | U.S. Green Building Council (n.d.): *LEED Credit Library: LEED BD+C: New Construction v5 - LEED v5 Fundamental commissioning*. https://www.usgbc.org/credits/new-construction-core-and-shell/v5/eap3?return=/credits/New%20Construction/v5/Energy%20&%20atmosphere

[60]USGBC | U.S. Green Building Council (April 24th, 2025): *LEED BD+C: New Construction and Core+Shell Development from LEEDv4 to LEED v5: Summary of changes to LEED v5*

respect to the baseline model. Here the metrics of evaluation to define the improved efficiency can be:

- energy cost: evaluation based on economic savings
- source energy: based on the analysis of primary energy required
- greenhouse gas emissions: analysis of CO_2 emissions as response to the energy use[61]

All the energy consumption and costs should be included in the modelling, and the unregulated loads shall be reported and modelled trying to best represent the prevision of building use.

- Option 2- Prescriptive compliance: ASHRAE 50% Advanced Energy Design Guide: the project is realized by following the provisions of AHSRAE 90.1:2010 respecting all the requirements for HVAC and Water Heating Services as specified in the standard.
- Option 3- Prescriptive compliance: Advanced Buildings™ Core Performance™ Guide: appliable only for project less than 10 000 square feet. [62]

This prerequisite has been modified in LEED v5 setting the requirement to a different threshold value depending on the period of realization of the construction.

Projects registered before January 1 2028 can follow option 1 or 2, projects registered after January 1 2028 follow the option 2.

Option 1 has been modified considering the future energy source metric instead of costs to be more aligned to the performance evaluation of the building in terms of decarbonization and impact reduction.

To be compliant with this new interpretation of the rating method, all the references in the Appendix G related to costs must be translated and converted into future energy source parameters and specifically, the ASHRAE building performance factors coming from table 4.2.1.1, which are indicators to normalize the performance of building to make it comparable through different project and dependent on climatic zone and typology of building, must be

[61]USGBC| U.S. Green Building Council (n.d.): *LEED Credit Library: LEED BD+C: New Construction v4 - LEED v4: Minimum Energy Performance (2024 Update)* https://www.usgbc.org/credits/BDC/v4/ea403/2024update?return=/credits/New%20Construction/v4/Energy%20&%20atmosphere

[62]USGBC| U.S. Green Building Council (n.d.): *LEED Credit Library: LEED BD+C: New Construction v4 - LEED v4: Minimum Energy Performance* https://www.usgbc.org/credits/new-construction-core-and-shell-schools-new-construction-warehouse-and-distribution-centers?return=/credits/New%20Construction/v4/Energy%20&%20atmosphere

substituted with another equivalent table considering the future source energy as metric reported below:

Table 7- BPF values according to LEED v4 - USGBC. (n.d.-g). USGBC. https://www.usgbc.org/credits/new-construction-core-and-shell/v5/eap2?return=/credits/New%20Construction/v5/Energy%20&%20atmosphere

Building type	**Climate zone**																		
	0A	0B	1A	1B	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
Multifamily	0.74	0.69	0.73	0.70	0.73	0.70	0.71	0.70	0.63	0.70	0.71	0.69	0.68	0.70	0.70	0.68	0.68	0.68	0.74
Healthcare/hospital	0.72	0.72	0.73	0.73	0.74	0.71	0.72	0.74	0.71	0.72	0.73	0.71	0.74	0.73	0.80	0.73	0.77	0.78	0.79
Hotel/motel	0.72	0.71	0.72	0.71	0.71	0.70	0.71	0.73	0.72	0.71	0.73	0.73	0.71	0.73	0.74	0.70	0.72	0.70	0.70
Office	0.62	0.63	0.61	0.62	0.58	0.60	0.57	0.62	0.55	0.55	0.61	0.57	0.58	0.61	0.59	0.58	0.60	0.54	0.58
Restaurant	0.65	0.62	0.63	0.61	0.62	0.58	0.63	0.63	0.63	0.67	0.66	0.66	0.70	0.70	0.68	0.73	0.72	0.74	0.77
Retail	0.57	0.54	0.53	0.53	0.48	0.47	0.47	0.47	0.47	0.52	0.50	0.56	0.57	0.53	0.59	0.58	0.56	0.53	0.60
School	0.57	0.57	0.58	0.57	0.55	0.54	0.57	0.51	0.49	0.48	0.51	0.52	0.51	0.53	0.51	0.53	0.50	0.51	0.58
Warehouse	0.28	0.30	0.24	0.27	0.23	0.24	0.27	0.23	0.20	0.33	0.26	0.28	0.40	0.32	0.29	0.44	0.38	0.40	0.44
All others	0.65	0.62	0.64	0.62	0.57	0.54	0.57	0.56	0.58	0.59	0.57	0.60	0.60	0.59	0.65	0.62	0.62	0.61	0.64

The option 2, appliable only for projects submitted after January 1, 2028, which must be compliant with AHSRAE 90.1:2022 can use additional different metrics in substitution of the energy cost evaluation which specifically are: future source energy, source energy and site energy. Even in these cases, the references table of the AHSRAE 90.1:2022 related to BPFs for energy cost metric are substituted with equivalent tables. The site energy takes into account only the portion of energy which is directly consumed by the building without considering its production and transportation, for this reason the source energy can represent a more complete way of rating the efficiency by considering all the phases, from energy production to energy consumption. The future energy source is the more advanced metric which considers even future predictions about the way in which the energy production will vary in the future.[63]

[63]USGBC | U.S. Green Building Council (n.d.): *LEED Credit Library: LEED BD+C: New Construction v5 - LEED v5 Minimum Energy Efficiency* https://www.usgbc.org/credits/new-construction-core-and-shell/v5/eap2?return=/credits/New%20Construction/v5/Energy%20&%20atmosphere

Table 8- Minimum energy performance prerequisite variation between LEED v4 and LEED v5

<table>
<tr><th>LEED v4</th><th colspan="2">LEED v5</th></tr>
<tr><td>Option 1- whole building simulation with ASHRAE 90.1:2010 with energy cost or source energy or GHG emissions</td><td rowspan="2">Projects submitted before January 1,2028</td><td>Option 1- whole building simulation with ASHRAE 90.1:2019 with future energy source</td></tr>
<tr><td>OR Option 2- Prescriptive compliance with ASHRAE 50% Advanced Energy Design Guide</td><td>OR Option 2- whole building simulation with ASHRAE 90.1:2022 with future energy source or source energy or site energy</td></tr>
<tr><td>OR Option 3- Prescriptive compliance: Advanced Buildings™ Core Performance™ Guide</td><td>Projects submitted starting from January 1, 2028</td><td>Option 2- whole building simulation with ASHRAE 90.1:2022 with future energy source or source energy or site energy</td></tr>
</table>

Building-level energy metering/Energy metering and reporting- Prerequisite

The main scope of this prerequisite is to guarantee a good management of the energy sources avoiding useless waste and determine real consuming with respect to the operational previsions.

In the previous version, the installation of energy meters to measure the energy consumption of the whole building was required; an alternative solution was represented by the use of submeters which, combined together, were still representative of the overall energy consumption. The data collected was required to be submitted to the USGBC for a period of 5 years starting from the date of LEED certification release or the date of occupancy starting, depending on which was the first providing at least collection of data with interval of one month.[64]

A big introduction in the version 5 is represented by the inclusion of all the energy sources as the onsite electrical generation considering the different request depending on the energy source considered and the monitoring of the peak demand at least monthly. Furthermore, differently

[64] USGBC| U.S. Green Building Council (n.d.): *LEED Credit Library: LEED BD+C: New Construction v4 - LEED v4: Building-level energy metering* https://www.usgbc.org/credits/new-construction-schools-new-construction-retail-new-construction-data-centers-new-14?return=/credits/New%20Construction/v4

from the previous version, the reporting must be differentiated according to the different energy sources even if the period of reporting and the interval of reporting remain unmodified.[65]

Table 9- Energy metering prerequisite variation between LEED v4 and LEED v5

LEED v4	LEED v5
Installation of energy meters or submeters	Inclusion of all energy sources AND differentiated report
/	Monitoring of peak demand monthly

Fundamental refrigerant management- Prerequisite

In the perspective of sustainability deeper attention is devoted to the effect on the ozone layer depletion. For this reason, already in version 4, the use of CFC refrigerant for the functioning of HVAC and Refrigeration system was forbidden to be eligible for LEED certification and for those projects using already existing equipment it was required to conversion for the depletion of these refrigerants. Nothing was mentioned about other types of refrigerants as the HFCF still presenting great impact on sustainability because of their effect on Global Warming Potential.[66] These aspects, highly correlated to the main focus areas of LEED v5, have been implemented in this version. In fact, v5 presents 2 main options:

- The avoidance of refrigerant use in the project
- The reporting, in case of already available equipment, of refrigerant typologies present, quantity of each typology and specific GWP for each typology. Avoidance of HFCF refrigerants and in case of existing or new equipment provided with refrigerants, a leakage test and potential repair is required before completion.[67]

This highlights the increased awareness and concern about sustainability and impact of human action, recognizing the effects of used products both on the ozone layer and global warming.

[65] USGBC | U.S. Green Building Council (n.d.): *LEED Credit Library: LEED BD+C: New Construction v5 - LEED v5: Energy metering and reporting* https://www.usgbc.org/credits/new-construction-core-and-shell/v5/eap4?return=/credits/New%20Construction/v5

[66]USGBC| U.S. Green Building Council (n.d.): *LEED Credit Library: LEED BD+C: New Construction v4 - LEED v4: Fundamental refrigerant management* https://www.usgbc.org/credits/new-construction-core-and-shell-schools-new-construction-retail-new-construction-data-86?return=/credits/New%20Construction/v4

[67] USGBC | U.S. Green Building Council (n.d.): *LEED Credit Library: LEED BD+C: New Construction v5 - LEED v5: Fundamental refrigerant management* https://www.usgbc.org/credits/new-construction-core-and-shell/v5/eap5?return=/credits/New%20Construction/v5

Table 10- Fundamental Refrigerant Management prerequisite variation between LEED v4 and LEED v5

LEED v4	LEED v5
No CHFC	Option 1- No refrigerants used
	OR Option 2- reporting of refrigerant types used, quantity and GWP.

Operational Carbon Projection and Decarbonization Plan- Prerequisite

This prerequisite represents a brand-new requirement introduced in LEED v5, following the trend of basic goals. The main scope is to clearly visualize the impact of design choices on the long operational carbon emissions in such a way to ensure the individuation of low- carbon impact decisions and design from the beginning.

Design Analysis

For this reason, the analysis of results is conducted starting from the very early stage in order to estimate the efficiency with respect to a reference building, peak load reduction through a better management, and decarbonization measures adopted according to the design. This analysis can be led through one of the following methodologies:

- Simplified energy modeling
- Analysis from similar projects
- Analysis from published data

This procedure is essential to guide the decision making and be aware of the impact of choices from the early stages to adjust, adapt and vary solutions to reach better performances.

Site Energy Estimate

It is a measure of the energy consumed in one year by the building considering just the portion released to the site and not all the energy consumption starting from the production point up to the delivering site.

Review Carbon Projection

A projection of the building's future emissions is set up to the next 25 years based on the assessment of the annual energy consumption data, converted into CO_2 emissions, and consumption coefficients of the grid in the project's site. The calculation of the estimated carbon footprint is based on a "Business As Usual" model according to which the carbon footprint projection is evaluated without considering, in the 25 years, any variation in the destination of the use of the building and any efficiency interventions. Also, this evaluation is realized for the common purpose of determining the impact of the project in its normal conditions of use.

Decarbonization plan

It is subdivided into two different paths:

Path 1- assignation of 4-5 credits for projects which are already fully electrified without the use of fossil fuels sources

Path 2- It represents the identification of a clear and gradual path through the progressive decarbonization of the site in a period of 25 years. It is required to write a two-pages document to clarify the planned strategy for the decarbonization. The retrofitting plan should specify the equipment to be substituted and the way to discharge them, and the alternative solution selected; moreover, the costs and the timeline are required to be specified.[68]

Table 11- Operational Carbon Projection and Decarbonization Plan new prerequisite of LEED v5

LEED v4	LEED v5	
/	Design Analysis	
	AND Site energy estimate	
	AND Review carbon projection	
	AND Decarbonization plan	Path 1
		OR Path 2

Enhanced Commissioning

In addition to the Fundamental Commissioning prerequisite, representing the base of the verification process, a relevant credit of the Energy and Atmosphere category is represented by the enhanced commissioning which cover the role of verification of the building system and operational in a deeper and detailed way, ensuring that the building performance maintains the efficiency and performances as hypnotized in the design phase. The role of this commissioning can be assumed by experts in the field with the same qualifications as the one defined in the Fundamental Commissioning prerequisite.

[68] USGBC | U.S. Green Building Council (n.d.): *LEED Credit Library: LEED BD+C: New Construction v5 - LEED v5 Enhanced commissioning* https://www.usgbc.org/credits/new-construction-core-and-shell/v5/eap1?return=/credits/New%20Construction/v5/Energy%20&%20atmosphere

The credit, according to LEED v4, provides the project with a maximum of 6 points which can be reached following two main options (they can be both implemented), in which first one is divided into 2 paths:

- Option 1 Path 1- Enhanced Commissioning: as an implementation of the fundamental enhancing, the Commissioning must review the technical sheets, drawing submitted by the design and construction team to verify compliance with the OPRs; control the presence of guideline of systems installed in the building to guarantee a reference document for the well operation and maintenance of the systems during occupancy; check the presence of operators training in the construction documents and control if training is effectively delivered; participate to seasonal testing; verify operational after 10 months from the project completion; definition of the phases of commissioning's update.
- Option 1- Path 2: Enhanced and monitoring-based commissioning: it doesn't substitute path 1 but represents an ampliation of it, introducing monitoring in addition to commissioning. This path establishes the definition of specific measurement points to continuously gather information related to energy and water consumption, defines algorithms to evaluate differences between the predictive consumption and the real one, provides plans to adjust any inefficiency occurring and maintenance planning to ensure performance over time.

Option 2- Envelope Commissioning: is related to the evaluation of building thermal envelope's performances following the specific prescription of ASHRAE Guideline 0-2005 and of NIBS Guideline 3-2012 related to exterior enclosure technical requirements for commissioning. Defines that the Commissioning should analyse the submittals of construction materials, verify updates of material performances, seasonal testing and plan about future commissioning.[69]

This credit which rewards projects that go further the basic commissioning, is deeply modified in LEED v5 to better enhance efficiency and establish that the commissioning must be involved in the project from the very first stages to provide modification and ensure compliance to the OPR from the beginning, avoiding to integrate modification in successive phase leading to a decreased efficiency. The compliance with previous standard is substituted by compliance with ASHRAE 202-2024. All these modifications refer to Option 1 path 1. As regards the envelope,

[69] USGBC | U.S. Green Building Council (n.d.): *LEED Credit Library: LEED BD+C: New Construction v4 - LEED v4:Enhanced commissioning* https://www.usgbc.org/credits/new-construction-core-and-shell-schools-new-construction-retail-new-construction-warehouse?return=/credits/New%20Construction/v4/Energy%20&%20atmosphere

requirements linked to it become part of path 2 of Option. Here, Guideline 3-2012 has been substituted by ASTM E2947-21a which includes testing of air leakages, water penetration and infrared imaging for thermal bridges.

With respect to option 2, devoted to monitoring-based commissioning, the process has been divided into two paths; in the first one the monitoring-based commissioning has to be implemented for a required period of at least three years from the occupancy setting specific rules which incorporate the ones defined in LEED v4. Specifically, the Monitoring-based Commissioning is required to submit quarter summaries related to possible anomalies and annual report of trends, faults and possible improvement for energy savings.

To just provide a collection and visualization of summary graphs reporting the main trends coming out from the basic monitoring or to visualize any variation in energy use between successive years or months, a remote accessible system is provided. This software is required to collect hourly data and to gather information at detailed level, also relative to elevators and kitchens. Path 2 of option 2 includes an advanced metering software.[70]

Moreover, this credit is rewarded with a maximum score of 4 points in LEED v5 differently from the previous version.

Table 12- Enhanced Commissioning credit variation between LEED v4 and LEED v5

<table>
<tr><th colspan="2">LEED v4</th><th colspan="2">LEED v5</th></tr>
<tr><td rowspan="2">Option 1- Enhanced systems commissioning (3-4 points)</td><td>Path 1- Enhanced Commissioning (3 points)</td><td rowspan="2">Option 1. Enhanced Commissioning (1–3 points)</td><td>Path 1. Enhanced commissioning for MEP systems (2 points)</td></tr>
<tr><td>OR Path 2- Enhanced and monitoring-based commissioning (4 points) (embeds path 1)</td><td>AND/OR Path 2- Enhanced Commissioning for building enclosure (1 points)</td></tr>
<tr><td colspan="2" rowspan="2">AND/OR Option 2- Envelope Commissioning (2 points)</td><td rowspan="2">AND/OR Option 2- Monitoring-Based Commissioning (1–2 points)</td><td>Path 1- Basic Software (1 point)</td></tr>
<tr><td>OR Path 2- Enhanced Software (2 points)-</td></tr>
</table>

[70]USGBC | U.S. Green Building Council (n.d.): *LEED Credit Library: LEED BD+C: New Construction v5 - LEED v5: Enhanced commissioning* https://www.usgbc.org/credits/new-construction/v5/eac5?return=/credits/New%20Construction/v5/Energy%20&%20atmosphere

		embeds also path 1 requirements

Optimize Energy Performance/Enhanced Energy Efficiency

This section represents the core of the energy and atmosphere category both in LEED v4 and v5 with a maximum point allocation of, respectively, 18 points and 10 points. It must be underlined, however, that some of the requirements established in this section for LEED v4, have been reallocated to other credits assignment as Electrification and Reduced Thermal Peak Load which represent new credits introduced in LEED v5.

The main scope of this section is to emphasize the central role of energy efficiency, in fact, this aspect is already part of the prerequisite to access LEED certification scoring but the presence of this credit is a major incentive for designer and constructors to reach higher percentage of energy saving with respect to the minimum required in the prerequisite, which represents an advantage both from an economical point of view and a sustainable point of view. In addition, it incentivizes the energy performance analysis from the early stages, in fact, the energy performance target, expressed in source energy, should be defined from the design phase in such a way to orient and influence all the following phases. Depending on the percentage of energy saving reached, in addition to the minimum required, the points allocation varies.

In LEED v4, the option 1 includes the whole-building energy modelling and simulation, as for the prerequisites, highlighting the potential reduction in HVAC consumption, load reductions, passive solutions to be implemented. Based on the same procedure of the prerequisite, depending on the percentage of saving reached with respect to the baseline building, the project is rewarded with different points according to a table defined in the credit library of LEED v4. [71]

The option 2 in LEED v4, related to ASHRAE 50% Advanced Energy Design Guide, is applicable only for those projects that used this option in the prerequisite. Moreover, depending on typology of building considered, the AHSRAE 50% Guideline set different requirements to

[71] USGBC | U.S. Green Building Council (n.d.): *LEED Credit Library: LEED BD+C: New Construction v4 - LEED v4: Optimize Energy Performance (2024 Update)* https://www.usgbc.org/credits/BDC/v4/ea404/2024update?return=/credits/New%20Construction/v4/Energy%20&%20atmosphere

follow for the envelope, interior lighting, exterior lighting and plug loads, each of which is scored with 1 point. [72]

In this category, LEED v5 already introduces a compulsory requirement for those projects that want to achieve the Platinum certification setting a minimum threshold scoring of 8/10 points.

Even in this case, LEED v5 requires compliance with ASHRAE 90.1:2019 or ASHRAE 90.1:2022 depending on the date of project's registration. In Option 1, path 1, points allocation is related to regulated loads, and the project is scored with a certain number of points depending on the improvement with respect to the provisions defined by the standard which, depending on the case adopted, is 90.1:2019 or 90.1:2022. The path 2 of the Option 1 considers also the management of the unregulated loads introducing a platform with the data related to the energy consumption due to plug loads (Case 1) or gives the possibility to get the score if efficient plug system is used according to a specific table with defined criteria to be respected at least for the 90 % of the equipment of the eligible typology (Case 2). If one category satisfies the criteria defined, a point is obtained; if 2 categories are satisfied, two points are gained; from the third category and beyond the project is rewarded with 3 points. Or, as other option, gives the possibility to evaluate an improvement in the efficiency as a percentage result obtained from an energy simulation, conducted following the Performance Rating Method based on the same 90.1 version used for the prerequisite and modelling the plug loads according to the G2.5 section "Exceptional Calculation Methods". Option 2 establishes the energy simulation according to which all the evaluation must be done with reference to future energy source instead that with costs and for this reason the BPF factor, for the evaluation of the Performance Rating Index, used is no more the one coming from the Table 4.2.1.1, but a table defined in the LEED credit itself. Moreover, introduces the possibility to include the renewable energy in the evaluation of the PI.[73]

Table 13- Optimize energy performance credit variation between LEED v4 and LEED v5

LEED v4	LEED v5		
Option 1- Whole building modelling		Path 1- Regulated	Case 1- ASHRAE 90.1:2019

[72] USGBC | U.S. Green Building Council (n.d.): *LEED Credit Library: LEED BD+C: New Construction v4 - LEED v4: Optimize energy efficiency* https://www.usgbc.org/credits/new-construction-core-and-shell-warehouse-and-distribution-centers-new-construction-0?return=/credits/New%20Construction/v4/Energy%20&%20atmosphere

[73] USGBC | U.S. Green Building Council (n.d.): *LEED Credit Library: LEED BD+C: New Construction v5 - LEED v5: Enhanced energy efficiency* https://www.usgbc.org/credits/new-construction/v5/eac3?return=/credits/New%20Construction/v5/Energy%20&%20atmosphere

<table>
<tr><td rowspan="4"></td><td rowspan="4">Option 1- Prescriptive path</td><td>loads (1-7 points)</td><td>OR Case 2- ASHRAE 90.1:2022</td></tr>
<tr><td rowspan="3">AND/OR Path 2- Plug and process load (1-4 points)</td><td>Case 1- Plug Load Management (1 point)</td></tr>
<tr><td>AND/or Case 2- Efficient plug and Process Load Equipment (1–4 points)</td></tr>
<tr><td>OR Case 3. Plug and Process Load Exceptional Calculation (1–4 points)</td></tr>
<tr><td rowspan="2">OR Option 2- Prescriptive compliance path Advanced Energy Design Guide</td><td rowspan="2">OR Option 2- Energy simulation</td><td colspan="2">Path 1- Percentage Reduction excluding On-Site Renewable Contribution</td></tr>
<tr><td colspan="2">Path 2. Percentage Reduction including On-Site Renewable Contribution</td></tr>
<tr><td>/</td><td colspan="3">Platinum Requirements: eight points</td></tr>
</table>

Advanced energy metering- LEED v4

This credit existing only in LEED v4 has been partially incorporated, as the demand response credit, into the new LEED v5 “Grid Interactive” credit.

The main scope was that of implementing the basic monitoring required as prerequisite to better facilitate consciousness and awareness about the energy use for each typology of energy and identify specific inefficiencies. In this case the advanced monitoring established a recording interval of less than one hour analysing and reporting data about energy demand and consumption among others ensuring the possibility to access data remotely and that system should be capable of storing data for at least 36 months. This credit was responsible for 1 point allocation.[74]

Demand response/Grid Interactive

A crucial concept present in LEED certification is the demand response program which represents the capability of the building to be connected to grid adapting its uses, energy

[74] USGBC | U.S. Green Building Council (n.d.): *LEED Credit Library: LEED BD+C: New Construction v4 - LEED v4:Advanced energy metering* https://www.usgbc.org/credits/new-construction-schools-new-construction-retail-new-construction-data-centers-new-13?return=/credits/New%20Construction/v4/Energy%20&%20atmosphere

demand and consumption as a consequence to the exigencies of the grid. This typology of interaction is able to reduce CO_2 emissions and guarantee the well-functioning of the grid.

In LEED v4, a distinction between two cases, one considering the already availability of demand response program and one considering demand response not already available, was made. In the first case, to achieve the score, it was required that the building was able to receive external signals from a DR provider in real time and automatically activate an energy consumption reduction. In addition to this, it was established a minimum period of participation to the DR program of one year defining even a DR plan in case of possible signal from the grid to determine which energy uses should have been reduced, the interval of time in which the reduction was implemented and inclusion of the DR program in the Commissioning's work, requiring participation to at least one simulation of DR event.

The second case, buildings are rewarded in case the infrastructure is already set up for the participation to future DR programs by installing all the metering devices required, able to register information each hour or for shorter intervals, capability to be connected to automation systems and to be set up to reach external signals. Furthermore, in the project was required to include a plan of the ways and phases to activate the response to a DR event demonstrating a reduction of the consumption of the 10% during the event. The inclusion of the commissioning authority to this preparation was required too.[75]

In LEED v5, as previously mentioned, the credit has been renamed to "Grid Interactive", including even some prescriptions coming from the "Advanced energy metering". The scope of this credit is to improve the performances with respect to what was set in the previous version in such a way to promote the building as an active partner in the DR, guaranteeing the reliability of the grid and resilience of the buildings.

Independently from the availability on site of a DR program, the buldings are required to be provided with metering devices and systems able to receive external signals. Moreover, as first option it gives the possibility to use an energy or thermal storage system able to collect energy in the off-peak period and to reuse it in the on-peak period or in period in which carbon intensity of the grid is really high actively contributing to the decarbonization goal.

[75] USGBC | U.S. Green Building Council (n.d.): *LEED Credit Library: LEED BD+C: New Construction v4 - LEED v4: Demand response* https://www.usgbc.org/credits/new-construction-core-and-shell-schools-new-construction-retail-new-construction-data-85?return=/credits/New%20Construction/v4/Energy%20&%20atmosphere

For those buildings which cannot directly participate to the DR program but still maintaining an active role in the energy use control of the building itself, can be rewarded providing control over 2 systems between HVAC, lighting with a control capacity of the 50%, service water heating with a capacity of 90% and automatic receptacle control and electric vehicle supply equipment. As alternative path the project should be provided with a plan ensuring the capability of reducing the peak electricity demand for at least one hour considering both winter and summer peak load. In addition, the system should be able to respond to external impulse regarding, for instance, high carbon intensity of the grid.

As last option, which introduces a big innovation with respect to the previous version, the equipment which is required to operate on continuous must be clearly identified and should provide a project design and plan to enable the functioning of this equipment independently from the grid operational mode by means on energy produced on site or through energy storing for at least three days. This ensures the resilience of the building.[76]

Table 14- Demand response/ Grid interactive. The evolution of credit between LEED v4 and LEED v5

<table>
<tr><th>LEED v4</th><th colspan="2">LEED v5</th></tr>
<tr><td>Case 1- Demand response program available</td><td colspan="2">Option 1- Energy Storage</td></tr>
<tr><td rowspan="4">Case 2- Demand response program not available</td><td colspan="2">AND/OR Option 2- Demand Response Program</td></tr>
<tr><td rowspan="2">AND/OR Option 3. Automated Demand-Side Management</td><td>Path 1- System-level controls</td></tr>
<tr><td>OR Path 2- Building automation system</td></tr>
<tr><td colspan="2">AND/OR Option 4- Power resilience</td></tr>
</table>

Renewable energy production/Renewable energy

This credit has as primary objective the reduction of non-renewable energy use in the optic of sustainability incentivising the renewable ones and guaranteeing even economical savings. The percentage of renewable energy is evaluated in terms of cost identifying the ratio between the equivalent cost of renewable energy produced and the total building annual energy cost; depending on the percentage value obtained the project is rewarded with a certain score. If the

[76] USGBC | U.S. Green Building Council (n.d.): *LEED Credit Library: LEED BD+C: New Construction v5 - LEED v5: Grid interactive* https://www.usgbc.org/credits/new-construction-core-and-shell/v5/eac6?return=/credits/New%20Construction/v5

energy modelling was the chosen option for the minimum energy efficiency evaluation, the total annual energy cost can be derived from the modelling output, otherwise it can be estimated using the CBECS database.[77]

LEED v5, even in this category, introduces more rigid requirement for projects to be scored with a Platinum certification establishing that, for this credit, that the building should use 100% renewable energy coming from Tier 1,2 or 3. Specifically:

- Tier 1: refers to the renewable energy production on site or in the boundaries of the project or on the site of the social impact project provided that the installation of the equipment has no cost for the social community. The tier is evaluated according to the capacity per gross floor area or as a percentage of the annual site energy use. Depending on the results obtained different points are assigned to the project.
- Tier 2: off-site renewable energy production from new generation systems; even in this case the points assignment depends on the percentage of annual site energy
- Tier 3: off-site renewable energy production from existing but green-certified systems.[78]

Table 15- Renewable energy credit variation between LEED v4 and LEED v5

LEED v4	LEED v5
Points assignment depending on energy saving express in terms of costs	Tier 1- On-site renewable energy generation or social impact project
	AND/OR Tier 2- New off-site renewable electricity
	AND/OR Tier 3- Off-site renewable energy

Green power and carbon offsets

Removed from LEED v5 and incorporated in the updated Renewable Energy credit above described this credit of v4 has the common goal of reducing the greenhouse gas emissions using renewable energy sources. To incentivize this typology of sustainable actions, it established that

[77]USGBC | U.S. Green Building Council (n.d.): *LEED Credit Library: LEED BD+C: New Construction v4 - LEED v4: Renewable energy production* https://www.usgbc.org/credits/new-construction-core-and-shell-schools-new-construction-retail-new-construction-data-44?return=/credits/New%20Construction/v4/Energy%20&%20atmosphere

[78]USGBC | U.S. Green Building Council (n.d.): *LEED Credit Library: LEED BD+C: New Construction v5 - LEED v5:Renewable energy* https://www.usgbc.org/credits/new-construction/v5/eac4?return=/credits/New%20Construction/v5/Energy%20&%20atmosphere

projects should have signed contracts of at least 5 years for the provision of 50% (1 point) or 100% (2 points) of green power, certified renewable energy.[79]

Enhanced refrigerant management

In a more rigid way, this credit pursues the same objective as the prerequisite of avoiding the use of refrigerants considering their environmental impact on global warming and ozone layer depletion. In LEED v4 only two options could be followed; according to the first one the use of refrigerants is not allowed or their impact on ozone layer depletion must be zero and that on GWP less than 50, the second option, for those projects in which the use of refrigerants cannot be eliminated, requires a combination of the two previously defined impacts under a certain threshold value measured according to formulas.[80]

In the new version, option 1 keeps the path related to the no-refrigerant use and add a different path 2 in which a total weighted average GWP of the actual refrigerant adopted is compared to that of benchmark and, depending on the resulting percentage from the comparison, different points are assigned. A new option added by LEED v5, for those projects using refrigerant, is the score rewarding in case any leakages are prevented, and monitoring and maintenance are ensured. LEED v5 devotes a specific section to the category of food retails in which the usage of refrigerants can have a larger impact; those projects filling this category receive the score if GreenChill Certification program is observed.[81]

Table 16- Enhanced refrigerant management credit variation between LEED v4 and LEED v5

LEED v4	LEED v5	
Option 1- No refrigerants or low-impact refrigerants	Option 1- No refrigerants or Low GWP	Path 1-No refrigerants
		OR Path 2- Low GWP refrigerants
OR Option 2- Calculation of refrigerant impact	AND/OR Option 2- Limit Refrigerant Leakage	
/	AND/OR Option 3- GreenChill Certification for Food Retailers	

[79]USGBC | U.S. Green Building Council (n.d.): *LEED Credit Library: LEED BD+C: New Construction v4 - LEED v4: Green power and carbon offsets* https://www.usgbc.org/credits/new-construction-schools-new-construction-retail-new-construction-data-centers-new-12?return=/credits/New%20Construction/v4/Energy%20&%20atmosphere

[80]USGBC | U.S. Green Building Council (n.d.): *LEED Credit Library: LEED BD+C: New Construction v4 - LEED v4: Enhanced refrigerant management* https://www.usgbc.org/credits/new-construction-core-and-shell-schools-new-construction-data-centers-new-construction?return=/credits/New%20Construction/v4/Energy%20&%20atmosphere

[81]USGBC | U.S. Green Building Council (n.d.): *LEED Credit Library: LEED BD+C: New Construction v5 - LEED v5: Enhanced refrigerant management* https://www.usgbc.org/credits/new-construction-core-and-shell/v5/eac7?return=/credits/New%20Construction/v5

Electrification

It represents a big innovation of v5 responsible for a total scoring of 5 points; it is a crucial credit in the renewed perspective and objectives of LEED certification emphasizing the necessity to substitute all the fossil fuel energy sources with fully electrified systems to favour and facilitate decarbonization process and environmental quality. The relevance of this credit is underlined by the limits imposed by the rating method to be certified as Platinum establishing the full accomplishment (5 points) of this credit. The requirements are regulated according to two main options in which the second one can be accomplished by following different paths or by summing the effects of these paths to gain a higher score. The first option implies the absence of on-site combustion, made exception for critical support system. Furthermore, the heating pumps used in substitution of on-site combustion, should have a minimum value of COP, presenting some exception even in this case depending on climatic zones and operational temperatures.

As regard option 2, it refers to partially electrified buildings which don't use on-site combustion except for low temperatures[82]. The possible paths are listed below:

- path 1: related to space heating in climatic zone 3 with a COP that must be >1.8
- path 2: related to service water heating
- path 3: Design cooking, laundry, process equipment; those projects which don't have these typologies of equipment earns the point automatically[83]

Table 17- Electrification new credit description of LEED v5

<table>
<tr><th colspan="2">LEED v5 only</th></tr>
<tr><td colspan="2">Option 1- No On-Site Combustion</td></tr>
<tr><td rowspan="3">OR Option 2- No On-Site Combustion Except at Low Temperatures</td><td>Path 1- Space heating</td></tr>
<tr><td>AND/OR Path 2- Service water heating</td></tr>
<tr><td>AND/OR Path 3- Cooking and other process loads</td></tr>
</table>

[82] According to LEED certification "low temperatures" refers to dry-bulb outdoor air lower than 20 °F corresponding to -6.5 °C

[83] USGBC | U.S. Green Building Council (n.d.): *LEED Credit Library: LEED BD+C: New Construction v5 - LEED v5:Electrification* https://www.usgbc.org/credits/new-construction/v5/eac1?return=/credits/New%20Construction/v5/Energy%20&%20atmosphere

Reduced peak thermal loads

Even this credit represents an introduction of version 5 whose main goal is that of reducing the thermal loads to increase energy efficiency still ensuring comfort and building resilience. The compliance with the ASHRAE 90.1 section 5.5 related to Prescriptive building envelope compliance path or with ASHARE 90.1 section 5.6 related to Trade-off building envelope compliance path.

It includes 4 options, the first of which requires both balanced ventilation, guaranteeing a maximum tolerance of ±10% between supplied and exhausted ventilation including TABs report, and air leakages control ensuring maximum threshold values according to tables in function of the typology of intervention, the building conditioned floor area and the pressure testing conditions. With reference to infiltration, another option, different from that of threshold leakage values defined in table, is available for residential projects. In this case is required to ensure compartmentalization between the different dwelling units and verify leakages between them through blower door tests limiting infiltration to values 1,5 times those specified in the table.

Moreover, option 2 requires an energy or enthalpy recovery system with varying recovery ratios depending on the typology of recovery; as alternative or additionally to this, option 3 includes thermal bridges control, however already requiring compliance with ASHRAE 90.1:2022. Finally, and most importantly, option 4 aims at quantifying the peak loads reduction. In general, it requires to includes ventilation loads in peak calculation, air leakages testing and balanced ventilation as option 1.

3 different paths can be followed as specified below:

- sum of peak loads for heating and cooling per unit of treated floor area lower then specified threshold values
- points recognition depends on improvement percentage with respect to ASHRAE 90.1:2022[84]

[84] Appendix C, ASHRAE 90.1

- energy modelling with a final PI coming from the Performance Rating Method and substituting all cost references with building peak coincident heating and cooling loads and achieving a score depending on the obtained PI[85]

Table 18- Reduced peak thermal loads credit description of LEED v5

LEED v5	
Option 1- Infiltration and Balanced Ventilation	
AND/OR Option 2- Ventilation Energy Recovery	
AND/OR Option 3- Thermal Bridging	
AND/OR Option 4- Peak Thermal Load Reductions	Path 1- Peak load intensity
	OR Path 2- ASHRAE 90.1 trade-off methods
	OR Path 3- Energy simulation

2.4. ASHRAE 90.1:2010 vs AHSRAE 90.1:2019

2.4.1. ASHRAE 90.1:2010- main scope, introduction and evolution

The standard presents as main scope the realization of criteria and specific requirements to achieve minimum energy performance. It refers to new buildings or new portions of buildings and their systems or the systems alone if included in an already existing building. It represents an essential guideline for designers and engineers to model and design an efficient building and to realize an operational and maintenance plan.

The updated version of 2010 is the results of suggestions and feedback related to the outcomes of the previous versions to improve the criteria and enhance the energy efficiency of the real estate market; for this reason a form for a maintenance plan is available for all the standard's users to raise suggestions which are, successively, analysed to implement further modifications to the standard to achieve significant improvements.

The main goal that led to the AHSRAE 90.1:2010 formulation was the 30% reduction of the energy costs resulting from the buildings' design with respect to the released version of the standard in 2004. The main introductions of this updated version were:

- inclusion of receptables and process loads to better simulate the operational energy uses;

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[85] USGBC | U.S. Green Building Council (n.d.): *LEED Credit Library: LEED BD+C: New Construction v5 - LEED v5: Reduce peak thermal loads* https://www.usgbc.org/credits/new-construction-core-and-shell/v5/eac2?return=/credits/New%20Construction/v5/Energy%20&%20atmosphere

- the role of envelope has been recognized as crucial in the energy savings and, subsequently, the requirements were more rigid including the identification of minimum albedo for roofs and air barriers in the criteria
- the interior lighting power densities values were reduced with respect to previous versions
- addition of occupants sensing devices providing efficient energy used
- mandatory requirements for daylighting depending on the space use
- improvement in the equipment efficiencies requiring economizer and energy recovery in most applications
- a clear path to energy modelling with the aim of achieving energy certification as LEED certification

The standard is structured according to main chapters that starting from section 5 define all the requirements inside a building to enhance energy efficiency and specifically they are:

- section 5: building envelope
- section 6: heating, ventilation and air conditioning
- section 7: service water heating
- section 8: power
- section 9: lighting
- section 10: other equipment[86]

2.4.2. ASHRAE 90.1:2019 - main scope, introduction and evolution

The release of ASHRAE 90.1:2019 signs an important evolution on the standards and on the methodology to reach energy efficiency underlining the importance to overcome just the minimum prescription required and to move over thanks to the introduction of a lot of energy-saving measures. Even in this case, the release of this new version represents a normal evolution of the standard, not only from a content point of view but from a structural and formal point of view. Its structure, indeed, has been modified to make the document clear and well organized. For this reason, the form, available for users, is still opened for suggestions and opinions to always improve content and structure of the released standards.

[86] ASHRAE 90.1 (2010) (SI): *Standard 90.1-2010 (SI Edition) - Energy Standard for Buildings Except Low-Rise Residential Buildings* (ANSI/ASHRAE/IES). www.ashrae.org/standards. pag. 4

Depending on the considered section many changes have been introduced as schematized below:

Administration and enforcement: for the first time, commissioning was included in the standard showing a radical change in the standard and moreover showing the relationship between the LEED credits and the application of the standard itself. The section 4.2.5. "Verification, Testing and Commissioning" has been deeply modified and investigated.

Building Envelope: the values representing the requirements of each envelope component changed showing a more stringent approach; the thermal transmittance and solar heat gain coefficients limit values has been reduced for each element and for each climatic zone. As regards vestibules, it introduces a minimum area requirement and a specification related to vestibules for large spaces. The exceptions have been modified and include air curtain option.

Lighting model: many changes through years occurred in the lighting systems themselves, for this reason and to better represent the real operating conditions, the lighting power allowance have been modified, both for the space-by space methodology and for the building-area methodology. Always in this perspective of obtaining results more realistic and representative, even the room cavity ratios, used to identify the proportions of the rooms and the way in which this influences the lighting distribution, are more precise and detailed showing several option also in the proportions of the same typology of space; furthermore the new standard includes a 100% LED technology.

One big introduction is represented by the so-called "simplified building method compliance path", in section 9.3, related to interior lighting for those buildings up to 2300 m^2 which is mainly devoted to offices, retail or schools, which include the Light power allowance values and the controls requirement according to specific tables. Even parking lighting were modified to include LED technology and an updated setback and control.

Mechanical: the section has been deeply updated introduction the definition of pumps with correlated efficiencies table and its requirements in addition to modification to efficiencies tables already existing in the previous versions

Performance Rating Method (Appendix G): Here specifications on how differently the proposed model and the baseline model should be realized is deeply analysed defining for example the rules for automatic receptacle controls or infiltration modelling as well as updated building performance factors.[87]

2.4.3. Comparison between ASHRAE 90.1:2010 and ASHRAE 90.1:2019

A detailed and accurate analysis of the differences and updates apported passing from ASHRAE 90.1:2010 to ASHRAE 90.1:2019 is below reported:

Table 19- Comparison between ASHRAE 90.1:2010 and ASHRAE 90.1:2019

Comparison of ASHRAE 90.1 mandatory requirements, 2010 and 2019		
Administration and enforcement	ASHRAE 90.1:2010	ASHRAE 90.1:2019
Compliance Paths 4.2.1	Compliance with section from 5 and 10 or section 11	Additional possibility to comply with Performance Rating Method, Appendix G with the determination of PI and comparison with PI of the target building
Verification, Testing and Commissioning 4.2.5.1	N.A.	To confirm compliance with the standard requirements, verification and testing are required. Commissioning is included with respect to ASHRAE 202 or other accepted standards.
Building Envelope	ASHRAE 90.1:2010	ASHRAE 90.1:2019
Envelope alterations 5.1.3.	/	Exception to requirements includes specification on storm windows and roof recovering
Compliance path 5.2.	Prescriptive Building Envelope Approach for Skylight fenestration of 5% of gross roof area	Varied Skylight fenestration % to 3%per gross roof area to allow Prescriptive Building Envelope Option
Whole building air leakages 5.4.3.	Describes the design, installation process and documentation to obtain a continuous air barrier	Include testing to verify whole building air leakages with a limit value of 2.0 L/s·m^2 for a differential pressure of 75 Pa or up to 3.0 L/s·m^2 if diagnostics and remedial air sealing are performed.
Fenestrations and doors 5.4.3.2.	Presents limit air leakages for nonswinging doors	Relaxes the limit for nonswinging doors for vehicle access and material transportation (Table 5.8.3.2.)

[87] ASHRAE 90.1 (2020) (SI): *Standard 90.1-2019 (SI Edition) - Energy Standard for Buildings Except Low-Rise Residential Buildings* (ANSI Approved; IES Co-sponsored) www.ashrae.org/continuous-maintenance pag. 3, 4

Vestibules 5.4.3.4./ 5.4.3.3. [88]	Revolving doors considered as an exception	1. Introduces option for revolving doors as an option to maintain air barrier, nomore an exception 2. Exceptions: • Gross floor areas specified in the exceptions are modified • Included exception for semiheated space • Included exception for elevator lobbies • Included exception for self-closing doors with air curtains 3. Introduce specific vestibule requirements for large spaces modifying distance between interior and exterior doors
Opaque areas 5.5.3.	/	1. Increased minimum R-values 2. Decreased maximum U-factor 3. Decreased maximum U factor for fenestration 4. “Metal framed” and “non-metal framed” are incorporated, replaced with “fixed” and “operable” Tables from 5.5.1 to 5.5.8.
Roof insulation 5.5.3.1.	1. Solar reflectance according to ASTM C1549 or E1918 2. Solar thermal transmittance according to ASTM C1371 or ASTM E408	Testing method modified to CRRC S100.
Minimum Skylight Fenestration Area 5.5.4.2.3	/	Changed requirements for minimum skylight fenestration area (reduced area)
Fenestration Solar Heat Gain Coefficient (SHGC) 5.5.4.4	/	Exception for north orientated fenestration SHGC to be greater than other orientations
Fenestration Orientation 5.5.4.5	/	Varied formulas and requirements for the fenestration depending on their orientation
Visible Transmittance/SHGC Ratio 5.5.4.6	N.A.	Introduced threshold values for VT/SHGC Ration in tables from 5.5.1 to 5.5.8 to enhance daylights entering without increasing heat gains
Verification, Testing, Commissioning, and Inspection 5.9	N.A.	New Includes specification for testing commissioning and verification for building envelope
Heating, Ventilating, and Air Conditioning	ASHRAE 90.1:2010	ASHRAE 90.1:2019

[88] Where a second title is specified or whether another chapter numeration is specified, the first one is related to ASHRAE 90.1:2010 and the other to the ASHRAE 90.1:2019

Criteria 6.3.2	The system shall comply with demand control ventilation requirements	The system shall comply with demand control ventilation requirements, occupied-standby controls, ventilation design requirements and door switch requirements
Water-cooled centrifugal chilling packages. 6.4.1.2.1	1. AHRI Standard: 550/590 2. Defines leaving chilled-fluid temperatures and entering condenser-fluid temperatures	1. AHRI Standard: 551/591 2. Temperatures vary
Ceiling fans 6.4.1.3.	N.A.	Adds requirements for large diameter ceiling fans as blade span, rated airflow, and power consumption at the max speed.
Setback Controls 6.4.3.3.2	1. Heating setpoint adjustable down to 13°C or lower. 2. Cooling systems located in climate zones 1b, 2b, and 3b shall be equipped with controls to automatically restart and temporarily operate to maintain zone temperatures below a cooling setpoint adjustable up to 32°C or higher	1. Heating systems shall operate to maintain zone temperatures above an adjustable heating set point at least 5.6°C below the occupied heating set point. 2. Cooling systems shall operate to maintain zone temperatures below an adjustable cooling set point at least 2.8°C above the occupied cooling setpoint
Optimum start controls 6.4.3.3.3.	Heating and cooling system with a design supply air capacity greater than 5000 L/s should have optimum start controls	Heating and cooling systems with setback controls and Direct Digital Control systems should have optimum start controls
Automatic Control of HVAC in Hotel/Motel Guest Rooms 6.4.3.3.5.	N.A.	New. Includes requirements for automatic setback and ventilation control for HVAC equipment in hotels and motels with greater than 50 guest rooms
Damper Leakage in ventilation systems 6.4.3.4.3	/	Table related to maximum damper leakages presents different threshold values
Humidification and Dehumidification 6.4.3.7/6.4.3.6	Includes only systems to prevent simultaneous humidification and dehumidification	1. Dehumidification: don't use mechanical cooling to reduce RH under 60% 2. Humidification: Don't use electric or fossil fuel to humidify above 30% 3. Requires deadband on humidity controls
Ventilation Controls for High-Occupancy Areas. 6.4.3.9/6.4.3.8	Includes demand control ventilation (DCV) for spaces occupied by more than 40 people per 100 m^2	Includes demand control ventilation (DCV) for spaces occupied by more than 25 people per 100 m^2 Exceptions varied
Heated or Cooled Vestibules 6.4.3.9	N.A.	Adds control requirements for heating systems in vestibules and defines temperature limits for the operating of heating and cooling systems
Chilled Water Plant Monitoring 6.4.3.11	N.A.	New. Adds requirements for measurement devices to monitor electric energy use and efficiency
Economizer Fault Detection and Diagnostics 6.4.3.12	N.A.	New. Includes requirements for air-cooled direct-expansion cooling units in which an air economizer is installed.

		Establishes to include a fault detection and diagnostics systems with specific capabilities
Duct Leakage Tests 6.4.4.2.2	/	Varied leakage class which is present in the equation of maximum allowable ducts leakages reducing it
Walk-In Coolers and Walk-In Freezers 6.4.5	N.A.	New. 1. Specifies requirements for walk-in coolers and freezer defining the requirements for thermal resistance of the envelope, mechanism of closing and systems to reduce infiltration when door is open. 2. Requirements for evaporator fan motors, lighting and glass properties when glazed doors and windows are present
High-Limit Shutoff Control Settings for Air Economizers Table 6.5.1.1.3	/	Updates on the allowed control setting types and the setpoints to determine whether the outdoor air intake reduces the energy use for cooling
Sensor Accuracy 6.5.1.1.6	N.A.	Introduces requirements for air economizer sensor accuracy
Fluid Economizers 6.5.1.2	The exception regarding computers rooms presents a fluid economizer dry bulb temperature of 4 °C and wet bulb temperature of 2°C	Values modified and determined through table 6.5.1.2.1
Integrated Economizer Control 6.5.1.3	/	Introduces requirements for the integrated economizer control as the interlock connection to enable contemporary operation of economizer and mechanical cooling
Economizer Humidification System Impact 6.5.1.5	N.A.	Establishes requirements for maintaining inside humidity depending on system type
Dehumidification 6.5.2.3	Exceptions: • individual fan cooling unit with design capacity of 23 kW capable of unloading to 50% capacity before simultaneous heating and cooling takes place. • At least 75% of the energy for reheating is provided from a site-recovered or site-solar energy source.	Exceptions: • individual fan cooling unit with design capacity of 19 kW capable of unloading to 50% capacity before simultaneous heating and cooling takes place. • At least 90% of the energy for reheating is provided from a site-recovered or site-solar energy source.
Humidification 6.5.2.4	/	Add requirements for the insulation of the dispersion surfaces that must be insulated with materials presenting an insulating value of at least R-0.09.
Preheat Coils 6.5.2.5	N.A.	Includes new requirement for preheat coils to stop their preheating function if mechanical cooling occurs

Ventilation Air Heating Control 6.5.2.6	N.A.	New category for units that provide ventilation air to multiple zones shall not use heating to warm supply air above 16°C when the majority of zones require cooling.
Fan System power limitation 6.5.3.1	/	1. Fan Power Limitation Pressure Drop Adjustment (adjustment of fan power) includes deductions for those systems without central heating or cooling devices. 2. Includes a minimum value of fan efficiency calculated through the fan energy index (FEI)
Fan control 6.5.3.2.	/	1. This section has been fully reconstructed and includes limits in the fan speed. 2. Varies requirements for static pressure controls 3. Includes relief/return fan controls to maintain building pressure and should be provided with adjustable speed. 4. Provides requirements to increase efficiency in parallel-flow fan powered VAV air terminal. 5. Imposes minimum efficiency even for small fans motors. 6. Occupied-standby controls can reduce ventilation rate to zero when the space is in occupied-standby mode
Boilers turndown 6.5.4.1	N.A.	Introduces limits for turndown ratio showing how much the power can be reduced maintaining efficiency
Hydronic variable flow systems 6.5.4.1/6.5.4.2.	1. HVAC pumping systems including control valves should be able to reduce pumping flow rate to 50% 2. Individual pumps motors exceeding 3.7 kW shall have controls resulting in pump motor demand of no more than 30% of design wattage at 50% of design water flow. 2. Exceptions: • systems with nomore than 3 valves • systems where minimum flow is less than minimum flow required by manufacturer	1. Chilled and Hot-water distribution system including control valves should be able to reduce pumping flow rate to nomore than larger between: • 25% of design flow rate • minimum flow rate defined by manufacturer for the operation of equipment 2. The nameplate kilowatt of motor is defined through table 6.5.4.2 3. Exceptions include cases as: • 50% or more of heat is generated by boilers • primary pumps in primary/secondary systems • differential setpoint reset not required depending on valve position (Section 6.5.4.4)
Pump Isolation/Chiller and Boilers Isolation 6.5.4.2/6.5.4.3	In a plant, when multiple chillers/boilers are used, the flow in the chiller plant/boiler plant shall be reduced when one of the chillers is shut off.	In a plant, when multiple chillers/boilers are used, the flow through the chiller/the boiler shall be shut off when one of the chillers is shut off.

Chilled- and Hot-Water Temperature Reset Controls 6.5.4.3/6.5.4.4	1. / 2. Exceptions include systems with variable flow regulation and for system in which reset comprises heating/cooling or humidification/ dehumidification processes	1. Where DDC controls is present, it defines rules for the temperature reset depending on valve position and opening 2. Exceptions include system in which cold water comes from district cooling or energy storage, hydronic systems where valve control is already present and even includes process for which constant temperature is required
Chilled-Water Coil Selection 6.5.4.7	N.A.	New. Adds requirements for chilled-water coil selection providing 8.3 °C temperature differences and a minimum 14 °C leaving water temperature at design conditions. Includes exceptions.
Buildings with High-Capacity Space-Heating Gas Boiler Systems 6.5.4.8	N.A.	Includes, for system with input capacity in a certain range, requirements for boilers' thermal efficiencies of at least 90% and hot water distribution system design by defining the max return water temperature or flow entering the boiler
Fan speed control 6.5.5.2	1. For fan with motor of 5.6 kW or more, system to reduce the flow to 2/3 of full speed are required 2. / 3. /	1. Fan systems with motor capacity of 3.7 kW should have control to reduce to nomore than 30% the motor demand for the 50% of design wattage. 2. Exceptions related to multiple fan systems and climatic zone are removed. 3. Includes multiple cell requirements avoiding fans to work at full speed while others are turned off. Control for the fan speed to be the same for all fans
Tower Flow Turndown 6.5.5.4	N.A.	Open-circuit cooling towers with multiple or variable-speed pumps should be designed so that cells can run in parallel with 50% of design flow rate or the flow rate of the smallest pump
Exhaust air Energy Recovery 6.5.6.1/6.5.6.1.1-6.5.6.1.2	1. Each fan system shall have an energy recovery system when the system's supply air flow rate exceeds the value listed in Table 6.5.6.1 2. Energy recovery systems shall have at least 50% energy recovery effectiveness.	1. Distinguishes between nontransient dwelling units (1) and others (2). (1) Requires enthalpy recovery ratio of 50% in cooling design conditions and 60% in heating design conditions (2) Energy recovery is required for systems where design supply fan airflow rate exceeds values in table 6.5.6.1.2 (varied with respect

		to 90.1:2010 and distinguished depending on operating hours) 2. Exceptions varied.
Heat Recovery for Service Water Heating 6.5.6.2	/	Varied minimum threshold value of design water-heating system load in the requirements for heat recovery (reduced)
Heat recovery for space conditioning 6.5.6.3	N.A.	Where heating water is used for space heating, a condenser heat recovery system shall be installed for impatient hospital provided that some features are respected.
Indoor Pool Dehumidifier Energy Recovery 6.5.6.4	N.A.	Dehumidifiers for specific areas of indoor heated pool are required to have a sensible recover of 50%, an enthalpy recover of 50% and to reuse heat generated by dehumidifier to heat the pool.
Transfer Air 6.5.7.1	/	Adds requirements for supply air delivered to spaces with mechanical exhaust
Hot Gas Bypass Limitation 6.5.9	/	Reduced values of maximum hot-gas bypass
Door Switches 6.5.10	N.A.	New. Conditioned spaces with outdoor opening should have controls to disable or reduce the heating/cooling within 5 minutes doors opening
Refrigeration Systems 6.5.11	N.A.	Includes requirements for condensers and compressors serving refrigeration systems as walk-in coolers, or walk-in freezers
Computer Rooms Systems 6.6.1	N.A.	Introduces as an alternative path for heating and cooling system serving rooms with IT equipment load >10 kW, the compliance is with ASHRAE 90.4
Minimum Efficiency Requirements Table 6.8.1A/ Table 6.8.1-1	/	Minimum Efficiency requirements have been increased and even the number of tables due to the addition of tables for water-source heat pumps, heat pump and heat recovery chiller packages, air conditioners and condensing units serving computer rooms have been split into floor-mounted and ceiling-mounted. Tables were also added for walk-in cooler and freezer display doors and nondisplay doors, and walk-in cooler and freezer refrigeration systems. The liquid-to-liquid heat exchangers table was deleted
Service Water Heating	ASHRAE 90.1:2010	ASHRAE 90.1:2019

Service Hot-Water Piping Insulation 7.4.3	/	Add a new requirement for pipe insulation regarding the first 2.4 m of branch piping connecting to recirculated, heat-traced, or impedance heated piping
Buildings with High-Capacity Service Water-Heating Systems 7.5.3	N.A.	New. New buildings with gas service water-heating systems with a total installed capacity of 293 kW or greater, shall have equipment with a minimum thermal efficiency (Et) of 90%.
Completion Requirements 7.7.3	/	Includes specifications for SWH documents and manuals delivery to the building owner respectively within 90 days from the building envelope acceptance and from the systems acceptance
Verification, Testing, and Commissioning 7.9	/	Includes specification for verification testing and commissioning
Performance Requirements for Water-Heating Equipment TABLE 7.8	The required performance is specified through formulas including thermal efficiencies and energy factors	Includes higher specifications on the subcategory division, distinguishes between electric storage and instantaneous water heaters and removes formulas with EF and Et to comply instead with DOE
Power	**ASHRAE 90.1:2010**	**ASHRAE 90.1:2019**
Low Voltage Dry-Type Distribution Transformers. 8.1.2/8.4.4	Nominal efficiencies shall be established in accordance with the NEMATP-1 2002 test procedure	Nominal efficiencies shall be established in accordance with the 10 CFR 431 test procedure
Automatic Receptacle Control. 8.4.2	Occupancy sensors shut off the receptacles after 30 minutes the room is empty	1. Includes more spaces for which the control is required. 2. Includes control on at least 25% of branch circuit feeders installed for modular furniture not shown on the construction documents. 3. Reduces the area over which a single schedule program can have control. 4. Occupancy sensors shut off the receptacles after 20 minutes the room is empty. 5. Controlled receptacles should be marked to differentiate from uncontrolled ones.
Electrical Energy Monitoring 8.4.3	N.A.	New. 1. Adds requirements for the monitoring of whole energy use and differentiated typology of energy use 2. Recording should be at intervals of 15 minutes and system should be able to store data for 36 months
Alternative Compliance Path 8.6	Not used	Introduces alternative path for power distribution equipment for

		computer rooms over a certain load.
Drawings/Record Documents 8.7.1/8.7.3.1	Requires provision of the documents to the building owner within 30 days from the system acceptance	Requires provision of the documents to the building owner within 90 days from the system acceptance
Verification, Testing, and Commissioning 8.9	N.A.	Introduces specific requirements of testing verification and commissioning for power systems
Lighting	**ASHRAE 90.1:2010**	**ASHRAE 90.1:2019**
Lighting alterations 9.1.2	Exceptions: 1. Alteration that involves less than 10% of the connected load in a space or area	Exceptions: 1. Alteration that involves less than 20% of the connected load in a space or area 2. alterations that only involve replacement of lamps plus ballasts/drivers 3. Routine maintenance
Compliance Path(s) 9.2	/	Introduces compliance with a Simplified Building Method Compliance Path
Interior Lighting Power 9.2.2.3/ 9.2.3.1	/	Removed exception for compliance with interior lighting power: - exit signs - lighting in spaces designed for occupants with special lighting needs. Includes exception for lighting in photographic processes Defines the required control for each category
Simplified Building Method Compliance Path 9.3	N.A.	New. 1. It is allowed for interior and exterior lighting in buildings where at least 80% of the floor area supports either office buildings, retail buildings, or school buildings. 2. Applicable for new buildings or tenant improvements of less than 2322 m2. 3. Tables 9.3.1-1 to 9.3.1-3 list lighting power allowance for each building type.
Interior lighting control 9.4.1.1- 9.4.1.2.- 9.4.1.4-9.4.1.5/ 9.4.1.1	All control systems are required. -Shutoff: automatic depending on schedule or occupant sensors or signals. - On-control: manual on or automatic to 50% of power -Space control: includes control steps at 30% and 70% of full power (step dimming), occupant sensors and restricted control area for each control device.	Deeply modified. Includes tables with specific control requirements depending on space type. -Shutoff: divides between automatic partial off (reduces to 50% power) and full off after 20 minutes of inoccupancy and scheduled shutoff.

	-Daylight control for sidelight/ toplight: requires photocontrol presenting certain control steps for spaces with a specified area or greater	-On control: divides between restricted to manual ON and to partial automatic ON -Space control: requires restricted local control area for each control device and also bilevel control (step dimming or continuous dimming) -Daylight control for sidelight/ toplight: for spaces with specified input lighting power photocontrol is required to reduce lighting power on continuous dimming till 20%
Parking Garage Lighting Control 9.4.1.3/ 9.4.1.2	/	1. Varied parking garage luminaire power reduction from 30% to 50% depending on inactivity time varied from 20 minutes to 10 minutes. 2. Varied control requirements for daylight control
Additional Control/ Special Applications 9.4.1.6/9.4.1.3	1. Control devices for all receptacles at entry door is required 2. Bathrooms shall have control device to shut off lighting after 60 minutes unoccupied	1. For guestrooms an automatic shutoff after 20 minutes of inoccupancy is required 2. Bathrooms shall have control device to shut off lighting after 30 minutes unoccupied
Exterior Lighting Control 9.4.1.7/9.4.1.4	/	1. Increased reduction percentage of lighting power for advertising signage and others in specific conditions 2. Introduces automatic control for power reduction for luminaires with specific wattage and height serving outdoor parking areas
Individual Lighting Power Allowances for Building Exteriors TABLE 9.4.3B/ 9.4.2-2	/	1. Varied lighting power allowances. 2. Includes loading docks
Dwelling Units 9.4.3	N.A.	New. Includes provisions for dwelling units
Functional Testing/ Verification, Testing, and Commissioning 9.4.4/9.9	/	Specifies testing procedures to be followed for occupancy sensors, time switch-off and daylight control.
Lighting Power Density Allowances Using the Building Area Method/Space-by-space method Table 9.5.1/Table 9.6.1	/	Varied Lighting Power Density allowances for building typology
Additional Interior Lighting Power 9.6.2	/	Varied Lighting Power Density allowances
Daylighting Documentation 9.7.3.3	N.A.	New. Includes requirement for daylighting documentation
Other Equipment	**ASHRAE 90.1:2010**	**ASHRAE 90.1:2019**

Electric Motors 10.4.1	1. Compliance with Energy Police Act before December 2010, with Energy Independence and Security Act after	1. Electric motors with a specific rated power shall comply with requirements for NEMA designs according to tables 10.8-1/10.8-3 2. Includes requirements even for small motors 3. Exceptions varied
Elevators 10.4.3	/	NEW: -10.4.3.4 Design documents: defines usage category and energy efficiency class
Escalators and Moving Walks 10.4.4	N.A.	New. They shall automatically slow to the minimum permitted speed in accordance with ASME A17.1/CSA B44
Air Curtains 10.4.5	N.A.	1. Testing: accordance with ANSI/AMCA 220 or ISO 27327-1 2. Installation: accordance with the manufacturer's instructions 3. Jet velocity: not less than 2.0 m/s at 15 cm above the floor 4. Direction: not less than 20 degrees towards the opening. Automatic controls.
Whole-Building Energy Monitoring 10.4.6	N.A.	1. Includes requirements for measurement devices to be installed at building site to monitor the energy use, recorded at least every 60 minutes and reported at least hourly, daily, monthly, and annually. 2. System shall be capable of maintaining data for a minimum of 36 months and creating user reports.
Pumps 10.4.7	N.A.	Clean water pumps meeting specific criteria shall comply with the requirements shown in Table 10.8-6 about Maximum Pump Energy Index (PEI)
Verification, Testing, and Commissioning 10.9	N.A.	Introduces chapter for verification and commissioning for other equipment
Energy Cost Budget Method	**ASHRAE 90.1:2010**	**ASHRAE 90.1:2019**
Compliance 11.1.4/11.2	/	Adds compliance with: - verification, testing, and commissioning requirements of Section 4.2.5 - proposed building systems, controls, or building envelope that do not have criteria in Sections 5 through 10 shall have verification or testing to document proper installation and operation in accordance with Section 4.2.5.

Documentation Requirements/Permit Application Documentation 11.1.5/ 11.7.2	/	Adds further requirements relative to the documentation: -software and version used -an overview of the project -building elevation and floor plans -explanation of modelling assumptions -calculation to support data input -purchased energy rates used -reduction in design energy cost due to the use of renewable energy
Simulation General Requirements 11.2	1. Simulation program should be able to model a minimum of 1400 hours per year 2. Simulation program shall be tested and results shall be furnished by the software provider.	1. Simulation program should be able to model 8760 hours per year 2. The test results shall be posted on a publicly available website .
Modelling Requirements for Calculating Design Energy Cost and Energy Cost Budget TABLE 11.3.1/11.5.1	1. Schedules: / 2. Building envelope: / 3. Lighting: / 4. Thermal zones: perimeter spaces are those located closer than 5 meters to the exterior wall 5. HVAC: / 6. Service water heating: Exceptions for budget building design define that service water heating system, if not present in table 7.8, shall be modelled as the proposed one 7. Miscellaneous load: / 8. Refrigeration: N.A.	With respect to what defined for the 90.1:2019, addition and variation are: 1. Schedules: includes specification for temperature and humidity schedules; introduces rules for fan schedules and exceptions for unconditioned buildings and for spaces with health, safety-mandated minimum ventilation requirements 2. Building envelope: for E-W fenestration area of proposed design exceeding limit set in Section 5.5.4.5 the budget building design shall be design with its actual orientation and rotating it to 90, 180, and 270 degrees averaging the results. Introduces visible transmittance requirements and specification for skylights 3. Lighting: Includes specification for dwelling units and hotel/motel lighting; considers automatic control and automatic daylight control in modelling; additional interior lighting power for nonmandatory controls shall not be included in the budget building design 4. Thermal zones: Includes possibility to consider spaces in the same thermal zone if peak loads differ by less than a certain value or if schedules differ by less than certain full-load hours. Perimeter spaces are those located closer than

		4.6 meters to the exterior or semiexterior wall 5. HVAC: If the efficiency rating includes even supply fan energy, this should be removed form efficiency in budget building design, for the proposed design manufacturer's data without fan power must be used. 6. Service water heating: piping losses must not be modelled. Exceptions for budget building design defines that service water heating system, if not present in table 7.8 shall be modelled following G3.1.1-2. Service water loads and use shall be the same for proposed and budget building. 7. Miscellaneous load: adds specification for power and other systems related to section 8 and 10 8. Refrigeration: New. In proposed design the equipment is rated in accordance with AHRI 1200 and energy use shall be modelled or proposed design shall be modelled using actual equipment capacities and efficiencies. For budget building design: if refrigeration is specified in the proposed design and listed in Table 6.8.1-13, the budget building design shall be modelled as specified in Table 6.8.1-13 using the actual equipment capacities. Otherwise, it must be equal to the proposed
Purchased Energy Rates/On-Site Renewable Energy and Site-Recovered Energy 11.4.3.1 /11.2.3	On-site renewable energy sources or site-recovered energy shall not be included in the design energy cost.	1. Site-recovered and on-site renewable energy (the last one only if specific requirements are fulfilled) shall be subtracted from energy consumption prior to the calculation of the design energy cost. 2. Reduction in design energy cost due to on-site renewable energy shall be no more than 5% of the calculated energy cost budget. 3. When using on-site renewable or site-recovered energy, the budget building design should consider same energy source as backup

		energy or electricity when backup energy is not specified
Exceptional Calculation Methods 11.2.5/11.4.5	/	Updated requirements to document and report exceptional calculation method
Calculation of Design Energy Cost and Energy Cost Budget 11.3/11.5	/	Includes exception: energy used to recharge or refuel vehicles that are used for off-building site transportation purposes shall not be modelled for the design energy cost or the energy cost budget.
HVAC Systems 11.3.2/11.5.2	1. / 2. In evaluating the energy efficiencies, fan energy should be modelled separately 3. / 4. Supply air rates for the budget building design: based on a supply-air-to-room-air temperature difference of 11°C.	1. Adds specification for chillers that shall use path A efficiencies shown in Table 6.8.1-3. 2. Requires the use of specific formulas depending on the budget system type 3. Includes two exceptions for minimum outdoor air ventilation rate requirements to be the same between proposed and budget building. 4. Supply air rates for the budget building design: based on supply-air-to-room-air temperature difference of 11°C or minimum outdoor airflow rate or airflow rate to comply local codes, whichever is greater.
Water Chiller Types TABLE 11.3.2C/11.5.2-3	/	Electric chiller type varied for individual chiller plant capacity ≤352 kW
Economizer High-Limit Shutoff TABLE 11.3.2D/11.5.2-4	/	Economizer type "water nonintegrated" removed
Energy Cost Budget Method	**ASHRAE 90.1:2010**	**ASHRAE 90.1:2019**
Performance Rating Method Scope. G1.1	Intended for rating energy efficiency of building designs exceeding requirements of the standard. It is not an alternative compliance path for minimum standard compliance	Offers an alternative path for minimum standard compliance
Performance Rating G1.2/G1.2.1	Compliance: mandatory provisions from section 5 to 10	Compliance for the proposed design: -adds compliance with LP allowance as defined by Table G3.7 plus Section 9.6.1, or Table G3.8 plus Section 9.5.1; -energy efficiency of installed components meets or exceeds the efficiency used to calculate the proposed building performance;

		-compliance with verification, testing, and commissioning requirements of Section 4.2.5; -proposed building systems, controls, or building envelope that do not have criteria in Sections 5 through 10 shall have verification or testing in accordance with Section 4.2.5.
Performance Rating/ Performance Rating Calculation G1.2/G.1.2.2	Percentage improvement= 100x (Baseline Building Performance-Proposed Building Performance)/ Baseline Building Performance	Performance Cost Index = Proposed building performance/ Baseline building performance Includes exception: energy to recharge vehicles shall not be modelled
Documentation Requirements G1.4/G1.3	/	Adds: - reduction in proposed building performance associated with on-site renewable energy; -version of the software and link to the website containing ASHRAE Standard 140 results for the version used in accordance with Section G2.2.4.
Simulation Program G2.2	/	1. Introduces obligation to post test results along with the results of the other simulation programs and modeler reports on a publicly available website. 2. The modeler report in Standard 140, shall be completed for results exceeding the maximum or falling below the minimum of the reference values or for missing results.
Energy Rates/Annual Energy Costs G2.4 /G2.4.2	1. On-site renewable energy sources or site-recovered energy are not included in the proposed building performance. 2. Where on-site renewable or site recovered sources are used and no backup energy source has been specified, the baseline building performance should be based on electricity. 3. /	1. On site-recovered energy shall be subtracted from the proposed design energy consumption prior to calculating the proposed building performance. The same applies to on-site renewable energy provided that specific requirements are fulfilled. 2. When on-site renewable energy or site-recovered energy is used, and no backup energy source has been specified, the baseline building design shall be based on the baseline system energy source in that category. 3. When on-site electricity generation systems other than on-site renewable energy systems, are included in the proposed design, the baseline design should consider the same generation systems excluding its site-recovered energy.
Baseline HVAC System Type and Description. G3.1.1	1. HVAC systems in the baseline building design shall be based on usage, number of floors,	1. HVAC systems in the baseline building design shall be determined according to the

	conditioned floor area, and heating source. 2. /	building type with the largest conditioned floor area, number of floors, gross conditioned floor area and climate zone 2. Varied exceptions: c) includes even system 11,12 and 13 d) varied exhaust rate for which exception applies Includes exception for computer rooms and hospital and removes that referring to kitchens
Modeling Requirements for Calculating Proposed and Baseline Building Performance TABLE G3.1 1. Design model	Exception: Spaces with Baseline system type 9 or 10 shall not be simulated with mechanical cooling while the remaining spaces are simulated as both heated and cooled	Exception: Spaces with heating only as stairway/storage rooms and mechanical ones not transferring air from mechanical cooled shall not be modelled with mechanical cooling
Modeling Requirements for Calculating Proposed and Baseline Building Performance TABLE G3.1 2. Additions and alterations	/	It is specified that if the proposed model excludes existing components, even the baseline model should exclude them
Modeling Requirements for Calculating Proposed and Baseline Building Performance TABLE G3.1 3. Space classification	1. It is possible to classify spaces using either section 9.5.1. (Building space method) or section 9.6.1. (space-by-space method) but without mixing the two together 2. Specifies that more building types can be used within the same building if it is a mixed-use facility	1. It is required to classify spaces using section 9.6.1 (space-by-space method), the building space method can be used only as exception for those spaces for which space type is not identified 2. Space classification should be done by considering thermal blocks
Modeling Requirements for Calculating Proposed and Baseline Building Performance TABLE G3.1 4. Schedules	/	1. Includes another exception for HVAC fan schedules: they should remain on during unoccupied hours in system serving computer rooms 2. Adds exceptions for baseline model to differ from proposed one when schedules automatically provide thermal comfort with means of other than directly controlling the air dry-bulb and wet-bulb temperature and if section G3.3.1.c applies
Modeling Requirements for Calculating Proposed and Baseline Building Performance TABLE G3.1 5. Building envelope	1. / 2. Baseline model: opaque assemblies shall conform with U-factors and it is valid for new or existing buildings, alterations shall comply with section 5.1.3 3. Baseline model: vertical fenestration equal to the minimum between proposed and 40% of gross wall area 4. Baseline model: skylight should be equal to the proposed or to 5% of roof whichever is smaller	1. Includes specifications on infiltrations: shall be modelled using the same methodology and adjustments, for each time step, for weather and building operation in both the proposed design and the baseline building design. Should include strategies that are intended to positively pressurize the building. 2. Baseline model: opaque assemblies shall conform with U factors and Appendix A and specification on U-factors are

	5. Baseline model: The solar reflectance and thermal emittance of exterior roof surfaces should be as required in Section 5.5.3.1.1. Roof exempted from section 5.5.3.1.1 should have the solar reflectance equal to 0.30 and the thermal emittance equal to 0.90 6. / 7. /	made also for below-grade walls. It is valid for new., existing buildings and alterations 3. Baseline model: vertical fenestration area is taken by table G.3.1.1-1 depending on building type, if the building has multiple building types each area has the % of vertical fenestration as specified for the building type. Where building type is not specified the 40% of the gross wall area or the % in the proposed is used. 4. Baseline model: skylight should be equal to the proposed or to the 3% of gross roof area whichever is smaller 5. Baseline model: the solar reflectance of exterior roof surfaces should be 0.30 and the thermal emittance should be of 0.90 6. Baseline model: roof reflectivity should be 0.30 7. Baseline model: air leakage evaluated at pressure differential of 75 Pa shall be 5.1 L/s*m^2
Modeling Requirements for Calculating Proposed and Baseline Building Performance TABLE G3.1 6. Lighting	1. For those spaces where lighting systems are connected via receptacles and are not specified in documents and plans, identical lighting power for the proposed and baseline building designs as to be assumed 2. Credit ca be given for the use of daylight automatic controls if operation is either modelled directly in the building simulation or through schedule adjustments determined by a separate daylighting analysis. 3. Others automatic lighting controls shall be modelled reducing the lighting power according to occupancy sensor and/or timing control according to percentage specified in table G3.2 4. Baseline model should be realized following the space-by-space method or the building area method as for the proposed model, and the power is derived by section 9.2	1. For those spaces where lighting systems are connected via receptacles and are not specified in documents and plans, lighting power shall be modelled equal to the values specified in Table 9.6.1 for the appropriate space type or as designed, whichever is greater. For the dwelling units, lighting power used in the simulation shall be equal to 6.5 W/m2 or as designed, whichever is greater. 2. Specific lighting controls including automatic daylight controls, occupancy sensors etc become mandatory according to section 9.4.1., and specifically the automatic daylight controls should consider separately the different lighting areas (primary and secondary sidelighted and toplighted areas) 3. Other automatic lighting controls included shall be modelled reducing the lighting

	depending on the considered method 5. The baseline model considers only the automatic and manual controls as defined in section 9.4	schedule according to occupancy sensor reduction factors as specified in Table G3.7 for space type or, whenever controlled by programmable control, in building less than 500 m^2, the reduction is 10%. 4. The baseline model is realized in accordance with table G3.7 as regards interior lighting power; the exterior lighting power is derived from table G3.6 for specific cases and for the others is modelled equal to the proposed. 5. Baseline model shall have automatic shutoff for those buildings >500 m^2 and, in specific cases, even the occupancy sensors
Modeling Requirements for Calculating Proposed and Baseline Building Performance TABLE G3.1 7. Thermal blocks- HVAC Zone designed	1. Different HVAC zones can be combined into a single thermal block if the space use classification is the same	1. Different HVAC zones can be also combined into a single thermal zone if all the zones' peak internal loads differ by less than 31.2 W/m^2 from the average or if the space classification is the same. 2. Different HVAC zones can be also combined into a single thermal zone if all the zones have schedules variation of or less than 40 equivalent full-load hours per week.
Modeling Requirements for Calculating Proposed and Baseline Building Performance TABLE G3.1 8. Thermal blocks- HVAC Zone not designed	1. Those HVAC systems not yet designed should be defined considering interior spaces those located greater than 5 meters from exterior wall	1. Those HVAC systems not yet designed should be defined considering interior spaces those located greater than 4.6 meters from exterior wall
Modeling Requirements for Calculating Proposed and Baseline Building Performance TABLE G3.1 10. HVAC systems	1.The efficiencies of mechanical equipment shall be adjusted from actual design conditions to the standard rating conditions as defined in Section 6.4.1 2. Where the heating system has not been specified, the heating system type should be considered electric, and its characteristics shall be the same of the system modelled in the baseline building design. 3. When the cooling system is not specified it must be equal to the one modelled for the baseline building design 4. /	1. In addition to what defined in 90.1:2010 it has been specified that when fan energy is included in the efficiency, it should be adjusted to remove the supply fan energy in the baseline building design. As regards the proposed design, HVAC system shall be modelled using manufacturers' data without fan power 2. In case the heating system has not been designed, the system type shall be the same of the baseline building design and compliant with the requirements of Section 6. 3. When the cooling system is not specified, it must be equal to the one of the baseline building design and must be compliant with requirements of Section 6

		4. Requirements for baseline building model includes specifications about humidification systems, systems serving computer rooms and fossil fuel systems
Modeling Requirements for Calculating Proposed and Baseline Building Performance TABLE G3.1 11. Service water-heating systems	1. When the hot-water system has not been specified, it shall be modelled equal to the system in the baseline building design serving the same hot water loads. 2. / 3. / 4. The hot-water system in baseline model shall use the same energy source as the proposed model 5. When a system already exists, the service water-heating system in baseline shall use the actual capacities and efficiencies. When a new system is designed, sizes and efficiencies must be compliant with Sections 7.4.1 and 7.4.2 6. Where the system is not specified but the building presents hot-water loads, the baseline model system shall be electric, with efficiency compliant with section 7.4.2 and must be the same as the proposed one 7. When space heating and service water-heating loads are satisfied by a common system, the baseline model shall use separate system with efficiencies as required for each system 8. The reduction in use of service hot-water can be demonstrated by documented water conservation measures. Reduction shall be demonstrated by calculations. 9. /	1. In addition to what specified in 90.1:2010, the system is required to be compliant with Section 7. 2. If space heating and service water-heating loads are satisfied by a combined system, the proposed design uses actual component capacities and efficiencies. 3. Piping losses shall not be modelled bot in proposed and baseline models 4. The hot-water system in baseline model shall be determined through table G3.1.1-2 5. When a service water-heating system exists or is specified in design, a system must be assigned for each building are type in the proposed model with sizes and efficiencies as specified in Sections 7.4.1 and 7.4.2. 6. Where no system has been specified, the baseline building system type shall be the same as the proposed ones for each building area type and efficiencies shall be compliant with section 7.4.2. 7. / 8. When water conservation measures are applied, the baseline building flow rate shall be determined as specified in Table G3.1 9. Gas storage water heaters must be designed using natural gas, an exception is defined.
Modeling Requirements for Calculating Proposed and Baseline Building Performance TABLE G3.1 12. Receptacles and other loads	1. Receptacle and process loads shall be identical in the proposed and baseline building design, except when approved by the rating authority 2. When efficiency requirements are specified in Sections 5 through 10, these systems should be modelled in baseline model with the lowest efficiency allowed, otherwise power and capacity of the equipment shall be identical between the baseline building and the proposed one.	1. Receptacle and process loads shall be identical in the proposed and baseline building design. Exception to the rule is approved by the rating authority only when performance exceeds requirements of Standard 90.1 but not when the Performance Rating Method is used. When receptacle controls are installed in spaces not required by Section 8.4.2, the hourly receptacle shall be reduced

	3. Other systems included in section 10 and miscellaneous load should be the same between proposed and baseline model 4. Variation between baseline and prosed is admitted if the project is very different from documented common practise	2. Motors should have efficiencies as specified in table G3.9.1, other systems of section 10 should be the same between proposed and baseline model 3. Specifies: energy used for cooking equipment, receptacle loads, computers, medical or laboratory equipment, and manufacturing and industrial process equipment shall be identical between the proposed building performance and the baseline building performance. 4. Variation between baseline and proposed is admitted only if performance exceeds the requirements of Standard 90.1 except when the Performance Rating Method is used
Modeling Requirements for Calculating Proposed and Baseline Building Performance TABLE G3.1 14. Exterior Conditions	1. The effect on the solar shading being received by building due to the presences of other structures and vegetation shall be adequately reflected in the computer analysis. If the computer program has a subroutine to simulate shading by adjacent structures, it must be used. If not, the portion of the building which is shaded most of the time, can be modelled having a north-facing orientation.	1. The effect on the solar shading being received by building due to the presences of other structures and vegetation shall be adequately reflected in the computer analysis.
Modeling Requirements for Calculating Proposed and Baseline Building Performance TABLE G3.1 15. Distribution transformers	N.A.	1. Low-voltage dry-type distribution transformers shall be modelled if transformers in the proposed design have efficiency exceeding values in Table 8.4.4. 2. In baseline model, the condition for which the modelling of distribution transformers is required is the same. If required to be modelled, the transformers shall have efficiencies as defined in table 8.4.4
Modeling Requirements for Calculating Proposed and Baseline Building Performance TABLE G3.1 16. Elevators	N.A.	1. Where elevators are included in the proposed design, the elevator motor, ventilation fan, and light load shall be included in the model. The cab ventilation fan and lights shall be modelled with the same schedule as the elevator motor. 2. In baseline building model, the elevator peak motor power is determined through a specified formula in which the weight of car, the rated load and the speed of the car are as in the proposed design, and the remaining terms are derived from table G3.9.2.

Modeling Requirements for Calculating Proposed and Baseline Building Performance TABLE G3.1 17. Refrigeration	N.A.	1. When refrigeration equipment in the proposed design is rated in accordance with AHRI 1200, the rated energy use shall be modelled, otherwise the actual equipment capacities and efficiencies shall be used. 2. The baseline model, if refrigeration equipment is specified and listed in Tables G3.10.1 and G3.10.2, shall be modelled as specified in Tables G3.10.1 and G3.10.2 using the actual equipment capacities, otherwise it should be the same as the proposed model.
Modeling Building Envelope Infiltration G3.1.1.4	N.A.	The air leakage rate of building envelope at a pressure differential equal to 75 Pa shall be converted to appropriate units for the simulation program using different formulas where air leakage is expressed as function of floor area or area of above-grade walls separating conditioned or semiheated space from exterior space A multizone airflow model can be used as alternative method to modelling building envelope air leakage if specific criteria are satisfied.
Equipment Efficiencies G3.1.2.1	1. For the baseline building design minimum efficiency levels shall be adopted to model all HVAC equipment as defined in Section 6.4. 2. / 3. In case efficiency ratings includes fan energy, the different components must be identified to model supply fan energy separately.	1. For the baseline building design minimum efficiency levels shall be adopted to model all HVAC equipment as defined in Tables from G3.5.1 to G3.5.6. 2. In case different HVAC zones are combined into a single thermal block and the baseline HVAC system type is 1,2,3,4,9 or 10, the efficiencies shall be based on the equipment capacity of the thermal block divided by the number of HVAC zones; if, instead, HVAC System Types are 5 or 6, the efficiencies shall be based on the cooling equipment capacity of a single floor when grouping identical floors. 3. COPnfcooling and COPnfheating exclude supply fan power.
Sizing Runs G3.1.2.2.1	1. Weather conditions used in sizing runs should derive from hourly historical weather files containing typical peak conditions or on design days 2. /	1. Weather conditions used in sizing runs shall be based on design days developed. 2. Schedules for internal loads in cooling sizing runs should be derived from annual simulation runs and the highest hourly value is the one used and applied to the

		entire design day. (Specification on exception for residential dwelling units) 3. Differently, for heating sizing runs, schedules for internal loads derived from the annual simulation runs shall be taken equal to the lowest hourly value but those for infiltration shall be equal to the highest hourly value and applied to the entire design day.
Ventilation. G3.1.2.6/G3.1.2.5	1. Intake flow for ventilation system should be the same between proposed and baseline except when DCV in proposed model in not required by Section 6.3.2(p) or Section 6.4.3.9. 2. /	1. Intake flow for ventilation system should be the same between proposed and baseline except for specific conditions of system outdoor air capacity and average design capacity of the served area. 2. Includes specification on baseline systems that shall be modelled with 100% of outdoor air when serving laboratory spaces for which recirculating return air is prohibited.
Economizers G3.1.2.7/G3.1.2.6	1. Outdoor air economizers shall be included in baseline HVAC Systems 3 through 8 based on climate as specified in Table G3.1.2.6A. 2. /	1. Air economizer control shall be included in baseline HVAC Systems 3 through 8, and 11, 12, and 13 based on climate as specified in Table G3.1.2.6 2. Includes specification on exception for systems serving computer rooms and compliant with Section G3.1.2.6.1.
Computer Room Economizers G3.1.2.6.1	N.A.	If the serving system is type 3 or 4, it shall not have an economizer. When the system type considered is 1, an economizer shall be integrated in the baseline building design.
Baseline System Types 1 through 8/ Baseline All System Types Except System Types 9 and 10 G3.1.2.9.1/G3.1.2.8.1	1. The design air flow rate in baseline building design shall be the greatest between supply-air-to-room-air temperature difference of 20°F or minimum outdoor airflow rate 2. Exception: For laboratory spaces the design airflow rate is the greatest between a temperature difference of 17°F or required ventilation or makeup air 3. /	1. The supply-air-to-room-air temperature difference is specified to be a setpoint temperature difference and expressed in °C In case systems serves multiple zones, the design set point to be used is the one resulting in the lowest supply air cooling set point or highest supply air heating set point. 2. Exception: for laboratory spaces, ascertained that the design air flow rate is the greatest between the same terms as defined in 90.1:2010, the temperature set point difference is set to 9°C 3. Whenever in the proposed design HVAC system airflow rate based on latent loads is greater than the one based on sensible loads, then the supply-air-to-room-air humidity ratio difference used to

		calculate the proposed design airflow shall be used to calculate that of baseline building design.
Baseline System Types 9 and 10. G3.1.2.9.2/G3.1.2.8.2	The design air flow rate shall be the greatest between the minimum air flow rate and the difference between supply air temperature setpoint of 105°F and the design heating temperature setpoint	The design air flow rate shall be the greatest between the minimum air flow rate and the difference between supply air temperature setpoint of 41°C and the design heating temperature setpoint
System Fan Power. G3.1.2.10/ G3.1.2.9	1. / 2. Fan motor efficiency derived from Section 10.8B	1. Varied some multiplicators in the formulas for the calculation of fan electric power 2. Efficiencies taken from table G3.9.1
Exhaust Air Energy Recovery. G3.1.2.11/G3.1.2.10	Exhaust air energy recovery shall be modeled following Section 6.5.6.1.	Specifies conditions of supply air capacity and minimum design outdoor air supply for which fan systems are required to have an energy recovery system with at least 50% of enthalpy recovery ratio. Includes exceptions for which the energy recovery is not required to be modelled in the baseline building design as for spaces not cooled and heated to less than 16°C, systems exhausting toxic fumes, specific kitchen hoods, heating and cooling systems for defined climatic zones, systems with dehumidification with energy recovery in series
Heat Pumps (Systems 2 and 4). G3.1.3.1	Electric air source heat pumps with auxiliary electric heat are provided with multistage space thermostats and an outdoor air thermostat. Auxiliary heat is only provided on the last thermostat stage and when outdoor air temperature is less than 4°C.	1. Auxiliary electric heat is only a function of the outdoor air thermostat; the multistage space thermostats are nomore mentioned 2. It is specified that heat pump continues operating even when auxiliary electric heat is provided.
Hot-Water Supply Temperature Reset (Systems 1, 5, and 7). G3.1.3.4	/	Includes exception for systems using purchased heat
Hot Water Pumps. G3.1.3.5	1. The pumping system shall be modeled as primary-only with continuous variable flow. 2. /	1. Is included specification, in addition to what defined in 90.1:2010, on a minimum % equal to the 25% of design flow rate when modelling the pumping system. 2. Varied conditions for hot-water systems to be modelled with variable-speed drives or as the riding curve
Chilled-Water Supply Temperature Reset (Systems 7, 8, 11, 12, and 13) G3.1.3.9	/	Adds exceptions for baseline chilled-water system serving a computer room HVAC system for

		which the supply temperature reset is higher and function of the HVAC system requiring the most cooling and also for systems served by purchased chilled water.
Chilled-Water Pumps. G3.1.3.10	1. Chilled water systems are modelled as primary/secondary systems with variable speed drives on the secondary pumping loop or with secondary pump riding the pump curve depending on the cooling capacity 2. The baseline building design pump power is a fixed value without any specification on primary and secondary pump and their flow 3. /	1. Specifies that system present constant flow primary loop and variable-flow secondary loop. Depending on the cooling capacity it is specified when secondary pump is modelled with a variable-speed drives and a minimum flow or when it is modelled as riding the curve. 2. The baseline building pump power is defined considering separately the constant-volume primary pump power and the variable-flow secondary pump power 3. Includes specification for computer room systems using System 11 with an integrated fluid economizer
Heat Rejection (Systems 7 and 8)/ Heat Rejection (Systems 7, 8, 11, 12, and 13) G3.1.3.11	1. The device is an axial fan cooling tower with twospeed fans whose performance shall comply with requirements of Table 6.8.1G. 2. Condenser water design supply temperature can be a fixed value or one depending on design wet-bulb temperature, whichever is lower. 3. The leaving water temperature is controlled to be maintained at 21°C 3. / 4. / 5. /	1. The device is an axial-fan open-circuit cooling tower with variable speed fan control and with defined efficiency for conditions specified in Table 6.8.1-7. 2. Condenser-water design supply temperature shall be calculated using a formula function of the 0.4% evaporation design wet-bulb temperature. 3. The leaving water temperature is controlled following Table G3.1.3.11 4. The baseline building design condenser-water pump power modelled as constant volume. 5. Specification is included for computer room systems using system 11 with an integrated fluid economizer
Fan Power (Systems 6 and 8)./ Fan Power and Control (System 6 and 8) G3.1.3.14	/	Adds specification for VAV fan-powered boxes with fans in parallel according to which fans should run the first stage of heating before the reheat coil is energized.
Computer Room Equipment Schedules G3.1.3.16	N.A.	Computer room equipment schedules shall be modelled as a constant fraction of the peak design load depending on months
System 11 Supply Air Temperature and Fan Control G3.1.3.17	N.A.	1. Defines the minimum volume set point as the greatest between the 50% of the maximum design airflow rate or the minimum ventilation outdoor airflow rate, or

		the airflow rate required to comply with applicable codes. 2. Fan volume and supply air temperature set point shall be modulated as a function of the cooling load. 3. In heating mode supply air temperature shall be modulated to maintain space temperature, and fan volume shall be fixed at the minimum airflow.
Dehumidification (Systems 3 through 8 and 11, 12, and 13) G3.1.3.18	N.A.	The baseline model should be provided with mechanical cooling for dehumidification and with reheat to avoid overcooling whenever the proposed HVAC systems have humidistatic controls.
Baseline Building Vertical Fenestration Percentage of Gross Above-Grade-Wall Area Table G3.1.1-1	N.A.	A different % of vertical fenestration is defined according to the building area type
Baseline Service Water-Heating System Table G3.1.1-2	N.A.	To be used to determine the service water-heating system type when not listed in Table 7.8
Baseline HVAC System Types TABLE G3.1.1A/ Table G3.1.1-3	/	Varied building type classification with respect to 90.1:2010 and includes distinction in the systems to be selected according to climatic zones. Distinction between energy source (fuel or electric) is nomore highlighted in this table
Baseline System Descriptions TABLE G3.1.1B/ Table G3.1.1-4	/	Adds 3 new systems (11,12 and 13)
Climate Conditions under which Economizers are Included for Comfort Cooling for Baseline Systems 3 through 8 and 11, 12, and 13 TABLE G3.1.2.6A/ Table G3.1.2.6	/	Includes climatic zone 0
Economizer High-Limit Shutoff Temperature TABLE G3.1.2.6B/Table G3.1.2.7	/	Varied conditions for certain climatic zones
Baseline Fan Motor Power TABLE G3.1.2.9	/	Includes system 11
Heat-Rejection Leaving Water Temperature Table G3.1.3.11	N.A.	Differently from 90.1:2010 which defined a fixed temperature, here the leaving temperature is determined as a function of the climatic zone
Performance Rating Method Building Envelope Requirements Tables from G3.4-1 to G3.4-8	Expressed in Section 5	It's a specification, depending on climatic zones of the envelope requirements.
Performance Rating Method Gas- and Oil-Fired Boilers—Minimum Efficiency Requirements Tables from G3.5.1 to G3.5.6	Expressed in Section 6	Varied classification, minimum efficiency values and testing procedures

Performance Rating Method Lighting Power Densities for Building Exteriors Table G3.6	Expressed in Section 9 as function of the lighting zone	Defines fixed values
Performance Rating Method Lighting Power Density Allowances and Occupancy Sensor Reductions Using the Space-by-Space Method Table G3.7	Lighting controls are defined in Section 9.4.1 as compliance with provisions and in addition to this they can be controlled automatically reducing the connected lighting power by the applicable percentages listed in Table G3.2.	Defines the lighting power density and the reduction for occupancy sensors according to the space type
Performance Rating Method Lighting Power Densities Using the Building Area Method Table G3.8	Expressed in Section 9	Expresses the lighting power density according to building area method
Performance Rating Method Motor Efficiency Requirements Table G3.9.1	N.A.	Defines motors efficiency ratings
Performance Rating Method Baseline Elevator Motor Table G3.9.2	N.A.	Defines typology of motor in function of the number of storey and also mechanical efficiency and counterweight
Performance Rating Method Hydraulic Elevator Motor Efficiency Table G3.9.3	N.A.	Defines motor efficiency
Performance Rating Method Commercial Refrigerator and Freezers Table G3.10.1/Table G3.10.2	N.A.	Defines how to model refrigeration systems

89 90 91 92

[89] ASHRAE 90.1 (2010) (SI): *Standard 90.1-2010 (SI Edition) - Energy Standard for Buildings Except Low-Rise Residential Buildings* (ANSI/ASHRAE/IES). www.ashrae.org/standards

[90] ASHRAE 90.1 (2020) (SI): Standard 90.1-2019 (SI Edition) - *Energy Standard for Buildings Except Low-Rise Residential Buildings (ANSI Approved; IES Co-sponsored)* www.ashrae.org/continuous-maintenance

[91] Delaware Department of natural resources and environmental control (n.d.): *Delaware Energy Code Update-Commercial (ASHRAE 90.1).* https://documents.dnrec.delaware.gov/energy/buildings/Delaware-ASHRAE-90-1-2016-Major-Changes-Commercial-Buildings.pdf

[92] Delaware Department of natural resources and environmental control (n.d.): *Delaware Energy Code Update-Commercial (ASHRAE 90.1).*https://documents.dnrec.delaware.gov/energy/buildings/2016-2019-ASHRAE-90-1-Changes-Commercial.pdf

3. Case study analysis

3.1. Project description

In this paragraph, the case study's presentation on which the thesis is based on, is conducted. Specifically, it must be noticed that the analysed structure, constituted by an already existing building located in Northern Italy and precisely in Turin, has previously undergone major renovation and its main destination of use is represented by office. The building is part of the "International Training Centre of the ILO- International Labour Organization" campus.

The choice to analyse this existing office building, is due to the fact that it has already been recognized with a LEED certification (version 4), when subjected to the major renovation, making the building an example of the effect that the modifications on codes and standards can have on how a defined construction with unvaried features can be scored, awarded and recognized to be oriented to sustainability and efficiency. This study enables to understand and quantify the impact of stricter codes increasingly oriented to low environmental impact, high performances and well-being of occupants as a response to changing and updated global concerns and goals on the real estate.

Focusing on the project's description, the building is one of the pavilions constituting the high education campus, the complex is surrounded by green areas on one side and the river on the other side creating a barrier with rest of the city. Realized in occasion of the Expo 1961 as a celebration of the Italian Unification, the complex was firstly meant to be demolished at the end of the exposition but instead it was restored and reused after an agreement between the Italian government and the International Training Centre of the International Labour Organization (ITCILO) with the aim of providing spaces for education, training activities as meeting rooms, classrooms, laboratories and conference rooms. Nowadays, it even includes spaces for relax and entertainment including fitness rooms, areas for sports and services as post-office, medical centre and laundry. The considered building, composed by two blocks respectively called "Africa 10" and "Africa 11", has undergone a major renovation in the last decade with the scope to restore safety and health conditions still maintaining the original destination of use. In terms of constraints and characteristics of the considered site, the two blocks are identified as building of historical interest located in a plan area with a modest geomorphological risk.[93]

[93] Città di Torino, Geoportale e governo del territorio (n.d.): *"Carta di sintesi della pericolosità geomorfologica e dell'idoneità all'utilizzazione urbanistica" (Allegati tecnici P.R.G.C. Tavola 3 - scala 1 : 5.000),* http://geoportale.comune.torino.it/web/sites/default/files/mediafiles/prg_all3_5000_f17a.pdf (10/02/2026)

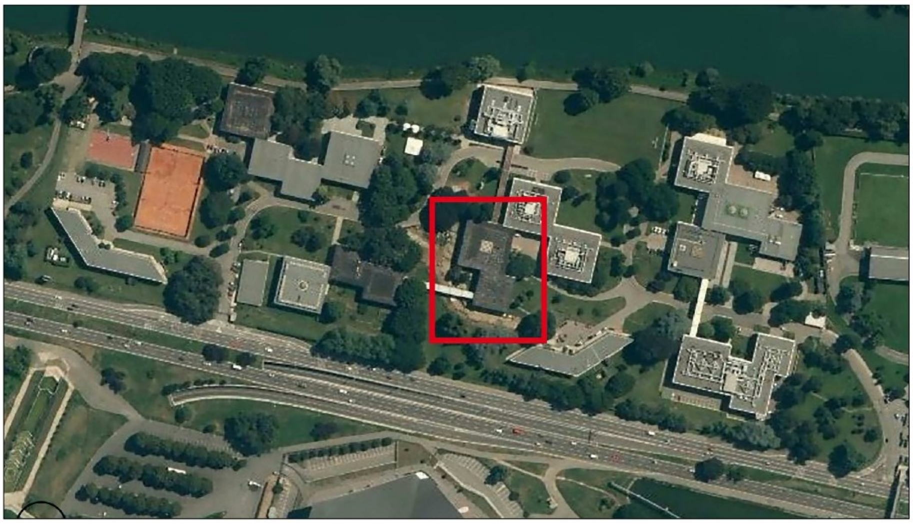


Figure 13- Orthophoto of the area of interest

Analysing the structure in detail, its geometry has been maintained unvaried after the major renovation; specifically, the building is represented by two cubic blocks which are interconnected to each other with an overall gross floor area equal to 2178 m^2 subdivided into two floors and a courtyard in the centre of the right top block as presented on Figure 14.

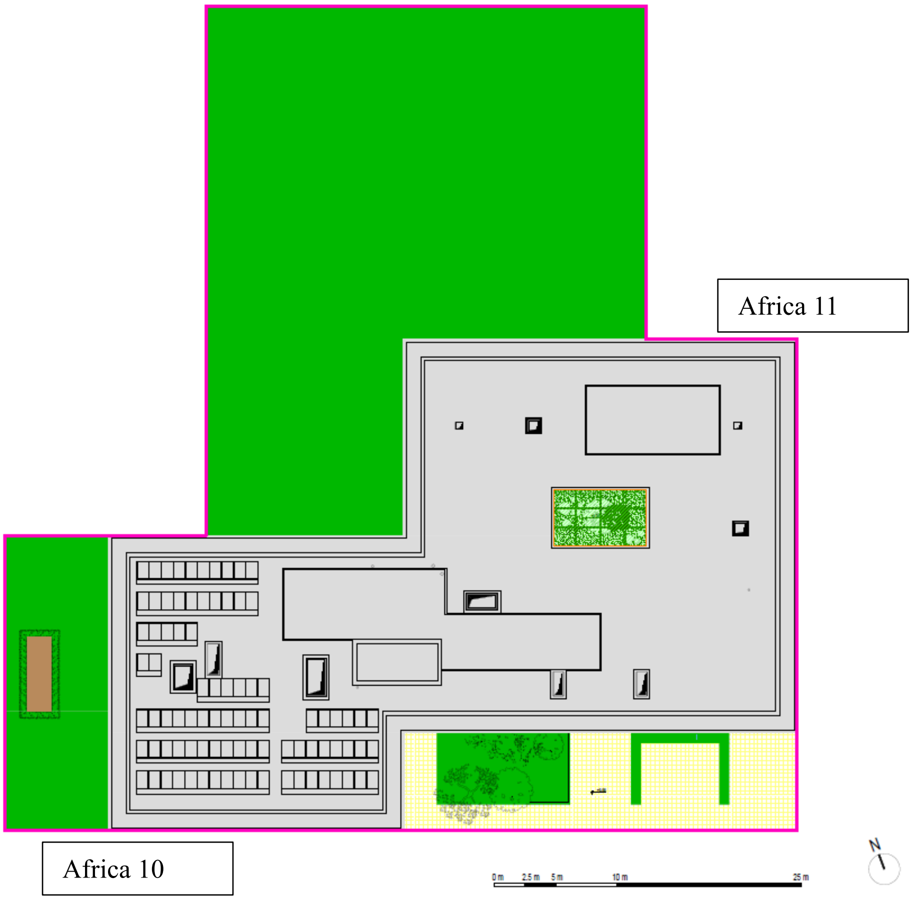


Figure 14- Site plan

Moreover, there is an existing building, close to the one under examination creating shading on it, which, as defined in the following sections, is included in the energy modelling to determine the effect of this shading over the building itself.

With specific focus on the space distribution, at the ground floor several offices, both enclosed and open offices, are located, as well as two meeting rooms which, specifically are enclosed in the North-east block of the building while several service rooms (technical rooms, storage and archives) are located in the South-west block. A similar scheme is reproposed at the first floor where other enclosed and open offices, a meeting room and a large multifunction space are located. Some break areas are distributed along the open common spaces. Specifically, the portion of building, at ground floor, destinated to technical rooms presents a total height of 3,09 m but is reduced to 2,42 m due to the presence of a false ceiling considering the non-permanent presence of people in these spaces while the portion destinated to offices presents a net height of 2,80 m. At the upper floor, the scheme is reproposed for the spaces devoted to offices while higher ceilings of about 5 m are meant for spaces as the innovation lab. Furthermore, at the top floor, a huge percentage of the whole facades' area is provided with vertical overhangs as well as balconies overhanging the below structure and creating shading on it. The block "Africa 10" is located at +0,51 m with respect to "Africa 11" and at +0,53 m with respect to ground level and subsequently the access is guaranteed by a staircase.

Moreover, a PV system constituted by 88 panels with dimensions equal to 1000 x 1560 mm is included on the top of the flat roof with a total peak power equal to 28.8 kWp. A separated simulation of the panels' energy production, considering the inclination of the panels and a reference annual irradiance, led to an overall energy production equal to 36,928 kWh.

3.2. Methods

The building, as mentioned in the previous paragraph, has already been recognized with LEED certification by applying the version 4 of it. Considering it as a starting point, the scope of this analysis is that of evaluating the impact of the updated version of LEED v5, and specifically the effect of the energy and atmosphere category updates. It is now known that for the credits' analysis of the energy and atmosphere category in LEED, the enhanced energy efficiency credit presents as option the whole building energy simulation in compliance with ASHRAE 90.1 standard which represents the energy standard for all buildings excluding low-rise residential buildings. The new version of LEED refers to the updated energy standard ASHRAE 90.1:2019 different from the ASHRAE 90.1:2010 used in the previous energy simulation and whose outcome led to the recognition of the certification to the building under examination.

For this reason, the IESVE software has been employed to proceed to the dynamic energy simulation of the building ensuring the performance analysis at hourly steps. The use of dynamic simulation enables to conduct an analysis representing as much as possible the reality and the actual performances of the building as well as in compliance with what required from the ASHRAE 90.1:2019; indeed, it requires the use of a simulation software able to simulate 8760 hours per year, hourly variations in occupancy, lighting power, set points and HVAC system operation, performances of mechanical equipment at part-load, capacity and efficiency for mechanical heating and mechanical cooling equipment among others.[94]

The procedure required the generation of a proposed building model for which all the features and characteristics of the existing building, as resulting from the major renovation, have been accurately reported; contemporary the generation of the baseline building model is conducted and presented as the "target building" which is compliant with the performances required by

[94] ASHRAE 90.1 (2020) (SI): Standard 90.1-2019 (SI Edition) - Energy Standard for Buildings Except Low-Rise Residential Buildings (ANSI Approved; IES Co-sponsored) www.ashrae.org/continuous-maintenance pag. 299

the standard. The performances of the proposed building are then evaluated as a comparison with this target building generated through the baseline building model.

The first step of the analysis is that of reporting the proposed building "as is" to determine, maintaining all the features unvaried, the performance and efficiency of the building according to the new target represented by the baseline building model which presents same geometrical features, orientation and shape as the proposed but with envelope, HVAC performance and controls as defined by the updated ASHRAE 90.1:2019.

Once the updated performances of the proposed building have been obtained with respect to the baseline building model, it is possible to define the credit's assignment to building itself and clearly identify if it is still well-performing, as recognized with the application of the previous versions of LEED and 90.1, or if it is considered less performing with respect to what new rules and regulations define or, as worst case scenario, if it is no more compliant with standards and subsequently not certifiable. This outcome can clearly give an overview of the how impacting the changes in the standards are and if the archetype of building, with a defined destination of use, is still as performant and valid as in the past.

The output of this analysis enables to determine eventual possible improvement strategies or innovative strategies to be implemented to the proposed model in such a way to reach higher performances guaranteeing alignment with changing goals. This analysis shall be implemented separately for each identified strategy to visualize its impact on the overall performance and only successively the strategies ca be, eventually, combined to see if the contemporary application of them is effective or antagonistic and worth the modification to the proposed model. The procedure described can be visualized and summarized in the below scheme, showing the logical chain of all steps.

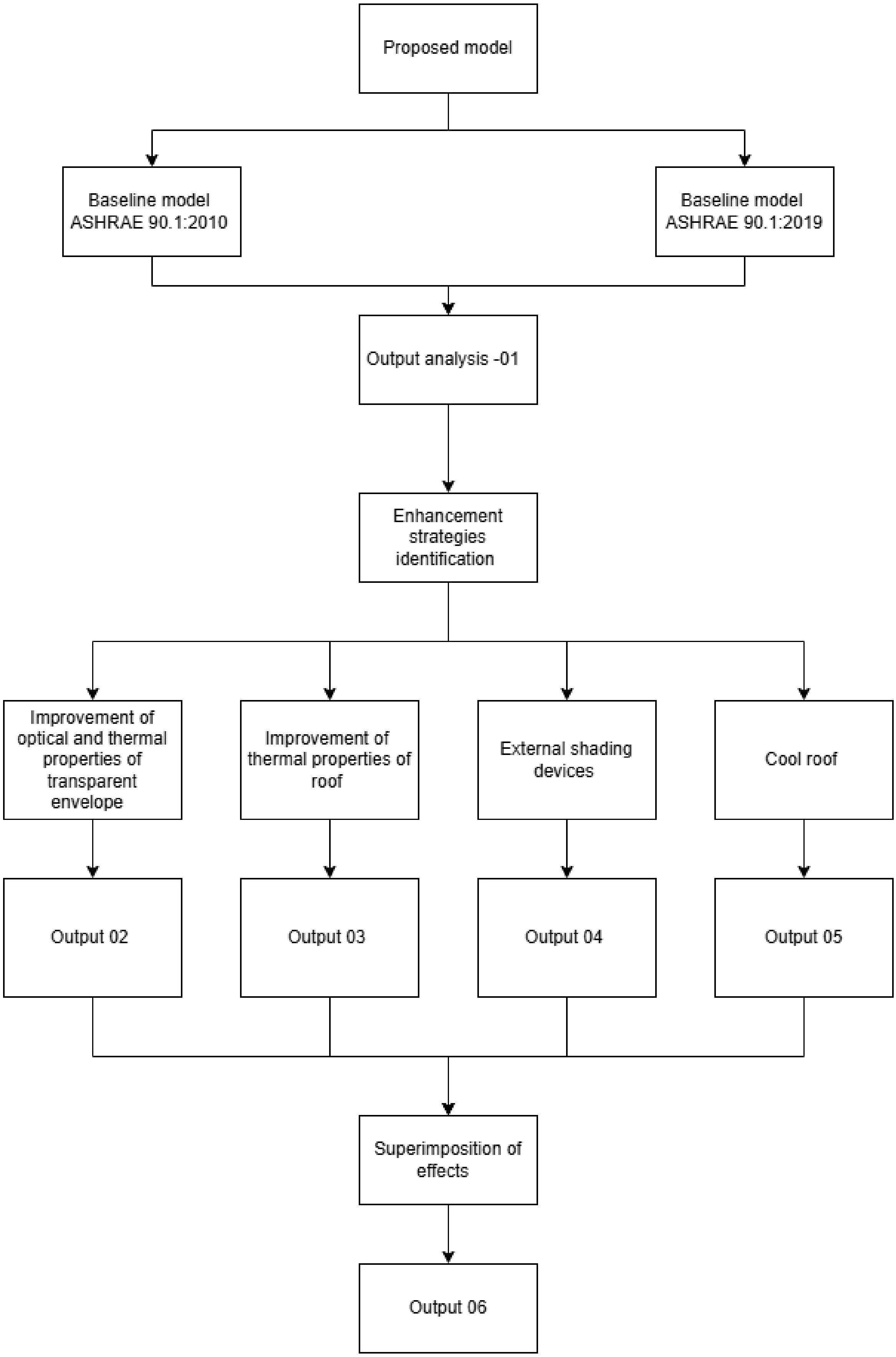


Figure 15- Method of investigation

3.3. Proposed building model

Geometry creation

The energy modeling starts with the realization of the proposed model and specifically by creating the geometry. It can be imported starting from a DXF file or from a gbXML file from Autodesk Revit or it can be directly realized using the available tools in the software. This phase consists in the creation of all spaces with a certain simplification level ensuring the model to still be representative of reality. For the analysed case study, the geometry has been imported from the previous project since it is an already existing building whose energy simulation has been already realized. Each created room has been assigned with a defined ID according to be clearly identified. Any obstruction, vertical and horizontal overhangs, existing adjacent building were modelled, as a simple geometry, to includes the effect of their shading during simulation.

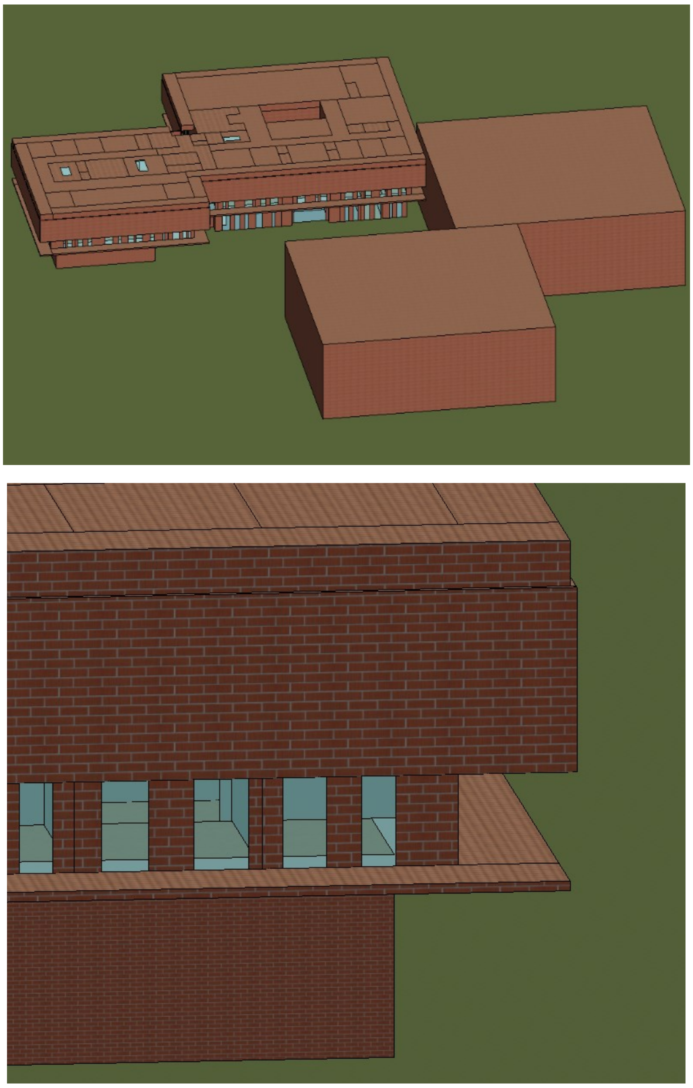


Figure 16- Adjacent building and detail overhangs

Location and climatic data

It is essential to determine and assign a specific climatic and location file according to which the building performance can be derived. It includes specification on altitude, latitude, elevation and wind exposure as regards the location definition, while, with respect to climatic data, information on dry bulb temperature and wet bulb temperature, design outdoor temperature in winter and summer are provided. The site definition is essential to determine even the sun path and the effect of it over the building at each timestep depending on solar azimuth and altitude. Based on this, it is recognized the importance to even model the surrounding buildings creating a solar obstruction over the analysed one and to model any designed overhang to determine how the solar gain is affected thanks to the SunCast simulation which generate solar shading calculations. The site of interest is represented by a flat area where the only obstruction is represented by the neighbour building. The climatic data used is the IWEC data of Turin and the derived climatic zone for the site is 4A.

Thermal properties assignment and space classification

Until the moment of geometry definition, the environments are assigned with default thermal properties defined by the simulation program, for this reason the creation of ad hoc stratigraphy is essential to properly define the rooms. The software is provided with specific sections and tools to model each layer of the stratigraphy inserting the properties of the selected materials based on design or standard regulations. In this project, importing the geometry, all the rooms lost its thermal properties and assigned stratigraphy; however, they were still available in the database of the software. For this reason, the process was simplified but still requiring a certain precision to assign the correct stratigraphy to each element (wall, floor, ceiling etc..) for the whole building. This procedure led to a comprehensive definition of the rooms features.

☐	ID	Category	Description	U value (W/m²·K)	cm (SBEM thermal capacity) (kJ/(m²·K))	Thickness (mm)	Notes etc.	Total R value (m²K/W)
☐	STD_CEIL	Internal Ceiling/Floor	ILO_IB_2013 Internal Ceiling/Floor_noCavity	2.1535	207.0000	180.000		0.2495
☐	STD_FLO1	Ground/Exposed Floor	ILO_GroundContactFloor	0.1099	198.2000	952.310		4.0606
☐	ASHROOF3	Roof	ILO_Roof_nocavity	0.2066	193.6000	340.000		4.7034
☐	ASHFLOO1	Ground/Exposed Floor	ILO_IB_Floor_Concrete Floor with Spray-on Insulation (R-20 Ins.)	0.2476	130.9761	381.000		3.8266
☐	STD_ROOF	Roof	IB_Roof	0.1801	98.7500	317.000		5.4163
☐	ASHWLL1	External Wall	ILO_ExternalWall	0.2127	87.1300	320.000		4.5508
☐	STD_WAL1	External Wall	STandard wall	0.2613	21.9500	208.900		3.6778
☐	STD_PART	Internal Partition	ILO_DefaultPartition	0.5246	17.5000	100.000		1.6667
☐	CEIL	Internal Ceiling/Floor	ILO_Controsoffitto	2.6500	8.7157	26.000		0.1625
☐	ASHROOF1	Roof	ILO_Roof_cavity	0.1888	6.3000	650.000		5.1600
☐	STD_EXTW	External Window	ILO_External Window	1.5372	-	28.000		0.7394
☐	STD_RFLT	Roof Light	ILO_IB_Rooflight	2.3142	-	24.000		0.3170

Figure 17- Stratigraphies and thermal properties

Each room needs then to be assigned with a specific destination of use but, in this case, the standard and the software require a higher level of detail in the space definition with respect to the previous model and applied standard distinguishing some of the space types, as enclosed offices and storage rooms, between elements with areas above or below a certain threshold value. The destination of use for each room has been assigned.

Table 20- Space classification

Space: Corridor- all other corridors
Space: Electrical/Mechanical
Space: Lounge/Breakroom
Space: Office enclosed and ≤ 250 ft^2
Space: Office enclosed and >250 ft^2
Space: Office- Open plan
Space: Restrooms- all others
Space: Stairway
Space: Storage < 50 ft^2
Space: Storage ≥ 50 ft^2
Space: void

Internal loads

Once each room has been identified with a specific space type, default internal loads are assigned to it. It is necessary to modify internal loads as occupancy, internal lighting and equipment according to the design project still in compliance with threshold value defined by standards. The lighting, in the proposed model, presents the following illuminance features:

- 500 lux for spaces as offices and meeting/conference rooms for which a higher visual comfort and illuminance is required
- 300 lux in break areas
- 215 lux for mechanical rooms and storage rooms
- 150 lux in corridors, restrooms and stairways.

Occupancy sensors and daylight controls are provided to modulate artificial lighting depending on the needs. Additionally, lighting is controlled through a "continuous dimming" profile which ramp through specific values with a minimum lighting power of 20% as represented in the figure below related to the dimming profile of lights with 500 lux and reported as an example:

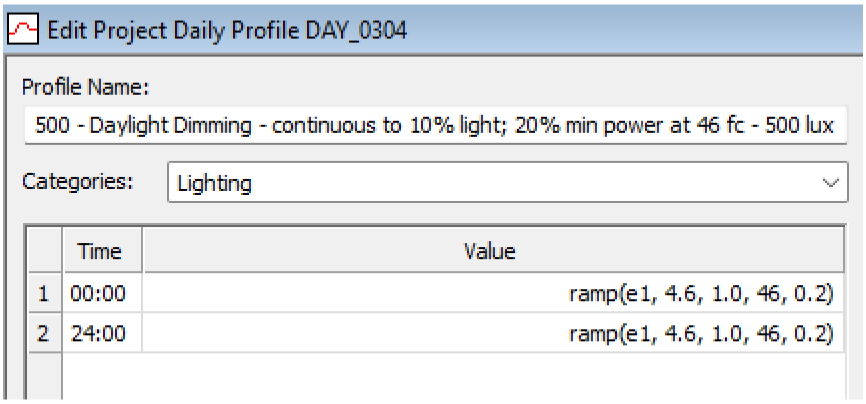


Figure 18- Daylighting dimming profile- formula definition

Moreover, all these systems must be provided with profiles which define the time variation of the input parameters. They can be daily profile, weekly profiles or annual profiles, depending on the time variation to be investigated. Lighting system is indeed provided with a specific profile showing the real functioning of them and corresponds to the standard profile "Lighting - Office".

With respect to external lighting, LED lighting luminaires are meant to be located all over the walkaways around the two floors of the building with a total power of 330 W. Furthermore, it is provided with daylight control.

As regards occupancy the design specifications consider:

- 2 people in enclosed offices
- from 2 to 12 people in open offices
- up to 100 people in the multifunctional room
- from to 2 to 20 people in the breakrooms depending on the area of the specific room

with a maximum occupancy gain of 73.368 W/person.

Even in this case, occupancy profile is required to be modelled. This is essential to determine the entity of the internal gains through the day, to quantify it during weekends and holidays and even to modulate, depending on occupancy, the HVAC functioning profile. The occupancy profile was modelled as follows:

	Weekday	Saturday	Sunday	Holiday
12-1AM	0%	0%	0%	0%
1-2AM	0%	0%	0%	0%
2-3AM	0%	0%	0%	0%
3-4AM	0%	0%	0%	0%
4-5AM	0%	0%	0%	0%
5-6AM	0%	0%	0%	0%
6-7AM	10%	10%	5%	5%
7-8AM	20%	10%	5%	5%
8-9 AM	95%	30%	5%	5%
9-10AM	95%	30%	5%	5%
10-11AM	95%	30%	5%	5%
11AM-12PM	95%	30%	5%	5%
12-1PM	50%	10%	5%	5%
1-2PM	95%	10%	5%	5%
2-3PM	95%	10%	5%	5%
3-4PM	95%	10%	5%	5%
4-5PM	95%	10%	5%	5%
5-6PM	30%	5%	5%	5%
6-7PM	10%	5%	0%	0%
7-8PM	10%	0%	0%	0%
8-9PM	10%	0%	0%	0%
9-10PM	10%	0%	0%	0%
10-11PM	5%	0%	0%	0%
11-12PM	5%	0%	0%	0%

Figure 19- Occupancy profile

Finally, for those rooms provided with computers and appliances, the assigned values, in compliance with 90.1 specifications, were reported as in the original project design and are below reported:

Table 21- Appliances

Conference/meeting/multipurpose	13.20 W/m2
Corridor/transition	7.10 W/m2
Electrical/mechanical	10.20 W/m2
Lounge/recreation	7.90 W/m2
Office - enclosed	11.90 W/m2
Office – open plan	10.50 W/m2
Restrooms	10.50 W/m2
Stairway	7.40 W/m2
Storage	6.80 W/m2
Elevator	5000 W/m2

With respect to the elevators, the previous standard ASHRAE 90.1:2010 required just the definition of peak power which was set equal to 5 kW in the original model, the updated version ASHRAE 90.1:2019, instead, requires definition of factors as: the elevator fan power, elevator fan air flow, elevator lighting power, elevator area, car weight, elevator load and speed as well as the peak load; these specification are derived from the producer's data sheet.

To be thorough and to conclude the analysis of the internal loads, the daily profiles of appliances were set according to the standard "Receptacle-Office" and "Elevator-Office" profiles.

Space Conditions

Proceeding to the definition of the model, it is essential to define which of the modelled spaces should be conditioned. For the analysed case study, storage and mechanical rooms are in free-floating without an active conditioning system leading to a total conditioned area of 1807 m^2, while the unconditioned one is equal to 371 m^2.

The systems setpoints have been set equal to 20°C and 26°C for heating and cooling respectively and with setback temperatures equal to 16°C and 32°C.

The requirements in terms of air exchanges are defined not only by the minimum outdoor air rate according to ASHRAE 62.1 but also by the Italian code UNI 10339:1995 whose requirements are more restrictive. Even air extraction in restrooms is determined according to the UNI 10339:1995 AC rates and infiltrations are modelled considering, for all rooms, 0.1 ACH. Specifically, the required outdoor air supply is provided by three different air handling units:

- one serving the left block at first floor with a total outdoor air supplied equal to 1139 l/s

- one serving ground floor and right block at first floor providing a total outdoor air supply equal to 2578 l/s

- one serving the multipurpose room at first floor with an OA supply equal to 1389 l/s

in the respect of the minimum indoor air quality performance.

HVAC systems

The proposed model, as in the previous project, is realized to accurately reproduce the real design and, specifically, 4 different DOAS-VRF serving the different thermal blocks are used. The systems used come from the available templates of the IESVE software which clearly represents a simplification of the real system but can be a base starting from which the modelling can be modified and properly finished to better represent the reality. Specifically:

- 1 DOAS-VRF system serves the right block first floor
- 1 DOAS-VRF system for the left block first floor
- 1 DOAS-VRF system only serving the multipurpose space located in the right block at the first floor
- 1 DOAS-VRF system for the ground floor

reported with heating and cooling capacities and seasonal efficiencies as defined from the manufacturer's technical sheet. In case of restrooms the system considered is a packaged terminal air conditioner.

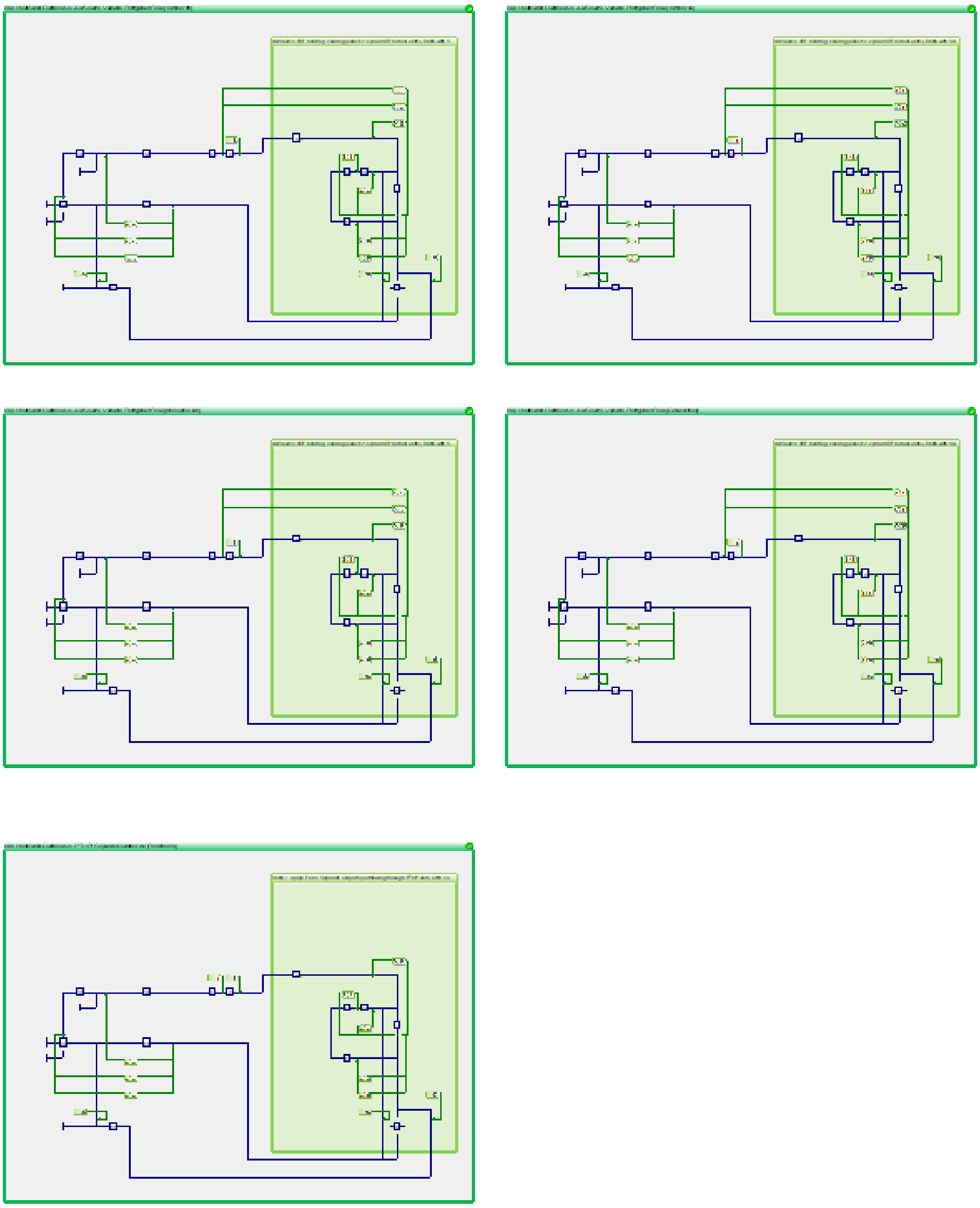


Figure 20- HVAC systems modelling in IESVE for the thermal blocks

Some simplifications are made for the modelling of the systems, indeed, the auto sizing option to withstand the internal loads and needs is used as well as the performances curve for the part-load performances are set as the default performance curves from template. These choices are done to be consistent with the previous project, whose modelling was realized as above mentioned, and to obtain a proposed model equal to the existing one to better understand its performances nowadays with varied performance targets. Moreover, DOAS systems are realized with 70% of sensible heat recovery effectiveness. The systems are scheduled to work from 6:00 to 22:00 during the weekdays and from 6:00 to 18:00 during the weekend with optimal start considering a morning extension hours equal to 1.5 and after hour operation of 0.5.

Service hot water system

The service hot water system has been realized considering the heat source “illustrative ASHP + Electric backup” with an inlet water temperature equal to 15 °C and supply temperature equal to 48°C. Furthermore, the system is provided with a total volume of the storage tank equal to 500 l. The maximum flow of hot water was recognized to be equal to 67 l/h and derived from the calculation of the daily hot water demand based on national regulations.[95]

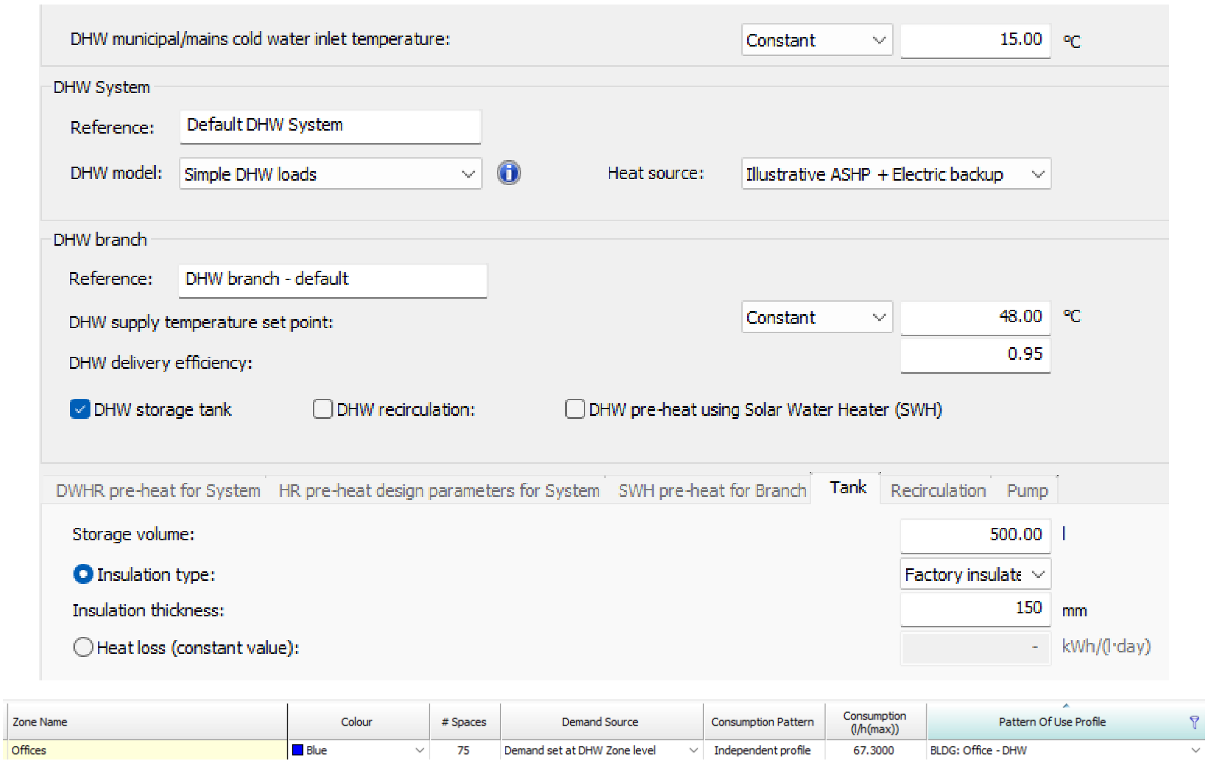
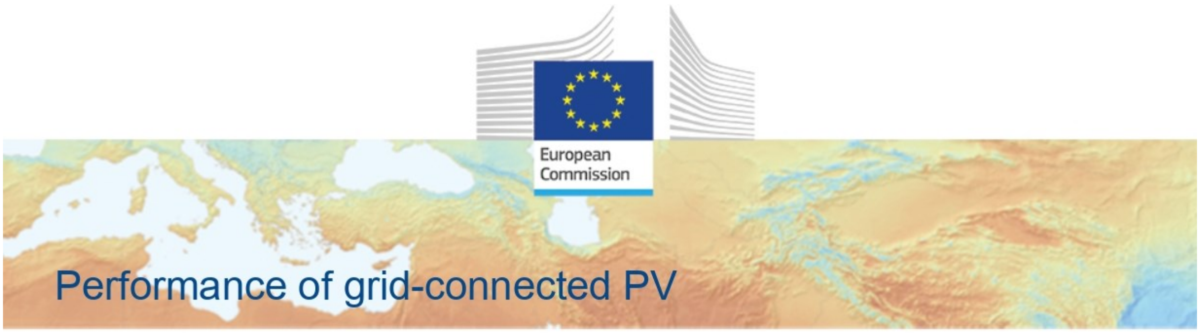


Figure 21- SHW system

Photovoltaic system

As previously anticipated, the building is provided with PV system which has not been included into the energy modelling software “IESve” but has been separately evaluated and considered and whose outcomes are below reported:

[95] UNI (February 2nd, 2019): *UNI/TS 11300-2:2019 Prestazioni energetiche degli edifici - Parte 2: Determinazione del fabbisogno di energia primaria e dei rendimenti per la climatizzazione invernale, per la produzione di acqua calda sanitaria, per la ventilazione e per l'illuminazione in edifici non residenziali*



PVGIS-5 estimates of solar electricity generation:

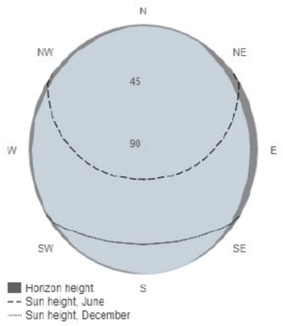
Provided inputs:

Latitude/Longitude:	45.023,7.672
Horizon:	Calculated
Database used:	PVGIS-SARAH2
PV technology:	Crystalline silicon
PV installed:	28.78 kWp
System loss:	14 %

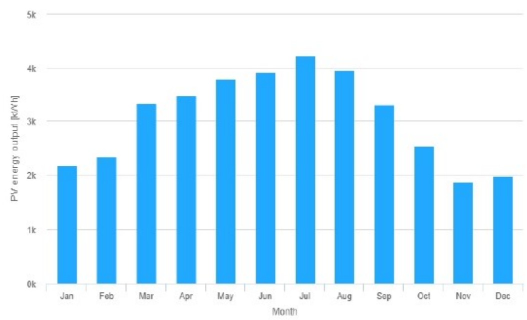
Simulation outputs

Slope angle:	30 °
Azimuth angle:	10 °
Yearly PV energy production:	36927.63 kWh
Yearly in-plane irradiation:	1757.89 kWh/m²
Year-to-year variability:	1461.97 kWh
Changes in output due to:	
Angle of incidence:	-2.69 %
Spectral effects:	0.95 %
Temperature and low irradiance:	-13.61 %
Total loss:	-27.01 %

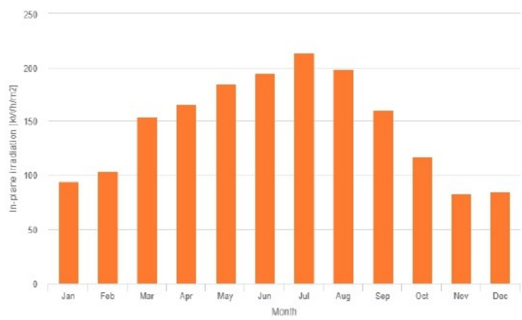
Outline of horizon at chosen location:



Monthly energy output from fix-angle PV system:



Monthly in-plane irradiation for fixed-angle:



Monthly PV energy and solar irradiation

Month	E_m	H(i)_m	SD_m
January	2184.9	94.2	445.2
February	2330.8	103.7	483.7
March	3339.8	154.2	423.0
April	3477.8	166.2	424.5
May	3806.5	185.4	324.2
June	3917.9	195.4	259.1
July	4228.9	214.4	203.4
August	3956.9	198.9	182.8
September	3299.7	160.6	227.3
October	2535.7	116.5	365.6
November	1876.1	83.5	406.0
December	1972.8	84.9	316.3

E_m: Average monthly electricity production from the defined system [kWh].
H(i)_m: Average monthly sum of global irradiation per square meter received by the modules of the given system [kWh/m²].
SD_m: Standard deviation of the monthly electricity production due to year-to-year variation [kWh].

Figure 22- Photovoltaic system performance

3.4. Baseline model definition according to ASHRAE 90.1:2010

As previously anticipated, the baseline building model is a target building realized, in accordance with Appendix G of ASHRAE 90.1:2010 whose main purpose is the performance evaluation for those buildings that exceed the standard requirements.

Design Model and Space Classification

Following the procedure defined in the Appendix G, the baseline model is realized with the same portions, geometry, orientation, openings and space classification as the real one adapting its features and performances to those defined by the standard.

Building envelope

Starting from the building envelope the thermal properties of each element of the baseline model, both opaque and transparent, are assigned according to limit values imposed by the ASHRAE 90.1:2010 according to table 5.5-4 for the climatic zone of the specified site.[96] The difference between the proposed model and the baseline model is summarized in the table below:

Table 1.4 - Proposed vs Baseline Const.

Model Input parameter Construction	Proposed		Baseline	
	Description	Input U value / % (area weighted)	Description	Input U value / % (area weighted)
Exterior wall construction	ILO_ExternalWall	0.21	CZ4 Ext Wall (Non-Res) - Steel Framed; R-13.0 + 7.5 c.i; U=0.064 (0.363)	0.36
Roof construction	ILO_Roof_cavity	0.19	CZ4 Roof (Non-Res) - Ins Above Deck; R-20; U=0.048 (0.273)	0.27
Roof construction	ILO_Roof_nocavity	0.21		
Floor/slab construction	ILO_GroundContactFloor	0.11	CZ4 Floor (Non-Res) - Steel Joist; R-30.0; U=0.038 (0.218)	0.22
Floor/slab construction	ILO_IB_Floor_Concrete Floor with Spray-on Insulation (R-20 Ins.)	0.25		
Window to gross wall ratio	Overall	23%	Overall	24%
Window to gross wall ratio	North / South / East / West	24 / 26 / 23 / 19%	North / South / East / West	25 / 27 / 24 / 20%
Fenestration U-Value (North)	ILO_External Window	1.54	CZ4 Window (Non-Res) - Metal framing (all other) U=0.55(3.12); SHGC=0.40	3.12
Fenestration U-Value (non - North)	ILO_External Window	1.54	CZ4 Window (Non-Res) - Metal framing (all other) U=0.55(3.12); SHGC=0.40	3.12
Fenestration SHGC - North	ILO_External Window	0.39	CZ4 Window (Non-Res) - Metal framing (all other) U=0.55(3.12); SHGC=0.40	0.40
Fenestration SHGC - non - North	ILO_External Window	0.39	CZ4 Window (Non-Res) - Metal framing (all other) U=0.55(3.12); SHGC=0.40	0.40
Fenestration visual light transmittance (N)	ILO_External Window	0.66	CZ4 Window (Non-Res) - Metal framing (all other) U=0.55(3.12); SHGC=0.40	0.76
Fenestration visual light transmittance	ILO_External Window	0.66	CZ4 Window (Non-Res) - Metal framing (all other) U=0.55(3.12); SHGC=0.40	0.76
Shading devices				

Figure 23- Variation in the building envelope features between proposed model and baseline one

[96] ASHRAE 90.1 (2010) (SI): Standard 90.1-2010 (SI Edition) - *Energy Standard for Buildings Except Low-Rise Residential Buildings (ANSI/ASHRAE/IES).* www.ashrae.org/standards pag. 29

Schedules

With reference to schedules, they are all maintained unvaried with respect to the proposed model made exception for the lighting control according to which the baseline model should be equipped with the following lighting controls:

- automatic shutoff: can be controlled on a scheduled basis control that turns the lights off at a programmed hour or by employing occupant sensors to turn the light off after 30 minutes from when the room was left unoccupied or even by a signal from another control. The automatic shutoff is regulated by Section 9.4.1.1[97]
- automatic daylighting controls for primary sidelighted areas: it is provided for those spaces where the combined primary sidelighted area is equal or greater than 23 m^2. Here, one multilevel photocontrol should be provided reducing lighting, in response to daylight variation, with a first step control set at 60% of the maximum power and the other step control equal to 35% of the maximum power in compliance with Section 9.4.1.4 [98]
- automatic daylighting controls for toplighting: provided where the total daylight area under skylights is 84 m^2 or higher. Here, these spaces are provided a multilevel control according to which lighting should be reduced, depending on daylight variation, with a first control step set to 60% of the design power and another step control equal to 35% of design power in compliance with Section 9.4.1.5[99]

Lighting

Still analysing lighting system, the power density in the baseline building design is determined considering the space-by-space method with values coming from table 9.6.1[100] and below reported:

Table 22- LPD for Baseline model

Space Type	LPD Baseline W/m^2
Conference/Meeting/Multipurpose	13.20
Corridor/Transition	7.10
Electrical/Mechanical	10.20

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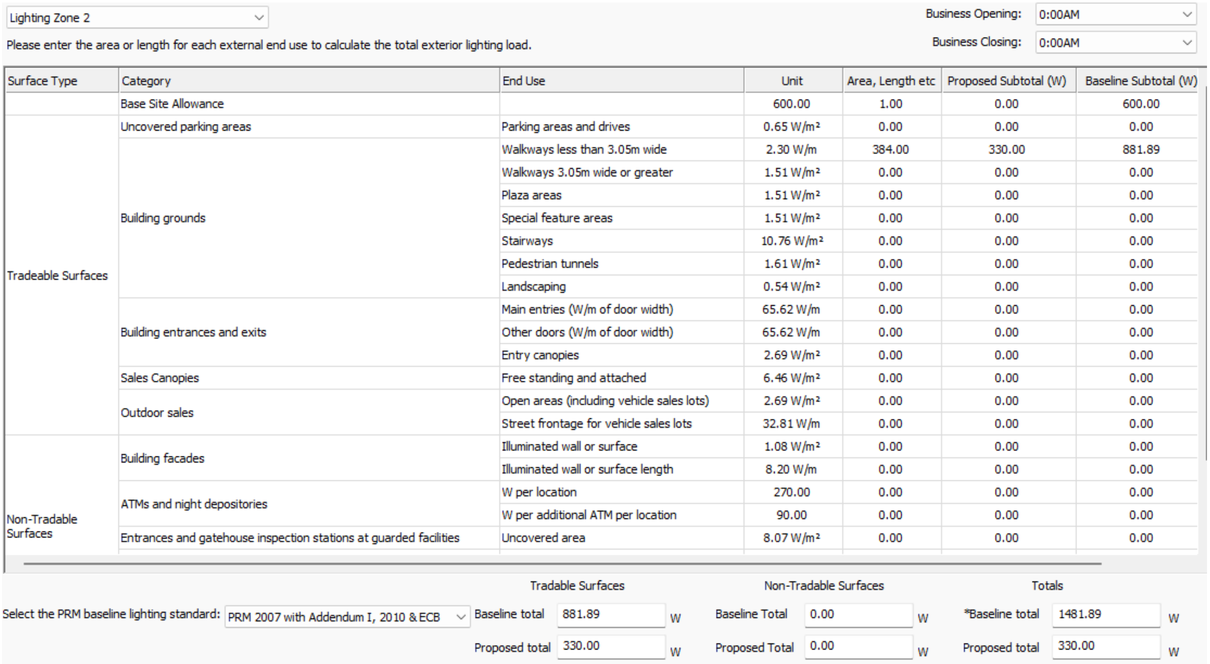
[97] ASHRAE 90.1 (2010) (SI): Standard 90.1-2010 (SI Edition) - *Energy Standard for Buildings Except Low-Rise Residential Buildings (ANSI/ASHRAE/IES).* www.ashrae.org/standards. pag. 76
[98] ASHRAE 90.1 (2010) (SI): Standard 90.1-2010 (SI Edition) - *Energy Standard for Buildings Except Low-Rise Residential Buildings (ANSI/ASHRAE/IES).* www.ashrae.org/standards. pag. 77
[99] ASHRAE 90.1 (2010) (SI): Standard 90.1-2010 (SI Edition) - *Energy Standard for Buildings Except Low-Rise Residential Buildings (ANSI/ASHRAE/IES).* www.ashrae.org/standards. pag. 77
[100] ASHRAE 90.1 (2010) (SI): Standard 90.1-2010 (SI Edition) - *Energy Standard for Buildings Except Low-Rise Residential Buildings (ANSI/ASHRAE/IES).* www.ashrae.org/standards. pag. 83

Lounge/Recreation	7.80
Office- Enclosed	11.90
Office- Open plan	10.50
Stairway	7.40
Storage	6.80

With respect to the exterior lighting, the baseline model, differently from the proposed one, is realized following the specification of Section 9.4.3. for a lighting zone 2[101]. The main differences between the proposed and baseline exterior lighting modelling are highlighted below:



Lighting Zone 2

Please enter the area or length for each external end use to calculate the total exterior lighting load.

Business Opening: 0:00AM

Business Closing: 0:00AM

Surface Type	Category	End Use	Unit	Area, Length etc	Proposed Subtotal (W)	Baseline Subtotal (W)
	Base Site Allowance		600.00	1.00	0.00	600.00
Tradeable Surfaces	Uncovered parking areas	Parking areas and drives	0.65 W/m²	0.00	0.00	0.00
	Building grounds	Walkways less than 3.05m wide	2.30 W/m	384.00	330.00	881.89
		Walkways 3.05m wide or greater	1.51 W/m²	0.00	0.00	0.00
		Plaza areas	1.51 W/m²	0.00	0.00	0.00
		Special feature areas	1.51 W/m²	0.00	0.00	0.00
		Stairways	10.76 W/m²	0.00	0.00	0.00
		Pedestrian tunnels	1.61 W/m²	0.00	0.00	0.00
		Landscaping	0.54 W/m²	0.00	0.00	0.00
	Building entrances and exits	Main entries (W/m of door width)	65.62 W/m	0.00	0.00	0.00
		Other doors (W/m of door width)	65.62 W/m	0.00	0.00	0.00
		Entry canopies	2.69 W/m²	0.00	0.00	0.00
	Sales Canopies	Free standing and attached	6.46 W/m²	0.00	0.00	0.00
	Outdoor sales	Open areas (including vehicle sales lots)	2.69 W/m²	0.00	0.00	0.00
		Street frontage for vehicle sales lots	32.81 W/m	0.00	0.00	0.00
Non-Tradable Surfaces	Building facades	Illuminated wall or surface	1.08 W/m²	0.00	0.00	0.00
		Illuminated wall or surface length	8.20 W/m	0.00	0.00	0.00
	ATMs and night depositories	W per location	270.00	0.00	0.00	0.00
		W per additional ATM per location	90.00	0.00	0.00	0.00
	Entrances and gatehouse inspection stations at guarded facilities	Uncovered area	8.07 W/m²	0.00	0.00	0.00

Select the PRM baseline lighting standard: PRM 2007 with Addendum I, 2010 & ECB

	Tradable Surfaces	Non-Tradable Surfaces	Totals
Baseline total	881.89 W	0.00 W	*Baseline total 1481.89 W
Proposed total	330.00 W	0.00 W	330.00 W

Figure 24- Exterior lighting

Appliances

Appliances and elevators are required to be modelled identical to proposed building model including, as above mentioned, the schedules "Receptacle-Office" and "Elevator-Office" defined according the ASHRAE 90.1.

Service hot-water systems

Furthermore, the Appendix G defines, for the service hot-water systems, that the baseline model should be realized with capacities and efficiencies reflecting reality and that whenever the

[101] See tables 9.4.3A and 9.4.3B in Section 9 of ASHRAE 90.1 (2010) (SI): Standard 90.1-2010 (SI Edition) - *Energy Standard for Buildings Except Low-Rise Residential Buildings (ANSI/ASHRAE/IES)*. www.ashrae.org/standards.

energy source is electricity, the system should be modelled as electric resistance in the baseline model. For this reason, the heating system is the electric resistance, as above defined, while the remaining parameters are unmodified with respect to the proposed model.

HVAC and Air exchanges

A substantial difference between the proposed model and the baseline one is represented by the HVAC system's definition. In fact, based on the table G3.1.1A[102], the baseline system has been determined according to building type, conditioned floor area and numbers of floor and finally identified as equal to system 4 PSZ-HP which is a packaged single zone direct expansion cooling heat pump system modelled in auto sizing and where the heating equipment capacity considers an oversizing of 25% and an oversizing of 15% for the cooling capacity. Moreover, as indicated in Appendix G, the energy recovery system has been modelled following the prescriptions of Section 6.5.6.1[103] which specifically requires an energy recovery effectiveness equal to 50%.

With respect to air exchanges and differently from what presented in the proposed model, the baseline ventilation rate was set to the minimum required and infiltration was maintained unvaried.

3.5. Baseline model definition according to ASHRAE 90.1:2019

Even though the modelling of the proposed building is maintained unvaried with respect to the version of ASHRAE 90.1:2010, the baseline building model follows the rules of the Appendix G of ASHRAE 90.1:2019 used as an alternative path for the evaluation of building performance.

Design Model and Space Classification

Even in this case, the geometry, number of floors, gross conditioned floor area and space classification are the same as those defined for the proposed building.

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[102] As defined by modelling requirements of Table G3.1 the baseline system should be individuated through table G3.1.1. ASHRAE 90.1 (2010) (SI): Standard 90.1-2010 (SI Edition) - *Energy Standard for Buildings Except Low-Rise Residential Buildings (ANSI/ASHRAE/IES).* www.ashrae.org/standards. pag. 218

[103] ASHRAE 90.1 (2010) (SI): Standard 90.1-2010 (SI Edition) - *Energy Standard for Buildings Except Low-Rise Residential Buildings (ANSI/ASHRAE/IES).* www.ashrae.org/standards.pag. 52

Building envelope

With respect to the building envelope, even in the ASHRAE 90.1:2019 the thermal properties of transparent and opaque elements of baseline building model are assigned according to limit values imposed by the standard for the defined climatic zone according to Table G3.4-4 and, equally, the optical properties of the transparent elements are taken from the same table.

The difference between the proposed model and the baseline model is summarized in the table below:

Table 1.4 - Proposed vs Baseline Const.

Model Input parameter Construction	Proposed		Baseline	
	Description	Input U value / % (area weighted)	Description	Input U value / % (area weighted)
Exterior wall construction	ILO_ExternalWall	0.21	PRM CZ4 Ext Wall (Non-Res) - Steel Framed; R-13.0 (2.3); U=0.124 (0.705)	0.71
Roof construction	ILO_Roof_cavity	0.19	PRM CZ4 Roof (Non-Res & Res) - Ins Above Deck; R-15 (2.6); U=0.063 (0.360)	0.36
Roof construction	ILO_Roof_nocavity	0.21		
Floor/slab construction	ILO_GroundContactFloor	0.11	PRM CZ4 (NonRes) Steel Joist Floor with Spray-on Insulation (R-8 Ins. + R-9.0 Cont. Ins.); U=0.052	0.29
Floor/slab construction	ILO_IB_Floor_Concrete Floor with Spray-on Insulation (R-20 Ins.)	0.25	Prototype ID: AGSOG114 (Ground contact floor: Calculation Method=F-Factor; f=0.45)	0.20
Floor/slab construction			Prototype ID: APGFLO18 (Ground contact floor: Calculation Method=F-Factor; f=0.45)	0.29
Window to gross wall ratio	Overall	24%	Overall	24%
Window to gross wall ratio	North / South / East / West	25 / 27 / 24 / 20%	North / South / East / West	25 / 27 / 24 / 20%
Fenestration U-Value (North)	ILO_External Window	1.54	PRM CZ4 Window 0-40% (Non-Res); U=0.57; SHGC=0.39; VT=0.43	3.24
Fenestration U-Value (non - North)	ILO_External Window	1.54	PRM CZ4 Window 0-40% (Non-Res); U=0.57; SHGC=0.39; VT=0.43	3.24
Fenestration SHGC - North	ILO_External Window	0.39	PRM CZ4 Window 0-40% (Non-Res); U=0.57; SHGC=0.39; VT=0.43	0.39
Fenestration SHGC - non - North	ILO_External Window	0.39	PRM CZ4 Window 0-40% (Non-Res); U=0.57; SHGC=0.39; VT=0.43	0.39
Fenestration visual light transmittance (N)	ILO_External Window	0.66	PRM CZ4 Window 0-40% (Non-Res); U=0.57; SHGC=0.39; VT=0.43	0.43
Fenestration visual light transmittance	ILO_External Window	0.66	PRM CZ4 Window 0-40% (Non-Res); U=0.57; SHGC=0.39; VT=0.43	0.43
Shading devices				

Figure 25- Proposed and baseline building envelope's variation

Schedules

As regards schedules, they are maintained unmodified in the baseline building model like happened for the ASHRAE 90.1:2010.

Lighting

The interior lighting power for the baseline building design is determined using the threshold values imposed in Table G3.7.[104] Additionally, the lighting system should be provided with automatic shutoff controls for buildings whose area overcomes 500 m^2 and should be modelled considering occupancy sensors in break rooms, conference/meeting rooms while other automatic controls should not be included.

Table 23- Baseline model LPD

Space Type	LPD Baseline W/m^2
Conference/Meeting/Multipurpose	13.99
Corridor/Transition	5.38
Electrical/Mechanical	16.15
Lounge/Recreation	12.92
Office- Enclosed ≤ 250 ft^2	11.84
Office- Enclosed > 250 ft^2	11.84
Office- Open plan	11.84
Stairway	6.46
Storage ≥ 50 ft^2	8.61

The exterior lighting, instead, are distinguished between tradable surfaces and all the other types. Specifically, the tradable surfaces are modelled following the LPD defined in table G3.6[105] while all the others are maintained unvaried with respect to the proposed model.

[104] ASHRAE 90.1 (2020) (SI): *Standard 90.1-2019 (SI Edition) - Energy Standard for Buildings Except Low-Rise Residential Buildings (ANSI Approved; IES Co-sponsored)* www.ashrae.org/continuous-maintenance pag. 333
ASHRAE 90.1 (2020) (SI): *Standard 90.1-2019 (SI Edition) - Energy Standard for Buildings Except Low-Rise Residential Buildings (ANSI Approved; IES Co-sponsored)* www.ashrae.org/continuous-maintenance pag. 332

Lighting Zone 2

Please enter the area or length for each external end use to calculate the total exterior lighting load.

Business Opening: 0:00AM

Business Closing: 0:00AM

Surface Type	Category	End Use	Section 9 Unit	Area, Length etc	Proposed Subtotal (W)	Baseline Subtotal (W)
	Base Site Allowance		400.00	1.00	0.00	400.00
Tradeable Surfaces	Uncovered parking areas	Parking areas and drives	0.43 W/m²	0.00	0.00	0.00
	Building grounds	Walkways less than 3.05m wide	1.64 W/m	384.00	330.00	1259.84
		Walkways 3.05m wide or greater	1.08 W/m²	0.00	0.00	0.00
		Plaza areas	1.08 W/m²	0.00	0.00	0.00
		Special feature areas	1.08 W/m²	0.00	0.00	0.00
		Dining areas	7.00 W/m²	0.00	0.00	0.00
		Stairways	7.53 W/m²	0.00	0.00	0.00
		Pedestrian tunnels	1.29 W/m²	0.00	0.00	0.00
		Landscaping	0.43 W/m²	0.00	0.00	0.00
	Building Entrances, Exits and Loading Docks	Pedestrian and vehicular entrances and exits	45.93 W/m	0.00	0.00	0.00
		Entry canopies	2.69 W/m²	0.00	0.00	0.00
		Loading docks	3.77 W/m²	0.00	0.00	0.00
	Sales Canopies	Free standing and attached	4.31 W/m²	0.00	0.00	0.00
	Outdoor sales	Open areas (including vehicle sales lots)	2.15 W/m²	0.00	0.00	0.00
		Street frontage for vehicle sales lots	22.97 W/m	0.00	0.00	0.00
	Building facades	Illuminated wall or surface	1.08 W/m²	0.00	0.00	0.00
		Illuminated wall or surface length	8.20 W/m	0.00	0.00	0.00
	ATMs and night depositories	W per location	135.00	0.00	0.00	0.00

Select the PRM interior space type: No Space Type required

Select the PRM baseline lighting standard: 90.1 2019 Section 9 and App G

	Tradable Surfaces	Non-Tradable Surfaces	Totals
Baseline	Baseline total 1259.84 W	Baseline Total 0.00 W	*Baseline total 1659.84 W
Proposed	Proposed total 330.00 W	Proposed Total 0.00 W	Proposed total 330.00 W

Baseline values have been taken from table G3.6 where appropriate

Figure 26- Baseline exterior lighting according to ASHRAE 90.1:2019

Receptacles and elevators

Receptacles should be modelled to be equal to the proposed model as well as their schedules. Focusing, instead, on the elevators, they should be modelled with a peak power calculated as:

kW = (weight of car + rated load – counterweight) × speed of car × 0.00981/hmechanical

Pm = kW/hmotor

where: the weight of the car, the rated load and the speed of the car are those of the proposed model, while the counterweight of the car is taken from table G3.9.2 as well as the mechanical efficiency and the motor efficiency.

With respect to its scheduling, it should be maintained as in the proposed design.

Service water heating system

The service water heating system for the baseline model must be selected from table G3.1.1-2[106] depending on the building type and for the specified case study is the electrical resistance storage water heater. It should present entering-water-temperature in function of the considered site and leaving-water-temperature in function of the final end-use and, for this reason, are set equal to those defined in the proposed model. Even the service water heating load is modelled

[106] ASHRAE 90.1 (2020) (SI): *Standard 90.1-2019 (SI Edition) - Energy Standard for Buildings Except Low-Rise Residential Buildings (ANSI Approved; IES Co-sponsored)* www.ashrae.org/continuous-maintenance pag. 319

equally to the proposed model in respect of section 7.4.1[107] which requires to calculate the service water heating load according to accepted standards.

HVAC systems

The major and recognizable variation in the baseline building model's definition is related to the HVAC system, indeed, its selection depends on the building type, number of floors and conditioned area and it is even determined as function of the climatic zone as defined in Table G3.1.1-3 and as describe in Table G3.1.1-4.[108] For the selected case study, the corresponding baseline HVAC system is the System 3- PSZ- AC which is a packaged rooftop air conditioner with a constant volume control fan, direct expansion cooling type and fossil fuel heating type. The system has been modelled in auto sizing considering a heating equipment capacity's oversizing of 25% and an oversizing of 15% for the cooling capacity. Moreover, as indicated in Appendix G, the energy recovery system has been modelled following the requirements of Section G3.1.2.10[109] which specifically requires an energy recovery effectiveness equal to 50%.

As for baseline model of ASHRAE 90.1:2010, the baseline ventilation rate is different from what presented in the proposed model and set to the minimum required, with respect to infiltrations they are unmodified with respect to the proposed model.

3.6. Comparison between baseline models

The variations between baseline models and Appendix G with Performance Rating Method need to be investigated starting from the standard evolution. Indeed, up to 2016 the Appendix G was not used as an alternative compliance path to the standard, but it was only used as an investigation method to determine the performance of the building with respect to rating system, for instance, as LEED certification. Since 2016, Appendix G has been adopted as alternative path to demonstrate compliance with the 90.1 Standard. In this optic, the baseline design, from that moment on, has been maintained fixed and stable to the performance levels required in 90.1:2004 with the perspective to still maintain it unmodified towards future modification. By doing so, the evaluation of building's performance is conducted considering the Performance Cost Index which can assume a value between 0 and 1 where the two extremes respectively

[107] ASHRAE 90.1 (2020) (SI): *Standard 90.1-2019 (SI Edition) - Energy Standard for Buildings Except Low-Rise Residential Buildings (ANSI Approved; IES Co-sponsored)* www.ashrae.org/continuous-maintenance pag. 152
[108] ASHRAE 90.1 (2020) (SI): *Standard 90.1-2019 (SI Edition) - Energy Standard for Buildings Except Low-Rise Residential Buildings (ANSI Approved; IES Co-sponsored)* www.ashrae.org/continuous-maintenance pag. 320
[109] ASHRAE 90.1 (2020) (SI): *Standard 90.1-2019 (SI Edition) - Energy Standard for Buildings Except Low-Rise Residential Buildings (ANSI Approved; IES Co-sponsored)* www.ashrae.org/continuous-maintenance pag. 315

represent a building close to the net zero energy cost building and the other represent a performance close to that defined in 2004.[110]

This enables to understand the variations between the two baseline models and the reintroduction of the gas as heating source even when the proposed model is represented by an electric source. With this new version the correspondence between proposed model and baseline one falls, highlighting that the PRM follows the standard requirements more than a variation of the proposed building and, as remarked, since the evaluation method is based on energy cost or future energy source, the conversion factor underlines that it is not just sufficient to have an electric system to provide a performant building making the code more rigorous and stricter. Whenever the building is a small structure, the selected system is a simple one, or, if the considered construction is an imponent building, the selected system is usually a multiple-zone one. Moreover, depending on climatic zone, the predominant demand for heating or cooling can be easily derived and can easily direct the choice. By this overview it is clear that the system selection follows specific rules making this procedure and the baseline modelling deterministic and stable and based on clarity and uniformity.

[110] ASHRAE Journal (December, 2016): *A Conversation on Standard 90.1-2016*. www.ashrae.org. pag. 36

4. Results and comparative analysis

The following chapter is devoted to the analysis of the output resulting from the two energy modelling with ASHRAE 90.1:2010 and ASHRAE 90.1:2019 of the same proposed building which was defined and outlined previously in this thesis. The main purpose of this section is to determine the effect of normative modifications towards the investigation of the main differences in the final energy uses, the reasons for their variations and the final energy performance recognized to the building in the LEED certification process.

The output of the two energy modelling are obtained through a in-depth simulation starting from the shading calculations according to the considered site and obstruction and from the evaluation of the room loads as needs of the building itself, to the assessment of the system load leading to the definition of sizing runs and efficiency associated with their performance curves and finally to the daylight simulation with lighting control and the overall energy simulation.

The IESVE software is, moreover, equipped with another tool represented by the final Building Performance Rating Method report (BPMR report), at the end of the simulation process, which provides a summary of the modelling results. This report is organized to present the general modelled features as the conditioned area, the location and climate zone, the overview of building envelope thermal properties both in baseline and proposed building. Anyway, the most effective result reported in it is the accurate evaluation, in tabular way, of the final energy uses of the proposed and baseline model and the % of saving for each of them. The comparison between the two BPRM reports, related to the models realized following the ASHRAE 90.1:2010 and ASHRAE 90.1:2019 standards ,enables to clearly identify the energy uses for which the percentage of saving is higher and the delta between the percentage of saving for the same energy use in the two reports.

Specifically, the table resulting from the modelling through the implementation of the ASHRAE 90.1:2010 is organized through a whole list of energy uses while the table coming from the application of ASHRAE 90.1:2019 is subdivided into “regulated energy uses” and “unregulated energy uses”. With respect to the terminology, the regulated energy uses are, in detail, part of the mandatory provisions of the ASHRAE standard including final energy uses as heating, cooling, lighting, fans, pumps to just mention some of them. As regards the unregulated energy uses are those excluded by the compliance with the standard as for instance process loads.[111] The assessment considers the annual energy consumption expressed in kWh/year for each

[111] Based on the ASHRAE definitions.

considered category and moreover distinguishes between the energy sources defining whether the specific end use presents electricity or gas as main vector.

4.1. Energy performance and GHG emissions of the proposed model in LEED

Entering in the detail of the analysis, the proposed model presents the same characteristics between the two energy simulations perfectly reporting the design choices explained in the previous chapter. Equally, the two baseline models differ between each other due to the different standard requirements and modelling rules defined in the Appendix G of the ASHRAE 90.1 versions. The conducted evaluation starts with the identification of absolute indicators as the final annual energy consumption and comparative indicators as the percentage of variation and impact over the whole performance of single energy uses.

Starting from the overall performance of the building and from the absolute comparison, the total annual energy uses for both proposed and baseline buildings in the two energy models are below reported distinguishing the comparison without considering the on-site energy production and the comparison including the renewable energy production:

Table 24- Total annual energy use according to ASHRAE 90.1:2010 and ASHRAE 90.1:2019 without and with renewable energy production

ASHRAE 90.1:2010	Proposed design energy	Baseline design energy	Percentage of saving
Total annual energy use kWh/year without renewable energy production	261,019.27	332,543.46	21.5%
Renewable energy production	36,927.63	/	/
Total annual energy use kWh/year with renewable energy production	224,091.64	332,543.46	32.6 %
ASHRAE 90.1:2019	**Proposed design energy**	**Baseline design energy**	**Percentage of saving**
Total annual energy use kWh/year without renewable energy production	261,019.27	553,748.1	52.9%
Renewable energy production	36,927.63	/	/

Total annual energy use kWh/year with renewable energy production	224,091.64	553,748.1	59.5%

where specifically the percentage of saving is calculated as follows:

$$\% \; saving = \frac{Baseline\ total\ energy\ use - Proposed\ total\ energy\ use}{Baseline\ total\ energy\ use}$$

Nevertheless, this mere comparison between the two percentages of saving is not so effective for three main reasons, the first of which is due to the fact that this huge difference in percentage of saving mainly depends on the big variations introduced in baseline modelling rules between ASHRAE 90.1:2010 and ASHRAE 90.1:2019. Indeed, as previously specified, the baseline is renovated in the 90.1:2019 version with respect to the previous ones and made more stable by reintroducing rules similar to those of the 2004 version. This modelling choice does not stand for a better performance of the proposed model due to the simple difference between the energy consumption assessed in the two baseline and proposed models. This introduces, in fact, the second reason for which the effectiveness of the pure comparison is weakened. Indeed, the real performance is differently calculated according to the two standards and to the LEED certifications v4 and v5, however, it will be descripted and assessed in the following subchapter. Additionally, the baseline model in the updated version of ASHRAE 90.1 includes gas as energy carrier for heating making the outputs of the two model not comparable. This stresses the need of comparing results by the converting them through a common metric as cost or primary energy source in such a way to obtain an effective and comparable analysis.

In any case an analysis of the single end uses is below presented, even though, by just evaluating the variation in percentage of savings an increment of them passing from the ASHRAE 90.1:2010 to ASHRAE 90.1:2019 is registered for most of the end uses as demonstrated below:

Table 25- Final energy uses comparison between ASHRAE 90.1:2010 and ASHRAE 90.1:2019

	Proposed model kWh	Baseline 90.1:2010 kWh	Percentage of saving	Baseline 90.1:2019 kWh	Percentage of saving
Interior lighting	11,288.94	43,513.08	74.1%	60,080.38	81.2%
Exterior lighting	1,663.86	7,471.69	77.7%	8,368.92	80.1%
Space heating	76,730.01	38,852.37	-97.5%	243,324.36	/

Space cooling	45,887.85	58,395.98	21.4%	30,251.42	-51.7%
Pumps	981.67	0	/	0	/
Fans interior	43,281.21	106,389.43	59.3%	128,883.88	66.4%
Service water heating	2,109.36	6,012.15	64.9%	6,012.15	64.9%
Heat rejection	10,895.01	3,727.40	-192.3%	1,930.94	-464.2%
Elevators	7,635.35	7,635.35	0 %	14,350.07	46.8%
Receptacles	60,546.01	60,546.01	0 %	60,546.01	0 %

It must be remarked, as previously mentioned, that the percentage of saving is not comparable for the category of space heating which refers to two different energy carriers. Moreover, the receptacle category is not worth mentioning due to the equal modelling between proposed and baseline model and between the two versions, even if a proper evaluation and control system definition for the category increases the overall performance of the analysed building. Equally, it is not so effective analysing the elevators category which for the 90.1:2010 was equally modelled between proposed and baseline while for the updated version the baseline model follows specific rules. With respect to other categories, as cited before, the percentage of saving generally increases, nevertheless, this evaluation does not include the categories of space cooling and heat rejection characterized by a decreasing trend and showing an increased minimum performance as demonstrated by baseline variation. This trend inversion can be ascribed to variations in efficiency between proposed model and baseline one especially when working at partial-load, indeed the systems in the proposed model are realized considering default performance curve that can worsen or crash of the final output. Additionally, the use of DOAS in the proposed model that guarantees outdoor air exchange and a high indoor air quality, even if its aim is to ventilate and not directly to cool or heat the indoor environment, entails that the immitted air must be preheat or precooled contributing to the above-mentioned energy uses.

Proceeding to the analysis of the energy uses, an evaluation of how impacting each category of the proposed model is on the final proposed energy consumption is conducted.

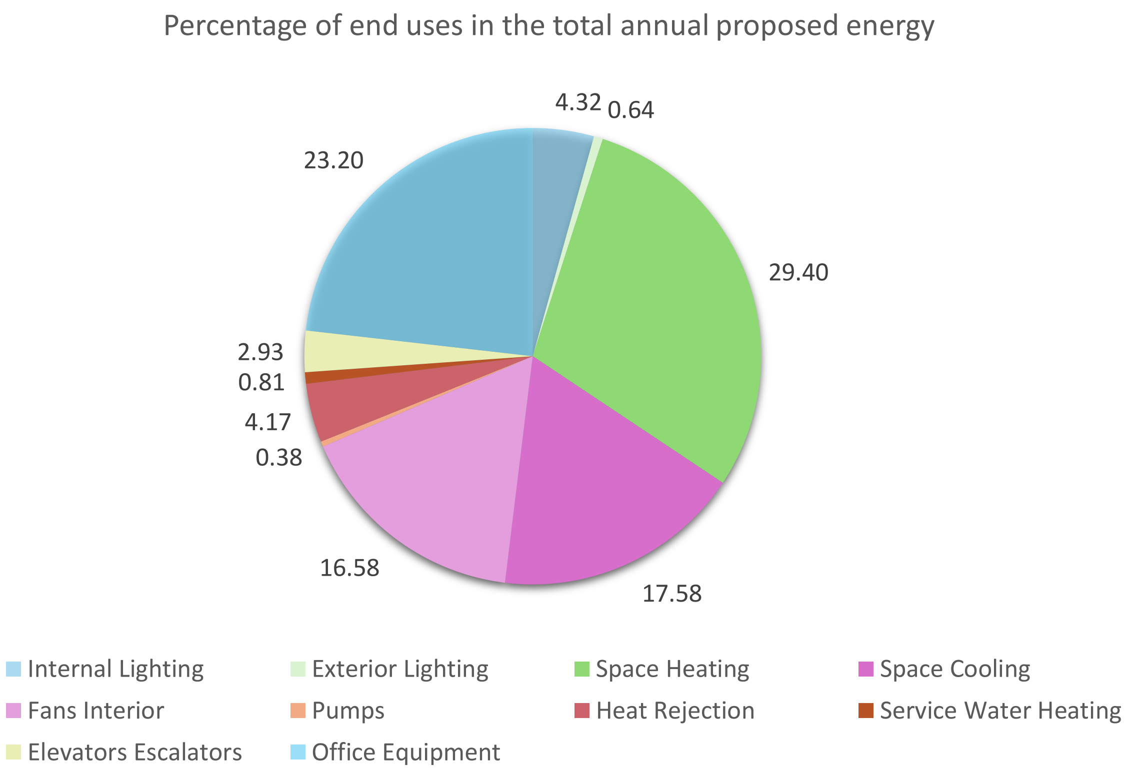


Figure 27- Percentage of the proposed end uses over the total annual proposed energy

As expected, the most relevant categories over the total proposed energy use are represented by office equipment (23,20%) reasonably with the considered destination of use, space heating (29,40%), space cooling (17,58%) and fans interiors (16,58%). This assessment represents an essential evaluation of the end uses over which each any enhancement can lead to a considerable improvement of building performances and an essential step of the output analysis. Indeed, additionally to office equipment, space heating and cooling are major contributors to the final energy use as in the majority of buildings and finally, the presence of DOAS and the highly contribution to the fan interior category increases its role in the final consumption.

A further remarkable evaluation is the determination of the index of the proposed energy end use over the gross floor area furnishing a result in $\frac{kWh}{year \cdot m^2}$.

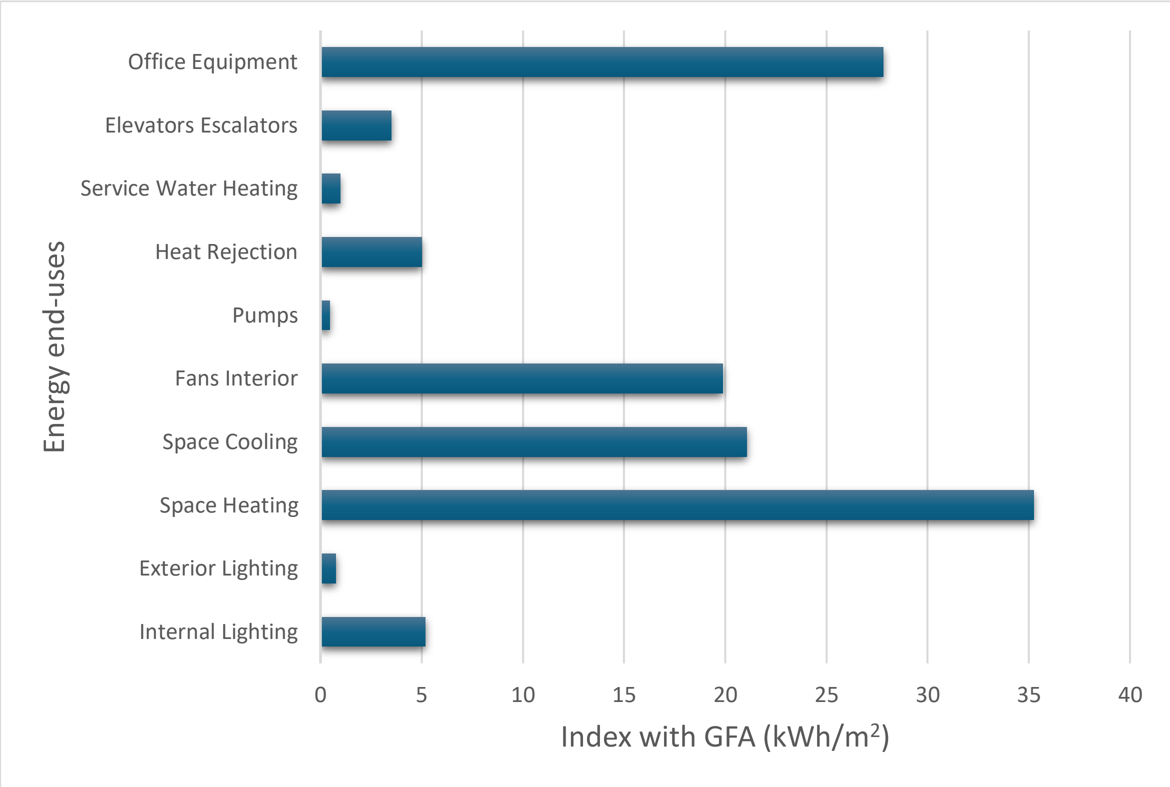


Figure 28- Index of the proposed energy end use over the gross floor area

As expected, the most impacting categories are the same for which the percentage over the total are predominant. In any case, the resulting index for space heating equal to 35 $\frac{kWh}{year \cdot m^2}$ is representative of a good performance level, good level of insulation and with reference to the defined climatic zone even though not representative of the highest performance level. Even the remaining categories are coherent with the building type considering a great contribution of office equipment that, combined with the occupancy level, contributes to the need for cooling and ACH requirements.

Finally, another analysis to be conducted to better investigate the proposed model, without reference to the baseline model, is the determination of the GHG emissions. Making reference to the latest available data (2025) of GHG emission intensity of electricity in Italy, the emission rate considered for the electricity is equal to 0.235 $kgCO_2e/kWh$[112] leading to an overall GHG emission of the proposed model equal to 61339,5 $kgCO_2e/kWh$ without considering the renewable energy production and equal to 52661.5 $kgCO_2e/kWh$ considering the reduction due to the presence of the photovoltaic system.

112 Istituto Superiore per la Protezione e la Ricerca Ambientale ISPRA (May, 2025): *Le emissioni di CO2 nel settore elettrico nazionale e regionale,* https://emissioni.sina.isprambiente.it/wp-content/uploads/2025/05/Le-emissioni-di-CO2-nel-settore-elettrico_r413-2025_def.pdf

In any case, it is worth noting the variation with respect to the baseline models using a metric which makes the comparison effective and even considering the GHG emission rate for gas to provide a coherent result with respect to the baseline model realized following the ASHRAE 90.1:2019.

Table 26- GHG emission according to ASHRAE 90.1:2010 and ASHRAE 90.1:2019

	Proposed model	Baseline model 2010	Percentage of saving	Baseline model 2019	Percentage of saving
Emission rate electricity $kgCO^2e/kWh$	0.235				
Emission rate gas $kgCO^2e/kWh$	0.20[113]				
Without renewable energy production	61,339.5	78,147.71	21,5 %	122,101.0	49.8%
With renewable energy production	52,661.5	78,147.71	32,6%	122,101.0	56,9%

The comparison highlights the same percentage of saving for the ASHRAE 90.1:2010 model since, having electricity as energy carrier in both proposed model and baseline model, the multiplication factor is the same leading to an unvaried final percentage of saving. Despite that, in this case, the use of a normalization metric removes the incomparability problem of the two baseline models by transforming the energy carriers into comparable GHG emission rates. The overview of the final results still highlights a huge difference in the final percentage of saving which is still tied to the different baseline modelling rules. For this reason, the proper analysis is conducted in the following subchapter with the procedure to assess the real performance according to the indexes defined in the energy code and rating system.

[113] Expressed in CO2 emission factor (kg/TJ) and equal to 56100 kg/(TJ), which converted into $kgCO^2e/kWh$ leads to the reported value. Garg, A. & Weitz, M. M. (2019): *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 2: Energy* https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/2_Volume2/19R_V2_1_Ch01_Introduction.pdf

4.2. LEED credit assignment variation between v4 and v5

The overall performance of the building and the real comparison between the two energy modelling output is provided by the assessment of LEED scoring.

Specifically, the credit "Optimize energy performance" of LEED v4, related to the energy simulation conducted according to the ASHRAE 90.1:2010 specification and in accordance with the updated version 2024 of the LEED credit, has been evaluated following the option 1 related to the whole-building energy simulation with a maximum achievable score of 18 points for the considered building category. The final scoring is obtained through the summation of the points which can be allocated with respect to "Table 1 and 2" of the credit itself that, specifically, explore the energy performance in terms of costs and GHG emissions with the related percentage of improvement beyond ASHRAE 90.1-2010 Appendix G. Moreover, it is admitted subtracting the renewable energy production from the final energy performance of the proposed model to determine the scoring according to "Table 1 and 2" as specified in the credit. [114]

The results in terms of costs are then reported below:

Table 27- Energy performance in terms of costs according to LEED v4 credit

	Proposed model	Baseline model 2010	Percentage of saving
Cost of electricity €/kWh [115]	0.25		
Performance with renewable energy production	56,022.91	83,135.87	32,6%

Even in this case, the common energy carrier makes the multiplication factor equal between proposed and baseline model leading to the same final percentage of saving even when applying the metric of costs. In any case, as even identified in the previous chapter related to the presentation on the "Energy and Atmosphere" category, the points allocation follows the threshold values defined in "Table 1" of the "Optimize energy performance" credit as below reported:

[114] USGBC | U.S. Green Building Council (n.d.): *LEED Credit Library: LEED BD+C: New Construction v4 - LEED v4: Optimize Energy Performance (2024 Update)* https://www.usgbc.org/credits/BDC/v4/ea404/2024update?return=/credits/New%20Construction/v4/Energy%20&%20atmosphere

[115] Reported as in the original model

Table 28- Points for percentage improvement in energy performance beyond ASHRAE 90.1-2010 Appendix G (cost or source energy)https://www.usgbc.org/credits/BDC/v4/ea404/2024update?return=/credits/New%20Construction/v4/Energy%20&%20atmosphere

Points	New Construction, Major Renovation, Warehouses & Distribution Centers, Hospitality	Schools	Core and Shell, Data Centers[1]	Healthcare[2]
Prerequisite	10%	10%	8%	5%
1	20%	20%	10%	7%
2	25%	25%	15%	10%
3	30%	30%	20%	15%
4	35%	35%	25%	20%
5	40%	40%	30%	25%
6	45%	45%	35%	30%
7	50%	50%	40%	35%
8	55%	60%	45%	40%
9	60%	-	50%	45%
10	-	-	-	50%
Exemplary Performance	100%	100%	100%	100%

According to the defined table the first essential consideration is related to the full accomplishment of the prerequisite represented by a minimum percentage of improvement equal to the 10% that is abundantly satisfied. Furthermore, the building deserves 3 points allocation highlighting that the building, additionally to the respect of minimum requirements and mandatory provision, arises the final performance to advanced standards and quality levels recognizing the validity of the adopted technical choices.

With respect to “Table 2” of the credit, the performance is evaluated in terms of greenhouses gases emission and the results, obtained from the evaluation led in the previous subchapter, are summarized below:

Table 29- GHG emissions for LEED v4

	Proposed model	Baseline model 2010	Percentage of saving
Emission rate electricity $kgCO^2e/kWh$		0.235	
Final performance	52,661.5	78,147.71	32,6%

Clearly, since the proposed and baseline models according to ASHRAE 90.1:2010 are fully electric the percentage of saving between proposed and baseline models are unvaried since the new metric implies the simple multiplication of a common factor. Even in this case the final score is provided considering the threshold identified in “Table 2” of LEED v4 credit “Optimize energy performance” reported below:

Table 30- Points for percentage improvement in greenhouse gas emissions beyond ASHRAE 90.1-2010 Appendix G https://www.usgbc.org/credits/BDC/v4/ea404/2024update?return=/credits/New%20Construction/v4/Energy%20&%20atmosphere

Points	New Construction, Major Renovation, Warehouses & Distribution Centers, Hospitality	Schools	Core and Shell, Data Centers[1]	Healthcare[2]
Prerequisite	10%	10%	8%	5%
1	20%	20%	10%	7%
2	25%	25%	15%	10%
3	30%	30%	20%	15%
4	35%	35%	25%	21%
5	42%	42%	32%	27%
6	50%	50%	40%	35%
7	60%	60%	50%	45%
8	70%	70%	60%	55%
9	85%	-	75%	65%
10	-	-	-	80%
Exemplary Performance	100%	100%	100%	100%

Equally to what described before, the final performance overcomes the minimum threshold value imposed by the prerequisite and worths 3 points allocation leading to an overall scoring equal to 6 points with respect to the "Optimize energy performance" credit of LEEDv4.

It is worth noting that the evaluation has been conducted with respected to the updated version of credit "Optimize energy efficiency" that aligned its threshold values to increased standard and ambitious goals. Indeed, the recognition of 6 points over a total of achievable 18 points does not stand for a failure of design choices, quite the opposite, the obtained results demonstrate the high performance of the building that succeeds in overcoming the minimum requirements and obtaining a significant scoring despite the rigorousness of the applied protocol.

When considering instead LEEDv5 procedure, "Option 1" of the prerequisite "Minimum energy efficiency", related to the application of ASHRAE version 90.1-2019, specifies that the building should: "*comply with ANSI/ASHRAE/IES Standard 90.1-2019 with addendum cr. Use any applicable compliance path in ASHRAE 90.1, Section 4.2."*[116]. Therefore, drilling down through the specifications reported in section 4.2 of ASHRAE 90.1:2019, compliance with one of the following is required:

- *"mandatory provisions related to building envelope, HVAC, service water heating, power, lighting and other equipment or*
- *energy budget method or*
- *Appendix G "Performance Rating Method*"[117]

The prerequisite furthermore specifies that, for projects applying the Normative Appendix G, Performance Rating Method compliance path, the future source energy metric may be used in place of cost, despite that, further specifications in the "Enhanced energy efficiency" LEEDv5's credit, clearly require the replacement of all reference to costs with the metric of future energy source leading to the major update of the protocol. Indeed, this modification stresses the change of perspective in LEEDv5 and the higher focus over responsible uses of energy sources by

[116]USGBC | U.S. Green Building Council (n.d.): *LEED Credit Library: LEED BD+C: New Construction v5 - LEED v5 Minimum Energy Efficiency* https://www.usgbc.org/credits/new-construction-core-and-shell/v5/eap2?return=/credits/New%20Construction/v5/Energy%20&%20atmosphere

[117] ASHRAE 90.1 (2020) (SI): *Standard 90.1-2019 (SI Edition) - Energy Standard for Buildings Except Low-Rise Residential Buildings* (ANSI Approved; IES Co-sponsored) www.ashrae.org/continuous-maintenance pag. 46

replacing all possible economic savings with enhanced energy use that better validates the performance of adopted technical solutions.

Focusing on the updated credit "Enhanced energy efficiency" and specifically to "Option 2" that requires the energy simulation of building, two paths can be followed as possible alternatives to determine the building performance with a maximum achievable score of 10 points. Specifically, the first path doesn't account for renewable energy production while, the alternative path considers this contribution in the overall assessment. [118]

Moreover, it must be underlined that, when using Normative Appendix G and Option 2 of "Enhanced energy efficiency", the performance of the building is calculated in function of a Performance Cost Index, then compared to the Performance Cost Index Target (PCI_t). This, additionally to the metric variation to primary energy source, represents one of the biggest innovations introduced in the passage from ASHRAE 90.1:2010 and LEEDv4 to ASHRAE 90.1:2019 and LEEDv5. Indeed, the building performance is normalized with respect to a stable and fixed target making the proposed model less sensitive to standard variation. Specifically, the Performance Cost Index (PCI) of the building shall be less than or equal to the Performance Cost Index Target (PCI_t), identified as the reference target.

Entering in the details of calculation method, the PCI_t in accordance with Normative Appendix G, must be determined through the following equation:

$$PCI_t = \frac{[BBUEC + (BPF \cdot BBREC)]}{BBP}$$

Where:

- BBUEC (baseline building unregulated energy cost): the portion of energy uses that are subject to compliance with the ASHRAE 90.1 standard. In this case, it specifically refers to the baseline model
- BBREC (baseline building regulated energy cost): portion of the energy uses required to be compliant with the ASHRAE 90.1 standard's specification. Even in this case, it refers to the baseline model

[118] USGBC | U.S. Green Building Council (n.d.): *LEED Credit Library: LEED BD+C: New Construction v5 - LEED v5 Enhanced Energy Efficiency* https://www.usgbc.org/credits/new-construction/v5/eac3?return=/credits/New%20Construction/v5/Energy%20&%20atmosphere

- BPF (building performance factor): derived from Table 4.2.1.1 of ASHRAE 90.1:2019[119] has a key role in the determination of final performances of building and will be further investigated in this chapter
- BBP (baseline building performance): considers the whole energy uses (regulated and unregulated) of baseline model converted according to the future energy source with respect to the specific energy carrier of identified energy uses.

Once defined the PCI_t, to proceed with the evaluation, the PCI (Performance Cost Index) must be calculated according to the following formula:

$$PCI = \frac{Proposed\ building\ performance}{Baseline\ building\ performance}$$

As previously specified, the BPF holds an essential position in the final performance assessment according to ASHRAE 90.1:2019. Indeed, till now, the presented percentages of saving between proposed and baseline models have been affected by a baseline system fixed to 2004 reference standard. The passage to comparable performances of the proposed model with target representative of current standards, is mainly devoted to the BPF. Specifically, the ASHRAE 90.1-2019, Table 4.2.1.1, provides Building Performance Factors determined according to the analysis of a stock of buildings prototypes corresponding to different building typologies located in different climatic zones to determine the impact of variation over the years. Indeed, the BPFs are calculated as follows:

$$BPF_{year} = \frac{\left(\sum \frac{Prototype\ Building\ Regulated\ Energy\ Cost_{year}}{Prototype\ Building\ Regulated\ Energy\ Cost_{2004}}\right)}{N_p}$$

where:

- Prototype Building Regulated Energy $Cost_{year}$: portion of regulated annual energy cost use referring to given building prototype, climate zone and year of considered 90.1 Standard.
- Prototype Building Regulated Energy $Cost_{2004}$: portion of regulated annual energy cost use referring to given building prototype, climate zone for the 90.1:2004 Standard.

[119] ASHRAE 90.1 (2020) (SI): *Standard 90.1-2019 (SI Edition) - Energy Standard for Buildings Except Low-Rise Residential Buildings* (ANSI Approved; IES Co-sponsored) www.ashrae.org/continuous-maintenance pag. 47

- Np: Number of prototype buildings for the given typology[120]

Nevertheless, the BPFs adopted to assess the performance according to LEEDv5 "Enhanced energy efficiency" credit are those presented in "Table 1" of prerequisite referring to future source energy metric and as below reported:

Table 31- ASHRAE 90.1-2019 — Equivalent Building Performance Factors for a Future Source Energy Metric

Building type	Climate Zone																	
	0A	0B	1A	1B	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
Multifamily	0.74	0.69	0.73	0.70	0.73	0.70	0.71	0.70	0.63	0.70	0.71	0.69	0.68	0.70	0.70	0.68	0.68	0.68	0.74
Healthcare/hospital	0.72	0.72	0.73	0.73	0.74	0.71	0.72	0.74	0.71	0.72	0.73	0.71	0.74	0.73	0.80	0.73	0.77	0.78	0.79
Hotel/motel	0.72	0.71	0.72	0.71	0.71	0.70	0.71	0.73	0.72	0.71	0.73	0.73	0.71	0.73	0.74	0.70	0.72	0.70	0.70
Office	0.62	0.63	0.61	0.62	0.58	0.60	0.57	0.62	0.55	0.55	0.61	0.57	0.58	0.61	0.59	0.58	0.60	0.54	0.58
Restaurant	0.65	0.62	0.63	0.61	0.62	0.58	0.63	0.63	0.63	0.67	0.66	0.66	0.70	0.70	0.68	0.73	0.72	0.74	0.77
Retail	0.57	0.54	0.53	0.53	0.48	0.47	0.47	0.47	0.47	0.52	0.50	0.56	0.57	0.53	0.59	0.58	0.56	0.53	0.60
School	0.57	0.57	0.58	0.57	0.55	0.54	0.57	0.51	0.49	0.48	0.51	0.52	0.51	0.53	0.51	0.53	0.50	0.51	0.58
Warehouse	0.28	0.30	0.24	0.27	0.23	0.24	0.27	0.23	0.20	0.33	0.26	0.28	0.40	0.32	0.29	0.44	0.38	0.40	0.44
All others	0.65	0.62	0.64	0.62	0.57	0.54	0.57	0.56	0.58	0.59	0.57	0.60	0.60	0.59	0.65	0.62	0.62	0.61	0.64

For the specified case study, corresponding to a building typology "Office" and climatic zone "4A", the derived BPF value is 0.55. Despite that, a further specification for building subjected to major renovation considers a multiplication factor of the BPF equal to 1.05 as defined in the credit description. [121]

[120] Rosenberg, M. & Hart, R. (February, 2016): *Developing Performance Cost Index Targets for ASHRAE Standard 90.1 Appendix G – Performance Rating Method.* Pacific Northwest National Laboratory for the U.S. Department of Energy. https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-25202.pdf

[121]USGBC | U.S. Green Building Council (n.d.): *LEED Credit Library: LEED BD+C: New Construction v5 - LEED v5: Enhanced energy efficiency* https://www.usgbc.org/credits/new-construction/v5/eac3?return=/credits/New%20Construction/v5/Energy%20&%20atmosphere

Finally, proceeding to the calculation of all the terms above described, it has been necessary to individuate conversion factors into source energy, and specifically, they have been identified equal to 1,9 for electricity[122] and equal to 1,05 for gas[123] in Europe.

The below reported table provides an overview of the final energy uses according to the energy simulation model reporting all the required input data to assess the PI.

Table 32- Final energy uses of proposed model and baseline model according to ASHRAE 90.1:2019

	Proposed model	Baseline model	Percentuale di saving
Total Gas energy (kWh) (regulated)	0,00	243,324.36	100%
Total Electrical energy (kWh) (regulated)	200,473.26	249,877.76	19.8%
Total Annual Regulated Energy Use	200,473.26	493,202.12	59.4%
Total Annual Unregulated Energy Use (all electrical)	60,546.01	60,546.01	0,00 %
Total energy (without PV)	261,019,27	553,748.1	**52.9%**
Renewable energy	36,927.63	/	/
Total annual energy use included renewable energy	224,091.64	553,748.1	**59.5%**

Based on the provided data, the PI_t[124] and PI results are below provided:

Table 33- PI_t calculation

$$PI_t = [BBUE + (BPF \times BBRE)]/ BBP$$

[122] *Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955 (recast)* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023L1791&qid=1762935822223 pag. 70 point 3

[123] D.M. (26.06.2015): *Applicazione delle metodologie di calcolo delle prestazioni energetiche e definizione delle prescrizioni e dei requisiti minimi degli edifici.* GU Serie Generale n.162 del 15-07-2015 - Suppl. Ordinario n. 39 https://www.mimit.gov.it/images/stories/normativa/DM_requisiti_minimi_allegato1.pdf Table 1

[124] Reference to costs has been removed since the obtained results are converted in energy source

PI	Results
BBUE	115,037.419
BPF	0.55
BPF for major renovation	0.5775
BBRE	730,258.32
BBP	845,295.741
PI_t	0,635

Table 34- Proposed building Performance Indexes

PI	Results
PInre	0.587
PI	0.504

Moreover, to be fully compliant with section 4.2 prescription it is necessary to verify that: "*When* $(PBP_{nre} - PBP)/BBP > 0.05$*, new buildings, additions to existing buildings, and/or alterations to existing buildings shall comply with the following:*

PI[125] $+ [(PBPnre - PBP)/BBP] - 0.05 < PI_t$" [126]

where:

- PBP_{nre} (proposed building performance not inclusive of renewable energy production): calculated as summation of the products between the whole energy uses (regulated and unregulated) referring to all the energy carriers (in this case full electric) and the respective conversion factors for each energy carrier.
- PBP is the proposed building performance inclusive of renewable energy production: it is calculated as the PBPnre but considering reduced energy use due to the subtraction of renewable energy production.
- BBP is the baseline building performance above calculated.

[125] To demonstrate compliance the renewable energy contribution cannot be considered.
[126] ASHRAE 90.1 (2020) (SI): *Standard 90.1-2019 (SI Edition) - Energy Standard for Buildings Except Low-Rise Residential Buildings* (ANSI Approved; IES Co-sponsored) www.ashrae.org/continuous-maintenance

Proceeding to the above-described verification, the calculation proceeded and led to the below summarized results:

Table 35- Final verification of compliance

Factors	Results
PBPnre	495,936.6
PBP	425,774.1
BBP	845,295.741
Final result	**0.083**
Factors	Results
PInre	0.587
PBPnre-PBP/BBP	0.083
Final result	**0. 62**

The obtained value, equal to 0.62, is lower than the PI_t previously calculated and equal to 0.635 guaranteeing the certifiability of the building.

The output of this analysis represents a valuable result of the work thesis underlining that, a building previously recognized at "Gold" level according to LEEDv4 with the described features and design choices, with specified destination of use and climatic zone, can still be recognized as certifiable with LEEDv5 demonstrating the validity and resilience of the adopted technical solutions over years and over the described targets and metrics defined by the ASHRAE 90.1 Standard.

With respect to points allocation, the "Option 2" of credit "Enhanced energy efficiency" with a maximum achievable points equal to 10, as mentioned, can follow two alternative paths:

- path 1- Percentage Reduction Excluding On-Site Renewable Contribution: (100% – PInre / PIt) or

- path 2- Percentage Reduction Including On-Site Renewable Contribution: (100% – PI / PIt)

Table 36- Points for Percentage Improvement in PI Below PI_t https://www.usgbc.org/credits/new-construction/v5/eac3?return=/credits/New%20Construction/v5/Energy%20&%20atmosphere

Path 1. Percentage Reduction Excluding On-Site Renewable Contribution (100% – PI_{nre} / PI_t)	OR	Path 2. Percentage Reduction Including On-Site Renewable Contribution (100% – PI / PI_t)	Points
3%		10%	1
6%		20%	2
9%		30%	3
12%		40%	4
15%		50%	5
18%		60%	6
21%		70%	7
24%		80%	8
27%		90%	9
30%		100%	10

Specifically, based on the results obtained, the final percentage for the two paths were:

Table 37- Percentage reductions calculation

Path 1-percentage reduction excluding on-site renewable energy . (100% - PInre/PIt)	Path 2- percentage reduction including on-site renewable energy . (100% - PI/PIt)
7.61%	20,68%

These results lead to an overall scoring equal to two points with both paths. The output and the comparison with the result obtained for LEEDv4, more than representing the performance of the building itself, highlights the stringency and rigorousness of the ASHRAE 90.1:2019 and LEEDv5 protocol pointing out the shift and raise of the new minimum standards. The metric shift to the energy source metric better validates the obtained results demonstrating the efficiency of building with respect to energy use more than economic saving perfectly aligning with the spreading goals.

5. Optimization strategies

Based on the resulting score and performance obtained from the assessment previously descripted, this chapter focuses on the identification of the possible enhancement strategies. The process considered, firstly, the analysis of the most impacting categories concerning the building needs, both cooling and heating ones, evaluated in absence of HVAC system operation and, therefore, purely considering the envelope properties and internal gains/losses. Finally, as outcome of this analysis combined with the previous identification of the prevalent energy end uses in the final energy performance of the building, the strategies were properly evaluated and selected.

When considering the cooling need, it is necessary to underline that the assessment at building level is obtained as combination of spaces' needs at peak conditions. Nevertheless, the peaks of the whole spaces are not coincident and pertains to different times of cooling period, so it is worth nothing that the following analysis has been conducted considering the day and the hour corresponding to the maximum peak of the overall building which not necessarily corresponds to the maximum peak for all spaces.

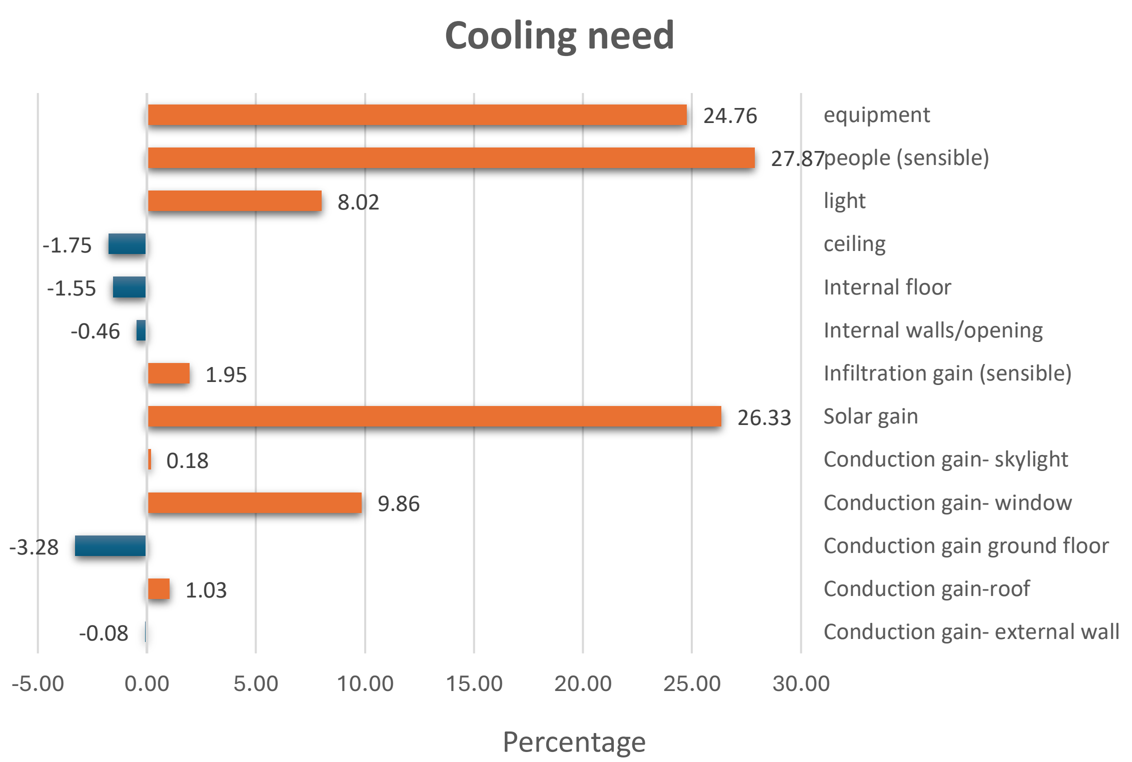


Figure 29- Cooling need

As highlighted in the above scheme, the major contribution to the cooling need is to be attributed to occupants (27,87%)[127]. The result is coherent with the building typology considered and, in any case, not modifiable to still guarantee the functionality of the spaces as originally designed and conceived. Additionally, another worth mentioning component, is represented by solar gains (26,33%) that, differently from the previous component, set the basis for the individuation of optimization strategies aimed at their reduction. And finally, the last component majorly contributing to the cooling need is represented by the office equipment (24,76%) that, even in this case, is reasonable for the considered destination of use.

With respect to the heating need the evaluation is instead conducted in design conditions that, differently from what defined for the cooling need, are coincident for all spaces leading to an analysis that is not affected by variations similar to those previously highlighted. The results of the assessment are below reported:

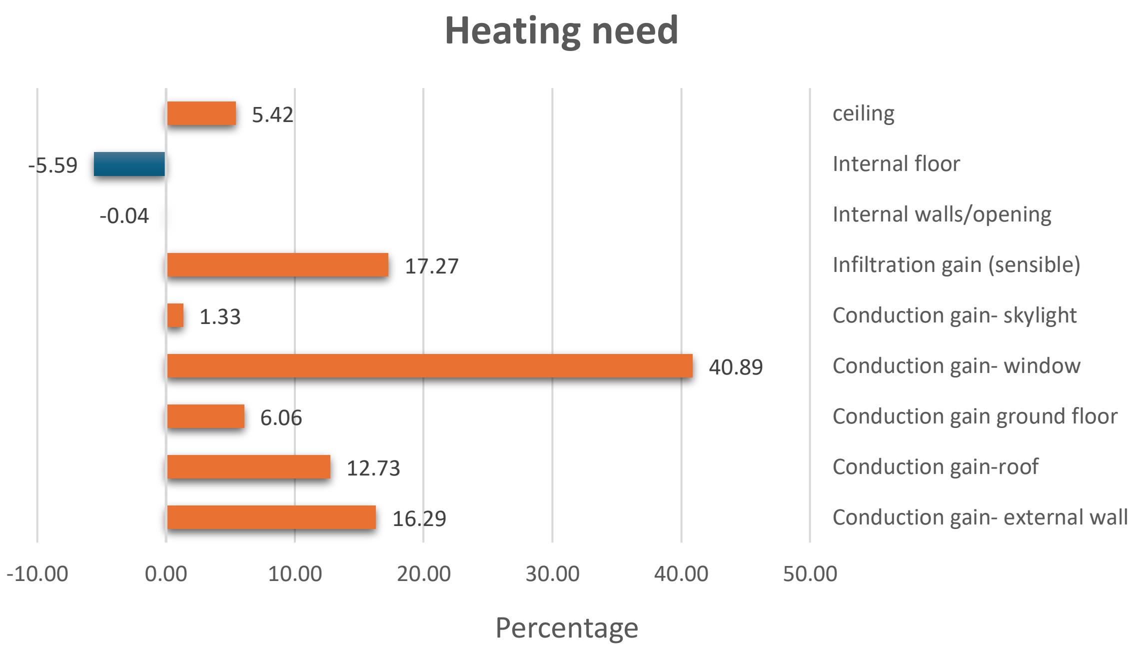


Figure 30- Heating need

As clearly identified in the graph, the most relevant component of heating need is related to losses through windows (40,89%), result that was subsequently considered for the evaluation of improvement strategies considering the inclusion of more performant transparent elements. Moreover, as expected, an important percentage of the whole heating need is to be attributed to

[127] The graph only considers the sensible contribution

infiltration losses representing the 17,27% as well as envelope losses through walls (16,29%) and roof (12,73%) that resulted in the opaque envelope thermal enhancement.

The obtained outputs set basis for the identification of the possible enhancement strategies just like the consideration of mandatory provisions of energy standard ASHRAE 90.1:2019. Indeed, despite the section 4.2. of the ASHRAE 90.1:2019 requires compliance to one of the following:

-section 5, “Building Envelope”; Section 6, “Heating, Ventilating, and Air Conditioning”, Section 7, “Service Water Heating”; Section 8, “Power”; Section 9, “Lighting”; and Section 10, “Other Equipment,” or

- section 11, “Energy Cost Budget Method,” or
- Normative Appendix G, “Performance Rating Method”[128]

and having already identified the PRM as the selected compliance path, it was considered the possibility to improve the building envelope properties in compliance with the specification of ASHRAE 90.1:2019 and of the Italian requirements defined in D.M. 26/06/2015 with respect to the updated version of 2021.[129]

All the strategies are evaluated with the aim to identify possible and suitable design choices that could have been defined in the decision-making process with the scope of increasing the performance of the building and the possibility to obtain a higher score in LEED v5 highlighting the necessity for an integrative process already in design phase. Nevertheless, the majority of the identified solutions can still be applied in a renovation intervention.

Improvement of thermal and optical properties of the transparent envelope

The first improvement that could be implemented is represented by the enhancement of thermal and optical properties of the transparent envelope with the scope of determining the impact of this variation in the overall performance output and in consideration of the major impact of these elements over the cooling need and heating one.

[128] ASHRAE 90.1 (2020) (SI*): Standard 90.1-2019 (SI Edition) - Energy Standard for Buildings Except Low-Rise Residential Buildings (ANSI Approved; IES Co-sponsored)* www.ashrae.org/continuous-maintenance pag. 46

[129] [129]D.M. (26.06.2015): *Applicazione delle metodologie di calcolo delle prestazioni energetiche e definizione delle prescrizioni e dei requisiti minimi degli edifici*. GU Serie Generale n.162 del 15-07-2015 - Suppl. Ordinario n. 39 https://www.mimit.gov.it/index.php/it/normativa/decreti-interministeriali/decreto-interministeriale-26-giugno-2015-applicazione-delle-metodologie-di-calcolo-delle-prestazioni-energetiche-e-definizione-delle-prescrizioni-e-dei-requisiti-minimi-degli-edifici

Indeed, here an overview of the proposed model performances, the original one and the one including the improvement strategy, is provided even highlighting the threshold imposed by the above cited standards:

Table 38- Windows' enhancement

Windows	Previous proposed model	Proposed model	Mandatory provisions 90.1:2019	D.M. 26 Giugno 2015 (2021 update)
U-value	1,537	1,298	2,04	1,40
g-value	0,398	0,35	/	0,35
SHGC	0,394	0,3455	0,36- fixed 0,33- operable	/
WWR	23%	23%	40%	/
Assembly Min VT/SHGC	1,67	1,73	1,1	/

The considered modifications, as presented in the above table, are related to the adoption of thermal properties and optical properties typical of a selective and low-emissivity IGU and frame with thermal-break. The improvement of these properties has properly modelled into the IESVE software by editing the project construction related to windows and defining the features of inner pane, outer pane and cavity as well as frame properties as below reported:

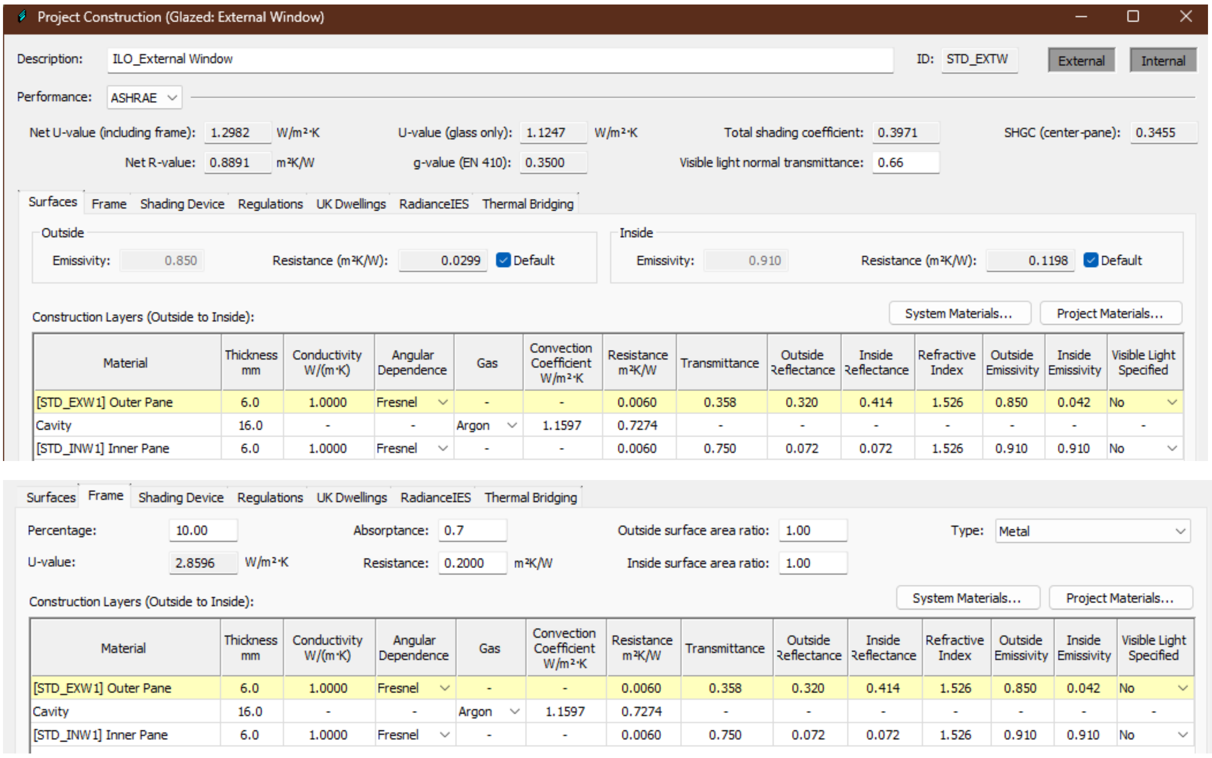


Figure 31- Windows' enhancement- Modelling definition

It is worth noting that, despite the modification of optical and thermal properties of the panes, their thicknesses as well as that of the cavity were maintained unmodified with respect to the original model.

The output of this improvement strategy was obtained by running again the simulations starting from the solar shading calculation and daylight simulation up to the energy simulation to properly visualize the effect of this improvement in the overall analysis. The output of this evaluation is below reported considering the impact of the modification with respect to the previous model and with respect to both the versions of the ASHRAE 90.1 standard.

Table 39- Variation in the total annual energy use and impact on the energy performance

Previous model	Proposed model 90.1:2010	Baseline model 90.1:2010	Percentuale di saving	Proposed model 90.1:2019	Baseline model 90.1:2019	Percentuale di saving
Total annual energy use (kWh)	261,019.27	332,543.46	**21,5 %**	261,019.27	553,748.1	**52.9%**

Renewable energy (kWh)	36,927.63	/	/	36,927.63	/	/
Total Annual Energy Use included Renewable	224,091.64	332,543.46	**32,6%**	224,091.64	553,748.1	**59.5%**
New model	Proposed model 90.1:2010	Baseline model 90.1:2010	Percentuale di saving	Proposed model 90.1:2019	Baseline model 90.1:2019	Percentuale di saving
Total annual energy use (kWh)	259,720.18	332,543.46	**21,9%**	259,720.18	553,748.1	**53.1%**
Renewable energy (kWh)	36,927.63	/	/	36,927.63	/	/
Total Annual Energy Use included Renewable	222,792.55	332,543.46	**33%**	222,792.55	553,748.1	**59.8%**

Obviously, the analysed result is not sufficient to properly demonstrate the performance improvement, since, as demonstrated in the previous chapters, the percentage of saving is not comparable when passing from the ASHRAE 90.1:2010 to the ASHRAE 90.1:2019 due to the variation of intent and concept with which the baseline model should be modelled. Despite that, it still provides a good comparative result in the output for the same considered standard's version, indeed, since the baseline model is fixed, it consequently not influences the final percentage of saving in the passage from the actual proposed model and the one where the optimization strategy has been implemented. So that, the gap between the two percentage of saving, relative to the two subsequent models realized with the same version, are representative of the improvement's effectiveness. To better interpret the results, an overview of the most impacted categories of the proposed model is below remarked:

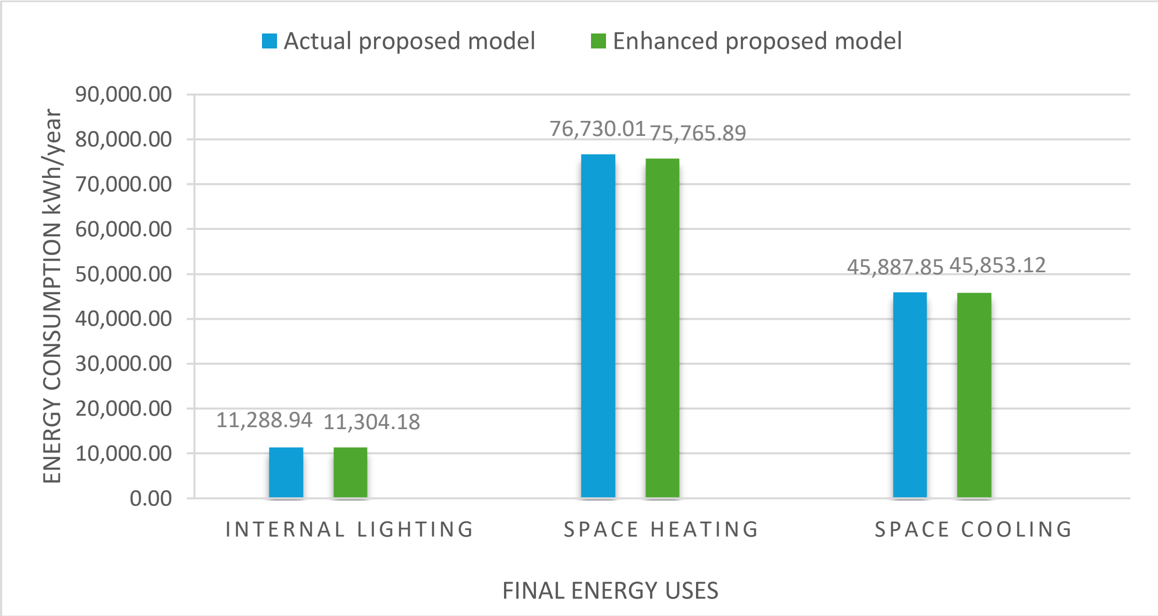


Figure 32- Final end uses variation due to the enhancement

As expected, the improvement sorted a negative impact to the interior lighting category, indeed by changing the optical properties of the window and reducing the g-value, the lighting sensors recognize this variation leading to an increase of the lighting density and subsequently the interior lighting energy consumption. With respect to space heating and cooling, the improved thermal and optical properties on both cases led to a reduction of the energy consumption even if slightly. Indeed, as regards the space heating, the reduction of thermal transmittance even reduces losses through windows and subsequently the heating need and consumption. With respect to space cooling, the g-value reduction is the responsible for its slight decrease.

Lastly, the final performances, obtained considering the LEEDv4 and LEED v5 credits and the above defined assessment's procedure, are below reported:

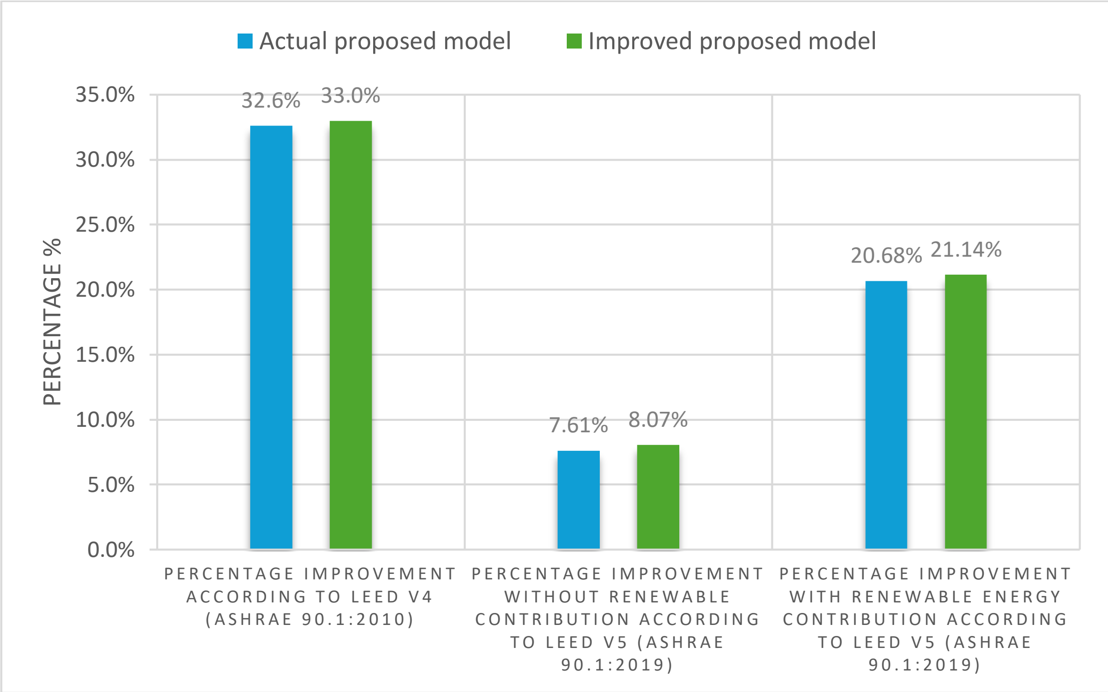


Figure 33- Output of the improved performances and comparison with actual proposed model

The graph not only highlights the variation of final performance within the same model but, additionally, remarks the change in the final performance assignment passing from ASHRAE 90.1:2010 and LEEDv4 to ASHRAE 90.1:2019 and LEEDv5. The adoption of this strategy enables to improve the performance of the building itself, nevertheless, its implementation is not sufficient to provide a better scoring in the points allocation according to LEED credits, that, requires the achievement of the minimum threshold of 35% in LEEDv4 and of 9% and 30% in LEEDv5 respectively without and with renewable energy's contribution. Despite that, the solution still provides an improvement of the overall performance and subsequently stands as a valid strategy regardless of LEED score.

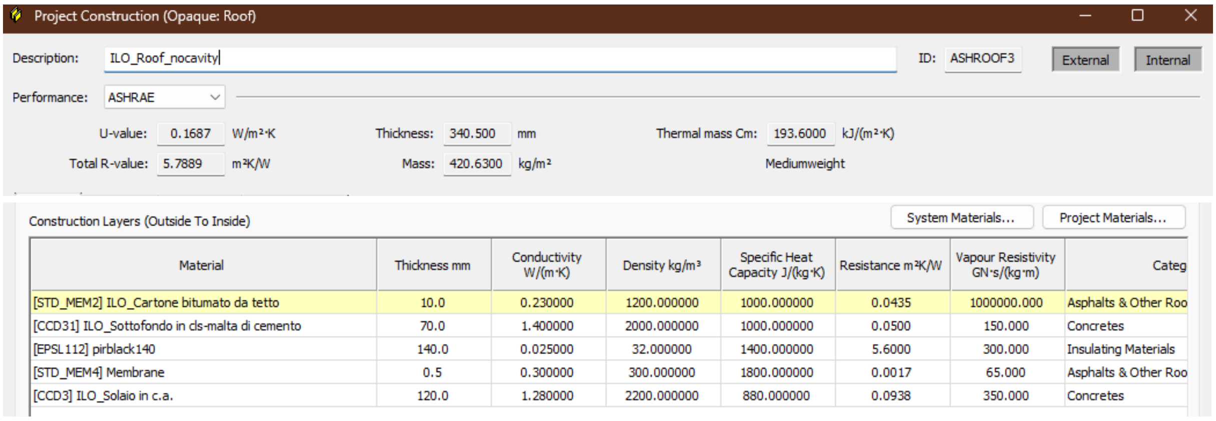
Improvement of roof thermal properties

Another considered improvement that could have been implemented in the design choices to favour an enhanced behaviour, is represented by the variation and improvement of roof in consideration of the mandatory requirements of ASHRAE 90.1:2019 and Italian legislation as below highlighted.

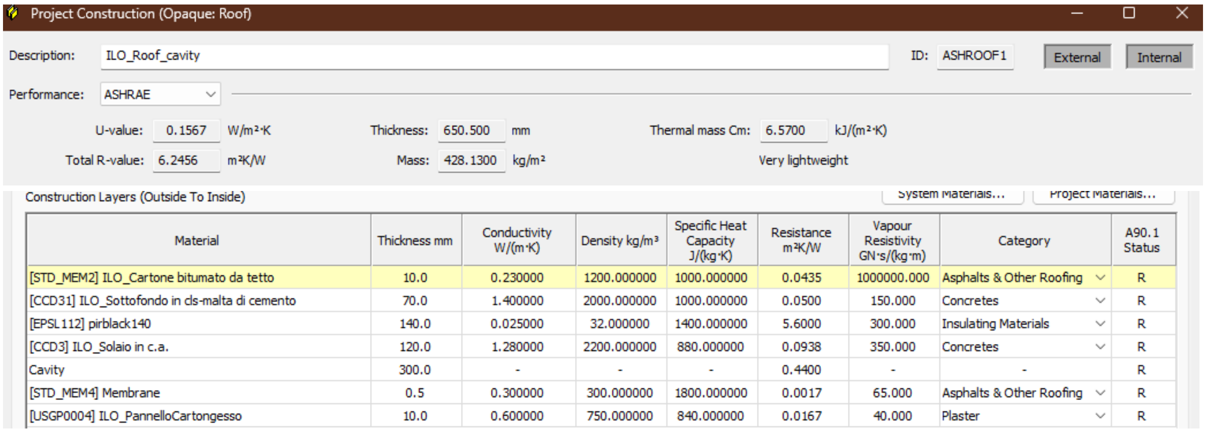
Table 40- Roof's enhancement

ILO roof no cavity	Previous proposed model	Proposed model	Mandatory provisions 90.1:2019	D.M. 26 Giugno 2015 (2021 update)
U-value	0,2555	0,1687	0,184	0,22
Min R-value	3,777	5,7889	5,3	/
ILO roof cavity	**Previous proposed model**	**Proposed model**	**Mandatory provisions 90.1:2019**	**D.M. 26 Giugno 2015 (2021 update)**
U-value	0,1888	0,1567	0,184	0,22
Min R-value	5,1600	6,2456	5,3	/

It is worth noting that the model presents two main stratigraphies related to the roof depending on the considered space. The modification, as in the previous case, was modelled in IESVE by properly editing the layers of the roof stratigraphies. The modelling considered the substitution of a polystyrene insulation layer with a more performant insulation layer[130] with the scope of improving the thermal properties of the opaque component. Furthermore, the modelling included a vapour barrier[131] which was not considered in the original project's model in order to verify the absence of interstitial condensation.



[130]Isover, Saint-Gobain, *Isover PIR Black* https://www.isover.it/prodotti/pannello/isover-pir-black#descrizioni (16/12/2025)
[131] Rhotoblaas (n.d.), *vapor 150 freno al vapore*,https://www.rothoblaas.it/attachments/258176-product-361/VAPOR%20150-it-technical-data-sheet.pdf?_gl=1*151mtuo*_up*MQ..*_ga*OTMxNzYxNDAuMTc3MDE5NTg0NQ..*_ga_B30VE6K3V5*czE3NzAxOTU4NDQkbzEkZzAkdDE3NzAxOTU4NDQkajYwJGwwJGgw (16/12/2025)



Material	Thickness mm	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m)	Category	A90.1 Status
[STD_MEM2] ILO_Cartone bitumato da tetto	10.0	0.230000	1200.000000	1000.000000	0.0435	1000000.000	Asphalts & Other Roofing	R
[CCD31] ILO_Sottofondo in cls-malta di cemento	70.0	1.400000	2000.000000	1000.000000	0.0500	150.000	Concretes	R
[EPSL112] pirblack140	140.0	0.025000	32.000000	1400.000000	5.6000	300.000	Insulating Materials	R
[CCD3] ILO_Solaio in c.a.	120.0	1.280000	2200.000000	880.000000	0.0938	350.000	Concretes	R
Cavity	300.0	-	-	-	0.4400	-	-	R
[STD_MEM4] Membrane	0.5	0.300000	300.000000	1800.000000	0.0017	65.000	Asphalts & Other Roofing	R
[USGP0004] ILO_PannelloCartongesso	10.0	0.600000	750.000000	840.000000	0.0167	40.000	Plaster	R

Figure 34- Thermal properties of the enhanced roof

The overall annual energy use variation due to the improvement strategy is reported considering its effect both in the ASHRAE 90.1:2010 and ASHRAE 90.1:2019 models as below reported:

Table 41- Variation of the final energy use according to roof thermal properties improvement

Previous model	Proposed model 90.1:2010	Baseline model 90.1:2010	Percentuale di saving	Proposed model 90.1:2019	Baseline model 90.1:2019	Percentuale di saving
Total annual energy use (kWh)	261,019.27	332,543.46	**21.5%**	261,019.27	553,748.1	**52.9%**
Renewable energy (kWh)	36,927.63	/	/	36,927.63	/	/
Total Annual Energy Use included Renewable	224,091.64	332,543.46	**32.6%**	224,091.64	553,748.1	**59.5%**
New model	Proposed model 90.1:2010	Baseline model 90.1:2010	Percentuale di saving	Proposed model 90.1:2019	Baseline model 90.1:2019	Percentuale di saving
Total annual energy use (kWh)	260,323.63	332,543.46	**21,7%**	260,323.63	553,748.1	**53%**
Renewable energy (kWh)	36,927.63	/	/	36,927.63	/	/

Total Annual Energy Use included Renewable	223,396.00	332,543.46	**32,8%**	223,396.00	553,748.1	**59.7%**

As in the previous case the percentage of improvement, even if not already converted according to the credit procedure for points allocation, highlights a minimum improvement in the performance demonstrated by the gap between the percentages of saving. In any case a further and in-depth analysis is below reported showing the major impacts of the improvement over the principal final energy uses:

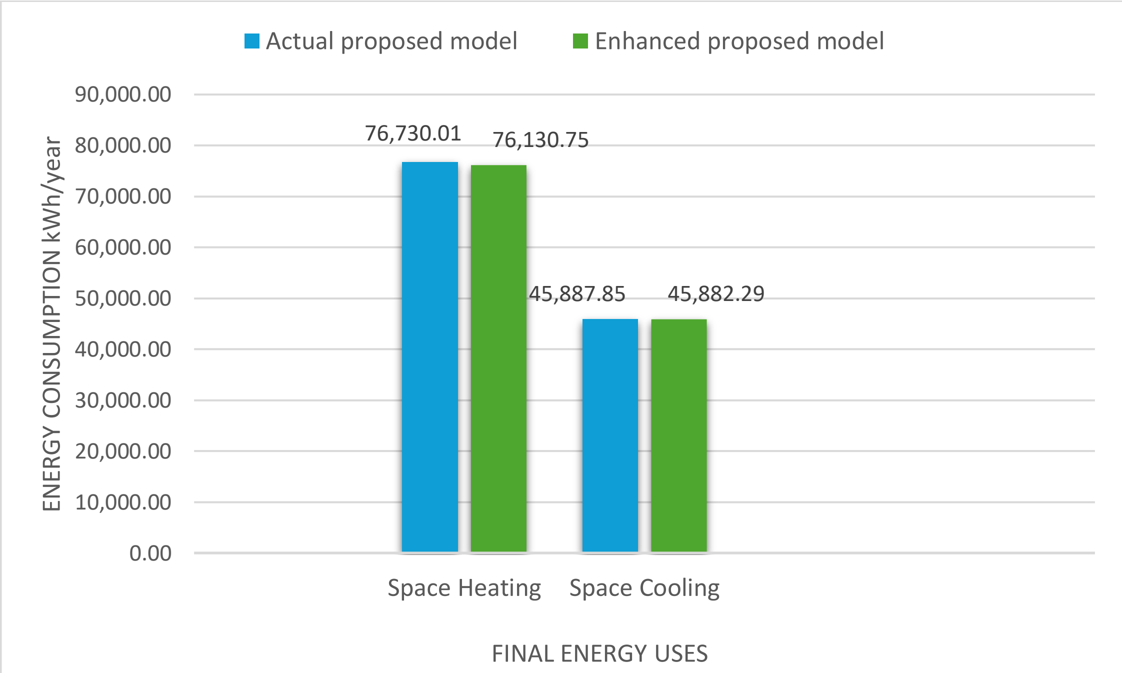


Figure 35- End uses variation due to roof thermal properties enhancement

Even in this case, a slight reduction of the space heating and space cooling is registered due to a better isolation level and reduction of gains/losses. The small variation furthermore highlights the fact that the original project was already designed with high performances and as result of an integrative process. Indeed, the recognition of "Gold" level in LEEDv4 well represents the enhanced performances of the building itself, therefore, the margin of improvement is restricted. Finally, the output in terms of final percentage reduction with respect to the baseline models and as resulting from the credits procedure for the final scoring of the building energy performance is reported as follows:

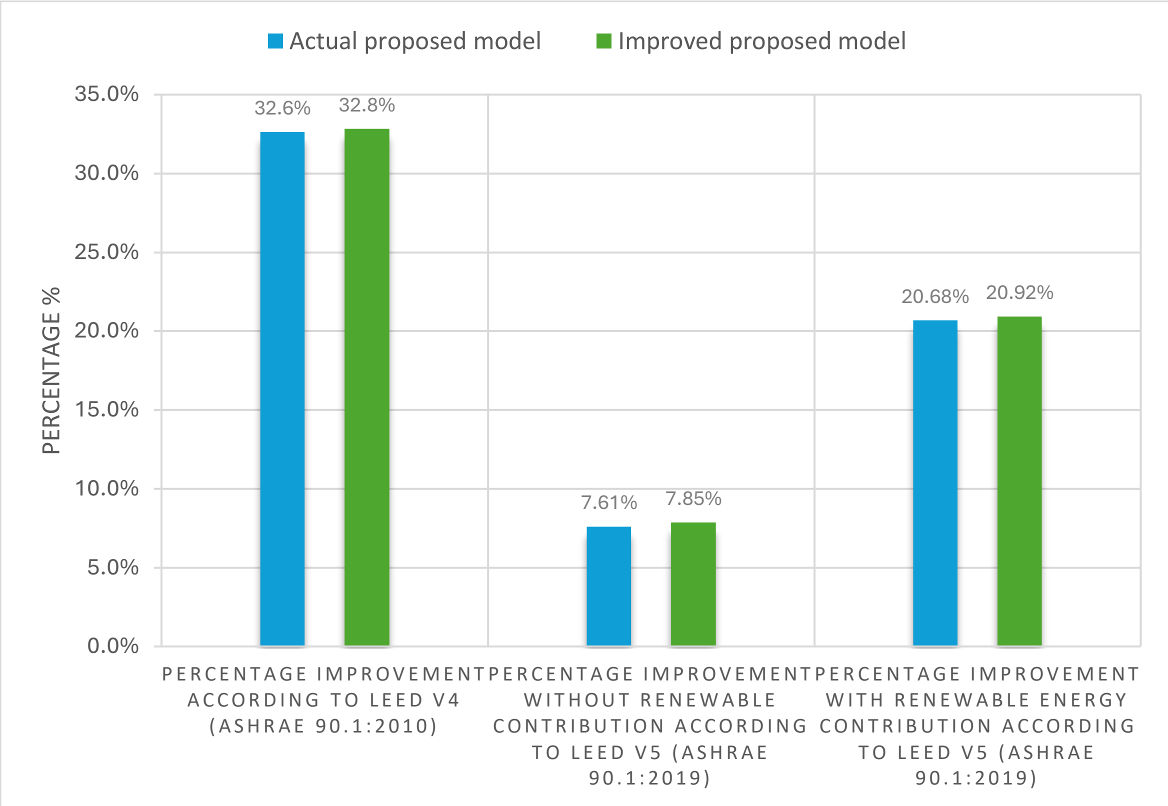


Figure 36- Output of the improved performances and comparison with actual proposed model due to roof enhancement

Clearly the obtained improvement is not sufficient to reach an upgrade in the points allocation according to LEED protocol even though an enhancement is highlighted.

All the strategies so long identified are related to the envelope enhancement in response to the major contribution assessed in cooling and heating needs analysis. The changes were related to the achievement of the minimum threshold requirements in order to better result is energy efficiency, indoor air quality and comfort.

Adoption of cool roof strategy

This enhancement strategy is spreading out in zones where the temperature rise is increasingly affecting the performances of buildings and their need for cooling. Furthermore, the application of this strategy is truly suitable for cities densely lived, indeed, it positively impacts over the heat island effect by reducing the absorbed heat that remains entrapped. The strategy, which involves the use of high-reflectance and high emissivity materials and generally represented by light membranes, paintings or tiles, guarantees the surface temperature's reduction up to 28-33 °C with respect to traditional roofing systems.[132] Indeed, thanks to the high reflectance the

[132] EU Build Up (n.d.): *I cool roof in Europa: Iniziative ed esempi* https://build-up.ec.europa.eu/sites/default/files/content/Cool%20Roofs_IT_0.pdf

greatest part of radiation is reflected back in the atmosphere and, additionally, the high emissivity reduces the portion of remaining heat which is transmitted inside consequently reducing the internal gains in summer period and cooling need. Despite the presented scenario, that seems to demonstrate the effectiveness of cool roofing and consequent energy consumption reduction, CO_2 emission reduction, some counteracting effects should be considered too. Indeed, the use of these special materials with high reflectance also affects the solar gains in the winter period, therefore it is necessary to properly evaluate the strategy in such a way to perfectly balance the need for heating and cooling avoiding compromising the effectiveness of the solution itself.

Therefore, this strategy has been implemented into the IESVE by varying the solar absorptance of the roof's upper layer to a value equal to 0.35 accordingly to the identified product.[133] The choice of a material with the above mentioned properties, with respect to material with a lower solar absorptance, was meant to avoid a huge negative impact over the possible solar gains in winter period which remain essential in the defined climatic zone.

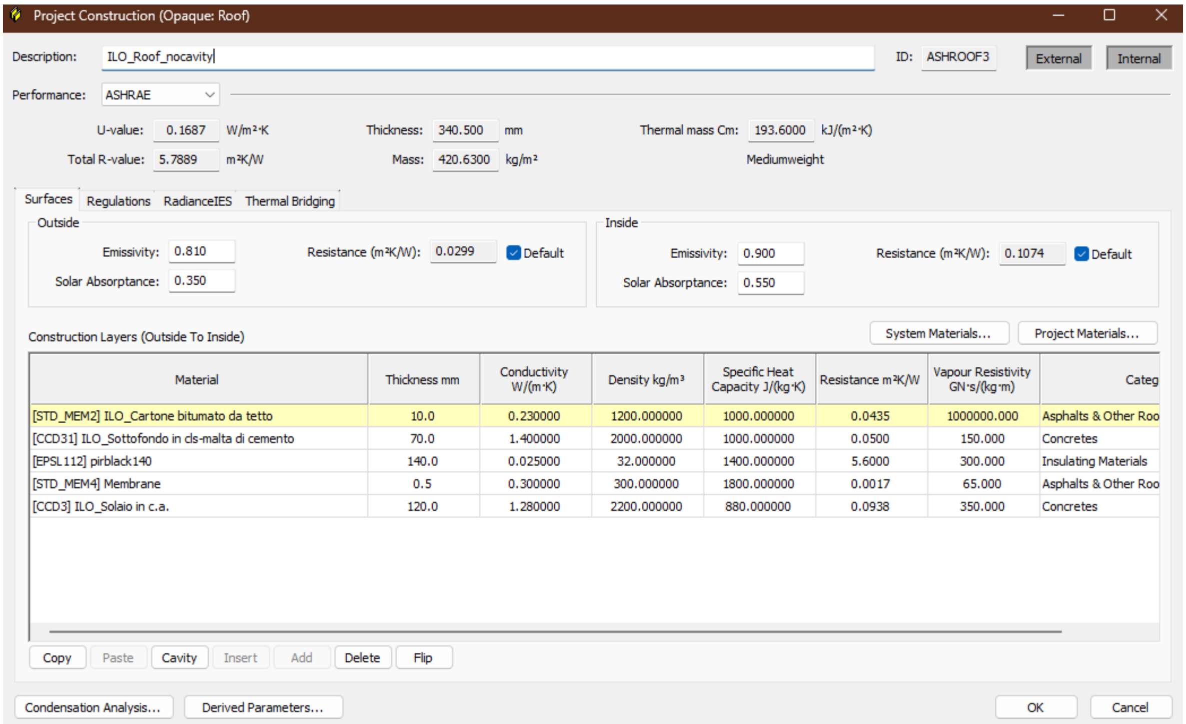


Figure 37- Cool roof modelling

[133]Bluescope (n.d.): Colorbond Steel cool roofing colours for Building Professional, Surfmist Matt, https://cdn.dcs.bluescope.com.au/download/colorbond-steel-cool-roofing-colours (16/12/2025)

As reported for the previous cases, an overview of the total annual energy use variation is properly presented to determine the contribution of the strategy on the final performance passing from the original project to the enhanced one.

Table 42- Variation of the final energy use according to cool roof improvement

Previous model	Proposed model 90.1:2010	Baseline model 90.1:2010	Percentuale di saving	Proposed model 90.1:2019	Baseline model 90.1:2019	Percentuale di saving
Total annual energy use (kWh)	261,019.27	332,543.46	**21.5%**	261,019.27	553,748.1	**52.9%**
Renewable energy (kWh)	36,927.63	/	/	36,927.63	/	/
Total Annual Energy Use included Renewable	224,091.64	332,543.46	**32.6%**	224,091.64	553,748.1	**59.5%**
New model	Proposed model 90.1:2010	Baseline model 90.1:2010	Percentuale di saving	Proposed model 90.1:2019	Baseline model 90.1:2019	Percentuale di saving
Total annual energy use (kWh)	261,431.77	332,543.46	**21,4%**	261,431.77	553,748.1	**52,8%**
Renewable energy (kWh)	36,927.63	/	/	36,927.63	/	/
Total Annual Energy Use included Renewable	224,504.14	332,543.46	**32,5%**	224,504.14	553,748.1	**59,5%**

From this overview it is evident that the adoption of the strategy, leads to weakened performances even with the above-mentioned care in the selection of the material. The impact over the main end uses is presented in the below graph:

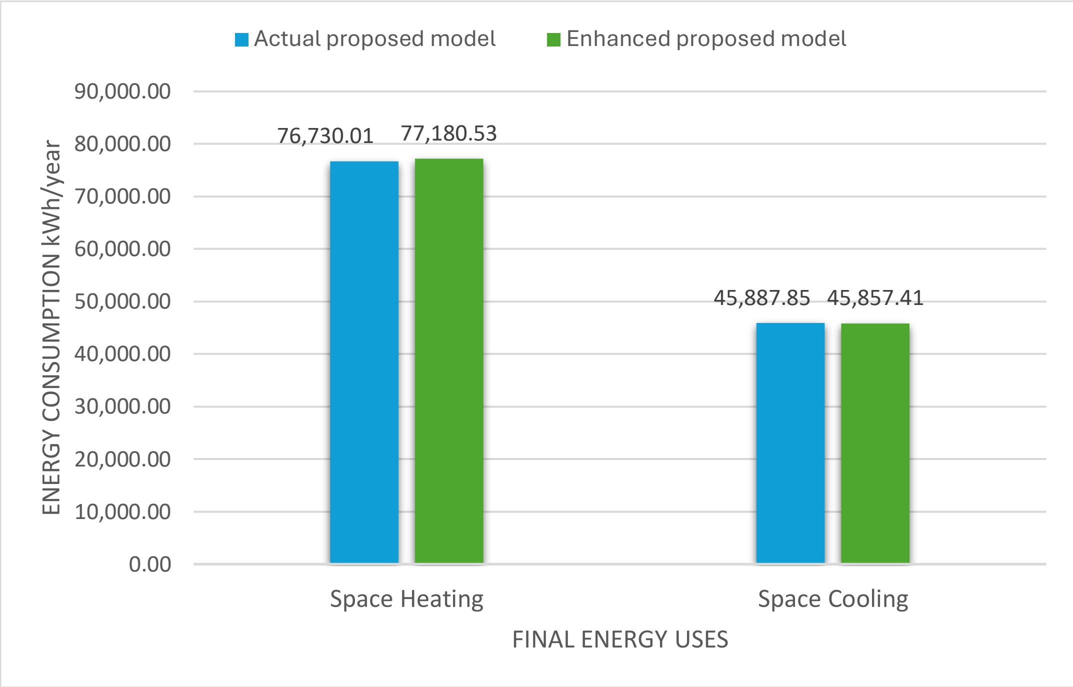


Figure 38- Impact of the cool roof strategy over the final energy uses

The graph highlights that the intervention affects, as expected, the space heating even with this modest solar absorptance value reducing the contribution of solar gains. In addition, as equally expected, there is a reduction in the space cooling but, however, not sufficient to justify the effectiveness of the considered solution due to major contribution to space heating increase more than to the space cooling decrease. Nevertheless, the final performance in terms of LEED v4 and v5 is still below reported:

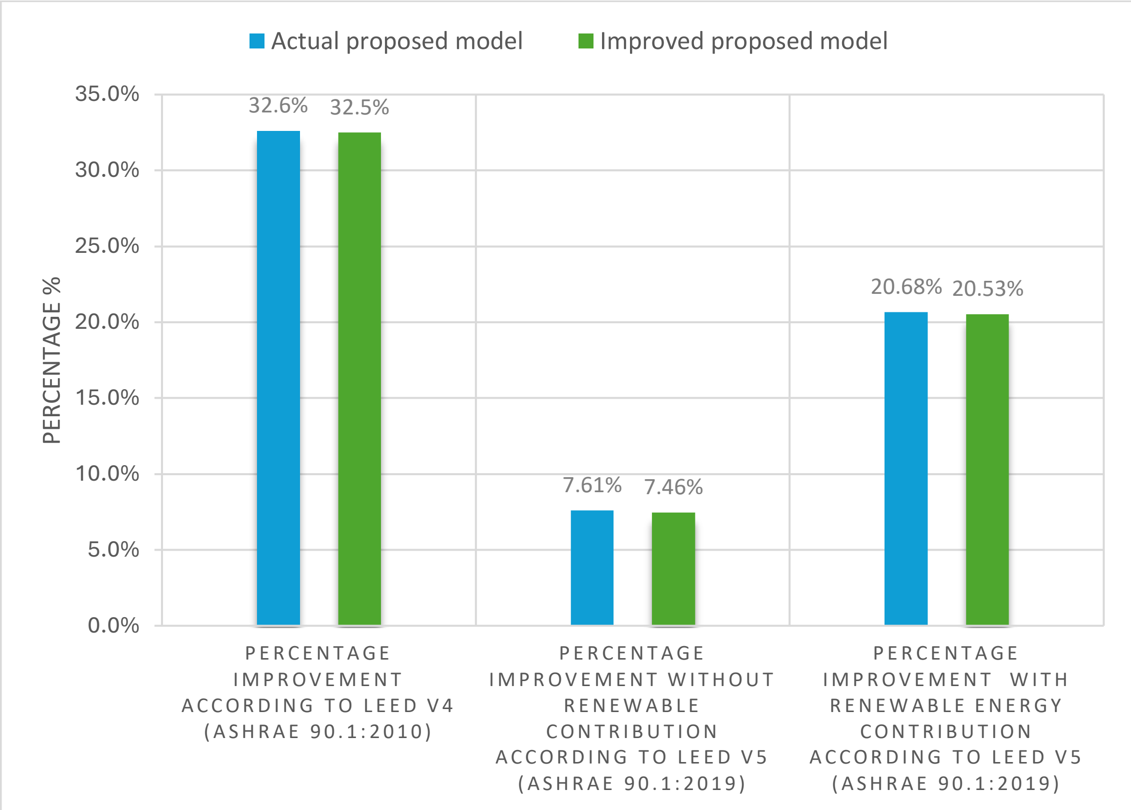


Figure 39- Output of the improved performances and comparison with actual proposed model due to cool roof

The defined output aligns with the analysis of the previous results. In any case, the intervention does not entail the final point allocation in both models realized respectively considering ASHRAE 90.1:2010 and ASHRAE 90.1:2019.

Adoption of external solar shading devices

In consideration of the relevant portion of the building cooling needs due to solar gains it has been hypnotized and consequently modelled the presence of external solar shading devices. The strategy, indeed, aims at reducing the solar gains in summer period trying to no affect the winter ones by providing a motorized system which regulated the opening and closure of the devises. The qualitative beneficial effects are several as higher comfort, reduced glare, higher capability to control interconnection between indoor and outdoor environment, among others, as well as quantifiable beneficial effects as the reduction in cooling need and reduction in energy consumption.

Focusing of the specific case study, despite the presence of brise soleils and horizontal overhangs a qualitative analysis of the solar path, thanks to the SunCast tool of the IESVE software, over the building during the days of solstices and equinoxes at each time step highlighted that the east façade was majorly exposed to sun rays and for this reason the considered strategy was only hypnotized for this building's façade maintaining the others unvaried. To proceed with the modelling, the project construction related to windows and their features have duplicated and the modification of this construction typology was only related to the windows assigned to the east façade and provided with the additional shading devices. The modelling, according to IESVE software, considers the possibility to include internal or external shading devices to the window. Once selected the exterior shading device the following data need to be inserted:

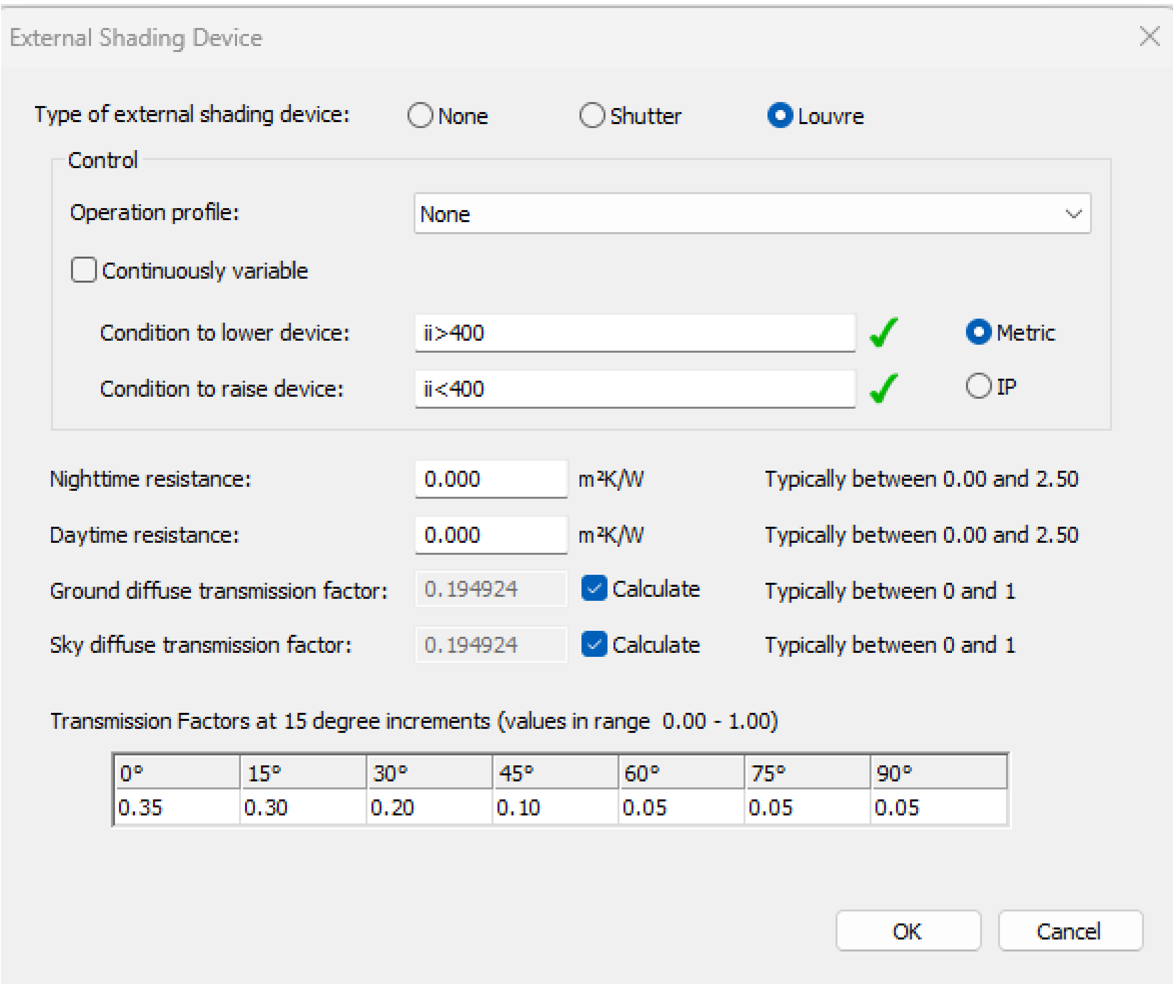


Figure 40- External shading modelling

These devices are modelled according to a motorized system able to control their raising or lowering. For this specific case, it was decided to impose this control condition in function of the solar radiation inserting a threshold value equal to 400 W/m^2 to regulate the full opening or closure of the devices. This irradiance threshold value was selected in order to avoid the closure of the shading devices during winter implying solar gains' losses which are essential in winter. Nevertheless, the selected value enables to reduce excessive solar gains during summer.

The output of the analysed solution is below reported:

Table 43- Variation of the final energy use according to the adoption of external shading devices

Previous model	Proposed model 90.1:2010	Baseline model 90.1:2010	Percentuale di saving	Proposed model 90.1:2019	Baseline model 90.1:2019	Percentuale di saving
Total annual energy use (kWh)	261,019.27	332,543.46	**21.5%**	261,019.27	553,748.1	**52.9%**
Renewable energy (kWh)	36,927.63	/	/	36,927.63	/	/
Total Annual Energy Use included Renewable	224,091.64	332,543.46	**32.6%**	224,091.64	553,748.1	**59.5%**
New model	Proposed model 90.1:2010	Baseline model 90.1:2010	Percentuale di saving	Proposed model 90.1:2019	Baseline model 90.1:2019	Percentuale di saving
Total annual energy use (kWh)	260,894.41	332,543.46	**21,5%**	260,894.41	553,748.1	**52,9%**
Renewable energy (kWh)	36,927.63	/	/	36,927.63	/	/
Total Annual Energy Use included Renewable	223,966.78	332,543.46	**32,7%**	223,966.78	553,748.1	**59,6%**

The considered result shows a minimum improvement with respect to the previous model, the slightness of this improvement is however justified by its application to only one façade of the building reducing its impact to the overall performance. Nevertheless, its impact on the most relevant final energy uses is reported:

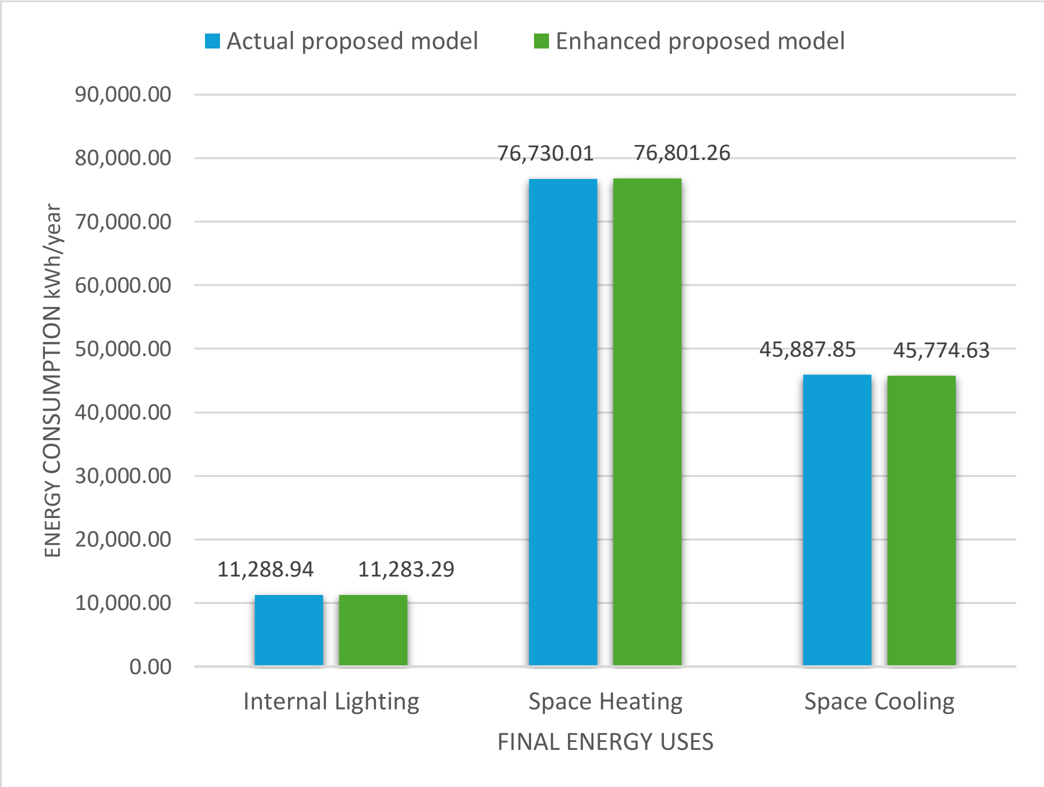


Figure 41- Impact of the solar shading devices over the final energy uses

As highlighted, the selected irradiance threshold value for the devices' control does not compromises the performance of the building in terms of interior lighting functioning. Despite this, a small increase in the space heating is registered, even if not so impacting, due to a possible lowering of the devices in mid-season reducing favourable solar gains, instead with reference to the space cooling, as expected, there is a reduction in the final calculated kWh/year.

The final performances in terms of LEED points allocation is below conducted:

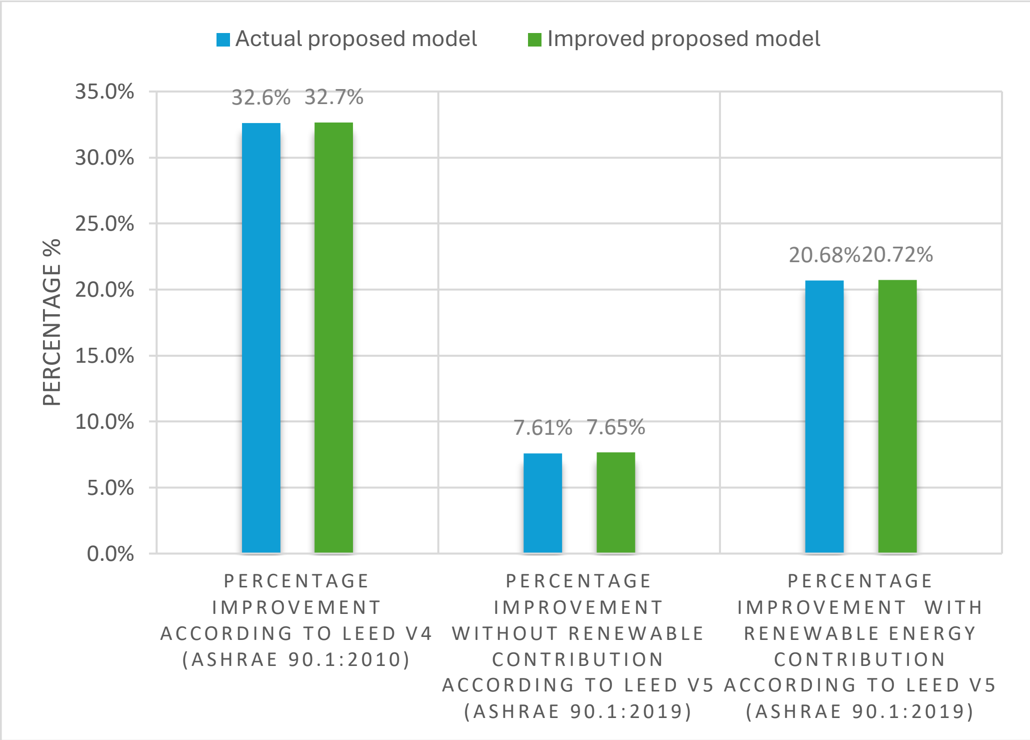


Figure 42- Output of the improved performances and comparison with actual proposed model due to solar shading devices adoption

In consideration of the application and simulation of the shading devices only on one side of the facades this strategy implies an enhancement of the final performances of the building even if not enough to guarantee additional points according to LEED protocol.

Superposition of the strategies

As final step, the superposition of the strategies was considered to evaluate the combined effects and evaluate their effectiveness, eventual strengthening or antagonistic effects. As for the previous cases a summary of the final performances is provided:

Table 44- Variation of the final energy use according to the superposition of the strategies

Previous model	Proposed model 90.1:2010	Baseline model 90.1:2010	Percentuale di saving	Proposed model 90.1:2019	Baseline model 90.1:2019	Percentuale di saving
Total annual energy use (kWh)	261,019.27	332,543.46	**21.5%**	261,019.27	553,748.1	**52.9%**
Renewable energy (kWh)	36,927.63	/	/	36,927.63	/	/

Total Annual Energy Use included Renewable	224,091.64	332,543.46	**32.6%**	224,091.64	553,748.1	**59.5%**
New model	Proposed model 90.1:2010	Baseline model 90.1:2010	Percentuale di saving	Proposed model 90.1:2019	Baseline model 90.1:2019	Percentuale di saving
Total annual energy use (kWh)	259,683.26	332,543.46	**21,9%**	259,683.26	553,748.1	**53,1%**
Renewable energy (kWh)	36,927.63	/	/	36,927.63	/	/
Total Annual Energy Use included Renewable	222,755.63	332,543.46	**33%**	222,755.63	553,748.1	**59,8%**

By purely evaluating the percentage of saving's gap between the real proposed model and the improved one, the assessment proves that the proposed strategies could have led to enhanced performances of the building independently from the LEED certifications enabling a better operational performance of it. Even in the case, to better quantify the impact of proposed modifications, an overview of the effect on the relevant energy end uses is reported.

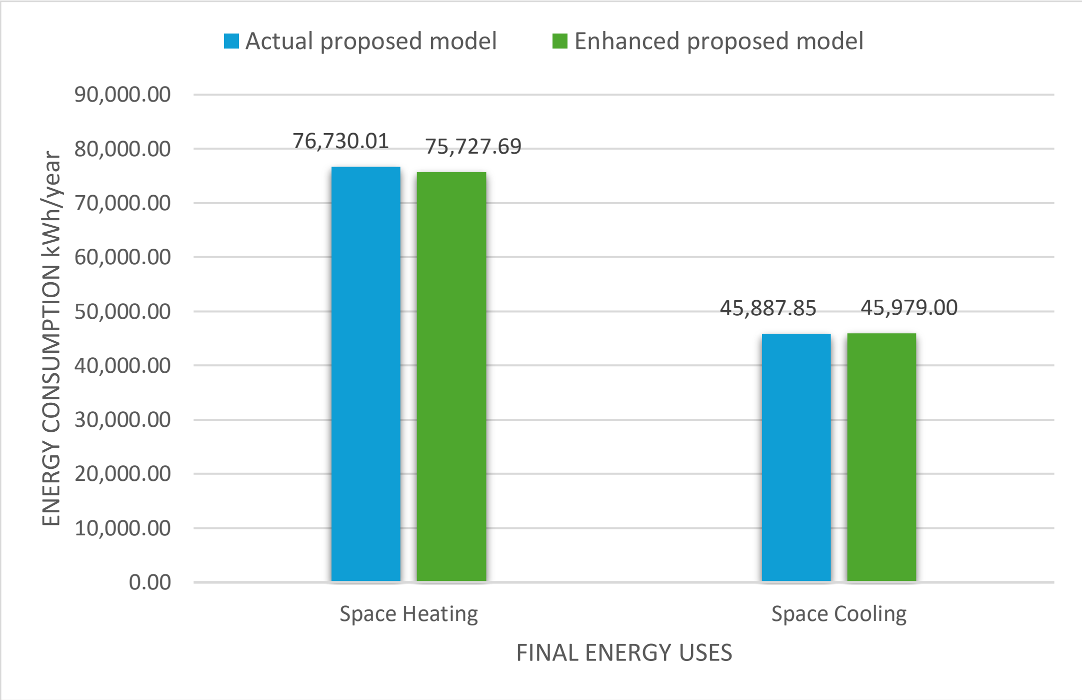


Figure 43- Effect of the superpositioning of the strategies over the main final energy uses

It is worth noting that the superposition of the effects does not lead to final output obtained as a simple summation of the results from the above analysed strategies, indeed, the dynamic simulation considers the interrelationship between the strategies and how their contemporary application affects the building behaviour, therefore, is not so unusual to obtain these results that seem to be counterintuitive by just considering the previous single results.

Indeed, a slight improvement in the space heating can be registered by the contemporary application of the strategies due to a better insulation of the envelope itself and the adoption of selective glass units, nevertheless the effect is different of the space cooling, even if of small entity. In this case the increased level of insulation sealed the building with respect to the outdoor environment reducing the transmission between inside and outside leading to the heat's entrapment due to internal gains. However, the small entity of the variation can be purely attributed to the sensitivity of the software, setting in any case the basis for possible future implementations.

Finally, the results in terms of percentage improvement and scoring according to LEED protocols is summarized as follows:

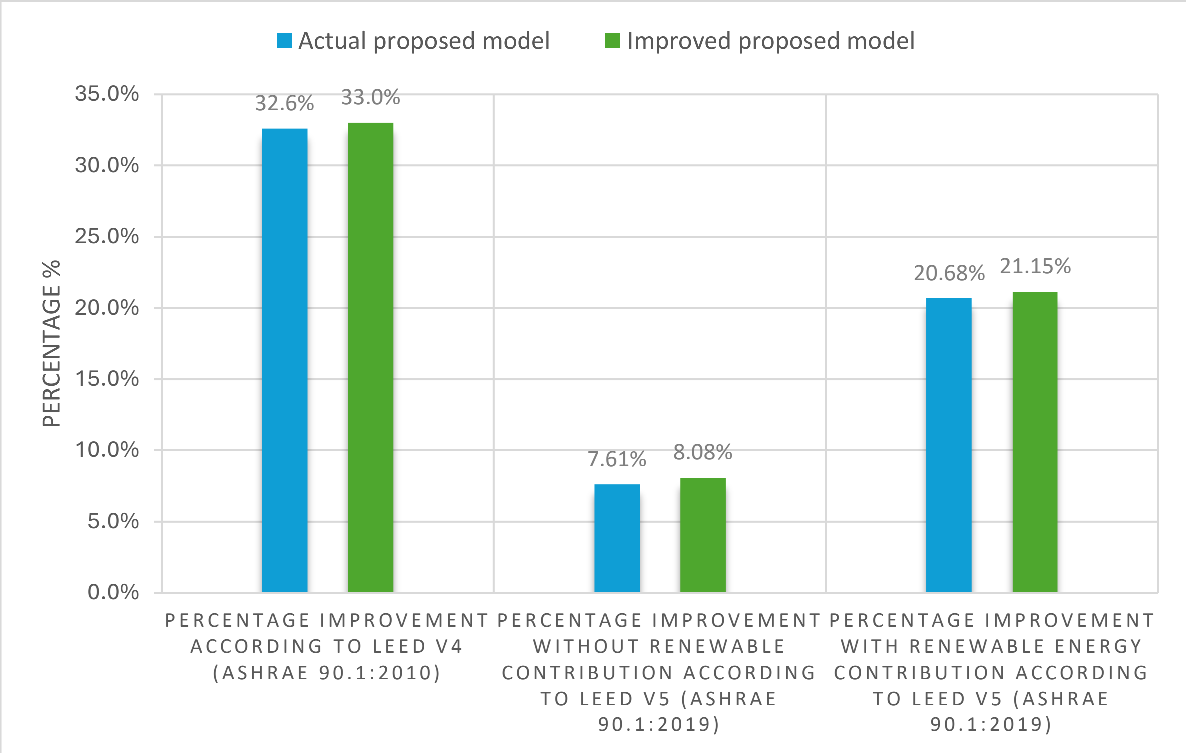


Figure 44- Output of the improved performances and comparison with actual proposed model due to superposition of strategies

Despites the improvement strategies are not enough consistent with an upgrade in the achievement of a higher score, they reduce the gap with the upper threshold value for the allocation of an additional point that specifically corresponds to the 35% for LEEDv4 and the 9% for LEEDv5 following the path 1 that doesn't account for the renewable energy production. This demonstrated the validity of the conducted analysis that, overcoming the finality of LEED recognition, present effective and quantitative output in terms of building performance enhancement.

Nevertheless, the graph below provides a clear overview of the reduced impact of the enhancement strategies due to the already efficient technologies, operation and materials, selected and designed, that conducted the building to the recognition of LEED v4 level "Gold", demonstrating the marginality of further enhancements at least as regards the envelope enhancement and control over solar gains.

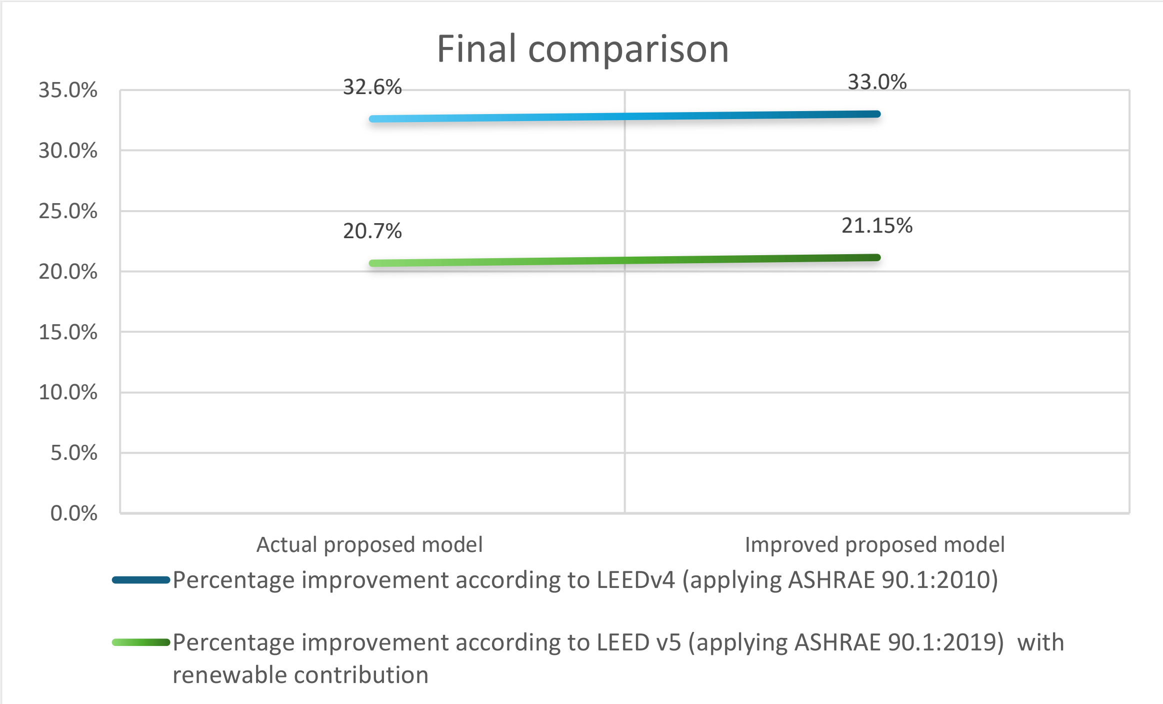


Figure 45- Final comparison

Additionally, the resulting reduction and the gap in the performance of the building passing from ASHRAE 90.1:2010 to the ASHRAE 90.1:2019 and from LEED v4 to LEEDv5 highlights the stringency of the standard more than a decreased efficiency of the building itself. Indeed, this change perfectly demonstrates the increase of standard's rigorousness and the effect of metric shift passing from an evaluation based on the cost effectiveness of the intervention to the assessment according to future energy source as a response to varied focus areas and objectives of the LEED protocol and energy standard.

Conclusions

The thesis work assessed the impact of variation of the energy code ASHRAE 90.1 in the versions 90.1:2010 and 90.1:2019 and the impact of the varied procedure of LEED certification's recognition to buildings according to the new LEED v5 protocol in response to variable global climatic goals and challenges. It, furthermore, analyses the effectiveness of the current design practices with respect to the ecological transition supported by the standards' evolution.

The investigation of the varied requirements and procedure led to a comprehensive vision of the stringency of the cited standards and protocols highlighting the gap reduction between the target and the recognized performances of building. Indeed, the analysed case study, already recognized with LEED v4 "Gold" level, has been investigated with respect to the "enhanced energy efficiency" credit regarding the whole-building energy simulation, to assess the variation in the final performance with respect to the updated LEED v5 credit. The previous awarding to level "Gold" of LEEDv4 certification to the analysed case study underlines the innovation and forward-looking of the adopted technologies with respect to the applied standard version, whereas LEED v5 recognizes the building with a reduced final performance still ensuring the certifiability of the defined case study and the suitability for points allocation. Anyway, this decreased final percentage of improvement does not depict inefficiency or low quality of the designed building instead underlining, above all, the standard evolution towards higher objective. The result, indeed, most represents the standardization of the strategies previously considered innovative.

The thesis, furthermore, investigated possible alternative strategies, applied to the specified case study, with the scope of determining their effectiveness in the overall building performance recognition according to LEED v5 protocol.

Among the possible improvement strategies of building energy performance, the considered ones focused on the envelope enhancement and inclusion of automatized solar shading devices since the envelope investigation represents the first milestone in the design process. Indeed, a proper and effective envelope definition covers a key role in the determination of the building needs that subsequently affect the HVAC operation. An improvement of these last, indeed, may be representative of enhanced and more efficient systems more than representative of the whole building synergy and dynamic behaviour. Additionally, the envelope enhancement stands as a long-term intervention that sets the basis for the whole building useful life.

Specifically, the conducted study analysed the effectiveness of building envelope improvements in compliance with the mandatory provisions of the updated ASHRAE 90.1 standards and of Italian legislation. In detail, it considered the improvement of optical and thermal properties of the transparent envelope and enhancement of thermal properties of the roof component. Additionally, included strategies which recently spread out in the building design as the cool roof strategy and, finally, the application of automatized system of control over solar gains with the aim of reducing the overall energy impact of the building.

The analysis demonstrated the validity of the considered strategies whose implementation reduces the gap with the upper threshold of LEEDv5 for a better scoring and, beyond any award, guarantee an advanced performance of building. Nevertheless, the overall assessment resulted in the evidence of reduced margin of manoeuvre for buildings which are already designed as performant, in consideration of an omni comprehensive vision of the building itself and of its social and environmental impacts. Indeed, the proper design of the original project reduces the incremental potential leading to an asymptotic behaviour towards enhanced efficiency.

The thesis work, through data analysis, underlines the importance of conceiving buildings in deep correlation with the surrounding environment more than a “per se” entity strongly reinforcing the belief that the interaction with the environment and integrative process can lead to enhanced results more than the mere exploitation of resources, adapting the design procedure to variable challenges. It is recognized that the implementation of energy efficient and mitigating solutions, can provide beneficial effect on the building performance, when combined together, and increasingly providing to adaptation and mitigation of the building stock over the climate change.

Finally, on the basis of the relevant results obtained, it can be argued that the current business practises and design strategies enhancement, even if standing as valid and resilient over years, conduct to a lower recognition of the building performance due to the increased stringency of energy codes and green building rating system that shifted the focus on higher goals in the field of climate resilience, mitigation and transition toward a decarbonized building stock.

Future implementations

The analysed solutions mainly devoted to the envelope enhancement and a possible control strategy over the solar gains, as first step in the hierarchic design, highlighted an asymptotic behaviour and convergence of the target standard and the proposed model considered when applying evolved and mature energy standards and rating systems as the presented ones. Nevertheless, the obtained results show that further strategies could lead to enhanced results.

The conducted analysis and consequent results point out that a shift of focus on further advanced strategies is required as, for instance, the adoption of a dynamic response of building envelope. An eventual strategy can be the free cooling strategy that could provide beneficial exchanges with the outdoor environment whenever the external temperature during night can mitigate internal loads and excessive temperature in the indoor environment reducing the final energy uses impacts. Another passive thermoregulation strategy, that can be considered in new constructions facing the updated energy standard's boundaries, is the adoption of phase changing materials that through change of state stabilize the internal comfort making the envelope adaptive to variable environmental conditions and suitable for future enhanced codes. The strategy of translation from immobility of building properties to dynamicity, responsivity and proactivity can be the key for enhanced building stocks able to stand as valid and to preserve their efficiency feature over years and over any standard variation.

The overall output could suggest that, from a technical point of view, a more detailed modelling could lead to enhanced results by reducing the level of approximation specifically when the asymptotic behaviour reduces the marginality of involved intervention. The removal of simplification in modelling can be related, for instance, to the proper definition of HVAC system's performance curve when working at partial-load or full-load representing a technical solution, for modellers, to withstand the standard stringency. This limitation in approximation's level validates the effectiveness of identified design choices in simulations where the incremental beneficial effects wear thin.

Finally, the leading direction towards upper standards and limits leaves the door open to future evolution and implementation of modelling approaches, technical solutions and control systems that respond to dynamic impulse. This overcomes the operational phase of building structured according to fixed schedules based on assumed habits and percentage of occupants and provides, instead, perspective of future machine learning and IOT integration to better simulate the real behaviour of buildings and to adapt the systems operation and controlled motorization according to predictions in conditions' variation.

These strategies do not only provide an enhanced behaviour whose validity in time is guaranteed by adaptation and mutable features but additionally guarantee precision and reliability of the final performance evaluation increasing the marketability and attractiveness to clients.

Based on the final results of the thesis work, it is worth noting that a similar analysis conducted over an extended portion of the building stock could lead to an increased awareness of the building stock impacts and potentialities over climate change. The study furthermore provides some possible paths to follow to redirect the decision-making process and the design choices with the objective of guaranteeing the efficiency and forward-looking effectiveness of the implemented strategies to positively reduce the building energy impact over the years.

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