Supporting the launch of advanced technological solutions on the energy-efficient building market through new financial-economic metrics

Summary

Nowadays, buildings play a central role in the clean energy transition for both their ability to save energy and reduce emissions, and their potential to promote health and well-being of occupants. Specifically, taking action on the building sector has become a priority to align with the net zero emissions scenario by 2050, as it accounts for 30% of global final energy consumption and 28% of energy-related CO_2 emissions worldwide. Simultaneously, as people usually spend more than 90% of their time indoors, ensuring satisfactory indoor air quality (IAQ) represents a key measure in the design of future buildings that should be not only smart, able to monitor and manage energy optimally, but also healthy, able to positively influence the health and well-being of their occupants.

These features are the focus of this Ph.D. dissertation as it is set in a specific historical period, which includes the Covid-19 pandemic emergency in 2020 and the Russia-Ukraine war in 2022. Therefore, ensuring an adequate IAQ in the indoor environment for human health and well-being in response to the pandemic, as well as improving energy efficiency in buildings through end-use electrification in response to rising energy prices, are identified as the two main pillars in the design and operation of the building of the future and the main frameworks of the two case studies.

In the light of the above, building technology is widely recognised as the key instrument in improving the energy efficiency and reducing the CO_2 emissions, while ensuring a good IAQ in buildings. This Ph.D. thesis addresses the challenge faced by industrial companies in introducing their technologies and make them competitive in the current building energy market despite the high investment costs that may prevent consumers from investing in them. Therefore, the Ph.D. dissertation aims to guide and support industrial companies in the launch of advanced technological solutions, which play a key role in the design and operation of the building of the future, in the current building energy market.

Two applications are presented and discussed, aiming to address the aforementioned challenges. Starting from the first application, in line with the main targets of ensuring adequate IAQ and promoting human health-related status following the spread of Covid-19, great focus is put on the role of air filtration technologies in reducing the airborne transmission of indoor

contaminants. Specifically, this application aims to valorise the benefits offered by the implementation of innovative biocidal and photocatalytic filtration technologies in air handling unit configuration compared to the use of traditional filtering solutions in different school building typologies. The need to economic-financial metrics in the assessment and comparison of alternative technological solutions was demonstrated through the application of the Cost-Benefit Analysis methodology. This tool has proven to be effective in supporting investment decision-making process of industrial companies enabled to demonstrate that the high investment costs associated with the use of innovative filtration technologies can be totally repaid by energy savings and socio-economic benefits (e.g., health and learning performances) in the long-term.

Moreover, the second application of this Ph.D. dissertation, in line with the main challenges of ensuring long-term energy security and achieving a clean energy transition, focuses on the electrification of end-use building energy consumption through the use of renewable energy sources. For this reason, the adoption of heating and cooling systems that rely on a carrier that is no longer gas has led to heat pumps being considered as the key technology for increasing the overall energy efficiency of the system and reducing the environmental impact of the building sector. Contrary to the previous analysis, this study does not rely on economic-financial assessments as the high investment costs of heat pumps are covered by the introduction of financial incentives (e.g., the Superbonus 110% in Italy) that promote their market penetration. Therefore, this application aims to demonstrate the benefits, in terms of energy savings and CO_2 emissions reduction, offered by air-to-water heat pump technologies as an alternative to conventional condensing boilers in typical Mediterranean residential buildings. The development of a step-by-step methodological approach, which includes the definition and computation of specific key performance indicators through the application of a quasi-steady-state simulation, has proven to be effective in supporting industrial companies. In fact, this approach demonstrated the energy and environmental benefits of this technological replacement in both new and existing buildings.

To conclude, this Ph.D. dissertation is the result of a collaboration during these years with an external industrial company with expertise in this field. The research activity has allowed to identify potential methodological approaches to assess the energy, environmental, and socio-economic benefits of implementing advanced technological solutions in the Heating, Ventilation and Air-Conditioning system. Specifically, the main results of the two applications allowed to support the industrial company to launch its advanced technologies in the building energy market, demonstrating to consumers that the high investment costs were totally repaid by the multiple benefits.

The originality of this Ph.D. dissertation lies in the first application, in which a widely-used evaluation technique was applied within a rarely-explored domain, specifically the energy sector, to assess the overall IAQ and its impacts on occupants' health and well-being. Additionally, another interesting aspect relates to the replicability of the proposed methodology for other emergencies in the future. While the second application addresses a current issue, by providing interest insights into local and non-local energy policies.