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Key Performance Indicators: their use in the energy efficiency retrofit for historic buildings

Beatrice Bartolucci[a,b], Francesca Frasca[c], Inês Flores-Colen[d], Chiara Bertolin[b]*, Anna Maria Siani[c]

[a]*Department of Earth Science, Sapienza University of Rome, Piazzale Aldo Moro, 5, 00185, Rome, Italy*
[b]*Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology, Richard Birkelands vei 2B,7034, Trondheim, Norway*
[c]*Department of Physics, Sapienza University of Rome, Piazzale Aldo Moro, 5, 00185, Rome, Italy*
[d]*CERIS, DECivil, Instituto Superior Técnico, University of Lisbon, Av. Rovisco Pais, 1049-001 Lisbon, Portugal*

Abstract

Energy efficiency in the built environment is gaining ground due to policies to mitigate climate change impact. This contribution focuses on investigating the role of Key Performance Indicators (KPIs) that can be useful for the energy retrofit of historic buildings. The KPIs were hinged upon PESTEL domains (Political, Economic, Social, Technological, Environmental, and Legislative) in order to define objective and measurable criteria that allow for a comprehensive evaluation of an energy retrofit performance. A literature review carried out through the PRISMA flow chart allowed to select 59 papers, subsequently analyzed to investigate the occurrences of the selected KPIs. The findings showed that the political domain is the less considered, differently from the legislative one, whose KPI highlighted the importance of being compliant with regulations. The domains representing economic, social, technological, and environmental KPIs are mostly present together in the scientific literature, underlining the importance of a holistic and multidisciplinary approach. Future research should be oriented towards delineation of best practices to meet sustainability and conservation needs, and to better integrate current policies and international requirements.

Keywords: Key Performance Indicators; Energy Efficiency; Historic Buildings; PESTEL Analysis.

* Corresponding author. Tel.: +4748507716.
E-mail address: chiara.bertolin@ntnu.no

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1. Introduction

The building sector is responsible for approximately 40% of European Union (EU) energy consumption and 36% of carbon dioxide equivalent (CO_{2eq}) emissions. About 50% of all the EU-28 buildings are estimated to be not energy efficient and the 95% of the building stock needs to be renovated and decarbonized for achieving the goal of EU Green Deal, i.e., the climate neutrality and reduction of CO_{2eq} emissions by 2050 (International Renewable Energy Agency and European Commission (2018)). Therefore, the EU has promoted research focused on increasing energy sustainability while reducing the carbon footprint. In recent years, many governmental energy grants and new loan programs have been activated in the EU countries to support the retrofit of buildings, which include all interventions aimed at both improving the energy performance and the thermal comfort for occupants (Mazzarella (2015), and Posani et al. (2021)). Other aspects should be considered such as the building age, the climate zone, the thermal and physical properties of building materials (e.g., thermal transmittance, water vapor absorption), and the building use. In case of historic buildings, an energy retrofit is a challenging task since it has to combine the conservation requirements of the building, its aesthetics, and the surrounding cultural environment according to EN 16883:2017. In this framework, any energy retrofit should be addressed through a systematic approach to facilitate the proper improvements. In the last decades, building energy simulation is used to evaluate in advance the effectiveness and suitability of interventions (Lo Faro et al. (2021)). More recently, this tool is used to assess the impact of interventions from both conservation perspective and thermal comfort of the users (Coelho et al. (2019); Frasca et al. (2019a, 2019b, 2021); Mancini et al. (2016)). As the environmental impact due to the emission of CO_2 is a core topic for the building sector, the Life Cycle Assessment (LCA), standardized in the framework of UNI EN ISO 14040:2021 and UNI EN ISO 14044:2021, is used to evaluate the retrofitting interventions in terms of environmental sustainability and circular economy. LCA can be used in parallel with the Life Cycle Cost (LCC) to simultaneously assess the economic impact during the life cycle.

The present work aims to outline the state of the art related to case studies focused on energy retrofit of historic buildings, considering the impact of climate change, and the use of innovative methodologies such as LCA to make more efficient and sustainable the refurbishment process for those buildings. Then, quantitative, and measurable criteria (i.e., Key Performance Indicators, KPIs) underlying the choice of the suitable energy retrofit will be searched within the content of the selected papers, by structuring them in the framework of the PESTEL domains (Political, Economic, Social, Technological, Environmental, Legislative) (Rothaermel (2015)).

2. Materials and Methods

2.1. Selection of scientific papers

Scientific papers dealing with energy retrofit in historic buildings were identified via *Scopus* and *Web of Science* (WoS) databases without setting a starting year and stopping the search at the end of 2022. The systematic literature review was performed through the three-steps process “PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) flow diagram” (Page et al. (2021)). The query strategies involved ten combinations of ten keywords, with the Boolean operators “AND” and “OR” in the field “titles, abstracts, and keywords”: “zero emission”, “refurbishment”, “retrofit”, “intervention”, “building”, “historic* building”, “neighborhoods”, “conservation”, “climat* change”, “LCA”. The asterisk has been used on some words to include the various forms in which they can be found in the literature (e.g., historic/al) thus avoiding many duplicates. In the first step, 1194 papers were extracted from both databases. Then, after the merge, duplicates were removed. The 621 remaining papers were further screened to exclude the ones with no authors (7 papers), no English language (18 papers), no full text (25 papers), and out of scope (240 papers). In the end, 59 papers were critically reviewed, (Agliata et al. (2020) - Zazzini and Capone (2018)).

2.2. Definition of Key Performance Indicators (KPIs)

Key Performance Indicators (KPIs) are objective and measurable criteria commonly used in the corporate/business sector. This contribution aims at extending the use of KPIs to the field of historic building retrofit. KPIs were retrieved through a critical reading of the case studies present in the reviewed papers and then clustered in the six domains of the PESTEL Analysis (Rothaermel (2015)), i.e., the Political (P), Economic (Ec), Social (S), Technological (T), Environmental (En), and Legislative (L) domains. The KPIs are listed in Fig. 1, reported by number in each PESTEL domain.

	Key Performance Indicators
P	**1**. Government Influence; **2**. Government Policy
Ec	**1**. Investment costs; **2.** Operating and Maintenance costs; **3**. Pay-back period; 4. Economic savings
S	**1**. Change in health & well-being; **2**. Social awareness; **3**. Change in intended use; **4**. Heritage significance; **5**. Visual impact
T	**1**. Retrofitting materials; **2**. Energy consumption savings; **3**. Historic materials risk; **4**. Compatibility of materials
En	**1.** Change in IEQ; **2**. Change in EPC; **3**. CO_{2eq} emission savings; **4**. Impact on the outdoor environment; **5**. CC impact
L	**1**. Compliance with current legislations

Fig. 1. KPIs clustered in PESTEL domains (IEQ = Indoor Environmental Quality, EPC = Energy Performance Certificate, CC = Climate Change)

Once all the criteria were outlined, the number of KPIs per paper were counted to define which KPI is actually the most considered in the reviewed scientific literature. Then, the KPIs' occurrences were also transposed into "PESTEL units" through Equation 1. This proposed equation allows to determine the occurrences of PESTEL domains by normalizing them based on the number of categories per domain.

$$\%_{PESTEL} = \frac{n}{\Sigma n} \cdot 100 \qquad (n = n_{KPI}/n_{cat}) \tag{1}$$

Where n_{KPI} are the occurrences of KPI in each domain and n_{cat} is the number of categories of KPIs per each domain (e.g., political domain has two criteria, so $n_{cat} = 2$, with 16 occurrences for P1 and 13 occurrences for P2).

3. Results and discussion

3.1. Historic buildings retrofit in scientific literature

The Journal Citation Report categories via Web of Science has provided information about the most occurring subject areas associated with the selected papers, i.e., "Environmental Science", "Energy & Fuels", "General Energy", "Green & Sustainable Science & Technology", "Environmental studies", and "Construction & Building Technologies". Journals dealing with heritage and conservation are two, with one publication each: "Journal of Cultural Heritage" and "Journal of Architectural Conservation", highlighting as this topic is mostly linked to engineering and architecture disciplines, in particular to those involved in energy studies. The reviewed papers describe the retrofit in 62 case studies: 54 are located in Europe (33 in Italy), and eight in non-European countries, and this suggests that European culture is paying more attention to this type of issues. Most of the case studies are historic buildings built in 18^{th}, 19^{th}, and 20^{th} centuries mainly located in urban contexts (57 sites), three in rural, and two in not defined sites. Specifically, 16 places are residential buildings, and 37 are non-residential, divided into the following categories: schools and universities (11), museums and galleries (8), workplaces (8), industrial complexes (4), worship places (3), and hotels (3); the remaining nine sites are not defined. The review papers showed that a major simulation contribution is perceived: 57 out of 59 papers use building simulation tools (with BIM and/or BEM software) sometimes combined with LCA. As for this latter, the most used impact assessment methods are Impact 2002+, ReCiPe, EDIP 2003, Ecoinvent V.3 database, ECO Indicator 99. Moreover, the case studies treating environmental impacts are not using the same approach concerning the LCA stages considered in the analysis of materials and processes. Actually, four case studies are approaching the "Cradle to Gate" stage (A1-A3 phases), i.e., they only assess the impact of the materials production, two of which are also measuring the "transport to site" stage (A4 phase); 17 case studies treat the LCA as "Cradle to Grave" stage (A1-C4 phases), which include the materials production (A1-A3), the construction process (A4-A5), the Use stage (B1-B7), and the End of Life stage (C1-C4); finally, only one case study treats the "Cradle to Cradle" stage, where the LCA is assessed beyond the system boundary (A1-D Phases, all LCA stages). Since the energy/environmental field is prevalent in this research, information was sought on how energy consumption and CO_{2eq} emissions have changed from "*pre-*" to "*post-*" retrofit. Table 1 presents papers considering energy consumption and CO_{2eq} emission savings simultaneously, both expressed in percentage (%). Retrofit where both passive (e.g., application of thermal insulation) and active (e.g., replace of air conditioning systems) approaches are used lead to greater savings.

Table 1. List of case studies, i.e., the reference (1st column) with building type (2nd column) and construction year (3rd column), containing both energy consumption and CO_{2eq} emissions savings (last two columns) both measured in percentage, after the retrofit intervention (4th column).

Reference	Building type	Year	Retrofit intervention	Energy Consumption Savings	CO_{2eq} Emissions Savings
Bennadji et al. (2022)	Building stock	Pre 1945	Replacement of windows Installation of mechanical ventilation with heat recovery	87 %	76 %
Ascione et al. (2022)	University	1224	Insulation of external vertical wall and roof (PUR) Replacement of windows New heat pump Installation of PhotoVoltaic	55.8 %	46 %
Ascione et al. (2017)	University	1513	Replacement of windows Replacement of the boiler	59%	57%
Dalla Mora et al. (2015)	Residence	1894	Insulation of internal and external (inner part) walls (EPS + MW) and roof (WF) New insulated windows New mechanical ventilation Installation of PhotoVoltaic New heat pumps and chiller	92.5 %	81 %
Knox (2015)	Residence	1933	Replacement of HVAC Setting of solar hot water Installation of PhotoVoltaic	65 %	32 %

3.2. Analysis through the Key Performance Indicators

Figure 2a shows the number of papers considering a specific KPI. It was found that the most used KPIs in the literature review are:

- T2, "Energy Consumption Savings", cited by 53 papers, confirming that the design of the retrofit mainly aims at improving the energy consumption of the building.
- S4, "Heritage significance", considered by 49 papers, meaning that declarations of interest as well as protection and conservation of historical buildings by law play a key role in designing the retrofit project.
- En3, "CO_{2eq} emission savings", considered by 38 papers. This KPI considers both the emissions of CO_{2eq} and other harmful substances in the environment. This aspect is usually considered in LCA.
- L1, "Compliance with current legislations", 44 papers referred to the legislations in use, highlighting the importance of strictly follow the regulations.

The other KPIs have been considered by several papers ranging from six to 28 (Figure 2a). The social domain is the least explored: S2 (Social Awareness, six papers), and S3 (Change in intended use, seven papers). En2 (Change in Energy Performance Certificate) reach at least 10 papers and it starts appearing from 2015, testifying as the energy issue has been more recently studied in the scientific literature about the retrofit in historical buildings.

Figures 2b and 2c were plotted taking as reference values the "$\%_{PESTEL\ units}$" (from the proposed Eq. 1). This analysis confirms that the legislative domain is mandatory to be compliant with the regulations during a retrofit intervention. Comparing the two different periods (Figure 2c), the economic domain seems to have had a slight decrease in interest in papers (from 19% to 12%), while the technological and environmental domains had a slight increase of 3% and 4%, respectively, as if to demonstrate a greater tendency to activate interest in issues related to environmental protection and climate change.

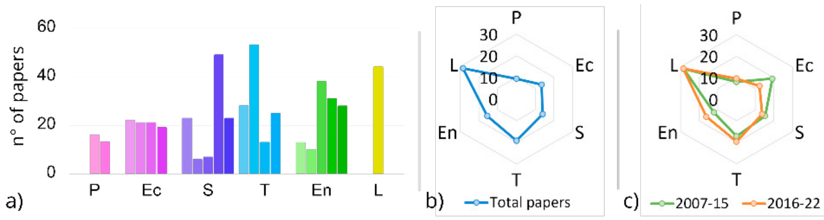

Fig. 2. a) Column plot showing the most impactful Key Performance Indicators. b-c) Radar plots showing the “$\%_{\text{PESTEL units}}$” considering the whole number of analyzed papers (b) and the number of papers split over two periods: 2007-2015 (green line) and 2016-2022 (orange line) (c).

Figure 3 shows how a combination of KPIs occurs in the reviewed papers. The social and technological domains are presented coupled in about 90% of the cases (15 groups out of 17) emphasizing great attention to users and conservation aspects (social field) together with material and structural aspects (technological field). Moreover, a great correlation between Social, Technological, Environmental and Legislative domains is perceived, and the number of papers increases when these domains are considered in conjunction with the economic field. These articles deal with the topic of energy retrofitting in a holistic way, in some cases even making it explicit in the title, although the main focus is related to the technological and environmental domains (i.e., energy consumption and related environmental impacts). These "EcStEnL" articles are all very recent, (from 2017 onwards), and this demonstrates the importance of new policies and legislation, such as the EBPD 2018/844 on the energy performance of buildings that amended already existing European directives (Ogut, O. et al (2023)), or such as the Paris Agreement, which promotes economic growth and sustainable development.

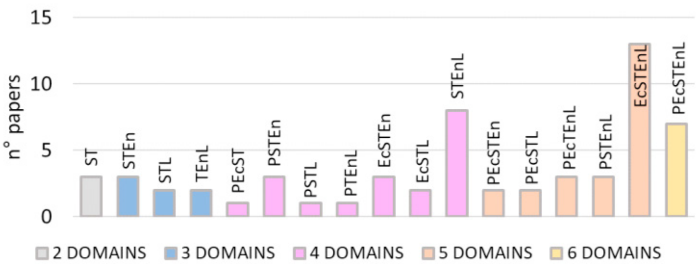

Fig. 3. Combination of PESTEL domains per number of papers.

4. Conclusions

A retrofit intervention on the historical building sector means focusing attention on recent legislation aimed at a "green transition" by 2050 (i.e., Green Deal). This paper aimed at determining the criteria (Key Performance Indicators, KPIs) underlying the choice of the retrofit for historical buildings. First, we explored 59 papers and a total of 62 case studies on the retrofit of historical buildings. Then, the reviewed case studies were critically analyzed considering KPIs categorized in the six domains of the PESTEL Analysis. It emerges that the political domain is the less considered in scientific literature, probably due to the near lack of real retrofit scenarios with respect to the simulated ones. The interest towards the economic domain has tended to decrease in the most recent papers, but it’s still taken into account as it allows to estimate the cost feasibility of the energy retrofit. The social domain is related to two main categories, concerning the impact of the retrofit on: 1) the society, paying attention to KPIs related to users’ well-being (i.e., quantifying thermal comfort with indices), and 2) the heritage building, with great attention paid to the cultural value significance (i.e., citing the historical value to be maintained on a visual level). The technological domain seems to be closely related to the field of application to which the papers of this review mostly belong, i.e., energy and environmental science/engineering studies. The environmental domain is mainly explored through the LCA and global warming calculation. Although a high quantity of papers is linked to these aspects, no unique calculation methodologies or impact assessment methods are used. Finally, the legislative is the most considered domain, pointing out it is mandatory to strictly follow the regulations when retrofitting historical buildings, both during a simulation scenario and a real retrofit case study.

The PESTEL Analysis can be a useful tool in retrofitting historical building to outline a holistic approach methodology that considers both the heritage significance and the environmental related impacts within the mitigation and CO_{2eq} emission reduction perspective. For this reason, KPIs were hinged upon PESTEL domains to define objective and measurable criteria that allow for a comprehensive evaluation of an energy retrofit performance. Further research is still needed to better integrate all these domains, especially the political one, thus directing future research in the perspective of implementation on real case studies.

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