

GREEN BUILDING CERTIFICATION SYSTEMS, INDOOR ENVIRONMENTAL QUALITY AND POST-OCCUPANCY EVALUATION METHODS: A CRITICAL REVIEW

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Abstract

This paper presents a critical review and a comprehensive analysis of existing methods and tools for the post-occupancy evaluation (POE) of indoor environmental qualities in buildings, with specific reference to the criteria embedded in the credit requirements of the most popular green building certification schemes. POE procedures allow the quantitative and qualitative analysis of buildings' and occupants' performance in new and existing buildings (e.g. offices, schools, and universities, residential, commercial, hotels, libraries and mixed-use) based on the collection of objective and subjective data.

Keywords: Post Occupancy Evaluation, Indoor Environmental Quality, Building Monitoring, Building Certification, Occupant Comfort, Occupant Satisfaction.

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Introduction

In developed countries, the urban population spends more than 90% of its time indoors (Leech et al., 1997), this emphasising the importance of the conditions of well-being and the performance provided by buildings. The occupants of buildings characterised by more satisfactory comfort conditions are more efficient, with lower rates of absenteeism due to illness (Altomonte et al., 2019).

Current certifications schemes are generally voluntary systems whose diffusion is linked primarily to the energy benefits they entail, although they can also provide economic benefits. Certified buildings, in fact, have a higher commercial value compared to uncertified buildings. "Labels" have been developed especially for buildings with a business purpose (e.g., offices), although, more recently, they have also been applied to the residential sector. This is an important aspect considering that the largest share of energy use is linked to the residential sectors, and its insufficient adoption of proper environmental practices. Certifying a building can lead to better Indoor Environmental Quality (IEQ), although the link between green building certification and a more efficient and satisfactory workplace or residential space for its users has not yet been consistently demonstrated (Altomonte et al., 2019).

Towards these goals, rigorous Post Occupancy Evaluations (POE) methods and techniques can allow monitoring the conditions reported by building occupants. A POE allows to obtain feedback on building performance, which is essential in all sectors of the construction industry. In healthcare, education, commercial and residential buildings, poor performance negatively affect operating costs, occupants' comfort and well-being and corporate efficiency. The data obtained from POEs can be used to address problems highlighted by occupants or fine-tune the building's operation, towards an improvement of microclimatic conditions, and the perceptions of comfort and productivity.

POE campaigns can be based on two methodological approaches: 1) subjective or qualitative, including occupant surveys, focused interviews, questionnaires, etc.; and, 2) objective or quantitative physical methods, including collection

of energy and water data and in-situ measurements of indoor environmental parameters, such as temperature, light, air quality, and sound pressure.

POE procedures can be distinguished in three sub-types:

- transversal: usually online surveys aimed at capturing, in a cross-sectional way, the general perception that occupants have of the building (or workspace) they occupy;
- point-in-time: mostly paper-based surveys that are administered to occupants at specific points in time, simultaneously with the collection of environmental data;
- longitudinal: used to collect occupant feedback, and the continuing evolution of indoor environmental quality parameters, over a certain period of time.

Method

A broad literature review focusing on POE procedures, protocols and tools was conducted retrieving journal articles and other scientific documents from selected search engines (Science direct, Scopus, Google Scholar and Web of Science) and based on the use of 6 keywords: Post Occupancy Evaluation;

Indoor Environmental Quality; Building Monitoring; Building Certification; Occupant Comfort; Occupant Satisfaction.

Over 4,000 research items have been initially identified, and 54 papers have subsequently been selected and catalogued according to the three mentioned POE procedures: transversal, longitudinal and point-in-time. All papers have been organised in tables, by title, author, year of publication, keywords, type of building, POE evaluation criteria, and key results.

All selected papers were published in the period 2004-2019, with a higher frequency detected in the years 2017-2019, this demonstrating a recent increase in scientific interest (Fig. 1).

POE survey tools and feedback categories: compliance with environmental certification requirements

The study of the selected papers has allowed a systematic classification and definition of the main POE survey tools currently available, together with the identification of their

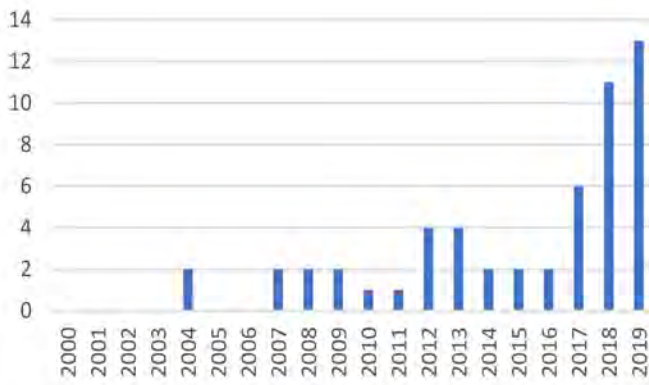


Fig. 1

methods, techniques, feedback categories, procedures (transversal, longitudinal, point-in-time), and compliance with different green building certification schemes such as LEED, BREEAM, NABERS, GREEN MARK and GREEN STAR. Information regarding the year of development, the minimum time of building occupation required for the survey, the characteristics of the POE methodology (e.g., if applicable for before/after comparisons), and the building type have also been included (Table 1, Appendix).

The main survey tools identified are listed below:

- CBE Occupant Indoor Environmental Quality Survey. A survey tool developed by the Center for the Built Environment at the University of California, Berkeley (USA). This tool is the most frequently used in the scientific papers focusing on Transversal POE surveys.
- BOSSA (Building Occupants Survey System Australia). An IEQ assessment system specifically developed for Australian office buildings. There are three types of BOSSA survey tools: BOSSA TIME-LAPSE; SNAP-SHOT BOSSA; and BOSSANOVA. The first implies a transversal procedure, while others are point-in-time surveys. The BOSSA tool frequently recurs in the papers describing the point-in-time method.
- BUS (Building Use Studies). A survey tool created about 30 years ago and acquired by ARUP in 2009. Since 2013, this Transversal survey tool is managed by the BUS Partner Network.
- SPEQ (Space Performance Evaluation Questionnaire). This is a Transversal survey tool developed by the High Performance Environments Lab (HiPE) at the University of Oregon (USA) that has been used in a variety of building types since 1998.
- Leesman Index. A tool that acquires employee feedback on the quality of the workplace and compares with a vast database that collects the experience of thousands of office workers. This longitudinal questionnaire is designed to be adopted also for the assessment of interventions within before/after studies.
- Occupant Comfort & Wellness Survey. This longitudinal tool has been developed by the Institute for the Built Environment (IBE) at Colorado State University (USA). The survey is primarily designed for offices, although future developments plan the integration of residential and multi-family projects.
- Comfort-meter. This transversal tool is compatible, among others, with the BREEAM, LEED and WELL certification systems. The building must have been occupied at least for 12 months, hence including at least a winter and a summer season.

- BeWellLeadWell. This is a transversal survey tool that is structured in 4 different programs: Be Well Lead Well Women; Be Well Lead Well Coaching; Executive Wellbeing Program; Be Well Lead Well Leadership Circles.
- OHFB Afriforte. This is a transversal scientific-based organizational diagnostics suite developed since 1998 at the Faculty of Economics and Management Sciences of the North-West University (South Africa).

The above mentioned survey tools are all pre-approved by the International WELL Building Institute (IWBI) and can be utilised to obtain prerequisite or optimisation points for the WELL v.2 certification, under the category "Community": C03 Occupant Survey (prerequisite); and C04 Enhanced Occupant (max. 4 points). These tools are also relevant for other type of certification protocols, such as LEED, NABERS and BREEAM.

Looking at different building typologies, data from the papers included in the literature review shows that the majority of POE campaigns are conducted in office buildings (48%), followed by residential (22%) and schools (13%) (Fig. 2).

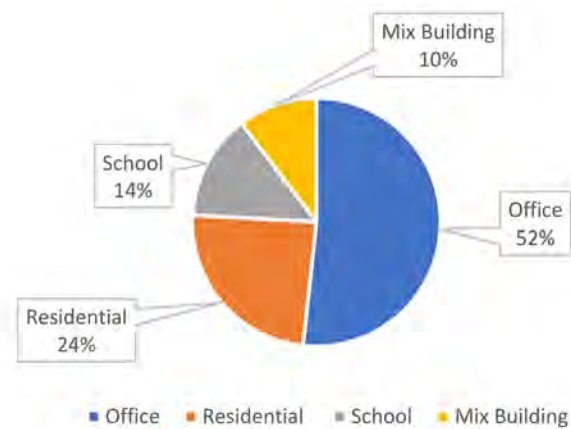


Fig. 2

The data collected in POE campaigns are mainly used to collect occupant feedback and detect eventual environmental and microclimatic discomfort problems so as also to offer a financial benefit in the interest of the management of corporations. The transversal POE procedure was used by over 53% of the papers analysed, followed by the point-in-time (26%) and the longitudinal (20%) methods. In the 29 papers that described the application of a transversal POE procedure, the distribution of building types follows the general trends previously presented, as follows: offices (52%), schools (14%), residences (24%) and mixed-use buildings (10%) (Fig. 3).

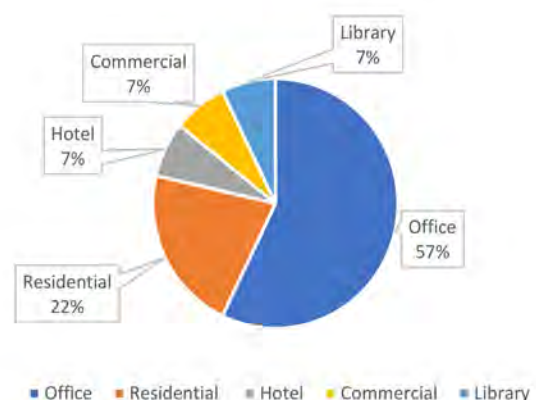


Fig. 3

In terms of the POE techniques applied, the papers focus on methodologies based on the survey created by the Center for the Built Environment at UC Berkley, modified and adapted according to the specific needs of the project. This survey technique is, in fact, the most widely used for the survey of public and private buildings.

The questionnaire is typically structured on several categories (e.g., Thermal comfort, Lighting, Noise, etc.), and it might include the possibility of open questions. Answers are provided using a 7-point Likert scale, ranging between -3 and +3, and implies an average response time is 12 minutes. The use of this technique implies an invitation to participate, normally sent via e-mail, and the request to complete and return the questionnaire within a specific date (Graham et al., 2020).

For the point-in-time POE procedure, 14 Papers have been selected and catalogued, corresponding to 26% of the total. Specifically, they described data collection campaigns conducted in offices (57%), residences (22%), commercial buildings (7%), hotels (7%) and libraries (7%) (Fig. 4).

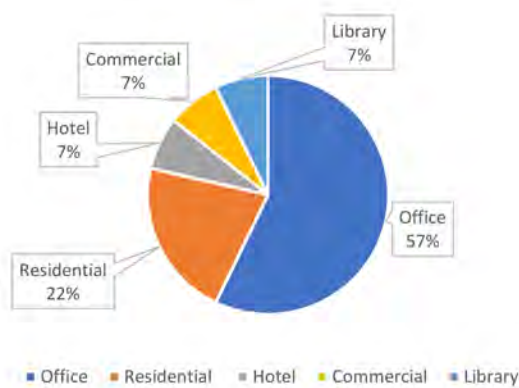


Fig. 4

The main feature of these POE campaigns consists in the administration of a (generally) paper-based questionnaire aiming to collect occupants' perception and feedback (on a Likert scale or as Yes/No binary codes) while environmental measures are taken with fixed sensors or hand-held instruments (Candido et al., 2016).

For the longitudinal POE procedure, 11 Papers (22% of the total) have been selected and catalogued. In particular, authors describe POE campaigns conducted in offices (37%), residences (27%), mixed-use buildings (18%) and schools (18%) (Fig. 5).

This data collection methodology often uses pop-up tools, either delivered on a PC or on a mobile device whereas the occupant is asked to answer simple questions about their perception of comfort or well-being. The answers are generally based on binary codes (e.g., Yes/No, Cold/Hot). The questionnaire might also present a Likert scale, with a maximum score of 5 points. The answers provided by occupants are then compared with data from simultaneous monitoring or from simulation models (for example, using advanced software such as Energy Plus or Design Builder).

Certification systems requirements, feedback categories and POE criteria

Several building certification systems have recently started to integrate credits linked to POE criteria. For the most popular of such systems – LEED v.4.0, LEED v.4.1, BREEAM, WELL v.2, Green Mark and Green Star – Table 2, in Appendix, summarizes the credit requirements with respect to the type of build-

ing (e.g., new or existing) and the environmental certification sought. Table 2 has been informed by a detailed analysis of the manuals and online guidelines of each certification system, and provides an indication of the criteria necessary for the obtention of prerequisite and/or optional credits for post-occupancy evaluation campaigns.

This analysis highlighted how *transversal* POE campaigns might often be initiated by the desire, from the part of the client, to obtain a relatively quick examination of the occupants' level of satisfaction with the building and its features. The questionnaires are generally aimed at collecting feedback under various categories including, for example: layout and furnishing, thermal comfort, visual comfort, air quality, acoustic quality, cleanliness and maintenance, ease of interaction, perceived job performance, etc. (Zagreus et al., 2004). The data gathered are processed, statistically analysed and compared with similar buildings that have previously been surveyed. The questionnaire can be modified and adapted in accordance with the building typology or the specific purpose of the analysis (Lee et al., 2010). These surveys can be useful for benchmarking purposes, although the use of standardized questions – and the relative little freedom for occupants to express their feedback in the form of open-ended comments – might hinder the obtention of a detailed snapshot of the effective state of the building. This limitation may over-simplify the complexity of buildings and of the differences in perception among occupants (Wargoeki et al., 2012).

Point-in-time evaluations, also known as “right now” surveys, involve environmental data gathering through sensors positioned on mobile carts, or via hand-held instruments. This POE procedure makes it possible to collect simultaneous occupant and building data in several points and at different times of the day, reducing the costs for the positioning of fixed sensors in different areas. The data collected, stored on MicroSD cards or transmitted via wireless connection to a remote server, can be catalogued and divided by pre-set categories (e.g., age, gender, position, work activity), while preserving sensitive data and individual information. A disadvantage of this procedure may consist in the granularity of the data gathered, which can only provide a partial overview, spatially and temporally, of the state of a building. It is also important to know the technical specifications of each sensors that are in use, so that the accuracy and the error range (after calibration) of the data is known. Further information on this methodology is provided by Stevenson (2019) and Kim et al. (2016).

Longitudinal surveys can allow the investigation of the continuing evolution of occupant satisfaction with specific indoor environmental parameters over a certain period of time. The recent ubiquitous diffusion of mobile technologies (e.g., hand-held devices, smartwatches and smartphones) is offering significant scope to the evolution of this POE procedure, due to the imme-

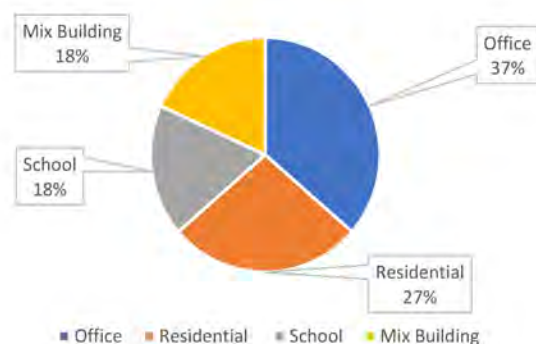


Fig. 5

diacy with which occupant response to simple question can be given. Yet, the principal weakness of these surveys consists in the simplified nature of the questions asked, the limitations in feedback collected (e.g., binary code) or the difficult correlation of responses with IEQ parameter readings that can continuously record the evolution of the environmental conditions to which people are exposed. However, combination of these response modes with the data gathered via wearable sensory technologies is offering significant promises. Further information on this methodology of POE data collection is provided by Gonzalez-Caceres et al. (2019).

Concluding remarks

The administration of POE surveys and data collection campaigns is progressively becoming a fundamental instrument to allow a correct evaluation of the design and operation choices to be carried out in working and in residential environments, for both new buildings and for interventions on the existing stock.

The appropriate selection of POE procedure (transversal, point-in-time and longitudinal) must be based on well-defined indicators, including the building location and typology, and a thorough understanding and analysis of the environmental factors (e.g., humidity, temperature, ventilation, etc.) associated with the problem encountered. These factors need to inform the choice of POE tools and methods based on the objectives of the study.

The building type to be analysed can also orientate the selection of the most appropriate certification scheme, if a green rating or the acknowledgement of environmental performance is sought. Most certification tools, in fact, are differentiated based on typology (e.g., schools, offices, hospitals, retail, residential) and stage of construction (e.g., new or existing).

From the analysis of the literature, it is evident that building certification, indoor environmental quality, and post-occupancy evaluation are becoming recurring themes in building practice and research, together with the increased awareness of the importance of providing for the comfort and well-being of occupants.

To this aim, this study has highlighted significant steps ahead that the development of POE procedures has made over recent years, although there is still a significant gap to be filled particularly in terms of the application of these monitoring methodologies to sectors other than commercial (i.e., office and retail), particularly including educational buildings (e.g., schools, universities), and homes, also due to the significant share of energy use they entail.

It would also be important to deploy POE preventive campaigns in the older residential building stock, for a prompt detection of potential causes of 'sick building syndrome', and to increase their energy performance, as well as for raising awareness and educating occupants about good energy management practices.

Nowadays, to face the increasing challenges of climate change, it is more and more important to combine human comfort and well-being in the built environment with more efficient building performance at all scales (Andreucci, 2019).

Evidence-based design strategies leveraging on POE campaigns, aiming at improving the effectiveness of building design and operation strategies, while promoting sustainable practices and behaviours, are certainly an important contribution in this direction.

Acknowledgments

The literature review at the basis of this paper has been supported by the COST Action CA16114 'RESTORE' (Restoring Sustainability TOWARDS a Regenerative Economy) through a Short-Term Scientific Mission in 2019, organised by Sergio Altomonte and Maria Beatrice Andreucci. The study has been conducted by Marco Giampaolletti, in Brussels (Belgium), at the Faculty of Architecture, Architectural Engineering, Urbanism (LOCI) of the Université catholique de Louvain, under Sergio Altomonte's supervision. An extended version of this paper has been published, also with other co-authors, as the chapter "POE Protocols" featured in the booklet "Regenerative Technologies for the Indoor Environment: Inspirational Guidelines for Practitioners" published by Working Group 4 of the RESTORE COST Action (WG4 Coordinators: Roberto Lollini, Wilmer Pasut).

Author Contributions

Conceptualization: Sergio Altomonte and Maria Beatrice Andreucci; Literature Review: Marco Giampaolletti with Sergio Altomonte supervision; Writing – Original Draft Preparation: Marco Giampaolletti and Maria Beatrice Andreucci; Writing – Review and Editing: Maria Beatrice Andreucci; Visualization: Marco Giampaolletti, with Maria Beatrice Andreucci supervision; Funding Acquisition: Sergio Altomonte and Maria Beatrice Andreucci.

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Appendix

Survey Tool	Year	Min. n° of occupants to be interviewed	Procedure	Technique	Evaluation	Before and/or after?	Feedback Categories	Compliance with certification requirements	Main building type
CBE Occupant Survey	1999	not specified	Transversal	Questionnaires Online	Collection of questionnaires in a database to plan future strategies	Survey valid if the occupants moved to the building for last 6 months	General Building, Air Quality, Maintenance, Thermal Comfort, General Workspace, Acoustic Quality, Lighting, Office Furnishings, Office Layout, etc.	LEED, WELL	Office, Laboratory, School, Residence, Health Care, etc.
BOSSA TIME-LAPSE	2013	not specified	Point in time	Questionnaire Right Now	Questionnaire to the occupants with selected key words	Pre and Post evaluation criteria	Indoor Air Quality, Spatial comfort, Noise distraction and Privacy, Connection to Outdoor Environment, Building Image and Maintenance, Individual Space, Thermal Comfort, Visual Comfort, Perceived Health and Productivity	NABERS, LEED	Office Buildings
SNAP-SHOT BOSSA	2013	not specified	Point in time	Questionnaire Right Now	Questionnaire to the workers of an office to evaluate their work area	Measurement real-time	Acoustics, Thermal Comfort, Visual Comfort, IAQ	WELL	Office Buildings
BOSSANOVA	2013	not specified	Point in time	IEQ Mobile Right Now	Mobile cart equipped with sensors	Measurement real-time	Thermal Comfort, IAQ, Lighting and Acoustics	WELL	Office Buildings
BUS	2009	not specified	Transversal	Questionnaire Online	Questionnaire based on the perception of comfort and well-being	Before or After an intervention	Work organization, Water, Nutrition, Movement, Mind and Community Programs, etc.	WELL, BREEAM, LEED	Office Buildings, Residential School, Health Care
Space Performance Evaluation SPEQ	1998	not specified	Transversal	Questionnaire Online	Online questionnaire of 76 questions on 7 different categories (average completion time 12 minutes)	Survey for the quality, comfort, performance, health of the workplace or living space	Thermal Comfort, Visual and Acoustics, Air Quality	LEED, WELL	Office Buildings, Residential School, Health Care
Leesman Index Leesman+	1970	50	Longitudinal	Survey Online	Questionnaire for the future organization of the company, for future decisions and investments	Before or After an intervention	Collaboration, Environment Design, Facilities and Services, Furniture and Layout, Indoor Environment Quality, Technology	WELL	Work Activities, Workplace Impact, Physical and Service Features, Mobility
Occupant Comfort & Wellness Institute Built Environment IBE	1994	not specified	Longitudinal	Survey Online	Performance survey in the workplace	Before or After the operation	Office Layout, Workspace, Thermal Comfort, Air Quality, Lighting, Acoustic Quality, Building cleanliness, Wellbeing, Health conditions	WELL	Office
Comfortmeter	1992	100	Transversal	Questionnaire Online	Questionnaire of 59 questions, online, average response time 10 minutes, anonymous	Survey valid if the occupants moved to the building for last 12 months (1 winter and 1 summer)	Lighting, Air Quality, Office Environment, Thermal Comfort, Acoustics, Individual control	LEED, BREEAM	Office, Schools, University, Retail, Industry
BeWell.LeadWell *Women *Coaching *Leadership Circles	1989	not specified	Transversal	Questionnaire Online	Questionnaire of 133 questions divided into 6 categories and 19 sub-categories	Improve leadership in the workplace	Prosperity, Fuel, Flow, Wonder, Wisdom and Amplified Prosperity	WELL	Work Activities, Office
OHFB Afriforte	1998	not specified	Transversal	Questionnaire Online	Service for the company to maximize profits	Guide to maximize profits and to invest in your company, increase productivity	Maximize ROI, Increase Productivity, Workspace	WELL	Work Activities, Office

Tab. 1

LEED V.4.0 2013	Type	Building type	Feedback category	POE Evaluation Criterion	C/P	Requirements
	O+M	Existing Buildings Retail School Hospitality Warehouses and Distribution center	INDOOR ENVIRONMENTAL QUALITY	Occupant Comfort Survey	C	<p>1 Credit</p> <p>Administer at least one occupant comfort survey to collect anonymous responses regarding the following criteria: Acoustics, Building cleanliness, Indoor air quality, Lighting, Thermal comfort.</p> <p>The responses must be collected from a representative sample of building occupants making up at least 30% of the total occupants. At a minimum, perform one new survey at least once every 2 years.</p>
	ID+C	Commercial Interiors Retail Hospitality	INNOVATION	Occupant Engagement	C	<p>1 Credit</p> <p><u>Request:</u> Feedback on consumption, implementing communication methods to inform occupants on the energy consumption of the building or workspace. It can be done in real time or on a monthly basis; minimum requirement 1 year of occupation of the same space.</p> <p><u>Request:</u> Occupant responsibility, implement programs to involve the occupants through communications to contribute to the achievement of the sustainability objectives for the building.</p> <p><u>Request:</u> Performance, trace and document the results to the occupants through meetings specifying the areas to be improved and the performances achieved.</p>
	BD+C	New Construction Major Renovation Core and Shell Data Center Hospitality Retail School Warehouse and Distribution Center		Design for Active Occupant	C	<p>1 Credit</p> <p>Improve the health of building users through physical activity by reducing environmental impacts.</p> <p><u>Request:</u> Buildings must have at least a staircase that allows occupants to move; moreover, 7 out of 11 design features must be included.</p>
				Occupant Comfort Survey	C	<p>1 Credit</p> <p>Administer at least one occupant comfort survey to collect anonymous responses regarding the following criteria: Acoustics, Building cleanliness, Indoor air quality, Lighting, Thermal comfort.</p> <p>The responses must be collected from a representative sample of building occupants making up at least 30% of the total occupants. At a minimum, perform one new survey at least once every 2 years.</p>

Legend: C: Credit, P: Prerequisite, O+M: Building Operations + Maintenance, ID+C: Interior Design + Construction, BD+C: Building Design + Construction

	Type	Building type	Feedback Category	POE Evaluation Criterion	C/P	Requirements
LEED V.4.1 2013	O+M	Existing Buildings Retail School Hospitality Warehouses and Distribution center	INNOVATION	Occupant Engagement	C	1 Credit Goal: improving building performance by enabling energy-efficient behavior of building occupants. Request: inform the occupants of the actual energy consumption of the building, in real time or through reporting mechanisms on a monthly basis. Minimum data registration period 1 year. Empowering occupants with periodic communications to achieve building sustainability goals.
	ID+C	Commercial Interiors Retail Hospitality		Design for Active Occupant	C	1 Credit Improve the health of building users through physical activity by reducing environmental impacts. Request: Buildings must have at least a staircase that allows occupants to move; moreover, 7 out of 11 design features must be included.
	BD+C	New Construction Major Renovation Core and Shell Data Center Hospitality Retail School Warehouse and Distribution Center		Occupant Comfort Survey	C	1 Credit Administer at least one occupant comfort survey to collect anonymous responses regarding the following criteria: Acoustics, Building cleanliness, Indoor air quality, Lighting, Thermal comfort. The responses must be collected from a representative sample of building occupants making up at least 30% of the total occupants. At a minimum, perform one new survey at least once every 2 years.

Legend: C: Credit, P: Prerequisite, O+M: Building Operations + Maintenance, ID+C: Interior Design + Construction, BD+C: Building Design + Construction

	Building type	Category	Category of credits	POE Evaluation Criterion	C/P	Requirements
BREEAM V.2014	Communities Infrastructure New Construction In-Use Refurbishment& Fit-Out	NEW COSTRUCTION REFURBISHMENT& FIT-OUT	Management Man 05 "Aftercare" 3 credits	Post Occupancy Evaluation	C	1 Credit The client or the occupant of the building undertakes to carry out a post-occupancy evaluation (POE) one year after the initial occupation of the building. The occupant of the building undertakes to carry out adequate dissemination of information on the post-occupation performance of the building.
WELL 2018 V.2	User and Professional Communities New Construction In-Use Schell and Core (WELL CORE)	All project	Community category	Prerequisite C03 Occupant Survey	P	Prerequisite This prerequisite requires that projects collect feedback from users on well-being and health. The survey can be provided by third parties (IWBI approved) or be personalized and must be provided to the occupants at least once a year. Protection of personal data is guaranteed by privacy and anonymous results are provided to WELL online.
GREEN MARK 2005	Residential and non-Residential Building (new or existing)	Existing Buildings	Category Other Green Requirements	Post Occupancy Evaluation 3 Credits	C	2 Credits Post occupancy survey for occupants on the energy performance of the building. Required number of respondents 10% of minimum occupancy and up to a maximum of 100, at least 5 people must be interviewed if the building users are less than 50. 1 Credit For the creation of a list of good actions undertaken after the Post Occupancy Evaluation, if performed.
GREEN STAR 2003	New Construction In-Use Refurbishment Fit-Out	All project	Category Indoor Environmental Quality	Occupant Satisfaction (survey and levels)	C	4 Credits The Occupant Satisfaction credit rewards the assessment of building occupants' overall comfort by way of an occupant survey, with points awarded where at least 80% of respondents indicate satisfaction during the analysis period.

Legend: C: Credit, P: Prerequisite, O+M: Building Operations + Maintenance, ID+C: Interior Design + Construction, BD+C: Building Design + Construction

Tab. 2

Fig. 1 - Yearly distribution of selected papers. Credits: Author

Fig. 2 - POE procedures distribution according to building typology. Credits: Author

Fig. 3 - Building types distribution in papers describing a POE transversal procedure. Credits: Author

Fig. 4 - Building types distribution in papers describing a POE point-in-time procedure. Credits: Author

Fig. 5 - Building types distribution in papers describing a POE longitudinal procedure. Credits: Author

Tab. 1 - POE survey tools and feedback categories: compliance with protocols.

Tab. 2 - Certification system requirements, feedback categories and POE criteria.