4 MONITORING AND POST-OCCUPANCY EVALUATION OF A REGENERATIVE INDOOR ENVIRONMENT

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4.1 HOW, WHY AND WHEN TO MEASURE BUILDING PERFORMANCE

4.1.1 WHAT IS POST-OCCUPANCY EVALUATION (POE)?

Post-Occupancy Evaluation (POE), among many other definitions in the scientific literature, has been characterized as "*… the process of evaluating buildings in a systematic and rigorous manner after they have been built and occupied for some time.*" [Preiser, 1995].

Data collection, evaluation and feedback are the cornerstones of continuous improvement in the supply of buildings. A robust data-collection procedure is an intrinsic part of good building briefing and design. POE is a way to obtain this information during the life cycle of a building and is often used as a generic term that can include both: a review of the process delivery of a project; and, an evaluation of the technical and functional performance of the building during the time of its occupancy. Other than driving the operation of the building and its related systems, the information from data collection, evaluation and feedback can also be transferred to future projects.

POE can serve several purposes, including the following:

Short-term benefits

- Identification of building-related problems and definition of possible solutions;
- Response to user needs;
- Improvement of space utilization, based on feedback from users;
- Understanding the implications of changes within buildings (e.g., budget cuts, working context);
- Informed decision-making.

Medium-term benefits

- Built-in capacity for the adaptation of buildings to organizational change and growth;
- Finding new uses for buildings;
- Designer accountability for building performance.

Long-term benefits

- Long-term improvements in building performance;
- Improvement in design process quality;
- Strategic review.

4.1.2 THE IMPORTANCE OF POE

The focus of a Post-Occupancy Evaluation (POE) can be considered in terms of three major areas: a) Process evaluation; b) Functional performance evaluation; and, c) Technical performance review.

a) Process evaluation

The aspects that should be considered are:

Brief	The way in which the team develops the design brief including financial management aspects.
Procurement	The way in which team selection, and contractual and technical processes, among others, are undertaken, including time and value aspects.

Design	The way in which the team develops and refines the design including space planning, engineering and financial management aspects.
Construction	The way in which the construction phase until handover is managed, including financial and change management processes.
Commissioning process	The way in which the final commissioning of the building is managed, including final adjustments and the provision of documentation.
Occupation	The way in which the handover process is managed, including the rectification of last-minute problems and the removal/relocation process.

b) Functional performance evaluation

This evaluation addresses the goals and aspirations of the developer/building owner and how well the user needs are supported:

Strategic Value	Achievement of original business objectives.
Aesthetics and Image	Communication of company ethos, relationship with the context.
Space	Size, relationships, adaptability.
Indoor Environmental Quality	Lighting, temperature, humidity, ventilation, soundscape, control (overall and individual), among other aspects.
Amenity	Services and equipment: completeness, capacity, positioning.
Serviceability	Cleaning, routine maintenance, security, essential changes.
Operational and Life Cycle Cost	Construction investment, energy use, water and waste, leases, cleaning, insurance policies, maintenance and repairs, alterations and demolition.
Operational Management	Space allocation systems, user support systems, help desks, manuals, training, etc.

c) Technical performance review

This review includes measuring the way in which technical systems perform, for example, by including the performance of mechanical (heating, cooling, ventilation) and lighting systems.

Physical systems	Lighting, heating, ventilation, acoustics, etc.
Environmental system	Energy consumption, water consumption, CO2 emissions.
Resilience	Ability to accommodate change and maintain performance levels facing context dynamics.
Durability	Robustness, need for routine extensive maintenance, incidence of “down time” for unplanned technical reasons.

Occupant behaviour has an important role in driving the performance of buildings [Preiser et al., 2014]. If occupants are dissatisfied with their indoor environment, they are likely to take action to meet their comfort expectations [Bolchini et al., 2017]. Occupant behaviour has been identified as one of the most common factors that can help to explain the gap between actual and predicted energy use [Balvedi, Ghisi and Lamberts, 2018]. In this context, POEs focus on analyzing the perceptions and satisfaction of occupants within their built environment, as well as the impact of users on the performance of the buildings [Agha-Hossein et al., 2013]. In POE studies, occupant data can be analyzed in relation to measured indoor environmental parameters (e.g., air temperature, mean radiant temperature, relative humidity, ambient illuminance and noise levels, etc.), thereby linking occupant satisfaction and actions to the conditions recorded in the buildings.

4.1.3 AIMS AND METHODOLOGY

This chapter aims to present a critical systematization of the following:

a) Procedures for conducting Post-Occupancy Evaluation (POE) campaigns (e.g., longitudinal, point-in-time, transversal);
b) Protocols and tools (including the identification of sensors, instruments, etc.) to measure building performance data (related to the Key Performance Indicators (KPIs) presented in Chapter 2);
c) Protocols and tools (including questionnaires, forms, etc.) for collecting quantitative (e.g., surveys, etc.) and qualitative occupant data (e.g., focus groups, structured interviews, etc.).

Considering that several procedures, protocols and tools are currently available, the systematization has been structured through the following methodological steps: 1) review of scientific papers from peer-reviewed journals, online documentation, extracts from books and conference proceedings, among others; 2) collection of information from existing POE providers (e.g., websites, direct contact, etc.); and, 3) analysis of criteria and requirements embedded in current standards and green building certification systems.
For each of the above aspects, the information is presented discussed, and synthetized in tables. A comprehensive reference list at the end of this chapter offers a wide overview of the various literature sources from which all the information presented in this booklet has been gathered.

4.2 POE PROCEDURES

Decisions on POE and monitoring methods are based on contextual parameters such as:
- Location of the building subject to the campaign;
- Type of building (e.g., office, school, hospital, residential, etc.);
- The nature of the problem to address (e.g., humidity, temperature, ventilation, etc.).

These parameters define the choice of one of the three procedures:
- Transversal
- Point in Time
- Longitudinal

The context also affects the selection of monitoring tools depending on the current state of the building and its occupants, and on the available resources [Olivia and Christopher, 2015].

4.2.1 TRANSVERSAL STUDIES

This procedure is used, for example, when the client requires simple and quick analyses of occupant satisfaction levels with a number of indoor environmental qualities or building features and characteristics. The “Transversal” methodology is mainly based on questionnaires and surveys [Frontczak et al., 2012a]. Among these, for example, are the CBE Occupant Survey, the BUS methodology, the SPEQ and Comfortmeter, etc., which are also compatible, and in some case pre-approved, with most existing green building

certification protocols [Wargocki et al., 2012000 occupants collected mainly in US office buildings using a web-based survey administered by the Center for the Built Environment (CBE].
The survey, which is generally administered online to occupants, is delivered in an email that informs the occupants of the questionnaire that is to be completed within a certain period of time. If the occupant forgets to fill it out, a customizable number of notification alerts can then be sent. Upon acceptance, the link to access the online questionnaire is forwarded to the user. The average duration of the questionnaire is 10-15 minutes with an average of 20-30 questions. The answers can be based on a score or on discrete assessment scales (for example, a Likert-type scale with 5-7 points) and with various open-ended questions. These options can reveal further problems for investigation that might have not been reported by the client [Kim et al., 2013; Liang et al., 2014].
The answers to the questionnaires can be stored on an online cloud or on a mass memory database incorporating personal data and privacy protection. The questionnaires are generally based on the expression of satisfaction with a number of categories and parameters, which might include, for example: office layout, furnishings, thermal comfort, visual comfort, temperature, relative humidity, air quality, lighting quality, acoustic quality, cleanliness and maintenance of the building, perceived job performance, etc. [Zagreus et al., 2004]. Once gathered, the data are processed, statistically analyzed and compared with similar cases 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 [Stevenson, 2009] [Li, Froese and Brager, 2018].
Transversal surveys can be useful for benchmarking purposes, although their standardized questions may not provide a sufficiently detailed snapshot of the complexities of inhabiting buildings, interactions between occupants, both cultural and social behavioural differences and actions, etc. Self-reported satisfaction and comfort responses based on memory may, in fact, provide a limited view from which the full picture may not be established (e.g., tolerances, acceptability, and variations in temporal and seasonal expectations within the buildings, etc.). These limitations may overly simplify the complexity, the diversity and the dynamic use of buildings and the perceptions among occupants of inter-seasonal changes between different building areas or spaces, and between different user types, especially in relation to cultural expectations, within the indoor environment.

4.2.2 POINT-IN-TIME STUDIES

Point-in-time (also known as “right now”) procedures are mostly used when sources of discomfort from IEQ parameters need to be identified and measured. These studies can be conducted in many building typologies, including offices, schools, residences, etc. [de Dear et al., 2018]. The main feature of this methodology is the administration of paper questionnaires (for example, the Snap-Shot BOSSA survey) presenting binary (e.g., YES/NO) answers and Likert scales with relatively short compilation times. Once collected, the data are then sorted under pre-set variables (e.g., age, gender, position, work activity) and catalogued, while preserving sensitive data. While collecting “right-now” information on the perceptions provided by occupants, measurements through sensors positioned on mobile carts, or through specific on-site or hand-held instruments, are taken. Environmental data may therefore be collected at several points, at different times, reducing the installation costs of fixed sensors positioned in each area. The new generation of mobile carts (for example, BOSSA NOVA system) can manage the use of multiple sensors simultaneously, with a quick average data reading. The data can be processed by interactive systems and saved on MicroSD cards or transmitted via wireless connection to a remote server. Some disadvantages of this procedure might be found in the accuracy of the sensors and in the quantity and granularity of the data to be processed; it is important to know the technical specifications of the sensors that are in use, so that the data error range (after calibration) is known. Furthermore, consistent comparisons of different zones of a building cannot be completed without sensors, and manual monitoring campaigns are often only limited to a few hours a day [Stevenson, 2019], [Wong, Mui and Hui, 2008], [Kim et al., 2016], [Wagner et al., 2007], [Hirning et al., 2013].

 Luminance Meter	 Illuminance Meter	 HDR Camera
 Temperature and Humidity Sensor	 Temperature and Humidity Sensor	 Temperature and Humidity Sensor
 Sound Level Meter	 Portable Weather Station	 Thermo-hygrometer + CO2 Sensor

Figure 16. Examples of hand-held instruments for point-in-time studies

4.2.3 LONGITUDINAL STUDIES

Longitudinal studies are used to analyze the perception of environmental comfort, and the continuing evolution of indoor environmental parameters, over a certain period of time. This methodology can be applied to the analysis of different building typologies (e.g., schools, universities, office buildings, etc.). Questions to occupants might be presented as pop-ups on computer screens or via mobile apps, requiring simple feedback on specific aspects to be given with a response score based on a Likert scale or a binary (e.g., YES/NO, hot/cold, positive/negative, etc.) response. Responses are collected and organized in accordance with pre-set parameters [Berquist et al., 2019]. These monitoring campaigns can be supported by physical measurements and/or by energy simulations of the building to which the POE analysis is applied [Konis, 2013; Jin et al., 2018; Karami et al., 2018; Kim et al., 2019]

The weakness of this procedure is mainly related to the composition of the questionnaire; the few questions based on simplified (e.g., binary code) answers might be insufficient for the collection of extensive feedback that could be used for further exploration of the causes of occupant-perceived environmental discomfort. Moreover, with this evaluation procedure, the correlation of responses with IEQ parameter readings would require the installation of fixed sensors (or, for example, wearables) that can continuously record the evolution of the environmental conditions, so that the information may be correlated with the times when feedback is provided [Gucyeter, 2018; Piselli and Pisello, 2019; Pritoni et al., 2017; Gonzalez-Caceres, Bobadilla and Karlshøj, 2019; Parkinson et al., 2019a; Parkinson et al., 2019b].

4.3 SURVEY QUESTIONNAIRES

4.3.1 THE ROLE OF OCCUPANTS WITHIN THE INDOOR BUILT ENVIRONMENT

On the one hand, indoor environmental quality can have significant effects on any user of a building. On the other hand, occupants can strongly influence the performance of a building thorough their actions and behaviours. Consideration of such issues can lead to better control strategies, to a better estimation of the final energy demand of a building and, finally, to better indoor conditions [Choi et al., 2012]. Considering the performance of a building as a whole, two different perspectives should be taken into account: (i) building performance in terms of construction, technical, technological, physical and climate-related factors; and, (ii) building performance in terms of the so-called human factors, i.e. occupant behaviour, indoor environmental quality, control actions, social dynamics and attitudes.
Despite the UN Office of the High Commissioner for Human Rights promoting recommendations on the enjoyment of safe, clean, sustainable and healthy environments [UN General Assembly, 2012], occupant behaviour and wellbeing in indoor spaces are still treated in a marginal way. In fact, only a few references can be extrapolated from the most recent legislative documents. Directive 2012/27/EU [EU, 2012] establishes that Member States must promote measures for behavioural change among the occupants of existing buildings and to increase public awareness of energy efficiency. Directive 2018/844/EU [EU, 2018] focuses on the use of smart readiness indicators, in order to adapt the operational strategies of the building to the needs and attitudes of occupants, as well as to increase user confidence in energy saving strategies. From a perspective of indoor environmental quality, the Directive states that better performing buildings must also improve occupant comfort and health conditions. In this direction, Member States have to promote the requalification of existing assets, so as to enhance indoor conditions for users.
In this context, building occupants can play a double role:

- As *active* users, they can interact with the environment and modify it, so as to meet their needs for comfort and wellbeing. The consequence of such operational actions is a modification of the state of a building, which leads to changes in its performance and energy requirements.
- As *passive* users, dwelling in a particular indoor environment, they are subject to its conditions, which can have certain repercussions, on both their comfort and wellbeing and, in consequence, on their performance, mental state and health.

The achievement of energy and IEQ goals depends both on the technical features of a building and on the key-role of its occupants. In fact, the difficulty of bridging the gap between actual and predicted energy needs has, at least partially, been attributed to the as yet incomplete characterization of occupant behaviours in response to environmental stimuli [Delzendeh et al., 2017]. While the need for adequate indoor environmental quality is regulated by standards and codes, and has largely been investigated in research, the behaviour of occupants and their interactions with environmental controls still represent a 'grey' area that has only recently received attention. Occupants are still often modelled in simplistic ways, as passive subjects rather than active and adaptive agents. However, consideration of both the role of the occupant within the environment and IEQ aspects, can lead to a better understanding of building performance and to the identification of the most suitable and effective management strategies, in relation to different dynamics between users and their environment.

4.3.2 ASSESSMENT OF IEQ CONDITIONS

Ensuring good IEQ conditions is a fundamental requirement, because it directly affects health aspects, occupant productivity, cognitive activities, mood and motivation. According to [Mishra and Ramgopal, 2015], several studies have confirmed the crucial role of indoor environmental conditions on occupant performance, although there is scarce little research encompassing all aspects of IEQ. Instead, most studies have been centred on thermal and ventilation aspects. These two areas, besides having important effects on health and productivity, are in fact strictly related to energy use.
In the literature, different methods have been used to evaluate environmental conditions within indoor spaces. In terms of the comprehensiveness of the studies, two approaches can be recognized:

- *single aspect:* focus on just one IEQ area at a time;
- *comprehensive approach:* simultaneous assessment of all IEQ areas.

As pointed out in the previous section, surveys and data collection can be based on different approaches and assessment methods:

- *subjective:* administration of response survey questionnaires to occupants;
- *objective:* short/long term monitoring campaigns of indoor environmental parameters;
- *numerical analysis:* based on calculations or application of existing models and standards;
- *model simulation:* use of dynamic simulation to assess building performance.

Despite the difficulties, a complete assessment of indoor environmental conditions is better achieved through a comprehensive approach, which implies the simultaneous evaluation of the thermal, olfactory, visual and acoustic qualities perceived by occupants. In fact, any discomfort in each one of these areas could compromise the experience of users within the indoor environment. As mentioned, different assessment methods can be used to evaluate conditions in buildings, together with analyzing human behaviours within indoor spaces. However, consistent and robust methodologies are nowadays often hard to find. The current challenge is to outline and to elaborate a standardized method, in order to implement IEQ evaluations, using an efficient and structured approach. In fact, although standards offer recommendations on ways of gathering user feedback in practice and performing energy audits, systematic methods to implement subjective assessments through methodical, repeatable and uniform approaches are still missing, especially when related to personal perceptions. The consequence is that subjective evaluations are often performed, based on the researchers' best knowledge, thus obtaining data that are difficult to integrate together in a comprehensive database. As mentioned, besides transversal (also known as cross-sectional) appraisals of occupant satisfaction, two further approaches can be found in the literature: long-term longitudinal campaigns and point-in-time/right-now surveys. The former refers to questionnaires that are periodically administered at different times throughout the year and that are repeated in selected spaces of the building, without necessarily taking simultaneous objective measurements. Conversely, right-now surveys are administered at selected times, in specific spaces, while IEQ monitoring is simultaneously taking place. In general, a survey questionnaire can be structured, so that general information, demographics, and anthropometric data may be gathered from the occupants, as well as their perceptions and/or levels of satisfaction with the different IEQ areas, i.e. thermal, visual, acoustic and air quality [Pastore and Andersen, 2019]. For each domain, different questions are presented using various typologies of evaluation scales. Scales can be used in different ways, sometimes modified depending on the purpose of the survey, in order to grasp diverse information by looking at subjective patterns of votes, depending on the objective that is pursued.

4.3.3 EVALUATION SCALES

A brief review of the most common scales is summarized below in Figure 17.

Vote	Sensation
+3	Hot
+2	Warm
+1	Slightly Warm
0	Neutral
-1	Slightly cool
-2	Cool
-3	Cold

(A)

Vote	Sensation
+3	Much too warm
+2	Too warm
+1	Comfortably warm
0	Comfortable
-1	Comfortably cool
-2	Too cool
-3	Much too cool

(B)

Vote	Sensation
7	Very satisfied
6	
5	
4	
3	
2	
1	Not satisfied

(C)

Temperature preference
Hotter
No change
Colder

(D)

Vote	Sensation
+1	Clearly acceptable
0	Just acceptable
0	Just unacceptable
-1	Clear unacceptable

(E)

Figure 17. Examples of evaluation scales referring to the thermal environment

a) Perception scale: used to assess occupant perceptions of the indoor environment. Although it is based on the thermal comfort model proposed by Fanger [Fanger, 1970], this scale is also usually extended to other IEQ areas. It consists of a Likert scale, with votes ranging from -3 to +3 and with a neutral central point, 0. People voting from -1 to +1 are generally assumed to be comfortable. This scale is commonly featured in standards such as EN ISO 10551 [CEN, 2001], EN ISO 7730 [CEN, 2005], and in ANNEX H of EN 16798 [CEN, 2019] and ANSI/ASHRAE Standard 55 [ASHRAE, 2013]. For thermal studies, the scale is also known as Thermal Sensation Vote or ASHRAE Scale.

b) Bedford scale: as an alternative to the above scale, this is a 7-point scale, graded from -3 to +3, where the central point, 0, stands for the comfortable sensation. This evaluation scale is an attempt to combine the comfort acceptability of the environment with information on the perceptions.

c) Satisfaction scale: used to denote satisfaction graded by increments in satisfaction from 1 to 7. This scale is featured in ANSI/ASHRAE Standard 55 [ASHRAE, 2013]. In the literature, similar examples of this scale feature 4, 5 and 13 points. However, in a seminal paper on cognitive information processing, [Miller, 1955] indicated that the human ability to process information and make judgments significantly decreases with more than 7 simultaneous alternatives, thereby suggesting that multi-choice scales should be limited to between 5 and 7 options.

d) Preference scale: also known as the McIntyre scale, this scale is used to gather information on user preferences towards their actual environmental conditions. It is a scale with 3 options, proposed in the ANNEX H of UNI EN 15251 [CEN, 2007].

e) Acceptability scale: a 4-point scale, which gathers opinions on levels of acceptability of the environment, although it provides no information on perception. Introduced in 1992, it is reported in ANNEX H of UNI EN 15251 [CEN, 2007].

Evaluation scales can be presented in various graphical ways, with different levels of detail. No standard gives specifications on the choice of the most suitable configuration; thus, the selection is often a matter of the specificities of the study. The main difference between the various types of presentation is given by the level of accuracy and the visual hints presented to the survey participant. Scales can be partially or completely labelled, depending on the required level of accuracy. Scales can also be presented with a vertical or horizontal arrangement. In the case of questionnaires administered to children, it can be useful to simplify the ability of processing information and giving responses using graphical tools and drawings. In this case, Visual Analogue Scales [VAS], composed of single lines with anchor descriptors at each end, are recommended.

4.3.4 SURVEY ELABORATION PROCESS

As stated before, no standardized survey methodology is specified in building codes. Developing a survey is therefore a stepwise approach, which can be summarized in the following phases.

Phase 1. In this phase, it is important to define the design of the experiment or data-collection campaign. Hence, the objectives must be identified, along with the definitions of the analyses and the evaluations that will be performed with the survey data. The aim of this phase is to set out, in advance, the goals that are to be achieved and the necessary analysis, so as to draft the survey questionnaire in the most suitable way. For example, this can include:

- main objective;
- selected investigation areas;
- types of questions and evaluation scales;
- additional evaluations;
- restricted focus;
- methods for statistical analysis.

Phase 2. In this phase, the questionnaire will be elaborated. It is important to approach this task with knowledge of the selected occupants, in particular their cognitive levels and information processing capabilities, especially when it involves young occupants. For example, if the sample of analysis includes infants, there can be no interactions with them, due to their inability to understand the questions; thus, the assessment of comfort sensations can be derived from physiological factors or from indirect experiments conducted by specialists. Apart from individual cultural issues and social processes, adolescence is, unlike infancy, a growth period where the capability to understand questions is comparable to the understanding of adults.
Aside from evolutionary phases, environmental and social aspects strongly influence human perception and responses. According to the user-centred theories for the built environment, two different positions can be identified: (i) environmental *determinism*, in which the environment is assumed to be a determiner of user behaviour; (ii) social *constructivism*, in which the human attitudes are determined by the social context. Although the first position is favoured for its immediate applicability, it can minimize and oversimplify all the possible variables that drive human behaviour, whereas human experience is also highly influenced also by social norms, interactions and constructions. According to [Vischer, 2008], a user-centred theory is located between these two extremes: subjective behaviour is influenced, but not determined by the environment, while it is affected by such other aspects as feelings, intentions, attitudes, expectations and social context.

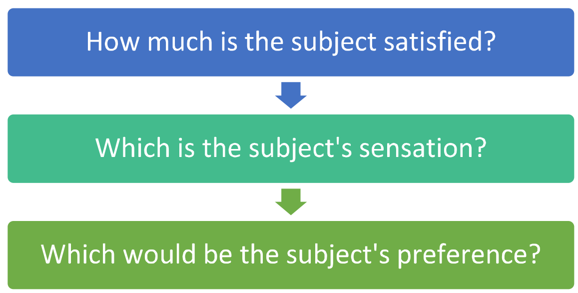
This perspective is quite remarkable, if we think about shared indoor environments, where social context and occupant-to-occupant relationships could play an important role in determining the individual actions and feelings within the group environment. According to [Watson et al., 2016], group mechanisms include: (i) organizational cultures, referring to both organizational and institutional social order; (ii) management strategies or the processes that control individual users and user groups; and, (iii) social norms and practices, referring to the tacit knowledge and related behavioural patterns of individual users. In these challenging scenarios, a multi-level comprehensive approach could be useful, so that the different factors may be grasped that influence personal experiences where the human-environment chain of cause and effect is more complex and less linear, and takes into consideration environmental, individual, and group stimuli [Barrett et al., 2013]. Data collection on occupant experiences within indoor environments should therefore gather sufficient information to grasp aspects that are related to individual attitudes and group dynamics, as well as to satisfaction and individual perceptions. Understanding the process that leads to action or non-action towards environmental conditions could be a significant step forward in the elaboration of user-oriented management strategies. From this perspective, a multi-disciplinary approach towards the elaboration of POE surveys is certainly needed.

Structuring the survey questionnaires

The structuring of a survey questionnaire is proposed in the following sections.
Section 1 - Instructions. Occupants are provided with some information before filling in the questionnaires. A brief explanation of the reasons for the survey are given, so that users will feel part of the project as active occupants of their own building. Making the users aware of the general scope of the research can raise their awareness and motivate them to disclose personal data. Finally, indications on the evaluation scales and the different types of questions are provided.
Section 2 - Demographics and anthropometrics. Occupants respond to requests for personal information of a general nature. For example: (i) gender; (ii) year of birth; (ii) weight; (iv) height; (v) work-type; and, (vi) date and time. The aim is to collect the main physical and psychological characteristics of each user, for eventual correlation with the responses. For example, some generalization could be found regarding comfort preferences depending on the gender, body mass, etc. In addition, users might be asked other questions related, for example, to the clothes they are wearing, e.g., estimate their clothing thermal insulation, if they are facing any psychological stress, e.g., to assess their general mood, etc.
Section 3 - General comments and specific questions. The aim of inviting occupants to express their general comments is for a better characterization of their satisfaction levels with the building and to identify potential aspects that might affect their answers. Different aspects can in fact influence subjective responses: for example, the satisfaction level might be affected by the level of appreciation of the general social context and of the interpersonal relationships. In addition to this, specific questions may be posed that, for example, inquire into levels of interest in the energy consumption of a building. These questions could then be evaluated on a Likert satisfaction scale or via binary (e.g., yes/no) answers. Some questions on occupant behaviour towards energy efficiency might also be asked: an individual occupant might be required to indicate their level of action towards simple energy conservation measures, and the reasons leading to an active/passive behaviour. Finally, the specific location of the occupant during the survey is considered, so that the responses may, wherever possible, be linked with the configuration of the room/built environment (or with simultaneous environmental monitoring).
Sections 4 to 7. The views of occupants and their feedback on indoor environmental qualities are shown here. These sections will all generally follow the same structure, which can be summarized as follows.

1. Perceived control over the environment: users are asked to indicate the types of control available for modifying their surrounding environment. This information is useful to understand if there is any gap between the real control provided by building systems and the control levels perceived by the occupants.
2. Level of satisfaction with each specific IEQ domain: evaluated for each domain, it can be ranked by the subject with a Likert-type scale of either 5 or 7 points.

3. Comfort sensation: rated, for example, on a scale from -3 to +3, the responses provide information on user perceptions, in relation to a specific IEQ domain.
4. Preference: using, for example, the McIntyre 3-point scale, the subject can express a preference regarding their actual environment. This question follows those on satisfaction and sensation, in order to follow, as with the survey elaboration process, the following logical sequence:



1. Attitude: in this part, the aim is to grasp user attitudes and behaviour towards a sensation of discomfort. The goal is to understand whether subjects take action by themselves or whether their behaviour is reliant on a leader or other users, and therefore influenced by the social context and group dynamics.

Optional modules:

2. Room/space setup: users can give some information on the configuration of the room or space they are occupying and provide additional details on the system operation. This approach is especially useful in the case of long-term surveys, when the researcher might not be able to carry out a direct appraisal of the conditions under which the responses would be provided.
3. Reasons and patterns of discomfort: the underlying purpose of this question is to identify the reasons for discomfort in each IEQ domain, according to occupant opinions, and to recognize potential patterns of discomfort. A picture that will give a better grasp of possible problems and malfunctioning as perceived by the occupants, with a view to the preparation of better control and management strategies, thereby ensuring acceptable IEQ conditions, whilst fostering energy-saving strategies.

Phase 3. This phase defines the way that a survey questionnaire is best administered to occupants, in particular concerning the choice of surveyed locations, representative times, and the delivery method. Online-based surveys and mobile applications could be used, because they can encourage user engagement, facilitate data collection and processing, and gather information from occupants with a tool that is nowadays part of their everyday routine. According to UNI EN 15251 [CEN, 2007], surveys should be administered in representative spaces within the building, at representative times throughout the year.

Phase 4. In this phase, results are elaborated and analyzed, matching the goals set in Phase 1. For each IEQ domain, the main questions are framed that are considered significant for the proposed objectives. The flow chart shown below in Figure 18 is proposed.

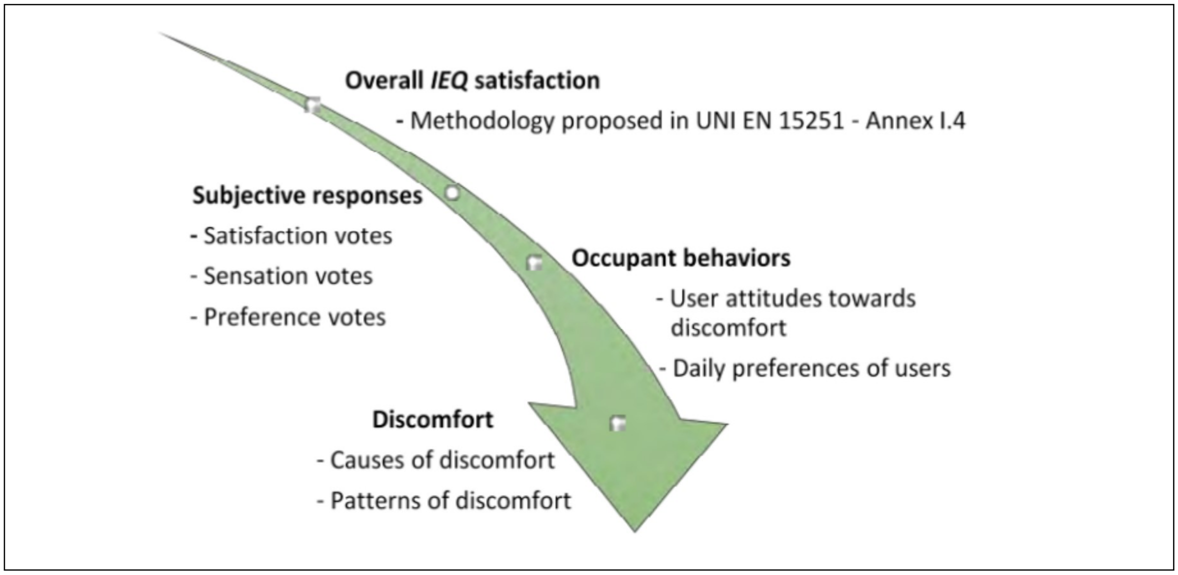


Figure 18. Data-elaboration process

1. *Overall IEQ satisfaction evaluation methodology, proposed in EN 15251 [replaced, in 2019, by EN 16798-1].*
   The method prescribed in EN 15251 – Annex I.4 [CEN, 2007] can be applied to evaluate the overall IEQ inside a building. According to the aforementioned standard, "*the percentage of people voting acceptable (thermal environment and air quality) is calculated for each of the representative spaces in the buildings. A weighted average according to the number of people in the different spaces is calculated and used for classification. More details can also be included by showing the distribution of votes on the 7-point thermal sensation scale and showing the percentage of people wanting higher, no change and lower room temperatures*". Even though this approach is only proposed for thermal comfort and air quality, it can be adapted to the other domains of indoor environmental quality.

2. *Satisfaction votes, perceived subjective sensation and occupant preferences.*
   As suggested in the standard, more details are added to the analysis where relevant. Answers on a Likert 7-point scale are taken into consideration for the assessment of satisfaction (votes higher than or equal to 4 can be considered as an expression of user satisfaction). In addition, more detailed information can be reported, such as the percentage of answers under both the sensation vote scales (-3/+3 perception scale) and the preference vote scales (3-point McIntyre scale).

3. *Occupant behaviour*
   Some further details on occupant behaviour and attitudes towards discomfort can be presented, together with the user preferences in the survey on their indoor environment in everyday life.

4. *Discomfort causes and patterns*
   Finally, analysis can be performed, for insight into the main causes of discomfort and the patterns of their occurrence.
   Focusing on subjective evaluations, the proposed stepwise methodology enables the final administration of a tailored questionnaire, considering both the building typology and the occupants. This approach allows us to:
   - gather occupant responses regarding the main IEQ domains;
   - understand user satisfaction levels and comfort perceptions;
   - assess user preferences within the indoor environment as well as in everyday life scenarios;
   - understand occupant behaviour, attitudes and actions in reaction to discomfort;
   - gain a deeper understanding of user moods and psychological attitudes;

- grasp potential group dynamics and social norms that can affect the individual will of the occupants;
- evaluate potential recurrent patterns in perceived discomfort.

Further developments of the methodologies for delivering and collecting data from survey questionnaires still need to be carried out, especially in the field of user behaviour. To do so, an inter-disciplinary approach is required, so as to identify physical, physiological and psychological factors, particularly in shared spaces (e.g., group dynamics), that can strongly affect the individual occupants.

4.4 POE PROTOCOLS

Figure 19 below provides an illustration of the structure of POE protocols, looking specifically at measuring the operational performance of buildings (e.g., energy, water use, wastes, etc.), parameters of indoor environmental quality (e.g., air quality, lighting, thermal comfort, soundscape, etc.), and the satisfaction levels of occupants towards building features and/or interior spaces.

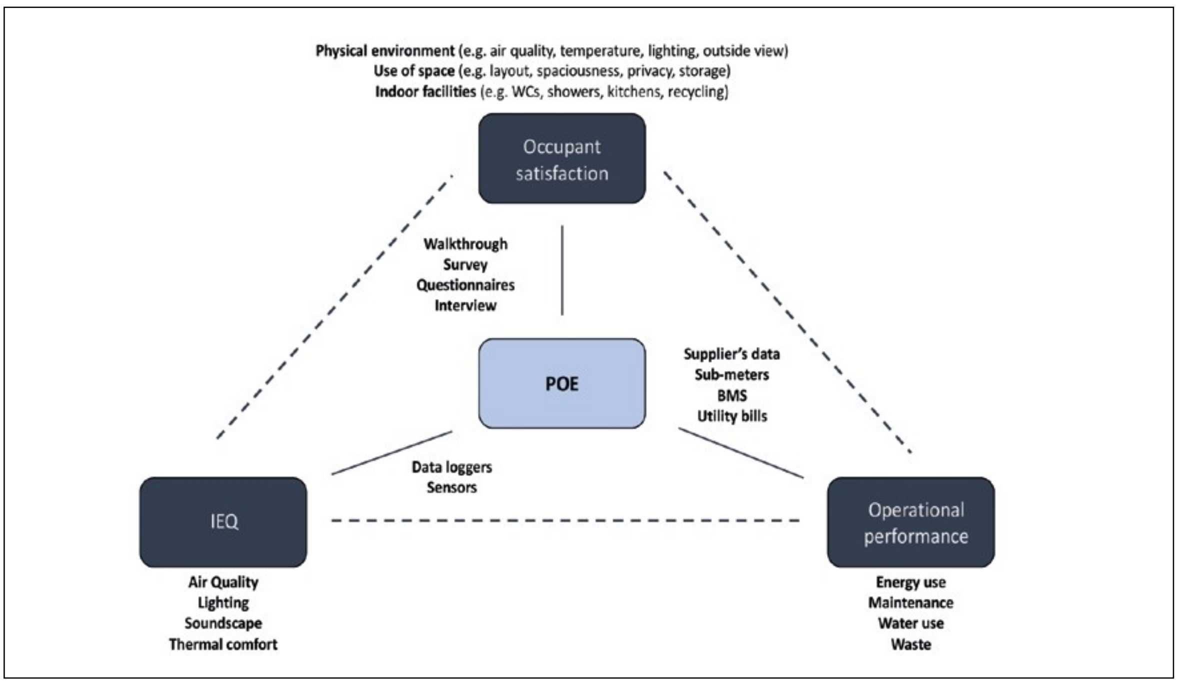


Figure 19. Structure of POE Protocols

Table 10 lists the main POE protocols that are available for the performance of post-occupancy evaluation and monitoring campaigns. These protocols have been selected, based on the vast scientific literature available on their application and the fact that they are considered as "pre-approved" third-party survey providers under the criteria established by several building codes and certification tools, such as the International WELL building standard v.2 [WELL, 2019a].
The table below illustrates the type of POE procedure (e.g., transversal, point in time, longitudinal), the assessment method, the type of evaluations that are performed, the categories that are analyzed, compatibility issues with green building certification systems and other standards, the common types of buildings under analysis, and the availability of online links and references.

Table 10. POE Protocols

Protocols	Procedure	Method	Evaluations	Notes	Categories	Standards	Type Of Building	References
CBE Occupant Survey	Transversal	Online Questionnaire	Collection of questionnaires to monitor performance and plan strategies	Survey valid if users occupied the building for last 6 months	General building, Workspace, Cleanliness, Ease of Interactions, Amount of light, Comfort of furnishing, Amount of Space, Visual Comfort, Colours and Textures, Furniture Adjustability, Visual Privacy, Noise level, Temperature, Sound Privacy	LEED and WELL	Office, Laboratory, School, Residence, Health Care, etc.	Zagreus et al., 2004
BOSSA TIME-LAPSE	Point in time	Right now Questionnaire	Occupant questionnaire on key aspects of their indoor space	Pre- and Post-evaluation criteria	Indoor Air Quality, Spatial comfort, Noise distraction, Sound privacy, Connection to Outdoor, Building Image and Maintenance, Individual Space, Thermal Comfort, Visual Comfort, Perceived Health and Productivity, etc.	NABERS and LEED	Commercial Buildings	Cândido et al., 2013b
SNAP-SHOT BOSSA	Point in time	Right now Questionnaire	Occupant questionnaire to evaluate the qualities of indoor spaces	Measurement real-time	Thermal Comfort, Visual Comfort, Acoustics, Indoor air quality	WELL	Commercial Buildings	Cândido et al., 2016a
BOSSA NOVA	Point in time	IEQ mobile + Right now survey	Mobile instrument equipped with sensors	Measurement real-time	Thermal Comfort, Visual Comfort, Acoustics, Indoor air quality	WELL	Commercial Buildings	What is BOSSA?
BUS	Transversal	Online questionnaire	Questionnaire focusing on the perceptions and wellbeing of the occupants	Before or after the operation	Work organization, Water, Nutrition, Movement, Mind and Community Programmes, etc.	WELL, BREEAM and LEED	Commercial Building, Residences, Healthcare, Schools, etc.	CIBSE – PROBE Studies
Space Performance Evaluation (SPEQ)	Transversal	Online questionnaire	Online questionnaire with 76 questions and 7 different categories	Survey focusing on quality, comfort performance,and health of the workplace	Thermal Comfort, Visual and Acoustics, Air Quality improvement	LEED and WELL	Commercial Building, Residences, Healthcare, Schools, etc.	Space Performance Evaluation Questionnaire (SPEQ)

Protocols	Procedure	Method	Evaluations	Notes	Categories	Standards	Type Of Building	References
Leesman Index	Longitudinal	Online survey	Survey focusing on the future organization of the company, decisions and investments	Before or after the operation	Collaboration, Environmental Design, Facilities and Services, Furniture and Layout, Indoor Environment Quality, Technology, etc.	WELL	Workplace	What is the Leesman Index and what is it measuring? Leesman, PF 1497 Annex 3 Employee Experience & Workplace Performance | Leesman
Occupant Comfort & Wellness Institute Built Environment	Longitudinal	Online survey	Performance survey focusing on the workplace	Before or After the operation	Office Layout, Workspace, Thermal Comfort, Air Quality, Lighting, Acoustic Quality, Building cleanliness, Wellbeing and Health, etc.	WELL	Workplace	Occupant Comfort & Wellness Surveys
Comfortmeter	Transversal	Online questionnaire	Web-based survey tool that assesses user satisfaction with office buildings	Survey valid if the occupants moved into the building over the past 12 months (1 winter and 1 summer)	Indoor Environmental Quality and Wellbeing	LEED and BREEAM	Office, Schools, University, Retail, Industry, etc.	Comfortmeter Building Performance
BeWell LeadWell *Women *Coaching *Leadership Circles	Transversal	Online questionnaire	Questionnaire of 133 questions divided into 6 categories and 19 sub-categories	Survey to improve leadership in the workplace	Prosperity, Fuel, Flow, Wonder, Wisdom and Amplified Prosperity, etc.	WELL	Work Activities, Offices	BE WELL LEAD WELL®
OHFB Afriforte	Transversal	Online questionnaire	Service for the company to maximize profits	Guide to profit maximization and investment	Productivity, Absenteeism, Customer satisfaction, Incidents Employee turnover, Safety	WELL	Work Activities, Office	Afriforte – Metrics that matter

4.4.1 CBE OCCUPANT INDOOR ENVIRONMENTAL QUALITY (IEQ) SURVEY

The CBE Occupant IEQ Survey is a protocol and webtool based on 20 years of research and developed by the Center for the Built Environment (CBE) at the University of California, Berkeley (USA). It allows building managers and researchers to assess the performance and effectiveness of different built spaces and for easy acquisition of structured feedback from the users. The survey has been implemented in over 1,000 buildings around the world, with responses from over 100,000 occupants. It is completely anonymous and provides comparative statistics on the responses against benchmarks from a vast database featuring information from other buildings, for improvements to management decisions [Frontczak et al., 2012b]. The feedback collected via the occupant survey toolkit can facilitate the identification of problematic areas and the proposal of solutions. This tool helps to meet the requirements of many certification programmes including LEED and WELL. The survey, a component of the Transversal POE procedures, is structured into several categories. For each category, occupants are requested to indicate their level of satisfaction on a Likert scale ranging from -3 to +3. The categories include, among others, the following:

- General Building: expressing overall satisfaction with the building;
- General Workspace: collecting overall perceptions of the workspace;
- Office Furnishings: gathering comments on ergonomics and materials;
- Office Layout: exploring perceptions of storage, space, and privacy;
- Maintenance: understanding the effect of operations, cleaning, etc.;
- Air Quality: identifying sources of pollutants;
- Thermal Comfort: gathering feedback on temperature and air movement;
- Lighting: examining the impact of electric and natural illumination;
- Acoustic Quality: assessing speech privacy and noise levels.

The survey is applicable to many types of buildings including offices, laboratories, schools, residences, healthcare facilities, etc. Over time, new modules have been added to improve the granularity of the questionnaire and obtain more detailed feedback related to specific aspects of investigation. The survey is valid if the building has been occupied for at least 6 months.

Further information available at: https://cbe.berkeley.edu/resources/occupant-survey/

4.4.2 BOSSA

The Building Occupants Survey System Australia (BOSSA) is an IEQ assessment protocol for Australia's office buildings aimed at improving occupant health, comfort and productivity. BOSSA is endorsed for use by the National Australian Built Environment Rating System (NABERS) promoted by the Green Building Council of Australia and the New Zealand Green Building Council [Cândido et al., 2016a].

The BOSSA system includes the following tools:

- BOSSA TIME-LAPSE: This is a transversal survey tool aimed at assessing occupant satisfaction and IEQ performance of office buildings. It can be used to address NABERS, LEED and WELL pre- and post-occupancy evaluation criteria. The core questionnaire items ask building occupants to rate their overall satisfaction on key IEQ dimensions, including among others:
  - Indoor air quality and air movement;
  - Spatial comfort;
  - Noise distraction and privacy;
  - Connection to outdoor environment;
  - Building image and maintenance;
  - Individual space;
  - Thermal comfort;
  - Visual comfort;
  - Perceived health and productivity.

- SNAP-SHOT BOSSA: a point-in-time questionnaire administered to the occupants of a work space to assess the environmental quality within their work area. It is available in four modules: Acoustics, Thermal Comfort, Visual Comfort, and IAQ. The questionnaire is accompanied by simultaneous real-time IEQ measurements.
- BOSSANOVA: an IEQ point-in time-mobile assessment cart equipped with an integrated array of sensors that, combined with the SNAP-SHOT BOSSA questionnaire, allows the collection of high-resolution IEQ data. The instrument includes sensors for thermal comfort, IAQ, lighting and acoustics.

Further information available at: http://www.bossasystem.com/

4.4.3 BUS

The BUS methodology was created about 30 years ago on the basis of 70,000 surveys administered in the context of the PROBE studies [Leamann and Bordass, 1999]. PROBE was a research project (1995-2002) funded by the UK government and implemented by the Builder Group, Energy for Sustainable Development (ESD), William Bordass Associates. The methodology was based on standardized survey methods, based on the collection and evaluation of the energy consumption of buildings and their occupant data.
The Building User Survey (BUS) is a transversal questionnaire investigating the performance of buildings on the basis of responses from their occupants. The BUS questionnaires can be applied to study domestic and non-domestic buildings and transient spaces. BUS facilitates benchmarking and comparisons of measured building performance and occupant satisfaction. Data are collected to identify the views and the satisfaction levels of occupants, from which the capability of the building to meet the physical, psychological and health needs of occupants is inferred. The participants rate their overall perception of comfort in the building in summer and winter, their satisfaction with the design, with aspects of environmental control and with overall performance. The BUS methodology is extremely useful for benchmarking and comparison purposes. The main points consist of the identification of the features to be improved, evaluation before and after the intervention, and compliance with the POE criteria that can contribute to the achievement of certifications including BREEAM, LEED, WELL, and NABERS.
Within the tools and frameworks promoted by BUS, Soft Landings was introduced, in 2008, by the Building Services Research & Information Association (BSRIA) and was extended, in 2010, to the school building sector [BSRIA, 2008]. It was implemented in 2014 with the new RIBA 2013 work plan. Soft Landings is used for new constructions or renovations of existing buildings; it increases the sensitivity of performance in the early stages of briefing and feasibility; it helps set specific objectives by coordinating the roles of designers, builders and operators; and, it helps manage expectations concerning the design, construction and commissioning of the building in the first weeks after the intervention, through monitoring, reviews, and responses from the occupants, to make the best possible use of the work spaces. The monitoring is performed in the first weeks immediately after the operation, after the first year of occupation and then for the second and third year.
In 2009, the BUS methodology was acquired by Arup to create the BUS partner network. Recently, the Arup Building Performance team has partnered with Delos to promote compliance with the WELL v.2 Building standard via the creation of a new survey called the BUS Wellbeing Survey. New question items have been introduced on the quality of the workplace and work organization, water, nutrition, movement, mind, community programmes, etc.

Further information is available at:
https://www.cibse.org/knowledge/building-services-case-studies/probe-post-occupancy-studies
https://www.usablebuildings.co.uk/

4.4.4 SPACE PERFORMANCE EVALUATION QUESTIONNAIRE (SPEQ), HIGH PERFORMANCE ENVIRONMENTS LAB (HIPE)

The Space Performance Evaluation Questionnaire (SPEQ™) from the HiPE Lab (University of Oregon) has been developed and tested in a variety of building types since 1998. It has been applied to evaluate more than 150 buildings to date, with a robust database containing more than 100 LEED™ and other green certified buildings. It provides a wide series of questions to benchmark buildings against comparative baselines. The online survey of occupants features categories and scales identified as affecting occupant comfort, satisfaction, performance, health, and wellbeing. SPEQ™ has been cross-tested and calibrated in the field and in lab settings. The transversal questionnaire evaluates 30 issues in 76 questions classified into 7 main categories. All questions contain a skip-logic approach, to avoid irrelevant information that the respondent might otherwise have to provide, so the questionnaire becomes more effective and less tiresome. The average response time of the questionnaire is 12 minutes.

Further information available at: https://hipe.uoregon.edu/

4.4.5 LEESMAN INDEX

The Leesman index aims at measuring the experience of employees, acquiring feedback on the quality of the workplace, by comparing it with a database that collects the experience of thousands of office workers. The tool awards a Lmi score of between 0 and 100; workplaces with a scores of 70 or higher, with a minimum of 50 respondents and a maximum error margin of 5%, are awarded the Leesman+ Certification. The survey has four standardized sections that provide a comprehensive assessment of how well the workplace is functioning for the organization and its employees:

1. Work Activities: what the activities of the employees are and how well these are supported in the workplace;
2. Workplace Impact: how the workplace supports productivity, pride, sense of community, etc.;
3. Physical and Service Features: which physical features are important to the employees and how satisfied the employees are with those features;
4. Mobility: the extent of employee mobility within and outside the workplace.

The categories available in the questionnaire include:

- Collaboration;
- Environment Design;
- Facilities and Services;
- Furniture and Layout;
- Indoor Environment Quality;
- Technology.

The responses to the questionnaire can be used to assess employee involvement, the effectiveness of decisions and the benefits of new strategies. It can also be the basis for planning future investments. Additional context-specific modules (e.g., environmental wellbeing, flexible working, etc.) are also available and tailored questions can be added to the standardized survey. The questionnaire can be administered before and/or after the operation as a longitudinal instrument.

More information on: https://www.leesmanindex.com/

4.4.6 OCCUPANT COMFORT AND WELLNESS SURVEY FROM THE INSTITUTE FOR THE BUILT ENVIRONMENT AT COLORADO STATE UNIVERSITY

The Institute for the Built Environment (IBE) at Colorado State University has developed a survey that addresses comfort, health, wellbeing and performance of building occupants. The survey is primarily designed for use in offices, although future developments plan the integration of residential and multi-family projects. The survey includes the following aspects:
- Office layout
- Workspace adjustability
- Thermal comfort
- Air quality
- Lighting
- Acoustic quality
- Building cleanliness
- Wellbeing and Health conditions

The survey belongs to the longitudinal procedures and customizable items can be added, including tools for management and analysis of responses (e.g., customization of interviews, social networks and programme management for the realization of an action plan for the building analyzed, etc.).

Further information available at: https://ibe.colostate.edu/occupant-comfort-wellness-surveys-2/

4.4.7 COMFORTMETER

Comfortmeter is based on scientific research from 6 European universities supported by the European Commission through a dedicated H2020 project. This tool measures comfort satisfaction in a scientific way and is compatible with the BREEAM, LEED and WELL certifications. The building must have been occupied for at least 12 months, a period of time that implies occupancy over at least one winter and one summer, hence one heating and one cooling season. This transversal satisfaction survey is composed of 59 questions and it is based, among others, on the following parameters:
- Lighting: including healthy natural light, artificial lighting and views;
- Air Quality: including fresh air flow, replacement of polluted air and reduction of contaminants;
- Office Environment: including type of workplace and personalization;
- Thermal Comfort: including air and radiant temperature, humidity, air speed, and activity level;
- Acoustics: including external and internal noise level, reverberation;
- Individual control: including ability to regulate the temperature, open the windows, management of lighting levels, etc.
-

Further information available at: https://www.comfortmeter.eu/

4.4.8 BE WELL LEAD WELL

Well Lead Pulse is an evaluation tool that facilitates transformations toward a new way of thinking about a team and an organization at work. It is the result of scientific research combined with over 30 years of development by Fortune 500, exploring six dimensions that include prosperity, fuel, flow, wonder, wisdom and amplified prosperity. The questionnaire features 133 questions divided into 6 categories and 19 sub-categories focusing on wellbeing and transformation. There are 4 types of programmes:
- Be Well Lead Well Women: 9-month programme for women leaders to develop their leadership;
- Be Well Lead Well Coaching: learning programme for leaders to update their knowledge;
- Executive Wellbeing Program: a programme to provide a personalized, evidenced-based approach to top leaders for wellbeing and optimal performance;

- Be Well Lead Well Leadership Circles: a 9-month programme to accelerate the effectiveness of leaders and leadership teams.

Further information available at: https://www.bewellleadwell.com/

4.4.9 OHFB-AFRIFORTE

The Organisational Human Factor Benchmark (OHFB) is a scientific-based organizational diagnostics suite developed since 1998 by Afriforte and the WorkWell research unit at the Faculty of Economics and Management Sciences of the North-West University (South Africa). The applications of the benchmark include:

- Bringing the human factor into the workplace: integrating the effectiveness of the workplace and quantifying it in the corporate performance of the organization;
- Managing the result: connecting the results of human factors with impact tests;
- Guiding interventions to maximize returns of investments: focusing on risk factors that affect critical results;
- Increasing productivity, understanding the reasons for absenteeism, helping employees in difficulty, forecasting the turnover of organizations to better manage available resources.

Further information available at: http://www.afriforte.com/home/ohfb/

4.5 POES IN STANDARDS AND RATING TOOLS

Table 11 to Table 16 below list the main criteria featured in selected green buildings certification systems (LEED, BREEAM, GREEN MARK and GREEN STAR) and in building standards (WELL v2, 2019a) related to the implementation of post-occupancy evaluation campaigns or building monitoring and surveys.
These criteria will be presented in greater detail in the following sections.

Table 11. POE Criteria in LEED v.4.0

TYPE	BUILDING	CATEGORY	CRITERION	C/P	DESCRIPTION
O+M	Existing Buildings Retail Schools Hospitality Warehouses and Distribution Centres	Indoor Environmental Quality	Occupant Comfort Survey	C	1 Credit Administer at least one occupant comfort survey to collect anonymous responses regarding at least the following: acoustics, building cleanliness, indoor air quality, lighting, thermal comfort. The responses must be collected from a representative sample of building users making up at least 30% of the total occupants. As a minimum, perform one new survey at least once every 2 years.
ID+C	Commercial Interiors Retail Hospitality	Innovation	Occupant Engagement	C	1 Credit Requirement: Feedback on consumption, implementing communication methods to inform occupants of 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. Requirement: Occupant responsibility, implement programmes to involve the occupants through communications to contribute to the achievement of the sustainability objectives for the building. Requirement: Performance evaluation to trace and to document the results for occupants through meetings, specifying the areas to be improved and the performance that has been achieved.
BD+C	New Constructions Major Renovations Core and Shell Data Centres Hospitality Retail Schools Warehouses and Distribution Centres		Design for Active Occupant	C	1 Credit Improve the health of building users through physical activity. Requirement: Buildings must have at least a stairway that allows occupants to move between floors.
			Occupant Comfort Survey	C	1 Credit Administer at least one occupant comfort survey, to collect anonymous responses on, at least, the following: acoustics, building cleanliness, indoor air quality, lighting, thermal comfort. The responses must be collected from a representative sample of building users making up at least 30% of the total occupants. As a minimum, perform one new survey at least once every 2 years.

C=Credit P= Prerequisite

Table 12. POE Criteria in LEED v.4.1

TYPE	BUILDING	CATEGORY	CRITERION	C/P	DESCRIPTION
O+M	Existing Buildings Retail Schools Hospitality Warehouses and Distribution Centres	Innovation	Occupant Engagement	C	1 Credit Intention: improving building performance by promoting energy-efficient behaviour among building occupants. Requirement: inform the occupants of the actual energy consumption of the building, in real time or through a reporting mechanism on a monthly basis. Minimum data registration period: 1 year. Empowering occupants through periodic communications, to achieve the sustainability goals of buildings.
ID+C	Commercial Interiors Retail Hospitality		Design for Active Occupant	C	1 Credit Improve the health of building users through physical activity. Requirement: Buildings must have at least one stairway that allows occupants to move between floors.
BD+C	New Constructions Major Renovations Core and Shell Data Centres Hospitality Retail Schools Warehouses and Distribution Centres		Occupant Comfort Survey	C	1 Credit Administer at least one occupant comfort survey, to collect anonymous responses regarding at least the following: acoustics, building cleanliness, indoor air quality, lighting, thermal comfort. The responses must be collected from a representative sample of building users representing at least 30% of the total occupants. At a minimum, administer one new survey at least once every 2 years.

Table 13. POE Criteria in BREEAM v. 2014

TYPE	BUILDING	CATEGORY	CRITERION	C/P	DESCRIPTION
Communities Infrastructure New Construction In-Use Refurbishment & Fit-Out	New Constructions	Management - Man 05 “After-care”	Post-Occupancy Evaluation	C	1 Credit
	Refurbishment & Fit-Out				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 client or the occupant of the building undertakes to carry out adequate dissemination of information on the post-occupancy performance of the building.

Table 14. POE Criteria in WELL v.2

TYPE	BUILDING	CATEGORY	CRITERION	C/P	DESCRIPTION
User and Professional Communities, New Construction and In-Use, Shell and Core	All projects	Community Category	Prerequisite Occupant Survey	P	Prerequisite
					This prerequisite criterion requires that projects collect feedback from users on wellbeing and health within the building. The survey can be provided by third parties (IWBI approved) or can be customized. The survey must be administered to the occupants at least once a year, personal data is guaranteed by privacy and the results are shared with the WELL community online.
			Enhanced Occupant Survey	C	3 Credits
					This feature requires the collection of data from building occupants related to their health and wellbeing and other topics relevant to WELL, both before and during occupancy.

Table 15. POE Criteria in GREEN MARK v. 2005

TYPE	BUILDING	CATEGORY	CRITERION	C/P	DESCRIPTION
Residential and non-Residential Buildings (new or existing)	All projects	Other Green Requirements	Post-Occupancy Evaluation	C	2 Credits
					Post-occupancy survey for users focusing on the performance of the building. There is a minimum number of respondents of 10% and at least 5 people must be interviewed if the total number of building occupants is lower than 50.
					1 Credit
					Creation of a list of strategies of intervention undertaken after the Post-Occupancy Evaluation.

Table 16. POE Criteria in GREEN STAR v. 2003

TYPE	BUILDING	CATEGORY	CRITERION	C/P	DESCRIPTION
New Construction In-Use Refurbishment & Fit-Out	All projects	Indoor Environmental Quality	Occupant Satisfaction	C	4 Credits
					This credit rewards the assessment of the overall perceptions of comfort among building occupants through a survey, with points awarded where at least 80% of respondents indicate satisfaction during the period under analysis.

4.5.1 LEED V.4.0

LEED, or Leadership in Energy and Environmental Design, is one of the most widely used green building rating systems in the world. Available for virtually all building, community and home project types, LEED provides a framework to create healthy, efficient and cost-saving green buildings [Altomonte and Schiavon, 2013].

The LEED building certification system is constituted by a flexible framework that allows design and construction groups to evaluate the strategies that can optimize the relationship between the building and the surrounding environment. The LEED rating system is structured in different sections and organized in prerequisites and credits. The prerequisites of each section are mandatory; the credits can be chosen based on the characteristics of the project. The level of certification is related to the sum of the credit scores. The sections that make up LEED include those listed below:

- Location and Transportation: rewards decision-making on building location, with credits that encourage compact development, alternative transportation, and connection with amenities;
- Sustainable Sites: this section deals with the environmental aspects related to the site within which the building is built and its relationship with the surrounding area. The objectives are to limit the impact generated by construction activities, by controlling rainwater flows, and stimulating methods and construction techniques that respect the balance of the ecosystem, etc.;
- Water Efficiency: this section approaches environmental issues related to the use, management and plumbing of water in buildings, by monitoring the efficiency of water flows, promoting the reduction of consumption water, reuse of rainwater, etc.;
- Energy and Atmosphere: this section promotes the improvement of the energy performance of buildings and the use of energy from renewable and alternative sources;
- Materials and Resources: in this area, environmental issues related to the selection of materials, the disposal and the reduction of waste, transport, etc., are taken into consideration;
- Indoor Environmental Quality: this section deals with the quality of the internal environment, including issues of health, satisfaction, safety and comfort of building occupants;
- Innovation: this section aims to identify the design aspects that stand out for their innovation and application of sustainability practices in the construction of buildings;
- Regional Priority: this area aims to encourage design teams to focus attention on environmental features that are unique to the location of the project.

The sum of the credit scores determines the certification level of the building. Out of a maximum of 110 points available in the LEED system, projects need to obtain at least 40 to be awarded the basic rating. The certification levels are articulated on 4 awards according to the score that is obtained:

- Platinum: over 80 points;
- Gold: 60-79 points;
- Silver: 50-9 points;
- Base: 40-49 points.

Under the Indoor Environmental Quality category, the credit Occupant Comfort Survey awards 1 credit for the administration of at least one occupant comfort survey to collect anonymous responses regarding at least the following:

- 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. It is also necessary to develop a corrective action plan to address comfort issues and to implement it, if the results indicate that more than 20% of occupants are dissatisfied. At a minimum, one new survey should be performed once every 2 years.

Under the Innovation category, the Occupant Engagement criterion awards 1 credit based on feedback on consumption, implementing methods to inform occupants of energy consumption levels within the building or workspace. This can be achieved in real time or on a monthly basis. There is a minimum occupancy requirement of 1-year. The credit also involves raising occupant responsibility, implementing programmes to involve the occupants through communications that will contribute to the achievement of the sustainability objectives for the building. Performance results should be traced and documented for the occupants through meetings, specifying the areas for improvement and the performance that is achieved. The Design for active occupants (only for existing buildings) criterion awards 1 credit for improving the health of building users through physical activity. Buildings must have at least one staircase that allows occupants to move. Moreover, at least 7 out of the following 11 pre-set design strategies must be included in the project:

- Classify floors to allow occupants regular access;
- Make the stairs visible from the corridor (transparent glass on the doors), stairs not closed;
- Provide accessibility to an open staircase for at least half of the occupants;
- Locate a main staircase to be visible from the main lobby;
- Locate a main staircase to be visible from each floor entrance/vertical circulation;
- Install lighting fixtures on staircases and at each floor;
- Provide daylight using skylights or windows;
- Place signs to encourage the use of health stairs;
- Use inviting sensory stimulation on the stairwells;
- Provide health and exercise equipment for the occupants;
- Provide a multipurpose space to act as on-site exercise room.

For LEED O+M Schools and Homes Multi-Family, this criterion also includes provision for a recreational space and for gymnastic equipment for daily exercise.

Further information available at: https://new.usgbc.org/leed

4.5.2 LEED V.4.1

The categories under which the LEED v.4.1 tool is structured are essentially the same as in version 4.0, although some sections have been modified with respect to the previous version. LEED v4.1 Building Operations and Maintenance (O+M; total points 100) is used for buildings that are operational and have been occupied for at least one year. LEED 4.1 for Building Design and Construction (BD+C; total points 110) applies to buildings that are new construction or major renovations. LEED 4.1 for Interior Design and Construction (ID+C; total points 110) focuses on interior spaces fit-out. For BD+C and ID+C, at least 60% of the gross floor area of the project must have been completed by the time of certification.

Under the Innovation category, the Occupant Comfort Survey awards 1 credit for the administration of at least one occupant comfort survey every two years, for collecting anonymous responses regarding IEQ aspects. The Occupant engagement criterion awards 1 credit for informing the occupants of the actual energy consumption of the building, in real time or through reporting mechanisms on a monthly basis. A minimum data registration period of 1 year is required. Empowering occupants through periodic communications to achieve building sustainability goals is an attempt to improve building performance by enabling energy-efficient behaviour. The Design for active occupants criterion awards 1 credit if buildings have at least one staircase that allows occupants to move between floors, and if the projects respond to a series of pre-set design strategies.

Further information available at: https://new.usgbc.org/leed-v41#bdc

4.5.3 BREEAM V.2014

BREEAM is an international green building rating tool that provides independent third-party certification of the sustainability performance of individual buildings, communities and infrastructure projects. Assessment and certification can take place at different stages throughout the building life cycle, from design and construction through to operation and renovation. Third-party certification involves the evaluation of a building or project by a qualified and licensed BREEAM Assessor to ensure that it meets the quality and performance standards of the scheme. At the heart of this process are rating bodies – organizations with government approval (through national accreditation bodies) – that certificate products, systems and services. The main output from a certified BREEAM assessment is the rating, reflecting the performance achieved by a project, as measured against the standard and its benchmarks (max. 150 credits):

- Outstanding: >85% score;
- Excellent: >70% score;
- Very Good: >55% score;
- Good: >45% score;
- Pass: >30% score;
- Unclassified: <30% score.

BREEAM measures sustainable values under a series of categories, including: Energy, Health and Wellbeing, Innovation, Land Use, Materials, Management, Pollution, Transport, Waste, Water. Available BREEAM tools include: Communities, Infrastructure, New Construction, In-Use, Refurbishment and Fit-Out.
Under the New Construction and Refurbishment and Fit-Out, the category Management - Man 05 Aftercare awards 1 credit for fulfilling the Post-Occupancy Evaluation criterion. The client or the occupant of the building is requested to carry out a POE one year after the initial occupation of the building. This is done to get feedback by the occupants on building performance in use, to inform them of operational processes, including re-commissioning activities, and to maintain or improve productivity, health, safety and comfort. The POE is carried out by an independent third party and must include:

- A review of the design intent and of the construction process (e.g., revision of the design, procurement, construction and delivery processes);
- Feedback from a wide range of building users.

The client or the occupant of the building also undertakes to carry out adequate dissemination of information on the post-occupation performance of the building. This is done to share good practices and lessons learned and to inform of changes in user behaviour, building processes, operating procedures and system checks.

Further information available at: https://www.breeam.com/

4.5.4 WELL V2

WELL v2 builds on the pioneering foundations of WELL v1, drawing from its community of users and professionals, as well as from researchers and health and construction experts around the world. The main objective in the development of WELL v2 was to create a single version of this building standard that could evolve to meet the needs of any type of building anywhere in the world. It was achieved by reaffirming and relying on scientific evidence for effective health interventions within built spaces and organizational practices, referring to the essential elements of what a healthy building must be and introducing new options for what a healthy building could be. WELL is a tool currently used in over 30 countries. WELL v2 consolidates previous iterations and pilot projects in a single instrument for all project types. The system is designed so that system specificity can grow and adapt over time to different design interventions and geographical areas, and in response to new evidence and the constant evolution of public health imperatives.
There are ten concepts in WELL v2: Air, Water, Nourishment, Light, Movement, Thermal Comfort, Sound, Materials, Mind and Community. The credits (Features) can be either preconditions or optimizations. WELL

v2 operates on a point-based system, with a total of 110 points available for each project. All optimizations have a maximum point-value determined by their potential impact. All parts in the optimizations maintain a point value equal to or lower than the maximum optimization. Projects must reach all the prerequisites and a certain number of optimization points to obtain different levels of certification:

- WELL Platinum certification: 80 points;
- WELL Gold certification: 60 points;
- WELL Silver certification: 50 points.

Projects must earn at least two points per concept (or, in the case of the Air and Thermal Comfort concepts, at least four combined points). Each project cannot pursue more than 12 points per concept and no more than 100 points in total among the ten concepts. Projects can also pursue another 10 points for Innovation. At the time of submission for documentation review, projects must present a scorecard that contains a selection of points and features in accordance with these rules.

Under the Community category, the prerequisite C03 Occupant Survey requires that projects collect feedback from users on wellbeing and health within the building. The survey can be provided by one of the IWBI (International WELL Building Institute) pre-approved parties or be customized, and must be administered to the occupants at least once a year. The Enhanced Occupant Survey feature requires the collection of an exhaustive spread of information from building occupants related to their health and wellbeing and other topics relevant to WELL, both before and during occupancy. The requirements include the following:

- For offices (max. 1 point): with 10 or more employees, use pre-approved surveys with one or more specific add-on modules listed on the IWBI website. These surveys will examine consumption, basic occupant data, occupant satisfaction, health and wellbeing, etc. The data must be communicated annually via WELL online and published;
- For all spaces (max. 1 point): with 10 or more employees, the designers manage a pre-occupancy survey, pre-approved, with the basic data of the occupants, the completion of which is mandatory for all occupants. The data will be transmitted to WELL online;
- Monitor survey responses (max. 1 point): improve satisfaction strategies for survey responses;
- Facilitate interviews (max. 1 point): conduct interviews annually to explore the wellbeing of the occupants through qualified personnel. The data must be sent annually to WELL online.

Further information available at: https://www.wellcertified.com/

4.5.5 CROSSWALKS AND ALIGNMENTS

Crosswalks and Alignments are devised to identify synergies and equivalence rules between WELL v.2 and other building certification systems, in order to perform a double assessment of buildings that meet those requirements. Currently, Crosswalks and Alignments are available between WELL v2 and LEED, BREEAM, Green Star, GIGA, and the Living Building Challenge. Crosswalks are based on the following definitions:

- E (Equivalent): when the level of compliance of the external building certification system is considered equivalent, the credit responds to the requirements of WELL;
- A (Aligned): when the credits are aligned but the requirements do not completely overlap. In this case, it is necessary to present reports and evidence to support the award of the credit.

4.5.6 LEED V4.0 AND WELL V2

The correspondence between the WELL v2 and LEED v.4.0 O+M credits requires the LEED Occupant Comfort Survey credit to be aligned (A) with the WELL Select Project Survey requirement. The LEED and WELL surveys have different question categories. WELL requires submission of aggregate survey data through WELL online.

4.5.7 GREEN STAR AND WELL V2

The Green Star's Occupant Satisfaction Survey credit is equivalent (E) to the WELL Select Project Survey prerequisite. It is only valid if the projects use recognized surveys (e.g., CBE, BOSSA, BUS, etc.), otherwise it is considered aligned (A). Furthermore, the survey data must be communicated annually to IWBI. The Green Star's Occupant Satisfaction Levels credit is aligned (A) with the WELL Pre-Occupancy Survey and Report Results credit.

4.5.8 BREEAM AND WELL V.2

In the Aftercare category, the BREEAM's Post-Occupancy Evaluation credit is aligned (A) with the WELL prerequisite Select Project Survey. The BREEAM and WELL surveys have different question categories and requirements for frequency of administration.

Further information available at: https://standard.wellcertified.com/well-crosswalks

4.5.9 GREEN MARK

The Green Mark assessment program was launched by the Building and Construction Authority (BCA) of Singapore in January 2005 to promote environmental sustainability in building design and construction and to foster awareness among industry stakeholders The Green Mark certification system awards a maximum of 140 points for residential and 190 points for non-residential buildings based on a range of environment-friendly criteria. The programme evaluates both new and existing building to measure their performance under the following categories:

- Energy Efficiency;
- Water Efficiency;
- Environmental Protection;
- Indoor Environmental Quality;
- Other green features.

Certified Green Mark buildings are required to be re-assessed every 3 years to maintain their status. Before beginning the assessment process, developers and government agencies have to submit an application form to BCA. The assessment includes design and documentary reviews as well as site verification. The ranking is as follows:

- Green Mark Platinum (90 and above);
- Green Mark Gold (75 to 85 points);
- Green Mark Gold Plus (84 to 90 points);
- Green Trademark Certificate (50 to 75 points).

For Existing Buildings, under the category Other Green Requirements, 3 credits are awarded for the Post-Occupancy Evaluation criterion. More specifically:

- 2 credits for post occupancy surveys. There is a minimum number of respondents of 10% and at least 5 people must be interviewed if the total building occupants are lower than 50;
- 1 credit for the creation of a list of good actions undertaken after the Post-Occupancy Evaluation.

Further information available at: https://www.bca.gov.sg/greenmark/green_mark_buildings.html

4.5.10 GREEN STAR

Green Star, developed by the Green Building Council of Australia, is a certification system under which a building is awarded a rating by an independent third-party panel through a documentation-based assessment. Green Star project evaluations are under nine categories: Management; Indoor Environment Quality; Energy; Transport; Water; Materials; Land Use and Ecology; Emissions; and, Innovation. The Green Star overall rating scale includes the following levels:

- 75+ points: Six Stars – World Leadership;
- Score 60-74 points: Five Stars – Australian Excellence;
- Score 45-59 points: Four Stars – Best Practice;
- Score 30-44 points: Three Stars – Good Practice;
- Score 20-29 points: Two Stars – Average Practice;
- Score 10-19 points: One Star – Minimum Practice.

Under the Indoor Environment Quality category, the Occupant Satisfaction criterion requires the assessment of thermal comfort, acoustics, indoor air quality, lighting and other issues relevant to the comfort and health of building occupants. A maximum of 4 credits are awarded, if at least 80% of respondents indicate satisfaction during the performance period.

Further information available at: https://new.gbca.org.au/green-star/rating-system/

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4.7 ANNEX 1: EXAMPLE OF POE MEASURING SHEET

Building Name:

Monitoring sheet : Participant : Date: Time:

Building Plan

Floor:
Orientation:
Office: Area:

N

- Windows: Yes ☐ No ☐
- Operable windows: Yes ☐ No ☐
- Operable blinds: Yes ☐ No ☐
- Thermostat control: Yes ☐ No ☐
- Task lighting: Yes ☐ No ☐

Other observations:

Room Plan

Temperature °C	D.B 1	☐	D.B 2	☐	D.B 3	☐	Globe	☐
	Ground	☐	Ceiling	☐	Front wall	☐	Right wall	☐
					Entrance wall	☐	Left wall	☐
Humidity %	H1	☐	H2	☐	H3	☐		
Air speed m/s	AS1	☐	AS2	☐	AS3	☐		
Lighting lux	EV Horizontal 1	☐	EV vertical (facing screen)	☐	EV vertical (facing occupant)	☐	Photo mapping	☐
	EV H 2	☐	EV VS 2	☐	EV VO 2	☐	PM2	☐
	EV H 3	☐	EV VS 3	☐	EV VO 3	☐	PM3	☐
Acoustics dB	dB 1	☐	dB 2	☐	dB 3	☐		
Photos	Photo1 number	☐	Photo2 number	☐	Photo3 number	☐		

4.8 ANNEX 2: EXAMPLE OF A RIGHT NOW SURVEY FORM

Participant Number	
Date	
Time	
Weather Conditions	

What is the current external?				
Air temperature	Relative humidity	Air speed	Hor. illuminance	Sound level

Please complete the following personal details					
Age					
Sex					
State of Health	Ill		Generally OK		Extremely good
How many years have you lived here	<1	Between 1 and 2	Between 2 and 8	Between 9 and 15	Since born

Which of the following climates describes your country of origin before coming to UK?				
Tropical moist	Dry	Moist mid-latitude with mild winters	Moist mid-latitude with cold winters	Cold climate

Have you consumed any of the following in the last 15 minutes?				
Hot drink	Caffeinated drink	Snack or meal	Cold drink	Cigarette

Is your current location close to:	
Perimeter wall	
Partition wall	
Window	
Door	
Source of heat (e.g., radiator)	

What have you been doing in							
	Sleep (0.7 met)	Read (0.8 met)	Seat, relaxed (1.0 met)	Seat, typing (1.1 met)	Standing relaxed (1.2 met)	Walking about (1.7 met)	Walking 2mph (2.0 met)
The last 10 minutes							
The 30 minutes before that							
The 60 minutes before that							

What are you wearing today?		
Walking shorts, short-sleeve shirt	0.36 clo	
Typical summer indoor clothing	0.50 clo	
Knee-length skirt, short-sleeve shirt, sandals	0.54 clo	
Trousers, short sleeve shirt, socks, shoes	0.57 clo	
Trousers, long sleeves shirt	0.61 clo	
Knee-length skirt, long-sleeve shirt	0.67 clo	
Sweat pants, long-sleeve sweatshirt	0.74 clo	
Jacket, trousers, long-sleeve shirt	0.96 clo	
Typical winter indoor clothing	1.0 clo	
Long-sleeve sweat shirt, long-sleeve shirt, trousers, socks	1.14 clo	

Right-Now Survey

Building:.......................... Floor:........... Room :............. Monitoring n.: .... Participant n.: ....

1. Temperature

T1. How best would you describe the temperature in your workspace at the moment?

Too cold ☐ ☐ ☐ ☐ ☐ ☐ ☐ *Too hot*

T2. What is the degree of control that you have over the temperature of your workspace?

No control ☐ ☐ ☐ ☐ ☐ ☐ ☐ *High control*

2. Lighting (Natural/Artificial)

a) Natural

L1. How best would you describe the quantity of natural light in your workspace at the moment?

Far too little ☐ ☐ ☐ ☐ ☐ ☐ ☐ *Far too much*

L2. What is the degree of control that you have over the natural lighting at your workspace?

No control ☐ ☐ ☐ ☐ ☐ ☐ ☐ *High control*

L3. Are you experiencing discomfort with natural lighting in your workspace at the moment?

No discomfort ☐ ☐ ☐ ☐ ☐ ☐ ☐ *A lot of discomfort*

If you are experiencing discomfort with natural lighting in your workspace, please describe where the discomfort is coming from:

b) Artificial

L4. How best would you describe the quantity of artificial light in your workspace at the moment?

Far too little ☐ ☐ ☐ ☐ ☐ ☐ ☐ *Far too much*

L5. What is the degree of control that you have over the artificial lighting in your workspace?

No control ☐ ☐ ☐ ☐ ☐ ☐ ☐ *High control*

L6. Are you experiencing discomfort with artificial lighting in your workspace at the moment?

No discomfort ☐ ☐ ☐ ☐ ☐ ☐ ☐ *A lot of discomfort*

If you are experiencing discomfort with artificial lighting in your workspace, please describe where the discomfort is coming from:

3. Sound/Noise

S1. How best would you describe the level of noise in your workspace at the moment?

Far too quiet ☐ ☐ ☐ ☐ ☐ ☐ ☐ *Far too loud*

S2. How best would you describe your satisfaction with noise at the moment?

Very dissatisfied ☐ ☐ ☐ ☐ ☐ ☐ ☐ *Very satisfied*

S3. What is the degree of control that you have over the noise in your workspace?

No control ☐ ☐ ☐ ☐ ☐ ☐ ☐ *High control*

4. Ventilation and Air Quality

V1. How best would you describe the ventilation in your workspace at this moment?

Very still ☐ ☐ ☐ ☐ ☐ ☐ ☐ *Very draughty*

V2. How best would you describe the air quality in your workspace at this moment?

Very stuffy ☐ ☐ ☐ ☐ ☐ ☐ ☐ *Very fresh*

V3. What is the degree of control that you have over the ventilation in your workspace?

No control ☐ ☐ ☐ ☐ ☐ ☐ ☐ *High control*

5. General comments

Please describe any other issues related to the comfort in your workspace or building overall:

Thank you for your time and cooperation

5 CASE STUDIES

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5.1 CASE-STUDY COLLECTION METHODOLOGY

The methodology conducted to collect the case studies consists of the following phases: (1) determination of the initial premises to search the case studies; (2) development of a template to include the information of each case study; and, (3) identification of the search tools used to collect the case studies.

Case studies incorporating technologies aimed to improving the indoor environment quality were collected on the basis of the following premises:

- Type of buildings: the typologies of collected buildings followed the classification as provided in the introduction, i.e.: residential, office, education, lodging and retail/service.
- Type of technologies: the case studies collected should contain at least one technology designed to improve the indoor environment quality. Technologies can cover a wide range of possibilities, such as materials that reduce indoor contaminants and equipment that improves the indoor comfort.
- Key Performance Indicators (KPIs): as defined in Chapter 2, i.e.: indoor air quality; hygro-thermal environment; visual environment; acoustic environment; and, human values.

Once the initial premises were established, a template to include the information on the case studies was developed. Based on the previous templates elaborated within the COST action RESTORE (by WG1 and WG3), this template was adapted to both the aims and the needs of the case studies repository we are presenting here. The final version of the template included characteristics relating to cultural habits, local climate, a description of the various types of technology in use, etc. It not only includes general information on the building and the technologies, but also more detailed numerical information on the indoor environment and its performance.
The first page of the template (Figure 20) shows the title of the case study, a picture and a general description of the building with some technical data. Information regarding the KPIs which are addressed in the case study is then identified with a tick alongside the relevant KPI. On the left-hand side of the document, some key information of the case study is highlighted, such as: the location and climate zone, the building typology and the sustainability level. At the end of the page, the first technology is presented by indicating the name of the product and a general classification of whether it is a passive, active or control technology. The description of the technology continues on the second page (Figure 21) where the reasoning behind the choice of this technology is explained in a brief justification. In this section, numerical values for the KPIs indicated in the first page are included (if available). Moreover, a detailed description of technology is included as well as information on the positive-negative dependencies to other parameters and the deficiencies or research gaps for further improvements. Finally, potential providers of the technology are indicated. On the left-hand side of the second page, information is included on the client, project team, completion year and awards. More technologies can be included in the template by duplicating the section describing the first technology.

Rethinking technology through case studies
Restore Cost Action WG4.1.F

RESTORE
REthinking Sustainability
TOwards a Regenerative Economy

Name of the Building

Photo credits

General description of the building. Text 3-4 sentences

LOCATION
(incl address, GPS or Lat Lon so we can map)

CLIMATE ZONE
(according to KFICAT)
(according to KFICAT)

BUILDING TYPOLOGY
(color and highlight the correct one)

- **R** Residential
- **O** Office
- **E** Education
- **L** Lodging
- **RS** Retail/Services

SUSTAINABILITY LEVEL
(Optional - Please give your opinion about the sustainability level)

- **C** Conventional *Building as usual*
- **S** Sustainable *Limiting impact. The balance point where we give back as much as we take*
- **RS** Restorative *Restoring social and ecological systems to a healthy state*
- **RG** Regenerative *Enabling social and ecological systems to maintain a healthy state and to evolve*

TECHNICAL DATA

Gross area: XXXX sqm

Key performance indicators (KPIs) *(Please tick ✓ the KPI's which are addressed in the case study)*

INDOOR AIR QUALITY	
Contaminants – % of Formaldehyde	✓
Outdoor/Indoor - Particulate matter: PM10 / PM2.5	
Occupants satisfaction - % satisfied people	
HYGRO-THERMAL ENVIRONMENT	
Temperature/humidity/air speed - Standard Effective Temperature (SET)	✓
Occupants satisfaction - % satisfied people	
VISUAL ENVIRONMENT	
Daylight - Daylight factor (DF)	
Occupants satisfaction - % satisfied people	
ACOUSTIC ENVIRONMENT	
Background noise level - Noise criteria (NC)	
Occupants satisfaction - % satisfied people	
HUMAN VALUES	
External view and Right to light - % workstations with windows access	

REGENERATIVE TECHNOLOGY #1

GENERIC NAME/PRODUCT NAME

Classification of the technology: Passive/Active/Control

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1

Figure 20. Case study template. Page 1

Rethinking technology through case studies
Restore Cost Action WG4.1.F

RESTORE
REthinking Sustainability
TOwards a Regenerative Economy

CLIENT / OWNER / INVESTOR
(include the client OR building owner OR investor)

PROJECT TEAM
(name)

COMPLETION YEAR
(year)

AWARDS
(Include any certificates, prizes, etc. If not applicable, delete the section)

Effects/improvements on indoor environment of the case study
Please justify in one or two sentences why this technology was chosen in the project. For example, to improve indoor air quality, reduce heat loss, energy saving, etc. Add data regarding the % of improvement *(coming from the technology: climate, living, user behavior, materials, durability, maintenance, ...) In addition, if available, please add numerical values for the KPIs indicated above. If more than one technology is used, the general improvements or numerical KPI values of the case study can be incorporated above (in the general description of the building).*

Sustainability level: Regenerative/ Restorative/ Sustainable/ Conventional

Detailed description of technology: Max. 100 words. You can include information about the composition, appearance, dimensions, drawings, calculations, etc.

STRENGTH MEASURE OF EFFECTS *(optional if available)*
Max. 100 words. You can include information about the positive-negative dependencies to other parameters, state of pareto-optimality, other reconditions for effect achievements, appropriate for Building Certification System, ...

STRENGTH-WEAKNESS ANALYSIS OF THE TECHNOLOGY *(optional if available)*
Max. 100 words. (Superiority of the technology relative to conventional ones, deficiencies, research gaps for further improvements, limits according to current state of technology, ...)

Possible providers of technology: Include one or two manufacturers, executers, etc.

REGENERATIVE TECHNOLOGY #2

GENERIC NAME/PRODUCT NAME

If more than one technology is used, please complete this section as done above. Add as many sections as needed. If not applicable, delete the section.

ACKNOWLEDGEMENTS
One or two sentences maximum. If not applicable, delete the section.

LINKS AND REFERENCES

Please note that the document should not exceed 3 pages

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2

Figure 21. Case study template. Page 2

Finally, a call to collect case studies was issued and circulated to all the RESTORE participants as well as to the trainees attending the Training School organized in Venice (December 2019).
Case studies were collected using the personal experience of each RESTORE participant and their direct contact with the industry. In addition, several platforms and online tools were also used to collect case studies:
Build up platform: http://www.buildup.eu/en/practices/cases
Living-future map: https://maps.living-future.org/

5.2 OVERVIEW OF CASE-STUDY COLLECTION

An overview of a collection of 36 case studies is provided in Table 17. Most of the case studies are in Europe, but some are also from Asia, North and South America. No case studies were collected from either Africa or Australia.
At an earlier stage, it was decided to create an Atlas or a repository Map to present information on collected case studies. The great advantage of a map rather than lists and tables is that the geographic location of individual cases may be visualized, clearly indicating their distribution. When additional filters are applied, it further facilitates the quick search for information of interest. It was decided to use free tools from Google My Maps and Google Earth to create the Atlas. The Atlas is accessible as an online platform embedded in the RESTORE website (https://www.eurestore.eu/).
A comprehensive .xls/.csv file was compiled from the information in previously completed case-study templates. This file serves as a source database to create the Atlas or the repository Map. It was decided to include the following information: name and location of the building, climate zone, building typology, sustainability level, information on client/owner/investor, project team, completion year as well as relation to KPIs. The information regarding the KPIs which are addressed in a case study is identified by assigning a binary Yes/No value to each of the KPIs. More descriptive information of the building itself and the technologies it employs are not included in the Map source file. They are still accessible via the Map (Figure 22), as each placemark is linked to the appropriate form that provides further details, links and references.
Several filters (grouping) were applied to the Map to facilitate further differentiation in terms of the parameters that are considered important when analysing solutions for the regenerative environment, namely building typology, sustainability level and 5 KPIs (Figure 23):

- Grouping case studies by building typology into 5 groups: Residential, Office, Education, Lodging and Retail/Services
- Grouping case studies by sustainability level into 4 groups: Conventional, Sustainable, Restorative and Regenerative
- Grouping case studies into 2 groups (Yes/No) for each of the 5 KPIs identified: (1) Indoor Air Quality; (2) Hygro-Thermal Environment; (3) Visual Environment; (4) Acoustic Environment and (5) Human Values. Thus, those case studies that are related to a certain KPI may be easily distinguished on the Map.

Table 17. Overview of collected case studies

No.	Name	Location	Year	Build. Typ.1	Sust. Level2	Technologies				
						IAQ3	HTE4	VE5	AE6	HV7
1	Semi-detached house	Barajas, Spain	2014	R	S	N	Y	N	N	N
2	Art Gallery-Cultural centre	Nottingham, UK	2008	RS	S	N	N	Y	N	N
3	The Edge - office	Amsterdam, The Neth-erlands	2014	O	S	N	Y	Y	N	Y
4	Agencia Andaluza	Sevilla, Spain	2013	O	S	N	Y	Y	Y	N
5	François Mitterrand High School	Brasilia, Brazil	2016	E	S	N	Y	Y	N	Y
6	Live Work Home	Syracuse, USA	2010	R	RS	N	Y	Y	Y	N
7	The Research Support Facility	Golden, USA	2010	E	RG	N	Y	Y	N	N
8	Manitoba Hydro Place HQ	Winnipeg, Canada	2009	O	C	N	Y	Y	N	Y
9	B+A House	Skopje, North Mace-donia	Under cons.	R	RG	Y	Y	Y	Y	Y
10	Apt. Building with Wood-Polymer Windows	Zürich, Switzerland	2012	R	S	N	Y	N	N	N
11	Ed70 Ciemat Building	Madrid, Spain	2008	O	S	Y	Y	Y	N	Y
12	NZEB Medical centre	Lodosa, Spain	2019	O	S	Y	Y	N	N	Y
13	ZEB LivingLAB	Trondheim, Norway	2016	R	RS	Y	Y	Y	Y	N
14	NZEB 29 dwellings	Pamplona, Spain	2017	R	S	Y	Y	N	N	N
15	WeEBuilding	R. de Pena, Portugal	2016	R	S	Y	Y	Y	Y	N
16	Nursery School and kindergarten CASANOVA	Bolzano, Italy	2017	E	RS	Y	Y	Y	N	Y
17	Prismian HQ	Milan, Italy	2017	O	RS	N	Y	Y	N	Y
18	Aulario IndUVA	Valladolid, Spain	2018	E	RS	Y	Y	Y	N	N
19	Villa Castelli - Italy	Bellano, Italy	2015	R	RS	N	Y	N	N	N
20	Solar XXI	Lisbon, Portugal	2006	O	S	Y	Y	Y	Y	Y
21	Dynahaus	Halbergmoos, Ger-many	2014	R	RS	Y	Y	N	N	N
22	Ca' Foscari - Palazzo	Venice, Italy	2014	O	C	Y	Y	Y	Y	Y
23	Hungarian Nest +	Szentendre, Hungary	2019	R	S	Y	Y	N	N	N
24	Rokko Shidare Observatory	Kobe, Japan	2010	RS	RG	N	Y	Y	N	N
25	Greenpeace Spain Headquarters	Madrid, Spain	2019	O	RS	Y	Y	N	N	N
26	CERC Boldesti-Scaeni	Boldești-Scăeni, Roma-nia	2015	E	RG	Y	Y	N	N	N
27	VP22	Milan, Italy	2021	O	RG	Y	N	Y	N	Y
28	Detached house	Prishtina, Kosovo	2016	R	RS	Y	Y	Y	N	Y
29	National Headquarters E.ON ROMANIA	Tg. Mureș, Romania	2015	O	S	N	Y	N	N	Y
30	CopenHill	Copenhagen, Denmark	2017	RS	RG	Y	Y	N	N	Y
31	Espacio itdUPM	Madrid, Spain	2016	O	RS	N	Y	N	Y	N
32	Bullitt center	Seattle, USA	2013	O	RG	Y	Y	Y	N	Y
33	Copenhagen Tower Buildings 405-406	Copenhagen, Denmark	2015	O	S	N	Y	N	N	Y
34	Liko – Vo	Slavkov u Brna, Czech Republic	2019	RS	RG	N	Y	Y	N	Y
35	Administrative Building	Skopje, North Mace-donia	In cons.	O	S	Y	Y	Y	Y	Y
36	70 Wilson	London, UK	2016	O	RS	Y	Y	Y	N	Y

[1] Build. Typ.=Building Typology: R=Residential; O=Office; E=Education; L=Lodging; RS=Retail/Services;
2 Sust. Level=Sustainability Level: C=Conventional; S=Sustainable; RS=Restorative; RG=Regenerative;
3 IAQ=Technologies for Indoor Air Quality; 4 HTE=Technologies for Hygro-Thermal Environment; 5 VE=Technologies for Visual Environment;
6 AE=Technologies for Acoustic Environment; 7 HV=Technologies for Human Values

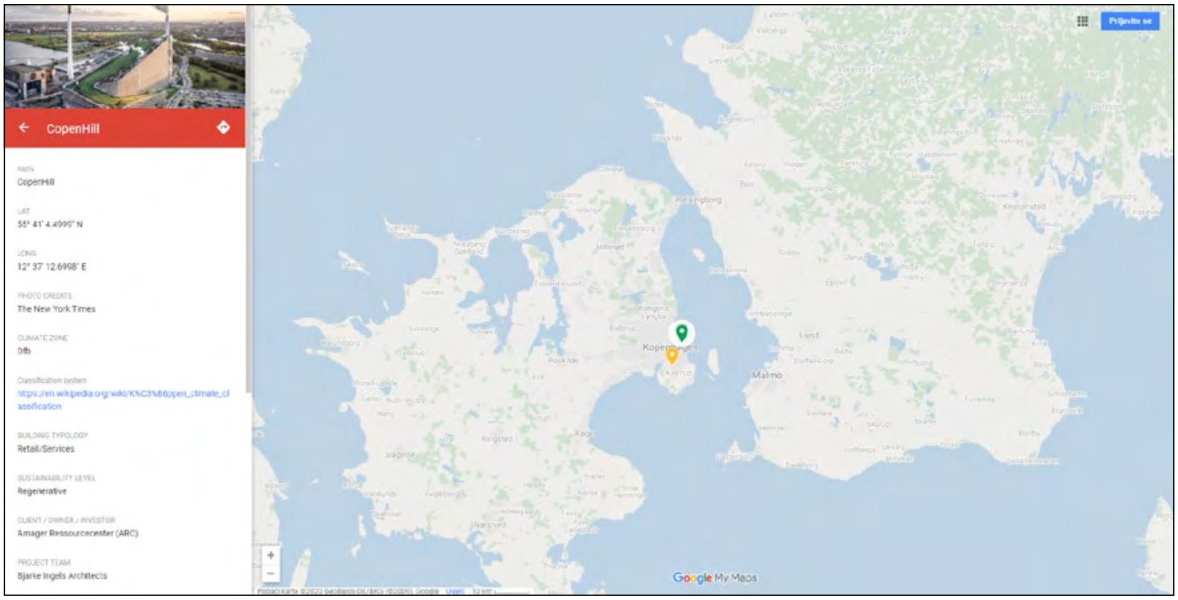

Figure 22. An example of more detailed information with further links for a case-study provided in the Map representation

Figure 23. Distribution of case studies depending on sustainability level

The map was created using Google My Maps. Members of the public interested in accessing the map may do so through the interactive map on the COST RESTORE website https://www.eurestore.eu/. In addition, data from the map were transferred in a .kmz file that can be downloaded for viewing through locally installed Google Earth Pro applications or with Google Earth online, which requires no local installation. In the case of the Google Earth, a layer was added containing the world map of the Köppen-Geiger climate classification, version March 2017 (.kmz file with medium resolution, available from http://koeppen-geiger.vu-wien.ac.at/present.htm) (Figure 24).

The placemarks for both Google My Maps and Google Earth were positioned with the latitudinal/longitudinal data provided by the author(s) of each case study. In several cases, the exact location was not disclosed – so the placemark points to a wider location (generally city centre) with an appropriate note that it is an approximate location. For some case studies 3D building views are available (Figure 25).

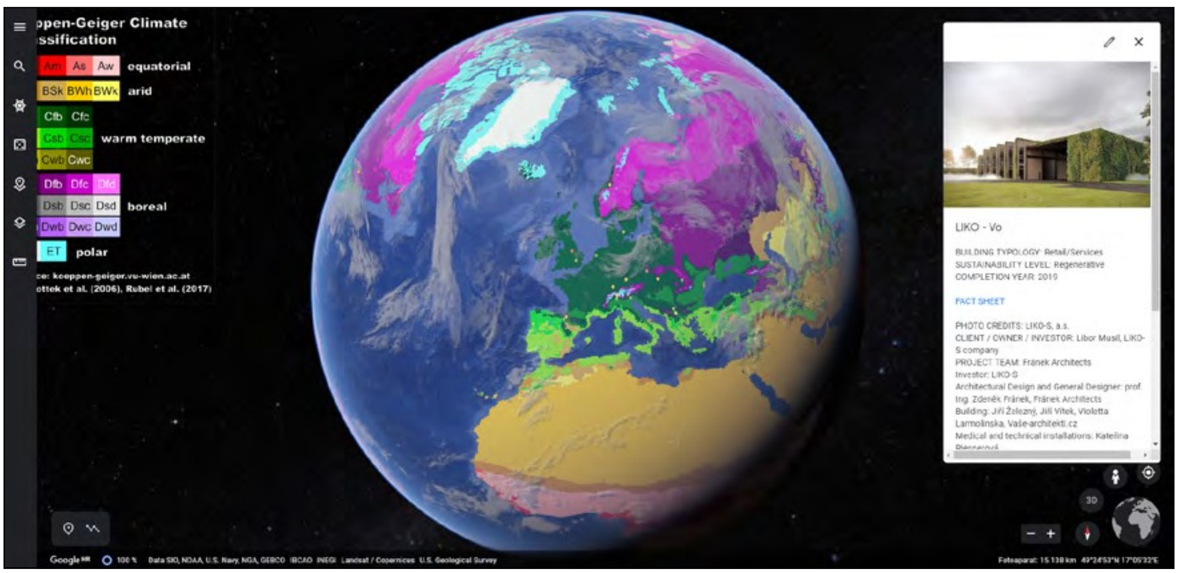

Figure 24. Case study mapping in Google Earth

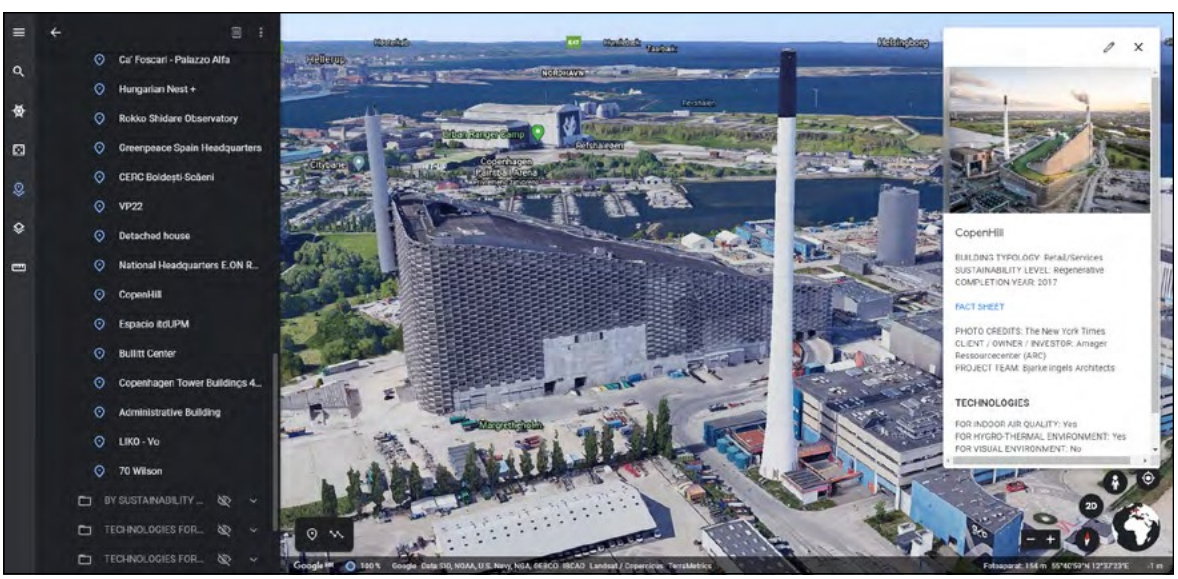

Figure 25. 3D building view of a case study in Google Earth

5.3 STATISTICS

The collection of case studies is accompanied by some statistical results, which summarize the main features of the template in use and include, among others, the types of building, the sustainable level and the year of completion. More importantly, statistical results related to the types of technology applied in the collected case studies were categorized as follows: technologies for indoor air quality, technologies for hygro-thermal environments, technologies for visual environments, technologies for acoustic environments and technologies related to human values. The analytical results are discussed in the following paragraphs.

5.3.1 GENERAL STATISTICAL DATA

Figure 26 shows the statistical information on building types from the case-study collection. The information shows that Office buildings represented 44% and are the type of building where technologies are most often applied for indoor air quality improvement. The second most popular case-study was on Residential buildings, representing 31%, and the third most popular selection was Educational buildings, representing 14%. In contrast, Retail/service buildings are the types of buildings with the least involvement in the application of technologies for indoor air quality improvement. Lastly, the Lodging type of buildings option does not appear in any of the collected case studies.

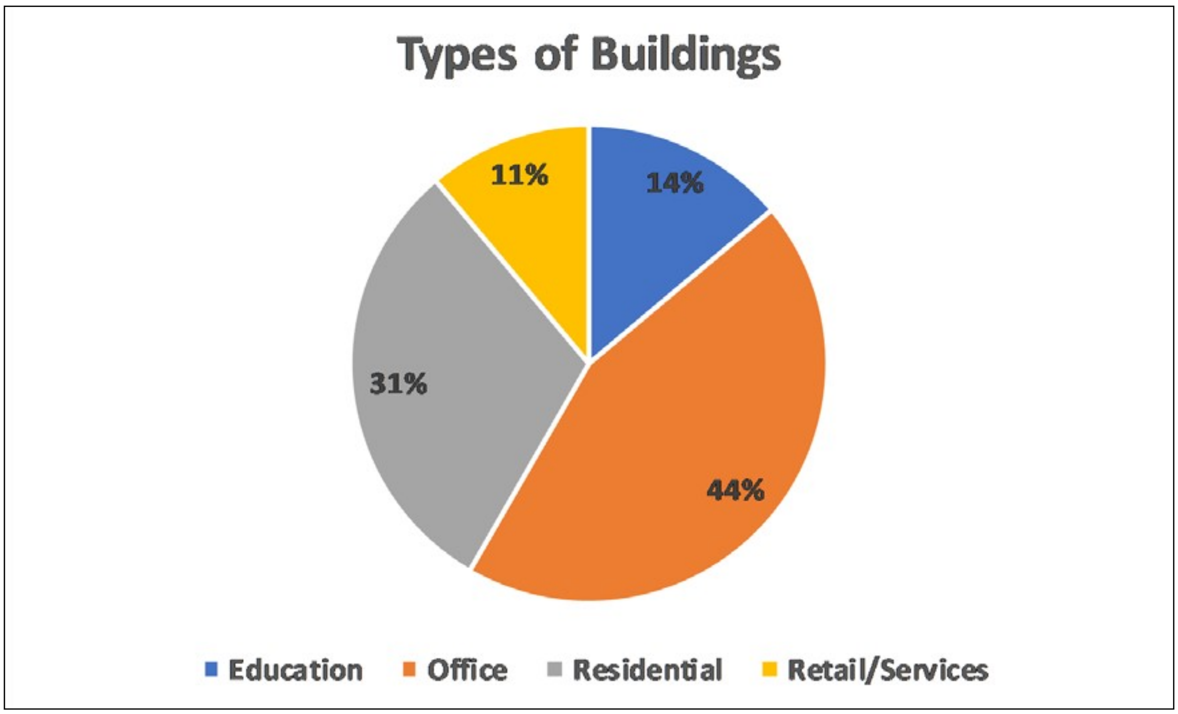

Figure 26. Results of statistical data on the types of buildings that apply technologies for indoor air quality improvement from the case-study collection

Figure 27 shows the statistical information on the Sustainability levels taken from the collection of case studies. The results showed that the Sustainable and the Restorative levels, respectively representing 42% and 31%, were the sustainable levels that the users selected most often in the evaluation of their case studies. The third most popular level, Regenerative, represented 22% of the levels that were selected. Lastly, 5% of the responses were characterized as Conventional.

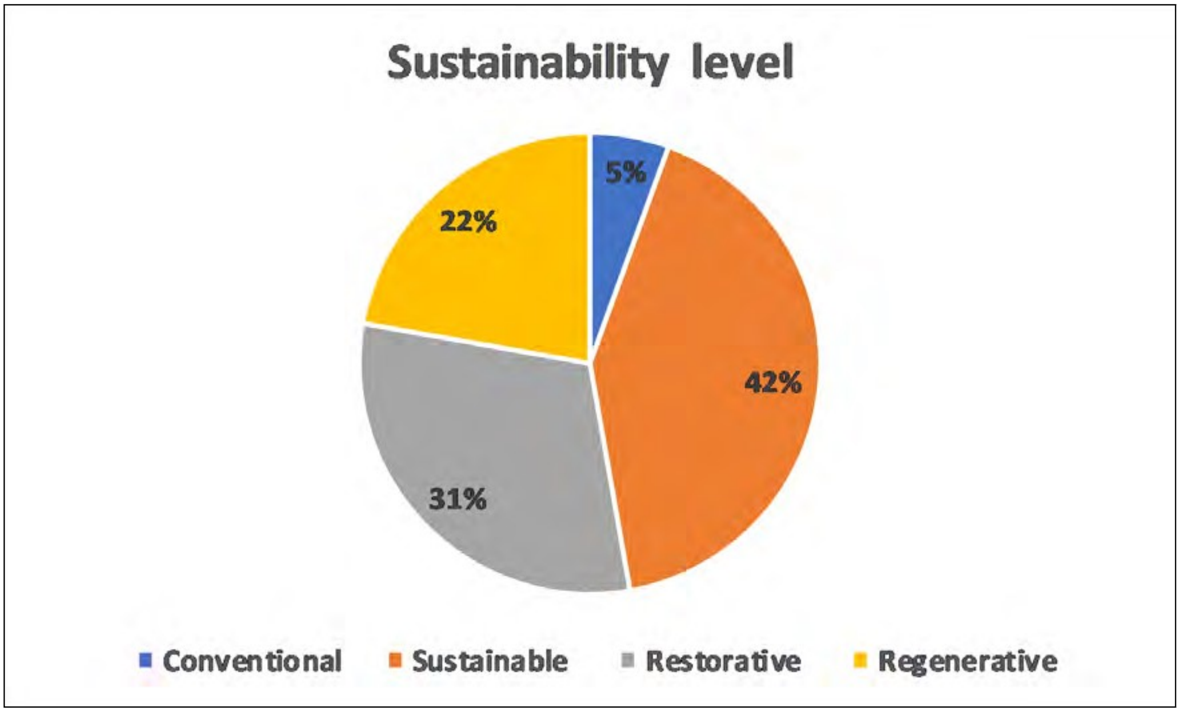

Figure 27. Results of statistical data on the Sustainability level of each case study from the case study collections

Figure 28 shows statistical information from the collection of case studies regarding their Year of completion. In this case, the results showed that the vast majority of cases were completed between 2011-2020 with some case studies, still under construction, representing 81% of the statistical results. The second most popular answer regarding the year of completion was the period between 2001-2010. Information on case studies completed before the Millennium year, 2000, are not provided.

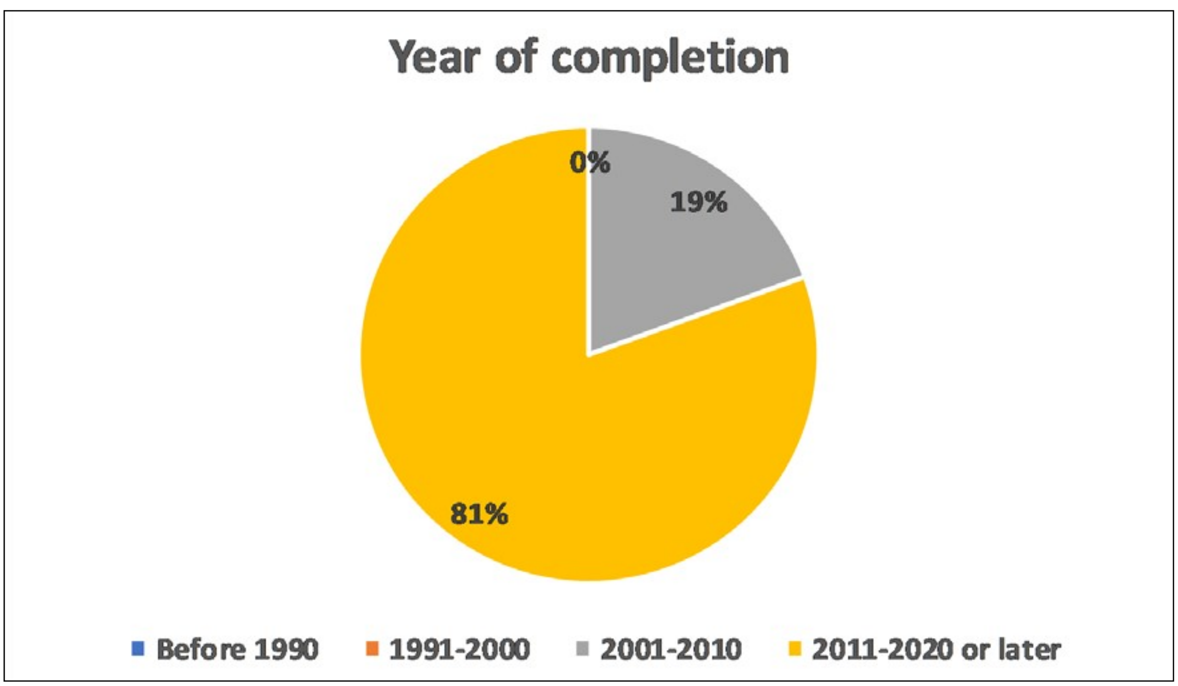

Figure 28. Results of statistical data on Year of completion for each case study from the collection.

5.3.2 TECHNOLOGIES

Figure 29 shows a bar chart of the total number of technologies applied in the selected case studies for indoor air quality, hygro-thermal environments, visual environments, acoustic environments and human values. The results showed that the most frequently applied technologies were the improvement of the hygro-thermal environment, and the second most popular technologies were for improving the visual environment. The technologies for improving the indoor air quality were in third place, while the technologies for human values and improvements to the acoustic environment occupied the final two places.

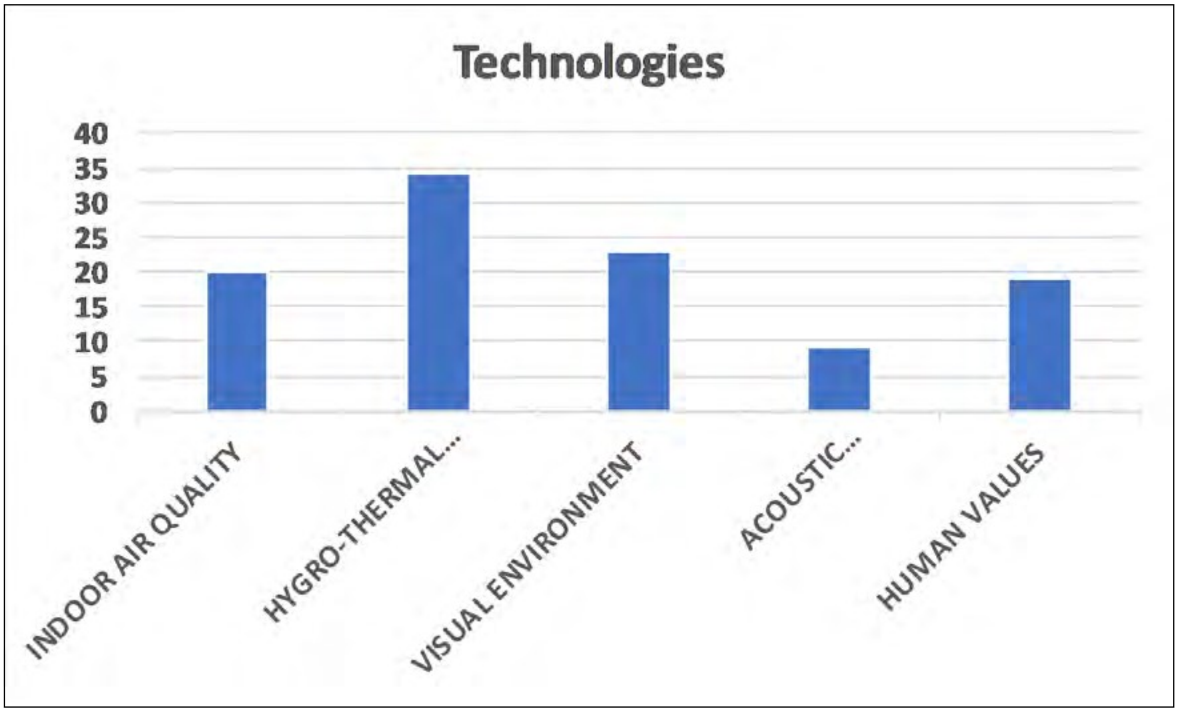

Figure 29. Type of technologies applied in the collected case studies

5.3.3 LESSONS LEARNT

The case studies that were received were then analyzed in terms of their sustainability level, building type, year of completion, and the types of technology they incorporated, to find ways of improving their indoor air quality. It was concluded that a considerable number of the case studies were characterized as sustainable and restorative, and fewer as regenerative. Also, the Atlas of case studies presents a large number of contemporary buildings, built since 2011, over the past nine years.

In addition, office buildings mainly incorporate technologies for the improvement of their indoor air quality, while educational, retail/service and lodging buildings still needed to enhance the use of similar or new technologies, if they were to reach similar levels of indoor air quality. Architects and designers need to consider regenerative technologies when designing their work, specifically in education, retail/service and lodging buildings, if they are to extend the range of technologies, implementing them for the improvement of indoor air quality in those categories of buildings and others, and achieving a transition from the sustainable to the regenerative level.

Finally, while the majority of the technologies are applied with the aim of improving both the hygrothermal and the visual environments, further investigation towards the development and the application of technologies designed to improve acoustic environments and human values should be promoted, in order to extend their implementation in buildings and to achieve regenerative sustainability.

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