Building and Environment 204 (2021) 108109

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Agri-food building performance evaluation by an integration of different measurement techniques: Case study of a bakery in south Italy

Francesco Barreca *, Giuseppe Davide Cardinali

Università Degli Studi Mediterranea di Reggio Calabria, 89124, Reggio Calabria, Italy

ARTICLE INFO

Keywords:
BPE
Agri-food industry
Rating systems
Buildings architecture
Food facilities

ABSTRACT

The performance of a building plays a key role in its sustainability, since a building cannot be sustainable if the needs of its users are not satisfied. In fact, the priority of a sustainable building is to meet the user requirements in an adequate manner, while limiting its environmental impact. The aim of this study is to supply a suitable Building Performance Evaluation method (BPE) to technicians, facility managers and designers, in order to improve the quality of management, design and construction by providing more sustainable agri-food buildings. In this study, in order to measure building performance with respect to user requirements, the simultaneous application of three different measurement techniques was proposed: a User survey by means of a questionnaire; an analysis of building documents and a walkthrough analysis by experts; and instrumental measurements and a direct survey of building characteristics. The proposed BPE method was based on a fuzzy weighted average at three levels. The fuzzy method proved to be particularly suitable for describing the vagueness of users when answering the questionnaire, for translating the document analysis, or considering the instrumental measurements for performance measures. The proposed method was applied to a typical agri-food building in southern Italy. This application demonstrated the correctness of the setting, its ease of application, and its ability to manage real cases. The method allowed for the evaluation of building performance by taking advantage of the positive characteristics of each measurement technique: the users' and occupants' perception, the knowledge and critical sense of expert technicians, and the accuracy and objectivity of instrumental measures. The results of the model were represented by mean fuzzy membership functions, which preserved the "vagueness" of the initial performance attributes. To obtain more synthetic values, a normalization procedure was applied to obtain a value performance judgment, expressed by a number in the range of 0 and 1 (where 0 is the worst and 1 is the best). The general performance of functional areas and the differences in performance in the same functional area were compared using this operation. The results of the case study demonstrated the reliability of the proposed method; in particular, it can determine the state of the building's functionality, drawing attention to weak points that should be monitored to prevent potential faults. The method proposed is a key element intended to help develop agri-food buildings that are effective and efficient and perform as expected and it contributes to improve the general quality of agri-food buildings.

1. Introduction

Building performance plays a key role in the sustainability of a building; in fact, the priority of a sustainable building is to meet, in an adequate manner, the user requirements while limiting its environmental impact. A building cannot be sustainable if the needs of its users are not satisfied. In general, buildings are design objects: they are the products of design involving many specialists from different fields (structural, architectural, electrical, etc.). In the last decade, several models were developed to assess the building structures. Models, such as LEED, BREEAM, Sbtool, CASBEE [1], were created to assess the level of sustainability, mainly environmental, through systems based on the evaluation of elements by experts in the sector and/or specially trained personnel. Models, such as PROBE [2], BuPESA [3], Standard Assessment Procedure (SAP), Simplified Building Energy Model (SBEM), Building Occupants Survey System Australia (BOSSA) [4], were specifically designed to determine the performance of buildings, mainly in the residential sector, through the use of online questionnaires. The actual

* Corresponding author.
E-mail address: fbarreca@unirc.it (F. Barreca).

https://doi.org/10.1016/j.buildenv.2021.108109
Received 2 April 2021; Received in revised form 28 June 2021; Accepted 29 June 2021
Available online 2 July 2021

building design quality can be evaluated while the building is being utilized. In fact, during the occupancy stage, measurements and feedback, such as Building Performance Evaluations (BPEs), can be carried out in order to acquire relevant data to determine the level of design quality in satisfying the needs and requirements of the building occupants [5]. Only after the BPE is it possible to determine whether the suitability of a building's design quality is in accordance with the specifications required by the design. The BPE is generally applied to determine building defects, propose design and construction efficiency criteria, diminish facility life cycle costs, extend the life of the building, highlight design errors that could lead to increased maintenance and operational costs, and clarify design objectives [6]. Overall, the above ensures the sustainability of building performance. Furthermore, the BPE is applied to understand the match between a building's performances and the aspirations of its users, further proposing how to improve the environment to meet these aspirations [7]. In the past, it was applied particularly to public buildings and facilities [8–10]. In many cases, BPE methods were applied to more than one building type. According to scientific literature reviews, the most popular targets were residential buildings, followed by office, university and educational buildings, and, in few cases, law courts. BPE of residential buildings often focuses on occupants' experience and use of the facility, and, therefore, almost every BPE method uses an occupant survey or interview. The BPE method for office buildings focuses on occupants' comfort and productivity and sometimes utilizes both a questionnaire and a physical survey. The purposes of BPE are always to evaluate occupants' comfort, satisfaction, wellbeing or health, sometimes to understand the energy spent, usually to design energy retrofit [11,12]. There is no example of BPE application to agri-food buildings [13,14], yet BPE plays a key role in agri-food building sustainability and is important not only for the company, as it allows for the reduction of costs and the improvement of productivity, but also for the environment [15]. An agri-food building is a place where different users should obtain the best conditions to carry out their activity, and raw products and food should be safe and stored and processed under good hygienic conditions. In fact, the efficiency analysis of an agri-food building allows for the saving of energy, while also pursuing an important aim: to reduce food loss and waste production. A good and hygienic indoor environment is the first condition to obtain a high production quality standard and safeguard the food product while decreasing loss and, consequently, requirements of waste disposal [16]. Production buildings form an important rung of the food system chain, which is sometimes not fully considered; however, in recent years, the policies of European countries have paid more attention to food facilities [17], by means of funding opportunities related to innovation in food production and food facilities. For these reasons, it is crucial to develop and apply specific tools to analyse and improve the agri-food building performances. These tools for BPE should be easy to apply by technicians, facility managers and designers. Several studies were conducted to define a fast and simple method to give construction industry stakeholders some performance indicators which could help them to make the best decisions when acquiring, operating, maintaining and repairing a building [2,18–20]. Some of them were based on a technical index to assess building degradation and maintenance in order to measure the aging of the facility. Other methods were based on document indexes, which measured the quality and quantity of available building documents, thus showing if the building fulfilled its legal requirements. Yet, in case one or more serious problems were detected, a specific analysis was required, no matter what the final value of the assessment index was. A BPE is a multifunctional tool that supports the building quality evaluation through the identification of successful design features, thereby reducing maintenance works and costs [21]. In a BPE, three different levels are generally used, namely, indicative, investigative, and diagnostic approaches. The use of any of these approaches depends mainly on the level of information required and the available resources. In the past, data collection techniques were not used simultaneously, rather, they were applied separately. The different data collection techniques include, for example, walkthroughs, questionnaire surveys, document analysis, and physical measurements [22]. In this paper, an original BPE method, requiring an integrated data collection technique based on a worker questionnaire survey, documented technical observation of the building, and physical measurements, was proposed. Until the early 1980s, performance standards considered primarily parts of buildings, building products, materials, and components [23,24]. In 1995, the American Society for Testing and Materials International (ASTM) approved a set of standards that addressed the functionality and serviceability of whole buildings, from the end user's perspective, i.e., the "good fit for buildings purpose". Based on this set of standards, Davis and Szigeti [25] developed a method to describe the functionality requirements of users (demand), evaluating the serviceability of whole buildings and facilities (supply), and comparing the two by means of calibrated scales. This method is currently being standardized internationally (ISO TC 59/SC14/WG10) and adapted to the needs of other countries in Europe [26]. At the European level, two directives have been passed: The Construction Products Directive (93/68/EEC) and the Energy Performance of buildings directive (2002/91/EC). These directives include technical performance, cost performance, comfort and health performance, and environmental performance categories [27]. Currently, research and professional institutions are developing different methods spread over different performance approaches and tools, such as guidelines, checklists, data processing tools, and building passports for buildings. In Italy, interest in the good fit for purpose theme began in the 1980s, with the elaboration of the first national performance standard in 1981 by Ente Unificazione Italiano (UNI)–UNI 8289/1 [28] and UNI 8289/2 [29]—regarding building user requirements. Actually, in Italy, "the good fit for purpose of the buildings" has not been sufficiently investigated: after the voluntary performance standard UNI 8289, interest in the theme soon decreased, as the comfort, safety, and security of building users were established by specific laws. Instead, in recent years, the interest in environmental sustainability has increased; in fact, some building sustainability assessment methods have been developed and applied, such as ITACA [30], a protocol deriving from the Sustainable Building Tools (SBTools) international model [31]. However, it is important to highlight that building sustainability cannot be evaluated without preliminarily evaluating its performance and its fitness for purpose [32].

The BPE is more complex in the agri-food industry, as it is necessary to assess not only the satisfaction of workers' needs, but also the quality and hygiene safety of the products, which are largely conditioned by the indoor building environment and have to comply with international, European and national rules [33,34]. In particular, the Codex Alimentarius [35], a collection of standards, guidelines and codes of practice adopted by the Joint FAO/WHO Food Standards Program to protect consumer health and promote fair practices in food trade, highlights the important role of correctly designed hygienic food production buildings. Section 4 (Establishment: Design and Facilities) provides guidance about food facility requisites, their location and equipment stating that "Attention to good hygienic design and construction, appropriate location, and the provision of adequate facilities is necessary to enable hazards to be effectively controlled". Specifically, the code refers to the organization of the building, to its characteristic components and to the need for a good layout to improve hygiene practices and avoid cross contamination. Moreover, the Codex Alimentarius defines the maintenance of components (e.g., wall and floor coverings, waste management systems) to allow for more efficient cleaning and to ensure the highest level of food quality [36]. The main aim of this paper is to define a specific performance evaluation method for agri-food buildings that allows for more reliable and fast assessment and monitoring of performance of each functional area. To demonstrate the proposed method, a case study of an agri-food facility in Calabria was analysed.

2. Materials and methods

Fitness for purpose can be verified only after the performance evaluation of a building. In particular, Lützkendorf, T. et al. [25] defined seven different performance categories, in which user requirements are grouped in a coherent way.

Functional Performance: Requirements referring to the inside of the building, in terms of layout, accessibility and barrier-free design, adaptability to changes in user requirements and uses, etc.

Technical Performance: Requirements referring to structural and physical characteristics, such as the resistance to fire, control of noise transmission, heat insulation, and the load capacity of the building.

Economic Performance: Requirements referring to expenditures involved in designing, planning, construction, operation, maintenance, demolition, and waste disposal.

Environmental Performance: Requirements referring to the building's features and characteristics relevant to its impact on the environment, energy spent, and waste products. Correct integration of the landscape and atmospheric emissions.

Social Performance: Requirements referring to the health, welfare, comfort, and safety of users, visitors, and workers in the building.

Process Performance in Strategic Planning, Design, Construction, Operation, Maintenance, Management, and Use: Requirements referring to process of building realization, involving planning, construction, use, and facility management.

Likewise, the Italian standards UNI 8289:81 define the seven following different user requirement types [18,37]:

- *Safety:* The set of conditions related to the safety of the users, as well as to the defense and the prevention against damage caused by accidental factors, in the use of the technical system;
- *Wealth:* The set of conditions related to the state of the building system suitable to the life, health, and development of the activities of users;
- *Usability:* The set of conditions related to the attitude of the building system to be used by the users in carrying out activities;
- *Appearance:* The set of conditions related to the perceptive usability of the building systems;
- *Environmental safeguard:* The set of conditions related to the maintenance of the states of the upper systems belonging to the building system;
- *Integrability:* The set of conditions related to the possibility of easily joining different parts of the system; and
- *Management:* The set of conditions referring to the conditions for cost-efficiency in service use.

The peculiar production systems implemented inside agri-food buildings necessitate an additional requirement: the hygienic safety of food products. Hygiene is of paramount importance to produce food that is safe for consumption; the equipment and the building used for processing and handling food products must be designed and constructed according to correct hygienic design principles [38–40]. For this purpose, the requirements proposed in this study were integrated with the requirement of hygiene safety, defined as the set of conditions related to the hygiene safety of the food products and raw materials utilized in the production system. Each user's requirement must be compared to the buildings performance, in order to measure the characteristic criteria of building performance. Different techniques could be used to assess the performance degree of the building: planning, occupancy, and management records analysis; expert walkthrough analysis; occupancy and use analysis; questionnaire survey and interviews; and measurement and instrumental surveying. In general, it is possible to divide the measurements of the performance into two large categories: objective measurements (soft criteria) and subjective measurements (hard criteria). In this study, to measure the building performance with respect to user requirements, the simultaneous application of three different measurement techniques was proposed:

- user survey, by means of a questionnaire;
- analysis of the designs and plans of the building and expert walkthrough analysis;
- measurement by means of instruments and direct survey of building characteristics.

This method allowed for effective evaluation of the building performance by taking advantage of the positive characteristics of each measurement technique: the perceptions of users and occupants, the knowledge and critical sense of expert technicians, and the accuracy and objectivity of instrumental measurements.

For each user requirement and for each of the three measurement techniques, a set of building performance measures was defined to evaluate the appropriateness of fit for specific building purposes (Table 1).

The combination of these three measurement techniques defined the real use condition of the building; in particular, it was possible to assess user satisfaction through the administration of the questionnaire; while, in order to highlight the building weaknesses, the analysis of the building documents and the specialist walkthrough allowed for the evaluation of the building with respect to its design and conformity to authorizations and planning permissions. Finally, the physical measurement of some building conditions allowed confirming or rejecting the previous evaluations. However, each technique—in a different manner—has some limitations, which are mainly correlated to the vagueness of the relationships between the data survey and the building performance.

For example, the satisfaction with the internal building environment is subjective for each user and depends on different conditions, personal attributes, and cultural factors; thus, it is not always assessed by each person in the same way. At the same time, objective quantifiable measures are not able to effectively evaluate a building's performance, as they are based on empirical biophysical, physiological, and environment–behaviour models. In the proposed method, in consideration of the limitations described above, fuzzy theory was applied for the aggregation of the building performance measures [41]. In particular, fuzzy aggregation was carried out by means of a tree procedure based on three levels (Fig. 1); starting from the specific user's requirement, it allowed for evaluation of the fit for each functional area of the building and for an assessment simultaneously taking into account objective and subjective criteria based on user questionnaires, documental analysis, and physical measurements. At each level, the aggregation was based on the fuzzy weighted average of the below levels. The fuzzy method was particularly suited to describing the vagueness of users when answering a questionnaire, to translating documental analyses, or when considering instrumental measurements for performance measures.

2.1. Case study

The proposed method was applied to an agri-food building in Calabria, the southernmost region in Italy. The factory was Colacchio srl, which produces typical regional bakery goods using traditional recipes but with innovative technologies and production methods. The company boasts ISO 9001, ISO 2200, and United States Food and Drug Administration (US FDA) quality certificates. The building is located in Vibo Valentia (coords: 38°37′44.8″N 16°05′02.5″E), the smallest province of Calabria, which is located in the south-west of the region, near the Tyrrhenian Sea.

The building has a surface area of about 800 m^2 and a height of 6 m. It has a ground floor and a mezzanine floor; on the ground floor, there are production function areas, while, on the mezzanine floor, there is an office area. The functional areas of the building are shown in Fig. 2.

The building structure is of precast concrete construction and its

Table 1
Building performance measure for each user requirement.

Questionnaire	Documents	Measurements
WORKER SAFETY		
Questionnaire	Documents	Measurements
Knowledge of the position of the fire protection systems	Fire protection design	Light Measurements
Fire escape knowledge	Electrical System Design	Floor slip resistance measurement
Events of impacts and collisions with indoor elements	Structural Design	Carbon monoxide measurement
Events of water leaks	Fluids system Designs	Dangerous Obstacles
Events of electric system breakdown	Safety workers document	Fall from Above
Events of gas leaks	Lightning Protection System Design	Radon Measure
Presence of dust in air		Dust Measure
Presence of bad smells		Electromagnetic Field Measure
Presence of mold smell		Structural Damage
Presence of mold spots		Emergency Escapeway
Presence of cracks on the indoor surface (e.g. walls, beams, pillars, ceiling, floor)		Emergency Exit Door
Inadequate illumination		Air Temperature
Past events of falling or slipping down		Air Humidity
HYGIENE SAFETY		
Questionnaire	***Documents***	***Measurements***
Presence of dust	HACCP Plan	Bacterial Surface Contamination
Presence of Pests	Cleaning and Sanitizing Plan	Microbial Air Quality
Cleaning in Restroom	Contamination Control Program	Cleanliness of the floor
Proximity of a Contaminated Site	Hygienic Design	Dust Measure
	Pests Control Plan	VOC Measure
		Hygiene Standards
		Contaminated Area Separation
		Pest Prevention systems
WELFARE		
Questionnaire	***Documents***	***Measurements***
Thermal condition in cold Season	Lighting Design	Light Measure
Thermal condition in hot Season	Electrical System Design	VOC Measurements
Inside Noise level	Thermal Design	Radon Measurement
Comfortable working space	HVAC Design	Reverberation Measurement
Relaxation Area		Electromagnetic Fields Measure
		Ionizing Radiation Measure
		Site Orientation
		Air Exchange Rate
		IAQ Measure
		Glare Measure
USABILITY		
Questionnaire	***Documents***	***Measurements***
Adequate working conditions	Fire protection design	Light Measure
Adequate spaces for visitors	Electrical System Design	Open Measure
Adequate space for parking	Interior Traffic Flow Design	Door Measure
Goods Handling	Signages	Aisle Measure
Relaxation Area	Facility design	Internal Free Height Measure
	Accessibility design	Floor Slip
APPEARANCE		
Questionnaire	***Documents***	***Measurements***
Welcoming internal Space	Architectural design	Defects on Surface finishing
Adequate building finishing	Color planning	Last Refurbishment
	Maintenance Planning	
MANAGEMENT		
Questionnaire	***Documents***	***Measurements***
Goods Handling	Building Maintenance Plan	Floor Cleanability
Functionality of Service Area	Energy Performance Certificate	Wall Cleanability
Management costs	Cleaning and Sanitizing Plan	Ceiling Cleanability
Technical Maintenance Plan	HACCP Plan	Floor Maintenance Grade
Adequate Environmental Conditions	Pests Control Plan	Wall Maintenance Grade
Efficient Drainage System		Ceiling Maintenance Grade
Easily Cleaned		Windows Maintenance Grade
		Door Maintenance Grade
		Systems Maintenance Grade
		Access Management
INTEGRATION		
Questionnaire	***Documents***	***Measurements***
Aptitude to Building Extension	Systems Design	System connect
	Structural Design	Structural connect
		Partition connect
		Modular Sizes

(*continued on next page*)

Table 1 (*continued*)

WORKER SAFETY		
Questionnaire	Documents	Measurements
ENVIRONMENT PROTECTION		
Questionnaire	***Documents***	***Measurements***
Building Landscape Impact	Environmental Certificate	Structural Material Environment Impact
Smoke Emission	Landscape Impact	Partition Material Environment Impact
Odor Emission		Floor Material Environment Impact
Noise Emission		Smoke Emission
Wastewater emission		Odor Emission
		Noise Emission
		Wastewater emission

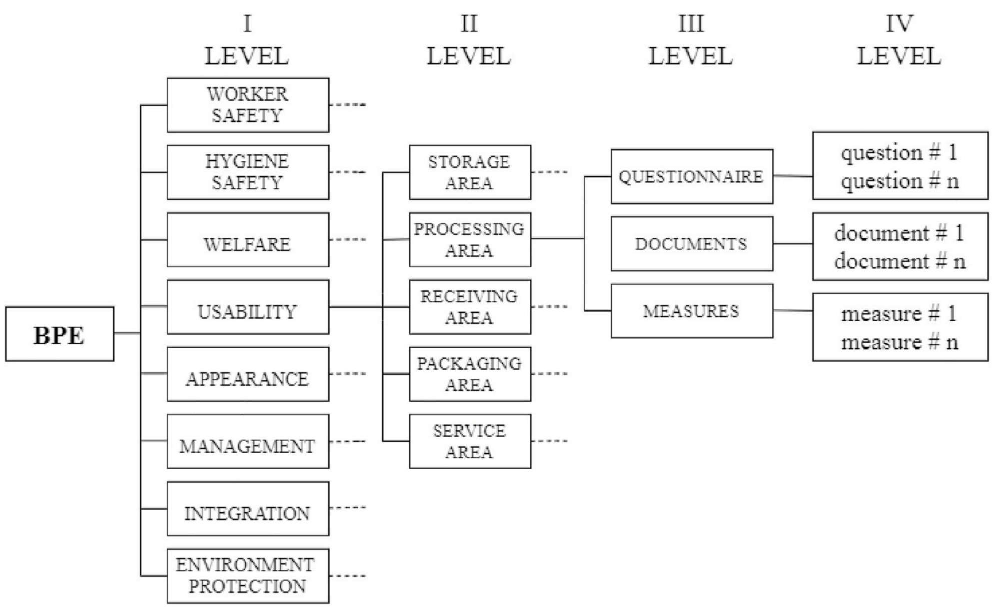
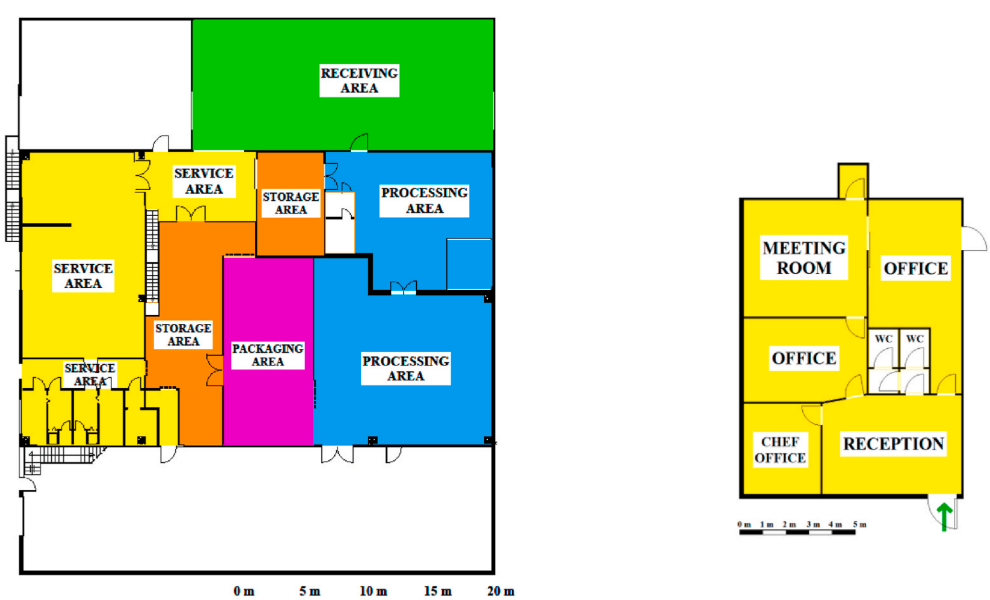


Fig. 1. Diagram of the proposed method for agri-food BPE.



(a) (b)

Fig. 2. Layout of the agri-food building: (a) Functional areas on the ground floor; and (b) Functional areas on the mezzanine floor.

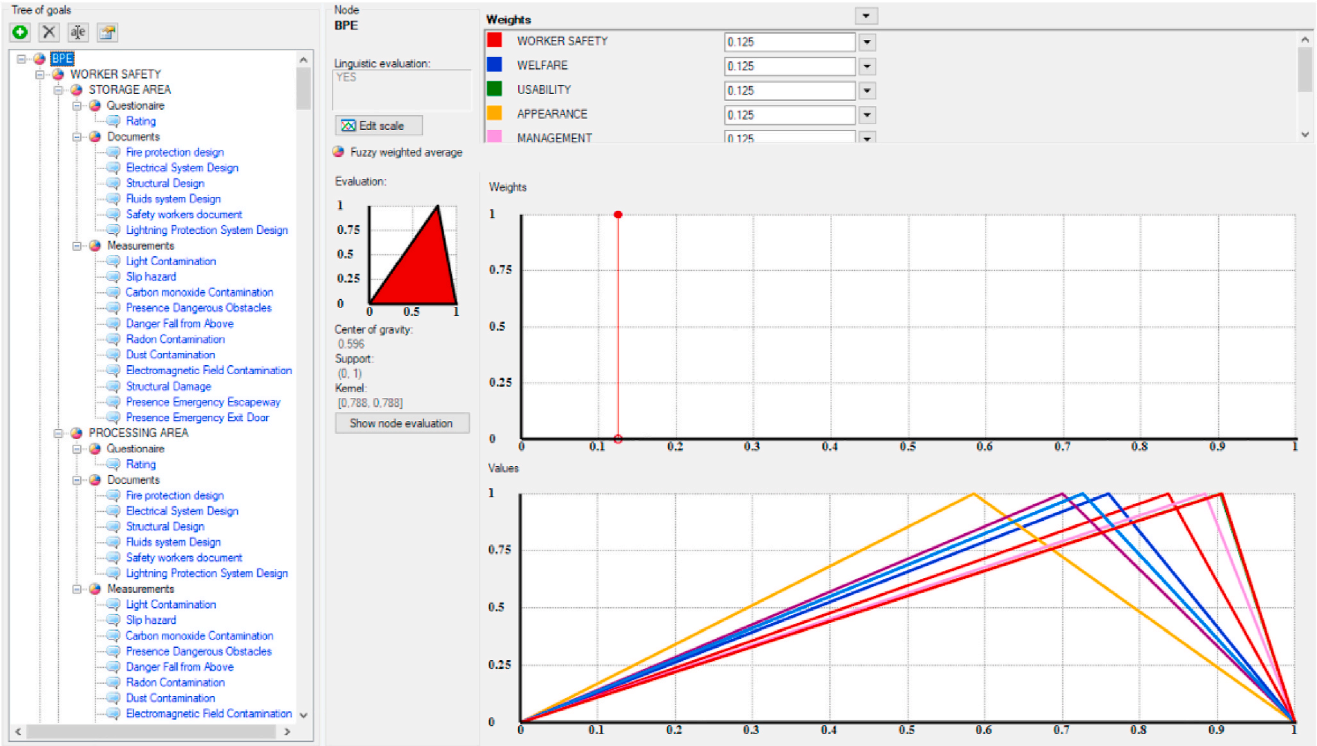
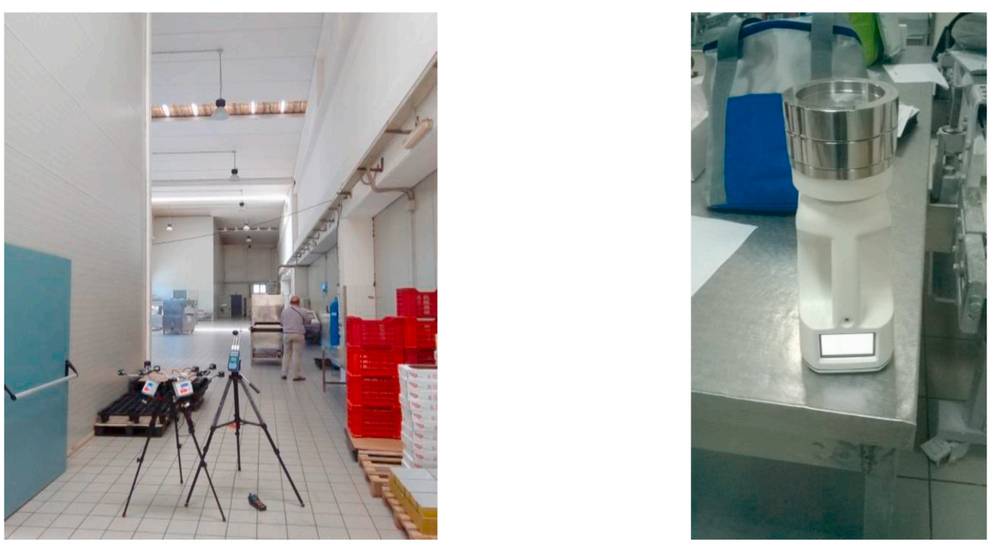


Fig. 3. Implementation of the proposed method for BPE with the FuzzME software.



(a) (b)

Fig. 4. Instrumental measurements inside the building: **(a)** Measuring thermal indoor condition; and **(b)** measuring (by Surface Air System) to determine the level of environmental microbial contamination.

maintenance is regular; in fact, it appears to be in good conditions. The users of the building are about 15 workers in the production areas, two production supervisors, and the manager of the company. A team of experts, composed of six researchers, engineers, and food technicians, applied the proposed method.

In the first stage, the building documents, the designs, the permissions, and all of the most important building plans were collected (Table 1). In the second stage, by means of an on-site inspection, the expert team (composed of 2 building engineers, 1 occupational safety and health expert, 1 food science technician, 1 food safety expert) examined each functional area of the building, checked the building components and the production phases, and verified the correspondence of the building to its designs, plans, and building permission documents. The expert team assigned “yes” to the fuzzy quality criterion if they observed a good fit for specific purpose, and “not” if there was not a good fit for the specific purpose of the building (Fig. 3).

After the document analysis, the team distributed the questionnaire to frequent building users. The interview concerned 15 workers in the production areas, 5 production supervisors, 10 visitors, and 4 cleaners. For each of them, a specific questionnaire was designed with the aim of assessing user/occupant satisfaction (Appendix Fig. S1). For this purpose, the primary requirement was to identify the attributes a user looks for in an agri-food building. The attributes were indicators by which the performance of the building could be measured. These attributes vary depending on the type of building, on the users (e.g., occupants, managers, and supervisors), and on the purpose of performance evaluation [42]. The questionnaires were designed in such a manner that considered those differences, in order to capture the user satisfaction or dissatisfaction regarding a specific performance of each functional area of the building. The possible answers expected in the questionnaire were "yes" or "no" and only few questions requested a specific comment to better highlight the weakness of the building. The judgment or assessment of a respondent is always subjective and afflicted by some grade of vagueness; for this reason, the answers and the user judgments were translated into fuzzy numbers and analysed as mean qualitative values of their answers. The last stage of the method applied was the measurement of physical and hygienic performance characteristics of the environment and the components of the building. This survey technique allowed acquiring a more objective measure of the building's performance as well as verifying the performance values obtained by the other two adopted techniques. In fact, if the previous stages highlighted some building performance uncertainty, the instrumental measures could bring an end to such doubts [43]. For the measurements, portable instruments were utilized, all of which were tested and calibrated to confirm their compliance with international standard measurement specifications [44] (Fig. 4a and b) (Appendix Table S2). The values of the measures were compared to the optimal range value for the specific performance, as indicated by codes, rules, technical documents, and scientific studies, with the aim to establish the performance level of each functional area with respect to user requirements [45]. It is not easy to choose an optimum measurement value to represent a higher performance level; in fact, the optimum measuring value ranges reported by codes, rules, or scientific studies relating to building performance often do not agree. For this reason, the expert team used a fuzzy set to evaluate the performance measurement values surveyed through instrumental techniques [46]. The fuzzy quality value "Yes" was assigned if the value measured was part of the optimal range, while "No" was assigned if it was not part of the optimal range.

The numerical analysis and the aggregation of the qualitative values were carried out by means of fuzzy logic. In particular, the model was implemented using the FuzzME software [47], a specific tool for creating fuzzy models for multiple-criteria evaluation and decision-making (Fig. 3). The qualitative values of indicators assigned by the expert team were transformed into fuzzy triangular membership values, taking into account two levels of judgment (Yes or No). The aggregation of the membership functions was carried out using a Sugeno average method. Moreover, the tree structure of the procedure provided an evaluation of the performance of each functional area, in order to highlight the possible deficiencies and to intervene in a correct and fast way.

3. Results

The application of the proposed method in the case study allowed for verification of the correctness of setting, ease of application, and applicability for the management of real cases. The users' interviews and the documents analysis with specialist walkthrough permitted to set up a suitable measurement stage. Moreover, the results of the case study highlighted that the combination of the three different measurement techniques permitted to enhance the precision and to overcome the limits and the subjectivity of each measurement technique. Each application stage showed a different level of complexity. At the start, it was necessary to collect the plans, documents, designs, and permissions of the building. The expert team had previously defined a checklist in order to get significant and useful documents more easily. Technical and administrative documents, such as Hazard Analysis Critical Control Point (HACCP) plan, cleaning and sanitizing plans, environmental certificates, etc., were collected. The expert team analysed and studied the documents to obtain data and information about the building characteristics. Later on, by means of a walkthrough of the building, they verified the correspondence of the building components and facilities to the designs, plans, and administrative certificates. The stage of the user satisfaction questionnaire was fast and reliable, as the questions chosen to identify the main dissatisfactions and problems described by the users were easy and understandable. In fact, the α-Cronbach correlation coefficient for the questionnaire varied from 0.75 to 0.87, which indicated a good correlation between the items. The participants took approximately 25–30 min to complete the questionnaire. In particular, the workers in the production areas were proud to fill out the questionnaire and participate in the improvement of the production conditions of the company. In the next stage, instrumental measurements were carried out. The principal environmental conditions and the performance characteristics of the functional areas in the agri-food building, such as light conditions, floor slip, microbial air quality, noise levels and emissions, etc., were measured. During this stage, an objective evaluation of the real performance of the building was carried out, confirming or excluding the user-assessed criticality. The main problem was interference to the production line, since the specific hygienic conditions and

Table 2
Normalized values (between 0 and 1) performance judgment of the building under study.

User Requirements	Storage	Processing	Receiving	Packaging	Service
Worker Safety	0.73	0.99	0.76	0.90	0.82
Welfare	0.86	0.78	0.61	0.73	0.82
Usability	1.00	0.69	0.89	1.00	0.95
Appearance	0.49	0.49	0.65	0.65	0.65
Management	0.93	0.86	0.83	0.75	0.96
Integration	0.84	0.67	0.42	0.67	0.92
Environmental Protection	0.67	1.00	0.67	0.62	0.67
Hygiene Safety	0.74	0.96	0.92	0.96	0.96

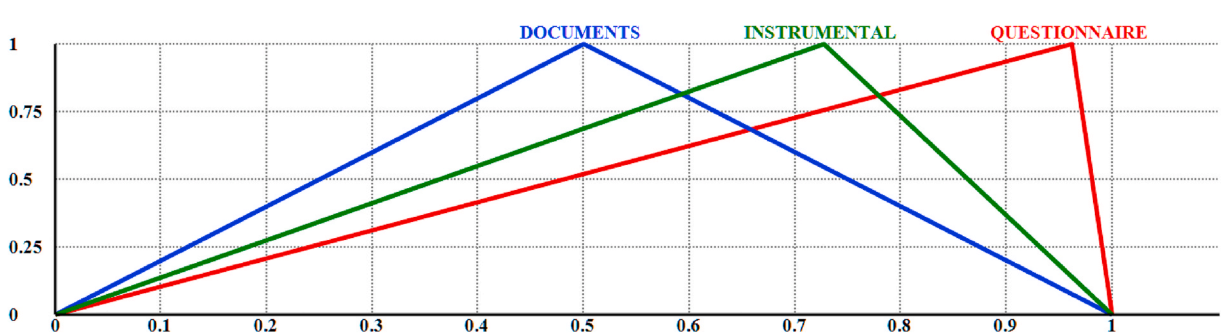


Fig. 5. Comparison between fuzzy functions of the three measurement techniques applied to evaluate the worker safety for the storage area.

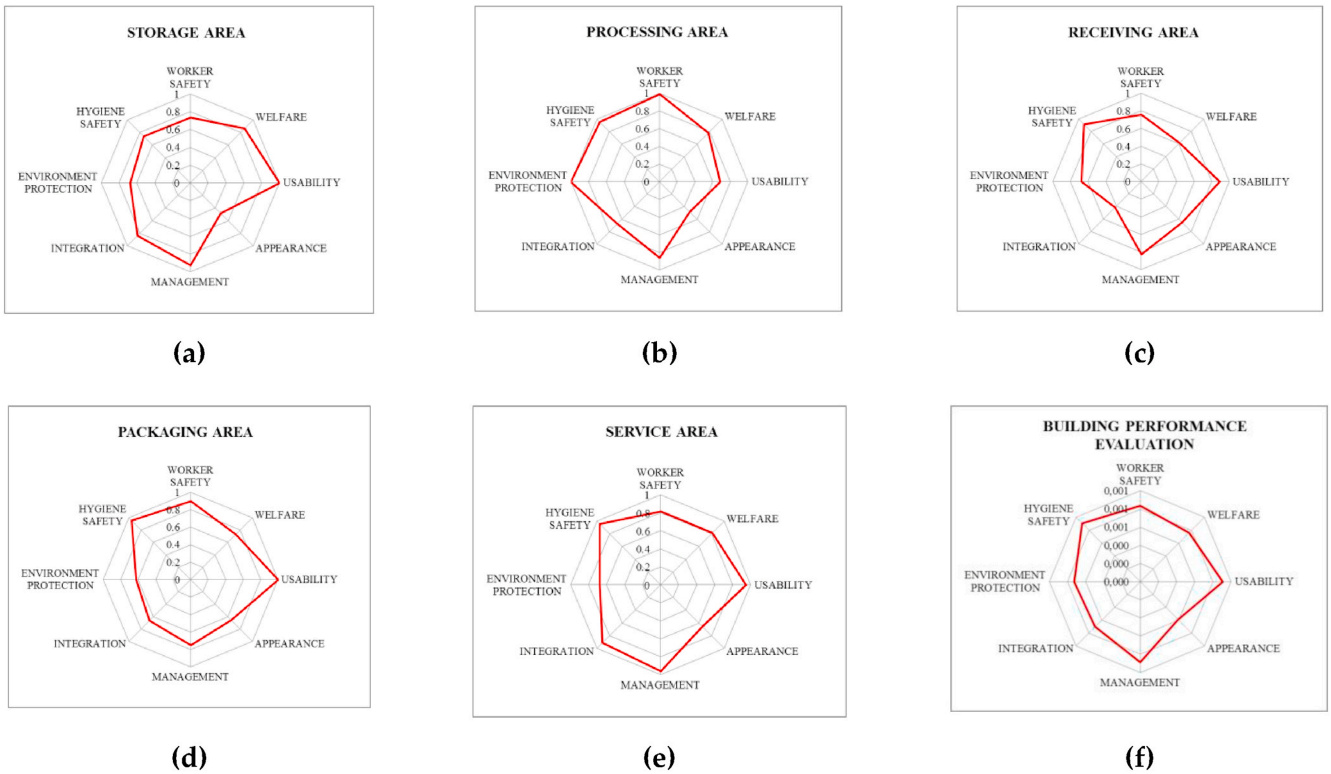


Fig. 6. Spider diagrams of the functional area performances: a) Storage area; b) Processing area; c) Receiving area; d) Packaging area; e) Service area; and F) Global BPE.

the product flow in agri-food buildings require care and safety for workers and food products. Moreover, the survey had to be completed during the production stages, in order to assess real operating conditions. The measurements were conducted by expert operators, who adopted some precautions, such as wearing hygienic coats, overshoes, headphones, and gloves, and who paid attention to the flow and stage production, with particular reference to critical functional areas, such as the production and storage areas. It is important to bear in mind that the company was conscious of the importance of the building performance evaluation but was afraid about product flow interference and possible food product contamination. An aggregation of the performance attributes detected by the three different measurement techniques was applied using the proposed fuzzy method, evaluating the performance of each functional area of the agri-food building individually. The result of each measurement technique was synthesized by a fuzzy function (Fig. 5); the simultaneous comparison between these functions showed if there was accordance in the evaluation of each functional area. For example, in the storage area, the evaluation of the worker safety by documents analysis (centre of gravity = 0,50) was lower than the one obtained through instrumental evaluation (centre of gravity = 0,58) and both were lower than the one resulting from questionnaires (centre of gravity = 0,65).

The results of the model were represented by mean fuzzy membership functions that preserved the “vagueness” of the initial performance attributes. In order to get more synthetic values, a normalization procedure was applied to obtain a performance judgment value expressed by a number in the range of 0–1 (where 0 is the worst and 1 is the best). A comparison between the general performance of functional areas and between different performances in the same functional area was carried out during this operation (Table 2). The results showed a good performance level for all functional areas of the building; only the performance of the Processing area in relation to appearance and the performance of the Receiving area in relation to Integration resulted in values slightly lower than 0.5. In fact, in the Processing area, there were some weak aesthetic points, mostly depending on the difference of floor colours, whereas, in the Receiving area, the performance integration result was low as the external area was not large and the widening of this functional area could be difficult. The same performance analysis highlighted the good hygienic performance of the entire building and, in particular, that of the processing area—the core of the building—where the hygiene and worker safety showed very high values (0.96 and 0.99). In fact, the microbiological measurement in the work areas showed a very low level of contamination. An aggregation at building level was carried out using the tree structure of the proposed fuzzy method in order to obtain a global BPE, and to verify the performance of the whole building, as compared to the user requirements. Most interesting was the spider diagram of the global BPE (Fig. 6 f), which highlighted the potential weak points of the building that lacked performance fitting user purposes. In the case study, the user requirement of appearance had the lowest value but was still higher than 0.5; this specific requirement should be monitored to prevent future criticality.

4. Conclusions

The contribution of this study is to improve the quality of agri-food buildings from the enterprise’s point of view, *i.e.*, diminishing the costs of use and management, and from the worker’s point of view, *i.e.*, raising the safety and wellbeing of the consumer and controlling food hygiene. The approach proposed allows detecting possible deficiencies of performance in functional areas or building components and remedying them in a timely manner. It allowed for the evaluation of many different performances required by agri-food buildings. At the same time, it allowed representing the functional failures or defects in the functional areas by synthetic diagrams, assessing the quality and functionality of facilities and planning maintenance management (Fig. 6). The study provides a suitable Building Performance Evaluation method

(BPE) for technicians, facility managers and designers to improve the quality and sustainability of management, design and construction in the agri-food sector. Its particular tree structure allowed technicians to evaluate the performance of a specific functional area or the performance of the entire building or also the performance with respect to a specific user requirement. The proposed method is based on fuzzy theory, which aggregates data originating from different sources with different vagueness and accuracy levels. In fact, the fuzzy theory is often used to handle imprecise and uncertain information. These features make the method flexible and useable for the continuous performance monitoring of agri-food buildings. The results of the case study demonstrated the reliability of the proposed method; in fact, they showed the state of the building's functionality, and weak points. Such points should be monitored in order to prevent potential faults. An interruption of the production to repair and refurbish the building components could be very expensive for the company and very problematic, above all for continuous food production lines, such as those in bakeries. The maintenance of an agri-food building cannot be carried out without a preliminary performance evaluation, which allows for the definition of an intervention order and facilitates planning by the management. Moreover, the building performance and respect of the user's requirements can condition the quantity and quality of food production. The application of the case study allowed for some limits of the proposed method to be highlighted. Many specific portable measurement instruments were needed to survey the building and environmental conditions, and this may limit the diffusion of the method among small food enterprises due to the high survey costs. Another limit which was observed is the low level of user experience. Some agri-food enterprises hire seasonal employees, who get less training time and low experience in the company. For this reason, their questionnaire answers are not very reliable and have not the same accuracy as the permanent workers, who have considerable experience in the company. The case study highlighted the complexity of collecting and managing data from different sources, therefore, the future of the research activity will be directed to the development of a data bank shared with a dedicated information system. It could be very useful, for both researchers and public administration, to collect and compare data coming from different agri-food buildings, since good knowledge of the real conditions of the agri-food building industry could better inform political activity and specific public funding measures. Furthermore, the development of a specific software tool will make the application of the method easier and will contribute to the diffusion of the proposed BPE method. The next research efforts will be targeted in this direction.

Funding

The research was funded by the project PON03PE_00090_1, included in the MIUR-MiSE National Operational Programme for Research and Competitiveness (PON R&C) 2007–2013, and co-funded by the European Regional Development Fund (ERDF) and by Sustanzeb Proof of Concept (MIUR - PNR 2015-2020).

CRediT authorship contribution statement

Francesco Barreca: Conceptualization, Investigation, Methodology, Supervision, Writing – original draft. **Giuseppe Davide Cardinali:** Data curation, Investigation, Software, Supervision, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.buildenv.2021.108109.

References

[1] S.C. Wong, N. Abe, Stakeholders' perspectives of a building environmental assessment method: the case of CASBEE, Build. Environ. 82 (2014) 502–516, https://doi.org/10.1016/j.buildenv.2014.09.007.

[2] P. Li, T.M. Froese, G. Brager, Post-occupancy evaluation: state-of-the-art analysis and state-of-the-practice review, Build. Environ. 133 (2018) 187–202, https://doi.org/10.1016/j.buildenv.2018.02.024.

[3] M. Baborska-Narozny, M. Grudzinska, Overheating in a UK high-rise retrofit apartment block -ranking of measures available to case study occupants based on modelling, Energy Procedia 111 (2017) 568–577, https://doi.org/10.1016/j.egypro.2017.03.219.

[4] C. Candido, R. De Dear, L. Thomas, J. Kim, T. Parkinson, Introducing BOSSA : the building occupants survey system Australia, 46th, Annu. Conf. Archit. Sci. Assoc. 1–4 (2012). https://www.airah.org.au/imis15_prod/Content_Files/EcoLibrium/2013/Dec13/Eco-Dec-13-004.pdf.

[5] H. (Cynthia) Hou, J.H.K. Lai, D. Edwards, Gap theory based post-occupancy evaluation (GTbPOE) of dormitory building performance: a case study and a comparative analysis, Build. Environ. 185 (2020), https://doi.org/10.1016/j.buildenv.2020.107312.

[6] C.J. Hopfe, R.S. McLeod, Enhancing resilient community decision-making using building performance simulation, Build. Environ. 188 (2021), https://doi.org/10.1016/j.buildenv.2020.107398.

[7] C. Berger, A. Mahdavi, Review of current trends in agent-based modeling of building occupants for energy and indoor-environmental performance analysis, Build. Environ. 173 (2020), https://doi.org/10.1016/j.buildenv.2020.106726.

[8] W. Preiser, U. Schramm, A conceptual framework for building performance evaluation, in: W. Preiser, J. Vischer (Eds.), Assess. Build. Perform., Elsevier Butterworth-Heinemann, Oxford, 2005, pp. 15–26.

[9] F.A. Mustafa, Performance assessment of buildings via post-occupancy evaluation: a case study of the building of the architecture and software engineering departments in Salahaddin University-Erbil, Iraq, Front. Archit. Res. 6 (2017) 412–429, https://doi.org/10.1016/j.foar.2017.06.004.

[10] A.O. Ilesanmi, Post-occupancy evaluation and residents satisfaction with public housing in Lagos, Nigeria, J. Build. Apprais. 6 (2010) 153–169, https://doi.org/10.1057/jba.2010.20.

[11] J. Dorsey, A. Hedge, Re-evaluation of a LEED Platinum Building: occupant experiences of health and comfort, Work 57 (2017) 31–41, https://doi.org/10.3233/WOR-172535.

[12] E. Mlecnik, T. Schütze, S.J.T. Jansen, G. De Vries, H.J. Visscher, A. Van Hal, End-user experiences in nearly zero-energy houses, Energy Build. 49 (2012) 471–478, https://doi.org/10.1016/j.enbuild.2012.02.045.

[13] N. Khair, H.M. Ali, I. Sipan, N.H. Juhari, S.Z. Daud, Post occupancy evaluation of physical environment in public low-cost housing, J. Teknol. 75 (2015) 155–162, https://doi.org/10.11113/jt.v75.5284.

[14] M.F. Silva, S. Maas, H.A. de Souza, A.P. Gomes, Post-occupancy evaluation of residential buildings in Luxembourg with centralized and decentralized ventilation systems, focusing on indoor air quality (IAQ). Assessment by questionnaires and physical measurements, Energy Build. 148 (2017) 119–127, https://doi.org/10.1016/j.enbuild.2017.04.049.

[15] M. Sinou, S. Kyvelou, Present and future of building performance assessment tools, Manag. Environ. Qual. Int. J. 17 (2006) 570–586, https://doi.org/10.1108/14777830610684530.

[16] A. Rajasekar, R. Balasubramanian, Assessment of airborne bacteria and fungi in food courts, Build. Environ. 46 (2011) 2081–2087, https://doi.org/10.1016/j.buildenv.2011.04.021.

[17] R. Rey, New challenges and opportunities for mountain agri-food economy in south eastern Europe. A scenario for efficient and sustainable use of mountain product, based on the family farm, in an innovative, adapted cooperative associative system – Horizon 2040, procedia econ, Financ. Times 22 (2015) 723–732, https://doi.org/10.1016/s2212-5671(15)00294-4.

[18] M.C. Dejaco, F. Re Cecconi, S. Maltese, Key performance indicators for building condition assessment, J. Build. Eng. 9 (2017) 17–28, https://doi.org/10.1016/j.jobe.2016.11.004.

[19] Y. Hua, Ö. Göçer, K. Göçer, Spatial mapping of occupant satisfaction and indoor environment quality in a LEED platinum campus building, Build. Environ. 79 (2014) 124–137, https://doi.org/10.1016/j.buildenv.2014.04.029.

[20] A. Gonzalez-Caceres, A. Bobadilla, J. Karlshøj, Implementing post-occupancy evaluation in social housing complemented with BIM: a case study in Chile, Build. Environ. 158 (2019) 260–280, https://doi.org/10.1016/j.buildenv.2019.05.019.

[21] C.J. Hopfe, Uncertainty and Sensitivity Analysis in Building Performance Simulation for Decision Support and Design Optimization, 2009. http://www.bwk.tue.nl/bps/hensen/team/past/Hopfe.pdf.

[22] B. Bordass, A. Leaman, Making feedback and post-occupancy evaluation routine 1: a portfolio of feedback techniques, Build. Res. Inf. 33 (2005) 347–352, https://doi.org/10.1080/09613210500162016.

[23] F. Szigeti, G. Davis, Performance Based Building, 2005.

[24] M.C.M. Parlato, S.M.C. Porto, Organized framework of main possible applications of sheep wool fibers in building components, Sustain. Times 12 (2020), https://doi.org/10.3390/su12030761.
[25] T. Lützkendorf, T. Speer, F. Szigeti, G. Davis, A comparison of international classifications for performance requirements and building performance categories used in evaluation methods, in: Proc. 11th Jt. CIB Int. Symp. Helsinki, Finland., Technical Research Centre of Finland (VTT)/Association of Finnish Civil Engineers (RIL), Helsinki (Finland), 2005, pp. 1–19.
[26] O. Catarina, M. Colombart-Prout, F. Bougrain, G. Davis, F.F. Szigeti, Méthode d'Evaluation de la Qualité de Service Attendue et de la Fonctionalité des Bâtiments de Bureaux avec Préoccupations environmentales, Paris, 2004.
[27] S. Turpin-Brooks, G. Viccars, The development of robust methods of post occupancy evaluation, Facilities 24 (2006) 177–196, https://doi.org/10.1108/02632770610665775.
[28] UNI 8289/1 : 1981, Building. Functional Requirements of Final Users. Classification, 1981.
[29] UNI 8289/2 : 1981, Buildings Elements. Analysis of Requirements, 1981.
[30] F. Barreca, G.D. Cardinali, ITACAFood: a model to certificate the sustainability of food processing facilities, Sustain. Times 11 (2019) 1–13, https://doi.org/10.3390/su11174601.
[31] R. Mateus, L. Bragança, Sustainability assessment and rating of buildings: developing the methodology SBToolPT-H, Build, Environ. Times 46 (2011) 1962–1971, https://doi.org/10.1016/j.buildenv.2011.04.023.
[32] R.F.M. Ameen, M. Mourshed, H. Li, A critical review of environmental assessment tools for sustainable urban design, Environ. Impact Assess. Rev. 55 (2015) 110–125, https://doi.org/10.1016/j.eiar.2015.07.006.
[33] EC, COMMISSION NOTICE providing guidance on food safety management systems for food retail activities, including food donations, Official J. European Union (2020). Official Journal of the European Union, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020XC0612(08).
[34] J. Færgemand, The ISO 22000 Series Global Standards for Safe Food Supply Chains, 2008, pp. 4–39.
[35] United Nations Food and Agriculture Organization, Codex Alimentarius: Food Hygiene Basic Texts, IV, FAO, Rome, 2009.
[36] L. Strano, P. Russo, P. Lanteri, G. Tomaselli, Defining the environmental and functional characteristics of the buildings used to produce prickly pear dried puree in terms of food hygiene and safety, Food Contr. 27 (2012) 170–177, https://doi.org/10.1016/j.foodcont.2012.03.012.
[37] F. Barreca, P. Praticò, Post-occupancy evaluation of buildings for sustainable agri-food production—a method applied to an olive oil mill, Buildings 8 (2018) 83, https://doi.org/10.3390/buildings8070083.
[38] C. Faille, C. Cunault, T. Dubois, T. Bénézech, Hygienic design of food processing lines to mitigate the risk of bacterial food contamination with respect to environmental concerns, Innovat. Food Sci. Emerg. Technol. (2017), https://doi.org/10.1016/j.ifset.2017.10.002.
[39] D.P. Van Donk, G. Gaalman, Food safety and hygiene, Chem. Eng. Res. Des. 82 (2004) 1485–1493, https://doi.org/10.1205/cerd.82.11.1485.52037.
[40] Z.M. Azizkhan, Comparison between ATP BioluminescenceTechnique and traditional microbiological method to detect contamination within food facilities in Saudi arabia (jiddah), Publ. Health Forum 3 (2014) 11–18, https://doi.org/10.5963/PHF0301003.
[41] E. Zarghami, H. Azemati, D. Fatourehchi, M. Karamloo, Customizing well-known sustainability assessment tools for Iranian residential buildings using Fuzzy Analytic Hierarchy Process, Build. Environ. 128 (2018) 107–128, https://doi.org/10.1016/j.buildenv.2017.11.032.
[42] C.S. Gopikrishnan, QUESTIONNAIRE DESIGN FOR OBJECTIVE EVALUATION OF PER- FORMANCE OF BUILT FACILITIES, 2014, pp. 192–203.
[43] F. Barreca, G.D. Cardinali, E. Borgese, M. Russo, Development of a method for evaluating floor dry-cleanability from wheat flour in the food industry, J. Food Sci. 82 (2017) 939–944, https://doi.org/10.1111/1750-3841.13659.
[44] F. Barreca, G. Modica, S. Di Fazio, V. Tirella, R. Tripodi, C.R. Fichera, Improving building energy modelling by applying advanced 3D surveying techniques on agri-food facilities, J. Agric. Eng. 48 (2017) 203–208, https://doi.org/10.4081/jae.2017.677.
[45] D. Pati, C.S. Park, G. Augenbroe, Roles of quantified expressions of building performance assessment in facility procurement and management, Build. Environ. 44 (2009) 773–784, https://doi.org/10.1016/j.buildenv.2008.06.018.
[46] F. Barreca, G. Cardinali, C.R. Fichera, L. Lamberto, G. Modica, A fuzzy-based model to implement the global safety buildings index assessment for agri-food buildings, J. Agric. Eng. 45 (2014) 24, https://doi.org/10.4081/jae.2014.227.
[47] J. Talašová, P. Holeček, Multiple-criteria fuzzy evaluation: the fuzzme software package, in: Int. Fuzzy Syst. Assoc. World Congr. 2009 Eur. Soc. Fuzzy Log. Technol. Conf. IFSA-EUSFLAT 2009 - Proc. (2009), 2009, pp. 681–686.