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Operational Performance Indicators and Causality Analysis for Non-Residential Buildings

Indicadores Operacionales del Performance y Análisis de Causalidad para Edificios No Residenciales

R. Bortolini (*), N. Forcada (**)

ABSTRACT

During the operation and maintenance of a physical asset its performance may decrease. While an array of tools and methods have been developed to facilitate building performance assessment processes, their complexity and the lack of causality analysis make them impractical. The research presented in this paper aims to understand the most relevant performance areas for non-residential buildings in general, and determine key performance indicators (KPIs) and their relationship to assess the performance of non-residential buildings. The research approach comprised a literature review, a focus group, and a questionnaire survey. The findings revealed that the core indicators used to evaluate building performance are related to safety and assets working properly, health and comfort, space functionality and energy efficiency. External factors were also found to condition the building performance. Results also identified the relationships between the performance indicators and factors with the aim to develop a causal model to accurately evaluate building performance.

Keywords: Building performance, indicators, facilities management, asset management, non-residential buildings.

RESUMEN

Durante la operación y el mantenimiento de los activos su performance puede disminuir. Si bien se han desarrollado una serie de herramientas y métodos para facilitar el proceso de evaluación del performance de los edificios, su complejidad y la falta de análisis de causalidad los hacen imprácticos. Este artículo pretende comprender las áreas de performance más relevantes para edificios no residenciales en general, y determinar los Key Performance Indicators (KPI) y su relación. Este estudio se basa en una revisión de la literatura, un focus group y una encuesta. Los resultados revelaron que los indicadores básicos utilizados para evaluar el performance de los edificios están relacionados con la seguridad y el correcto funcionamiento de los activos, la salud y confort, la funcionalidad de los espacios y la eficiencia energética. Los resultados también identificaron las relaciones entre los KPI y los factores externos para desarrollar un modelo causal para evaluar el performance de los edificios.

Palabras clave: *Building performance, indicadores, facilities management, gestión de activos, edificios no residenciales.*

(*) Architect. PhD Researcher. Department of Project and Construction Engineering (DPCE), Group of Construction Research and Innovation (GRIC), Universitat Politècnica de Catalunya (UPC), Terrassa, Barcelona (Spain)
(**) PhD, Associate Professor, Department of Project and Construction Engineering (DPCE), Group of Construction Research and Innovation (GRIC), Universitat Politècnica de Catalunya (UPC), Terrassa, Barcelona (Spain)
Persona de contacto/*Corresponding author:* nuria.forcada@upc.edu (N. Forcada)
ORCID: https://orcid.org/0000-0002-6911-4423 (R. Bortolini); https://orcid.org/0000-0003-2109-4205 (N. Forcada)

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1. INTRODUCTION

Buildings deteriorate over time, and even faster when they are not maintained properly (1). Apart from presenting serious indoor environmental quality problems, existing buildings often have a relatively poor energy performance, since they were constructed before the introduction of energy legislations (2). In Spain, for instance, the CTE (Código Técnico de la Edificación) incorporated many energy conservation measures that buildings need to fulfill from 2006. Moreover, the rate of degradation of the built environment in Europe is of enormous economic and technical importance, since about half of the expenditure in the construction industry is spent on repair, maintenance and remediation (3).

Performance assessment methods require measurable gauges that can be monitored through established performance indicators. Most existing studies tend to be very specific and often linear in investigating indicators in relation to one specific performance aspect, e.g. the impact of indoor environment quality on occupants' satisfaction (4). Furthermore, existing building performance assessments are complex, incorporate non-evaluable or qualitative indicators and do not determine the causal interdependency of indicators (5). Hence, there is a need to determine the core performance indicators and their dynamic interdependency to construct a causal model to optimize the performance of the built environment in a holistic manner (6). Such a holistic model needs to demonstrate the interactive effects of various indicators to evaluate a building's performance (7).

The aim of this paper is to determine the core operational performance areas, key performance indicators (KPIs) and factors that affect a building performance to better evaluate/manage the performance of non-residential buildings. The paper also proposes a holistic causal model to analyze the relationships between the identified KPIs and factors in the different performance areas, and how those areas are interrelated.

2. BUILDING PERFORMANCE

The performance concept was originally concerned mainly with improving the project delivery process for new construction. However, the term performance in a broad sense is related to buildings meeting the needs and requirements of users (8) in providing a conducive, safe, comfortable, healthy and secure indoor environment to carry out different activities, including work, study, leisure, family life, and social interactions (9).

2.1. Building performance evaluation tools

Building performance evaluation tools include: post-occupancy evaluation (POE), building rating systems, indexes, standards and regulations (10). One of oldest and most common methods for building performance assessment is POE (11). POE is a strategic performance evaluation technique that measures performance of building in use against specified standards from the perspective of the user (11).

Moreover, many building rating systems are currently in use. The systems cover different phases of a building's life cycle and take different issues into account. The majority of the commonly used building rating systems are credit-based systems (e.g. LEED, BREEAM, Green Star, CASBEE, BEAM) which determine specific weights for different categories (12).

Some performance indexes are focused on building condition (13) and include the identification of the most common defects and their severity (14).

A large body of literature can be found on assessment methods for environmental quality, occupants' health, and well-being as well as related building standards and regulations such as the American Society of Heating, Refrigerating and Air-Conditions Engineers' (ASHRAE) (15).

To meet building performance requirements, several parties were and are still involved in the development of performance-based codes, regulations and standards (16). For instance, the ASTM Standards on the Whole Building Functionality and Serviceability provides a strategic view for the evaluation of buildings using indicators of capability to assess how well a proposed design, or an occupied facility, meets the functional requirements specified by the business units, and facility occupants (17). Another example is the Operation and Maintenance Rating System (OMRS) developed by the National Center for Energy Management and Building Technologies (18), which includes the evaluation of different aspects such as HVAC system condition, building energy performance, occupant satisfaction and routine building walk-through assessment.

Building regulations and codes in some countries such as England, Wales, Spain, New Zealand, Japan and Canada are focused on health and safety requirements. These regulations cover requirements ranging from users' comfort to their safety, including structural, fire and electrical safety aspects. Japanese regulations, for example, are very concerned with fire safety. Other countries focus more on the habitability of buildings and determine air quality, ventilation, thermal comfort, noise and visual comfort requirements (16). All building regulations contain requirements related to the well-being of users, the promotion and protection of the environment, but with different approaches.

In summary, the previous tools are used to assess the performance of a building in different areas ranging from specific and detailed to broad and general in nature. These tools are complex, include a huge range of indicators, require a big amount of time and do not determine the causal interdependency of indicators.

3. RESEARCH METHOD

The research method consisted of an analytical approach divided into five main stages. First, a literature review was conducted to identify existing studies on areas and indicators for evaluating building performance. In the second stage, a focus group was formed to understand and define the most important building performance areas based on expert's opinion. The third stage consisted of validating the focus group's results by means of a questionnaire survey and identification of key performance indicators and key factors that affect these building performance areas. The final stage included the development of a causal model that illustrates the relationship between the performance areas, KPIs and factors. The scope of this study was limited to the operational phase of non-residential buildings, in which two main types of users coexist: (1) regular users, who work for a regular period in the building; and (2) sporadic users, who use the services inside the building for short and irregular intervals (e.g. a visitor or a student).

3.1. Stage 1. Literature review on building performance indicators

Data were collected through a literature search that included published articles in peer-reviewed journals, conference proceedings, sustainability assessment methods and existing building codes and standards. Each paper was studied in terms of what performance area is focused and which indicators and factors are offered.

3.2. Stage 2. Definition of performance areas by focus group

In the second stage, the research process used to conduct the focus group was based on Krueger and Casey (19). The focus group technique is defined as a carefully planned series of discussions to learn what people think about a specific area of interest in a permissive, non-threatening environment (19). Furthermore, interactions among participants can yield important data and the sense of belonging to a group can increase participants' sense of cohesiveness.

The focus group meeting followed a schedule divided into topics. To establish a sense of belonging to the group, in the opening question participants were asked to explain their current role within their organization and their experience in Facility Management (FM). Then, the introductory question was designed to get everyone talking, and was an easy question to answer. Thus, the experts were asked to present their company's main building management concerns.

In the next step, key questions were proposed and participants were asked to brainstorm and suggest the areas they considered important when evaluating the performance of a building. Furthermore, as an end question, the experts were asked to write on a post-it the 5 most important areas, based on their experiences. The experts were then put into groups of four to present their selection, to discuss and to reach an agreement on the most important areas. After this activity, a representative from each group was invited to present the results of their discussion to the whole group, and to explain why had selected the areas.

The meeting lasted two hours and was kept open using phrases such as "can you give me an example", "tell me more about it". Continuous effort was made to break any barriers that may have existed between the moderator and the participants. An assistant moderator took notes during the focus group, to support the digital transcription process, maintain validity and safeguard in case the digital recorder failed.

Sampling characteristics

Facility managers were chosen to determine the performance areas, as they have a holistic view of building management. Generally, facility managers communicate with all a building's stakeholders. For instance, they need to follow the owner's rules, manage end user complaints and periodically undertake end user satisfaction surveys (20). For that purpose, facility managers have a general, objective view of the interests of all stakeholders while owners' or end users' perceptions of performance are influenced by the "forgiving factors" of surrounding conditions (21) or economic interests.

The facility manager experts were selected based on purposive sample with predetermined criteria. The criteria required the experts with at least 5 years of working experience in facility management and currently working in any non-residential building. The selection priority was given to who has more than 20 years of experience (Level I), following by 10–20 years of work experience (Level II), and 5–10 years of work experience (Level III) (22). Experience in academic research and availability were also taken into account. Generally, individuals' judgment tends to become increasingly sophisticated and stable with the accrual of educational and work experience (22). Although the participants were selected for their knowledge of the topic to be discussed, some heterogeneity was also considered, to encourage active discussion and contrasting opinions. Therefore, experts from different companies with experience in different types of buildings were considered in the selection.

Participants were formally invited to take part in the focus group via an e-mail, in which the purpose of the group was explained. A total of twelve experts participated. Seven of the participants had over 20 years of experience in FM consulting and maintenance activities, two had between 10 and 20 years of experience, and 3 had between 5 and 10. Table 1 summarizes the participants' details. The experts included industrial engineers [8], an architect [1], quantity surveyors [2], and a technical engineer [1].

Table 1. Participants' positions and level of work experience.

Participant	Level of work experience	Position
1	I (more than 20)	FM consultant and director of an FM company
2		FM consultant at a company with experience in European projects and government administration
3		Head of the maintenance department on a public university campus
4		Coordinator of a maintenance department at a public university
5		Head of a maintenance department at a government building
6		Head of a department in a private foundation in the construction sector with experience in government administration
7		Project management consultant with experience in international projects and integrated project delivery
8	II (between 10 and 20)	Deputy head of a maintenance department on a public university campus
9		FM consultant at an international company
10	III (between 5 and 10)	FM at a company with experience in government administration
11		FM on a private university campus
12		FM consultant at an FM company

3.3. Stage 3. Validation of performance areas and factors by a questionnaire survey

In the third stage, a survey based on literature review was designed to validate the results of the focus group and identify the main factors that affect a building's performance. A questionnaire was developed on the basis of the focus group's results, existing studies and survey instruments (23, 24, 25). Prior to a full-scale survey, a pilot survey was carried out with a researcher and a maintenance expert from the Universitat Politècnica de Catalunya to test and verify the survey. The survey questionnaire was refined based on feedback from the pilot survey.

The questionnaire was divided into the following sections:

- Section 1: Interviewee's details, including academic and professional background, and years of experience (as a facility manager, maintenance manager, energy manager, asset manager, construction manager, designer or consultant).
- Section 2: Validation of the results of the focus group about the areas of building performance. The survey asked the experts to evaluate if the areas defined by the literature review and the focus group were the most significant to evaluate building performance. The Likert scale was 1-5, where 5 was "highly significant". An open ended question was included to give comments and add other areas and factors they personally found relevant.
- Section 3: Definition of factors that most affect the performance of a building (environmental agents and building properties) identified by literature review. The survey asked the experts to rate if the factors obtained from the literature review cover the most relevant factors affecting building performance. An open ended question was included to give comments and add other factors they personally found relevant.

Sampling characteristics

The survey was administered online, which allowed quick, easy access and systematic collection of responses. The survey was distributed in two languages, English and Spanish, so that it was accessible to international professional experts. It was distributed to associates of the International Facility Management Association (IFMA). IFMA is the main facility management association and its members are professionals with experience in asset management, maintenance, and energy management, among other fields. One hundred and twenty industry practitioners were randomly selected then approached by email. A total of 53 valid responses were received, representing a response rate of 44.1%, which is satisfactory and suitable for this kind of analysis (26).

Of the respondents, 86.8% had a technical degree (engineer or architect) and 13.2% were technicians. To highlight the expertise of the answers, 51% of the respondents had more than 20 years of experience, 34% had between 11 and 19 years, and 15% had less than 10 years of experience. These experts had a high level of expertise in building performance, due to their professional activity. Most respondents had experience in maintenance, energy management and consultancy on FM. Additionally, some experts had experience in design and construction management.

3.4. Stage 4. Determination of KPIs

The empirical material derived from the focus group discussion and the validation of these results by the questionnaire survey were analyzed. Then, these results were combined with the literature review results to determine the KPIs to assess building performance.

3.5. Stage 5. Causal Model

Based on the literature review and expert's interviews, the relationships among the KPIs obtained from the different performance areas were then established.

4. EXISTING STUDIES ON BUILDING PERFORMANCE INDICATORS

4.1. Building performance areas

The performance of a non-residential building is typically managed by a facility management (FM) team, which must ensure that facilities are constructed, managed and maintained efficiently without compromising their performance (7). Facility managers should consider a set of processes that operate at three levels: (1) strategic; (2) tactical; and (3) operational (27). The strategic level is characterized by decision makers whose mission is the achievement of the objectives of the organization in the long term. In the tactical level, the aim is to implement the objectives in the organization in the medium term. The operational level is managed by operators who deliver the planned services to the end users every day, and constantly monitor and check the service providers (27). At operational level, different areas of building performance have been described by previous studies.

Lützkendorf et al. (16) described the technical performance area, which is related to structural, physical and other technical features and characteristics of a building. Another area that has been described is functional performance, which is related to correct functioning of elements (28), the assessment of how well use-specific activities and processes can be performed, the extent to which the design is accessible and barrier-free, and the adaptability of the building to changing requirements and uses (16).

Other authors have described the behavioral performance area including the interaction between occupants and building systems to meet comfort and health needs (29). Another identified area is aesthetic performance, which is associated with the building's image and appearance, such as the absence of surface defects, and the homogeneity of color and finishes. Moreover, environmental performance area has been described by previous studies as the evaluation of building performance across a broad range of sustainable considerations and analyzing the building's features that affect the local and global environment (30).

In conclusion the areas to evaluate building performance identified by the literature review can be grouped in:

- Technical aspects including the building diagnosis through inspections and post-occupancy surveys,
- Functional aspects of the assets operation,
- Aesthetic aspects of the built-assets,

- Behavioral aspects including the comfort requirements of end users, and
- Environmental aspects including building energy use.

4.2. Factors affecting building performance

The performance of a building is influenced by many factors, such as the quality of materials, the weather conditions and maintenance actions (31). For instance, a building's performance depends on the environmental agents it is exposed to, which are associated with factors related to its location and type of exterior condition (32). A building's age, can also affect its performance (24). Building elements and equipment get deteriorated and reduce their performance with the passage of time (24). Furthermore, the quality of components and materials were identified as the most influential criteria that influence building performance (32).

Based on the literature review, the main factors affecting building performance can be grouped on environmental agents and building properties:

- Environmental agents:
  - Weather condition (solar radiation, wind, temperature, humidity, snow and rain water loads),
  - Surrounding environment (type of environment such as industrial, seaside, and if there is vegetation, pollutants, chemicals),
  - Natural disasters (storms, fire, landslide, earthquakes),
  - Geological conditions (type of soil such as clay, sand, loam).
- Building properties:
  - Type of structure/façade/roof (type of material and its properties (i.e. porosity, acoustical absorption, resistance, thermal conductivity, etc.),
  - Age (the period of time the building was built until the present),
  - Type of heating/cooling system (the type of system/equipment to heat and cool the building (i.e. gas-fired heaters, electric heaters, central heat, split unit, etc.),
  - Geometry (the shape of the building),
  - Orientation (solar orientation of façades),
  - Type of use (the building typology (i.e. schools, shopping centers, offices, government buildings, etc.)).

5. PERFORMANCE AREAS AND KPIS

Literature review results were used as a basis of the focus group and the questionnaire survey.

The results of the focus group revealed that the main areas to assess building performance are related to safety and user satisfaction rather than aesthetics. Regarding safety, all experts agreed that it was essential to meet regulations (as a threshold), so building regulations should be taken for granted. Consequently, prevention of occupational risks was considered the most relevant area of building performance, which is related to well-functioning of all elements and systems of the building.

Regarding building appearance, the results revealed that aesthetic aspects are relatively unimportant. In comparison with previous studies, aesthetics was valued, but was considered the least important category in a hierarchy of performance levels (33).

In addition, they considered user satisfaction an essential aspect to take into consideration. All experts believed that health and comfort aspects, such as air quality, were the main priority. Furthermore, space management based on users' needs was considered an essential aspect of performance, as was the level of cleanliness of a building. The experts also discussed the importance of assessing energy consumption considering the resources (electricity, gas, etc.) to save costs.

When joined in groups, although they used different terminology based on the type of buildings they had experience in, all experts agreed on the same areas to define building performance: safety and elements working properly, space functionality, cleanliness, and energy efficiency.

When analyzing the survey results, most experts (83% of the respondents) agreed that the areas selected by the focus group were the most important ones to consider when assessing building performance.

The results of the survey revealed that cleanliness was considered a minor area that should be incorporated into building maintenance activities.

The questionnaire results suggested including space flexibility within space functionality. Other suggestions were related to the functionality of the building, in other words, that the building provides the required features so that its users can satisfy their requirements or needs. Although the literature review suggested that there is a distinction between technical and functional performance (16), the results indicated that these two categories can be analyzed together.

Unlike previous studies (16), the results suggested that two levels of building functionality should be considered: asset level and space level. In the first level, the concern is to assess whether all building elements and systems are working properly, to guarantee the functionality and safety of the building. The second level is mainly related to the layout of the space and how people interact with it, for instance, if there are spaces for performing work activities.

The final building performance areas included:

- **Safety and Assets working properly:** The description and assessment of the structural and physical condition of the building and the correct operational functioning of its assets.
- **Health and Comfort:** The description and assessment of health and comfort aspects and needs of building users.
- **Space functionality:** The description and assessment of the availability of space to perform required activities, including the needs of building users.
- **Energy efficiency:** The description and assessment of building energy use and the control of the growth in energy consumption.

Literature review and discussions with industry leaders were used to determine the indicators within each area to evaluate building performance. An important aspect indicated by the literature review was the simplicity and meaningfulness of the indicators to allow benchmarking. The establishment of benchmarks allows comparison with other facilities, and helps guide management in decision-making.

5.1. Safety and Assets working properly

The KPI for safety and assets working properly involve the defects detected in each building element/system: structure, façade, roofing, flooring, interior partitions, electrical system, plumbing system, HVAC, fire system and elevators. This classification was based on OmniClass (34) standard, a classification system for the construction industry.

As an example, if we consider the façade of a building, the indicator to evaluate the performance of the façade should consider all its defects (cracks, erosion, water ingress, efflorescence, etc.) and their severity (35). The severity should take into account the repair costs and the propensity to cause other defects (14), and express how serious the impact of the defect is on the service or on the end user.

The defects are detected by conducting a technical building inspection. Technical building inspections are compulsory in some countries, to ensure that a building is safe and its environment is healthy. It consists of a visual inspection followed by a technical report to describe the condition of the building, any defects that have been found and their possible causes.

5.2. Health and comfort

Regarding health and comfort, indoor temperature is considered the most important indicator in non-residential buildings since it can directly be linked to employee performance (11). Relative humidity together with temperature has been claimed as one of the main comfort indicators (15). Moreover, air quality, light quality, noise and workplace pollution correspond mostly to the health and comfort of users (36).

These indicators can be quantified by analyzing the percentage of time outside of the comfort zone at building level/individual room level. These data could be drawn from Building Management Systems (BMS). Some EU regulations establish the main comfort parameters required for office working conditions. In Spain, for example, assuming typical working activity and clothing, the temperature should be between 21–25 degrees, the air velocity between 0.10–0.20 m/s, and the humidity between 40–60%.

Another method to quantify the health and comfort area is associated with incidents and complaints reported by regular users, for instance, when a space is too hot (37). The number of complaints and the severity of the problems detected by regular end users are therefore one way to quantify this indicator. Moreover, regular and sporadic user satisfaction can be measured by questionnaires to rank a set of criteria in levels of satisfaction.

5.3. Space functionality

Space functionality includes suitability of the space, and whether it is ergonomic and accessible. The suitability of a space can be evaluated by workers/m2 and use (38). Regarding whether it is ergonomic and accessible, there should be a periodic survey of regular users to gather information about ergonomic hazards in the workplace and complaints about accessibility.

5.4. Energy efficiency

Indicators in the energy management are related to consumption of resources (38). In this area, the most common indicator is electricity and gas consumption. A baseline energy performance indicator can be adopted to evaluate energy performance. First, past energy consumption is used to establish an energy baseline of the building under analysis. The variables that affect energy consumption (e.g. outdoor temperature and building occupancy) need to be identified to normalize the baseline. Then, any data points that fall outside the baseline limit are defined as an anomaly.

5.5. Factors affecting building performance

The results of the questionnaire survey revealed that nearly all the experts (86.8%) found the defined exterior conditions (weather condition, surrounding environment, natural disasters and geological conditions) suitable to determine the environmental agents that affect a building's performance. Some experts suggested the inclusion of human/urban environmental conditions, as buildings near schools, facades opening onto public spaces or buildings in deprived areas of cities are more prone to deterioration. This concept was considered relevant to incorporate in the surrounding environment agents.

Most of the experts (73.5%) agreed that the type of structure/façade/roof, age, type of heating/cooling system, geometry, orientation, and type of use were the most important properties that affect building performance. Additionally, some experts suggested that renovations over the years or any kind of refurbishment should be included. These suggestions were included in the list of factors about building properties and environmental agents.

6. SOURCES OF INFORMATION FOR DEFINING KPIS

The source of information for defining the KPIs can be obtained from:

- **FM/operators:** these indicators include those that can be measured by extracting data from simple databases, such as incidents on Computer Maintenance Management System (CMMS), sensors connected to BMS that report malfunctioning, energy consumption by area and by conducting technical building inspections.
- **Regular users:** these indicators are related to complaints about comfort or malfunctioning of elements through a call desk or intranet linked to CMMS. The end user notices a problem and can complain, for example, if the HVAC system is not working properly. However, the user cannot give feedback about internal characteristics such as problems with the HVAC pumps' pressure. Indicators can also be obtained by satisfaction surveys.
- **Sporadic users:** these indicators are obtained from questionnaires that mainly use satisfaction ratings about comfort-related aspects.

Regular users can report an incident relating to a system (such as elevators) not working properly, and can complain about the comfort of their working space (for example, its temperature). The term complaint is used here to mean a statement that a condition is unsatisfactory or could be improved (37), while an incident is an event that is either unpleasant or unusual, such as malfunctioning of some equipment. CMMS are the usual tool to gather incidents and complaints made by regular users.

Table 2 summarizes the indicators organized by areas and the data source: (1) CMMS + BMS + Inspections (FM/Operators); (2) CMMS + Questionnaires (Regular users); and (3) Questionnaires (Sporadic users). A period of a year was considered the ideal time interval for measuring all the indicators, since it covers all the seasons.

7. BUILDING PERFORMANCE CAUSAL MODEL

The understanding of the relationships between the three main performance categories is an essential task for the assessment of the building performance. Interactions among health and comfort of occupants, the energy efficiency and condition of the building elements and systems can be used to guide a way to achieve a comfortable, healthy and energy-efficient building.

Essentially, there is a need to understand how the performance loss or failure of one building element affects the performance of other elements, and systems and building as a whole (39). For instance, some construction elements not working properly may provoke other problems in the building (e.g., cracks in the façade may cause water infiltrations). Moreover, depending on the condition of the building envelope, higher thermal loads would be required to reach interior comfort temperature, provoking higher electricity consumption and thus reducing the energy performance of the building (31). This can be associated to energy related building defects such as ventilation losses, moisture related defects, and service faults (40). The effect of deterioration on building systems also affect the end users (39). Poorly maintained indoor environments have been linked to discomfort and health problems experienced by users (41).

The relationships that exist between KPIs and factors that affect building performance was then established and a Bayesian network (BN) model to depict these relationships was developed. BN has been recognized as one of the most successful complete and consistent tools to model causal relationships with uncertain data that represent a set of variables and their probabilistic dependencies and have been extensively used to develop decision support systems in a variety of domains (42).

The factors and indicators obtained from the literature review, focus group and questionnaire survey were used to determine the nodes of the BN. Some nodes had binary states such as "Yes" and "No", and others multiple states such as "High", "Medium" and "Low".

Most effective BNs are those that combine the qualitative structure based on expert knowledge, with the quantitative probabilities identified and revised using empirical data. To determine the relationships among factors and indicators expert judgement and the learning from data tool (using a database from 40 buildings) were used.

Probability distributions for the indicators and factors were defined from expert judgement and different reports and databases taking into account the existing non-residential building stock in the European context.

Figure 1 presents the causal effect among KPIs within each performance category. For instance, a malfunction in a drain pipe hanging on the façade may trigger another problem on the façade (e.g., cracks). Moreover, the causal effect among KPIs and different performance categories is also represented. For example, thermal quality, as a health and comfort KPI, is influenced by the condition of the façade and the HVAC system.

The causal effect between KPIs and factors is also represented in Figure 1. Environmental agents and building properties

Table 2. Operational KPIs for building performance assessment.

Building performance areas	Indicators	CMMS + BMS + Inspections (FM/Operators)	CMMS + Questionnaires (Regular users)	Questionnaires (Sporadic users)
Safety and Assets working properly	Building elements and systems condition	Number of defects detected in inspections * severity	Number of incidents/ complaints regarding safety and elements not working * severity	Satisfaction in a Likert scale
Health and Comfort	Thermal quality	% of time out of the comfort zone levels of temperature, humidity, air velocity	Number of incidents/ complaints regarding comfort * severity	
	Air quality			
	Light quality	% time out of the required luminance level		
	Acoustic quality	% time out of the acceptable noise level		
Space functionality	Suitability of space	Total actual area/total required area	Number of incidents/ complaints regarding space * severity	
	Accessibility	Number of incidents detected in inspections * severity		
	Ergonomic	Number of incidents detected in inspections * severity		
Energy efficiency	Electricity	Points out of the energy baseline	Not applicable	
	Gas	Points out of the energy baseline		

*All indicators are measured per year.

affect the KPIs related to all categories. For instance, the environmental exposure of a building may accelerate the degradation of the façade. Preventive maintenance can also be a factor of delay in the degradation of building elements and systems.

Through the definition of the main performance indicators and factors and their relationships, experts can understand the causality chain that exist when analysing multiple factors that affect building performance holistically. This definition makes explicit the multiple and often complicated nature of buildings and provides a more rational analysis of building performance.

The construction of a causality chain of these KPIS and factors will help to arrive at an understanding of the underlying interdependencies pertaining building performance. Additionally, the development of a Bayesian networks (BN) model to depict these relationships should be explored.

The development of a causal model based upon probabilistic causation can provide an alternative for estimating a building's performance. Furthermore, as BN allows easy what-if and sensitivity analysis, facility managers can forecast a building's performance through scenarios in which certain indicators are changed or improved. For instance, if a repair is conducted in a certain building element, they can determine the impact of this action on the entire performance of a building by changing variable states and observing the automatically updated decision outcomes. These results might help facility managers to take appropriate actions to improve building performance.

8. DISCUSSION AND CONCLUSIONS

Existing assessment tools are very complex, require a huge amount of time to collect the information and generally include many indicators and factors. These tools generally use linear analysis and do not effectively consider the interdependency between causal factors, since they employ an independent-cause approach to determining building performance. Consequently, this study selects the relevant indicators and factors associated to the performance of a building and presents a holistic building performance assessment approach. The core indicators and factors to optimize and simplify the data capture were obtained by means of a literature review, a focus group with experts and a questionnaire survey. Then, the data source where to obtain the performance indicators was also determined. Finally, a holistic causal model for analyzing building performance was presented.

The results revealed that the most important performance areas for non-residential buildings could be limited to safety and assets working properly, health and comfort, space functionality and energy efficiency. The results also highlighted that environmental factors and building properties are evidently key factors that affect the performance of a building, as identified in the literature and validated in the survey.

Those technical and functional areas considered by the existing studies and assessment tools were found to be considered together reducing the time to gather data. Periodical technical inspections will provide the condition assessment of the construction elements and systems of the building. The classification of these elements and systems should be based on classification standards so as to facilitate the data extraction if CMMS systems or Building Information Modeling (BIM) are implemented in the building.

The results of the focus group and experts' opinions found aesthetics not to be relevant enough to be incorporated in performance assessment tools. Results also highlighted that behavioral performance area basically focuses on users' health and comfort. Interior conditions such as temperature and humidity can be drawn from the BMS. Other non-monitored or difficult to monitor data can be obtained from the incidents and complaints reported by regular users. Finally,

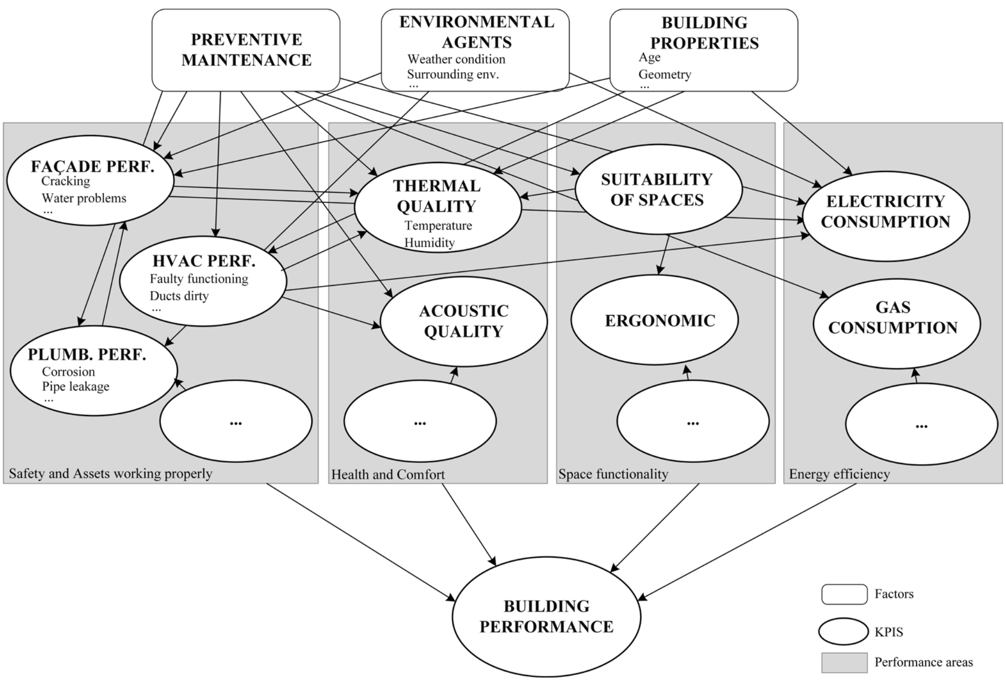

Figure 1. Holistic causal model.

the comfort perception should also be obtained from user satisfaction questionnaire surveys.

Focus group and questionnaire survey results also highlighted the need to evaluate space functionality in terms of ergonomic and accessibility. These data can be obtained from end users incidents and complaints and from the periodic user satisfaction surveys. Energy efficiency was also considered one of the main core areas of the building performance. This area includes energy consumptions and efficiency of the existing systems. These data can be obtained from the BMS.

The results of this study can also be used to define the user's survey questionnaires and the classification systems within the CMMS, BMS or BIM implemented in the buildings.

Literature review and experts' opinions were used to determine a global causal relationship among KPIs and factors which can provide a better understanding of the behavior of the building in the operational phase.

For a real understanding and effective analysis of the building performance, interdependencies among identified indicators and factors should be analyzed. In fact, some construction elements not working properly can provoke other defects; both comfort indicators and energy efficiency indicators are also dependent on the exterior conditions, the state of preservation of the envelope and type of HVAC systems among others; the state of preservation of building components and systems depend on the preventive maintenance and the quality of the materials, etc.

Through the definition of the main performance indicators and factors and their relationships, experts can understand the causality chain that exist when analyzing multiple factors that affect building performance holistically. This makes explicit the multiple and often complicated nature of building performance and provides accurate information for decision making.

BN can be used to create an easy risk analysis system and facilitate the causality analysis of building performance and determination of performance labels to be used in a certification system. Through the use of causality systems such as risk analysis system, facility managers and researchers can forecast a building's performance through scenarios in which certain indicators are changed or improved. The outcome of the causal model will help building owners and facility managers have a sense of where attention should be focused and where the budget should be allocated to improve the performance of a specific building, or in general for the whole building stock.

Future research will focus on a deep analysis of the interactions between the identified performance indicators and factors to build a detailed causal model to help the decision making process of facility managers to improve existing buildings' performance.

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