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REVIEW AND ANALYSIS OF EXISTING METHODS TO ASSESS THE INDOOR ENVIRONMENTAL QUALITY (IEQ) FOR OFFICE BUILDINGS

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Abstract. Population in developed countries spend most of their time indoors, whether in their homes, workplaces, stores or leisure areas. Due to the COVID-19 pandemic, this situation worsened and now, more than ever, the importance of a high Indoor Environmental Quality (IEQ) is highlighted. The IEQ is very important in building performance since it is directly related to its occupants' comfort, health, wellbeing, and productivity and the Sick Building Syndrome (SBS) concept.

Therefore, it is essential to develop tools to support designers' decision-making in the materialization of indoor environments with higher quality. From the state-of-art analysis, it is possible to conclude that the methods to assess the overall building performance already consider the IEQ. Still, most use an approach that does not cover all relevant indicators.

In this context, this paper presents the first milestone of a research work that aims to develop a new method to rate the overall IEQ of office buildings in Portugal.

The main objective of the present study is to propose a list of IEQ indicators for office buildings, adapted to the Portuguese context, based on the analysis of existing rating methods for buildings and the recommendations of national and international standards.

Keywords: Indoor Environmental Quality (IEQ) indicators, decision-support tools, office buildings.

1. Introduction

Since the first civilizations, humanity has been concerned with building shelters and creating a safe interior space to develop their activities, whether productive or leisure, under protection from the weather [1, 2]. As knowledge about building environments, both indoors and outdoors, improved over time, other conditions were added to the basic building requirements [2, 3]. Technological advances allowed the creation of new materials and construction techniques. Until a few decades ago, both the design and construction of buildings paid attention only to characteristics related to engineering, economy and aesthetics [3, 4]. The Indoor Environmental Quality (IEQ) only started to be considered after the appearance of pathological symptoms presented by occupants, associated with the construction [4].

Currently, one of the main objectives of buildings is to provide healthy and comfortable environments for human activities, providing shelter, light, space, and sufficient amenities to work, live, learn, heal, among others [5]. Before the COVID-19 pandemic, a study by Klepeis et al. [6] showed that people spend about 90 % of their time indoors, whether in their homes, workplaces, shopping, or leisure areas. Thus, it is clear the importance of a high IEQ since it is directly related to its occupants' comfort, health, and productivity [7].

In the path of raising awareness about the rational use of energy, reducing consumption and avoiding waste, both the architectural pattern and the building materials were modified to improve thermal insulation [8]. This resulted in buildings with more efficient thermal insulation, without external openings that would allow natural ventilation, creating the so-called "airtight buildings" [8, 9].

The limitation of air exchange through ventilation had negative consequences, such as increased relative humidity and condensation phenomena [2]. Thus, in the eighties, the first cases of Sick Building Syndrome (SBS) were reported, characterized by situations of work discomfort and/or acute health problems presented by workers, which were possibly related to the permanence inside some buildings [7].

This syndrome is classified by the World Health Organization (WHO) as a public health problem. In the USA alone, the annual cost attributed to it in commercial companies is estimated at between US$10 billion to US$70 billion [10]. In other words, in addition to the health problem, an economic problem is generated, as expenses on health and disability pensions increase and there is a loss in workers' productivity and in the repairs needed to overcome the problems of the sick building [11].

Several studies [12–16] demonstrate that improving

Methods	Country	Methods	Country	Methods	Country
Active House	Belgium	Fitwel	USA	LIDER A	Portugal
BEAM Plus Interiors	China	Green Globes SI	USA	NABERS IE	Australia
BREEAM	United Kingdom	Green Star - Interiors	Australia	SBTool PT	Portugal
CASBEE	Japan	HQE	France	WELL	USA
DGNB	Germany	LEED	USA		

Table 1. Methods analysed and their origin.

the IEQ results in increased team productivity and concentration, based on greater comfort, health, and wellbeing of workers. The Australian Property Council estimated that a 1 % improvement in productivity would be equivalent to the total energy cost of the entire building [15]. Moreover, the influence of a poor IEQ can generate employee health expenses twice as high as energy costs [16].

Recent data reveal that Portugal is the seventh country in the European Union with the lowest productivity per hour of work [17] and that the tertiary sector in the country is expanding, being responsible for employing 69.8 % of the active population in 2020 (in 2010, it was 61.5 % and in 2000, 52.6 %) [18]. Given this scenario, it is essential to invest in practices aimed at the IEQ in this sector to provide a good IEQ for employees to create competitive businesses.

Several building evaluation methods adopt the quality of the interior environment as one of their indicators. However, their analysis is often superficial and generic. Therefore, the main objective of this work involves raising and categorising the main factors that affect the IEQ in office buildings, based on existing classification methods that consider it in their analysis and on national and international reference standards. Thus, the indicators and categories that best suit the Portuguese building stock will be listed, which will serve as a basis for creating a method to assess the overall quality of the interior environment for office buildings.

2. Materials and Methods

The study was developed based on the analysis of 14 building assessment methods (Table 1), six European and eight non-European, which include IEQ indicators as part of their criteria. Each of them differs from the other since the design guidelines of each location are unique, which is the main reason each country sought to develop a system based on its specific context [19].

Thus, the IEQ indicators and categories were identified within each tool, using information contained in documents available on the official websites. In some of them, such as LEED and the DGNB, there are specific indicators for different buildings (commercial, retail, hotels, among others). However, for this study, only those applicable to offices were considered.

To approach the IEQ in a general way, the designations of the indicators that evaluate the same criterion were standardised, as well as the categories. Then, 9 categories were stipulated, with 38 indicators in total. Based on this, it was possible to perceive the scope of each method regarding the IEQ criteria and to select those that presented a more significant number of categories evaluated as the primary references of the study. For these, the weights of each category were evaluated within a global score, presenting the result using pie charts. In addition, the most mentioned indicators among the tools were identified, with the support of the VOSviewer software.

A comparative analysis was carried out between the proposed list of indicators and the standard for Sustainability of Construction Works, EN 16309:2014+A1 [20], was carried out, highlighting the relevant differences. Based on the results obtained, a list of categories and indicators best suited for the Portuguese office buildings context was developed.

3. Results and Discussion

The standardized categories stipulated in this study were: Indoor Air Quality, Thermal Comfort, Acoustic Comfort, Visual Comfort, Layout, Water Quality, Materials and Emissions, Nourishment, Occupant and Community. And its indicators were divided as follows:

- Indoor Air Quality: Ventilation, Air Pollution, Ventilation User Control.
- Thermal Comfort: Air Temperature, Humidity, Air Speed, HVAC Automation Systems, Occupant Temperature Control.
- Acoustic Comfort: Sound Insulation, Reverberation, Internal Noise, Noise Emissions.
- Visual Comfort: Light Comfort, Glare Management, Colour Rendering, Views, Occupant Lighting Control.
- Layout: Interior Design, Flexibility and Adaptability, External Areas, Biophilic Design.
- Water Quality: Water Quality Parameters, Water Quality Management.
- Materials and Emissions: Material Restrictions, Waste Management, Biological Control, Maintenance.
- Nourishment: Responsible Food Sourcing, Food Production, Nutrition Education.
- Occupant and Community: Active Life, Hygiene Support, Accessibility, Mobility Infrastructure,

Methods	Indoor Air Quality	Thermal Comfort	Acoustic Comfort	Visual Comfort	Layout	Water Quality	Materials and Emissions	Nourishment	Occupant and Community
Active House	x	x	x	x	x		x		
BEAM Plus Interiors	x	x	x	x	x	x	x		x
BREEAM	x	x	x	x	x		x		x
CASBEE	x	x	x	x	x		x		x
DGNB	x	x	x	x	x		x		x
Fitwel	x			x	x	x	x	x	x
Green Globes SI	x	x	x	x	x		x		
Green Star - Interiors	x	x	x	x	x		x		x
HQE	x	x	x	x	x	x	x		
LEED	x	x	x	x	x		x		x
LiderA			x		x		x	x	x
NABERS IE	x	x	x	x	x		x		
SBTool PT	x	x	x	x			x		x
WELL	x	x	x	x	x	x	x	x	x

Table 2. Categories presented by the studied methods.

Amenities, Security, Occupant Well-being, Neighbourhood Development.

It is important to note that not all tools cover the nine categories defined here. Table 2 shows a comparison between the certifications, indicating which criteria they address.

It is noticeable that most methods consider the main themes that contribute to the IEQ: Indoor Air Quality, Thermal Comfort, Acoustic Comfort and Visual Comfort [21, 22]. However, it should be highlighted that all certifications studied consider Materials and Emissions, reflecting the global concern with the abusive consumption of raw materials and with pollutants from the construction industry.

Although many of the certifications address the consumption and, mainly, the efficient use of water, encouraging the economy of this good, this study considered the indicators directly related to the occupant of the building. Thus, only four tools, BEAM Plus Interiors, Fitwel, HQE and WELL, have criteria that consider this aspect.

It is also noted that only three methods, Fitwel, LiderA and WELL, comprise parameters that refer to occupant nutrition. In addition, of the indicators that make up the Occupant and Community, the Mobility Infrastructure is the one that is present in most of the tools that involve this category. This exposes the fact that social sustainability criteria, which are the ones aimed at the occupant's wellbeing and health, are undervalued compared to traditional classifications of building-related aspects such as energy, water, or use of materials [23, 24].

To illustrate the different weightings attached by the tools to the categories, Figures 1 (a, b and c) show, respectively, the weight by category of the BEAM Plus Interiors, HQE and WELL certifications. These evaluation methods were selected because they presented the largest number of categories evaluated, all for WELL and one less (Nourishment) for BEAM Plus Interiors and HQE. When observing the graphs, WELL has a more balanced distribution of weights than the other two assessment methods. Since this assessment is focused on the quality of life of the occupant, the highest percentage of weight is dedicated to this category (Occupant and Community). In BEAM Plus Interiors, most of the weights are associated with other categories, not included in this study, such as Energy and Management, with only 34 % of the total evaluated destined for the rating of the IEQ. The HQE, in turn, has 51 % of the weight attributed to the assessment of the IEQ, with 16 % associated with the evaluation of Materials and Emissions.

However, it is worth mentioning that for the HQE, the third and fourth largest portions of the score (Thermal Comfort and Layout) are related to the physical comfort of the occupant, evaluating the temperature and ergonomics of the workplace, among others. For BEAM Plus Interiors, Indoor Air Quality and Visual Comfort represent the second and third largest share of the total score.

Looking at globally, the VOSviewer software was used to build a semantic diagram based on the standardized indicators of this study, in order to identify the most mentioned among the certifications. Thus, Figure 2 shows the indicators considered by all methods network, where the circles diameter expresses the frequency of the indicators are covered by the considered methods.

Analysing the diagram, the indicators that had the highest occurrence were Air Pollution and Light Comfort, with thirteen occurrences each, followed by Material Restrictions, Sound Insulation and Ventilation, with twelve. Once again, this demonstrates that most of the evaluation methods analysed are more focused on constructive than social aspects.

The different colours of the diagram represent groups of indicators that present simultaneous occurrences more frequently. Most indicators that evaluate constructive characteristics appear in the red group, while those that evaluate social characteristics appear in the green one. This demonstrates that, in general, there are some methods that majority evaluate constructive characteristics and others that mostly

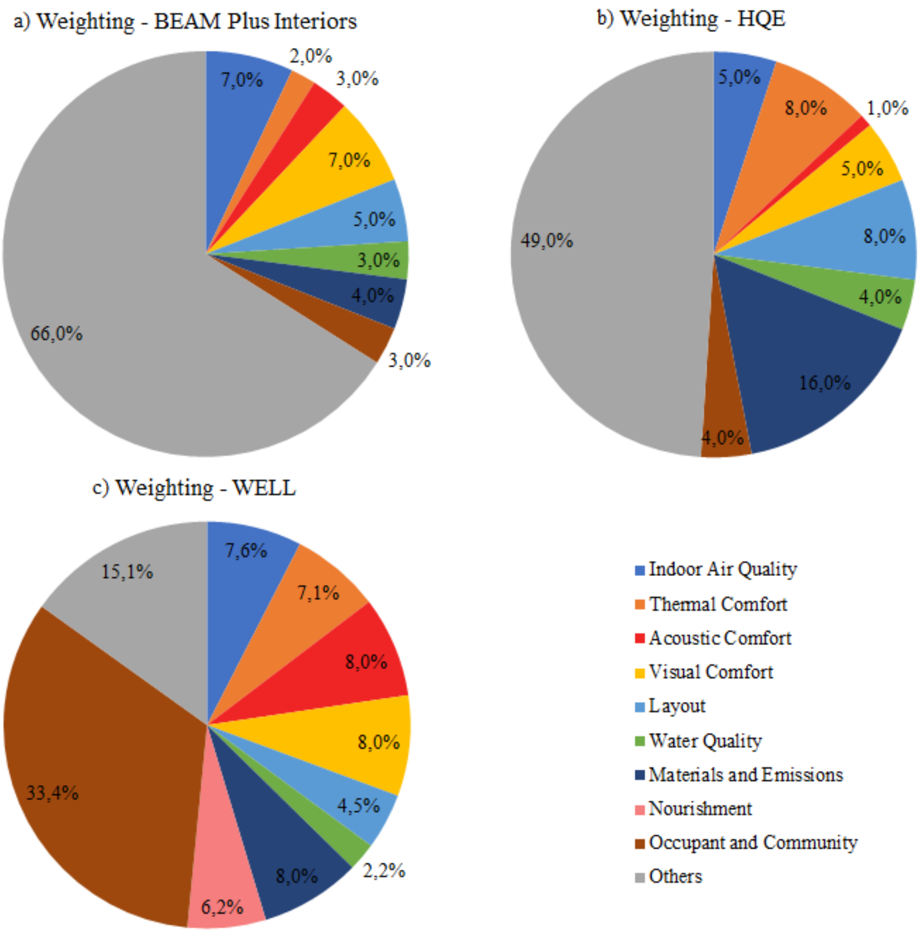

FIGURE 1. Weight by category of certifications: a) BEAM Plus Interiors, b) HQE and c) WELL.

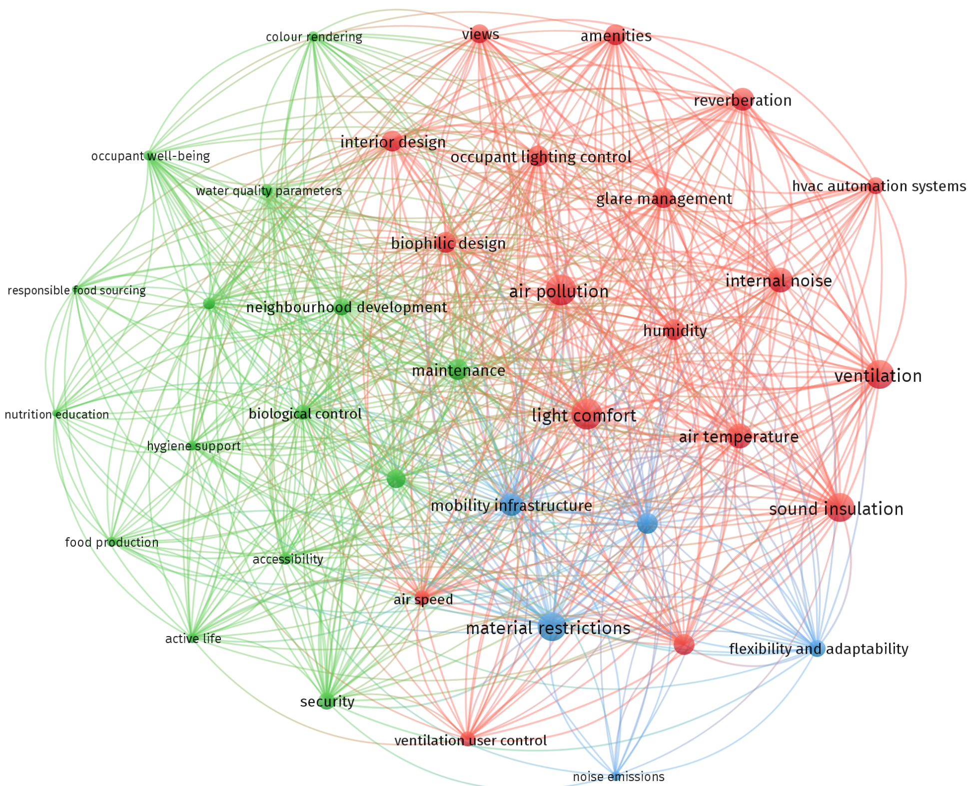

FIGURE 2. Semantic diagram of certification documents keywords.

Categories	**Indicators**		
Indoor Air Quality	Air Pollution	Ventilation	Ventilation User Control
Thermal Comfort	Air Temperature HVAC Automation Systems	Air Speed Occupant Temperature Control	Humidity
Acoustic Comfort	Internal Noise Sound Insulation	Noise Emissions	Reverberation
Visual Comfort	Colour Rendering Occupant Lighting Control	Glare Management Views	Light Comfort
Layout	Biophilic Design Interior Design	External Areas	Flexibility and Adaptability
Water Quality	Water Quality Management	Water Quality Parameters	
Materials and Emissions	Biological Control Waste Management	Maintenance	Material Restrictions
Nourishment	Food Production	Nutrition Education	Responsible Food Sourcing
Occupant and Community	Accessibility Hygiene Support Occupant Well-being	Active Life Mobility Infrastructure Security	Amenities Neighbourhood Development

Table 3. Categories and indicators selected for the method to be developed.

evaluate social characteristics.

The European Standard for Sustainability of Construction Works, EN 16309:2014+A1 [20], in its first version, considers the aspects and impacts of the use phase of a building, providing methods and requirements for evaluating its social performance. For this, its indicators are divided into six categories:

- Accessibility: Accessibility for people with additional needs, Access to building services.
- Adaptability: Ease of potential for adapting to other use.
- Health and comfort: Thermal characteristics, Thermal comfort, Characteristics of indoor air quality, Indoor air quality, Acoustic characteristics, Characteristics of visual comfort, Visual comfort, Spatial characteristics.
- Impacts on the neighbourhood: Noise, Emissions, Glare/overshadowing, Shocks/vibrations.
- Maintenance and maintainability: Maintenance operations.
- Safety and security: Resistance to climate change, Accidental actions (earthquake, explosions, fire, and traffic impacts), Personal safety and security against intruders and vandalism, Security against interruptions of utility supply, Security against intruders and vandalism

In an overall analysis, all categories of the Standard are addressed in the standardized categories of this study. Comparing the indicators, those presented in the "Health and Comfort" criteria were all considered in the categories "Thermal Comfort", "Indoor Air Quality", "Acoustic Comfort", "Visual Comfort" and "Layout".

The Adaptability category of the EN is compatible with the standardized indicator "Flexibility and Adaptability", while the "Accessibility for people with additional needs" and "Access to building services" indicators refer to "Accessibility" and "Amenities", respectively. The criteria evaluated in "Impacts on the neighbourhood" can be related to the parameters defined in the "Air Pollution", "Noise Emissions" and "Glare Management".

The "Maintenance and maintainability" category is consistent with the "Maintenance" indicator of the "Materials and Emissions" category. Finally, the category "Safety and security" is almost entirely encompassed in the standardized indicator "Security", except for the "Resistance to climate change". This will not be addressed in the method to be developed, because, even if it is related to the safety of the occupants, its assessment is made exclusively considering the structure of the building.

However, EN does not present any analysis on important issues such as Water Quality, Nourishment or Occupant and Community Well-being. This ends up corroborating the fact that most evaluation methodologies analysed in this study also do not include these topics in their requirements.

Based on these results, the method of valuation of office buildings in the Portuguese context to be developed should adopt the set of requirements presented in Table 3.

4. Conclusion

This study proposed a list of indicators and categories for the assessment of office buildings in Portugal. For this, fourteen certification tools of sustainability or IEQ of buildings were analysed. In addition, the legislation and standards in force in the country and in the European Union were considered in order to guarantee that the chosen requirements were relevant in the current context.

The results presented and discussed reinforce that the IEQ is already considered in several building evaluation methods. However, most of them do not cover all relevant indicators, especially those related to social aspects and occupant and community well-being.

This reflects the absence of regulation that encourages the adoption of these characteristics. Even the norms that are related to the social performance of the building often fail to address important criteria such as water quality, nourishment, among others.

The analysis of the selected methods showed that there is still no international agreement on the list of IEQ aspects to be considered in the sustainability assessments, since it differs from method to method. This can be explained from the regional, sociocultural, environmental and economic differences of the countries of origin of each certification. Despite these differences, it was also noticed that several tools evaluate some similar parameters, although they have different nomenclatures.

In view of what has been identified, this study will serve as a basis for the creation of a new method of evaluating the IEQ for office buildings in the Portuguese context. To this end, a list was prepared with 9 categories and 38 evaluation indicators that will be used in the method to be developed. In creating this list, care was taken to ensure that the number of indicators was sufficiently extensive to include the aspects that most influence the IEQ, health and well-being of the occupant, but also as small as possible to facilitate their use in practice.

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