Indoor Environmental Quality

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A discussion of sustainability in architecture cannot be meaningfully carried out without the inclusion of most buildings' central purpose, namely the provision of indoor environments that are accommodating of occupants' needs and requirements. To this end, building designers and operators are expected to demonstrate compliance with codes and standards pertaining to indoor environmental quality (IEQ). However, the majority of conventional IEQ standards, codes, and guidelines have a single-domain character, in that they address IEQ in terms of a number of isolated domains (i.e., thermal, visual, acoustic, air quality). In this context, the present contribution explores the current state of multi-domain IEQ evaluation approaches and the necessary conditions for their further development and application. Toward this end, a number of common building rating schemes were selected and analyzed in detail. The results of this assessment imply the necessity of both short-term improvements of the existing schemes in terms of the transparency and plausibility of the applied point allocation and weighting strategies and the fundamental need for a deeper empirically grounded understanding of the nature of occupants' perception of and behavior in the built environments.

Keywords: indoor environmental quality ; codes ; standards ; multi-domain ; human factor ; architecture ; building ; sustainability rating

1. The Need for Integrative Occupant-Centric Standards

As with other fields, the sustainability discourse in the field of built environment needs to address not only the environmental and economic aspects, but also the social—i.e., human-centric—dimension of building design and operation. Ultimately, the main purpose of most buildings is the provision of indoor environments that are accommodating of occupants' needs and requirements. Human requirements in design and operation of buildings can be adequately discussed in the context of built environments' effectiveness and efficiency [1]. Whereas provision of conditions conducive to people's health, comfort, satisfaction, and productivity are associated with buildings' effectiveness, such conditions must be provided in an efficient manner from the point of energy and environmental impact. In other words, buildings are expected to provide a high degree of habitability (the effectiveness requirement) in an energy and resource conserving manner (the efficiency requirement).

To this end, building designers and operators often rely on various codes, standards, guidelines, and other forms of assessment procedures and evaluation schemes. Deployment scenarios of such resources typically involve both effectiveness and efficiency considerations. The adequate (effective) attributes of designs (mainly in view of indoor-environmental quality) are to be realized in an efficient manner (e.g., in terms of energy and resource use). Thus, codes, standards, guidelines, and other building evaluation and certification instruments should ideally help planners and operators to find out if:

i. A design proposal or an operation regime is e ective, i.e., if it leads to a more habitable environment, and
ii. The provision of habitability is accomplished in an environmentally and economically efficient manner.

Particularly, the evaluation of buildings' effectiveness necessitates a deep understanding of habitability requirements, or—to use a more common parlance—buildings' indoor environmental quality (IEQ) as relevant to occupants' needs and expectations. It is common knowledge that IEQ requirements are diverse and multifaceted. As such, they pertain to multiple domains (i.e., thermal, visual, indoor air quality, acoustic) and disciplines (e.g., architecture, mechanical engineering, psychology, physiology). There is also a general agreement—albeit at a theoretical level—that achieving high-performance built environments requires a deep integration of such diverse IEQ domains. Nonetheless, most conventional standards, codes, and guidelines have arguably a single-domain character, in that they address IEQ in terms of a number of isolated domains. A tacit assumption thereby appears to be that achieving "best performance" in individual domains results in an overall optimum performance at the building level. Recently, efforts are being made to provide the necessary knowledge base for formulation of integrated multi-aspect building design support resources and procedures [2]. In this context, the present contribution explores the current state of multi-domain IEQ evaluation approaches and the necessary conditions for their further development and application.

2. Approaches to the Evaluation of Buildings' IEQ

As discussed in the previous section, the design, construction, and operation of buildings are expected to address multiple quality requirements. These include, among others, functional efficiency, economic feasibility, and IEQ. Commonly, both formulations of quality requirements (e.g., in terms of codes, standards, guidelines) and methods for their evaluation (e.g., code compliance methods and certification procedures) are organized along such aspects. The IEQ aspect, which is the focus of the present discussion, directly relates to user needs. The overarching objective of the specification and evaluation of IEQ-related performance criteria is presumably the provision of conditions that are conducive to building inhabitants' health, comfort, and well-being. Consequently, the formulation of IEQ requirements must be based on the knowledge of the effects of relevant indoor-environmental conditions on human health, comfort, and well-being.

However, the operationalization of such high-level concepts is rather non-trivial, given their arguably imprecise and at times overlapping definitions. For instance, health is frequently defined as "the state of being free from illness or injury", comfort as "a state of physical ease and freedom from pain or constraint", and well-being as "the state of being comfortable, healthy, or happy" [3]. A number of these attributes are included in WHO's definition of health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" [4].

These observations provide a conceptual basis for the understanding of conventional approaches toward formulation of IEQ standards. The basic function of current standardization practices in this area appears to involve the following ingredients:

- A number of measurable (typically physical) indicators of indoor-environmental conditions (e.g., air temperature, humidity, illuminance, sound level) are assumed to be pertinent independent variables in view of environmental quality
- These variables are mapped into another set of (in this case dependent) variables that are treated as indicative of human health, comfort, and well-being (e.g., thermal comfort, visual comfort).
- The logic of mapping operations is frequently based on a mix of causal (typically physiological) and data-driven (typically correlational)
- The mapping operations and the resulting rules of inference are structured in terms of multiple distinct
- These clusters follow loosely (not strictly) the typology of human sensory channels, e., haptic (relevant in view of thermal perception), visual, auditory, and olfactory (relevant in view of indoor air quality perception) senses.

The majority of conventional IEQ standards can be said to be mono-dimensional. In other words, the mapping of indoor-environmental variables to respective high-level indicators of health, comfort, and well-being is typically conducted in an isolated fashion for a distinct cluster, that is, one of the above-mentioned sensory modes, even though several distinct clusters may be included under the umbrella of a single standard. But this does not mean that there have been no efforts to develop and promote methods and procedures for multi-domain building quality evaluation and certification, which also include interactions between individual domains. However, before embarking on a closer inspection of a number of such methods, it may be useful to briefly reflect upon the related option space via a kind of logical analysis.

Consider the case of codes, standards, or guidelines that are meant to support decision making relevant to the design and operation of indoor environments. Generally speaking, such documents may be based on three approaches or strategies:

i. The first strategy—commonly deployed in the majority of current evaluation schemes—involves the categorization of requirements into distinct sets pertaining to separate domains (e.g., thermal, visual, acoustic). In this case, the evaluation is conducted (and the evidence of compliance is provided) separately for each

ii. The second strategy aims to subsume multiple quality evaluation domains in a unitary—typically point-based or credit-based—framework. Thereby, an overarching or total quality score is derived based on the combination (e.g., simple or weighted addition) of individual domains' scores. The strategy could also include additional features, such as requiring a mandatory minimum score for each domain as a condition of

iii. The third strategy would pursue a truly integrative path. Thereby, inherent—physiologically or psychologically relevant—interactions, independencies, and cross-effects among various influencing variables in different perceptual dimensions would be taken into consideration, including their complexity and presumptive non-linearity.

As alluded to before, the primary purpose of the present discussion is to obtain a general view of the state of art in view of multi-domain approaches to evaluation and certification of IEQ. Consequently, we consider a number of existing methods and procedures in this area. Specifically, we explore the extent to which the options (ii) and (iii) above have been actually realized. Note that the intention is not to provide an exhaustive review of all relevant documents, but to focus on a number of of common instances that may be considered to be typical. The related investigation is expected to deepen insights regarding the necessary conditions for future integrative methods and procedures for the evaluation of buildings' IEQ.

3. Concluding Reflections about the Selected Schemes

The preceding perusal of selected multi-criteria schemes and procedures for building evaluation and certification is by no means suggested to cover all existing instances in this category. Nonetheless, the selected cases do provide a useful overview of the state of affairs in this area. They include, in principle, multiple quality aspects (e.g., energy, resources, economy, indoor environment, social issues). Specifically, the main concern of the present contribution, namely buildings' IEQ, is explicitly addressed in all selected instances. Moreover, the multi-domain nature of occupants' exposure to buildings' indoor environments is recognized, as evidenced by the fairly consistent inclusion of thermal, visual, auditory, and olfactory components of the exposure. Nonetheless, the review of these schemes raises a number of critical questions and challenges. For one thing, from the fact that multiple domains are nominally included in the majority of the reviewed schemes, it does not follow that the implemented details are consistent across the board. This is especially true in view of the diverse and often inconsistent manner in which proxies and indicators are selected and treated in each domain. A case in point is thereby the degree of personal control (perceived control), which arguably plays an important role in evaluation processes of indoor environments [5][6][7][8]. However, the majority of the studied standards do not address design issues concerning personal control. Whereas Miljöbyggnad [9] does not consider personal control, WELL does address user control of windows and lighting [10]. The DGNB includes as such the personal control category ("user influence") as relevant to thermal comfort, ventilation, and lighting in their evaluation system [11]. However, this inclusion is limited by the assumption of a large number of digital user control interfaces. ASHRAE 10 [12] elaborates on the positive effect of personal control on user satisfaction. It also mentions relevant constraints (e.g., noisy outdoors deterring occupants from operating the windows). However, it does not address this related to the personal control potential for influencing interactions. LEED includes the evaluation option of personal lighting control, but not temperature or ventilation control [13]. It is not clear why a scheme may consider user control of the lighting system as a pertinent quality criterion, but not temperature or ventilation control. EN 15232 does not provide requirements or indicators for evaluating available degrees of control [14]. Such occurrences may be the consequence of the construction practices in a scheme's country of origin.

The motivation behind a majority of the efforts related to the reviewed schemes appears to be the provision of incentives to pertinent stakeholders and the community at large to raise consciousness and pay more attention to building quality. Credit-based quality evaluation and certification systems may indeed play a role in popularization of the building quality discourse and hence incentivize higher levels of intellectual and monetary investment in building design and operation. This motivation could also explain an underlying rather reductive tendency in the studied schemes. Thereby, presumably comprehensive and detailed evaluation procedures frequently result in rather simplistic quality labels (e.g., gold, bronze, silver). Such a simplification may make sense from the strategic, psychological, promotional, or policy-related perspectives, but it is not necessarily accompanied by transparent, objective, and scientifically based methods.

In this context, a central challenge pertains to the aggregation of evaluation results from individual categories or domains into overarching and unified ratings. Whereas the quality evaluation in individual categories is—at least in part—argued based on pertinent single-domain standards, the process of score aggregation into whole-building quality labelling remains frequently opaque, if not arbitrary. In the absence of hard and fast factual reasoning, the distribution of points and associated weights to different categories in rating schemes may be motivated by other factors, such as political ones. For example, when the DGNB system (for offices) was launched in 2009, summer thermal comfort had a higher weight than winter thermal comfort. This was motivated by the building and construction authority's intention to improve the summer heat protection of offices (DGNB [11]/BNB version 2009 [15]). More generally, rating schemes can be arguably influenced by value systems or political considerations. For instance, the degree of acceptance and adaptation of a scheme could depend on the fraction of the buildings in a specific (local or national) context that would obtain a successful rating.

These observations highlight the need for an overall reassessment and possibly re-thinking of the purpose, design, and handling of building evaluation, rating, and certification systems. Thereby, a central recurrent challenge remains the degree to which the multiplicity of evaluation criteria in general and the multitude of indoor-environmental domains in particular can be reduced into aggregated measures of building quality.

4. Where Do We Go from Here?

The discussion of schemes for total building quality evaluation and rating needs to take multiple viewpoints into consideration. There are arguments both in favor and critical of current practices in this area. Favorable comments suggest that building quality rating schemes, notwithstanding any weak points or flaws, serve important purposes. A positive impact is seen in raising the consciousness level of the stakeholders with regard to buildings' functional, environmental, social, and economic performance. Further implied positive effects pertain to the promotional and prestige benefits associated with achieving a high rating. Such accolades may also translate into competitive advantages and incentivize higher investments. On the other hand, it has been noted that formal rating schemes are prone to—and may be even encourage—"gaming". The contention is that, once a certain credit-based system is established, it might be exploited in terms of numeric maneuvering aiming at identifying the "cleverest" (or the cheapest) way to maximize the number of points earned, instead of focusing on truly essential measures.

There are, however, issues beside improper appropriation possibility that need to be addressed when reflecting on the current state and future development of building quality rating schemes. A central topic thereby is the previously mentioned challenge of integration. In other words, the procedures by which the rating schemes distribute, weight, and aggregate points related to different performance indicators in different quality categories are arguably neither consistent nor evidence-based. Of course, one could argue, that even in the case of the conventional single-domain standards, the mandated requirements (often expressed in terms of the minimum, maximum, or optimal values of assorted performance indicators) are not necessarily and completely evidence-based [16]. But one can—at least in case of indoor-environmentally relevant domains—trace such mandates back to some material from medically or physiologically based studies and experiments. Definition of maximum exposure times and levels to industrial noise, limitation of the maximum glare intensity, identification of tolerable ambient temperature ranges, or specification of maximum concentration of air pollution proxies may not be in all cases non-controversial. However, there is a certain consensus as to the nature of the underlying empirical evidence and the mode of translating the associated knowledge into IEQ specifications. As such, the majority of the schemes, which were discussed in the preceding review, refer to single-domain standards when treating the individual domains they consider. The case that can be made, at least to a certain extent, for the empirical legitimacy of single-domain standards, cannot be made for the rating systems and schemes that aim at integrated building quality evaluation encompassing multiple domains and their respective performance indicators. Here, the state of knowledge is simply wanting [2][12][16][17].

These observations underline the need for rigorous empirical investigation of the cross and combined effects of multiple influence factors from multiple domains. Short of such studies and the insights they could provide, the efforts toward holistic rating of indoor environments' quality in view of their effects on people's health and comfort remain limited and ultimately unconvincing. As such, a solid empirically based understanding of cross-domain effects of indoor-environmental exposure is arguably indispensable. The question remains though, if there are still good arguments for the continued application of the kinds of point-based building quality rating systems discussed in the present contribution, even though their embedded weighting procedures may be rather opaque.

We already mentioned arguments in the consciousness raising and quality popularization categories. Translating obtained higher quality rankings into market-relevant values (e.g., achieving higher revenues when real-estate properties are sold or let) constitutes another common argument. A further argument could be made in defense of existing rating procedures, not as an exact and detailed documentation of buildings' quality in general and indoor-environmental performance in particular but as a rough aggregate estimate, suitable, for instance, for coarse quality pre-screening or classification of a given building stock. In fact, there are numerous instances of application of pragmatic aggregate measures (also referred to as indices or scales) in areas such as social sciences, economics, or public policy. But for this argument to have any traction, at least three conditions must be met. First, the pragmatic nature of the rating procedure and result needs to be clear to all stakeholders involved. Strictly speaking, the rating systems are not to be thought of as measuring a pre-existing objective attribute (total building quality). Rather, they should be seen as constructing, to a certain degree, the entity they embark on measuring. Second, the effort, details, and expenses needed to conduct the rating should be of reasonable extent. In other words, it should be commensurate to the intended utility of the results, if they are understood as coarse indicators of building quality. Last and most importantly, the process delineated by—and the reasoning underlying—the rating systems must be of outmost transparency, and their results must be independently reproducible.

These observations imply the importance of a two-fold strategy in view of future developments in the area of multi-domain quality evaluation of built environments. The first, rather short-term strategy, needs to improve on certain key features of the existing—typically point-based—evaluation and ranking schemes. Such improvements should entail the provision of a transparent reasoning behind the point allocation process and employed weighting schemes. This would enable the users and stakeholders to better understand and gauge the underlying logic behind the numeric characteristics of the scheme's assessment procedures. The second, rather long-term strategy, must address the critical need for a deeper theoretical understanding of combined influences of multiple environmental parameters on people's perception and evaluation of the quality of indoor environments. This deeper scientific understanding of the relevant processes is understandably a gradual and iterative process, but it is the key condition for future instances of truly multi-domain building quality definition and assessment standards and guidelines.

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