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The role of user controls with respect to indoor environmental quality: From evidence to standards

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ABSTRACT

There are important reasons to offer building users the possibility to adjust indoor-environmental conditions. For one thing, people sharing the same indoor environment, may have different needs, requirements, and preferences. The same set of conditions would thus not satisfy everyone. Moreover, even an individual user's preferences can change considerably, given fluctuations in the state of their disposition and health, as well as their physical and cognitive activities. After a brief discussion of available information and evidence concerning the importance of user controls in buildings, the present contribution focuses on the reflection of the user control topic in indoor-environmental quality standards. To this end, a selection of common indoor-environmental quality standards and guidelines is reviewed. The results suggest that, whereas some standards and guidelines refer to user control related issues in a general manner, there is a paucity of more specific guidance in methods and means for incorporation of user control considerations in the building design and operation process.

1. Introduction

1.1. Motivational background

Most experts and professionals working in areas relevant to indoor-environmental quality (IEQ) generally agree that building users should be able to adjust indoor-environmental conditions according to their needs and requirements. Foundational theories in human ecology and ecological psychology [1,2] provide general insights with respect to the importance of user controls from both physical and psychological standpoints. Objectively speaking, the dynamics of human organism and activities in and of itself imply the adjustability requirement regarding indoor-environmental conditions. But there are also psychologically relevant processes pertaining

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to the environments' affordances and possibilities for users to recognize and exploit those to their satisfaction. The present contribution addresses the issue of user controls primarily from the perspective of their reflection in IEQ standards. As such, this contribution, not only revisits the existence of information and evidence concerning the importance of user controls in buildings, but also focuses on the question of if and to which extent the subject of user control is reflected in common IEQ standards and guidelines.

1.2. Users' influence with respect to indoor environment

The relationship between the user and the indoor environment (IE) is bidirectional. The IE influences, among others, the users' perception, behavior, and motivation. At the same time, the user constantly affects and interacts with its IE. Such user influences on the IE can be categorized into the ones being unintentional (and to a large extent unavoidable) and those intentional. The former category includes those influences happening due to the user's presence in the room, e.g., the increase in CO_2 concentration or the heat dissipation, both through human metabolic activities. These influences are unavoidable unless the user is leaving the room and will not be of interest for the present contribution. Given the motivation of the present contribution described above, it is the latter category, i.e., intentional influences, which is of interest.

Multiple categories of user actions have been distinguished [3]. Thereby, indoor-environmental adjustments by users are the most relevant for the present contribution and include, among others, the use or adjustment of heating, ventilation and air-conditioning systems, window opening and closing, and light switching actions, all adjustments on building level. All of these affect one or more of the four IEQ-domains. For example, adjusting a heating set point or a thermostat will affect mainly the thermal domain, while opening the window affects primarily the thermal domain and indoor air quality (IAQ). In addition, opening a window can also affect the acoustic conditions, in case of outdoor noise, or the visual domain by increasing daylight penetration. Adjustments on personal level include, among others, clothing level adjustments, change of body posture or the use of earplugs. These actions do not or marginally influence IEQ but have an effect on the perception of the IEQ. For example, adding more clothing layers reduces the heat exchange with the indoor environment and permits feeling comfortable at lower temperatures. As outlined in more detail below, reducing such opportunities for indoor-environmental adjustments on building level or adjustments on personal level may have negative effects on users' satisfaction and health.

1.3. Standards, scientific evidence, and practical applications

To identify those factors in the indoor environment that are relevant to maintaining users' health, comfort, satisfaction, and productivity, we rely on scientific research results in fields such as physiology, medicine, psychology, and ergonomics. Likewise, the question of suitable indoor-environmental condition for human occupancy is primarily a scientific one. The answers to this question facilitate the identification or indoor-environmentally relevant variables as well as the appropriate ranges for these variables. However, most practitioners in the building design and operation are not specialized scientists. Hence, for professionals and stakeholders in the building delivery process, IEQ-related standards and guidelines represent an essential source of information and guidance [4]. IEQ standards in fact typically specify the gamut of quality requirements that are relevant to the user needs and that must be addressed in the process of designing, constructing, and operating buildings [5]. It seems thus reasonable to suggest that standards do in fact play a mediatory role between scientific findings and professional practice. As such, the credibility of (and trust in) standards as reliable sources of guidance in the building planning may be claimed to be directly proportional to the strength of the scientific evidence underlying the requirements and mandates entailed in the standards. Of course, standards have, aside from their informational function, a major role in the procedural and legal aspects of the building delivery and commissioning process. The normative role of standards contributes to the accountability of the design, implementation, and quality assurance process: Both building designs and their actual performance are typically subject to quality assessment procedures, which require, among other things, compliance with IEQ-related mandates. In this context, it appears both relevant and important to investigate if and to what extent user control, which arguably represents a key aspect of building quality, is treated in common IEQ standards.

1.4. Overview of the paper's structure

In order to investigate this query, the paper first outlines the importance of the provision of user controls of indoor-environmental conditions by summarizing principal reasoning and empirical evidence for the significance of user controls, approaches to map, design and implement user controls (Section 2). Furthermore, the paper examines the provision and format of user control issues by performing a systematic review of a number of common IEQ standards (Sections 3 and 4). To this end, the authors developed an assessment matrix for the evaluation of information in the IEQ standards pertaining to five categories (general information, basic parameters, target design and performance variables, evidence, and usability). Finally, the paper presents key findings and observations of the treatment of user controls in IEQ standards and guidelines (Section 5).

2. How critical is the provision of indoor-environmental user controls?

2.1. Definition of terminology

In this paper we use the term user control to describe *human indoor-environmental control* and the means to achieve this we call *user controls*. However, several terminologies have been used to describe actions or means of human indoor-environmental control. Early description of human indoor-environmental control in the context of thermal comfort was called *behavioral thermoregulation* [6], *behavioral and techno-cultural adjustments* [7] and *behavioral adaptation* [8]. Gibson [2] introduced the term *affordance*. Norman, in the context of human-computer interaction, developed the meaning of the term affordances further to describe action possibilities as perceived by a human (*perceived affordance*) [9]. In the context of indoor thermal environment the term *adaptive opportunities* was introduced [10]. *Indoor-environmental affordance* has also been used recently [11]. What a building affords, and which adaptive opportunities occupants have in indoor spaces with regard to the indoor environment is shown in Fig. 1. The intersection of a building's affordances and adaptive opportunities constitutes occupant interfaces (which we call user controls in this paper) and their properties (Fig. 1). How they affect perceived control, hence the amount of personal control experienced, was described in Refs. [12,13].

2.2. Overview on principal reasons and empirical evidence for the significance of user controls

Personal control by user controls is one of the measures to ensure that the occupants experience an appropriate level of perceived control. Literature considering the importance of user control dates back several decades and has been summarized and synthesized in earlier work [3,14–18].

Several works demonstrated positive correlation between the occupants' possibility to control the indoor environment and their health. Boerstra et al. [19] found a negative correlation between the level of perceived control and the prevalence of building related symptoms, based on a re-analysis of the Health Optimisation Protocol for Energy-efficient Buildings data (HOPE) [20]: higher level of perceived control reduces building related symptoms. This confirmed earlier findings from large Sick Building Syndrome Studies as the German ProKlimA study [21] and the White Hall study II [22].

Personal control or an appropriate level of perceived control is fundamental to the adaptive thermal comfort approach [6–8] as demonstrated in numerous field studies [23–25]. From field studies it is known that indoor environments which do not provide opportunities for adaptation or user control tend to receive poor comfort evaluations [26,27].

Several other works demonstrated positive correlation between the occupants' opportunity to control or adjust the indoor environment and their *i)* satisfaction [19,28–34], and *ii)* comfort perception [10,31,35–38].

Based on the HOPE database [20], a significant correlation between perceived control on temperature, ventilation, noise and shading on the one hand, and satisfaction with overall comfort on the other hand was found [19].

Experimental investigation in lab condition was performed by Boerstra et al. [30] in Denmark on 23 people. Participants were subjected to personal or automated control of table fans. A significant number of participants were more satisfied with personal control over temperature, air movement and ventilation than in the case of automated control.

An increase in personal control over indoor environment is positively correlated with perceived, self-assessed performance as several research identified [19,29,36,39–42], though there are also examples of a negative correlation between perceived control and perceived and measured performance [30].

2.3. Concepts, models and factors influencing personal control

In 1990, Paciuk proposed an extended model of thermal comfort and satisfaction with an emphasis on personal control, distinguishing between available control, exercised control, and perceived control [43]. De Dear et al. [23] described, in their adaptive thermal comfort approach, behavioral and psychological feedback loops, which both involve behavioral adjustment and climato-cultural practices and norms shaping thermal comfort perception. Hellwig [12] summarized the available evidence on personal control and provided a conceptual approach for the IEQ context. A simplified representation of the model is shown in Fig. 2. The approach includes considerations from personality and environmental psychology, highlighting the role of personality and built and social environment to the level of personal control perceived. An important point to note is the statement that "satisfaction with the indoor environment occurs not only when 'comfort' is provided but also immediately after a successful control action". Boerstra identified personal control acting as a moderator in the indoor climate - comfort/health/performance relationship [33]. Schweiker and Wagner [31] and Schweiker [38] propose physical interpretation and mathematical descriptions of perceived control on thermal comfort by showing the impact variation of personal control related parameters might have on thermal sensation using the heat balance model by Fanger: personal control modifies thermal comfort and thermal sensation by enabling behavioral adaptation, decreasing stress level, thereby metabolic rate, and interacting with interpretation of perceived thermal loads. Al-Atrash et al. [44] hypothesized and partly

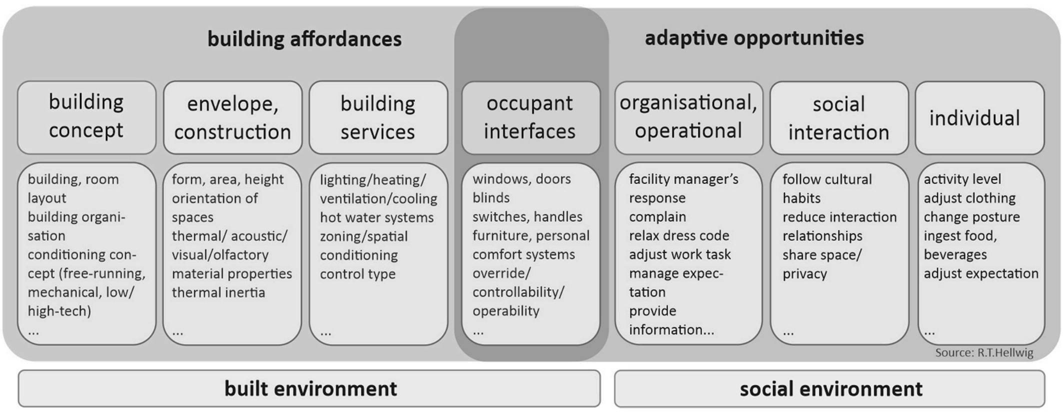

Fig. 1. Building affordances and adaptive opportunities for the indoor environment. The intersection between both constitutes occupant interfaces, described as user controls in the present contribution. Copyright figure: R.T. Hellwig, reprint with permission of the author.

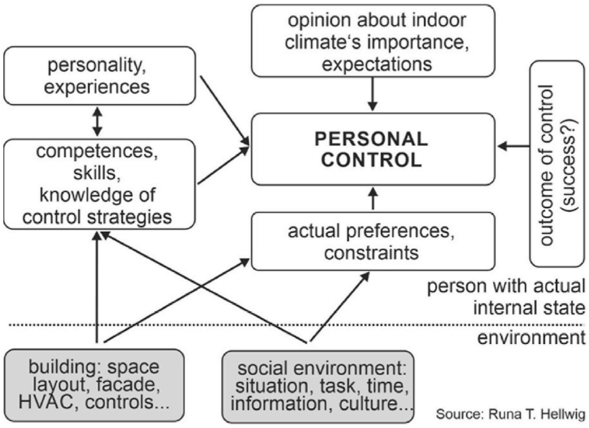

Fig. 2. Simplified representation of the conceptual model of perceived control from Ref. [17], slightly amended. Copyright: R.T. Hellwig, reprint with permission of the author.

proofed the role of conformity to expectation of controls, and its correlation with the level of personal control perceived.

Examples of factors from social environment influencing the level of perceived control are for instance: *i)* the level of privacy or how many people share user controls [29,31,39,45–49]; *ii)* social norms and expectations [15,50,51]; and *iii)* information on available user controls [12]. In the context of the built environment, examples of factors influencing the level of perceived control are: *i)* floor layout, façade, and HVAC systems [27]; *ii)* building's thermal responsiveness [12]; and *iii)* effectiveness of user controls [52,53]. Indoor environment-related self-efficacy [12,54] and indoor-environmental control expectations [44] are influencing factors grounded in the personality of users.

2.4. Approaches to map and certify personal control

Several efforts have been undertaken to find appropriate methods to document user controls in real buildings or to investigate personal control in the field. To this end, Ackerly et al. developed a data collection method [16]. Langevin developed a protocol [55], which helps to identify why or why not occupants use controls. Mahdavi and Berger argued that building control systems can offer various levels of affordance to occupants and thus explored the certification potential of such indoor-environmental affordances [11].

The Dutch guideline ISSO 74 [56] offered in its 2004 version a flowchart serving to identify buildings which provide occupants with control and buildings which do not provide control. In the updated version from 2014 [57] the previous criteria were simplified to the activity level, the presence (or not) of a strict clothing protocol, operable windows and a clearly perceptible mechanical cooling system used. The German directive for governmental buildings under summer conditions [58] adopted the thinking from Ref. [56] and implemented a flowchart which helps to decide - based on the level of control available to the occupants - which thermal comfort model to choose. The sustainability rating and certification scheme of the German government (BNB) and of the commercial German Sustainable Building Council (DGNB) in their version of 2009 [59] included already a classification scheme for user controls though critically commented in Ref. [60], at that time the only sustainability rating scheme including the evaluation of user control. The recent version [61–63] of the rating and certification scheme still involves user control in a revised version and will be analyzed later in this paper.

2.5. Approaches to design and implementation of personal controls

Given the importance of personal controls and hence user controls, it has been demanded that personal control is included as a design goal in standards [12,64,65]. In a framework for adopting adaptive thermal comfort principles in design and operation of buildings, Hellwig et al. [66] suggested to see indoor-environmentally relevant human adaptive responses and actions as a design goal. They later proposed an adaptive opportunities' design process, which supports building designers in adopting the occupants' perspective and supports the interaction with the building users in the design phase [13]. Both framework and design process are part of the guidelines for low energy building design based on the adaptive thermal comfort concept [64]. For personal control systems (PCS), Rawal et al. developed the Guidelines for Personal Comfort Systems in Low Energy Buildings [67].

With regard to how to implement personal control, it is important to identify related obstacles and misleading assumptions [68]. Design decisions, which affect user controls and building affordances were identified, as well as design stages through which information about occupants and user controls needs to be deployed [4]. Furthermore, stakeholder groups were identified whose actions is required to implement user controls effectively [64], including integrated design team (building designers), organizational management of the owner, investor or building user organization, the operators, and the occupants. In addition, their responsibilities and contribution were described [13]: The integrated design team decides on context-adjusted adaptive opportunities (referred to, in this paper, as user controls) and engages with all stakeholders in building operation already in the design process. The organizational management informs the design team about the intended use of the building and the occupants' needs, facilitates the deployment of user controls and informs the occupants about their opportunities to adjust their indoor environment. The operator informs the design, maintains the context-adjusted adaptive opportunities, and prepares a manual for users and operators. The occupants receive the information and make use of the provided adaptive opportunities.

With regard to the operation phase, documentation can be facilitated by using Building Information Modelling (BIM). There have been proposals as to how to implement qualitative information into a BIM system [4]. Hence, user control aspects would be documented such that the related means would remain functional during the operation phase of the building. Such a documentation could also serve as the basis for informing occupants regarding the available adaptive opportunities and the basic functioning of the building.

3. Materials and methods

3.1. Selection process

A selection of standards and guidance documents, known to the authors as potentially relevant to the study, formed the initial basis for analysis. These were technical documents specifying either building automation or controls of building services, the ergonomics and visual interfaces of systems and controls, and the design of natural ventilation systems. This latter (third) type was included due to its relevance to window and vent operation, which are typical types of ventilation-related user control commonly available in buildings. Additional standards were later added to this first selection, identified as potentially relevant by other studies undertaken, by the group of the authors of other review papers [69,70], which also included some of the authors of the present contribution. These previous review papers were concerned with the reasoning and evidence present in standards specifying thermal or air quality in indoor environments. For the purpose of the present review, standards and guidelines that were recognized as having an international standing in relation to their specialist subject were prioritized, and some documents published in languages other than English were also reviewed (by the native speakers among the authors of this paper).

A total number of 29 standards and guidance documents with content potentially relevant to the subject of user controls and its importance were reviewed. In order to carry out a systematic review effort, the authors developed an assessment matrix that provided the basis for the assessment of the selected documents.

3.2. Assessment matrix

The assessment matrix includes five main categories of information: *i)* general (bibliographic) information, *ii)* basic parameters, *iii)* target design and performance variables, *iv)* evidence, and *v)* usability. These categories were decided and specified upon in-depth discussion and exchange among the group of authors.

Table 1 gives an overview of the included instances in each of the five categories. Category 1 to 4 are assessed by providing descriptive information, whereas category 5 is assessed using a 4-point scale (fully agree/somewhat agree/somewhat disagree/strongly disagree). The subjective evaluation of category 5 was conducted by the authors' group in order to obtain an initial impression regarding the usability of the standard, as potential stakeholders might perceive. Thereby, the effectiveness attribute addressed mostly clarity of the stated criteria and their up-to-dateness, efficiency was framed in view of ease of navigation through the standard and the accessibility of its language and material, and finally satisfaction pertained to the standard's capacity to signal objectivity and to motivate toward developing creative solutions [69,70]. Note that, due to the small sample of query responses, the evaluation of this category is not suggested to be either conclusive or definitive.

4. Are user control issues reflected in existing IEQ standards?

4.1. General observations

Table 2 provides an overview on how user control is reflected in the reviewed documents. In total, 29 documents are reviewed, including six international, eight European, and fifteen national (e.g., Germany, UK, US, Switzerland, Canada) documents. The scope of the documents in terms of building types encompasses residential, non-residential, educational, and commercial buildings.

With regard to the main thematic foci, the majority of the assessed documents concerns IEQ domains, such as thermal, IAQ, visual, and acoustic domain. Thereby, the majority (13 documents) focuses on a combination of 2 or more IEQ domains. Some documents focus on one specific domain, including the thermal domain (7 documents), the visual domain (2 documents), and IAQ (2 documents). Moreover, 3 standards address building automation, and 2 standards concern ergonomics.

About one third of the reviewed documents (31%) do not refer to user controls. Few documents (14%) directly address user controls and some other documents (55%) mention user control in general terms.

In a further step, the reviewed documents that are identified to be relevant to user control and generally or directly refer to user control are further assessed (see Table 3). Thereby, a total of 20 documents are identified and analyzed in more detail. These

Table 1
Structure of the assessment matrix and the entailed information categories.

1. General (bibliographic) information	2. Basic parameter	3. Target design and performance variables	4. Evidence	5. Usability
● Abbreviation ● Full title ● Publication year	● Scope ● Building types ● Geographic coverage ● Thematic foci	● Design variables ● Design variables values ● Design classes ● Performance variables ● Performance variables values ● Performance classes	● General reference to standards ● Direct reference to standards ● General reference to technical literature ● Direct reference to technical literature	● Effectiveness ● Efficiency ● Satisfaction

Table 2
Reflectance of user controls in reviewed documents.

Document	Title	Geographic coverage	Year	Main foci	Relevance to user control
ISO 6385 [71]	Ergonomics principles in the design of work systems	International	2016	IAQ, thermal, visual	Generally mentioned
ISO 9241–161 [72]	Ergonomics of human-system interaction: Guidance on visual user-interface elements	International	2016	Ergonomic	None
ISO 9241–210 [73]	Ergonomics of human-system interaction: Human-centred design for interactive systems	International	2019	Ergonomic	None
ISO 17772–1/2 [74,75]	Energy performance of buildings — Overall energy performance assessment procedures — Part 2: Guideline for using indoor environmental input parameters for the design and assessment of energy performance of buildings	International	2018	IAQ, thermal, visual, acoustic	Generally mentioned
WELL v2 [76]	WELL v2™	International	2020	IAQ, thermal, visual, acoustic	Generally mentioned
EN 12098–1 [77]- EN 12098–5 [78]	Control of heating systems	Europe	2005	Thermal	None
EN 15193 [79]	Energy performance of buildings – Energy requirements for lighting – Part 1: Specifications, Module M9	Europe	2017	Visual	Generally mentioned
EN 15232–1:2017 [80]	Energy Performance of Buildings – Energy performance of buildings – Part 1: Impact of Building Automation, controls and Building management – Modules M 10–4,5,6,7,8,9,10	Europe	2017	Building automation effect on energy performance	Generally mentioned
EN 15500–1:2017 [81]	Energy Performance of Buildings – Control for heating, ventilating and air conditioning applications – Part 1: Electronic individual zone control equipment – Modules M 3–5, M 4–5, M5-5	Europe	2017	Thermal, IAQ	Generally mentioned
EN 16798–1/2 [82,83]	Energy performance of buildings – Ventilation for buildings – Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics – Module M1-6	Europe	2019	IAQ, thermal, visual, acoustic	Generally mentioned
EN ISO 16484–3 [84]	Building automation and control systems (BACS) – Part 3: Functions	Europe	2007	Building automation	None
NR24-28/2015E:2015 [85]	National building code of Canada	Canada	2015	Thermal, IAQ	Generally mentioned
ASR 3.5 [86]	Technische Regeln für Arbeitsstätten – Raumtemperatur – ASR A3.5	Germany	2010	Thermal	Directly mentioned
BNB_BN_2015_316 [62]	BNB Büro- und Verwaltungsgebäude: Einflussnahmemöglichkeiten durch Nutzer[a]	Germany	2015	IAQ, thermal, visual	Directly mentioned
BNB_UN_2017_316 [63]	BNB Unterrichtsgebäude Einflussnahmemöglichkeiten durch Nutzer[b]	Germany	2017	IAQ, thermal, visual	Directly mentioned
SIA 2024:2015 [87]	Raumnutzungsdaten für die Energie- und Gebäudetechnik	Switzerland	2015	Building automation	None
BS 5925 [88]	Ventilation principles and designing for natural ventilation	UK	1991	Thermal, IAQ	Generally mentioned
CIBSE Guide A 2021 [89]	Environmental design CIBSE Guide A	UK	2021	IAQ, thermal, visual, acoustic	Directly mentioned
CIBSE TM 40 [90]	Health and wellbeing in building services	UK	2020	IAQ, thermal, visual, acoustic	Generally mentioned
PD CEN ISO/TR 52127–1:2021 [91]	Energy performance of buildings – Building automation, controls and building management	UK	2021	Thermal	None
PD CEN ISO/TR 52127–2:2021 [92]	Energy performance of buildings – Building automation, controls and building management	UK	2021	Thermal	None
ANSI/ASHRAE Standard 55 [93]	Thermal Environmental Conditions for Human Occupancy	US	2013	Thermal	Generally mentioned
ANSI/ASHRAE Standard 62.1–2019 [94]	Ventilation for Acceptable Indoor Air Quality	US	2019	IAQ	Generally mentioned
ANSI/ASHRAE Standard 62.2–2019 [95]	Ventilation and Acceptable Indoor Air Quality in Residential Buildings	US	2019	IAQ	Generally mentioned
ASHRAE Guideline 13–2015 [96]	Specifying Building Automation Systems	US	2015	Thermal	None
ASHRAE Standard 90.1–2019 (Section 9) [97]	Energy Standard for Buildings Except Low-Rise Residential Buildings; Section 9 - Lighting	US	2019	Visual	Generally mentioned

[a] BNB Office and Administration Buildings, Quality criterium Opportunities for adjustments by users.
[b] BNB Educational Buildings, Quality criterium Opportunities for adjustments by users.

documents include 14 standards, 4 rating/certification schemes, 1 building code, and 1 technical memorandum. Table 3 provides an overview of the included evidence (general or specific reference to other documents or technical literature), the target control medium, and the type of requirement in the assessed documents.

Half of the reviewed documents (50%) do not include either specific or general references to standards that are relevant to user

Table 3
Description of target control medium, type of requirement, and evidence.

Document	Type	References to standard (general/specific)	References to technical literature (general/specific)	Target control medium	Type of requirement/ranking/evaluation
ANSI/ASHRAE Standard 55 [93]	Standard	YES/NO	YES/NO	Window	General/qualitative
ANSI/ASHRAE Standard 62.1–2019 [94]	Standard	NO/NO	NO/NO	Ventilation system	General/qualitative
ANSI/ASHRAE Standard 62.2–2019 [95]	Standard	NO/NO	NO/NO	Ventilation system	General/qualitative
ASHRAE Standard 90.1–2019 (Section 9) [97]	Standard	NO/NO	NO/NO	Lighting	Lighting control functions per space type with min/max values/allowances
ASR 3.5 [86]	Standard	NO/NO	YES/NO	Temperature (warm season)	General/qualitative recommendations for actions/adjustments
BNB_BN_ 2015_316 [62]	Rating/certification scheme	NO/NO	NO/NO	8 categories of user controls: ventilation, sun/glare shading, temperature, light (daylight and artificial), usability/user friendliness	Categories/classes (e.g., workplace level/room level/zone level/no control): 3 to 4 classes per control type; points for each class
BNB_UN_ 2017_316 [63]	Rating/certification scheme	NO/NO	NO/NO	9 categories of user control: ventilation, sun/glare shading, temperature, daylight, artificial light, user friendliness, usability of the HVAC system	Categories/classes (e.g., workplace level/room level/zone level/no control): 2 to 4 classes per control type; points for each class
BS 5925 [88]	Standard	NO/YES	NO/YES	Natural and mechanical ventilation	General/qualitative
CIBSE Guide A 2021 [89]	Rating/certification scheme	YES/YES	YES/YES	Temperature, ventilation	General/qualitative
CIBSE TM 40 [90]	Technical memoranda	YES/YES	YES/YES	Temperature, ventilation, lighting	General/qualitative
EN 15193 [79]	Standard	NO/NO	NO/NO	Lighting	General/qualitative
EN 15232–1:2017 [80]	Standard	NO/NO	NO/NO	Lighting	User control is rated with low energy efficiency; full automation OFF manual ON lighting solutions are rated energy efficient
EN 15500–1:2017 [81]	Standard	YES/YES	NO/NO	HVAC	General/qualitative
EN 16798–1/2 [82,83]	Standard	YES/NO	YES/NO	Window	General/qualitative
ISO 17772–1/2 [74,75]	Standard	YES/NO	YES/NO	Window, solar shading, fans, shutters, night ventilation	General/qualitative
ISO 6385 [71]	Standard	YES/NO	NO/NO	Selection, design, and position of user controls in the context of work equipment and interfaces	General/qualitative
NR24-28/2015E:2015 [85]	Building code	NO/NO	NO/NO	Accessibility, ventilation, temperature	General/qualitative
WELL v2 [76]	Rating/certification scheme	NO/NO	YES/YES	Shading, lighting, temperature, window	Point-based system

control. In a few cases (4) specific references are included to other standards relevant to the subject of user control. Likewise, half of the reviewed documents (50%) do not include specific or general references to technical documents in the context of user control requirements. In some cases (4), the authors could identify relevant specific technical documents. This identified literature is further assessed and reviewed in the next step of the analysis.

The reviewed documents include different target control media. Some instances focus on one control medium, such as window operation, lighting control or ventilation control [74,75,79,81,82,88,94,95,97], whereas other instances address multiple types of user control [62,63,71,76,85,89,90].

The importance of user control in the context of the thermal environment in general [62,63] and the adaptive thermal comfort in particular [82,89,90] is mentioned in some of the reviewed documents, albeit in a general manner. For instance, CIBSE Guide A states that providing the users with individual control over their thermal environment increases “satisfaction and productivity in buildings” [89]. CIBSE TM40 [90] suggests that occupants’ satisfaction improves if IEQ controls are provided. It specifically states that a uniformly tempered environment "cannot be comfortable to all individuals and providing the choice itself supports increased user tolerance of and satisfaction with the environment". Furthermore, one reviewed document states that the perceived comfort at workplace correlates with the occupants' satisfaction and energy use [62]. Some of the reviewed documents do not include references for these assertions [62,63,82]. Other documents, however, do include direct links to literature, which support the above described statements [89,90].

Window operation is referred to in some of the reviewed standards [62,63,76,82,88–90] in terms of its utility in providing access to ventilation, adjustment of temperature, and view to outside. For instance, CIBSE Guide A states that "with effective personal controls thermal discomfort can be almost eliminated" [89].

Ventilation control is mentioned in some of the reviewed documents in terms of comparing natural and mechanical ventilation [90,94,95]. For instance, ASHRAE Standard 62.1 emphasizes the requirement for manual/automatic controls for maintaining suitable levels of outdoor air intake flow [94]. CIBSE TM40 refers to the issue of providing feedback to the building users in the context of mechanical and natural ventilation control. It states that providing "controls that demonstrate a response to occupants […] does not mean that actual conditions should change quickly, but the users should know their action has been noticed and will be acted upon" [90].

Lighting control is referred to in some of the reviewed documents in the context of increased energy efficiency or access to blinds [79,89,97].

Some of the reviewed standards focus on the specific positioning, selection, and operability of user controls in work environments [71] and dwellings [90,95]. For instance, CIBSE TM 40 recommends, as a design strategy, to "remove unnecessary complexity by providing controls that are simple and well-labelled. These should be intuitive, especially in domestic buildings, and clearly explained in the operation & maintenance manuals and building user guide." [90].

4.2. Usability evaluation

The selected documents were subjectively evaluated by the authors with regard to their effectiveness, efficiency, and satisfaction, as illustrated in Fig. 3. Overall, the standards were classified on the positive side as being generally effective, with clear statements of intended design criteria and encouraged flexibility for identifying creative solutions through their entailed requirements. Mostly, they were also found to be efficient in terms of ease of navigation, accessibility, and ease of compliance control, and satisfactory with respect to their transparent agenda and motivational attributes that inspire development of better solutions. Despite the relatively positive evaluation, it is worth noting that there is not a complete consensus regarding the usability of the reviewed documents. This is in part due to certain fuzziness in the criteria and the small number of evaluating experts. Nonetheless, the results (shown in Fig. 3) do appear to indicate that there is room for further improvements in most of the standards to increase their applicability and clarity regarding definitions of target design and performance variables.

4.3. Specific observations to individual standards

In one of the reviewed documents (BNB_BN_2015_316), a dedicated category named "user friendliness" is included, which gives points for the usability of the respective user control element (including comprehensibility and usefulness of the user control elements) [62].

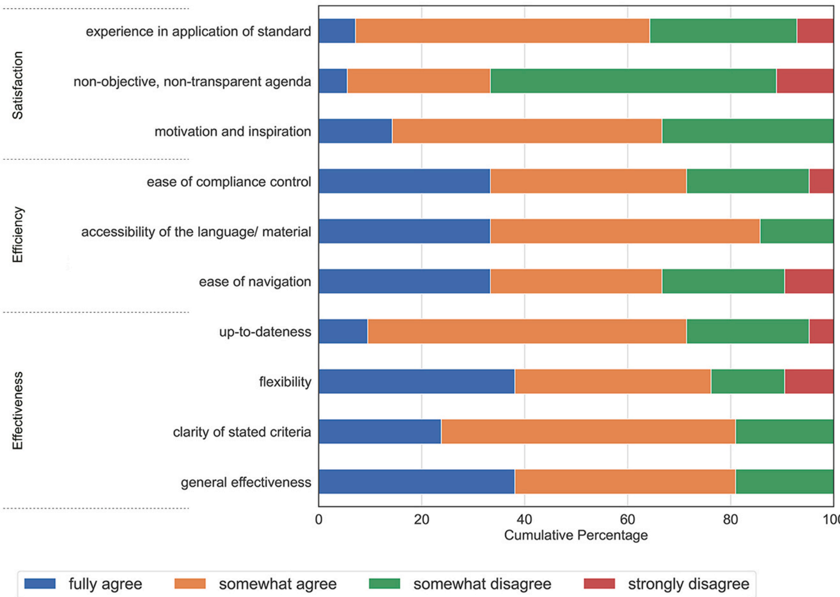

Fig. 3. Evaluation of the reviewed standards' usability by the authors.

BNB_UN 2017_316 includes a category for the usability of the HVAC system in which points can be given for attempts to explain to occupants the HVAC system (including criteria such as age-appropriate, target-orientated, visualization and explanation of the concept) [63].

In the context of designing for indoor air quality and ventilation, two standards (ISO 17772–2, DIN EN 16798–1) state that it "shall be possible to access operable elements in the building envelope (e.g., windows, ventilation flaps, skylights) provided for the ventilation to allow the building occupants to make ventilation and to provide contact to the outside" [74,82].

Window operation in order to adjust thermal conditions is for instance also included in the EN 16798-1 standard by stating: "occupants can freely adapt their clothing to the indoor and/or outdoor thermal conditions, where thermal conditions are regulated primarily by the occupants through opening and closing of openings (windows) in the building envelope" [82]. The ISO 17772-2 standard states that "occupants can have additional options for personal control over the indoor environment such as solar shading, fans, shutters, night ventilation, etc." [74].

Furthermore, CIBSE Guide A emphasizes the importance of individual user control to increase thermal comfort. In this context, it states that "individual control is more effective in promoting comfort than is group-control". Moreover, it highlights the health-related aspects of user controls, noting the role of "providing personal controls to avoid Sick Building Syndrome (SBS) risks" [89]. CIBSE TM40 also refers to "a lack of personal control" in relation to the SBS [90].

5. Conclusion

The importance of user controls toward the provision of adequate IEQ conditions in buildings appears to be uncontroversial. However, in practice, user control appears to be met with some reservation by practitioners [68]. Overall, it can be summarized that *i)* comfort requirements of the population of occupants in a building display a typically wide distribution; *ii)* even a single occupant's preferences can dynamically change over time; and that *iii)* availability of user control has positive effects on health, comfort, satisfaction, and performance and is beneficial toward the above-mentioned requirements. This contribution started from the assumption that user control can be more effectively implemented if adequate guidance is provided and minimum requirements are embedded in related standards. A relevant question thereby is, if this generally agreed-upon postulate is reflected in the resources and documents that are meant to support building design and operation professionals in their work. Consequently, a key objective of the present review effort was to explore if and to which extent user control of indoor-environmental conditions is currently addressed in common IEQ standards. This review was not intended to be exhaustive. Nonetheless, the assessment of the selected 29 standards and guidelines (with both single-domain and multi-domain IEQ agendas) could provide some insights with regard to this matter. Thereby, the major findings can be summarized as follows.

- A large part of the assessed standards and guidelines that refer to user control treat this topic in a rather general (descriptive and qualitative) manner (75%). For instance, many standards mention the contribution of personal control to increase satisfaction, productivity, and well-being of occupants. Some of the reviewed standards specifically refer to the provision of user control in the context of health-related aspects, such as the Sick Building Syndrome (SBS) [89,90]. However, such assertions appear insufficiently specific. As such, more detailed and specific requirements in IEQ standards or guidelines regarding user control issues in both residential and non-residential settings could help recognize their importance and integration in building design and operation.
- One key observation pertaining to those standards and guidelines that do address user controls, was the scarcity of provided scientific evidence for the significance of user control requirements. Half of the reviewed documents do not include references either to other standards (50%) or to technical literature (50%) in order to substantiate their treatment of the subject of user controls.
- A couple of the reviewed certification schemes [62,63] include specific criteria with regard to user friendliness and the usability of the HVAC system. This feature deserves recognition, as it displays an effort to actively consider the interactions between occupants and building systems interfaces.
- A further observation concerns the issue of providing feedback to occupants. For instance, one standard highlights the importance of feedback provision subsequent to the occupants' control actions [90]. As suggested in literature, providing feedback following occupants' control actions could be positively stimulating and hence improve the occupant's satisfaction: "Feedback can enable the occupants to learn, understand, interpret, motivate, and/or interact in and with buildings and information can be disseminated visually, auditorily, and/or haptically, depending on contextual need and available technology. Feedback plays a crucial role in occupants' perception, interaction, and engagement in buildings for sustainable adaptive strategies – particularly for slow responding (e.g., thermal) systems." [98].

Generally speaking, both the operation of building control devices by the users and the provision of feedback to the users necessitate the careful design of the interfaces of these devices. Developments in this area could benefit from foundational work involving occupant-centric theories of buildings' indoor-environmental control systems and their user interfaces [99]. As indicated in previous research, user interfaces can influence buildings' energy use and occupants' comfort both positively and negatively. It has been suggested that dealing with personal control can be a challenge for building designers, managers, and controls manufacturers [17,18,100,101] and further research is needed to explore this issue in more depth.

Although the principal importance of user controls towards health, comfort, and performance is already mentioned in the standards, it is necessary to further raise awareness – in the minds of all involved stakeholders – concerning the significance of offering the occupants adequate possibilities to influence their immediate environments. This could be facilitated by the integration of design processes targeting user control and the means for this control, as proposed in the adaptive opportunities design process [13]. The primary component of such an overall design approach towards user control is the implementation of user controls as adaptive opportunities a building affords to their users that are well designed, well-integrated with the building and its environmental control systems (e.g., HVAC, lighting), intuitive, and easy to use. Moreover, and no less important, occupants must be given the opportunity to learn about the existence and specific features and capabilities of the user controls in the buildings they live and work in, so that they could operate control devices in a convenient, competent, and responsible manner, that is energy-efficient and resource-conscious.

Author statement

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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.

Data availability

No data was used for the research described in the article.

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