Evaluation potential of indoor environments' ecological valency

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ABSTRACT

Buildings typically are expected to provide their inhabitants with the opportunity to influence the indoor environment using various control devices. These include, for example, windows, luminaires, radiators, and shading elements. The quality and adequacy of the indoor environment is thus dependent on the availability and effectiveness of such devices. There is arguably a lack of generally agreed-upon evaluation procedures for this aspect of buildings' indoor environment, namely its controllability by building users, or – in the terminology of Human Ecology – its "ecological valency". In this context, the present contribution explores the possibility to specify buildings' ecological valency in a systematic and reproducible manner. Toward this end, first the theoretical foundation for this purpose is identified and previous related efforts are briefly reviewed. Subsequently, a specific attempt for an ecological valency evaluation method is presented. As part of this approach, five main categories of control devices are documented in various rooms of a building. They include windows, shading, lights, heating and cooling systems. Whereas, the first component of this method deals with the basic availability of these control devices and elements, the second part looks at their spatial distribution, effectiveness (both objective and subjective), interface quality (to support user interaction), and ecological quality. The presented evaluation method is tested for six different rooms of an office area in an educational building in Vienna, Austria. Some thirty participants independently evaluated this area based on the proposed method and associated protocol. The results point to high degree of congruence between the evaluation results of different participants while judging the principle availability and typology of the control devices. Higher variation was observed in the evaluation of the quality of devices and their interfaces. As a whole, the results suggest that methods based on similar premises proposed in the present contribution may indeed provide a realistic opportunity to extend building performance evaluation procedures beyond energy and cost criteria to cover aspects pertaining to user control and satisfaction.

KEYWORDS

Indoor environment, building interfaces, ecological valency

1 INTRODUCTION

Buildings typically provide their inhabitants with the opportunity to influence the indoor environment using various control devices such as windows, luminaires, radiators, and blinds. The quality of the indoor environment is thus dependent on the availability and effectiveness of such devices. There is a lack of evaluation procedures for this aspect of buildings' indoor environment, namely its controllability by building users, or, its "Ecological Valency" (EV), as it is referred to in Human Ecology. The present paper explores the possibility to specify buildings' ecological valency in a systematic fashion. Toward this end, we first discuss needed theoretical foundations. Subsequently, a specific protocol for EV evaluation is presented. Thereby, five main categories of control devices are documented in different rooms of a building. They include windows, shading, lights, heating and cooling systems. Whereas, the first component of this method deals with the basic availability of these control devices and elements, the second part looks at their spatial distribution, effectiveness (both objective and subjective), interface quality (to support user interaction), and ecological quality (Mahdavi, 2019; Mahdavi and Berger, 2019).

The protocol was tested for six rooms of an office area in an educational building. Thirty participants evaluated these rooms using the mentioned protocol. The purpose of this exercise was not only to conduct a preliminary test of the usability of the method itself, but also to document the degree to which the different evaluation results could diverge when the same room is evaluated by different participants. While some of the participants work in this office area, others were not familiar with it before conducting the evaluation. Hence, aside from the overall consistency of the results, the difference between the results from the occupants and the visitors could be examined as well. The outcome of this experiment but also the feedback from the participants are presented. The results suggest that methods based on similar premises proposed in the present contribution may indeed provide a realistic opportunity to extend building performance evaluation procedures beyond energy and cost criteria to cover aspects pertaining to user control and satisfaction.

2 THEORETICAL FOUNDATION

2.1 Introductory remark

Our EV evaluation approach is informed by prior work in the Vienna School of Human Ecology and the Ecological Psychology. The following sections (2.2 and 2.3) provide a brief description of these sources.

2.2 Human Ecology and the concept of Ecological Valency

Human ecology is a promising instance of a theory, that can guide the efforts toward indoor environmental quality assessment. Human ecology may be simply defined as the ecology of the Homo sapiens. There are many traditions and associated approaches to human ecology. From the standpoint of the "Vienna School of Human Ecology" (Knötig, 1992a; Knötig, 1992b; Mahdavi, 2016; Mahdavi, 1996a), the construction and operation of buildings can be viewed as an integral part of the totality of largely regulatory operations initiated by human beings as they interact with their surrounding world. Human ecology offers a useful way of thinking about these interactions via a number of concepts, including the following pair: *i)* the human beings' ecological potency (EP); *ii)* the surrounding world's ecological valency (EV) (Knötig, 1992a; Mahdavi, 1996b). Thereby, EP refers to people's capability to cope and interact with the surrounding world. EV, on the other hand, denotes the totality of that surrounding world's characteristics (resources, opportunities, challenges, risks, hazards) as it relates to people's ecological potency. The concept of ecological valency was essentially dealt with in (Uexküll, 1920) and is also akin to Gibson's affordance (Gibson, 1977; Gibson, 1979).
Given this conceptual framework, we can describe the main consideration in human ecology as the complex and dynamic relationships between the ecological potency of human beings and the ecological valency of their surrounding world. Human ecologically speaking, buildings are constructed and maintained with the intention to favourably influence the relationship between people's ecological potency and the ecological valency of their surrounding world.

2.3 Ecological psychology and the concept of affordance

The interactions between people and their surrounding environment has been a central theme in cognitive and environmental psychology. An influential line of inquiry in this area goes back to the psychologist Gibson in general and his concept of "affordance" in particular (Gibson, 1977). In Gibson's diction, "affordances of the environment are what it offers the animal, what it provides or furnishes" (Gibson, 1979). Affordance, as Gibson defines it, is not dependent of a specific individual's recognition of it. But it can be recognized by individuals according to their needs. Moreover, perceiving affordances is connected with initiating actions. As such, people tend to intervene in their surroundings and modify affordances, such that they better match their needs. The conceptual background of Gibson's work display similarities to views formulated earlier by Uexküll (Uexküll, 1920). However, the latter does not postulate the existence of affordances independent of their representations ("Umwelt"). The concept of affordance has been used in other fields such as human-computer-interaction and industrial design (Norman, 2013). Hence, it can be also applied to environmental and architectural domains. Thereby, building design decisions and actual interventions (including control actions) in indoor environments could be suggested to enhance the respective repertoire of affordances.

3 A GENERAL FRAMEWORK FOR OPERATIONALIZATION OF ECOLOGICAL VALENCY [EV]

Given the preceding theoretical foundations, the problem of building quality assessment regarding inhabitants' control opportunities in indoor environments can be suggested to involve multiple challenges. First, how are we to simultaneously address the variance of inhabitants' ecological potency while we attempt to assess indoor environments' EV? Conventional comfort standards typically consider population variance in comfort requirements to a certain – albeit basic – degree, for instance via consideration of different building typologies (e.g., hospitals, schools, offices) and space use categories (e.g., operations room, corridor, lobby).

However, a more consequential coverage of the diversity of inhabitants' EP would be desirable, as indoor environment's EV should ideally accommodate people's diverse spectrum of ecological potencies. Nevertheless, we can at least partially justify the present contribution's concentration on EV and its operationalization with the following argument: Improving an environment's EV is associated with its capacity to offer a flexible range of conditions. Enrichment of EV is thus likely to benefit all occupants, irrespective of their diversity of their needs and capabilities.

To further pursue the operationalization potential of the EV concept, it may be useful to agree upon an adequate unit of observation. Assuming a number of background factors such as the climatic context and the building type, individual spaces (rooms) in a target building may be considered to be proper candidates for determination of EV levels (see figure 1). Even though the definition of discrete rooms and their function is not straightforward in all cases, most professionals and occupants have a fairly clear idea of the meaning of the concept. Specifically, maintaining desirable indoor environmental conditions is frequently practiced at the room level. Given rooms as units of observation, we can further reflect on various aspects (or dimensions) of the EV. In other words, we can discuss the conceptual space of EV (see figure 1).

Hereby, a natural starting point would be those properties of the indoor environment whose dynamic adjustability by inhabitants is desirable/necessary. For the purpose of the present discussion, consider variables pertaining to: *i)* hygro-thermal environment (temperature humidity), *ii)* air quality (fresh air volume flow), *iii)* visual environment (daylight, electrical lighting).

In a first approximation, the problem of EV characterization (for instance, in terms of an "EV-Index") may be reduced to the availability and attributes of devices that enable inhabitants to control the relevant environmental variables. The said devices typically facilitate the modulation of mass and energy supplied to (or extracted from) a space (see figure 2). They may also change the distribution and composition of mass and energy distribution in the indoor environment. For instance, as a control device, a window can modulate the magnitude of fresh air volume flow into a room and influence indoor environmental variables such as air temperature and humidity. It can also influence the concentration of pollutants and thus the air quality. A shading device such as an external blind can modulate the magnitude of transmitted solar radiation and daylight, thus influencing indoor environmental conditions in view of the temporal and spatial distribution of illuminance and luminance levels.

Control devices in a space can be thought of the constituents of its EV. Operationalization of EV must thus involve the appraisal of the availability and quality of these devices. Different criteria may be take into consideration toward quality evaluation of control devices and their interfaces. A number of such criteria are suggest below, formulated in terms of five basic questions (see figure 3). Note that they are not claimed to be either the only or the most conclusive criteria:

i. What is the spatial resolution level of the target zones of the control device? Can users control the state of their immediate surroundings?
ii. What is the degree of the objective effectiveness of the control device, i.e., can it fulfil, in a timely and sufficient manner, the intended task?
iii. Can the operation of the device be considered efficient in the sense of energy use and environmental impact?
iv. Can the device be deployed in a convenient and intuitive manner, or, in other words, does it come with an adequate user interface?
v. What is the degree of the subjective effectiveness of the control device, i.e., do the users have the impression that it satisfactorily performs the intended functionality?

The previous discussion suggests the following path to the operationalization of the indoor-environmental EV of a specific built space. For each domain of indoor climate (i.e., thermal, visual, air quality), an integral function over all available devices in that domain is derived, whereby weights for the aforementioned quality criteria (spatial distribution, objective effectiveness, ecological quality, user interface quality, subjective effectiveness) are assigned. Subsequently, another weighting function is needed to integrate EV indices of different domains. Following the above path involves a number of challenges. However, the biggest challenge might not be so much the formulation of a general mathematical formalism, e.g., a set of equations to calculate numeric values of the EV index (EVI). Rather, the main problem lies in the attribution of numeric values (or points) not only to the device criteria variables, but also to the weighting factors needed to arrive at integrated numeric values for a practically applicable general EVI. In fact, weights are not only needed to integrate over EVI values of different devices in a specific space, but also to integrate EVI values of different spaces in a building. This means that weighting factors would be required for integration of device level EVI values (EVI_D) into space level values (EVI_S), and space level values into building level values (EVI_B). To illustrate this challenge, consider the derivation of EVI for one device (EVI_{Di}) out of *n* devices in one space (S_j) out of *k* spaces in a building (B). Assuming this device can obtain, for each quality criterion (e.g., C1 to C5), a certain number of points (e.g., 0 to 10) and treating these points with respective weights (W_{C1} to W_{C5} totalling to 1), we obtain:

$$EVI_{Di} = EVI_{C1}.W_{C1} + EVI_{C2}.W_{C2} + \ldots + EVI_{C5}.W_{C5}$$

To further derive the EV of the space Sj, a weighted sum of individual devices in this space must be calculated:

$$EVI_{Sj} = EVI_{D1}.W_{D1} + EVI_{D2}.W_{D2} + \ldots + EVI_{Dn}.W_{Dn}$$

Finally, the building's EV index (EVI_B) would have to be derived from the weighted sum of the EV indices of all building's spaces:

$$EVI_B = EVI_{S1}.W_{S1} + EVI_{S2}.W_{S2} + \ldots + EVI_{Sk}.W_{Sk}$$

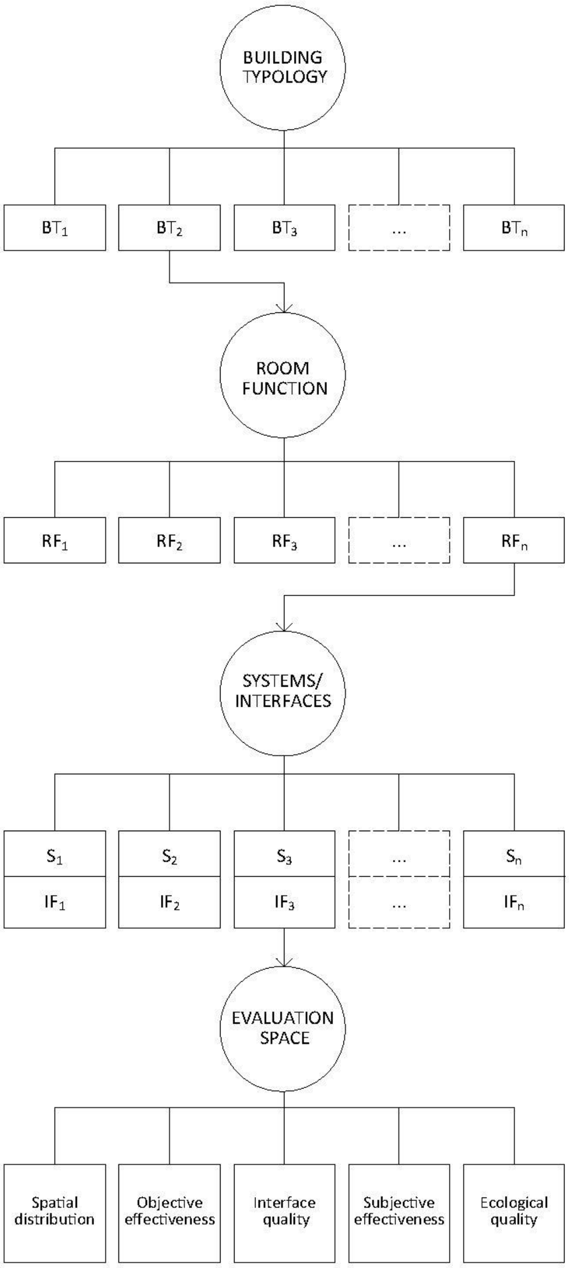

Figure 1: Illustration of the structure of a potential building EV certification scheme. Starting from typological classification of buildings and functional classification of spaces, the latter are identified as the appropriate units of observation for control device benchmarking in multiple domains. Devices are suggested to be assessed according to five evaluation criteria

DEVICES	Radiative energy modulation	Lighting modulation	Convective energy modulation	Air flow modulation	Humidity control
window	○	○	○	✓	○
exterior shades	✓	○	—	—	—
interior shades	○	✓	—	—	—
radiator	✓	—	○	—	—
radiant ceiling	✓	—	○	—	—
floor heating	✓	—	○	—	—
air diffusers	—	—	✓	✓	✓
humidifier	—	—	—	—	✓
illumination	○	✓	—	—	—
task lighting	○	✓	—	—	—
fan	—	—	—	✓	—
desk fan	—	—	—	✓	—

Figure 2: An illustrative taxonomy of buildings' control devices together with associated mechanisms (processes) they employ to influence indoor environmental conditions. "✓" stands for the main process mode, "○" stands for the secondary process mode (or side effect), and "–" for no impact

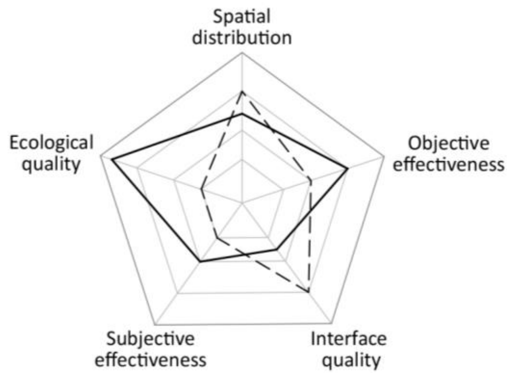

Figure 3: A polar diagram with illustrative evaluation results of environmental control devices (two domains) in a space in terms of five evaluation criteria (see text)

There are of course inherent complexities involved in the process of arriving at weighting factors pertaining to evaluation criteria of individual devices (i.e., W_{C1} to W_{C5}), consideration of multiple devices in a space (i.e., W_{D1} to W_{Dn}), and aggregation over multiple spaces (i.e., W_{S1} to W_{Sk}). As an alternative to a detailed and conceptually rigorous approach to the computation of numeric EVI values, one might consider the utilization of a kind of point-based rating system, similar to those deployed in common building quality rating and certification systems. Presumably, the availability, number, zonal distribution, objective and subjective effectiveness, user interface quality, and environmental efficiency could be captured via a simplified procedure, whereby (weighted) points would be assigned to each item and accumulated to arrive at overall scores or rankings. Such an approach may involve some benefits in terms of practical applicability. To further explore this possibility, we translated the above overall framework into a simplified protocol for a preliminary EV assessment. The next section of this paper describes this protocol and the results of its exploratory deployment in terms of a case study of an office area.

4 A PILOT STUDY

As previously mentioned, a preliminary EV assessment protocol was developed involving multiple criteria and using a point-assignment systems. To illustrate the main features of this method, consider its application to a specific room in a specific building as a case in point, for which the EVI is derived. EVI values are obtained for all rooms of the building, they could be aggregated in terms of a unified EVI value for the entire building as means of benchmarking and comparison with other buildings. The protocol for obtaining a room's EVI focuses on those features that facilitate inhabitants' interaction with the building's environmental control systems. Specifically, such features entail envelope components and technical systems such as windows, blinds, luminaires, as well as devices for heating, cooling, and ventilation controls. Thereby, following a standardised scheme, points can be assigned to the available devices and their respective basic functionalities. In the next step, quality, effectiveness, and performance aspects of these elements are evaluated with regard to the aforementioned five fundamental assessment criteria, namely: *i)* Spatial distribution, *ii)* Objective effectiveness, *iii)* Interface quality, *iv)* Subjective effectiveness, *v)* Ecological quality.

The devices are evaluated by assigning points in these five categories. In the pilot implementation of the methodology, performance evaluation of devices is suggested to involve a distinction in terms of the three basic categories of good, acceptable, and poor. Points can be defined for these three possibilities. Additional weighting factors can be included as well. They can be used if some of the evaluated devices can be seen as more important than others (i.e., have a greater influence on the indoor environmental conditions). The EVI of a room is derived via aggregating the individual devices' points. As mentioned before, to obtain an EVI for an overall building, the EVI of each room are aggregated. In this case too, weighting factors may be applied. Thereby, relevant weighting criteria could include, for instance, the areas of the room or the number of occupants. The general scheme of this evaluation method is illustrated in figure 4 (for a specific room). This structure can be supplemented depending on further aspects such as the building type, the climatic context, and the relevant attributes of the population of the building users. The figure shows, in generic form, the aforementioned two evaluation steps. Whereas the first step (table's upper rows) depict room's multiple devices together with relevant attributes and respective points, the second step (table's lower rows) entails placeholders for points to be assigned to quality and performance attributes of each device.

4.1 Approach

The presented ecological valency evaluation method was tested for an office area in an educational building in Vienna, Austria. To conduct this case study, the general structure of the proposed evaluation method had to be defined in more detail. To this end, the structure was adapted to fit to the climatic context as well as the usage of the tested space. In a first step, the control devices and elements were selected. This was done with regards to assess the controllability of the air quality as well as hygro-thermal, and visual aspects. The specific device categories covered windows, shading, lights, heating, and cooling. Subsequently, basic availability and functional options for these categories were established, together with the corresponding point assignment scheme. In a next step, key attributes of the control devices were selected. They are part of the first component of the evaluation protocol. For the specific purposes of the present case study, every device can receive up to five points in the protocol's first step. As it was alluded to before, the second part of the protocol involves a deeper quality (effectiveness) assessment. As this step arguably addresses a more important evaluation criterion, it included the possibility to assign a larger number of points (double) to each device category. Likewise, additional weighting factors were included in the scheme to account for the fact that certain device categories may be considered to have a greater influence on the pertinent indoor environmental conditions than others. The selected attributes and points for this specific case study are shown in table 1 (basic functions assessment).

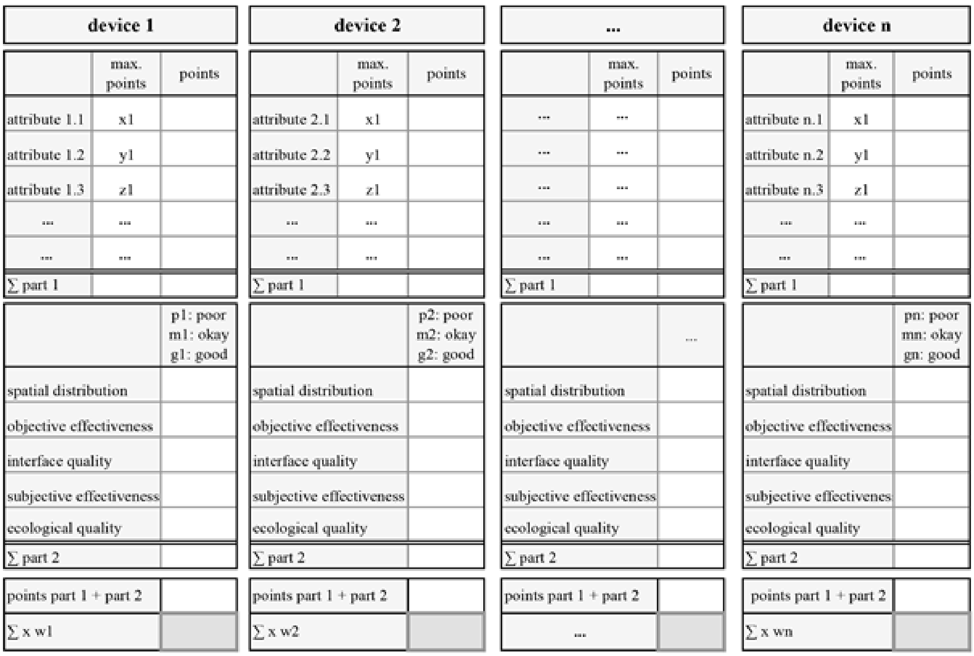

Figure 4: General structure of a room-level EV assessment protocol

Table 1: Basic device attributes and maximum points

Windows		Shading		Lights		Heating		Cooling	
available	2			ambient	2	available	2	available	2
turn function	2	interior shading	2	task	1	radiant	2	radiant	2
tilt function	1	exterior shading	3	Dimming; on/off	1;1	convective	1	convective	1

To conduct the second part of the assessment (effectiveness evaluation), for each device category and each evaluation criteria, points are assigned according to the following simple scheme: Evaluation of a device category as "good", "acceptable", and "poor" translates into 2, 1, and zero points respectively. Moreover, the points of the different categories are multiplied with the following weighting factors: 1.65 (windows, heating), 1 (shading, cooling), and 1.35 (lights). The protocol was tested using the case of an office area in an educational building in Vienna, Austria. Figure 5 shows a floor plan of this office area. Thirty people participated in the case study. Their task was to assess six rooms in this office area by filling out the proposed evaluation protocol and computing the EVI for each room and the overall building. The evaluation exercise was expected to shed light on the usability level of the method and the reproducibility of its results.

4.2 Results and discussion

Figure 6 shows the distribution derived EVI scores by participants for the six rooms. It is noticeable that the participants evaluated all six rooms rather similarly. Except kitchen, the mean EVI for each room is about 65. This makes sense, as the rooms in this office area are equipped rather similarly (similar types and arrangements of windows, radiators, and luminaires). Figure 7 illustrates, using CV (Coefficient of Variation) information, the degree to which participants' room-level EVI calculations diverge (results are shown separately for protocol's two parts as well as for both parts combined). As expected, participants completed the first part of the protocol more consistently than the second part: The evaluation of the availability of a device and its basic function is more straight-forward than its effectiveness. This suggests a need for finer differentiations between the choices (and points) provided in the protocol. Despite the small sample size of participants, we compared the resulting EVI scores from participants who work at the office (roughly one-third of the participants) versus visitors (see figure 8). The comparison suggests a more favourable rating on the side of the visitors. This is perhaps due to occupants' better knowledge of the conditions in their rooms and the workings of indoor environmental control systems. We also compared the votes of female (roughly two-third of the participants) and male participants (see figure 9). In this case, the female participants evaluated the rooms (particularly the kitchen) somewhat more favourably.

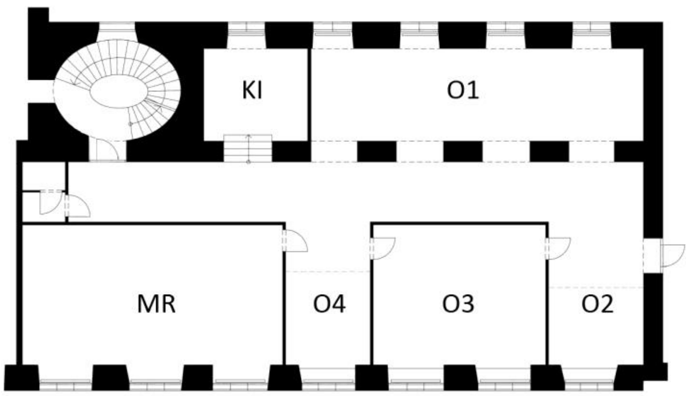

Figure 5: Floor plan office area (key: KI: kitchen, O1: office 1, O2: office 2, O3: office 3, O4: office 4, MR: meeting room)

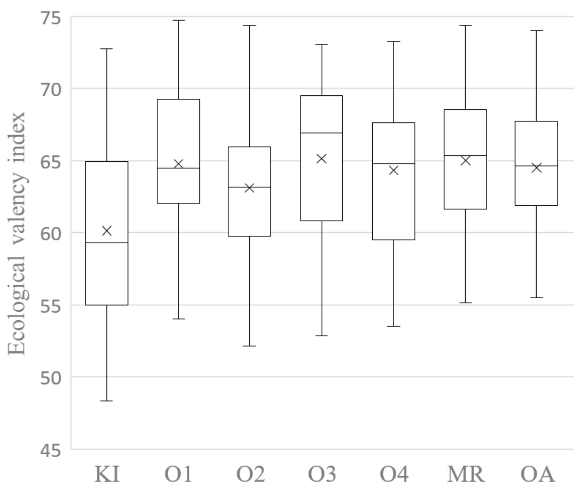

Figure 6. Room-level EVI assignments by participants (key: see figure 5)

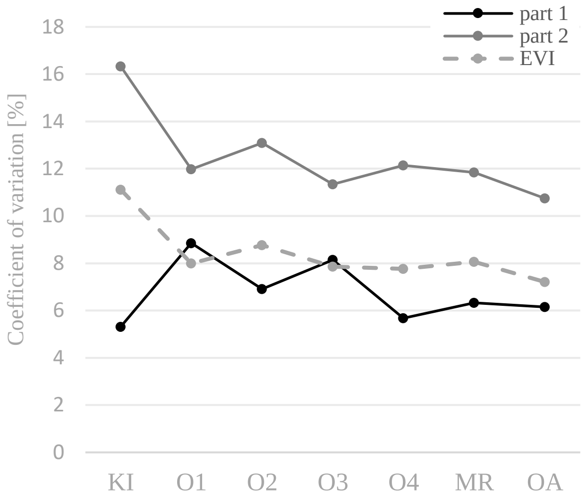

Figure 7. Coefficient of variation for EVI distributions (key: see figure 5)

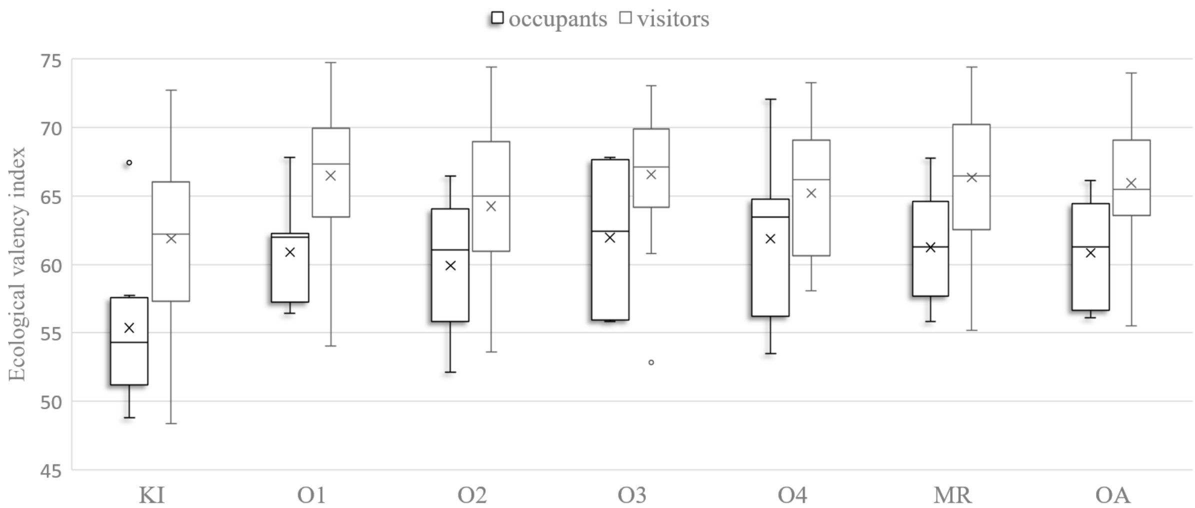

Figure 8. Comparison of EVI scores by occupants and visitors for different rooms (key: see figure 5)

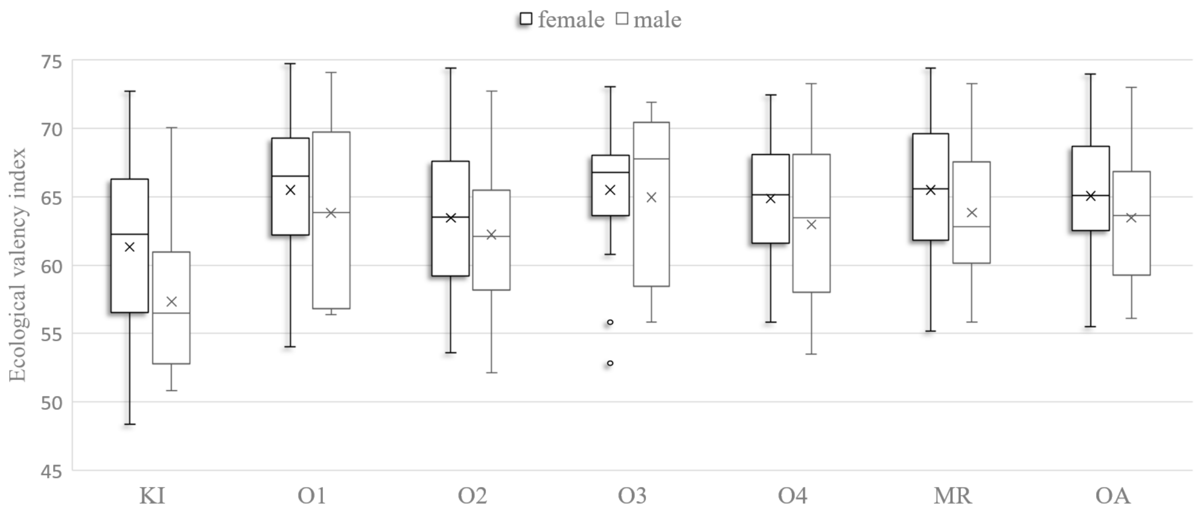

Figure 9. Comparison of EVI scores by female and male participants for different rooms (key: see figure 5)

5 CONCLUSIONS

This contribution explored the potentials and challenges for designing a certification procedure for indoor environments' EV. Toward this, we first described the theoretical foundations of the effort and their translation into a general framework as well as a specific attempt for derivation of ecological valency index (EVI) values. The associated protocol intends to facilitate the evaluation of indoor environmental control devices in buildings. These devices are assessed via the protocol's two parts. Part one deals with the availability of the control equipment and their attributes. The second part focuses on the effectiveness of the devices. Within the latter part, the devices are evaluated based on their spatial distribution, objective and subjective effectiveness, interface quality and ecological quality. The presented method was subjected to a preliminary test for an office area. Thereby, test participants evaluated the EV fairly consistently as far as the general availability and basic functions of the devices were considered. In comparison, the variation of EVI scores was noticeably larger when the effectiveness of devices was the evaluation target. In future, the potential for improving the proposed EV evaluation method will be further explored. As such, a larger (and more diverse) number of participants will be involved in testing the robustness of the proposed protocol and its future improved variations. Likewise, we intend to examine the utility of the proposed approach based on a greater variety of buildings of different types and in different climatic regions.

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