Application of the ecological valency concept to buildings' environmental control systems

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Abstract. Buildings are typically equipped with a number of elements and devices (such as windows, blinds, luminaires, radiators, and fans) to control indoor environmental conditions. The availability, effectiveness, and usability of control devices and their human interfaces constitute arguably an essential aspect of built environments quality and performance. We refer to this aspect as buildings' indoor-environmentally relevant "ecological valency" (EV) or the "affordance". It can be interpreted as a descriptor of buildings' responsiveness toward inhabitants' needs and requirements. Despite its critical importance, there is currently a lack of systematic evaluation or certifications procedures for objective characterization of indoor environments' EV as related to the availability and effectiveness of control devices and their human interfaces. The present contribution explores thus the potential for designing and implementing formal procedures toward measurement and certification of indoor environments' EV.

1. Introduction
Building quality specification and certification tools and processes typically focus on energy efficiency criteria. Thereby, it is commonly assumed that buildings' overall features (e.g., geometry and properties of the building fabric, thermal quality of the building envelope components) together with the assorted environmental control systems such as HVAC (Heating, Ventilation, Air-Conditioning) and lighting system are configured and operated such that appropriate indoor environmental conditions are maintained. Less attention has been paid to conception, description, and specification of the degree to which buildings' offer the occupants the opportunity to effectively and conveniently control the environmental conditions in their immediate surroundings. As such, most buildings are typically equipped with a number of devices to control indoor environmental conditions. Within the framework of this paper we generally use the term "device" to denote those building and systems components that can be operated by buildings' occupants to influence indoor environmental conditions (e.g., temperature and humidity, air flow and air quality, solar gains and daylight). Examples of such devices include windows, blinds, luminaires, radiators, and fans. The availability, effectiveness, and usability of control devices and their human interfaces constitute arguably an essential aspect of built environments quality and performance. To characterize this quality (availability of means and possibilities to influence buildings' indoor-environmentally relevant conditions), well-known concepts from the fields of human ecology and ecological psychology (i.e., "ecological valency" or "affordance") can be very useful. Ecological valency (EV), as originally defined in the context of ecology, is restricted neither to people nor to built environments. In the present context, however, it is applied in terms of a descriptor of buildings' responsiveness toward inhabitants' needs and requirements [1, 2, 3]. Note that the concepts of ecological valency [1, 2] and affordance [4, 5] precede the more recent notions of "perceived control" and "adaptive opportunity". In our experience, however, they provide a more systematic and generalizable conceptual framework for the present discourse. Despite its critical importance, there is currently a lack of systematic evaluation or certifications procedures for objective characterization of
indoor environments' EV as related to the availability and effectiveness of control devices and their human interfaces. The present contribution explores thus the potential for designing and implementing formal procedures toward measurement and certification of indoor environments' EV.

2. Theoretical foundation
Efforts to develop and implement systematic procedures for the evaluation of buildings' indoor environmental control devices can benefit from a sound theoretical foundation. An instance of such a theory is human ecology. It can be shown to have the potential to guide efforts towards indoor environmental quality assessment in general and affordance measurement in particular. Ecology as a scientific discipline deals with the relationship between organisms and their surrounding world. Accordingly, human ecology focuses on the interrelationship between a human being or a number of human beings and the outside surrounding world. There are many traditions and approaches to human ecology. Within this contribution we focus on the approach of the "Vienna School of Human Ecology". Human ecology offers a number of concepts that deal with the previously mentioned interactions [1, 2, 3]. One pair of concepts is as follows: i) the human beings' ecological potency; ii) the surrounding world's ecological valency. Ecological potency is defined as people's capability of coping and interacting with the surrounding world. Ecological valency, on the other hand, refers to the totality of the surrounding world's characteristics (resources, possibilities, opportunities, challenges, risks, hazards) as it relates to people's ecological potency [1, 2, 3]. The concept of ecological valency is also similar to Gibson's definition of "affordance" [4, 5]. Similarities can also be found in earlier formulated contributions by Uexküll [6].

3. Ecological valency evaluation method
This paper builds upon the work and ideas described in previous contributions [7, 8, 9]. They focus on the potential, limitations, and challenges in designing and implementing an ecological valency certification procedure. Given this context, a specific attempt for the structure of an ecological valency evaluation method was made. This preliminary attempt relies on the well-known point-assignment systems utilised in domains such as sustainability assessment (see, for example, leed, bream, etc. [10, 11]). However, the focus of the proposed approach is not so much the assessment of the prevailing indoor environmental conditions at any specific point in time, but rather the assessment of the principal availability and effectiveness of means for manipulating such conditions by occupants.

To illustrate the main features of this method, consider its application to a specific room in a specific building as a case in point. The idea is to derive for this room a kind of "ecological valency index" (EVI). Once EVI values are obtained for all rooms of a 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 (e.g., heating, cooling, ventilation, illumination). Specifically, such features entail envelope components and technical systems such as window, 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 five fundamental assessment criteria (see [8]): spatial distribution, objective effectiveness, interface quality, subjective effectiveness, and 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 1 (for a specific room).
Figure 1. General structure of a room-level ecological valency assessment protocol.

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) depicts 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. Case study
The presented ecological valency evaluation method was tested for an office area in an educational building in Vienna, Austria.

4.1. Approach
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).
Table 1. Selected basic device functional attributes and maximum points.

| Windows  | Shading | Lights | Heating | Cooling |
|----------|---------|--------|---------|---------|
| available| 2       | ambient| available| 2       |
| turn function| 2       | task   | radiant | radiant |
| tilt function | 1       | dimming| convective| 1       |
| on/off | 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 2 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.

![Figure 2](image)

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

4.2. Results and discussion

Figure 3 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 4 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 arguably more straightforward than its effectiveness. This suggests a possible 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 short-term visitors (see figure 5). The comparison suggests a more favorable 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. However, this conjecture must be treated with caution, given the (previously noted) small number of participants and the relatively large percentage of visitors in the sample. We also compared the votes of female (roughly two-third of the participants) and male participants (see figure 6). In this case, the female participants evaluated the rooms (particularly the kitchen) somewhat more favorably.
Figure 3. Room-level EVI assignments by participants (key: see figure 2).

Figure 4. Coefficient of variation for EVI distributions (key: see figure 2).

Figure 5. Comparison of EVI scores by occupants and visitors for different rooms (key: see figure 2).

Figure 6. Comparison of EVI scores by female and male participants for different rooms (key: see figure 2).
5. Conclusion
This contribution explored the potentials and challenges for designing a certification procedure for indoor environments' affordance. To this end, a specific attempt for an ecological valency evaluation method was presented. It intends to facilitate the evaluation of indoor environmental control devices in buildings. These devices are assessed via a two-part protocol. 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 in Vienna, Austria. Six rooms of this office area were evaluated by thirty participants. The case study showed that the participants evaluated the affordance 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. The results of this pilot study highlight both the challenges and potential of the proposed approach.

In future, the potential for improving the proposed ecological valency evaluation method will be further explored. As such, a larger (and more diverse) number of participants will be involved in testing the consistency and 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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