Building and Environment 122 (2017) 373–385

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

On occupant-centric building performance metrics

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A R T I C L E I N F O

Article history:
Received 20 February 2017
Received in revised form
8 June 2017
Accepted 13 June 2017
Available online 16 June 2017

Keywords:
Building performance
Occupancy
Occupant behavior
Metrics
Simulation

A B S T R A C T

Existing building performance metrics cover a wide variety of domains including energy performance, equipment performance, electric lighting, indoor environmental quality, capital and operating costs, and environmental impact. They facilitate building benchmarking and yield actionable insights at all phases of the building life-cycle. Yet, the occupant domain – one of the most significant with respect to building performance – is relatively immature with regards to performance metrics. This paper provides guidance, examples, and critical discussion for developing and applying occupant-centric building performance metrics. First, an approach is proposed for developing and evaluating the suitability of such metrics. Then, using samples of data from real and simulated buildings, this paper proposes metrics that are appropriate for quantifying occupants' impact on buildings. These metrics provide an indication of building performance from an occupant-building interaction perspective, serving a purpose much like traditional building performance metrics. They also force professionals to consider occupants through a new lens because people are the real recipient of the measures and services provided by buildings.

1. Introduction

The performance of a building, in which people spend the greatest share of their life, is the result of a complex interaction between a large variety of physical attributes. In the literature, an assortment of terminology is used when assessing building performance. Some studies make a distinction between metrics and key performance indicators [1], while others consider these terms synonymous [2]. Other papers focus on the difference between simple metrics (such as the floor area of a building) and performance metrics (such as building energy use intensity, or EUI, defined as the yearly energy demand per unit area of the building, e.g., in kWh/m^2) [3]. In this study, we refer to performance metrics as measurement standards of a function or operation, which can measure and communicate progress towards achieving performance goals [3]. A building performance metric is "intended to explicitly represent the performance objectives for a building project, using quantitative criteria, in a dynamic structured format" [4]. Developing significant building performance metrics is a required step to set appropriate goals in building design, which moved from traditionally being a prescriptive process to be performance-based [5].

Several hundred building performance metrics are available in the scientific literature and are adopted by standards and legislation to set requirements for building performance [6]. Those metrics address various aspects of the building performance [7], including occupant behavior and indoor environmental quality (IEQ). However, an effective and standardized way to quantify key aspects of building performance from an occupant perspective is not sufficiently developed. As a result, there lacks a common approach for the development of occupant-centric (i.e., focused on the occupant-building interaction) performance metrics for use in simulation and/or for assessing the operational performance of buildings. This gap renders it difficult to quantify and define objectives concerning building performance in relation to occupants. Moreover, neglecting this important aspect of building performance can lead to drawing incorrect or inappropriate conclusions about the actual energy consumption of the building stock. The primary objective of the occupant-centric metrics proposed in this paper is not to specifically evaluate individual occupants, but to assess the building through a new lens by gaining a better understanding of how occupants influence building performance. In

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http://dx.doi.org/10.1016/j.buildenv.2017.06.028
0360-1323/

contrast to when the prominent building performance metrics (such as the EUI) were established, new sensing and building automation and control system (BACS) technologies support high-resolution occupancy and occupant behavior sensing. For instance, numerous technologies are available to count and even locate occupants within a building. Moreover, modern BACS technologies can detect and log occupant interactions with lighting controls, thermostats, etc. (e.g., [8]). Overall, this research is made possible by the diffusion of BACS and building performance simulation (BPS) tools.

This paper first provides an overview of a few existing performance metrics, with the aim of highlighting the overlapping areas of interest and discussing where the current approach falls short of an objective building performance assessment. Next, an approach for the development of occupant-centric performance metrics is provided. A number of illustrative examples demonstrate the development and application of occupant-centric performance metrics to real data and simulation results. The findings and suggestions for developing occupant-centric building performance metrics and the lessons learned from this exercise are examined and summarized in the last section.

2. Existing building performance metrics related to occupants

This section introduces a selection of common existing building performance metrics and provides a critical assessment of their effectiveness in the current context of occupants. Later on in Section 4, metrics that help to address the current metrics' shortcomings, according to the same categories below, are proposed and tested.

2.1. Energy and comfort performance metrics

There are many possible ways to characterize a building performance, for example, its structural safety, aesthetic quality, economic value, or environmental impact. In this paper, however, building performance refers to buildings' energy and comfort performance. There is a number of very extensive frameworks for comfort and more in general IEQ assessment [9–11]. Some issues emerge when correlating discomfort metrics to occupants. For example, ASHRAE Standard 90.1 (Appendix G3.1.2.3) [12] requires a baseline building to have less than 300 unmet hours, or "hours of the modeled year in which at least one zone has an unmet cooling/heating load". However, the fact that there are no specifications concerning actual occupancy of the building nor how to deal with multiple zones is a shortcoming. To correlate the building thermal comfort performance to occupants, Carlucci [13] developed a long-term thermal discomfort index that assesses the whole-building performance by weighting the zonal indices by the number of people that occupy each zone for each hour.

2.2. Normalization factor

The role of occupants is largely overlooked when it comes to energy performance metrics. However, an extensive body of work emerged in recent years with concerns to normalization factor. The idea behind these studies is to progress from normalizing energy use per building size, to focusing on the actual service delivered by the building - that is, providing a comfortable and productive environment for people [56]. This approach is common to other fields. For example, it would seem illogical to most car users to normalize cars' fuel consumption by the empty mass of the car in kilograms rather than by kilometers (the actual service provided by the car). When analyzing energy use for travel between 1970 and 1987 [14], found that the energy intensities – expressed in terms of MJ/(passenger km) – generally increased in many OECD countries; although individual cars had become more energy-efficient, this improvement was offset by their greater size, power, weight, and load factor (i.e., passengers per car). The authors' findings are representative of the trends over time in terms of car industry environmental sustainability, but they would have been reversed if the performance metric's normalization factor was automobile size or weight.

Examples of building energy use per capita as a performance metric are found when presenting macro trends of the building sector regarding energy (e.g., [2]). The adoption of a similar logic is rarer when it comes to single buildings [15]. found that normalizing life-cycle energy and greenhouse gas (GHG) emissions by floor area revealed that a large suburban house performs nearly as well as an urban transit-accessible apartment. However, normalization by occupant for the same study revealed that the large suburban house was more than twice as energy and GHG-intensive as its urban counterpart. Similarly, Ueno [16] states that normalizing energy per floor area in residential buildings undoubtedly leads to a "small house penalty". The study shows that a dwelling whose area is 269 m^2 has an energy performance "advantage" of 30% over an identical, smaller version (158 m^2). From this perspective, the easiest way to reduce a dwelling's EUI would be to finish the basement, and include it in the floor area calculation. This logic clearly does not lead to an improved design of societal and environmental sustainability. On the other hand, normalizing energy by number of occupants leads to a "large house penalty" (which is representative of actual energy use), in addition to the difficulty of measuring and defining the number of occupants. This paper argues that considering how people use and occupy such spaces in reality could provide further insights on the efficiency of the services provided by a building.

2.3. Trend of increasing space utilization

Current metrics to evaluate office building utilization are static in nature and typically based on occupant density (on the basis of floor area divided by full-time equivalent employees) with little regard to true occupancy [17]. However, there is a trend of office tenants who are moving to hoteling-style office management, whereby there is only one desk for every two or three office workers to reflect their flexibility to work from home or other sites and be in meetings [18,19]. This form of building management has major potential economic and environmental benefits, as less floor area is required to conduct the same level of economic activity and it reduces pressure on commuting infrastructure. For instance, hoteling could allow a building operator to shut down part of a building (e.g., cease conditioning it) or it could allow a growing business to delay expanding into a new building. A similar trend can be seen in colleges and universities, which are beginning to offer online courses whereby physical classrooms are not necessarily needed. Meanwhile, the sharing economy has seen major growth in short-term person-to-person house sharing. All of these trends can greatly improve building utilization and ultimately require less building space for a given population. However, to the best of the authors' knowledge, no current metric gives credit for improved utilization nor quantifies the potential for greater utilization. In the past years, a variety of new technologies that allow detailed occupancy counts at various scales (building, suite, room) to better track space utilization emerged [20,21]; this development will be instrumental for the quantification of buildings' intensified utilization potential.