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Methods for adaptive behaviors satisfaction assessment with energy efficient building design

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ABSTRACT

Efficient and accurate methods and models are ever-demanding to determining the user satisfaction in energy efficient buildings. Thus, several techniques are developed based on sustainable building assessment tools and standards to achieve such target. However, the user satisfaction from adaptive behavior in the design phase of buildings lifecycle is never addressed. This paper attempts to identify the most applicable data input method to measure the satisfaction from adaptive behavior with energy efficient buildings in their design phase. A comprehensive literature survey on all user satisfaction data input methods is conducted to serve the taxonomy by classifying them into two major clusters depending on performance and perception. Kano method to measure satisfaction perception from cognitive experience is demonstrated to be the most suitable user satisfaction data input method. Furthermore, Kano method can delicately assist energy efficient building design consultants to assess the user contentment requirements for sustainable building accreditation effectively.

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1. Introduction

Certainly, sustainable building assessment tools (SBATs) are prerequisite to enhance the endurable and environmental affable aspects of construction practices. Since the early 1990s, approximately sixty building assessment tools are developed. These include Building Research Establishment Environmental Assessment Method (BREEAM), Leadership in Energy and Environmental Design (LEED), Sustainable Building tool (SBtool), Singapore Green Mark Scheme, etc. to cite a few. The main aim of these tools is to benchmark a 'Capacity Building' as a sustainable structure case from socio-economic and environmental perspectives. It includes both existing and new buildings (e.g. office, residential, and commercial) with diverse functionalities [1]. Though these assessment tools are not originally intended to serve as building design guidelines, however they are increasingly being used as such [2,3].

The SBATs and standards aid architects as well as construction engineers to evaluate buildings' energy economy in terms of consumptions and savings. This is related to social and economic factors together with indoor environmental quality [4]. According to Zhun [4] the energy consumption in a building is affected by several factors such as the building age, occupancy, climate, people, and energy end-use. Over the years, standards are developed to support the user requirements in building assessment. For instance, the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) 55 standard [5] measure the correlation of indoor thermal environmental parameters (temperature, thermal radiation, humidity, and air speed) and user parameters (clothing insulation and metabolism rate). The ASHRAE-55 standard assists building energy managers to determine thermal environmental conditions acceptable to the users [6]. The International Organization for Standardization (ISO) (ISO/TS 21929-1 [7]) monitors the energy efficiency features to develop a harmonized basis in achieving the sustainability. The EN15251 standard [8] establishes environmental input parameters from users' design and energy performance estimates. Yun and Steemers [9] identified the factors that influence the energy consumption in a building. These factors include climate, building- and user- related characteristics (not socio-economic); building services systems and operation; building occupants' behavior and activities; social and economic factors; and indoor environmental quality.

In building assessments, the user satisfaction is the foremost challenging factor inter-connected with energy efficiency [10]. The user satisfaction related energy efficiency issue is widely addressed across diverse disciplines, including building architectural design, building value management [11], building asset management [12] real estate management [12], and construction management. In this regard, SBtool is the first building assessment tool that considers the user satisfaction issue in terms of energy economy. It is acknowledged that [4,9,13] the building user behaviors and activities are the most common factors responsible for the fluctuation in actual energy consumption against the planned one. Nevertheless, the adaptive behavior being a measure of user satisfaction may certainly enhance the energy program [14–17].

2. The need

Exhaustive literature review reveals that a method for assessing user satisfaction with adaptive behavior in existing tools and models is absent. According to Gibson [18], present tools are not effective towards sustainability. Abdalla et al. [19] mentioned that these tools are not able to estimate accurately the project output in terms of energy consumption and sustainability measures. Lützkendorf and Lorenze [12] asserted that only a few tools such as LEGEP [20] and OGIP [21] determine and assess the cost, environment and to some extent occupational health as well as other social issues in the planning phase. Specifically, user satisfaction and developmental impact on community as social sustainability criteria must be considered in SBATs [22]. Besides, current methods pay less attention to functional variations in different types of buildings, which influences not only the emotional and physical comfort of human beings but also the design and management of buildings [23]. On top, they are somewhat unconvincing to provide reasonable assessment results in energy economy within the design phase of a building's lifecycle [23]. It is affirmed that [24] further advancement of assessment tools is mandatory to enable them in influencing the building's design.

Modeling and simulations are considered to be one of the advancements to evaluate users' adaptive behavior with building, where the major aim is to predict the user's actions for a better design performance. Thermal comfort models of Fanger [25], Jones [26], Wissler [27], and Gagge [28] analyze the users' adaptive behavior without distinguishing them. Other models such as Clo-Man [29], Tranmod [30], de Dear [31], and Kempton and Lutzenh [32] also fail to conduct satisfaction analyzes of the users' adaptive behavior. Moreover, the simulation models of Reinhart [33], Bourgeois et al. [34], Rijal et al. [35], and Mahdavi et al. [36] including DOE-2 (Department of Energy-2), BLAST (Building Loads Analysis and System Thermodynamics), eQUEST (QUick Energy Simulation Tool), ESP-r (Environmental Systems Performance, Research version), EnergyPlus, TRNSYS (Transient System simulation program), BESA (Building Energy System Analysis), and CFD (Computational Fluid Dynamics) are unable to measure user satisfaction with adaptive behaviors [9]. Despite much dedicated efforts a precise and proficient assessment model of user satisfaction with adaptive behaviors is far from being achieved.

Currently, the building energy and facility managers are being challenged with the demand to better satisfy all users. Critical literature survey indicated that many factors those may significantly impact the precision of user satisfaction measurements are not undertaken in the existing methods. Particularly, different levels of satisfaction being possessed by human are not yet explored by building assessment tools. These satisfaction levels are grouped into three levels including necessity (basic satisfaction), performance (moderate satisfaction), and attractiveness or happiness (superior satisfaction) [37–39]. Such satisfaction classification must be incorporated in user satisfaction measurement practices to get prioritized plans for both the present and future corrective actions towards a building's energy efficiency. Each satisfaction level may possess a significant importance-value in an energy management plan. Moreover, according to the theory of attractive quality, "the quality attributes are dynamic, which means that over time, a feature may change from satisfactory to unsatisfactory" [40]. Hence, user requirements and perceptions may be changing during a building's lifecycle. The building energy