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# User satisfaction adaptive behaviors for assessing energy efficient building indoor cooling and lighting environment

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ABSTRACT

Many techniques for managing sustainability including sustainable building assessment tools and standards have been developed globally. The sustainable building assessment tools measure the user satisfaction dependent to environmental and economic aspects of energy efficient building practices. However, these tools have not yet measure energy efficiency index by involving user satisfaction from adaptive behaviors dependently, which can determine the actual energy consumption versus the planed energy consumption of the building. Hence, this research aimed at providing a comprehensive list of adaptive behaviors for assessing energy efficient building indoor environment in design phase of building lifecycle. The study focused on identifying and establishing adaptive behaviors that are in response to indoor conditions provided by Cooling and Lighting systems in energy efficient office buildings. This research involves adaptations across Technological and Personal. The research was conducted in two phases. Phase one identified the list of user satisfaction adaptive behaviors through a systematic approach. Next, an expert input study was conducted to validate the findings of the literature review. Expert input data was collected using Delphi structured close group discussion method, and then analyzed through Grounded Group Decision Making (GGDM) method. Eight experts were involved in four sessions of the GGDM application procedure. The research established 18 adaptive behaviors relevant to cooling system in energy efficient indoor environments, and 18 adaptive behaviors relevant to the lighting system. The comprehensive list of user satisfaction adaptive behaviors can be applied in both current and future sustainable building assessment tools' energy efficiency indexes. This aids architects, engineers, facility managers, building owners, consultants, authorities, contractors, and academic researchers in accreditation of building users, building design and reduction of building's energy consumption.



**Contents**



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## 1. Introduction on sustainable building assessment tools

There are efforts to manage the implementation of sustainability methods and techniques in building practices. This is carried out with the aid of four sustainability methods and techniques; viz. (a) governmental status, (b) building codes, (c) private and professional associations or Non-Governmental Organizations (NGOs), and (d) marketing strategies [1]. Amongst, the largest contributor to enhance sustainability in building practices is the private and professional associations, NGOs [1]. NGOs have mainly resulted with multi-perspective 'Building assessment tools' to enhance sustainability of building practices in specific regional areas [2,3].

In the building constructions industry, assessment tools are specifically used to benchmark enhancement of sustainability in building practices [4]. Using assessment tools is a contribution of 'Managing Sustainability' to the building construction industry. These tools traditionally called 'environmental building assessment tools', 'green building assessment tools' and recently called 'sustainable building assessment tools'.

Building assessment tools are mainly aimed to benchmark a 'Capacity Building' as a sustainable building case (i.e. social, economic, and environmental building) in a specific geographic region. It includes existing buildings as well as new buildings across diverse functionalities, such as, office buildings, residential buildings, commercial buildings, etc. [5]. These tools involve a variety of features for sustainability assessment including, energy efficiency, water management, waste management, land use etc. [1]. Basically, these features cover the greenery/environmental issues, with consideration on economic and social-friendly approaches. To improve usability of tools with building lifecycle, it may benchmark building's 'sustainability' in design phase, construction phase, operational phase, and/or demolition phase [5]. According to Haapio and Viitaniemi [5] tools' end-users would be architects, engineers, facility managers, building owners, consultants, authorities, contractors, and/or academic researchers. The academic researchers indirectly use the sustainable building assessment tools as decision support tools in order to fulfill the requirement of building sustainability accreditation [6].

There are some efforts being undertaken to establish standardized requirements for building assessment tools. International Organization for Standardization (ISO) [7,8] investigated assessment features to develop harmonized basis to measure the sustainability of the subject matter. The ASHRAE-55 standard [9] measures the correlation of indoor thermal environmental parameters (temperature, thermal radiation, humidity, and air speed) and user parameters (clothing insulation and metabolism rate). Using ASHRAE-55 standard [9] aids building energy managers to provide thermal environmental conditions acceptable to a majority of the users [10] The EN15251 standard [11] established environmental input parameters for design and energy performance calculations within non-industrial buildings, such as, office buildings [10]. Recently, Temperature Limits guideline (ATG) was developed as an alternative to the Weighted Temperature Exceeding Hours method (GTO). The ATG has the flexibility to predict various types of buildings including naturally ventilated buildings, and the mechanically conditioned buildings with sealed facades [10]. Also, the Construction Related Sustainability Indicators Project (CRISP) is a thematic network on construction and city related sustainable indicators which have been introduced based on the review of all existing tools.

## 2. Gap in sustainable building assessment tools

Since early 1990s, about sixty 'sustainable building assessment tools' have been established by private professional associations, or NGOs all over the world, such as, Building Research Establishment Environmental Assessment Method (BREEAM), Hong Kong Building Environmental Assessment Method-HK-BEAM [12], Leadership in Energy & Environmental Design-LEED [13], Sustainable Building tool [14], Singapore Green Mark Scheme [15], and Green Building Index-GBI [16].

With regards to problems with sustainable building assessment tools, there are some shortcomings addressed by researchers in the available literature. Gibson [17] stated that the established tools do not work effectively towards sustainability. Abdalla et al. [6] mentioned that the sustainable building assessment tools do not consider end-user sustainable program. Furthermore, Pemsel et al. [18] express that lack of 'guidance and narrow focus' restricts the ability of tools in the assessment process. Moreover, there is always a deficiency in using any 'global standardized' assessment tools [4].

According to literature, majority of building assessment tools lack focusing on energy and environment aspects in the design phase of building life cycle. Lützkendorf and Lorenze [19] stated "… due to the complexity involved, only a few tools, such as, LEGEP [20] and OGIP [21] exist that allow for a combined determination and assessment of cost, environment and to some extent occupational health and other social issues in the planning phase". Christensen [4] stated that 'user satisfaction' and 'development impact on community' as social sustainability criteria need to be considered in sustainable building assessment tools.

Lützkendorf and Lorenz [22] stated that assessing a building's contribution to sustainable development requires an integrated building performance approach. This allows one to describe and assess buildings with respect to all dimensions of sustainable development including aspects of functionality and serviceability as well as the quality of planning, construction and management