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A REVIEW OF SUSTAINABLE RATING TOOLS IN RELATION WITH INDOOR ENVIRONMENT QUALITY AND THERMAL COMFORT

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ABSTRACT

Green building is an environmentally sustainable building that created by using the processes that are environmentally responsible from the initial stage of planning to the design, construction, maintenance, renovation and last but not least the deconstruction of the building. The green building is also known as a high performance and a well-designed building that will save money and create healthier environments for people to live and work which through an improved indoor environmental quality and thermal comfort. Nowadays, the green building is being evaluated by using various sustainable rating tools that available worldwide focusing on different areas of sustainable development and are designed for different types of projects and climates. These tools include energy systems assessments, management of building, indoor environmental quality, site planning, maintenance and many more. Hence, the objective of this paper is to provide a literature overview of various sustainable rating tools available worldwide in relation with the indoor environment quality aspects centering on the indoor thermal comfort. The paper wills emphasis on the sustainable rating tools criteria in three (3) tabulated summary form that will deliver better understanding on the relationship between the rating tools, the indoor air quality and the thermal comfort aspects in all selected green building's sustainable rating tools.

Keywords: green building, sustainable rating tools, indoor environment quality, thermal comfort.

INTRODUCTION

Green building also known as green construction or the sustainable building in construction industry worldwide. It often encompasses from the planning stage throughout the ultimate end of building life cycle, which comprises the design, construction, operations and renewal of the building structures. The green building brings together a huge range of knowledge, practices, techniques, and skills to reduce and eradicate the negative impacts of buildings on the environment and human health. Hence, this requires close collaboration and understanding between the design team, client, and developers at all stages of a project. Various researchers believed that green buildings have been shaped to lower the impacts to the environment and improve the health quality of the building occupants (Woo, 2010). According to (Erica, 2008), green building is sexy in their design and ambition, and with a proper design and executions, a green building does more than just conserve energy and resources where the green building is also getting an enhancement from agencies around the world to set standards for sustainable building and also helps in educate the public, industry and policymakers on the benefits of sustainable for future life. Green buildings could be considered as a technological innovation because it encapsulates a system that uses environmentally aware approaches to modifying conventional construction practices (Ofori-Boadu *et al.*, 2012). Green building often represents a complex integration of innovative green materials, products, processes, system and technologies. Green buildings mean toimprove in design, construction and landscaping practices so that it will last longer, cost less and will not harmful to our health (healthy living). It is also means protecting natural resources and improving the built Environment so that people, communities, and ecosystems can thrive and prosper (John and Michael, 2007). The development of green buildings have vast benefits such as it is built for long term (build durable, efficient homes and liveable communities), the green building also built for life and humans where it make homes, communities and environment safe for current and future generations. Last but not least, the green building also built for the planet and world environment with a wisely use of natural resources and the recycle materials (John and Michael, 2007). However beside its enormous advantages, green buildings are not yet perceived as attractive projects by most of the clients and developers. It is mainly because most builders associate green features and construction with expensive technologies that add cost to the overall budget allocation of the building (Metthiessen and Morris, 2007), (Sherwin, 2006). Nevertheless, careful design process and a comprehensive materials selection method of the green building may result in desired environmental goals inside for the building and save the energy consumption for a long term.

LITERATURE REVIEW

Sustainable construction design

Sustainable design is the philosophy of designing physical objects, the built environment, and services to comply with the principles of social,economic, and environmental sustainability.The intention of sustainable design is to eliminate the negative impacts by the

application of sustainability principles to building design (Kilbert, 2008) that create projects with meaningful innovations and a dynamic integration between the society and economy. Sustainable design can also be described as theinteraction of sustainable materials and components that assimilate into a sustainable building that connect people with the natural environment. According to (Thovichit, 2007), there are a few selection criteria of the sustainable materials namely the life cycle of the material, cost, energy saved, waste management and environmental impact. Hence, the transition from conventional to sustainable construction practice presents both challenges and opportunities for the design and construction industries. Often the green building design emphases its thoughtfulness on the sustainability of the end users and the end use of the green building, while the process in which the building is constructed is somehow being ignored and may not necessarily follow the truly sustainable process of the green construction (John & Michael, 2007). However, the idea of sustainable design is to ensure that actions and decisions today does not inhibit the opportunities of future generations where most of the time the green building and construction practices are mostly aimed at reducing environmental and resource impacts and improving the safety, health and productivity of a building's final occupants (John and Michael, 2007).Therefore, successful design and construction of green building for projects present a challenge for the designers to ensure the fulfilment of basic indoor environmental quality requirements of a rated sustainable building.

Earlier research by (Lebowitz *et al.*, 1985), found that people in developed world spend almost 75-90 percent of their time inside a building. The similar finding was found by (Singh, 1996) and (Klepeis et al., 2001) who believed that research suggests people tend to spend 80-90 percent of their time indoors. These facts highlighted the importance of building indoor environment quality improvements and the need for validating the related well-being and productivity benefits available in rated green buildings (Singh, Syal, Korkmaz, and Grady, 2011). With the greatest majority of people carry on 80-90percent of their lives inside buildings, the green rated building must able to satisfy the objective and subjective requests linked to vital functions of the occupants in existing and future buildings. Later, there will be an increasing focus on energy uses and indoor environmental quality in these rated green building in ensuring the optimum indoor environmental quality achieved in the post-occupancy period (Wolkoff and Kjaergaard, 2007). (Chen *et al*., 1998) stated that the indoor environment is crucial for people's health and welfare, because 90 percent of typical person's time spent indoors. Consequently, their production also related tothe indoor environment. He also pointed that satisfaction level and expectation of occupants in a built environment comprises of the illuminations, acoustics, air quality, diet, thermal comfort and social environment, habitually reflect the situation which surrounds them by their physiological and mental sensations such as sight, hearing, smell, taste, touch and mentality.

Indoor environmental quality

One of the aspects that closely related with human satisfaction in an indoor environment is the indoor environmental quality. Indoor environmental quality is getting more attention since most people nowadays spend most of their time indoors. The indoor environmental quality can be defined as “the measurement of the key parameters affecting the comfort and well-being of occupants" or the “elements to provide an environment that is physically and psychologically healthy for its occupants" (Garnys, 2007). The National Institute for Occupational Safety and Health in the United States has established a definition of Indoor Envuronment Quality (IEQ) which includes the integrated physiological and psychological influences of thermal, acoustic and luminous environments and air quality on occupants (Li, You, Chen, & Yang, 2013).

(Clements-Croome and Baizhan, 2000) stated that the indoor environmental quality comprises of a range of components such as humidity, indoor air quality, temperature, and ventilation, lighting, noise and work space density. Whereas (Sarbu & Sebarchievici, 2013) believed that, the main environmental factors that define the indoor environmental quality are the thermal comfort, indoor air quality, acoustic comfort and visual comfort. Another researcher such as (Woo, 2010) and (Prakash, 2005) added ergonomics as one of the factors that need to be taken into account in providing comfortablea indoor environment to the end users. Apart from that, indoor environmental quality also comprises of few other aspects such as the spectrum of the paints (Prakash, 2005), electric lighting, daylight, views, individual control, and indoor contaminants by materials and tenants as the components of the indoor environmental quality in a building. (GBCA 2009b).

Few studies conducted indicate that there is a significant relationship between indoor environmental quality with occupants satisfaction and work performance which includes increase in the amount of work done, enhanced work performance, improved worker retention, reduced sick day and absenteeism (Clements-Croome & Baizhan, 2000), (Fisk, 2000), (Loftness *et al*. 2005). Therefore, the building designers are striving to achieve internal environments that are comfortable for the occupants at any time of day, all year round, regardless of the prevailing external climate. Nevertheless, the concepts of green building early approach essentially focused on two basic objectives that are the human comfort and effective energy management in the rated green building.

Thermal comfort

Environmental factors that define the indoor environmental quality are thermal comfort, indoor air quality, acoustic comfort and visual comfort. This paper

wills emphasis on one of the most significant indoor environmental quality aspect that is the thermal comfort. Thermal comfort is defined in the ISO 7730 standard as "that condition of mind that express satisfaction with the thermal environment and is assessed mainly by subjective evaluation". (Harriman, 2008) describes human thermal comfort as the state of mind that expresses satisfaction with the surrounding environment. There are potentially large variations, physiologically and psychologically, from person to person that makes it difficult to satisfy everyone in a particular space. As a result, environmental conditions required for comfort are not the same for everyone (Castro-Lacouture *et al*., 2009). They also believed that the most commonly used indicator to measure the thermal comfort of a space is the air temperature as it is the easiest and most obvious indicator that most people will be able to relate to when determining thermal comfort in given space. Comfort is gained when body temperature is held within narrow ranges; skin moisture is low, and the physiological effort of regulation is minimized. Numerical prediction of thermal comfort in a chamber is performed by using the PMV -PPD model (Sarbu and Sebarchievici, 2013). There are a few factors that affect the human thermal comfort that can be divided into three categories: 1. The subjective measurement factor that includes perceptions, opinions, clothing, age, activities, gender, metabolic rate; 2. Administrative controls such as working time schedule; and 3. Engineering controls that include the controls of air conditioning, heating, and the air movement in the workplace. (Harriman 2008). The need for optimum indoor overall thermal comfort is a real challenge nowadays that worthy of everybody attention (client, consultants, developer, facilities manager, as well as the building occupants and buyers). Incorporating of a good design, construction and the selection of appropriate materials for building will provide significant effects to the building in terms of optimizing indoor thermal comfort as well as implementation of sustainable rating tools that emphasis on the important of the sustainable construction in preserving environment for future generations.

Sustainable standards

Over the past decade, rating standard for green buildings has been developed worldwide to promote the construction of green buildings and encourage green practice in the industry. Among the numerous efforts in the emerging green building movement, the establishment of green building certification systems worldwide is one of the most prominent and ensures a systematic approach to continuing these effort toward promoting environmental sustainability (Liang *et al*., 2014). Benefits of these systems are they can guide the development of construction industry towards best practice and improving the quality of building for tenants and occupants. The sustainable standard is a concept of sustainable practice, and environmental responsibility normally is an elective standard as opposed to a mandated regulation involving multiple constituents (building owner, design professionals, construction professionals, and code officials).

The USGBC- US Green Building Council and LEED -Leadership in Energy and Environmental Design green building rating system is a certification program that has been widely accepted as a benchmark for the design, construction and operation of green and sustainable built environment in the US. The LEED green building rating system is concerned mostly with the design of green building which require less energy for operation and with the processes to implement the design properly. The rating system provides a list of credits, measuring the environmental performance of construction processes in terms of sustainable development, energy efficiency and selection of material (USGBC 2009). Apart from the LEED, there are other sustainable rating tools that available such as BREEAM United Kingdom, HK BEAM Hong Kong, GREEN STAR Australia, and GREEN MARK Singapore and last but not least our own sustainable rating tools the Green Building Index (GBI) Malaysia.

Driven by environmental needs, Green Building Index (GBI) was founded and developed by the Pertubuhan Akitek Malaysia (PAM) and the Association of Consulting Engineers Malaysia (ACEM) in 2009 as one of the acceleration in Malaysia sustainable development. The Malaysian GBI is envisioned to promote sustainability in the built environment and enhance awareness among developers, architects, engineers, planners, designers, contractors and the public about environmental issues. Malaysian (GBI) will be the one of the rating tool for the tropical zones other than Singapore Government's GREENMARK that customized to suit the Malaysian climate and also the current state of the country's development and existing resources. As on May 2015, 298 buildings in Malaysia has been certified as green building in various categories through (GBI) ratings whereas 13 buildings has been awarded with Platinum, 71 buildings awarded as Gold, 34 buildings achieved Silver 34 and 180 buildings awarded as Certified green building.

LITERATURE ANALYSIS ON SUSTAINABLE RATING TOOLS

Since comfort is an instinctive feeling of human beings, these standards vary with countries and individuals. Table-1 shows the tabulated summary of selected sustainable rating tools that available throughout the world, especially in Asian. Various rating wasgiven, and vast category of certifications that suits with the country's requirements and criteria are shown.

Table-2 summarized on the evaluation criteria of selected sustainable rating tools as per Table-1. The tables show that different countries have different category and rating given that suits the climate and localized condition of the country. It also indicates that the selected reviewed sustainable rating tool comprises of various evaluation criteria. Two of the most common and similar criteria that being assess by all the sustainable rating tools are the

energy efficiency and indoor environmental quality. Both criteria are closely related with the end users and end use of the rated green building. Table-3. highlighted on the items that evaluated under the Indoor

Environmental Quality criteria of the selected sustainable rating tools. From the table, it is obvious that the most significant items evaluated under these criteria are the Thermal Comfort and Indoor Air Quality. This is because both of these criteria have great influence to the overall indoor satisfaction of the building occupants. This literature findings were parallel with previous research data findings from various author, as per finding made by (Frontczak and Wargocki, 2010) where thermal comfort is ranked by building occupants to be of greater importance compared with visual, acoustic and air quality.These findings was supported by (Wong et.al,2008) whose indicate that thermal comfort was found to be the most important aspect in indoor environment quality followed by air quality, noise, and visual However, their ranking was different in different countries and depending on whether the building was private or public

Table-1. Sustainable rating tools.

Item	Sustainable rating tools	Rating given	Category
1	Green Building Index (GBI) Malaysia	Certified Silver Gold Platinum	Non-Residential Residential Industrial Data Centre Township Interiors Hotel and Resort
2	Leadership in Energy and Environmental Design LEED United State America (US)	Certified Silver Gold Platinum	Building Design and Construction Interior Design and Construction Building Operations and Maintenance Neighborhood Development Homes (Residential)
3	BREEAM United Kingdom (UK)	Pass Good Very Good Excellent Outstanding **A star rating from 1 to 5 stars is also provided*	Planning Stage of Communities Design and Construction of New Buildings (Non-Domestic) Design and Construction of Domestic Buildings In-Use Assessment of an Existing Building Refurbishment and Renovation
4	HK BEAM Hong Kong	Unclassified Bronze Silver Gold Platinum	New Building Existing Building Interiors (BEAM PLUS)
5	GREEN STAR Australia	1 star Minimum Practice 2 star Average Practice 3 star Good Practice 4 star Best Practice 5 star Australian Excellent 6 star World Leadership	Green Star Communities Green Star Design and As Built Green Star Interiors Green Star Performance
6	GREEN MARK Singapore	Certified Gold Gold Plus Platinum	Non-Residential Building Residential Building School Building Healthcare Facilities Office Interior Landed Houses District Restaurant Supermarket Data Centre RetailParks

Table-2. Sustainable rating tools evaluation criteria.

Sustainable rating tools	Evaluation criteria													
	EE	WsE	IEQ	INN	SSPM	MS	RP	IP	LT	WaE	ECO	MP	P	EP
1.GBI	x	x	x	x	x	x								
2.LEED	x		x	x	x	x	x	x	x	x				
3.BREEAM	x	x	x			x			x	x	x	X	x	
4.HK BEAM	x		x	x	x	x				x				
5.GREEN STAR	x		x	x	x	x			x	x	x		x	
6.GREEN MARK	x		x	x						x				x

EE-Energy Efficiency; WsE-Waste Efficiency; IEQ-Indoor Environmental Quality; INN-Innovation; SSPM-Sustainable Site Planning and Management; MS-Material and Resources; RP-Regional Priority; IP-Integrative Process; LT-Location and Transportation; WaE-Water Efficiency; ECO-Ecology; MP-Management Process; P-Pollution/Emission; EP-Environmental Protection

Table-3. Sustainable rating tools indoor environmental quality criteria.

GBI Malaysia	LEED US	BREEAM UK	HK BEAM Hong Kong	GREEN STAR Australia	GREEN MARK Singapore
Indoor Air Quality Environmental Tobacco Smoke Indoor Air Pollutants **Thermal Comfort** Day lighting Daylight Glare Control Electric Lighting Levels High Frequency Ballasts External Views Internal Noise Levels IAQ Before and During Occupancy Post Occupancy Comfort Survey: Verification	**Indoor air quality** Environmental Tobacco Smoke Control Low Emitting Materials **Thermal Comfort** Interior Lighting Daylight Quality Views Acoustic Performance	Visual Comfort **Indoor Air Quality** **Thermal Comfort**	Safety Hygiene **Indoor Air Quality** Ventilation **Thermal Comfort** Lighting Quality Acoustics and Noise Building Amenities	**Indoor Air Quality** Acoustic Comfort Lighting Comfort Visual Comfort Indoor Pollutants **Thermal Comfort**	**Thermal Comfort** Noise Level Indoor Air Pollutants **Indoor Air Quality** High Frequency Ballasts

Table-1, Table-2 and Table-3 (Sources: 1. http://www.greenbuildingindex.org/ 2. http://www.usgbc.org/ 3. http://www.breeam.org/index.jsp 4.http://www.hkgbc.org.hk/eng/BEAM 5. https://www.gbca.org.au/green-star/ 6. http://www.bca.gov.sg/greenmark/)

CONCLUSIONS

As a conclusion, the implementation of the green building or normally known as the sustainable construction is important to be taken into vast consideration by all parties in the construction industry. This is because the concept of green in construction able to promote better and healthier quality of life to the end user of the rated building as the green building's sustainable rating tools were found significantly focuses on the aspects of the indoor environmental quality and the thermal comfort in ensuring maximum comfort satisfaction of the occupants as per previous results tabulated in Table-2. and Table-3. in this paper.

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