Post Occupancy Evaluation of Space Energy Intensity on Green Building Index Energy Efficiency (EE) Criteria

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Abstract. Green interior tool sustainable benchmarking system in Malaysian is relatively new. Despite of the launch of Malaysian Green Building Councils very own Green Interior Tools (GBI-IT) and implementation, there is still deficiency in post-occupancy measure being conducted in evaluating the holistic sustainability level on the post-certified interior project. The lacking is in particular related to the Space Energy Intensity (SEI). Thus, embark the study problem whether the certified project sustainability level is in accord to pre-occupancy rating score as parallel to vision by the designers upon occupation, in particular on Energy Efficiency (EE). The study objectives is to examine the SEI, to identify similarities and discrepancies of SEI and to weigh the main EE sub-criteria which effect SEI in order to enhance continuing sustainable EE after one year occupation. The SEI equation method and implementation approach are conducted in this concept paper by measuring the total space energy consumption per year/interior space area. The study design are devised into three key phases; 1. Content analysis of GBI-IT EE core criteria; 2. Comparative data analysis between post-occupancy and simulated pre-occupancy scoring level and; 3. Evaluation of key EE sub-criteria that affect SEI in order to improve continuing sustainability after occupation. The findings and discussions based on SEI comparative analysis will improve sustainability practice towards continuing sustainable agenda and will facilitate further enhancement for future sustainable approach in interior SEI.

Keywords: Post occupancy evaluation, space energy intensity, energy efficiency.

1. Introduction

The magnitude of sustainable development in the built environment sector, particularly in urban vicinities was established for quite a long time [1]. Urban development play an important function in pursuing sustainability via socio-economic growth and technological innovation [2]. Sustainable development at urban level suggest a well-balanced and broader specific requirement of its inhabitant which include earnings equity, job opportunities, accommodation, basic amenities, public infrastructure, accessibility connectivity and also protection to the environment [3]. Sustainable environment can be achieved at different steps and level in the urban development from the inside out of the interiors and the buildings, neighborhoods/township and cities.

Since the 90s, sustainability evaluation methods for an architecture, which generally recognized as green building index have been utilized to incorporate sustainability within the building industry sectors, and its vision presently at worldwide level. Buildings and its interior spaces are as imperative as any component in the growth of urban development [4], nevertheless the development and application of sustainable building interiors evaluation criteria principles just recently started to spread [5], and in this region, particularly in the emerging nation as Malaysia it's are however comparatively new. It is important to assess the current green building evaluation methods at this juncture of its development, in order to verify its strong point and limitations and the means to further enhance its. There are an intensifying concentration and requirement on the evaluation and endorsement of sustainable building interiors, but research on sustainable building interiors evaluation tools and certified green project are still lacking and insufficient. Current studies evaluate sustainable buildings assessment criteria based on its construct, the procedures of its implementation, its execution on circumstance studies [6] the elements its measure [7], its evaluation measures [8] and its common features [9]. These reviews offer a general explanation of sustainable buildings evaluation tools, yet their extent does not completely encompass the particulars of the evaluation structures, and there is no approach by which benchmarking structures can be accurately assessed [10].

Sustainable evaluation criteria structures comprise of indicators that acquired from a comprehensive content and literature review. Several analyses on evaluation indicators suggest the intent designations and characteristic [11], development means of a recent indicator categorizes [12], indicator significances threshold [13] and indicators framework [14]. Presently, there are numerous rating method approaches are accessible, consequently, it is rather challenging for stakeholders to actually judge the most across-the-board one. Diverse sets of requirement, significances threshold, physical factors and locale guidelines renders distinction. Currently, sustainable building development growth are mainly encouraged by governmental institution related agendas, strategies, outlines, policies, plans, programs and incentives [15] . On the other hand, collaboration by third party establishment such as building industry related professional body and institutions efforts, the development of urban sustainability evaluation systems which are based on market approach driven by has achieved significance and progressively implemented by the development project commissioners and developers.

Sustainability evaluation criteria approaches and indicator have set an apparent impact on efforts towards sustainable urban development, mostly on sustainable strategy and policy enhancement. Sustainability evaluation criteria approaches and indicators offer guidelines, material and support to urban development policy constituting [16]. Moreover, sustainability evaluation criteria also affect policy making unequivocally whereby its concern the anticipation of incentives, financial aids and award grant, for the implementation of evaluation criteria approaches, or its application procedure can be adequately shortened [17]. In certain towns, conurbations, provinces or even countries, sustainable evaluation criteria approaches have even turn out to be obligatory for recent urban development projects [18]. Nevertheless, for non-obligatory or market driven sustainable buildings evaluation criteria approaches might also augment the possibility of applying the most least sustainable, as an alternative to the utmost cost effective indicators for development projects [19].

GBI Assessment Criteria were established by Malaysia Institute of Architects (PAM) and Association of Consulting Engineers Malaysia (ACEM) as intents for Malaysia's primary sustainable urban rating instrument, which progressively will be updated and reviewed towards sustainable future. This joint initiatives between Malaysia Institute of Architects (PAM) and Association of Consulting Engineers Malaysia (ACEM) in green building indexing aims to support the construction development industry with regard to its sustainable development progression. GBI Interior Tools Assessment Criteria environmental rating approach is established to:

1. Distinguish sustainable building criteria by instituting a generic nomenclatures and standard evaluations;
2. Promote integration, holistic design; acknowledge and remunerate environmental leadership effort;
3. Regenerate built environment by reducing the environmental vulnerability of the development; and
4. Assure new building development continually significant in the forthcoming future and existing building development are rejuvenated and subsequently well sustained in remaining the relevancy.

Sustainable building rating criteria are perceived as a guidelines in assisting interior designers, architects, engineers, builders, building owners, government agencies, housing developers and finally the end users in understanding the effect of each design project option and problem-solution with regard to being a more sustainable-responsive. The Malaysian indexing in green building was established to deliver a generic and verifiable means in

sustainable benchmarking within the building industry of local context. GBI Interior Tools Assessment Criteria and its designed framework sets sustainability to additional level and lay out a vision for coherent approach in built environment paradigm. It's providing direction that will support all involved stakeholders in delivering sustainable developments.

Sustainable lifestyle and development in Malaysia especially in public interior buildings and amenities operation is imperative. The way of building designed, constructed and operated is significant to human health and environment impact. The fact that buildings required maintenance procedures, air ventilations, state-of-art equipment and 24hrs operation elevated the energy consumptions [20]. The resources used in building stressed on the importance of assessment criteria's in Malaysia green ratings and served as an initial point for the optimum and systematic green and sustainable interior practice in Malaysia [21]. Sustainable development is key to the strategic sustainability within a society. Sustainable neighborhoods are a fundamental element of a sustainable community, however the development of sustainable neighborhood as it selves will certainly not permit all stakeholders to efficiently address projected current or future issues that sit beyond of the extent of physical development scope. Holistic sustainable development of the built environment is concerning relationship full cycle between the environmental, social and economic dimension factors, and by what means it is thenceforth utilized by the society concerned. GBI Township Assessment Criteria will permit related stakeholders to presume a cohesive method in adopting the environmental dimension, social dimension, and economic dimension together with design aspects linked with the provision of a sustainable township. It offers a possibility for the implementation of collaboration centered approach during the course of the development progression and assist major stakeholders in planning, designing, building, managing and operating sustainable neighborhood development.

Thus, in evaluating these sustainability questions, the method to study is via post occupancy evaluation (POE). Post occupancy evaluation is described as; "a systematic study of buildings in use to provide architects with information about the performance of their designs and building owners and users with guidelines to achieve the best out of what they already have" [22].

2. Research Framework

The Malaysian construction and development sector has been over the years emerged and thrived in the direction of more progressive sustainable urban agendas. The subject of sustainable buildings benchmarking approach in the field of urban development in Malaysia is relatively new. Although GBI Building Assessment Criteria has been developed and implemented but there is no post-occupancy evaluation being conducted in

assessing the performance, effectiveness and sustainability level on the certified development? There has been lack of study done to measure the greenness' of the tools and the post certified building development. Even though there is study conducted on environment dimension, however fewer so are conducted on what really signifies socially or/and economically, and/or its application in the sustainable urban development context. Do sustainable buildings and its interiors evaluation criteria and frameworks in common signify sustainable holistically? [23]. Therefore, proficiency and comprehension on sustainability benchmarking criteria could strengthen buildings sustainable indicators, effectiveness and sustainability level among the Malaysian sustainable development actors are vastly still low. Studies has indicated one of the main obstacles that hinder sustainable development in ASEAN nations is the deficiency of knowledge in sustainable concerns subjects in relation to the involved building profession [24].

Past study done on sustainable building rating system potential in Malaysia also shows that Malaysia construction and development sector key stakeholders have insufficient understanding on sustainability development evaluation, benchmarking & indexing approach [25]. Due to this many green certified development project in Malaysia claim sustainability merely for label advertisement, marketing tools and higher premiums instead of fully addressing the sustainable pillars. Certified GBI projects normally a high-end urban development projects, study has indicated that sustainable certification do improve leasing and selling rate of developed properties, but this outcome is further substantial for end-users who are more innately concerned with sustainability, or pushing their 'green' appearance [26]. Even though the noble foundation for sustainable township/neighborhood is to promote and applied sustainable development, but there is no study was undertaken to address and gauge this issues.

GBI Interiors Tools ingenuity aims to support the building development industry in its direction towards green development approaches in interior design, architecture and urban design as a holistic manner. The intentions is to establish a mutual recognized standards; encouraging integrated based building and its interiors from beginning of the project; recognised and remunerated sustainable initiatives; and interior projects relevancy in the forthcoming. Nevertheless, this pre-occupancy evaluation measures and guides for certified green interior project is evaluated during design, construction and completion stage. Hence the benchmarking was not conducted and carried out after the interior spaces are inhabited by the end-users. Thus, embarking to the study problem whether the interior project's sustainability level are accordance to the pre-occupancy benchmark as vision by the designers after occupation, particularly on Energy Efficiency (EE).

From the research problem, the conceptual framework of this study was designed as indicated in Fig. 1.
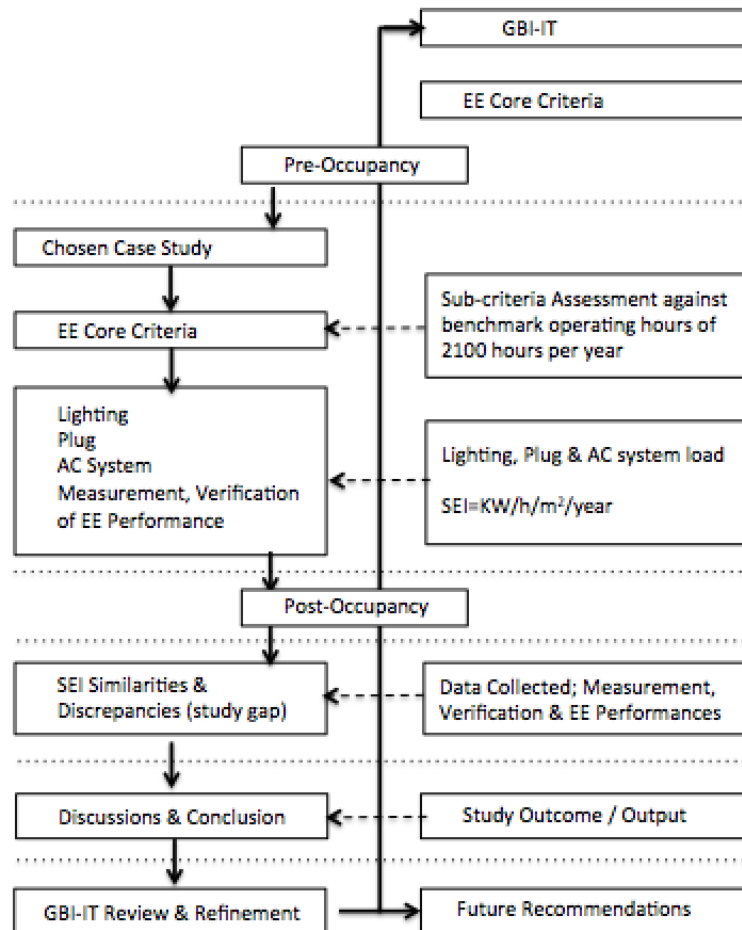
Fig. 1.   Framework of Study.

1.1   Research Questions

Based on the research problem, research questions are designed to address the objectives of this research. There are three main study questions:
1.   What is the SEI upon post occupancy in Interior Project?
2.   Why SEI might fluctuate throughout post occupancy evaluation.
3.   How the assessing factors will affect SEI EE sub-criteria and how to improve continuing sustainable EE upon post occupancy

1.2   Research Objectives

The research objectives are to establish the gap upon post-occupancy SEI of an interior project. There are three key objectives of the study:
1.   To examine the SEI upon post occupancy in GBI certified Interior Project.
2.   To identify the factors of SEI fluctuations throughout post occupancy evaluation.
3.   To assess the factors that affect SEI EE sub-criteria and to improve continuing sustainable EE upon post occupancy

3.   Research Methodology

The choosen case study is government establishment for training facilities. The building is eleven (11) storey full-fledged facilities and using centralized air conditioning system. It consists of training officer's accommodation, training officer's dining mess which can accommodate 270 guests at one time, auditorium, prayer hall, meeting rooms and recreational facilities such as gymnasium, reading room and television room. The building also has a multilevel car park. These training facilities were in operation for more than ten years. The architects vision for the buildings is to design training facilities which can occupied up to 300 pax of training officers at one time during full operation, however over the years, the growth demand in number of training officers and development of training courses changed over time. The gathered data, which includes the no. of training officers (no. of pax each year), total floor area (net total of interior occupied spaces) and yearly total energy consumption (lighting, plug and air-conditioning system load) for over 10 years of occupancy. Throughout ten years, the occupancy pax, the energy load growth and developed over the time and lifestyles, meanwhile the total net floor area remained constant.

The key changes of space usability and occupancy density will affect energy efficiency mainly and other

factors. Thus, the scope of the research is focusing on GBI-IT energy efficiency (EE) sub criteria, which includes lighting, plug and AC system load. In addressing this problem of study, the methodology of study employ Space Energy Intensity (SEI) equation method in order to measure total space energy load per year/net interior space area.

$$\mathbf{SEI} = \sum (\boldsymbol{l}^1 + \boldsymbol{l}^2 + \boldsymbol{l}^3)/\boldsymbol{F}(\boldsymbol{m}^2)$$

where Space Energy Intensity is defined follows:

SEI = Total Space Energy Consumption per year ($\sum$) / Interior Space Area (F)

where Total Space Energy Consumption per year; Total amount of energy used per year from all services required to operate the space [Air Conditioning (l^1); Electrical Lighting (l^2); and Plugged Load (l^3)].

SEI is to be calculated within the official operating hours.

The SEI may be rationalized for benchmarking against the industry through the following; Benchmark

operating hours 2700 hours per year as indicated in Table 1.

Table 1.   Factors of operation hours.

Official Operating Hours	Operation Hour Factor
2100	1.29
2400	1.13
2700	1.00
3000	0.90
3300	0.82

The SEI score in this study to gain energy benchmarking were proportionated against Building Energy Intensity (BEI) consumed from the total building measurement of energy consumption. In post-occupancy evaluation, whereby the total net internal spaces consumed centralized air conditioning systems, the load consumption from air conditioning system used is to be acquired through the base building operation, and to be included in the SEI calculation.

SEI benchmark values were derived as of formulation specified in Table 2.

Table 2.   SEI benchmarking based on 2100 hours of office operation.

BEI	SEI	AC Energy Load	Lighting Energy Load	Plug Energy Load
100%	55%	50%	20%	30%
150	83	41	17	25
140	77	39	15	23
135	74	37	15	22
120	66	33	13	20
110	61	30	12	16
100	55	28	11	17
90	50	25	10	15

The research design will be formulated into three key stages, which are:
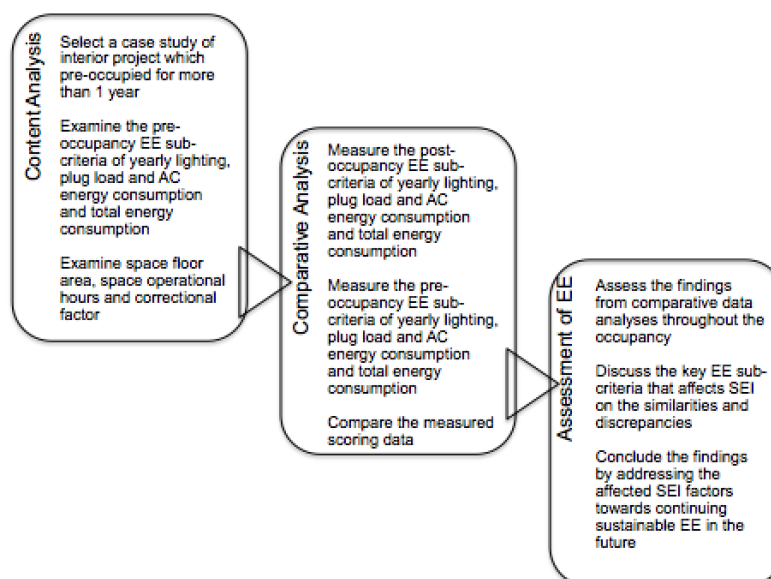

Fig. 2.   Sequence process of the study.

In this research, the research process sequence was designed in a way to achieve the study objectives and derived from the research problem statement. Based on the sequence research process as indicated in Fig. 2 above, there are three main processes were conducted in order to conclude the study outcome. The significance of the study is to pursue continuing sustainable agendas by addressing the energy efficiency criteria. This is important and highly significant in sustainability evaluation whereby the projected EE evaluation during pre-occupancy assessment is compared against the actual post-occupancy (Y1-Y10) assessment within 10 years of building operations. The generated outcomes will validate the variable factors against the ideal designer's vision and the actual habitual consumption of energy in the interior spaces be it for working, living or any other routines.

The first sequence of study process were content analysis of EE criteria in GBI-IT and to choose a case study of an interior project. The data were obtained by examining the pre-occupancy (Y0-Y1) EE sub-criteria of lighting & plug load, AC energy usage and total energy consumption. Next process was to examine space floor area (net total interior floor area), SEI, space operational hours and correctional factor. This data was a projected data of EE measurement and verification, which was projected for Completion and Verification Assessment (CVA) submission to GBI-IT evaluation procedure. The SEI equation and correctional factor was employed in calculating this data. This scoring data was then set as a baseline of the study.

The second sequence process was to compare the analysis data of pre-occupancy EE sub-criteria scoring benchmark (Y0-Y1) throughout post occupancy EE sub-criteria scoring benchmark (Y1-Y10). The selected case study of this research is GBI-IT evaluated interior project, which was occupied for about 10 years. The justification for 10 years post-occupied interior Project is to get the data of energy used based on actual data collection and calculations. The same method of data collection is used in measuring and calculating data of the same case study after it being occupied for 10 year. The gathered data is calculated using the same SEI equations in order the get consistency and validated results. This is very important as the research gap and research objectives on fluctuation factors of the variables can be identified and verified. Comparison of variables can be distinguished clearly on the SEI energy used between pre-occupancy and throughout post-occupancy. This is done by comparing the SEI progressive post-occupancy (Y1-Y10) scoring data with the pre-occupancy (Y0-Y1) baseline data. Assessment of variables fluctuation factors that affect Space Energy Intensity (SEI) and to improve continuing sustainable EE upon post occupancy.

The final stage is to assess the findings from comparative data analysis throughout pre-occupancy to post-occupancy measures. From the findings the variables that affect SEI fluctuation based on pre-occupancy baseline and upon post-occupancy measures will be used to validate the study. The findings is then addressed how the affected SEI can be improved towards continuing sustainable EE in the future. The continuing sustainable measure on-site and at real-time, particularly on energy efficiency is vital in promoting sustainable agenda holistically and thoroughly.

4. Findings and Discussions

The architects vision for the case study is to design training facilities which could occupied up to 300 pax of training officers at one time during full operation, however over the years, the growth demand in number of training officers and development of training courses changed over time. The findings of the study indicated an increased of no. of training officers for over 10 years. The annual increment of training officers approximately at 48.4 pax yearly. From originally vision 300 pax, the increment has increased to 734 pax by the tenth year. This has indicated the one of the variables factors that intensifies the energy consumption. Thus, affected the EE criteria from vision ideas by the architects or interior designers. Besides, the changing lifestyles and technological change might worth to be noted as minor factor that might affect EE criteria. The increment of yearly users suggested an increment of plug load and A/C system used. Figure 3 below indicated pax growth over 10 years.
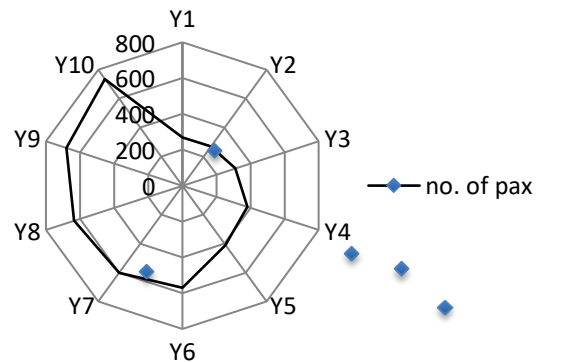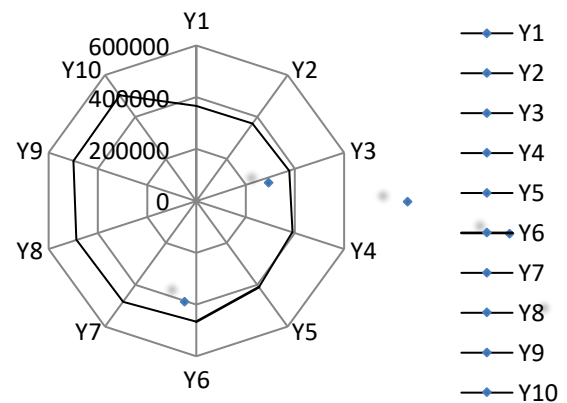

Fig. 3.   Pax growth over 10 years.

Fig. 4. $\sum$ consumption for over 10 years.

Another notable increment in SEI equation is energy load consumption ($\sum$=Air Conditioning (l^1)+Electrical

Lighting (l^2)+Plugged Load (l^3)), beside constant total net floor area (F=m²). The load consumption growths from Y0-Y1 to Y10 are almost parallel to no. of pax increment, from 366000 KW/h per year to 504000 KW/h per year. The yearly increment of ∑ from Y0-Y1 to Y2 is 1946 KW/h, from Y2 to Y3 is 9254 KW/h, from Y3 to Y4 is 13200KW/h, from Y4 to Y5 is 21200 KW/h, from Y5 to Y6 is 54880 KW/h, from Y6 to Y7 is 14520 KW/h, from Y7 to Y8 is 6300 KW/h, from Y8 to Y9 is 11900 KW/h and finally from Y9 to Y10 is 4800 KW/h. From Y0-Y1 to Y10, the ∑ consumption differences is 138,000 KW/h. Figure 4 below indicated ∑ consumption for over 10 years and Fig. 5 to indicated yearly increment of ∑ consumption.
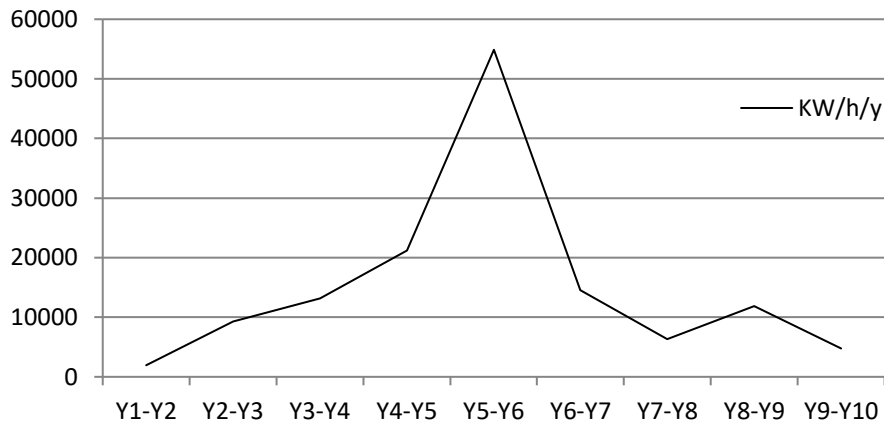

Fig. 5.   Yearly increment of ∑ consumption.

Table 3 below indicated the comparison of ∑ consumption, no. of pax and m² from Y0-Y1 to Y10. Both no. of pax and KW/h increased over the years meanwhile the m² is in constant. Increment of no. of pax and KW/h are steadily parallel even though the values are not uniformly multiplied. No. of pax increment particularly from Y5 to Y6 (159 pax) is more than double from architects or interior designers vision when designing the building (Y0-Y1) has indicated the highest leap in ∑ consumption as indicated in Fig. 5. This suggested no. of occupancy in the space directly increased of ∑ consumption. For over ten years (Y0-Y1 to Y10) the ∑ consumption has increased 72.6%. Thus, verify and validated that EE sub-criteria of lighting load, plug load and A/C system load changes due to no of pax increment.

Table 3.   Yearly data of no. of pax (+), m2 (constant) and KW/h (+).

Year	Y0-Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10
no. of pax	250	300	310	382	411	570	600	634	680	734
m²	17465	17465	17465	17465	17465	17465	17465	17465	17465	17465
KW/h	366000	367946	377200	390400	411600	466480	481000	487300	499200	504000

From the yearly data of Table 3, using SEI equations (SEI = ∑ $[l^1+l^2+l^3]/F$ $[m^2]$), the SEI score was calculated by multiplying correction factor (1.29) of 2100 official operation hours. The yielded corrected SEI score is as indicated in Table 4. The highest increased of corrected SEI among 10 years is from Y5 to Y6 at 4.05KW/h/m²/y, meanwhile it steadily increased at 1.5KW/h/m²/y before Y5 and after Y6. Total of 10.18 KW/h/m²/y increased of SEI throughout 10 years or equivalent to 72.6%. The highest increased of SEI at Y5 to Y6 are due to no. of pax factors which also see the highest no. of pax intake lead of that particular year.

Table 4.   SEI score based on 2100 Hours correction factor.

Year	Y0-Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10
SEI (KW/h/m²/y)	20.95	21.06	21.60	22.35	23.56	26.70	27.54	27.90	28.58	28.85
Corrected Factor	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29
Corrected SEI	27.03	27.16	27.84	28.83	30.39	34.44	35.52	35.99	36.86	37.21

Table 5.   GBI-IT Value against SEI.

GBI-IT Value	SEI
1 Point	SEI < 85 kWh/m2 /year
2 Points	SEI < 80 kWh/m2 /year
3 Points	SEI < 75 kWh/m2 /year
4 Points	SEI < 65 kWh/m2 /year
5 Points	SEI < 60 kWh/m2 /year
6 Points	SEI < 55 kWh/m2 /year
7 Points	SEI < 50 kWh/m2 /year

Based on GBI-IT score as indicated in Table 5, the case study SEI is still below the maximum score of GBI-IT value. Throughout 10 years of operations, the case study score 7 points (maximum score of GBI-IT Value) as the SEI is <50 KWh/m²/year. However, there is still escalated consumption in energy due to no. of pax demand. Even though the SEI is within the GBI-IT value, the main factor is still lies on the no. of pax which is the training officers. Based on GBI-IT EE core criteria of lighting, plug and A/C system load there is still room for improvement in maintaining the EE sustainability agendas. From SEI score in Table 4, throughout 10 years the increment patterns of SEI $\sum$ consumption are steadily escalate parallel to the no. pax, thus, indicated there is no improvement in term of pro-sustainable psycho-behavioural by administrator and training officers as the end users. Business as usual meaning constantly increase of $\sum$ consumption, which lead to increase of SEI. Few interventions on pro-sustainable psycho-behavioural need to address towards EE criteria of lighting load, plug load and A/C system load. Since the case study is government training facilities with ever-changing training officers yearly, new sustainable approach as simple as intake briefing on energy saving directed at lighting, plug and A/C system usage might save a lot of $\sum$ consumption. To conclude the discussions, the study have verified and validated that post occupancy evaluation of SEI EE criteria (light, plug and A/C system load) fluctuate or increased based on no. of pax (training officers intake) factor and to improved EE criteria sustainability agendas, pro-environmental psycho-behavioural need to be instilled to the end-users of the space.

5.   Conclusions

GBI-IT for interior projects is gaining acceptance as indexing works structure in implementing green interior benchmarking issues, disagreement and management requirements. The main goal of mainstreams green management for interior project and related assessment tools is to achieve sustainable use of design resources and user experience [27]. GBI-IT for interior project is a sustainable rating system developed by MGBC (Malaysia Green Building Councils) and MIID (Malaysian Institute of Interior Designers). The tool is a comprehensive assessment system for assessing the sustainable design and performance of interior design project upon six (6) main factors which is energy efficiency (EE), indoor environment quality (EQ), sustainable planning management (SM), materials resources (MR), water efficiency (WE), and innovation (IN). The heading criterias set is to maintain all of standards scoring criteria in all previously developed tools in GBI rating framework system [28] The GBI-IT is developed specifically for the Malaysian tropical weather, environmental and developmental context, cultural and social needs [10]

From the study outcome, it is verified and validated that SEI upon post occupancy increased parallel with the increment of no. of pax intake in the training facilities (case study). The highest increased on SEI throught 10 years of operation is due to almost 100% or double of increased of visioned no. of pax by the architects or designers when they built the project. The outcome also suggested that annual increment of no. of pax, due to whatever reason or policy set by this case, steadily increased the SEI. Thus, suggested there is no attempt by the administrator of the facility in addressing the improvement of EE criteria (light, plug and A/C system load). As discussed in sub-chapter no. 4, business as usual means no 'sustainable improvement' on EE criteria. Eventhough the case study SEI is still within GBI-IT value score, pro-environmental psycho-behavioral needed to be instilled to the training officers throughout their yearly occupancy in onder to maintain the continuing sustainable agendas.

Based on the discussion above, it can be concluded that projected measures of EE from pre-occupancy and during post occupancy are very important in promoting and parallel with the establisment of GBI-IT tools as an effort towards continuing sustainable development. However, it is also important that this effort is extended by reassessing all interior project particularly in EE criteria. This vital study is to addressed on affecting factors of EE criteria fluctuation or increment throughout post-occupancy. The designers vision of pre-occupncy assessment are based on projected energy used of ideal scenario of building occupancy. Logically, buildings or any built environment is a 'living organism', it may expand to grew or declined, or even died. Hence, the actual measurement of an interior space is to get the real on-site SEI data is important in order to assess the growing green 'health' of an interior space. The analysis of post-occupancy SEI data against other affecting factors data will offer variable factors towards a more sustainable EE criteria for future diagnosed.

Acknowledgement

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