A Study of The Practical Use of Green Engineering-Based Technology for Building Sustainability: Users’ Perspective

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Abstract. Sustainable construction has been the main priority in the global construction industry. For that reason, Malaysia is moving towards green building approach to promote built environment sustainability. Therefore, it is essential to raise awareness about the environmental-responsible practice among construction players particularly on the implementation of green engineering-based technology. This study aims to explore the existing green engineering-based technology and to investigate the preferred green engineering-based technology to upgrade the sustainability of existing residential buildings. The study focuses on the existing technology to be incorporated in the operation of buildings. A comprehensive literature review was carried out and 384 feedback was collected from questionnaire survey distribution among respondents in Johor Bahru. Various green engineering-based technology includes solar energy, wastewater treatment, rainwater harvesting, window shading, housing landscape, natural ventilation, smart PDLC film glasses, roof thermal insulation, and smart home control panel are discussed in this paper. From this study, it was found that that the housing landscape is the most preferred with the highest mean index value followed by daylighting system and solar panel. The results indicate the preferred green engineering-based technology is because of low cost and familiarity among users. The future study should consider relating the awareness of individuals on sustainability with their preferred green technology. Perhaps, the coverage of this study should be extended by involving respondents from all over Malaysia.

1. Introduction
Sustainable development is an important aspect of building construction in modern times. The development that incorporated a sustainability approach required sustainable principles in construction to be practiced. Thus, one of the solutions to support sustainable practice in construction is green engineering-based technology. It is a method to promote sustainable techniques like incorporating smart and advanced equipment in buildings to ensure more economical, high efficiency, and environmental-friendly. The adoption of green engineering-based technology in construction activities could promote sustainable buildings in terms of energy usage and minimization of waste. It enhances the use of wastes to be reused and recycled into useful products. This promotes less usage of natural resources and saves money. Sustainability is achieved by re-evaluating the issue that causes environmental pollution to design a more constructive way of green engineering to be more sensible to be applied in building [1].

In order to promote building sustainability, every phase of the building life cycle has to be guided by sustainable principles. Energy efficiency and application of renewable energy are among the important element to attend to. Many contractors recently implementing a sustainable approach to preserve the environment at the same time conducting their construction activities [2]. Materials should be selected
based on their significance of impacts to the environment as well as to the well-being of humans throughout the construction lifecycle. Besides, sustainable building features perhaps could maximise operational efficiency which contributing to the energy consumption efficiencies. However unfortunately, green practice in construction has been neglected among contractors due to unfamiliar exposure to this approach [3]. This situation needed further attention to make sure the construction practitioners aware of the technology that exists for protecting the environment, while simultaneously improving human health and well-being, and conserving valuable resources like water and energy. Therefore, the exploration of green engineering-based technology is necessary. The objectives of this study are to discover green engineering-based technology that contributing to building sustainability as well as preferred choice of users incorporating such technologies into their residence.

1.1. Green engineering-based technology
Green engineering-based technology is the incorporation of sustainable features in a product by modifying the existing technology to reduce implications towards ecosystem [4]. The equipment or technology based on sustainability purposes need to be designed to be practical to install and show benefits towards consumers. Commonly known as eco designs, which has endless conveniences that serve towards sustainable practices among users [5]. Eco design equipment able to reduce usage of energy and reduce emission of greenhouse gases towards environment [6]. This means eco design need to be environmentally efficient when in operation. The execution of eco design in retrofitting buildings need to focus towards achieving green building criteria. Thus, the green based technology is appropriate to replace the conventional technology in order to operate better towards sustainability focused.

Green engineering-based technology must ensure to not neglect the detrimental effects towards environment during production and operation [7][8]. The green technology needs to be durable and user friendly. The high durability of technology avoid frequent replacement as this will save resources in production [9]. The technology which is sustainability driven need to consume minimal amount of energy as this will provide great energy saving. For instance, power utilization can be reduced with installation of green engineering for the operation of buildings [7]. Addition to this, the ecoefficiency growth increases in time when existing buildings are been retrofit with green engineering.

Green engineering-based technology need to be profitable with the inclusion of eco-friendly requirements [10]. Underdeveloped nations faced barriers in practicing green engineering for buildings such as shortage of venture capital and exposure of its application [7]. Insufficient of proper execution of green engineering-based technology among stakeholders is caused by their ignorance about the applications and practicability [11]. This study perhaps could provide collective insight and idea in incorporating green engineering-based technology into building project development or even in redevelopment of existing building.

2. Materials and methods
There were two parts involved in this study which are comprehensive literature review and questionnaire survey.

2.1. Literature review
Literature review is important to gain information about related scope of research from past studies. In this study, comprehensive literature review was carried out to achieve the main objective of the study which is to explore the existing green engineering-based technology in promoting sustainable building. The green engineering-based technology explored in literature review are based on existing technology. The most used databases for literature review were ScienceDirect, Scopus, ResearchGate and Springer Link as they provide interdisciplined research databases. The Boolean operators consist of ‘AND’ or ‘OR’ were used with keywords in identifying chosen journals. The keywords and Boolean operators were used together which consist of “solar energy” AND “sustainability” OR “energy saving”, “wastewater treatment” AND “sustainability”, “rainwater harvesting” AND “sustainability”, “window shading” OR “window tint” AND “sustainability”, “landscape” AND “sustainability”, “natural ventilation” AND “sustainability”, “PDLC” OR “smart window” AND “sustainability”, “roof insulation” AND “sustainability”, “smart home” OR “building automation system” AND
“sustainability”. Next, the results were filtered according to publication years which were between 2010 to 2021.

2.2. Questionnaire survey
A questionnaire survey was used to investigate the preferred green engineering-based equipment to upgrade the sustainability of existing residential building. The questionnaire was distributed to respondents which are residents in Johor Bahru. A total of 384 feedbacks were collected and considered sufficient for analysis based on Krejcie and Morgan’s sample size table [12]. A brief information with photo of each green engineering-based technology were included in the questionnaire form. This is to give an idea to respondents regarding the green engineering-based technology in helping them to answer the survey. The first section of questions was using 5-point Likert scale to identify their preferable on the listed technologies, meanwhile the second section asking on price ranges that they willing to spend for each of the item. The IBM SPSS Statistics software is used to analyse the data obtained based on the mean index as shown in equation (1).

\[
\text{Mean Index} = \frac{\sum (X_1 + 2X_2 + 3X_3 + 4X_4 + 5X_5)}{\sum (X_1 + X_2 + X_3 + X_4 + X_5)}
\]

where; 
- \(X_1\) = Number of respondents on scale 1
- \(X_2\) = Number of respondents on scale 2
- \(X_3\) = Number of respondents on scale 3
- \(X_4\) = Number of respondents on scale 4
- \(X_5\) = Number of respondents on scale 5

3. Results and discussion
This section presents in details the findings of the study from comprehensive literature review and analysis of the questionnaire survey.

3.1. Exploration of the existing green engineering-based technology in promoting sustainable building
From the literature study, there are nine types of green engineering-based technology were identified and chose for this study includes solar energy, wastewater treatment, rainwater harvesting, window shading, housing landscape, natural ventilation, smart PDLC film glasses, roof thermal insulation and smart home control panel. All of them were found significantly contributed to the sustainability of a building in many ways as shown in Table 1.

Table 1. Contribution of green engineering-based technology towards sustainability.

| Green engineering-based technology | Contribution towards sustainability |
|------------------------------------|------------------------------------|
| Solar panel                        | The most environmental-friendly to generate power [13] |
|                                    | Enhance ecofriendly value of building [14] |
|                                    | Produce more renewable energy [15] |
|                                    | Reduce consumption of raw materials by replacing roof with building integrated photovoltaics (BIPV) [16] |
|                                    | Promote production of solar energy which considered as finest renewable energy [17] |
| Wastewater treatment               | Conserve water consumption [18] |
|                                    | Reduce pollutants to be released into catchment areas [19] |
|                                    | Curb scarcity of water supply [20] |
|                                    | Reduce power consumption and substitute for fertilizers [21] |
|                                    | Microfiltration to treat laundry wastewater require less expenses and polluted water not generated [22] |
| Rainwater harvesting               | Decrease consumption of water [23] |
|                                    | Prevent water wastage [24] |
|                                    | Decrease non-renewable energy usage [25] |
Green engineering-based technology | Contribution towards sustainability
---|---
Lessen utilization of clean water [26] |  
Conservation of water [27] |  
Window shading | Reduce energy consumption of cooling load [28]  
Enables conservation of energy from consumption of artificial lighting [29]  
Decrease thermal loading decrease, therefore consequently requires less cooling load [30]  
Minimise cooling loads consumption [31]  
Provide optimum natural lighting, thus save energy usage on electricity [32] |  
Housing landscape | Contribute to less gain of heat energy that requires high power consumption [33]  
Reduce consumption of cooling energy [34]  
Provide cooling effect to surrounding area consequently provide natural cooling [35]  
Provide catchment areas for runoff and contribute to indoor comfort temperature with minimal power required [36]  
Minimize heat gain, therefore requiring less air conditioning usage [37] |  
Natural ventilation | Decrease usage of energy in building [38]  
Provide comfort temperature, consequently reduce utilization of air conditioning and fans [39]  
Improve air flow without using so much electricity for cooling [40]  
Better efficiency of air flow and reduce power usage [41]  
Reduce cooling loads [42] |  
Smart PDLC | Decrease heat gain, then reduce usage of air conditioning [43]  
Lower the usage of lighting [44]  
Regulate thermal gain of building consequently lessen cooling loads [45]  
Promote energy efficiency [46]  
Enhance the performance of cooling loads with minimal power [47] |  
Roof thermal insulation | Decrease thermal radiation [48]  
Enhance thermal reflectance and requires less energy to cool the building [49]  
Enhance efficiency of building energy [50]  
Declining temperature in building for optimum usage of mechanical cooling [51]  
Minimise heat gain and deduction of energy required in building [52] |  
Smart home control panel | Saves energy consumption at home [53]  
Reduce unnecessary wastage of electrical consumption [54]  
Reduce the usage of artificial lighting [55]  
Decrease the usage of energy [56]  
Managing energy consumption with integrated automation system monitors power consumption of building [57] |  

Solar energy is recognized for its practicality as green energy. It is stated as the most environmentally-friendly in generating electricity [58]. Solar energy can be produced by integrating solar panels at home which able to harvest sunrays. With continuous evolving for the betterment of solar panels, the generation of electricity will be more significant with solar energy causing less dependent on fossil fuels. Hence, a significant reduction of carbon and greenhouse gas emissions can be achieved.

For wastewater treatment, reusing and treating wastewater enable to conserve the usage of freshwater [20]. Wastewater can also be reused for watering crops, even can be converted to fertilizers[18,21]. On the other hand, treating wastewater could reduce pollutants to be released into catchment areas and this prevents water contamination [19].

Besides that, consumption of water can be reduced by implementing rainwater harvesting [23][27]. The usage of daily water demand supplied from harvesting rainwater causing less burden on freshwater supply. With the demanding usage of water due to the increasing of the human population, practicing rainwater harvesting might conserve water for important usage.

Contributing to indoor comfort, window shading is significant to control sunrays entering the building. This is proven when upgrading window with double glazing and solar film reduces energy consumption of cooling loads [28]. Besides, optimization of blinds and louvers provides optimum...
natural lighting during daytime [32]. Thus, window shading is required to reduce the usage of cooling loads and artificial lighting in the building [29].

For the housing landscape, thermal gain inside the building can be controlled with a better shading mechanism [37]. Suitable tress can provide shading for housing from direct rays of sunlight. Another point, evapotranspiration from plants provides a cooling effect to the surrounding area of the building [35]. Hence, housing landscape is beneficial to ensure better efficiency of mechanical cooling performance in the building, thus contributes to lesser energy consumption.

Furthermore, natural ventilation is identified as a way to naturally cool the house with minimal usage of mechanical ventilation [38]. Night-time ventilation is identified as the best time to allow cool air from outside to cool the building [39]. Thus, incorporating natural ventilation and mechanical ventilation separately or together will reduce the power consumption of cooling loads required [42]. This lead building to be more energy efficient in operation.

Next, smart PDLC film glasses are advancements of green technology which able to regulate the thermal gain inside a building with minimal power required to operate. It is shown that utilizing PDLC contribute to lesser heat gain in a building [43,46]. The adoption of smart PDLC film glasses is beneficial to achieve thermal comfort in buildings with reducing consumption of cooling loads.

For roof thermal insulation, heat gain in a building can be reduced [49][51]. It was found that the adoption of aluminium insulation is better in efficiency to reduce the absorption of heat compared to low emissivity paint [48]. By reducing the thermal gain, excessive cooling energy needed can be reduced to achieve indoor thermal comfort.

Another technology, a smart home control panel is an integrated technology to control the usage of electrical appliances at home. More importantly, energy monitoring is possible with this technology. This enables the building occupants to optimize the energy consumption and manage the operating electrical appliances [54]. Thus, the integration of building automation system into homes or buildings is believed could significantly minimize the usage of electricity [54][56].

3.2. Users’ preference of the green engineering-based technology

Data of the preferred green engineering-based technology of the users to be incorporated into their homes is shown in Figure 1. Based on the mean value shown, the highest mean reflects the most preferred green engineering-based technology while the lowest mean reflects the least preferred green engineering-based technology in terms of upgrading existing houses to be more sustainable. According to the analysis shown, the highest mean value is 4.40 which is housing landscape, ranked as first. The second rank with a mean of 4.33 is a daylighting system. Both of these are more preferred among other technologies perhaps because they are easy to execute. Besides, they are also a low-cost solution. On the contrary, even the solar panel known as one of the expensive technology to adopt, it was ranked third with mean value 4.27. Probably this might due to the potential of electrical savings that could be earned by the users.

![Preferred green engineering-based technology to increase sustainability of existing house](image-url)

**Figure 1.** Mean for the preferred green engineering-based technology.
The least mean ranked is smart PDLC film glasses with a value of 3.68. This shows the retrofitting with this technology is the lowest preferred among respondents. The high cost and unfamiliar technology of smart PDLC film glasses might be reasons for respondents to not install it at their houses. Besides, most respondents are living in terrace houses and they perceived this technology is not necessary to be installed as their houses are not categorized as luxury type.

Table 2 shows the willingness to spend on green engineering-based technology among respondents. The price ranges for each item are shown in the table. For the solar panel, the highest chosen price range is ‘RM5000-RM20,000’ with 65.10%. This is the most chosen among respondents due to the affordable range to spend on solar panels. Only 0.8% willing to spend at the highest price range. For other items such as rainwater harvesting kit, tint film, housing landscape, exhaust fan, roof insulation and smart home system, high percentage of respondent are also willing to spend but with minimal range of spending. Differently for smart PDLC film glasses, it was found the percentage of respondents that unwilling to spend and willing to spend with minimal range is quite closed which are 43% and 40.1% respectively. This might because the cost of the technology is high and expensive. Most respondents probably are not familiar with the advanced technology of smart glasses. Consider among the cheapest solution, for wastewater treatment and daylighting system, the majority of respondents willing to spend as required. Perhaps both fall under affordable expenses.

| Cost to spend on Green Engineering-Based Technology | Frequency Percentage (%) |
|--------------------------------------------------|---------------------------|
| Solar panel                                      |                           |
| Not willing to spend                             | 29.40                     |
| RM5000-RM20,000                                 | 65.10                     |
| RM20,000-RM40,000                               | 4.70                      |
| >RM40,000                                       | 0.80                      |
| Wastewater treatment                            |                           |
| Not willing to spend                             | 17.70                     |
| Spend as required                                | 82.30                     |
| Rainwater harvesting kit                        |                           |
| Not willing to spend                             | 24.00                     |
| RM1000-RM5000                                   | 70.80                     |
| RM5000-RM10,000                                 | 4.70                      |
| >RM10,000                                       | 0.50                      |
| Install tint film on windows                     |                           |
| Not willing to spend                             | 15.60                     |
| RM100-RM300                                     | 47.90                     |
| RM300-RM500                                     | 24.20                     |
| >RM500                                          | 12.20                     |
| Daylighting system                              |                           |
| Not willing to spend                             | 16.10                     |
| Spend as required                                | 83.90                     |
| Housing landscape                               |                           |
| Not willing to spend                             | 11.50                     |
| RM100-RM300                                     | 44.80                     |
| RM300-RM500                                     | 27.30                     |
| >RM500                                          | 16.40                     |
| Exhaust fan                                      |                           |
| Not willing to spend                             | 11.50                     |
| RM100-RM200                                     | 55.20                     |
| RM200-RM300                                     | 22.40                     |
4. Conclusion
This study emphasizes on retrofitting existing residential buildings with practical green engineering-based technology for building sustainability. The green engineering-based technology that has been recognized are solar energy, wastewater treatment, rainwater harvesting, window shading, housing landscape, natural ventilation, smart PDLC film glasses, roof thermal insulation, and smart home control panel as comprehensively discussed. From a total of 384 feedbacks, it was found that the most three preferred green engineering-based technology are housing landscape, daylighting system, and solar panel with mean values 4.40, 4.33, and 4.27 respectively. From the willingness-to-spend survey, respondents are likely to spend as required for the daylighting system. Meanwhile for both housing landscape and solar panels, most of them only willing to spend in a minimum range. Thus, it can be concluded that the low cost and familiarity among users were the main criteria that contributed to green engineering-based technology preferred in this study. The findings of the study may be useful for construction practitioners to embed the green engineering-based technology to retrofit the existing residential buildings to enhance energy efficiency and sustainability.

5. References
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