CHEMICAL ENGINEERING TRANSACTIONS

VOL. 45, 2015

A publication of AIDIC
The Italian Association of Chemical Engineering
www.aidic.it/cet

Guest Editors: Petar Sabev Varbanov, Jiří Jaromír Klemeš, Sharifah Rafidah Wan Alwi, Jun Yow Yong, Xia Liu
Copyright © 2015, AIDIC Servizi S.r.l.,
ISBN 978-88-95608-36-5; **ISSN** 2283-9216 DOI: 10.3303/CET1545075

A New Green Index as an Overall Quantitative Green Performance Indicator of a Facility

Mohamad Asrul Mustapha[a,b], Zainuddin Abd Manan*[a,b], Sharifah Rafidah Wan Alwi[a,b]

[a]Process Systems Engineering Centre (PROSPECT), Research Institute of Sustainable Environment, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[b]Faculty of Chemical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
zain@cheme.utm.my

In assessing the greenness of a facility, a few green performance indicators and assessment tools such as the Building Research Establishment Environmental Assessment Method (BREEAM), the Leadership in Energy and Environmental Design (LEED), and Green Building Index have been developed. Although these tools can help promote green building designs and operations, they do not provide a quantitative measure of the overall impact of a facility on the environment. This is due to the fact that most of the current green rating assessment tools utilise the point-based rating system. Such system has several limitations. First, it can only provide a relative measure of the greenness of a system. Secondly, the points awarded may not be consistent as it can vary from one assessor to another. Finally, the available rating tools do not provide a single indicator of the greenness of a system as each green element of a system is evaluated separately rather than as a whole. This paper presents a new tool for assessing the greenness of a facility that overcomes the aforementioned limitations. The use of the stock market composite index as a tool to assess the stock market performance has been extended to the domain of facility management that includes industrial and commercial buildings. The composite index has been utilised as the basis to develop a Green Index to assess and manage an organisation's level of greenness. The advantage of the composite index that could capture the movement of price within each stock and reflect it into a single composite index could be used in measuring and monitoring the impacts contributed by the individual green elements, on the environment. Results show that the formulation of the Green Index with weighting assignment using factor analysis would help organisations simultaneously optimise and improve their energy and water consumption, as well as waste generation. In addition, the Green Index graph provides facility managers with a graphical tool to visualise and gain insights on the performance trend of a facility.

1. Introduction

The effectiveness of green assessment tool in portraying the actual greenness performance for facility has been an on-going debate. This issue is faced by both certified and non-certified green buildings globally. Although some researchers have paid attention to the positive impacts of green assessment tools, there are findings where LEED-certified buildings, for example, use more energy compared to non-LEED counterparts (Newsham et al., 2009). Another report by Scofield (2013) mentioned that LEED-certified buildings did not show a significant reduction either on the energy consumption or greenhouse gas emission as compared to non-certified LEED buildings.

In Malaysia, this issue has become a major challenge for certified green building owners. According to Huat and Bin Akasah (2011), they found that a few accredited green buildings did not perform as per their design specifications after the post-occupancy assessment. In another study, they mentioned that a certified green building such as the Malaysia Green Technology Corporation had difficulties in achieving targeted Building Energy Index (BEI), although it was designed based on the zero-energy building (ZEB) concept (Huat and Bin Akasah, 2011). The issue of the current green assessment tools not being able to portray the actual greenness of a facility has been rather well-documented. This issue is crucial to be

Please cite this article as: Mustapha M.A., Manan Z.A., Wan Alwi S.R., 2015, A new green index as an overall quantitative green performance indicator of a facility, Chemical Engineering Transactions, 45, 445-450 DOI:10.3303/CET1545075

resolved because green buildings have been considered as having a key role to play in environmental conservation by many countries.

Many studies have been done towards improving the current green building assessment tools' weighting schemes. According to Sabake (2008), a weighting assignment that depends on the needs and priorities of the origin countries would lead to non-standard, and varieties of assessment protocols. In addition, Zuo and Zhou (2014) highlighted that there has been lack of research to develop a green assessment tool that can show the actual performance of a facility. This paper aims to develop a new quantitative green indicator for a facility, known as the Green Index that can provide the actual green facility performance with a practical weighting assignment. There are two main objectives of this paper; 1. To explore the use of statistical methods in stock composite index to create a new green assessment tool as a quantitative and graphical performance indicator of a facility, which is known as the Green Index in this study, 2. To use statistical methods to create the weighting assignment methodology for each green criterion corresponding to the organisation's operation and activities.

2. Research Framework

The new green assessment tool will be developed in two parts. In the first part, the weighting scheme for the green elements is developed. Next, the Green Index that utilises the weighting scheme, is formulated using the composite index calculation. The steps involved in this study are described next.

2.1 Weighting Scheme for Green Elements

A statistical method known as Factor Analysis (FA) was used in this study to develop the green elements' weighting scheme. Factor analysis is a useful tool for investigating the relationships among multiple variables. The FA helps researchers to investigate concepts that cannot be measured directly, by factorizing variables into several interpretable common factors (Yong and Pearce, 2013). Each green element may have a few interacting common factors as shown in Figure 1. Note that, F1 and F2 in Figure 1 are the hypothetically common factor for green elements, or known as factor loading in factor analysis. For this study, F1 and F2 will be calculated and used as the weighting for green elements. Factor loading calculation using factor analysis method involves 3 steps; 1. Calculation of the correlation matrix for green elements, 2. Calculation of the eigenvalue and eigenvector of the produced correlation matrix, 3. Calculation of factor loading by multiplying the eigenvector with the square root of the corresponding eigenvalue. Software such as SPSS or Microsoft excel with XLSTAT can be used to facilitate the calculation of the factor loading. In this study, Microsoft excel with XLSTAT was used.

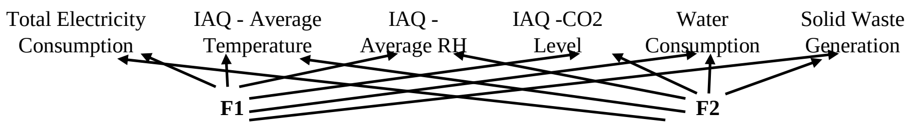

Figure 1: Hypothetical common factor for green elements

2.1.1. A case study on the Analysis of the Green Performance of an Office Space (OS Case Study)

Data required for computing the factor loading and for analysis was obtained from a case study on an office located in Kuching, Sarawak. The total office floor area is 410 m^2. There are 25 people working inside the office space. The lighting arrangements include 40 sets of 36 W fluorescent light, 3 sets of 36 W bar channel fluorescent light, and 8 sets of 13 W emergency light. The building is made of brick walls incorporated with 28.6 m^2 glass door and glass wall. The air conditioning for this space uses a direct expansion fan coil type where the electrical energy consumption is not constant and depends on the outside air temperature and the activities within the office. In this study, energy performance analysis simulation software, the Carrier Hourly Analysis Program (HAP) was used to perform energy simulation (Trcka and Hensen, 2010). All input data was based on the actual equipment data and conditions of the office space. The green elements selected to assess the green performance in the office space are electricity consumption, water consumption, solid waste generation, and indoor air quality. Elements of the indoor air quality in this study consist of several parts, which include the space average temperature (IAQ-Average Temperature), the average relative humidity (IAQ-Average RH), and the space carbon dioxide level (IAQ-CO_2 Level). Note that, the simulation results are only applicable for the performance of the office space under study. This is because selected green elements may vary depending on the activities within a facility. Table 1 shows the simulation output data of the green elements for the OS case study using the Carrier Hourly Analysis Program (HAP).

Table 1: Monthly data on the green elements of the OS case study

Month	Total Electricity Consumption (kWh)	IAQ - Average Temperature (°C)	IAQ - Average RH (%)	IAQ - CO_2 Level (ppm)	Water Consumption (m^3)	Solid Waste Generation (kg)
Jan-14	19,349	24.8	72.0	514	50.54	1.54
Feb-14	18,949	24.9	71.2	514	53.2	1.40
Mar-14	20,565	24.9	70.7	512	55.86	1.68
Apr-14	23,394	24.9	70.9	510	55.86	1.75
May-14	23,787	24.8	71.5	510	53.2	1.75
Jun-14	21,772	24.9	71.1	511	50.54	1.72
Jul-14	23,306	24.9	70.1	510	55.86	1.74
Aug-14	20,863	24.9	70.1	512	55.86	1.68
Sep-14	21,104	24.9	70.3	512	53.2	1.70
Oct-14	21,860	24.9	70.8	511	58.52	1.72
Nov-14	19,012	24.8	72.0	514	53.2	1.40
Dec-14	20,585	24.8	72.3	512	58.52	1.68

2.1.2. Green Index Development Using Composite Index Calculation

Stock composite index is a group of equities, indices, or other factors combined together in a standardised way to provide a useful statistical measure of the overall market or sector performance over time. For example, if the NASDAQ index drops by 10 %, the values of the stock also drop by 10 % proportionally (Galgani, 2013). In this study, the market capitalisation-weighted index method was adopted to formulate the Green Index. Market capitalisation-weighted index is a summation of stock price multiplied by the number of outstanding shares. Since it is a capitalisation-weighted index, any percentage change in the index represents a total value change for the overall market value of the company. The common capitalisation-weighted index equation is given in Eq(1):

$$\text{Capitalisation-Weighted Index} = (\sum p_t q_t / \sum p_o q_o) \times 100 \quad (1)$$

Since capitalisation-weighted index considers both the price and quantity differences, the calculation needs input for base year price (p_o), base year quantity (q_o), given period price (p_t), and given period quantity (q_t), which are the independent variables whereas the composite index is the dependent variable.

Referring to Eq(1), in this study, all independent variables can be represented by the green elements. Prices in the stock market fluctuate with time due to the buying and selling activities by traders. This is similar to the behaviour of the green elements that changes with time. For example, the electric consumption, water consumption, indoor air quality level fluctuate all the time due to human activities. The quantity or number of shares held by each stock has influence on the importance of the stock in relation to all the listed stocks. A stock with a large shareholding has more impact on the overall composite index as compared to a stock with small shareholding. Since the stock quantity is significantly important, it could be translated into weighting in the Green Index. The Green Index equation derived from the capitalisation-weighted index equation used in this study is given by:

$$\text{Green Index} = \sum I_t W_o / \sum I_o W_o \quad (2)$$

As in Eq(1), but applied for the Green Index development, variables in Eq(2) are represented in terms of the base year green elements (I_o), base year weighting (W_o) and given period green elements (I_t). The base year weighting (W_o) is calculated using the base year data. The performances of the green elements in subsequent years were then benchmarked against the base year data in order to monitor the green performance of the facility. The weighting in this equation is the factor loading, and was computed using the factor analysis technique described in section 2.1. Although the Green Index formulation proposed in this study is analogous to the stock composite index, note that in stock market, a positive index value means profit generated and is desired in the trading session. In contrast, an increment in the Green Index represents an increase in the environmental degradation, which is not desirable for a conservation programme.

3. Results and Discussion

3.1 Determining the Weighting Scheme

Factor analysis using excel with XLSTAT results show that F1 and F2 are the two key factors that have been found to have influence on all the green elements (see Table 2). However, only factor F1 will be chosen as the weighting scheme for this case because it has 56.32 % overall correlation strength, which was significantly higher than factor F2, that has 19.74 % overall correlation strength. The numbers assigned for each respective green element in Table 2 are the factor loading which represents the correlations between the common factor in group factor F1 and the input variables. This factor loading is used as the weighting scheme for green elements. Note that, the factor loading in Table 2 consists of positive and negative values. These values show whether the variable is proportional or inversely proportional to the factor. The results also show that the green element has a different correlation between each other. For example, the highest factor loading in group factor F1 is the IAQ-CO_2 level. The reason why IAQ-CO_2 level has the highest factor can be explained by studying the activities and operations of that space. In an office space, CO_2 gas is produced from human activities and from the usage of electrical equipment. In this case, HVAC system works by forcing fresh air into the space, and sucks the internal air into the HVAC system where it mixes again with fresh air to lower down CO_2 content within the office space. Although it is good to have lower CO_2 levels in a space, ASHRAE Standard 62.1-2013, "Ventilation for Acceptable Indoor Air Quality" has specified a guideline for the acceptable range of CO_2 in an office space, which is in the range between 1,000–1,200 ppm. The reason most designers follow this guideline rather than use 100 % fresh air intake is due to the high energy required to cool the fresh air going into the HVAC system. This also explains why there is a high correlation matrix between the electricity consumption and the IAQ-CO_2 levels. Since in this case, the HVAC system uses constant air volume, the fresh air intake is not controlled and has a constant flow into the HVAC regardless of the CO_2 level inside the space. This type of system would lead to excess fresh air intake and excessive electricity consumption during the cooling process. Therefore, the factor loading number is not merely an indication of the importance of the green element in a group, but also an indication of the need to improve the green performance of the facility. The conservation measures taken will be discussed later.

Table 2: Factor loading

Variables	F1 (56.32 %)	F2 (19.74 %)
Total Electricity Consumption (kWh)	-0.884	-0.335
IAQ - Average Temperature (°C)	-0.575	0.704
IAQ - Average RH (%)	0.688	-0.637
IAQ - CO_2 Level (ppm)	0.945	0.327
Water Consumption (m^3)	-0.327	-0.093
Solid Waste Generation (kg)	-0.882	-0.231

3.2 Green Index Determination

The results in Figure 2 show that the Green Index varies throughout the year. There are a few sharp rises particularly in April, May and July. This can be explained by the increase of electricity consumption due to the high operation of the HVAC system to maintain the internal air temperature when the external air becomes warmer than usual. The results also show that the water consumption and waste generation also increase during the same time. On the other hand the relative humidity was observed to decrease, giving an opposite effect to the electricity consumption that contributes to the sharp rise in the Green Index from March to April. Observation of the trend of the graph in Figure 2 enables facility managers to monitor and analyse the green performance of their facilities and coordinate green conservation measures.

3.3 Utilisation of the New Green Index for the Overall Facility Improvement

In Sections 3.1 and 3.2 we have discussed in detail the proposed new weighting and the use of the Green Index to determine an organisations' green performance. This section describes an overall facility can be improved using the Green Index methodology.

As mentioned earlier, the factor loading indicates the importance of each green element in the group of green elements. The result shows that IAQ-CO_2 level has the highest weightage compared to other green elements. Therefore, one of the usual conservation methods taken to control fresh air intake so that CO_2 gas can be controlled based on demand, is by installing Demand Control Ventilation (DCV) in the HVAC system. Using the Carrier HAP program with the HVAC system using DCV, the simulation result is as shown in Figure 3.

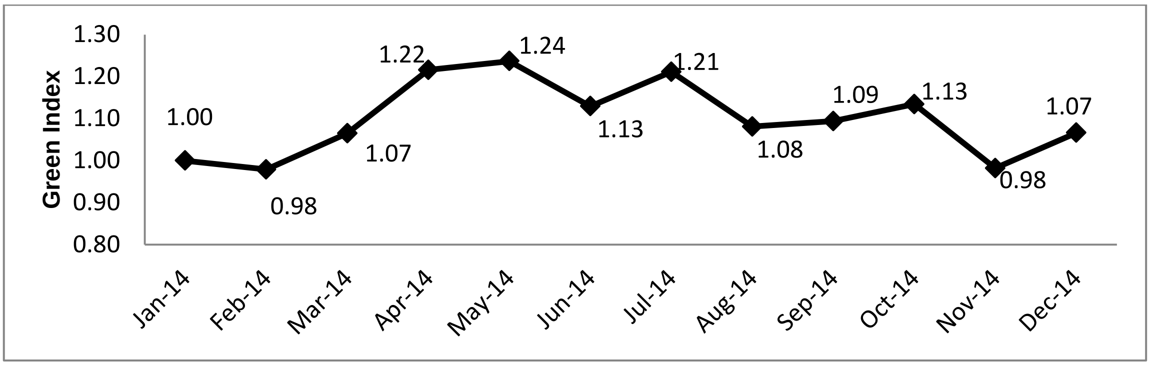

Figure 2: Green Index Trend

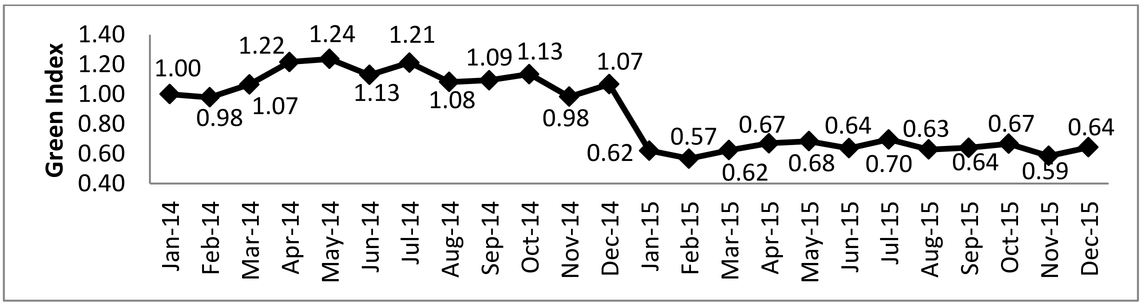

Figure 3: Green Index Trend after Conservation

The results show that there is a significant decrease in the Green Index value with an average of 36 % improvement. The improvement can be explained by looking at the large amount of electricity reduction after the installation of DCV in the HVAC system, although the fresh air temperature remains the same. The result also shows that the DCV is able to control the CO_2 gas level within the comfort range, and at the same time, limiting the fresh air from constantly entering the HVAC system. The use of DCV lessens the burden for the HVAC compressor to cool down the fresh air, hence reducing the electricity consumption. Thus, the Green Index trend allows facility managers to identify which green element that needs more attention and enable them to improve the facility's green performance.

4. Conclusion

A new Green Index has been developed as a quantitative green performance indicator in the management of a facility. The method consists of two parts: (i) Use of factor analysis to develop the weighting scheme (ii) use of the composite stock exchange index method as an analogy to construct the quantitative measurement of green performance. An office space has been selected as the case study, and simulated using the Carrier HAP program.

The statistical factor analysis (FA) method was first used to identify the correlation among the green elements and to pinpoint which green elements have the greatest impact on the Green Index performance. The results show that when the IAQ-CO_2 level controlled measure was taken, there is a significant decrease in the Green Index value that improved the organisations' green performance. By using this method, the weighting assignment can be distributed fairly based on the actual operation activities, and not based on the needs or perception.

In the second step of this study, the Composite index that was based on the stock exchange calculation method was adopted to determine the overall green performance of a facility that is influenced by several green elements. Note that, a lower green index represents better performance. The opposite applies for the stock composite index. With only one unique number as the indicator to represent a number of green elements, it becomes easier for facility managers to analyse and measure the actual level of green elements in a facility under their care. Furthermore, a single green indicator would help facility managers in the assessment of the improvement of the operational efficiency of a facility with respect to greenness. This is based on the observation by Kulcsar et al. (2014) who performed continuous monitoring of the energy consumption of a facility that led to the improvement of the operational energy efficiency. The graphical plots also help facility managers to visualise and monitor trends before and after any facility retrofit, and convey the performance of a facility to end users.

References

Galgani M., O'neil W., 2013, How to Make Money in Stocks; Getting Started. McGraw-Hill Education, United States of America, New York

Huat N.B., Akasah Z.A., 2011, Building performance analysis model using Post Occupancy Evaluation for energy-efficient building in Malaysia: A review, NPC 2011. DOI:10.1109/NatPC.2011.6136351.

Kulcsar T., Balaton M., Nagy L., Abonyi J., 2014, Feature selection based root cause analysis for energy monitoring and targeting, Chemical Engineering Transactions, 39, 709-714.

Newsham G.R., Mancini S., Birt B.J., 2009, Do LEED-certified buildings save energy? Yes, but…, Energy and Buildings, 41, 897–905.

Scofield J.H., 2013, Efficacy of LEED-certification in reducing energy consumption and greenhouse gas emission for large New York City office buildings, Energy and Buildings, 67, 517–524.

Sebake T.N., 2008, Overview of green building rating tools, Green building handbook South Africa, A guide to ecological design,1, 27–34.

Yong A.G., Pearce S., 2013, A Beginner's Guide to Factor Analysis : Focusing on Exploratory Factor Analysis, Tutorials in Quantitative Methods for Psychology, 9, 79–94.

Zaatari M., Novoselac A., Siegel J., 2014, The relationship between filter pressure drop, indoor air quality, and energy consumption in rooftop HVAC units, Building and Environment, 73, 151–161.

Zuo J., Zhao Z.Y., 2014, Green building research-current status and future agenda: A review, Renewable and Sustainable Energy Reviews, 30, 271–281.