ENHANCEMENT OF GREENNESS OF NEW CONSTRUCTION USING THE DEA

Gayatri Sachin Vyas[1], Kumar Neeraj Jha[2] and Dilipkumar Arvindkumar Patel[3]

[1&2] *Department of Civil Engineering, Indian Institute of Technology Delhi, Hauz Khas, New Delhi 110016, India.*

[3] *Civil Engineering Department, Sardar Vallabh National Institute of Technology Surat, Ichchhanath, Dumas Road, Surat-395007 (Gujarat), India.*

In India, the construction industry is the second largest after agriculture, accounting for roughly 5-6% of the gross domestic product. Therefore, sustainable construction plays an effective role to maintain a sustainable environment. Green building rating system provides a functional framework for evaluating building environmental performance and incorporating sustainable development into building and construction processes. It is used as a design tool by setting sustainable design priorities and goals, developing appropriate sustainable design strategies; and determining performance measures to guide the sustainable design and decision-making processes. To achieve sustainable development, higher attention has been paid to economic and environmental impacts associated with construction and operation of structures. Hence, prominence towards a more sustainable approach to green building design and cost effectiveness has gained momentum. In this research Indian green building assessment tools such as GRIHA, IGBC, and eco-housing are studied. The data envelopment analysis (DEA) assesses the relative efficiency of green building attributes relative to the rest of the green attributes in terms of cost. The main aim of this study is to maximize greenness of new construction in the limited fund by applying the data envelopment analysis (DEA). It is observed that the attributes: energy performance, utilization of fly ash, and use of regional materials are giving more green points at lesser cost. Findings of this paper can be helpful to green building planners, designers and developers.

Keywords: green building, AHP, sustainable buildings, rating systems, DEA

INTRODUCTION

As more and more construction activities are taking place it exerts huge environmental impacts. So there is a need to adopt a sustainable construction without spending a large cost (CCI, 2015). Sustainable construction is defined by Pearce and Turner (1990) as maximising the net benefits of economic development, subject to maintaining the services and quality of natural resources over time. Green building is the revolutionary development practice centred upon the mission of creating buildings which apply an increased efficiency of resources such as energy, water, and materials. In turn, green building reduces building impacts on human health and the environment by implementing improved site location, design, construction, operation, maintenance, and removal encompassing the complete life cycle of the building because they are using the recycled materials and using materials that are eco-friendly throughout

[1] gayatrivyasphd@gmail.com

Vyas, G S, Jha, K N and Patel, D A (2016) Enhancement of Greenness of New Construction Using the DEA. *In*: P W Chan and C J Neilson (Eds.) *Proceedings of the 32nd Annual ARCOM Conference,* 5-7 September 2016, Manchester, UK, Association of Researchers in Construction Management, Vol 2, 1181-1189.

(Vyas *et al*., 2012; Vyas and Jha, 2016). Practitioners of the green building often seek to achieve not only ecological but aesthetic harmony between a structure and its surrounding natural and built environment, although the appearance and style of sustainable buildings are not necessarily distinguishable from their sustainable counterparts. The built environment has a profound impact on our natural environment, economy, health and productivity. Breakthroughs in building science, technology, and operations are now available to designers, builders, operators and owners who want to build green and maximize both economic and environmental performance (Bartlett and Howard, 2000). Green buildings are energy efficient, water conserving, durable and non-toxic, with high-quality spaces and high-recycled content materials (Vyas *et al*., 2012; Vyas and Jha, 2016).

Several researchers (Ries *et al*., 2006; Agrawal and Tiwari, 2010; Cabeza *et al*., 2014) attempted to calculate the life cycle cost of a green building or green building components but it fails to find out and recommend where to invest. Therefore, there is a need to develop a cost model which increases green points in less cost. Thus the objectives of the study are: (1) to study different green building rating systems in India, and (2) to develop cost investment options for green building developers to achieve more green points in the available fund. For the second objective, the application of the Data Envelopment Analysis (DEA) is proposed. This is a linear programming-based technique for measuring the performance efficiency of organisational units which are termed Decision-Making Units (DMUs). This technique aims to measure how efficiently a DMU uses the resources available to generate a set of outputs (Charnes *et al*., 1978). The DEA has following advantages: (1) It allows effective use of multiple inputs and multiple outputs (Ramanathan, 2003), (2) The weights of inputs and outputs are not needed by decision makers, (3) each DMU efficiency is compared to that of the best operating unit, rather than to the average performance. On the other hand, the main limitation of the DEA is that standard formulation of DEA creates a separate linear program for each DMU. This will be computationally exhaustive when the number of DMUs is large (Raju and Kumar, 2006).

The remainder of this paper is organized as follows. First, the Indian green building rating systems are described. Second, the DEA technique is explained. Third, EMS software is applied for green building attributes. Finally, the results obtained are discussed.

CONCEPT OF GREEN BUILDINGS IN INDIA

The Leadership in Energy and Environmental Design (LEED) India green building rating system was developed by the Indian Green Building Council (IGBC) in October 2006. In 2015, the IGBC separately developed an IGBC green new building rating system. The categories and weights adopted in this rating system are: sustainable architecture and design-5%, site selection and planning- 14%, water conservation-18%, energy efficiency-28%, building materials and resources-16%, indoor environmental quality-12% and innovation development. The IGBC assessment tool is developed for new construction, existing buildings, commercial interiors, core and shell, homes, neighbourhood development, school, and retail. This system awards a rating of buildings as certified, silver, gold, platinum and super platinum. It uses simple checklist format to rate building performance (IGBC rating, 2015).

Green Rating for Integrated Habitat Assessment (GRIHA) is the Indian national green building rating system. It was developed by The Energy and Resources Institute

(TERI) in 2007. Recently, the GRIHA version 2015 is applied in Indian construction. The categories and weights adopted in this rating system are: sustainable site planning-8%, occupant comfort and wellbeing- 12%, sustainable building material-14%, energy -20%, water-17%, construction management - 9%, solid waste management-6%, socio economic strategies - 6%, and performance monitoring and validation -8%. The GRIHA rates the buildings one star if the score is from 25-40, two stars for scores 41-55, three stars for scores 56-70, four stars for scores 71-85, and five stars for scores above 86 % (GRIHA rating, 2015).

The eco-housing assessment tool was developed in 2006 for Pune City only. In 2009, Version II was introduced, and it is used in Pune and to some extent in Mumbai also. In Pune, it is popular in small to medium residential projects. The categories and weights adopted in this rating system are: site planning-14%, environmental architecture - 8%, efficient building material-19%, energy conservation -24%, water conservation-15%, solid waste management- 12%, and other innovative measures -8% (Vyas and Jha, 2016).

A green building may cost more upfront but saves through lower operating costs over the life of the building. The green building approach applies a project life cycle cost analysis for determining the appropriate upfront expenditure. Some benefits, such as improving occupant health, comfort, productivity, reducing pollution and landfill waste are not easily quantified. Fund allocation in the budget is essential to accommodate the cost for research and analysis of investment in green building attributes. Even with a tight budget, many green building measures can be incorporated with minimal or zero increased upfront costs and they can yield enormous savings (Environmental Building News, 2015).

DATA ENVELOPMENT ANALYSIS (DEA) METHODOLOGY

The DEA is used for measurement of efficiency amongst the data available. The DEA is a nonparametric method of measuring the efficiency of decision making units (DMU’s) (Ray, 2004). In the DEA, efficiency is defined as a weighted sum of outputs to a weighted sum of inputs. The DEA only gives relative efficiencies - efficiencies relative to the data considered. Efficient frontier encompasses the given input and output data. An efficiency measure quantifies in one way or another the distance to the efficient frontier. All efficiencies are restricted to lie between zero and one (i.e. between 0% and 100%). In calculating the numerical value of the efficiency of a particular DMU, weights are chosen so as to maximize its efficiency, thereby presenting the DMU in the best possible light. El-Mashaleh *et al*., (2010) carried out the DEA to benchmark safety performance of construction contractors. Vinter *et al*., (2006) constrained the DEA evaluation by the sum of number of inputs and outputs versus the number of DMUs. They considered inputs as cost work content, the level of monitoring, level of uncertainty, DMU as various type of projects (11 numbers), and output as design yield, operational yield, training yield, dimensional yield, project management yield, Schedule Performance Index (SPI), and Cost Performance Index (CPI). Several researchers presented techniques to reduce inputs and outputs and make it suitable to apply the DEA to study the project efficiency even though having multi project environment. Wakchaure and Jha (2011) presented a method using the DEA which is useful to allocate fund for repair and maintenance of existing bridges based on several factors rather than only on bridge condition. According to Ozbek *et al*. (2010), DEA models can be mainly classified into the model experiencing constant returns to scale- Charnes-Cooper- Rhodes formulation (CCR) or the model experiencing variable returns to scale -Banker-Charnes-Cooper formulation (BCC) (Charnes, 1978).

Generally, the following steps are used to apply the DEA and to determine the efficiency score.

11. Deciding the decision making units (DMU's)
12. Selecting input/output variables for the DEA and running the DEA model
13. Selecting an appropriate DEA model
14. Running the DEA model and determining efficiency scores for factors.

The CCR model assumes that measured efficiency is directly proportional to the inputs and output and it does not consider the effect of external factors. As in the present study cost and selected green building attributes play very important role, the CCR model is selected for analysis.

Charnes-Cooper-Rhodes (CCR) DEA model

This research makes use of the CCR model of the DEA to find out prominent green building cost attributes. The mathematical form of the CCR model is given in Eqs. 1, 2, 3, and 4 (Cooper *et al*., 2000). The objective function is to maximise the efficiency of DMU.

Maximise

$$Z_o = \sum_{r=1}^{s} u_r y_{r0} \quad (1), \quad subject\ to \sum_{i=1}^{m} v_i x_{i0} = 1 \quad (2), \quad \sum_{r=1}^{m} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 1 \quad (3),$$

i = 1,……m, j= 1,….,n , r=1,……, s and u_r , $v_i \geq 0$. (4)

Where,

Z_0: the measure of efficiency for DMU_0 (the DMU under evaluation), which is a member of the set j = 1, . . ., n DMUs.

u_r: the output weight. It is determined by the solution of the model and is assigned to the observed r^{th} output.

v_i: the input weight. It is determined by the solution of the model and is assigned to the observed i^{th} input.

y_{r0}: the known amount of the r^{th} output produced by DMU_0.

x_{i0}: the known amount of the i^{th} input used by DMU_0.

y_{rj}: the known amount of the r^{th} output produced by DMU_j.

x_{ij}: the known amount of the i^{th} input used by DMU_j.

The CCR model of the DEA is used to identify green building attributes. The model yields efficiency scores between 0 and 1. A green building attribute can be used if its efficiency score is 1. This means that one can invest in the respective green attribute which has less cost and greener points. Fig. 1 shows the related inputs and output.

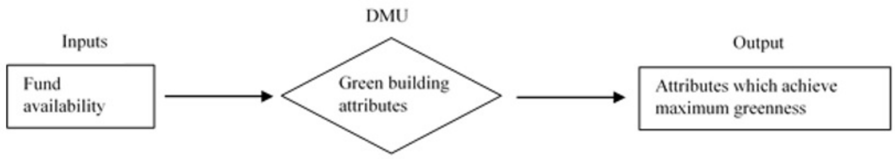

Figure 1 Inputs and output of green building parameters

Application of DEA in present study:
In the present study, an existing Indian green building is considered which is rated by the GRIHA and assigned five star rating and the IGBC which has rated it as platinum. The bill of quantity of each of selected buildings is collected.

Selection of variables for the DEA
For the selection of decision making units, the main criterion is limited fund. The factors that are selected are shown in Table 1. The reasons for the inclusion of the factors and other factors affecting the greenness are also provided in Table 1. The variables decided to be used in the DEA are: (i) cost involved in each factor, (ii) area of the site, (iii) maintenance cost of each factor.

Table 1: List of variables used in the DEA

S. No.	The possible variables	Whether considered for DEA analysis	Remarks/ reasons for exclusion
1.	Energy performance	Yes	If we invest in this, the possible points obtained can easily be increased.
2.	Water use reduction	Yes	The amount required is less and most of the cost is included in the pre requisite.
3.	Storm water usage	Yes	For efficient water use.
4.	Water efficient landscaping	Yes	The amount required is less and most of the cost is included in the pre requisite.
5.	Thermal comfort	Yes	It can be done during the design stage which includes less cost.
6.	Light sensors	Yes	It is related to the energy performance factor.
7.	Increased ventilation	Yes	It is done in the design phase with which more sun light is allowed,
8.	Low VOC paints	Yes	In this, the cost involved is less and the health of the occupant is related to this.
9.	Use of regional materials	Yes	This helps in cutting down the building materials cost.
10.	Utilization of fly ash	Yes	This helps in saving money during the construction of walls.
11.	Rapidly renewable materials	Yes	These are eco-friendly materials and very cost effective.
12.	Alternative transportation	No	It depends on the locality of the site.
13.	Green power	No	This is not possible when we consider limited funds.
14.	Outdoor air delivery management	No	It involves more cost.
15.	Brown field redevelopment	No	We are considering limited funds.

The DEA model selection
After selection of the input/output variables, it is necessary to determine the returns to scale experienced by the DMUs under investigation. In this study, the model CCR is applied as it considers constant returns to scale, and the output increases by the same proportional change of each proportional increase in the input (Ramanathan, 2003).

Efficiency Measurement System (EMS)
Efficiency Measurement System (EMS) is a software which computes the DEA efficiency measures. The EMS is used for the determination of efficiency scores of

the greenness factors. The output of the DEA model includes efficiency scores and benchmarks (Scheel, 2000).

Preparing the input and output data

The first and probably the most difficult step in an efficiency evaluation is to decide which input and output data should be included. The EMS accepts data in the MS Excel or in text format (Scheel, 2000). The prepared data sheet is shown in Table 2.

Table 2: Input, DMU and output data of considered green building

S. No.	DMU	Cost (INR)(I/P)	Area (sqm) (I/P)	Maintenance cost (INR)(I/P)	Change in greenness points (O/P)
1.	Energy performance	20,000	1500	5,000	13
2.	Water use reduction	30,000	1500	1,000	4
3.	Storm water usage	30,000	1500	1,000	2
4.	Water efficient landscaping	10,000	1500	1,000	4
5.	Thermal comfort	10,000	1500	500	2
6.	Light sensors	12,000	1500	1,000	1
7.	Increased ventilation	5,000	1500	500	1
8.	Low VOC paints	20,000	1500	5,000	2
9.	Use of regional materials	-5,000	1500	1,000	2
10.	Utilization of fly ash	-10,000	1500	2,000	2
11.	Rapidly renewable materials	20,000	1500	3,000	1

Table 3 shows the result of the DEA model obtained by the EMS 1.3 software.

Table 3: Results of the DEA model

S.No	DMU (2)	Efficiency score (3)	Ranking based on efficiency score (4)	Benchmarks (5)
1.	Energy performance	325.00%	1	2
2.	Water use reduction	100.00%	5	4
3.	Storm water usage	50.00%	7	2 (0.20), 4 (0.30)
4.	Water efficient landscaping	127.47%	4	6
5.	Thermal comfort	100.00%	6	2 (0.08), 4 (0.42)
6.	Light sensors	25.00%	9	2 (0.01), 4 (0.24)
7.	Increased ventilation	50.00%	8	4 (0.25)
8.	Low VOC paints	15.38%	10	1 (0.15)
9.	Use of regional materials	200.00%	3	0
10.	Utilization of fly ash	200.00%	2	0
11.	Rapidly renewable materials	11.76%	11	1 (0.06), 2 (0.01), 4 (0.05)

The output of the DEA model includes efficiency scores and benchmarks. These are shown in the columns 3 and 5 of Table 3. The attribute scores 100% and above are termed ‘efficient’ factors and the remaining as ‘inefficient’. The efficiency scores have been used for ranking the green building cost attributes (Scheel, 2000). The attributes with the maximum efficiency score are given the maximum priority. The ranks are established on the basis of efficiency scores in columns 3 of Table 3.

Out of the 11 attributes, 1) energy performance 2) water use reduction, 3) water efficient landscaping, 4) thermal comfort 5) use of regional materials and 6) utilization of fly ash are found to be efficient while the remaining attributes are found to be inefficient.

The DEA gives the relative efficiency, i.e. the ratio of weighted output to the weighted input. It is necessary to assign weights to input and output variables. These weights are chosen and optimized by the DEA program so as to provide an equal chance to every input and output variable (Scheel, 2000; Ramanathan, 2003). The main application of DEA for the current study is its ability to handle multiple inputs and multiple outputs. To achieve more green points in limited fund, DEA prioritise multiple options of green attributes based on its initial cost, O&M cost and area. In the current study, most referenced factors (DMUs) are the efficient attributes (with an efficiency score of 100), the values of which are used to determine and optimize the weights by the inefficient attributes. The relative weights are also given for the referenced attributes. Benchmarks (column 5 of Table 3) are the output of the DEA analysis. Benchmarks for inefficient (DMU) attributes indicate the referenced attributes (DMUs) with corresponding intensities (weights) in brackets (see column 5 of Table 3). For example, the attribute 'storm water usage' is an inefficient attribute, having a score of 50. This attribute (DMU) has two efficient attributes: 'water use reduction' and 'water efficient landscaping', as benchmarks with intensities (weights) of 0.20 and 0.30 respectively. This has been shown as 2 (0.20) 4 (0.30) in column 5of Table 3.

Benchmarks from Table 3 indicate the number of the inefficient attributes (DMUs) which have been chosen on the basis of the efficient green building cost. The efficient attributes should be selected first for the investment of cost in green building as they can increase greenness in an available cost. The most referenced attributes (DMUs) are energy performance, water use reduction, water efficient landscaping, and thermal comfort, use of regional materials and utilization of fly-ash.

DISCUSSION

The Indian construction industry currently lacks any readily available cost model of green buildings for the selection of attributes in limited funds. To judge investment model, the industry currently relies on the segregated and a large number of reports of the different types of green building attributes (Johannes, 2015). As such, the DEA approach is well suited to fill this gap and to assess where to invest. The DEA approach presented in this paper can be utilized by a particular green building developer to achieve more green ratings in a limited fund. Additionally, the proposed methodology is deployable at the project level. Every project has multiple DMUs of green building attributes. DMUs are ‘‘benchmarked” against each other in DEA. Consequently, developer will be able to identify their best performing green building cost attributes.

CONCLUSIONS

The data envelopment analysis helps in finding the efficiency of the factors which are selected based on the cost factor. The model selected for this project is the CCR model. In this model output increases by the same proportional change of each proportional increase in the input. The EMS 1.3 software has been used for the DEA to find out the efficiencies of the attributes. Energy performance is found as the most efficient attribute with an efficiency score of 325%.

Based on this study, following attributes are required to be considered while constructing green buildings: 1. Energy performance, 2. Utilization of fly ash, 3. Use of regional materials, 4. Water efficient landscaping, 5. Thermal comfort, 6. Water use reduction. When a building satisfies all the pre requisites of the IGBC then they should consider these attributes to get more green points and thus get a green rated building. All the factors proposed here are very economical when compared to the other parameters. The limitation of the current study is that developed cost model includes only one case study in Indian context only. This study can be applied to green buildings in other developing counties.

Even though the cost model in this paper is based on data collected from the Indian construction industry, the methodology would suggest a much broader geographical applicability on cost model for green construction projects internationally. The next step for the research team is to develop a cost model for a number of case studies from different geographical and climatic region.

REFERENCES

Agrawal, B and Tiwari, N (2010) Life cycle cost assessment of building integrated photovoltaic thermal (BIPVT) systems. *Energy and Buildings*, **42**(9), 1472–1481.

Bartlett, E and Howard, N (2000) Informing the decision makers on the cost and value of green building. *Building Research and Information*, **28**(5-6), 315-324.

Cabeza, F, Rincón, L, Vilariño, V, Pérez, G and Castell, A (2014) Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of building sand the building sector: A review. *Renewable and Sustainable Energy Reviews*, **29**(Issue C), 394-416.

Charnes, A, Cooper, W and Rhodes, E (1978) Measuring the efficiency of decision making units. *European Journal of Operational Research*, **2**(6), 429-444.

Cooper, W, Seiford, L and Tone, K (2000) *Data Envelopment Analysis: A Comprehensive Text with Models, Applications, References and DEA-Solver Software*. New York: Kluwer Academic Publishers.

Corporate Catalyst India (2015) *CCI*. Viewed 12 January 2015, http://www.cci.in/pdfs/surveys-reports/real-estate-sector-in-india.pdf

Eco-housing rating system India viewed on 1 January 2016, www.mcgm.gov.in/irj/portalapps/com.mcgm.ecohousing/docs/Eco_housing_Construction.pdf.

El-Mashaleh, S, Rababeh, M, and Hyari, H (2010) Utilizing data envelopment analysis to benchmark safety performance of construction contractors. *International Journal of Project Management*, **28**(1), 61-67.

Environmental Building News (2015) *Green Rating for Integrated Habitat Assessment 2015*. GRIHA, India, viewed on 21 June 2015, http:// www.grihaindia.org.

IGBC Green New Buildings (2015) *India*, viewed on 1 January 2016 https://igbc.in/igbc/redirectHtml.htm?redVal=showGreenNewBuildingsnosign.

Johannes, A, Anders, C and Zia, H (2015) *Energy-Efficient Buildings: A Business Case for India? An Analysis of Incremental Costs for Four Building Projects of the Energy-Efficient Homes Programme*. Berlin/New Delhi: Adelphi/TERI.

Ozbek, E, Garza, M, and Triantis, K (2009) Data envelopment analysis as a decision-making tool for transportation professionals. *Journal of Transportation Engineering*, **135**(11), 822-831.

Ozbek, E, Jesús, M, Garza and Triantis, K (2010) efficiency measurement of bridge maintenance using data envelopment analysis. *Journal of Infrastructure Systems*, **1**(31), 31-39.

Pearce, D W and Turner, R K (1990) *Economics of Natural Resources and the Environment*. New York: Harvester Wheatsheaf.

Raju, K and Kumar, N (2006) Ranking irrigation planning alternatives using data envelopment analysis. *Water Resources Management*, **20**(4), 553–566.

Ramanathan, R (2003) *An Introduction to Data Envelopment Analysis: A Tool for Performance Measurement*. New Delhi: Sage Publications India Pvt Ltd.

Ray, S (2004) *Data Envelopment Analysis Theory and Techniques for Economics and Operations Research*. Cambridge, UK: Cambridge University Press.

Ries, R, Melissa, G, Nuri, N and Kim, L (2006) The economic benefits of green buildings a comprehensive case study. *Engineering Economist*, **51**(3), 259-295.

Scheel, H (2000) *EMS Efficiency Measurement System User's Manual Version 1.3*. Dortmund, Germany: Universität Dortmund.

Vinter, G, Rozenes, S and Spragget S (2006) Using data envelop analysis to compare project efficiency in a multi-project environment. *International Journal of Project Management*, **24**(4), 323–329.

Vyas, G and Jha, N (2016) Identification of green building attributes for development of an assessment tool: Case of India. *Civil Engineering and Environmental Systems*, (Submitted - GCEE-2015-0124 R2).

Vyas, G, Jha, N, and Patel, D (2012) Development of a framework for green building rating system. *In*: S H Lodi, S M Ahmed, R U Farooqui and M Saqib (Eds.) *Proceedings of 3rd International Conference on Construction in Developing Countries (ICCIDC-III*), 4-6 Jul 2012, Bangkok, Thailand. Karachi, Pakistan: Department of Civil Engineering, NED University of Engineering & Technology.

Wakchaure, S and Jha, N (2011) Prioritization of bridges for maintenance planning using data envelopment analysis, *Construction Management and Economics*, **29**(9), 957-968.