Simulation-Based Comparative Study on Energy Efficiency Criteria for LEED and BREEAM Systems

Harisankar R and Rakesh P
Department of Civil Engineering, Amrita School of Engineering, Coimbatore, Amrita Viswa Vidyapeetham, India
E-mail: p_rakesh1@cb.amrita.edu

Abstract. Energy efficiency is regarded as one of the important elements of green building. Every Green Building Rating (GBR) system puts forward a set of criteria for energy efficiency and it is different for each system. A comparative study is done to distinguish between two GBR systems practiced worldwide- LEED and BREEAM, first on the criteria for energy efficiency and secondly on how efficient and effective each system in energy performance improvement. Building energy simulation tool, eQuest is used to obtain annual energy consumption of a case study multi-family dwelling residential building for its various design options. Different design cases were formulated by changing design parameters and the simulation results thus obtained are used for evaluating the performance improvement for energy, calculated as per the criteria for each system. This study primarily looks for the combinations which grab total achievable credits in energy efficiency for a particular system. For LEED, it was found that renewable energy allocation alone has the greater influence in achieving higher credits. For BREEAM, there requires specifically a considerable decrease in HVAC load which can be brought by the means of more natural ventilation or by adopting passive cooling techniques. BREEAM was also found more effective in reflecting any kind of improvement made in terms of awarding credits.

Keywords: Green Building Rating System; eQuest; LEED; BREEAM.

1. Introduction

The concepts of sustainability from the energy aspect are accomplished in green building through minimizing the demand for non-renewable energy, reusing and recycling renewable energy, and energy optimization through various control measures. There are many Green Building Rating (GBR) systems used as a tool for evaluating the environmental performance of a building through its life cycle. Such an evaluation is done based on a set of criteria for different parameters related to design, construction, and building operations. Different levels of certification are there for every rating system which is awarded according to the cumulative score it achieves. A project is rated under a particular rating system based on the credits or score awarded for the successful completion of the credit requirements. Energy efficiency is regarded as one of the important elements of green building. Every green building rating system puts forward a set of criteria for energy efficiency and it is different for each system. For evaluating the performance improvement over a baseline case or certain requirements, the use of Building Energy Performance Simulation tools is unavoidable for the annual energy consumption predictions [1]. Energy simulation can be utilized as a decision-making tool while
designing [14]. In a simulation software, a design can be made energy efficient by changing the input parameters and modifying the design by changing the materials of the wall so that it would satisfy the criteria for any particular rating system [2]. The tool used for this study is eQuest version 3.64, which is an interface to DOE-2, calculation engine of the Department of Energy, USA. Thermodynamic characteristics of a building, operating assumptions, and weather data of the location provided were incorporated in the engine forming complex algorithms to calculate estimated performance over time.

Jiafang Song et al. [3] conducted studies to know the effect of a single variable parameter on annual energy consumption using the simulation method. Studies on the accuracy of these predictions point out the fact that proper input data including the schedule of lighting power density, occupancy, and equipment power makes more accurate results [4]. Studies show that when the resistance value is increased for the main wall by selecting appropriate envelope material the energy consumption decreases to a greater extend [5,15]. But, for other building components like exposed floor, basement floor, and basement wall, even when the resistance value is increased, there is a decrease in the energy consumption but not to a greater extend [5]. So, altering the input parameters for the main wall only has greater significance. Elena Cuerda et al. [6] done a simulation-based study and found that when the U value of the building envelope is decreased by adding a thick insulation layer, the HVAC load is greatly affected [6]. All these studies showed the possibilities of developing different energy performance improvement design combinations that can be evaluated under a particular rating system [6,16]. Yair Schwartz et al. [1] conducted a study on how the results would vary on using different building performance tools namely, Tas, Energy Plus, and IES-VE, and on their impact over LEED and BREEAM rating systems. A comparison between the scores obtained for the same case study residential building under these GBR systems was done [1]. Some other previous comparative studies were based on the aspects like certification process, educational needs, implementation cost, and the difference in categories of each system and executed a SWOT analysis [7]. Some studies show how GBR systems differ in the calculation of renewable energy, credits awarded and involved renewable energy types [8].

This study performs a comparison between two green building rating systems practiced worldwide, Leadership in Energy and Environmental Design (LEED) developed by U.S. green building council and Building Research Establishment's Environmental Assessment Method (BREEAM) developed by BRE Global Limited, UK. The building typology considered for this study is a multi-family dwelling residential project and thus LEED v4.1 Residential BD+C Multifamily Homes and Multifamily Homes Core and Shell Adapted for India published on April 2020 by USGBC is considered for the study. BREEAM does not have a separate manual for a particular building typology but a manual for any new construction BREEAM International New Construction 2016 Technical Manual issued on 3rd July 2017 is considered for the study. BREEAM is regarded as the first standard green building rating system. A preliminary analysis is possible from the criteria requirement comparison as listed in Table 2. LEED provides a weightage of 31% for the section 'Energy and Atmosphere' and for BREEAM, 22.66% weightage is there for the chapter 'Energy'. On studying the manuals for these two GBR systems, there exists a difference between the various criteria for energy efficiency. One criterion found common, was the evaluation of performance improvement over specified baseline requirements. For evaluating the performance improvement over a baseline case or certain requirements, the use of energy simulation tools is unavoidable for the annual energy consumption predictions. By altering the design parameters of envelope condition and efficiency of the HVAC system, various design combinations can be formulated which gives a set of simulation results. This study executes a comparison between systems based on these simulation results, which is further used for the performance improvement evaluation for both the system. The main objective of this paper is to do a comparative study to distinguish these two rating systems, on how efficient and effective each system in identifying the energy performance improvement, and to rate different design cases, using energy simulation results.
2. Methodology

A case study building is selected for energy modeling in eQuest 3.64 and it is done by making use of AutoCAD drawings and other input parameters. The weather file for the selected location is also obtained for simulation in eQuest 3.64(.bin format). The method for performance improvement is different for every system. For any building, an improvement in energy performance takes place depending upon the energy-efficient design approaches considered. We have considered a multifamily dwelling residential building, where the major energy consumption is for the HVAC system, lighting load, and equipment load [9,10]. Among these three, load for HVAC takes up a greater part and design measures influencing HVAC load can bring a greater difference in annual energy consumption. To evaluate the performance improvement, a data set that would produce considerable variation in annual energy consumption shall be used. HVAC load greatly depends upon the envelope conditions, HVAC efficiency, and the temperature setpoint chosen [9]. For this study, different design combinations have been developed using the envelope conditions and the HVAC efficiency. Cases for Wall envelope are prepared based on U value and Residential Envelope Transmittance (RETV) calculated as per Eco-Nivas Samhita (R-ECBC) part-1,2018. A standard thermostat setpoint temperature of 24°C for cooling and 17°C for heating is considered for simulation for BREEAM. For LEED, the manual itself put forward a temperature schedule for the simulation as shown in Table. 3. Cases for HVAC based on efficiency are chosen according to the BEE star rating of India.

Efficiency improvement for lighting load can be greatly achieved by providing LED fixtures. Here, we consider that all the equipment is BEE 4-starred, and the equipment load input parameters are provided according to that. For this comparative study, we only consider electric energy consumption. No other source of energy including CNG and LPG is not considered. By default, all hot water equipment is provided with an electric source. Development of different simulation combinations, obtaining the annual energy consumption, application of different criteria, and carrying out the energy performance improvement calculations constitute the major part of this analysis. This study primarily looks for the combinations which grab total achievable credits in energy efficiency for a particular system.

3. Building general information and parameter setting

The case study building considered is a 10-storey multifamily dwelling residential building which is located in Thiruvananthapuram, India. This city belongs to the warm and humid climate zone as per R-ECBC 2018, part 1, Annexure 2. The total built-up area of the building is 5542.75 m$^2$ and on each floor 4 dwelling units are there. The entire ground floor covers the parking area. The plan layout with zoning for a typical floor is shown in fig. 1. In eQuest 3.64, we need to set an operational schedule of the building based upon which the usage profile for various loads is manipulated. Typical schedule found in Indian families with unoccupied timings, 8 am to 6 pm during the weekdays, on Saturdays, 8 am to 4 pm and on Sundays and holidays, 4 pm to 8 pm were kept.

| No. | Area Type   | % Area | Design Max. Occupancy m$^2$/per | Miscellaneous Loads (W/m$^2$) | LPD (W/m$^2$) |
|-----|-------------|--------|---------------------------------|-------------------------------|--------------|
| 1   | Bedrooms    | 31     | 13                              | 3.2                           | 1.5          |
| 2   | Corridors   | 11.8   | 9                               | 0                             | 1.07         |
| 3   | Parking     | 10     | 13                              | 0                             | 1.07         |
| 4   | Living Area | 24.6   | 13                              | 3.7                           | 1.8          |
| 5   | Kitchen     | 10.6   | 26                              | 11.8                          | 1.7          |
| 6   | Laundry     | 4.2    | 26                              | 10.75                         | 1.3          |
| 7   | Toilets     | 7.8    | 7                               | 0                             | 1.07         |
The activity area, lighting power density, and the load allocations for the building which include the equipment load are shown in table 1. All these loads are calculated using the building area method described in ECBC 2017, clause 6.3.2. LED tubes of 18 W and 3250 Lumen, CFL Lamp 1 of 11 W and 1200 Lumen, and CFL Lamp 2 of 4 W and 475 Lumen were used as the lighting fixtures. Lighting power densities (LPD) are calculated based on the number of fixtures provided for a space and the area of a particular space. All other input parameters with different cases are discussed below.

3.1. Wall envelope
For the construction of the wall envelope, four types of models are considered. All the envelope U value calculations are done as per R-ECBC 2018 Annexure 5 and the RETV calculations are done as per R-ECBC 2018 chapter 3.4. The types of models are the following,

- **Type 1:** It is the conventional case study building wall made of a solid concrete block of 200 mm thickness and cement plastering on either side of 15 mm thickness and with surface finishes. No insulations are provided. Total wall envelope U value = 2.83 W/m²k. RETV = 19.6 W/m².

- **Type 2:** Energy-efficient envelope case by replacing the block type of conventional case with hollow bricks. No insulations are provided. Total wall envelope U value = 1.89 W/m²k. RETV = 15 W/m².

- **Type 3:** Energy-efficient envelope case by providing external insulation of extruded polystyrene insulation board of 15 mm thick for the conventional case. Total wall envelope U value = 1.28 W/m²k. RETV = 12.56 W/m².

- **Type 4:** Energy-efficient envelope case by replacing the block type of conventional case to Autoclave aerated concrete blocks. No insulations are provided. Total wall envelope U value = 0.775 W/m²k. RETV = 10.6 W/m².

For Type 1, 3.1 mm thick single clear glass with Solar Heat Gain Coefficient (SHGC) = 0.86 & U = 5.8 W/m² is used for glazing. For all other cases, 6.38 mm thick grey-tinted single clear glass with SHGC = 0.63 & U = 5.7 W/m² is used, which is considered to be more energy-efficient. Roof is considered as RCC slab of 150 mm thickness, provided with an additional insulation of extruded polystyrene board of 75 mm thickness. Interior cement plastering of 10 mm thickness and a surface coating is provided. This makes U value for roof envelope = 0.4288 W/m²k.

3.2. HVAC system
Fig. 1 shows the conditioned and unconditioned spaces for the building. The area of toilet, kitchen, and passage was assigned as unconditioned zones in eQuest. Two HVAC systems were provided for this case study building for conditioning, namely, HVAC system 1 with a cooling capacity of 1 T for the bedrooms and HVAC system 2 of 2.5 T for the living spaces. The cooling and heating source for
both the systems are DX coil and a split system single zone heat pump is used. To obtain the different energy efficiency design combinations, four variants of Bureau of Energy Efficiency (BEE) rated Air-conditioning (AC) systems; 2-star, 3-star, 4-star, and 5-star with different Indian Seasonal Energy Efficiency Ratios (ISEER) of 3.39, 3.75, 4.24 and 4.7 respectively are used.

4. Study on rating systems

All the types of criteria which come for energy efficiency under each GBR system are listed in Table 2. There we can see that both these systems mostly have the same type of criterion but there exists a difference in requirements. Baseline requirements, energy performance improvement evaluation and the installation of energy monitoring systems were found as common criterion for both systems. Installation of energy monitoring systems for control have a greater impact on energy saving [17]. But, for every GBR system, energy performance improvement evaluation is treated as more important with more credits [1]. Comparative study between these systems becomes reliable only when the effectiveness of performance improvement calculations is checked which is carried out in this study. The design for renewable energy generation affects the net annual energy consumption based upon which the performance improvement calculations are done. Throughout this study, on the grounds of achieving maximum possible credits for energy efficiency under a particular system, an examination of various design combinations to evaluate the performance improvement is carried out. The method of performance improvement is also different in both systems. All criteria other than baseline requirements, energy performance improvement, and renewable energy generation are considered to be installed or adopted which is demanded by that particular system.

Table 2. List of criteria for rating systems

| No. | Criteria                        | LEED | BREEAM |
|-----|---------------------------------|------|--------|
| 1   | Baseline Requirement            | ✔    | ✔      |
| 2   | Energy performance improvement  | ✔    | ✔      |
| 3   | Renewable energy                | ✔    |        |
| 4   | Low ODP & GWP material          | ✔    |        |
| 5   | Energy Monitoring               | ✔    | ✔      |
| 6   | Equipment Efficiency            | ✔    |        |
| 7   | Commissioning process           | ✔    |        |
| 8   | Hot water pipe insulation       | ✔    |        |
| 9   | Grid Harmonization              | ✔    |        |
| 10  | Low carbon Design               | ✔    |        |
| 11  | Energy Efficient cold storage   | ✔    |        |
| 12  | Energy efficient transport system| ✔    |        |
| 13  | Energy efficient Lab system     | ✔    |        |
| 14  | Drying spaces                   | ✔    |        |

4.1. LEED

For the baseline case simulation, wall assembly, roof assembly and HVAC system all were provided so that it would satisfy the requirements as mentioned in Table 3. In the LEED system the performance improvement is always calculated in terms of energy cost and greenhouse gas emissions. For the LEED system, the performance cost is evaluated in terms of Performance Cost Index (PCI) as described in section 2.1 of “Developing Performance Cost Index Targets for ASHRAE Standard 90.1 Appendix G – Performance Rating Method” published by U.S. Department of Energy, February 2016 and the equation for PCI is shown below.

\[
PCI = \frac{\text{Proposed Building Performance}}{\text{Baseline Building Performance}}
\]  

(1)

Here, the Proposed Building performance is the annual energy cost for a proposed design and the baseline building performance is the annual energy cost for baseline building. The performance
improvement is always calculated by comparing the PCI of a proposed design with Performance Cost Index Target, PCI.

\[
\text{Percentage improvement beyond code} = \left( \frac{100 \times (\text{PCI}_t - \text{PCI})}{\text{PCI}_t} \right)
\]

(2)

\(\text{PCI}_t\) is the maximum Performance Cost Index for a proposed design to comply with a particular edition of Standard 90.1. It is also calculated by the method described in “Developing Performance Cost Index Targets for ASHRAE Standard 90.1 Appendix G – Performance Rating Method” published by U.S. Department of Energy, February 2016 and a PCI of 0.79 was fixed using the annual energy consumption for the baseline given in Table. 4. Greenhouse Gas (GHG) emissions are calculated in terms of \(\text{CO}_2\) equivalents. Here also a performance improvement for the proposed design over the baseline is evaluated. GHG emissions are calculated based on the \(\text{CO}_2\) Baseline database for the Indian Power sector published by Central Electricity Authority, Government of India, December 2018. From \(\text{CO}_2\) Baseline database for the Indian Power sector published by Central Electricity Authority, Government of India, December 2018, the weighted average emission factor is taken as 0.82 t \(\text{CO}_2/\text{MWh}\) and for the baseline case GHG emissions were obtained as 383.67 t \(\text{CO}_2\).

Table. 3. Requirements for LEED system

| Baseline Requirements                                                                 |
|---------------------------------------------------------------------------------------|
| • The compressor used for HVAC system must be able to take more than 90% of total heat gain/total heat loss. |
| • Baseline building Envelope shall comply with chapter 3, Code provisions R-ECBC 2018. |
| • In-unit lighting power Density = 9.7 W/m².                                          |
| • HVAC system: Packaged single zone heat pump with differential enthalpy economizer controls. Cooling Electric Input Ratio (EIR) = 0.34 and heating EIR = 0.32. |
| • Packaged single zone supply fans modelled as cycling on and off.                    |
| • System supply airflow rates: Supply air to room air temperature difference of 11°C. |
| • Cooling and heating system shall follow the daily schedule as detailed below.        |
|                                                                                       |
| **Time** | **Cooling Temperature (°C)** | **Heating Temperature (°C)** |
| 0:00 to 09:00 | 26                          | 21                           |
| 09:00 to 16:00 | 33                          | 20                           |
| 16:00 to 17:00 | 31.5                        | 20                           |
| 17:00 to 18:00 | 30                          | 20                           |
| 18:00 to 19:00 | 28.5                        | 20.5                         |
| 19:00 to 24:00 | 26                          | 21                           |

Table. 4. Credit Requirements Considered

| Description                                      | Point scale |
|--------------------------------------------------|-------------|
| Percentage cost PCI below PCI; 2% to 40%         | 1-9         |
| Percentage GHG emissions PCI below PCI; 2% to 65% | 1-9         |
| Points for Renewable energy allocation; 2% to 60% | 1-5         |

Table. 4. Design combinations and simulated results used for LEED and BREEAM

| Wall Envelope + BEE rated AC | Simulated result for Total annual energy consumption (KWh) |
|------------------------------|-----------------------------------------------------------|
|                              | LEED           | BREEAM          |
| Baseline                     | \(467.89 \times 10^3\) | \(489.67 \times 10^3\) |
| Case 2 + BEE 2               | \(442.83 \times 10^3\) | -               |
From the credit requirements shown in Table 3, for achieving maximum possible credits in Energy and Atmosphere, the percentage cost PCI should be 40% below PCI and percentage GHG emission should be 65% below the baseline. On satisfying all other requirements, a total credit of 11 can be achieved. This study is carried out based upon the requirements of criterion for optimize energy performance and renewable energy and evaluating the performance improvement over different design option considering all other requirements are satisfied. Thus, total credits for Energy and Atmosphere, 34 out of 110 can be achieved. Credits awarding for these two criteria is described in Table 3. Design combinations and the simulation results for annual energy consumption, detailed in Table 4 are considered. Using the simulation results, more design combinations is worked out based on the criteria for renewable energy. All these combinations and the calculation for percentage improvement in energy performance is shown in Table 5 and Table 6.

**Table 5.** Enhanced energy performance calculation for LEED with 2% on-site renewable energy allocation

| Wall envelope + BEE starred AC | On-site Renewable Energy (KWh) | Net Annual Energy Con. (KWh) | Energy Cost (Rs.) | GHG emission (t CO₂) | PCI Improvement in PCI (%) | Improvement in GHG emission (%) |
|-------------------------------|--------------------------------|-----------------------------|------------------|----------------------|---------------------------|-------------------------------|
| 2 + 2-star                    | 8856.6                         | 433973.4                    | 2356476          | 355.858              | -17.40                    | 7.24                          |
| 2 + 3-star                    | 8424                           | 417276                      | 2241374          | 338.476              | -11.67                    | 11.77                         |
| 2 + 4-star                    | 7958                           | 389942                      | 2171385          | 319.752              | -5.49                     | 16.65                         |
| 2 + 5-star                    | 7613.6                         | 373066.4                    | 2025751          | 305.914              | -0.92                     | 20.26                         |
| 3 + 2-star                    | 8688.4                         | 425731.6                    | 2311723          | 349.099              | -15.17                    | 9.01                          |
| 3 + 3-star                    | 8276.8                         | 405563.2                    | 2202208          | 332.561              | -9.72                     | 13.32                         |
| 3 + 4-star                    | 7825.4                         | 383444.6                    | 2082104          | 314.424              | -3.73                     | 18.04                         |
| 3 + 5-star                    | 7494.6                         | 367235.4                    | 1994088          | 301.133              | 0.64                      | 21.51                         |
| 4 + 2-star                    | 8529.4                         | 417940.6                    | 2269417          | 342.711              | -13.21                    | 10.67                         |
| 4 + 3-star                    | 8133.4                         | 398536.6                    | 2164054          | 326.8                | -7.95                     | 14.82                         |
| 4 + 4-star                    | 7699                           | 377251                      | 2048473          | 309.345              | -2.19                     | 19.37                         |
| 4 + 5-star                    | 7380.8                         | 361659.2                    | 1963809          | 296.560              | 2.03                      | 22.70                         |

**Table 6.** Enhanced energy performance calculation for LEED with 60% on-site renewable energy allocation

| Wall envelope + BEE starred AC | On-site Renewable Energy (KWh) | Net Annual Energy Con. (KWh) | Energy Cost (Rs.) | GHG emission (t CO₂) | PCI Improvement in PCI (%) | Improvement in GHG emission (%) |
|-------------------------------|--------------------------------|-----------------------------|------------------|----------------------|---------------------------|-------------------------------|

7
4.2. BREEAM

For the BREEAM system, energy performance improvement is evaluated based on Energy Performance Ratio for International New Construction (EPR\textsubscript{INC}) based upon which credits are awarded for a particular building. The credits awarded for a particular EPR\textsubscript{INC} value is shown in Table 7. EPR\textsubscript{INC} is calculated based on the 2016 Ene 01 Calculation Methodology. The credit criteria discussed in Table 7 is considered for this study and it grabs a total of 18 credits out of 37. All other criterion is considered to be adopted or installed. It was found that BREEAM system, particularly provides weightage for passive cooling techniques and energy saving. In order to identify the effect of saving of energy, on energy reduction calculations, even though for achieving credit, only 5% energy saving is the requirement, here 5% and 75% saving conditions are considered in Table 8 and in Table 9. BREEAM does not have criteria for renewable energy generation, if a feasibility study is carried out for low or zero carbon technologies, 1 credit is awarded. All design combinations and simulated results considered here are from Table 4. The 2016 Ene 01 Calculation Methodology has been designed to account three parameters of modelled building performance, heating and cooling energy demand, primary (or source) energy consumption and Carbon Dioxide (CO\textsubscript{2}) emissions. As per the manual, primary energy refers to energy produced at the site itself, i.e., from crude sources and there should not occur any kind of transmission losses. Here in this study, we have not considered any crude sources and only electric energy consumption is considered. So, EPR\textsubscript{INC} is calculated based on the other two parameters. Each parameter is calculated by the equation,

\[ \text{Parameter}_Y = 1 - (X^n) \]  

In equation (3), \( X \) is defined as Ratio of Building performance and is given by,

\[ \text{Ratio of Building Performance}, X = \frac{(\text{Actual Building Performance})}{(\text{Reference Building Performance})} \]  

And, \( n = \frac{\log(1-\text{policy decision})}{\log(\text{ratio of performance for BREEAM best practice})} \)  

The ‘policy decisions’ are fixed values and are 0.8 for Energy demand parameter and 0.6 for CO\textsubscript{2} emission parameter. 2016 Ene 01 Calculation Methodology put forward a best practice construction whose specifications are detailed in Table 7. Model based on these details are used for calculating the ratio of building performance for BREEAM best practice. The reference building is considered such that the baseline building Envelope shall comply with chapter 3, Code provisions \textit{R- ECBC 2018}. After simulation for the BREEAM best practice case and reference case, an annual energy consumption of 308.56 x 103 KWh and 432.67 x 103 KWh was obtained respectively. Thus, for the BREEAM best practices, 0.38 for energy demand and 0.71 for CO\textsubscript{2} emissions were obtained as ratio of performances. Based on these values, n value is calculated and for each design combination the ratio performance is calculated for both the parameters and the EPR\textsubscript{INC} obtained for a particular design.
combination is average of both the parameters. From the Table 7, for obtaining a full credit condition, there requires an $\text{EPR}^{\text{INC}}$ values of 0.9. All the design combinations considered and its calculated $\text{EPR}^{\text{INC}}$ with two percentage energy saving conditions are shown in Table 8 and Table 9.

**Table 7. Requirements for BREEAM system**

| BREEAM best practice specifications for Different elements |  |
| --- | --- |
| Roof U-Value (W/m²K) | 0.15 |
| Wall U-Value (W/m²K) | 0.2 |
| Window U-Value (W/m²K) | 1.2 |
| Light Transmittance (%) | 0.71 |
| Lighting Luminaire (lm/circuit watt) | 65 |
| Heating Efficiency (Hot water) | 4.5 |
| Roof U-Value (W/m²K) | 0.15 |

| Credit requirements considered | Point Scale |
| --- | --- |
| Credits for $\text{EPR}^{\text{INC}} = 0.06$ to $0.9$ | 1-15 |
| Free cooling and passive design; Adopted passive design measure to reduce the overall building energy demand, primary energy consumption or CO$_2$ emissions by at least 5% | 2 |
| Low and zero carbon technology feasibility study | 1 |

**Table 8. Simulation and calculation results with 5 % saving on Energy Demand for BREEAM**

| Wall Envelope + AC | Heating & Cooling Energy Demand (MJ/m²) | GHG emissions (KgCO$_2$/m²) | Individual Parameters | $\text{EPR}^{\text{INC}}$ |
| --- | --- | --- | --- | --- |
| 2 + 3-star | 177.185 | 68.778 | 0.18 | 0.18 | 0.18 |
| 2 + 4-star | 155.040 | 65.354 | 0.34 | 0.32 | 0.33 |
| 2 + 5-star | 137.320 | 61.318 | 0.46 | 0.42 | 0.44 |
| 3 + 3-star | 169.406 | 68.386 | 0.23 | 0.23 | 0.23 |
| 3 + 4 star | 146.547 | 63.179 | 0.40 | 0.37 | 0.38 |
| 3 + 5-star | 129.793 | 59.364 | 0.51 | 0.47 | 0.49 |
| 4 + 3-star | 159.824 | 65.952 | 0.30 | 0.30 | 0.30 |
| 4 + 4-star | 138.257 | 61.040 | 0.45 | 0.43 | 0.44 |
| 4 + 5-star | 122.454 | 57.440 | 0.55 | 0.52 | 0.53 |

**Table 9. Simulation and calculation results with 75 % saving on Energy Demand for BREEAM**

| Wall Envelope + AC | Heating & Cooling Energy Demand (MJ/m²) | GHG emissions (KgCO$_2$/m²) | Individual Parameters | $\text{EPR}^{\text{INC}}$ |
| --- | --- | --- | --- | --- |
| 2 + 3-star | 46.627 | 41.428 | 0.90 | 0.80 | 0.85 |
| 2 + 4-star | 40.800 | 39.332 | 0.93 | 0.82 | 0.88 |
| 2 + 5-star | 36.137 | 38.270 | 0.94 | 0.84 | 0.89 |
| 3 + 3-star | 44.580 | 39.953 | 0.92 | 0.82 | 0.87 |
5. Observations and discussion

On comparing the method of evaluating the performance improvement itself, there is a difference between these two GBR systems. The range of results obtained for each system shows how each design parameter affects the performance improvement calculation and thus how it influences credits for a particular system. For attaining full credits in LEED, the percentage cost PCI should be 40% below PCI and percentage GHG emission should be 65% below the baseline. Here, the calculations were done for two cases, for an on-site renewable energy allocation of 2% and for 60%. Even though none of the cases of 2% renewable energy allocation was able to make a full credit condition, all the combinations considered for the 60% renewable energy allocation was found satisfying the PCI condition and among them some combinations were able to satisfy the condition for GHG emissions. This indicates the fact that the renewable energy allocation has a greater significance in enhanced energy performance for the LEED. When the renewable energy allocation is 2%, the percentage improvement in PCI over PCI\textsubscript{t} is in the range between -17.40% to 2.03% and when the allocation is 60%, a range of 52.07% to 60.01% was obtained. In the case of 60% renewable energy allocation, on improving wall envelope, an average of 0.64% improvement in PCI over PCI\textsubscript{t} was found. When AC system changes, the increase in performance was found in a range between 3.5 to 1.7%. It means that an improvement caused by varying the envelope condition and selection of Air-Conditioning system, puts all the results in a range between 10% to 20%, but in order to achieve good improvements, more renewable energy allocation is the best way. The renewable energy generation here, as per the requirements lies in a range of 7517 kWh to 268608 kWh. Among the results of 60% on-site renewable energy requirement, all the cases of 5-Star rated and 4 star-rated Air-conditioning system showed reduction in GHG emissions. Also, the case ‘4 + 3-Star’ showed full credit condition.

| Design       | PCI\textsubscript{t} | PCI\textsubscript{t} | PCI\textsubscript{t} | PCI\textsubscript{t} | PCI\textsubscript{t} |
|--------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| 3 + 4 star   | 38.565                | 38.583                | 0.93                  | 0.83                  | 0.88                  |
| 3 + 5-star   | 34.156                | 37.581                | 0.95                  | 0.84                  | 0.90                  |
| 4 + 3-star   | 42.059                | 39.128                | 0.92                  | 0.83                  | 0.88                  |
| 4 + 4-star   | 36.383                | 37.836                | 0.94                  | 0.84                  | 0.89                  |
| 4 + 5-star   | 32.225                | 36.888                | 0.95                  | 0.85                  | 0.90                  |

For attaining the full credit condition in BREEAM, an EPR\textsubscript{INC} value of 0.9 was required. From the results, the whole EPR\textsubscript{INC} values were distributed across a range between 0.3 to 0.9. For the low carbon design criteria of BREEAM, use of passive techniques to reduce 5% of energy demand was recommended for achieving credits. Then a maximum value of 0.53 was only able to achieve for 5% energy saving. In this study, a trial of 75% energy saving was also performed. In the trial of 75% energy saving all the cases were in the range of 0.85 to 0.9 and two cases were able to achieve an EPR\textsubscript{INC} values of 0.9. For the 2% energy saving condition, maximum EPR\textsubscript{INC} for combinations vary within a value of 0.2. A design approach based only on building envelope, HVAC efficiency and renewable energy allocation is not satisfactory for BREEAM. Also, BREEAM does not have any requirement for renewable energy generation, rather it considers it as ‘low or zero carbon technology’ in which it is regarded as one method to cause reduction in energy demand. And, credits are not allocated particularly for any higher renewable energy generation, but for a 5% saving over cooling energy demand. The envelope and HVAC efficiency parameters showed negligible improvements over EPR\textsubscript{INC} value. When a 5% saving condition was considered, an improvement in wall envelope caused an average increase of 0.06, and on changing the AC system towards higher efficiency unit, there found an average increase of 0.135 on the EPR\textsubscript{INC} value.
6. Conclusion

This study was done by providing an improvement on envelope condition, the efficiency of the HVAC system, and allocation of renewable energy and looking upon the combinations which grab total achievable credits in energy efficiency. It was found that, for LEED, it was all the case with 60% renewable energy allocation fulfilled the criterion for full credit achievement. In case of BREEAM by these design approach alone, none of the models considered in this study was able to satisfy the full credit condition. For BREEAM, it was found that when a saving of 75% was made over the cooling energy demand, a full credit achievement was possible. That means both systems BREEAM requires considerable decrease in HVAC load. In this study, the cases considered include the Air Conditioning systems with higher ISEER values (4.24,4.7) too. So, such a considerable decrease will occur in the cases only when passive cooling techniques are adopted or on maximizing the natural ventilation considering that the comfort temperature is not increased.

The baseline case for LEED was made with compliance to R-ECBC 2018, from where baseline standards were chosen. More than an improvement on these baseline standards, it was the renewable energy allocation which made all the combinations energy efficient. When there was a renewable energy allocation of 2 % only, the PCI reduction was in the range -17.40% to 2.03%. This means that without higher percentage of renewable energy allocation, even no credits can be achieved. And all the combinations with 60% renewable energy allocation satisfied the full credit condition in terms of improvement in PCI. This indicates the fact that the renewable energy allocation has a greater significance in enhanced energy performance for LEED than any other approach to improve the efficiency. For the case of BREEAM, it was the 75% reduction on cooling energy demand brought all the combinations nearly towards the full credit condition. Also, even with only a 5 % energy saving too, a maximum EPRINC of 0.53 was obtained. That means, by the design approaches based on envelope condition and HVAC efficiency it is possible to achieve credits but for achieving full credits for enhanced energy performance reduction in cooling load has to made. Even BREEAM provides credit for the passive cooling techniques adopted. On discussing the criteria for renewable energy, for LEED, there could be a generation of 7,517 kWh to 2,68,608 kWh, which is a very large value. BREEAM does not have any requirement for renewable energy generation, rather it considers it as ‘low or zero carbon technology’ in which it is regarded as one method to cause reduction in energy demand. And, credits are not allocated particularly for any higher renewable energy generation, but for a 5% saving over cooling energy demand. The performance improvement evaluation is significantly influenced by the efficiency of the HVAC system for both systems.

From this study, BREEAM was found more effective than LEED in reflecting any energy performance improvements while awarding credits. For LEED, it is the renewable energy allocation alone determines a higher efficiency stage for a building and thus influences the credits. But for BREEAM all the combinations considered in the study were able to achieve a distinct credit and for the full credit condition, there required further more improvements in the building.

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