COMPARISON OF ENERGY PERFORMANCE ASSESSMENT BETWEEN LEED, BREEAM AND GREEN STAR

Ya Roderick, David McEwan, Craig Wheatley and Carlos Alonso

Integrated Environmental Solutions Limited, Helix Building, Kelvin Campus, West of Scotland Science Park, Glasgow, G20 0SP, U.K.
Email: ya.roderick@iesve.com Tel: 0141 945 8500

ABSTRACT

With the increasing awareness of sustainable development in the construction industry, implementation of an energy rating procedure to assess buildings is becoming more important. The most representative building environment assessment schemes that are in use today are Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Method (BREEAM) and Green Star.

This paper aims to focus on the investigation of energy performance assessment for new office buildings within the LEED, BREEAM and Green Star schemes. A review of the three schemes with regards to their assessment methods, scopes, performance criteria and energy rating scales are presented. A computational simulation, using software IES Virtual Environment has been conducted to quantitatively benchmark the energy rating method under the three schemes. The selected case study building was a typical open-plan office building located in Dubai. Through this study, an attempt is made to make clear how building energy performance is assessed and therefore awarded with energy credits under the LEED, BREEAM and Green Star schemes and to form a good basis for future development of a generic energy assessment framework across different nations.

KEYWORDS

Energy performance assessment; BREEAM; LEED; Green Star; Computational simulation

INTRODUCTION

Today, a great deal of effort is placed all over the world in achieving sustainable development in the construction industry with the aim of reducing energy consumption in both the construction and management of buildings, thus limiting its consequences on the local and global environment. Such effort can be seen at national and international levels with the launching of voluntary building environmental schemes to measure the performance of buildings. The most representative and widely used schemes are Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Method (BREEAM) and Green Star. LEED was developed by the U.S. Green Building Council (USGBC) and is nationally accepted as a benchmark for green building practices. BREEAM was launched by the U.K. Building Research Establishment (BRE) and is adopted by the U.K. government as a measure of best practice in environmental design and management. Green Star was launched by the Green Building Council of Australia (GBCA) and is established as a national guide to evaluate the environmental design and achievements of buildings. All three schemes are based on a rating system of collecting credits that applies to a wide range of building types, both new buildings and existing buildings. All cover considerable environmental issues such as materials, energy, water, pollution, indoor environmental quality and building site. The most important credit throughout all the three schemes, which is also the essential factor in the overall effort to achieve sustainable development, is the consumption of energy in buildings.

It is clear that a robust and credible building environmental assessment scheme will play a key role in assessing building energy performance. This is especially so for countries that does not have their own schemes and meanwhile undertake energy assessments for buildings. Therefore, it is necessary to understand the different schemes in terms of their assessment methods, scopes, performance criteria and credit scales. There have been some studies (W.L.Lee et. al. 2008, Patxi et. al. 2008, F.Asdrubali et.al. 2008 and Lamberto et.al. 2008) carried out to try and benchmark the well known building environmental schemes that are currently in use, however their research outcome are rather qualitative.

In this study, focus was given on the energy performance assessment of new office buildings within LEED, BREEAM and Green Star. A review of the three schemes with regards to their assessment of building energy performance was presented. To be able to quantitatively benchmark the energy rating methods under the three schemes, a case study based on a typical office building was undertaken by using computational simulation. The program selected for performing the compliance simulations was the IES Virtual Environment (VE). The case study office building was chosen to be located in Dubai, as currently it does not have its own assessment scheme and although predominantly using LEED is believed to be flexible in the use of either of the three assessment methods afore mentioned. Through this exercise, it seeks to make clear how the building energy performance is assessed and therefore awarded with energy credits under the LEED, BREEAM and Green Star schemes, and to form a good basis for future development of a generic energy assessment framework across different nations.

OVERVIEW OF ENERGY ASSEAAMENT METHODS

LEED, BREEAM and Green Star are performance-based, credit-rating assessment schemes, but they differ significantly in assessment method, scope and criteria with regards to the energy performance rating. In the following section, key features of the energy rating method in all the three schemes are reviewed.

LEED scheme

LEED is the most recognised building environmental assessment scheme. The current version for new construction is LEED-NC v2.2, which is based on a set of prerequisites and credits. Each credit refers to one of the following aspects. These are sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, and innovation & design process. One point will be awarded to each credit when the requirement are met except for the energy performance credit and the renewable energy credit in which a number of points will be awarded to each credit depending on by how much performance improvement is achieved. There are up to 69 points that can be achieved. Based on the awarded points, there are four levels the buildings can qualify, which are Certified (26-32 points), Silver (33-38 points), Gold (39-51 points) and Platinum (52-69 points).

There are two approaches to assess building energy performance known as Credit EA1-Optimmize Energy Performance. The first is the Prescriptive Compliance Path, which allows certain projects to achieve up to 4 points when they meet the prescriptive measures of the ASHRAE Advanced Energy Design Guide for Small Buildings 2004. The other approach is the Whole Building Energy Simulation, which allows up to 10 points when the building demonstrates improvement on energy cost against a normalised building. For both approaches, the assessed building needs to meet a minimum performance level, which is 2 points. This is equivalent to a 14% improvement in order achieve any of the levels in the LEED-NC certification.

The Whole Building Energy Simulation requires the use of a simulation program that can perform thermal analysis to the specifications that are laid down by ASHRAE Standard 90.1-2004 appendix G that is known as Performance Rating Method (PRM). The method specifies that two types of building models are created. The first is the proposed building model and the second is the baseline building model. Note that the baseline building needs to be set up with orientations of 0, 90,180 and 270 degrees respectively in order to normalise the self-shading effect. Table 1 shows the main requirements for setting up these two building models. The energy rating is calculated based on the annual energy cost of running the proposed building against the average annual cost of running the baseline building by using actual rates for purchased energy or State average energy prices, as displayed below.

$$\% \text{ of improvement} = 100 \times [1-(\text{Cost of Proposed}/\text{Average Cost of Baseline})]$$

BREEAM scheme

BREEAM is the most widely used building environmental rating scheme in the U.K. Although it is a voluntary standard, the energy performance assessment adopts the U.K. Building Regulation as a benchmark to rate the level of performance improvement. The latest version for office buildings is BREEAM Offices 2008. Similar to the credit rating system in LEED, BREEAM Offices 2008 defines categories of credits according to the building impact on the environment including management, health & wellbeing, energy, transport, water, materials, waste, land use & ecology and pollution. The total score is calculated based on the credits available, number of credits achieved for each category and a weighting factor. The overall performance of the building can be categorised as Unclassified (<30), Pass (≥30), Good (≥45), Very Good (≥55), Excellent (≥70) and Outstanding (≥85). For each category, there are a minimum number of credits that must be achieved.

The energy assessment in BREEAM is referred to as Credit Ene 1-Reduction of CO2 emissions. It allows up to 15 credits to be achieved when the assessed building demonstrates an improvement in the energy efficiency of the building fabric and building services. The energy performance of the building is shown as a CO_2 based index. The number of credits achieved is determined by comparing the building's CO_2 index taken from the Energy Performance Certificate (EPC). The EPC is generated based on the U.K. National Calculation

Methodology (NCM). It provides an energy rating for the building ranging from A to G where A is very efficient and G is the least efficient. To be able to set up the asset rating, two building models need to be created, which are the actual building and the reference building. The asset rating is then calculated as the ratio of the CO_2 emissions from the actual building to the Standard Emission Rate which is determined by applying a fixed improvement factor to the CO_2 emissions from the reference building. Table 2 shows the main requirements for setting up these two building models.

Green Star scheme

Green Star is the most followed voluntary building environmental assessment scheme in Australia. It was developed to accommodate the need of buildings in hot climates where cooling systems and solar shading are of major importance. It has also been adopted in New Zealand and South Africa (GBCA 2008). The current version for new offices is Green Star-Office as Design v3. Similar to LEED and BREEAM, Green Star uses the credit rating system based on a number of points allocated to the credits in order to determine the total scoring and hence the level of certification. The score is determined for each category based on the percentage of points achieved versus the points available for that category. Not all the credits are available for every project, which makes the scoring system flexible for each project. The credits are organised in the following aspect of the building and process: management, indoor environmental quality, energy, transport, water, materials, land use & ecology, emissions, and innovation. The building certification is then expressed as a number of stars: 1-3 Stars (10-44 points; not eligible for formal certification), 4 Stars (45-59 points; Best Practice), 5 Stars (60-74 points; Australian Excellence) and 6 Stars (≥75 points; World Leadership).

The energy credit in Green Star, known as Credit Ene-1 of Greenhouse Gas Emissions allows up to 20 points to be awarded based on the greenhouse performance of the rated space, which counts for around 14.5% of the schemes total score. There are two methods to calculate the predicted greenhouse emissions. The first is to use the Green Star Energy Calculator which is currently being piloted and the other is to use a software program to perform an energy modelling calculation that complies with the requirements and verifications detailed in the NABERS (National Australian Built Environment Rating System) Energy methodology. The methodology includes two approaches to the energy rating, which are NABERS Energy Whole Building rating and NABERS Energy Base Building rating. The latter is adopted by Green Star for the energy assessment.

The NABERS Energy Base Building rating rates the greenhouse performance of the landlord operated services in an office building. A base building model with a good representation of the building's physical shape is to be created to assess the energy consumption. Simulation input parameters need to follow the requirements that are laid down by the NABERS Energy methodology. Table 3 lists the key elements of the simulation input for the base building model. The total greenhouse gas emission is determined by the energy consumption, the rated area and a Greenhouse Gas Coefficient. The rated area is based on the Net Lettable Area (NLA) which excludes areas that are not offices or supporting the office, or not reasonably comparable to typical office spaces. The Greenhouse Gas Coefficient takes into account the total emissions embedded in the energy consumption of electricity or gas.

METHODOLOGY

Computational simulation

To assess building energy performance and calculate the corresponding energy rating credits in LEED, BREEAM and Green Star schemes, a computational simulation method was employed. There are many building energy simulation software available on today's market, however, the software that suits the purpose of the study needs to comply with all the requirements of the three schemes.

LEED recognises software that is capable of performing both load and dynamic simulations (ASHRAE Standard 90.1-2004) and being able to determine the performance of both the proposed and baseline buildings, as well as modelling building components. It also needs to be approved by the rating authority. Green Star recognises simulation packages that must either have passed the BESTEST validation test, or be certified in accordance with ANSI/ASHRAE Standard 140-2001 or European Union draft standard EN13791 July 2000. In BREEAM, there are two classes of approved software for energy performance assessment. The first is the approved software that interfaces with the Simplified Building Energy Model (SBEM) engine and the other is the approved Dynamic Simulation Modelling (DSM) tools. As a result, software IES Virtual Environment 5.9 was selected for this study as it meets all of the requirements of the three schemes.

Case study building

The case study building was intended to be representative as well as to allow the key assessment criteria aforementioned of the three schemes to be assessed. The building model was created as an eight-storey building with open-plan offices. The building also included a three-storey car parking area that ties into its main structure as shown in Fig.1. The building had multi-thermal zones comprising office space, data centre, changing and shower areas, toilet, storage, service/plant areas, elevators, circulation areas and car parking areas.

The total floor area of the building was 31291.8 m^2 and the Net Lettable Floor (NLA) area was 9500 m^2. The HVAC system that was proposed assumes a fully air conditioned plant for the building. The air conditioning system is based on a typical centralised Variable Air Volume system.

Weather data

The case study office building was chosen to be located in Dubai, as it currently does not have its own assessment scheme and although predominantly using LEED is believed to be flexible to any of the three assessment schemes. It can be seen in Tables 1, 2 and 3 that LEED requires hourly weather data that best represent the climate at the building location whilst Green Star requires ACADS-BSG/CSIRO Nominated Test Reference Year weather data for the nearest available climatic weather station. BREEAM adopts CIBSE Test Reference Year data sets. Therefore, to be able to accurately conduct energy performance simulations under all three schemes a test reference year weather data of Dubai is preferred. However, such weather data has not yet been made available. Therefore, in this study, hourly semi-synthetic meteorological data generated by METEONORM 6.0 for Dubai was used.

Energy rating calculation

The study focused on the investigation of energy assessment criteria of three representative building environmental assessment schemes: LEED, BREEAM and Green star, and their energy credit scales based on the open-plan office model developed in the above section. Simulation models were prepared, respectively for each of the schemes. A proposed building model and four baseline building models with orientations of 0, 90, 180 and 270 degrees were developed complying with specifications of the LEED scheme. Two building models of actual building and reference building were created under the BREEAM scheme. A base building model was developed for Green Star scheme. To be able to compare the energy rating credits between the three schemes it was necessary to benchmark input parameters which were allowed to be taken from the proposed design figures for all the simulation models mentioned above. Table 4 lists the input data of envelope, internal loads, domestic hot water service and HVAC systems of the simulation models. By simulating annual energy use and calculating the corresponding CO_2 emissions and energy cost, the number of credits awarded by each scheme was accordingly determined.

The following assumptions were made in the simulations:

- There was no renewable technology applied.
- There were no lighting controls such as a dimming system applied.
- The Greenhouse Gas Coefficient was assumed to be 0.434kgCO_2/kWh for Dubai (Arabian Business)
- The average energy price in Dubai was assumed to be 8$/kWh (DEWA 2008)
- The heat rejection energy consumption was taken as zero.

RESULTS AND DISCUSSION

The simulation results of the energy rating predicted by LEED, BREEAM and Green Star schemes for the case study office building are presented in Table 5. It can be seen that in the LEED scheme the calculated annual energy consumptions of the proposed building and the baseline building were 2525.78 MWh and 2761.86 MWh respectively, which led to a 7.8% improvement. This percentage improvement is below 10.5%, which is the threshold for the minimum point to be awarded. Therefore, the case study office building failed to be LEED certified.

Following the BREEAM scheme, based on the annual CO_2 emissions from both the actual building and reference building, the energy performance asset rating was calculated as 49. From the certificate, the rating obtained belongs to category B energy efficiency, and this would be awarded with 2 BREEAM credits out of the 15 that can be achieved.

Finally, with the Green Star scheme the calculated annual energy consumption from the base building model was 891.57 MWh. It is noted that this figure is relatively low compared with the energy figures predicted by the other two schemes. This may be due to the calculation methodology employed in the Green Star scheme. The annual energy consumption was then normalised to the greenhouse gas emission by using the Dubai local conversion factor. Based on the predicted greenhouse gas emission value which was 41kgCO_2/m^2, the case study office building achieved 11 points out of 20.

As shown above, it can be seen that the results of the energy performance of the building and the rating obtained are strongly dependent on the assessment scheme used. The case study office building received a high energy rating score in the Green Star scheme, but a low energy rating in BREEAM and it even failed to be certified in the LEED scheme. Given that the three schemes are based on different energy assessment methods and performance criteria, it is not surprising that the energy rating results differ.

To take a closer look at the results, Table 6 shows the energy use breakdown between the three schemes. It can be seen that the internal loads from interior lighting and equipment are at relatively similar levels between the LEED and the BREEAM schemes. There does not seem to be much performance improvement between the proposed and the baseline, the actual and the reference building respectively. The Green Star scheme predicted slightly different results as these two figures were taken from the default values specified by the NABERS Energy methodology.

Elevators and escalators seem to have little impact on energy improvement in the LEED scheme as they were equally considered in both the proposed and baseline building models. Green Star predicted much higher energy consumption from the elevators and escalators. This is due to the fact that a fixed default figure of 8 kWh/m^2 based on the Net Lettable Area (NLA) was specified for calculating the lift energy.

When looking at the total auxiliary energy figures between the three schemes, it is noted that there is an 18% improvement made from the proposed building compared to the baseline building in the LEED scheme. For the BREEAM scheme there was a significant difference between the two auxiliary energy values, which were 154.18 MWh for the actual building and 21.37 MWh for the reference building. This significant difference between the two values was due to the fact that the figure for the actual building was calculated based on the design value, whilst the reference building used a fixed default value that is specified by the NCM methodology.

There are also similarities in the predicted space cooling energy consumption between the LEED and the BREEAM schemes. The space cooling energy figures from the Green Star scheme is however slightly lower. It is worth mentioning that the simulation of the HVAC system is of great importance to the energy rating in the three schemes. In the Green Star scheme the HVAC system counts for 65% of the total energy consumption. Little changes or improvements that are made in the system will bring a direct effect on the final score. In addition, both the LEED and the Green Star schemes promotes innovative HVAC technologies and detailed HVAC networks to be simulated, therefore, a well-designed and highly-efficient HVAC system will be rewarded in the energy rating.

CONCLUSION

A computational simulation study was carried out to quantitatively benchmark three representative building environmental assessment schemes: LEED, BREEAM and Green Star with regards to the energy performance assessment. Based on the simulation results it can be concluded that the energy performance of a building and the corresponding energy rating obtained are strongly dependent on the assessment scheme used. Given that the three schemes are based on different energy assessment methods and performance criteria, it is not surprising to find that the case study office building received a high energy rating score in the Green Star scheme, but a low energy rating in the BREEAM scheme and it failed to be certified in the LEED scheme.

It can also be concluded that the HVAC system is the most heavily-weighted variable in the energy assessment of the three schemes. Both LEED and Green Star require the full configuration of the HVAC network to be simulated. This allows assessors to recognise the specific areas of the model or variables of the system that can be improved despite the complications involved with modelling.

Finally, it is noted that both the LEED and BREEAM schemes take into account quite a large number of parameters for assessing the building energy performance based on two comparable building models. On the contrary, the Green Star scheme predicts direct energy consumption from one single building model based on fewer parameters to be assessed; therefore, any changes that are made can have a considerable impact on the final energy rating scores.

The results of the work can provide useful information for future development in a generic building environment assessment scheme to facilitate international comparison.

REFERENCE

Dubai Electricity & Water Authority (DEWA) Tariff Calculator: http://www.dewa.gov.ae/

Department of Environment and Climate Change, NABERS Energy Guide to Building Energy Estimation, www.nabres.com.au

Department for Communities and Local Government, National Calculation Methodology (NCM) modelling guide (for buildings other than dwellings in England and Wales), 2008, London

F.Asdrubali, M.Bonaut, M.Battisti and M.Venegas, Comparative study of energy regulations for buildings in Italy and Spain, Energy and Buildings, 40 (2008) 1805-1815

Green Building Council Australia (GBCA) website, http://www.gbca.org.au/green-star/rating-tools/

Lamberto Tronchin and Kristian Fabbri, Energy performance building evaluation in Mediterranean countries: Comparison between software simulations and opening rating simulation, Energy and Buildings 40 (2008) 1176-1187

Meteonorm, Global Meteorological Database for solar application and system design, http://www.meteonorm.com/pages/en/meteonorm.php

Patxi Hernandez, Kevin Burke and J. Owen Lewis, Development of energy performance benchmarks and building energy ratings for non-domestic buildings: An example for Irish primary schools, Energy and Buildings, 40 (2008) 249-254

W.L.Lee and J.Burnett, Benchmarking energy use assessment of HK-BEAM, BREEAM and LEED, Building and Environment, 43(2008) 1882-1891

90.1 User's Manual, ANSI/ASHRAE/IESNA Standard 90.1-2004, 2004 American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.ISBN 1-931862-63-X

http://www.arabianbusiness.com/515534-energy-management-systems-top-of-agenda

Table 1 Summary of guidelines of setting up the proposed and baseline building models

	Performance Rating Method (PRM)	
	Proposed building	Baseline building
Weather file	Hourly weather data that best represents the climate at the construction site. The selected weather data shall be approved by the rating authority.	
Geometry	Same as design	Same as design except: -Vertical fenestration: Max. 40% window-to-wall ratio distributed in the each facade. -Skylight area: max. 5% skylight-to-roof ratio. -Orientation: Creating 4 baseline building models by rotating the entire proposed building model to 0, 90,180 and 270 degrees and then averaging the results.
Solar shading	-External shading devices and site obstructions are modelled; -Manuel fenestration shading devices such as blinds or shades shall not be modelled, but automatically controlled shades and blinds may be modelled.	No consideration for any shading devices and site obstructions.
Zoning requirement	Both proposed and baseline building models need to follow certain thermal zoning rules depending on whether HVAC zones are designed or not.	
Material & Construction	-Same as design, but if materials and constructions used are not listed in ASHRAE 90.1-2004 Appendix A, it needs to inform the rating authority. -Identifying cool roofs.	-External constructions need to conform to specified U-values based on the building type, space type, fenestration area and climate zone. -No consideration of cool roofs.
Room data	- Lighting power is determined based on whether the lighting system exists, designed or specified.	-Lighting power shall be determined using the same categorization procedure and categories as the proposed design with lighting power set equal to the max. allowed for the corresponding method and category in ASHRAE90.1 section 9.2.
	-Miscellaneous equipment and occupancy gains shall be estimated based on the building type or space type and are identical in proposed and baseline building designs. -Schedules of occupancy, lighting power, equipment power and HVAC operation system are the same as design for both the proposed and baseline models.	

	-Temperature and humidity control set-points shall be the same for proposed and baseline building models.	
HVAC system	HVAC system is determined based on whether the system exists, designed or specified.	HVAC system has to use a specified system type mainly based on building type, fuel type, floor area and building height.
Hot water system	-Same as the actual system when the water service system exists -Same as design when the system is specified - Matching the system used in the baseline model when the system hasn't been specified.	-Same as the actual system when the water service system exists -It shall match the min. efficiency requirements when the system is specified -It shall use electrical-resistance system and match min. efficiency requirements when the system has not been specified.
Infiltration & Ventilation	Infiltration rate is the same as design and minimum outdoor air ventilation rates are the same for the proposed and baseline building designs.	
Renewable	Yes	No

Table 2 Summary of guidelines of setting up the actual and reference building models

	National Calculation Methodology (NCM)	
	Actual building	Reference building
Weather file	CIBSE Test Reference Year weather data covering 14 locations in the U.K. are used for compliance simulations. The chosen weather data shall be taken as the one from the 14 locations, which is closest in distance to the building site and used for both actual and reference building models.	
Geometry	Same as design.	Same as design except areas of windows, doors and roof lights that must conform to rules set out in the NCM modelling guide.
Solar shading	-External shading including site obstructions and shading devices are to be modelled -Internal shading is to be modelled.	It must be subject to the same site shading from adjacent buildings and other topographical features as are applied to the actual building model.
Zoning requirement	Both the actual and reference buildings follow the same ruling arrangement that is defined based on HVAC and lighting.	
Material & Construction	Same as design.	-Construction U-values must conform to these U-values that are identified in the NCM modelling guide. -Special considerations apply to ground floors where the U-value is a function of the perimeter/area ratio.
	-U-values of display windows must be taken as 5.7 W/m^2K in both the actual and reference building models. -Smoke vents and other ventilation openings must be disregarded in both building models.	
Room data	-Each space must contain the same activity and therefore the same activity parameter values in both the actual and reference buildings. These activity parameters include occupancy times, density, sensible and latent gains, equipment gains and schedule profile, lighting lux level and schedule, heating set-point temperature, HVAC operation profile, hot water demand and outside air requirement. -The activity in each space must be selected from the NCM Activity Database.	
	-Lighting power density is allowed to use proposed design figures if known.	-Lighting power density is a fixed value dependent on the assigned room activity.
HVAC system	- System efficiency, fuel type and auxiliary energy figures are the same as design.	-Heating fuel type must be gas. -Heating SCoP must be 0.73 and auxiliary energy must be taken as $0.61W/m^2$.

		-Cooling set point is fixed at 27 ^{o}C and the cooling SSEER must be taken as 2.25.
Hot water system	-Hot water demand is defined by the selected room activity. -System efficiency and fuel type must be taken from the proposed design.	- Hot water demand is specified by the same room activity shared with the actual building. -System overall efficiency must be taken as 45% and it must be a gas-fired system.
Infiltration & Ventilation	-The calculation method used to predict the infiltration rate must use the air permeability. The air permeability of the actual building is modelled as design and the air permeability of the reference building must be 15 $m^3/(h{\cdot}m^2)$ at 50 Pa. -Ventilation rates and profiles are defined by the selected room activity based on the NCM Activity database.	
Renewable	Yes	No

Table 3 Summary of requirements for setting up the base building model

	NABERS Energy
	Base building
Weather file	Weather data must use ACADS-BSG/CSIRO Nominated Test Reference Year for the nearest available climatic weather station.
Geometry	Same as design
Solar shading	-Shading to be accurately represented including modelling of overhangs and window insets. -External shade from buildings and trees need to be modelled. Deciduous trees to be modelled as having time-varying transmissivity. -Moveable shadings must be represented as movable.
Zoning requirement	No specific requirements for zoning strategy, however zones need to be sympathetic to the operational and thermal characteristics.
Material & Construction	Same as design.
Room data	-Lighting power density, equipment load and occupant density shall be modelled with provided default figures. - Schedules of occupancy, lighting power, equipment power and HVAC operation system shall be modelled with provided profiles. -Overnight energy use of lighting, equipment, occupancy and HVAC system need to be considered, referred as ‘after-hours zones’ schedules. The ‘after-hours zones’ schedule must be applied to a single after-hours zone of the building. -Lighting controls are to be modelled realistically. - Temperature and humidity control set-points shall be modelled the same as design.
HVAC system	-HVAC system type, design and control are to be modelled to reflect the actual system. -Incremental cooling tower energy arising from electrical input to the tenant supplementary conditioners plus the mechanical energy delivered to the condenser water by pumps need to be considered. -Pumping energy must be accounted.
Hot water system	Hot water demand is to be calculated using the figure of 2kWh/m^2 based on Net Lettable Area (NLA), plus any system losses.
Infiltration & Ventilation	Same as design
Renewable	Application of renewable energy integrated into the building is to be modelled, but any planned or future purchase of Green Power is to be treated as normal electricity.
Others	-Car park intended for the sole use of tenants to be modelled including both lighting and ventilation. -No discount of on-site energy use is available against energy exported from the site under any circumstances. Fuels used to generate on-site energy must be included within the energy assessment.

Table4 Comparison of main simulation inputs between LEED, BREAM and Green Star schemes

	LEED		**BREEAM**		**Green Star**
	Proposed building	Baseline building	Actual building	Reference building	Base building
Weather file	Dubai MTN	Dubai MTN	Dubai MTN	Dubai MTN	Dubai MTN
Construction U-value (W/m^2K)	External wall:0.57 Ground floor:0.016 External glazing:2.1 Roof:0.25 Door:2.32 Internal wall:1.47 Ceiling type1:2.14 Ceiling type2:2.28 Ceiling type3:3.61 Ceiling type4:2.3	External wall:0.71 Ground floor:1.1 External glazing:6.9 Roof:0.36 Door:2.32 Internal wall:1.47 Ceiling type1:2.14 Ceiling type2:2.28 Ceiling type3:3.61 Ceiling type4:2.3	External wall:0.57 Ground floor:0.016 External glazing:2.1 Roof:0.25 Door:2.32 Internal wall:1.47 Ceiling type1:2.14 Ceiling type2:2.28 Ceiling type3:3.61 Ceiling type4:2.3	External wall:0.35 Ground floor:0.25 External glazing:2.2 Roof:0.25 Door:2.32 Internal wall:1.47 Ceiling type1:2.14 Ceiling type2:2.28 Ceiling type3:3.61 Ceiling type4:2.3	External wall:0.57 Ground floor:0.016 External glazing:2.1 Roof:0.25 Door:2.32 Internal wall:1.47 Ceiling type1:2.14 Ceiling type2:2.28 Ceiling type3:3.61 Ceiling type4:2.3
Lighting gain (W/m^2)	Data Centre:3.75 Changing facility:5.2 Lobby:7.8 Stair:5.2 Open plan office:12 Parking:2 Plant room:7.5 Storage:1.88 Toilet:5.2	Data Centre:12 Changing facility:6 Lobby:14 Stair:6 Open plan office:12 Parking:2 Plant room:13 Storage:3 Toilet:10	Data centre (IT equip.):3.75 Changing facility:5.2 Circulation:5.2 Open plan office:18.75 Plant room:7.5 Storage:1.88 Toilet:5.2		12
Equipment gain (W/m^2)	Data Centre: 50 Changing facility:5 Lobby: 5 Open plan office:12 Parking: 20 Storage:2 Stair:2 Plant room: 50 Toilet:5		Data centre (IT equip.):50 Changing facility:5 Open plan office:15 Circulation:2 Plant room:50 Storage:2 Toilet:5		Average: $11W/m^2$
Occupancy gain (W/person)	Data Centre: $1/9.09m^2$ Max. sensible:85.4 Min.sensible:54.6 Changing facility: $1/7.69\ m^2$ Max. sensible:70 Min.sensible:70 Open plan office: $1/9.09\ m^2$ Max. sensible:73.2 Min.sensible:46.8 Lobby: $1/9.09\ m^2$ Max. sensible:61 Min.sensible:39 Stair & Storage & Toilet: $1/9.09\ m^2$ Max. sensible:70 Min.sensible:70 Plant room: $1/9.09\ m^2$ Max. sensible:90 Min.sensible:90		Data centre (IT equip.): $1/9.09m^2$ Max. sensible:85.4 Min.sensible:54.6 Changing facility: $1/7.69\ m^2$ Max. sensible:70 Min.sensible:70 Open plan office: $1/9.09\ m^2$ Max. sensible:73.2 Min.sensible:46.8 Circulation & Storage & Toilet: $1/9.09\ m^2$ Max. sensible:70 Min.sensible:70 Plant room: $1/9.09\ m^2$ Max. sensible:90 Min.sensible:90		Occupancy density: $1/15m^2$ Max. sensible:70 Max. latent:60
HVAC system	VAV system with COP=4.52 and delivery efficiency=0.95	VAV Reheat system with COP=4.19 and delivery efficiency=0.95	VAV system with SEER=4.52 SSEER=4.29Delivery efficiency: 0.95 Auxiliary energy: $4.4W/m^2$	VAV system with SEER=3.6 SSEER=2.25Delivery efficiency:0.91 Auxiliary energy: $0.61W/m^2$	VAV system with COP=4.52 and delivery efficiency=0.95
Hot water system	Fuel type: gas Generator seasonal efficiency:1 Delivery efficiency:0.8		Fuel type: gas Generator seasonal efficiency:1 Delivery efficiency:0.8	Fuel type: Gas Generator seasonal efficiency:0.9 Delivery efficiency:0.5	$2kWh/m^2$ based on NLA
Infiltration	$0.25ACH^{-1}$	$0.25ACH^{-1}$	Air permeability: 10 at $50Pa/(m^3/(m^2h))$	Air permeability: 15 at $50Pa/(m^3/(m^2h))$	$0.25ACH^{-1}$
Others	Elevator: annual energy consumption 300kWh per elevator per floor Exterior lighting: allowable power density=$2.2W/m^2$		Elevator: n/a Exterior lighting: n/a		Elevator:$8kWh/m^2$ based on NLA Exterior lighting: allowable power density=$2.2W/m^2$

Table 5 Result comparison of the energy rating between LEED, BREEAM and Green Star

	LEED		**BREEAM**		**Green Star**
	Proposed building	Baseline building	Actual building	Reference building	Base building
Energy consumption (MWh)	2545.78	2761.86	1892.44	2044.70	891.57

CO_2 emission (tons)	-	-	776.40	959.01	386.94
Energy cost ($)	20366240	22094880	-	-	-
Normalisation formulae	*% improvement* = 7.8%		*EPC Rating* = 49		*Emissions* = 41 $kgCO_2/m^2$
Credit points	**0 (total 10 points)**		**2 (total 15 points)**		**11 (total 20 points)**

Table6 Results comparison of energy use breakdown between LEED, BREEAM and Green Star

End Use (MWh)	LEED		BREEAM		Green Star
	Proposed Building	Baseline building	Actual building	Reference building	Base building
Interior lighting	544.37	555.81	579.20	577.73	454.92* (total)
Tenancy lighting					351.5*
Common area lighting					81.42
Carpark lighting					22
Exterior lighting	92.55	92.55	n/a	n/a	92.55
Equipment	589.37	589.37	589.46	589.46	607.98*
Space heating	22.13	26.96	1.22	0	0.11
Space cooling	487.16	631.06	476.71	693.18	414.42
Service water heating	92.74	92.74	91.67	162.96	19.3
Pumps	11.51	12.89	154.18	21.37	37.51
Interior fans	242.42	296.96			136.08
Parking garage fans	439.2	439.2	n/a	n/a	n/a
Heat rejection	0	0	0	0	0
Refrigeration	n/a	n/a	n/a	n/a	n/a
Cooking	n/a	n/a	n/a	n/a	n/a
Elevators & escalators	24.33	24.33	n/a	n/a	77.2
Water treatment	n/a	n/a	n/a	n/a	10.98
Total energy consumption	**2545.78**	**2761.86**	**1892.44**	**2044.70**	**891.57**

*Do not count towards total energy consumption used for the energy rating in Green Star

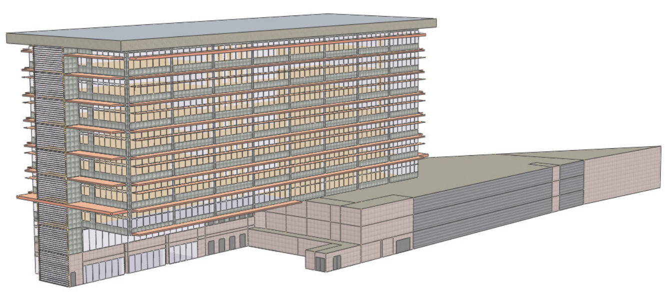

Fig.1 Geometric representation of the case study building (north-east view)