DEVELOPING A FRAMEWORK TO BENCHMARK OPERATIONAL ENERGY IN SUSTAINABLE COMMERCIAL BUILDINGS IN SRI LANKA

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ABSTRACT

Benchmarking of operational energy efficiency stands for an influential tool to promote the efficient use of energy in buildings. This research stands for developing a framework to benchmark operational energy efficiency in sustainable commercial buildings in Sri Lanka. The developed framework offers the opportunity to achieve advance efficiency in energy, compares to the buildings which are just built to code. The benchmark is to be served as a referencing point of comparing and contrasting best practices within local context, while offering a realistic energy goal and eligibility to sustainability. The developed framework can be adapted to any context in order to benchmark operational energy consumption as well as any other sustainability domains such as water, indoor environmental quality and site development. The motivation behind this paper is to provide an energy benchmarking framework to evaluate the facility, which gives competitive advantages and better approach to the up-coming challenges in the fast growing world.

Keywords: *Operational Energy Benchmark, Sustainability Initiatives, Operational Energy Aspects, Operational Energy Indicators, Weighted Average Method.*

1. INTRODUCTION

Sustainability is one of the most widely used words in the scientific field as a whole and in the environmental sciences in particular due to increasing natural disasters, depletion of natural resources and the growing problems of waste materials as a by-product of the global economy. World Commission on Environment and Development (1987) defined sustainability as the ability to meet the needs of the present without compromising the ability of future generations to meet their own needs. Sustainable buildings are regarded as buildings that use key resources like energy, water, materials and land more efficiently than buildings that are just built to code (Kats, 2003), while emphasising that sustainability is a moving goal with ‘green’ or ‘sustainable’ being reserved for those that are built ‘beyond compliance’ with regulation (Sayce *et al.*, 2007).

The aim of this paper is therefore to review different sustainability initiatives and develop a framework to benchmark operational energy in sustainable commercial buildings in Sri Lanka. The paper presents a brief introduction to the sustainability, sustainability initiatives and relationship between sustainability and energy. The paper finally presents the developed framework for benchmarking operational energy in sustainable commercial buildings in Sri Lanka.

2. SUSTAINABILITY INITIATIVES

Since, the prospects of climate change, resource depletion and emissions generation have combined to create an increasing awareness of sustainability issues and demand for green construction practices in general, a need has being appeared to rate practices and products in order to compare and contrast best practices (Presley and Meade, 2010) and the sustainability indicators have emerged as one widely accepted tool at all levels, national, community, organisation and company (Veleva *et al.*, 2003). According to Green Rating for Integrated Habitat Assessment (2010), these indicators/rating systems are an evaluation tool that measure environmental performance of a building throughout its life cycle which

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usually comprises of a set of criteria covering various parameters related to design, construction and operation. In that manner, the international ‘grading systems’ have been put in place to define and show levels of achievement in green, sustainable, intelligent and secure buildings such as Building Research Establishment Environmental Assessment Method (BREEAM), Comprehensive Assessment System for Building Environmental Efficiency (CASBEE), Green globes, Green star and Energy star (Miller *et al.*, 2008).

3. SUSTAINABILITY AND ENERGY

One of the common major criteria addressed by most of the sustainable built environment initiatives (rating systems) is the ‘energy’, as sustainable building design is about limiting their negative environmental effects and using materials, energy and other resources in a sustainable manner (Margret, 2008). Besides, Chandratilake and Dias (2010) have taken the ‘energy efficiency’ as one domain of sustainability, in order to undertake the survey of ‘sustainability rating systems for buildings: comparisons and correlations’, among other sustainability domains such as site, water, materials, indoor environmental quality and waste and pollution. As stated by the Gowri (2004), efficient use of energy is a key element in the design of a green building, whereas the principles of sustainable building design promote energy conservation, healthier and safer buildings for occupants, and a reduction in greenhouse gas emissions, environmental stewardship and social responsibility.

Energy use during the lifespan of buildings consists of embodied energy, operating energy and demolition energy. The total embodied energy demand includes energy used in producing and transporting the building materials and components, and energy used for various processes during the production and demolition of the building, whereas operational energy is the energy use in keeping the indoor environment within the desired range (Chen *et al.*, 2001). According to the Sartori and Hestnes (2007), the operational energy is the energy used in buildings during their operational phase, as for, heating, cooling, ventilation, hot water, lighting and other electrical appliances. However, managing operational energy in buildings becomes more significant, as Kofoworola *et al.* (2009) found that, the average annual energy consumption over 50 years of operation of the building, the embodied and operating energy of the building over its lifespan indicated that the embodied energy is about 15% of the operating energy. In addition, Sartori and Hestnes (2007) mentioned that the operating energy represents by far the largest part of energy demand in a building during its life cycle, also been shown a linear relation between operating and total energy. Hence, energy plays a key role, particularly in the context of sustainability, while, the operational energy plays a key role in the context of building energy usage. The framework, therefore, is developed to benchmark the building operational energy and can also be adapted to benchmark entire energy domain and other sustainability domains such as water, indoor environmental quality and site development.

4. METHODOLOGY

The research introduces a framework to benchmark operational energy in sustainable commercial buildings in Sri Lankan context. In order to facilitate the framework, the research has reviewed seven (7) key sustainability initiatives, namely, Leadership in Energy and Environmental Design (LEED) (USGBC, 2008), Building Research Establishment Environmental Assessment Method (BREEAM, 2010), Comprehensive Assessment System for Building Environmental Efficiency (CASBEE, 2008), Green Building Index (GBI, 2009), Green Rating for Integrated Habitat Assessment (GRIHA), Green Star (2012) and Green Mark (BCA, 2009), to identify common contributory aspects on operational energy efficiency within the sustainable built environment. The study further identified available indicators for such operational energy aspects along with benchmark values by referring same sustainability initiatives and energy efficiency building code published by Sri Lanka Sustainable Energy Authority (SSEA, 2008). The referred sustainability initiatives provide different contributory aspects and different weight allocations to such aspects based on miscellaneous dissimilarities of related countries. Therefore, an expert survey was undertaken to identify the importance levels (weights) of identified operational energy performance aspects within Sri Lankan context. Thirty experts from three different professions were selected based on their experience and awareness on subject matter. Hence, ten (10) Facilities Managers, ten (10) Engineers, ten (10) Architects were selected who have more than 5 year experience in the building industry and whose majority are involved in sustainable projects. Then a weighted average formula was developed and identified values were applied to such formula in order to obtain benchmarks for identified aspects. Finally, the framework leads to develop a benchmark for entire operational energy domain and continuous monitoring and review of the process.

5. THE OPERATIONAL ENERGY BENCHMARKING FRAMEWORK

In order to develop an operational energy benchmark, a proper consideration on all related operational energy performance aspects should be given in a systematic way. Because, the ultimate energy domain benchmark is to be represent a 'perfect target', covering all aspects. Therefore, to develop the operational energy benchmark, a framework has been developed as follows (Figure 1).

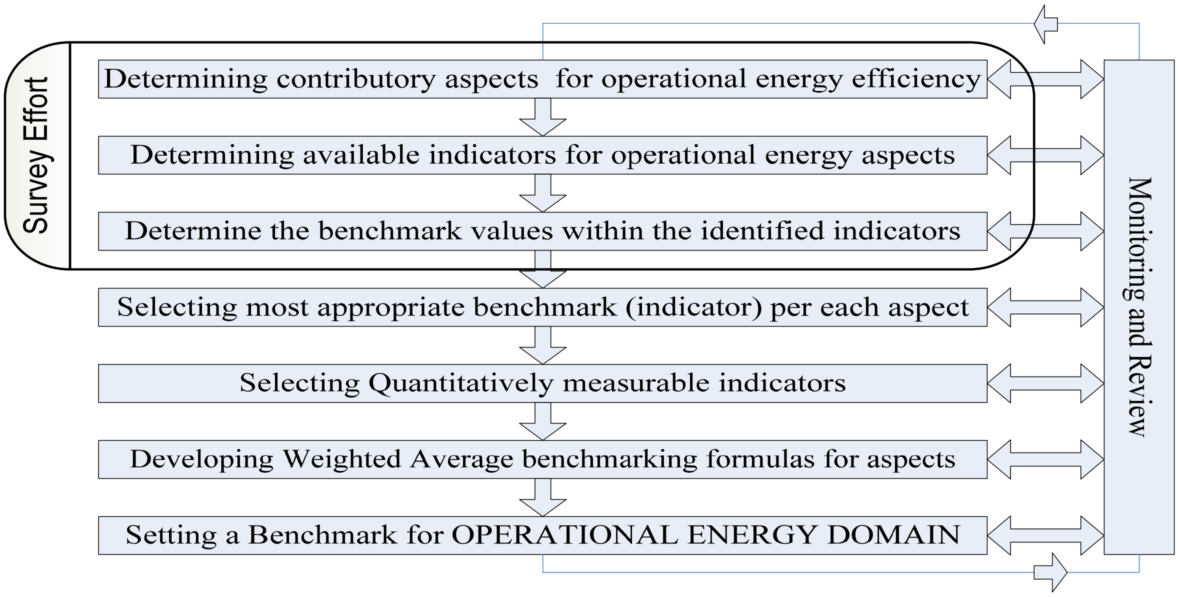

Figure 1: Framework for Benchmarking Operational Energy

5.1. DETERMINE ASPECTS CONTRIBUTING TO OPERATIONAL ENERGY EFFICIENCY

Sustainability initiatives/ rating systems have provided different criteria/ aspects, in order to achieve operational energy efficiency within the sustainable built environment, based on their own requirements. Therefore, from the referred key sustainability initiatives, a common list of contributory aspects for operational energy analysis was identified, by amalgamating and splitting sub-aspects among identified common aspects to undertake the survey in a common basis. The identified common operational energy aspects now follow.

BUILDING DESIGN / ORIENTATION

Building design refers to the broadly based architectural, engineering and technical applications to the design of the buildings, while the orientation of the building generally used to refer to solar orientation, which is the setting of building with respect to solar access. Building energy efficiency in design/ orientation of building is achieved in terms of, proper orientation of the building block and interior spaces; proper designing of the building, related to building typology, solar geometry, predominant wind direction, existing vegetation, climatic zone, Window to Wall ratio (WWR) etc; designing, installation, commissioning of energy-related systems, such as Heating, ventilating, air conditioning and refrigeration (HVAC&R) systems (mechanical and passive) and associated controls, lighting and day lighting controls, renewable energy systems (e.g., wind, solar) at an optimum to realise their full potential and intent; Extent of natural ventilation and day lighting to the building etc.

BUILDING ENVELOP PERFORMANCE

Building envelope is the separation between the interior and the exterior environments of a building. It serves as the outer shell to protect the indoor environment as well as to facilitate its climate control. This element contributes to a substantial share of the cooling or heating load. The HVAC system has to cater to this load as well as in order to maintain the comfort, process condition. The building envelop performance is optimised in terms of; U-values and Overall Thermal Transmission Value (OTTV) of facades and roof; Visual Light Transmission (VLT) for fenestrations; control of shading coefficient (glass type), Window to Wall Ratio (WWR) and use of internal shading devices (SCint), external shading devices (SCexe); envelop sealing, caulking, gasketing or weather stripping; fenestration and doors to limit air leakages.

SYSTEM/ SERVICE ENERGY PERFORMANCE

Building energy related systems/ services such as HVAC&R systems, lighting, elevators, plug loads and other miscellaneous loads totally contributes to operational energy consumption of a facility. Maximum energy performance of such systems is achieved in terms of; use of efficient energy-related systems, such as HVAC&R systems (mechanical and passive) and associated controls, lighting and day lighting controls, elevator systems, plug loads and other miscellaneous loads; use of energy efficient practices and features which are innovative and/or have positive impact; proper operation and maintenance of such systems/ services for optimised energy efficiency.

CO_2 EMISSION RATE REDUCTION

Control/ reducing of building carbon emission rate or the energy related CO_2 emission in terms of; use of low carbon emission energy sources (avoid use of coal, oil, natural gas etc); use of zero carbon emission energy sources (some renewable such as solar, wind etc).

REDUCED OZONE DEPLETION

Control of energy related greenhouse/ozone layer depleting gas emission in terms of; zero or minimum use of chlorofluorocarbon (CFC)-based refrigerants in new base building HVAC&R systems; provision of a replacement schedule for CFC-based refrigerants in existing HVAC systems; design and operate the facility without mechanical cooling and refrigeration equipment; select HVAC&R equipment with reduced refrigerant charge and increased equipment life; maintain equipment to prevent leakage of refrigerant to the atmosphere.

ON-SITE RENEWABLE ENERGY

The self sufficiency in energy through renewable technologies for on-site power generation and use within the building such as solar, wind, geothermal, low-impact hydro, bio-mass/ bio-gas, or any other forms of renewable energy.

OFF-SITE RENEWABLE ENERGY

Investments in off-site renewable energy technologies to be exported to the grid (engage in green power contract).

COMMISSIONING AND TESTING

Ensure building's energy related systems are designed and installed to achieve proper commissioning so as to realise their full potential and intent in terms of; begin the commissioning process early in the design process and execute additional activities after systems performance verification is completed; developing and incorporating commissioning requirements into the tender documents; Developing and implementing a commissioning plan; verifying the installation and performance of the systems to be commissioned; reviewing contractor submittals applicable to systems being commissioned for compliance.; developing a systems manual that provides future operating staff the information needed to understand and optimally operate the commissioned systems.; verifying that the requirements for training operating personnel and building occupants are completed.

MEASUREMENT AND VERIFICATION

Ongoing accountability of building energy consumption over time to evaluate building and/or energy system performance and verify predicted energy use of key building systems/ services, in terms of; install the necessary metering equipment to measure energy use including sub-metering.(Electrical sub-metering to encourage and recognise the provisions of energy sub-metering to facilitate energy monitoring of base building services while tenancy sub-metering to encourage and recognise the provisions of energy sub-metering to facilitate energy monitoring by tenant/end user); track performance by comparing predicted performance to actual performance; installing diagnostics within the control system to alert when equipment is not being optimally operated; use Energy Management System (EMS) to monitor and analyse energy consumption including reading of sub-meters.

ENERGY AUDIT AND VALIDATION

Auditing and validating the predicted energy consumption while maintaining proper process of auditing and validation.

5.2. DETERMINE AVAILABLE INDICATORS FOR IDENTIFIED ASPECTS

Appropriate benchmarks for each identified operational energy efficiency aspects have to be developed, in order to develop the benchmark for energy domain ultimately. The referred sustainability initiatives consist of variety of indicators for contributory aspects. However, appropriate indicator/s and locally applicable benchmark values for such indicators have to be found to facilitate benchmarking process of each aspect, therefore, available indicators for each and every aspect from each rating systems were identified as shown in Table 1. During the effort, both expressed indicators and implied indicators were taken out, which provide the most appropriate representation of aspect efficiency, but regardless to their characteristics of quantitative or qualitative measurability.

5.3. DETERMINE THE BENCHMARKS WITHIN THE IDENTIFIED INDICATORS

Initially, the indicators for each energy performance aspects have identified. Therefore, in this step, an attempt was taken to identify the benchmarks included in such indicators. For an instance, the building envelop performance aspect came about few benchmarks, namely, OTTV $\leq$ 50 W/m^2 (GBI), ETTV < 50 W/m^2 (Green Mark), PAL = 300 MJ/m^2/yr (CASBEE), OTTV < 50 W/m^2 (SSEA) and improved percentage of proposed building performance rating compared to baseline > 10% (LEED). In this manner, benchmarks included in each identified indicator were taken out for each aspect, however, some indicators were converted to format of benchmarks while some were directly come across in such a format.

5.4. SELECTING MOST APPROPRIATE INDICATOR PER EACH ASPECT

At this point, the finalising of benchmarks was undertaken. Some available local benchmarks from 'Code of practice for energy efficient buildings in Sri Lanka 2008' - Sri Lanka Sustainable Energy Authority (SSEA) were also selected for energy performance aspects. For other aspects, benchmarks were selected from referred rating systems. Since, each rating systems hold different benchmarks either by benchmark value or benchmark nature/ type/ definition etc. most appropriate benchmark was selected based on certain similarities (climatic, geographical etc) with the local context and presented in Table 2. Since, GRIHA (India), GBI (Malaysia), Green Mark (Singapore) are rather similar to Sri Lankan context in both climatic and geographical conditions, indicators from such rating systems were selected. Besides, LEED (US) and above mentioned rating systems are having strong positive relationships, which justifies the selection of appropriate indicators in advance.

Table 1: Available Indicators for Contributory Aspects

Energy Performance Aspects	Indicators							
	LEED	BREEAM	GRIHA	GBI	Green Mark	Green Star	CASBEE	Sri Lanka Sustainable Energy Authority
Building design/orientation	Building orientation performance	N/A	Level of Climate responsiveness	N/A	N/A	Green star office desing certified rating	N/A	N/A
Building envelop performance	Building performance Rating (BPR)	Minimum standards not available	Envelop Performance Factor (EPF)	Overall Thermal Transfer Value (OTTV)	Envelop Thermal Transfer Value (ETTV)	N/A	Peremeter Annual Load (PAL)	Overall Thermal Transfer Value (OTTV)
System/Service energy performance	Percentage of Energy cost savings	•Availability of energy efficient features in lifts •Luminous efficiency •Availability of sustainable IT equipment	Reduced energy consumption	Building Energy Intensity (BEI)	Energy Efficiency Intensity (EEI)	•Improvement in energy effciency •Peak energy demand reduction •Availability of office lighting zoning Lighting Power Density (LPD)	Coefficient of Energy Consumption (CEC)	•Energy Efficiency Rate (EER) •Integrated Part Load Value (IPLV) Lighting Power Density (LPD)
CO_2 emission rate	Maximum threshold for the combined contributions to ozone depletion and global warming potential	Power Usage Effectiveness(PUE) & CO_2 index	N/A	N/A	N/A	Percentage of reduced building's CO2 emission	Life Cycle CO_2 emission	N/A
Reduced Ozone depletion		Percentage of reduced building's CO2 emission	CFC-based refrigerants in HVAC system	N/A	N/A	N/A	Ozone Depletion Potential (ODP)	N/A
On-site renewable energy	Percentage of energy produced by the renewable systems over the building's annual energy cost	Percentage of reduced building's CO2 emission	Percentage of renewable energy over lighting and space conditioning load or its eqalent	Percentage of renewable energy generation from total electricity consumption	Percentage of replacement of electricity by renewable energy sources	N/A	Percentage of converted renewable energy usage	N/A
Off-site green power	Percentage of building electricity by renewable energy No of years of green power contract	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Commissioning & testing	Availability of proper commisiioning process	N/A	N/A	Availability of pre-comissioning, commissioning and post occupancy commisioning	N/A	N/A	N/A	N/A
Measurement & verification	The coverage of M & V period	•Availability of separate meters •Availability of BMS	N/A	Availability of EMS including Maximum Demand Limiting programme	Availablity of sub-metering	•Availability of sub metering for base building services •Availability of sub metering for end user	Introduction of BEMS	N/A
Energy Auditing	N/A	N/A	Availability of energy auditing process	N/A	N/A	N/A	N/A	N/A

Table 2: Finalised Benchmarks for Aspects

Energy Performance Aspects	Selected indicator benchmark	Reference
Building Design/Orientation	Building orientation performance (Computer based acceptance)	LEED
Building Envelop Performance	OTTV < 50W/m^2	SSEA
System/Service Energy Performance	EEI < 150 kWh/m^{2}y	Green Mark
CO_2 Emission Rate	LCGWP + LCODP x 105 ≤ 100	LEED
Reduced Ozone Depletion		
On-site Renewable Energy	Energy produced by the non-renewable systems over the building's annual energy cost <99%	LEED
Off-site Green Power	Percentage of building electricity by non-renewable energy < 65%	LEED
Commissioning & Testing	Availability of pre-commissioning, commissioning & post occupancy commissioning	GBI
Measurement & Verification	Availability of EMS including Maximum Demand Limiting programme	GBI
Energy Auditing	Availability of energy auditing process	GRIHA

5.5. SELECTING QUANTITATIVELY MEASURABLE INDICATORS

The finalised benchmark list consists of both quantitatively measurable benchmarks and qualitatively measurable benchmarks. Due to the incapability of developing benchmarks for qualitative measures at this research level, only the quantitatively measurable benchmarks were selected. Therefore, only six energy performance aspects were left to the benchmarking process ultimately. (Table 3)

Table 3: Finalised Quantitative Benchmarks

Energy Performance Aspects	Selected indicator benchmark	Reference
Building Envelop Performance	OTTV < 50W/m^2	SSEA
System/Service Energy Performance	EEI < 150 kWh/m^{2}y	Green Mark
CO_2 Emission Rate	LCGWP + LCODP x 105 ≤ 100	LEED
Reduced Ozone Depletion		
On-site Renewable Energy	Energy produced by the non-renewable systems over the building's annual energy cost <99%	LEED
Off-site Green Power	Percentage of building electricity by non-renewable energy < 65%	LEED

5.6. DEVELOPING WEIGHTED AVERAGE BENCHMARKING

The expert survey collected data from thirty (30) experts on the importance level/significance/ weights of each aspect, on the operational energy of buildings within the local context. The average comparison within local context allows identifying the weight of each aspect, where high averages stand for high importance and less averages stand for less importance levels (Table 4).

Table 4: Weights from Expert Survey

Aspect	Weight
Building design/orientation	16
Building envelop performance	9
System/Service energy performance	20
CO_2 emission rate	6
Reduced Ozone depletion	5
On-site renewable energy	9
Off-site green power	4
Commissioning and testing	11
Measurement and verification	10
Energy audit and validation	10

The highest average stands for the 'system/ service' aspect. Since the operating energy represents the largest part of energy demand in a building life cycle, it is evidently reasonable to have this highest average in the system/ service energy performances. The CO_2 emission rate and reduced ozone depletion hold relatively lower average when comparing to other aspects. Because, the Sri Lankan annual CO_2 emission is 0.04% while, calculated annual green house gas emission is 0.05% (Wikipedia, 2012), which is in a range of insignificance and, demarcates the necessity of less concern as an aspect. In the ranking list of CO_2 emission and calculated annual green house gas emission of countries, Sri Lanka is having the 91st place and 103rd place respectively. In order to calculate the benchmark values, a formula has then developed as follows (Equation 1), using identified base benchmarks and relevant weightings.

The aspects comprise of different measurements and weightings. Due to these comparative difficulties, the formula was developed in a manner that it to be normalised and derived unit free benchmarks, proportionate to their own weightings. However, final benchmark is a negative side benchmark where lower the better.

$$Aspect\ Benchmark = \frac{Building\ Aspect\ Value \times Weight}{Base\ Benchmark\ Value} \qquad \text{(Eq: 01)}$$

Base Benchmark value: *This stands for the benchmark value which is in the relevant indicator of the aspect. Simply, it means the indicator's benchmark with related to the aspect.*

Weight: *This stands for the importance of the particular aspect within the local context. Here, it is the average value of the aspect, which is derived from expert survey.*

Building aspect value: *This means the real value of commercial building with related to the relevant aspect which is going to be measured by the benchmark*

The Figure 2 consists of developed benchmarking formulas for each aspect using the standard format above discussed.

ASPECT	BENCHMARK FORMULAR
Building Envelop Performance	OTTV = $\frac{\text{Building OTTV}}{\text{OTTV Base Benchmark}} \times$ Weight
System/service Energy Performace	EEI = $\frac{\text{Building EEI}}{\text{EEI Base Benchmark}} \times$ Weight
CO_2 Emission Rate Reduced Ozone Depletion	Combined contribution = $\frac{\text{Building LCGWP+LCODPx105}}{\text{Base Building LCGWP+LCODPx105}} \times$ Weight
On-site Renewable Energy	$NRE_{on\text{-}site}$ = $\frac{\text{Building NRE \%}}{\text{NRE Base benchmark}} \times$ Weight
Off-site Renewable Energy	$NRE_{off\text{-}site}$ = $\frac{\text{Building NRE \%}}{\text{NRE Base benchmark}} \times$ Weight

OTTV - Overall Thermal Transfer Value
EEI - Energy Efficiency Intensity
LCGWP - Lifecycle Direct Global Warming Potential (lb CO2/Ton-Year)
LCODP - Lifecycle Ozone Depletion Potential (lb CFC 11/Ton-Year)
NRE on-site - Non Renewable Energy for On-site aspect
NRE off-site - Non Renewable Energy for Off-site aspect

Figure 2: Benchmark Formulas for Aspects

In this stage, the values are applied to developed formulas. Once the values are applied to the formulas, a unit free benchmark will be developed for each aspect due to the normalising effect. Generally the identified aspects are differing from each other by their measure of units. So in order to have a common benchmark later, the each aspect's formulas have been normalised (Figure 3).

ASPECT	BENCHMARK FORMULAR
Building Envelop Performance	OTTV = $\frac{\text{(Building OTTV) W/m}^2}{\text{50W/m}^2} \times 0.09$
System/service Energy Performace	EEI = $\frac{\text{(Building EEI) kWh/m}^2\text{y}}{\text{150 kWh/m}^2\text{y}} \times 0.2$
CO_2 Emission Rate Reduced Ozone Depletion	Combined contribution = $\frac{\text{(Building LCGWP+LCODPx105)}}{100} \times 0.11$
On-site Renewable Energy	$NRE_{on\text{-}site}$ = $\frac{\text{(Building NRE) \%}}{\text{99 \%}} \times 0.09$
Off-site Renewable Energy	$NRE_{off\text{-}site}$ = $\frac{\text{(Building NRE) \%}}{\text{65 \%}} \times 0.04$

Figure 3: Benchmarks for Aspects

5.7. *SETTING A BENCHMARK FOR THE ENERGY DOMAIN*

Since, the energy domain is made out of all above discussed aspects, the individual benchmarks for each energy performance aspects should be summed to have a benchmark for entire energy domain. By undertaking this matter, a unit free benchmark value has been received (Figure 4).

Figure 4: Benchmark for Energy Domain

5.8. MONITORING AND REVIEW

The monitoring and review should be incorporated with the process in order to determine that, expected results are achieved, results of benchmarking are in line with the actual experience, identified aspects, indicators, benchmarks are correct and remain valid, the factors on which developed benchmark is based, including internal and external context remain valid and developed benchmark is effective etc.

6. CONCLUSIONS

The rising population and extensive development activities around the world, has given an increasing intention on sustainability in the built environment, greater than ever. The sustainable buildings are to be capable of managing key resources, not only in an optimum way, but also in an environmentally, ecologically and socially acceptable manner. Thereby, energy use of buildings started to view broadly, with the increasing concern about ecological preservation, mainly in the context of global warming, energy resource depletion, and local and regional pollution. When undertaking the energy matter in detail, it is evidentially clear that operational energy shall be more concerned over embedded energy in a built environment, since, the operating energy represents by far the largest part of energy demand in a building during its life cycle, and also been associated with a linear relation between total energy. Besides, when considering energy in terms of sector, past as well as recent statistics provide evidences that, commercial buildings contribute significantly to energy consumption, as well as to other environmental impacts, such as air emissions among other sectors locally as well as globally.

However, an instrument or a measure is required to rate energy practices and energy products in order to compare and contrast best practices within a built environment. Therefore, this research was undertaken to develop an operational energy benchmarking framework for commercial buildings while, providing a benchmark to such buildings to make their facility efficient in energy use and eligible in sustainable accreditation as well.

The framework was developed by facilitating the process of developing benchmark for operational energy, by means of determining contributory aspect to operational energy, determining indicators to measure efficiency of such aspects, determining locally applicable benchmarks, finalising quantitative indicators, and development of benchmark for entire ‘Operational Energy Domain’. The research was based on a literature survey and an expert survey. The literature survey assisted the determination of aspects contributing operational energy performance of a commercial built environment and identification of available indicators for such aspects while selecting most appropriate indicators together with locally applicable benchmarks. The expert survey facilitated the obtaining importance levels or weights for each aspect with related to the local context, but in the mean time associating with individual perspectives, professional disciplinary, and awareness on sustainability.

As a whole, this benchmark framework enables an approach towards not only energy efficient commercial buildings, but also sustainable commercial buildings and, benchmark itself is a self and/or external reference towards the concept of sustainable built environments in the fast growing world, while, enhancing competitive advantages and sustainable development. The developed framework only facilitate a benchmark for operational energy domain by using quantitatively measurable aspects, however, it can be further developed to any sustainable domain (embedded energy, water, indoor environmental quality and site development) along both quantitative and qualitative measures. The framework can be adapted to other sustainability domains by following the same steps mentioned. However, future research works can also address the qualitative measures by referring related literature and undertaking case studies. The framework may be generalised to contexts which are still absent of sustainability initiative and/or energy performance reference point themselves.

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