DEVELOPMENT OF AN ENERGY RATING SYSTEM FOR OFFICE BUILDINGS

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Abstract
The paper reviews the two important parameters used to assess the energy performance of office buildings – one at the design stage and the other at the operational stage. The building envelope includes all external elements of the building and the performance measure generally covers both the heat conduction and solar transmission aspects. The Overall Thermal Transfer Value (OTTV) is a single number index that measures the resistance of the building envelope to heat gains. The OTTV is performance based and allows professionals responsible for the design and construction of buildings freedom to innovate and vary important envelope components so as to reduce the heat gain to the building from the exterior to a minimum. The operational performance of the building is measured by the Building Energy Index (BEI) which is the total annual energy consumed by the building per unit air conditioned area. The paper examines how these two indexes can be combined to derive an energy rating system for office buildings.

Keywords: Energy performance; Overall Thermal Transfer Value; Building Energy Index.

1. Introduction

The aim of a green building design is to minimize the demand on non-renewable resources, maximize the utilization efficiency of these resources, when in use, and maximize the reuse, recycling, and utilization of renewable resources. It maximizes the use of efficient building materials and construction practices; optimizes the use of on-site sources and sinks by bio-climatic architectural practices; uses minimum energy to power itself; uses efficient equipment to meet its lighting, air-conditioning, and other needs; maximizes the use of renewable sources of energy; uses efficient waste and water management practices; and provides comfortable and hygienic indoor working conditions.

Green building rating is now being implemented in many countries. Singapore's Building & Construction Authority (BCA) has launched the BCA Green mark which is a green building rating system to evaluate a building for its environmental impact and performance. Buildings are awarded the BCA Green Mark based on five key criteria:

- Energy efficiency
- Water efficiency
- Site/Project Development & Management(Building Management & Operation for existing buildings)
- Good Indoor Environmental Quality & Environmental Protection
- Environmental Innovation

In North America, US Green Building Council developed the LEED rating system with a market-driven strategy to accelerate green building practices. The categories of assessment include:

- Sustainable site
- Water efficiency
- Energy and atmosphere
- Materials and resources
- Indoor environmental quality
- Innovation and design process

With the current trend of rising energy prices and increasing interest in environmentally responsible "green" buildings, it is critical that such buildings be energy efficient. Hence a major proportion of the points awarded in the assessment for green buildings should go towards energy efficiency. Energy efficiency is important not only because of the environmental concerns surrounding energy use, but because among all potential environment facets of a green building it provides by far the most economic return. Energy efficiency is easy to implement and practice both at the design stage and the operational stage. It is therefore necessary to develop a realistic building energy efficiency rating system especially for office buildings.

2. Overall Thermal Transfer Value (OTTV)

The solar heat gain through the building envelope constitutes a substantial share of cooling load in an air-conditioned building. Whereas, in non air-conditioned buildings, the solar heat gain causes thermal discomfort. To minimise solar heat gain into a building is, therefore, a very important consideration in the design of an energy efficient building.

A design criterion for building envelope known as the overall thermal transfer value (OTTV) has been adopted in Malaysia. The OTTV requirement is simple, and applies only to air-conditioned buildings. The OTTV aims at achieving the design of building envelope to cut down external heat gain and hence reduce the cooling load of the air-conditioning system. The building envelope includes all external elements of the building and the performance measure generally covers both the heat conduction and solar transmission aspects. The OTTV is a single number index that measures the resistance of the building envelope to heat gains. The OTTV formulation is performance based. Its formulation allows professionals responsible for the design and construction of buildings freedom to innovate and vary important envelope components such as type of glazing, window size, external shading to windows, wall colour and wall type to meet the maximum OTTV criteria.

The Malaysian OTTV formula takes into consideration two basic components of heat gain through the external walls and windows of a building. These are:

Heat conduction through opaque walls
Solar radiation through glass windows

The original Malaysian OTTV formula as developed by J.J. Deringer et al April (1987) and specified in "MS 1525:2001 Code of Practice on Energy efficiency and use of renewable energy for non-residential buildings" published by the Department of Standards Malaysia (2001), is as follows:

$OTTV_i$ for a fenestration at a given orientation i is,

$$OTTV_i = 19.1\alpha\ (1 - WWR)\ U_w + (194 \times CF \times WWR \times SC) \qquad \text{Eq. 1}$$

Where,

α	is the solar absorptivity of the opaque exterior wall
WWR	is the window-to-gross exterior wall area ratio for the orientation under consideration.
U_w	is the thermal transmittance of opaque wall (W/m^2K)
CF	is the solar correction factor
SC	is the shading coefficient of the fenestration system

The OTTV is the area-weighted average of the $OTTV_i$ for the different orientations.

The MS 1525:2001 specifies that the OTTV of building envelope for a building, having a total air-conditioned area exceeding 4000 m^2 and above, shall not exceed 45 W/m^2.

The inclusion of solar absorptance (α) was new (included as typical Malaysian construction practice use little or no insulation in the walls) and in the interest of developing an equation that is both accurate and simple to use, the OTTV formula omitted the input for the U-value for glazed area as analysis indicated that conductance (as distinct from radiative) gains through windows do not contribute substantially to changes in energy use for the Malaysian climate conditions.

The Malaysian OTTV is related to the chiller load according to the following equation:

$$\text{Chiller load} = k_1 + k_2\,(OTTV) \qquad \text{Eq. 2}$$

where k_1 and k_2 are regression coefficients. The coefficients were determined by the method of least squares. The constant k_1 embodies internal gains from lights people, equipment etc. Since the value of the Solar Factor (SF) is known, the k_2 constant can be isolated from each physical coefficient in the OTTV equation, revealing the estimated values of the indoor-outdoor temperature for the fenestration (ΔT) and equivalent indoor-outdoor temperature difference for the opaque wall (ΔT_{eq}). Simulation studies were performed with data from a wide variety of buildings and using hourly weather data. For Malaysian climate, which is constant throughout the year, the values of (ΔT) and (ΔT_{eq}) show very little variation. Hence, the OTTV can be taken as most appropriate to reflect the impact of the building envelope on the energy use for air conditioning the building. It is noted that ASHRAE Standard 90.1-1989 has replaced OTTV with prescriptive criteria for window-wall ratio and thermal transmittance of envelope elements as stated in the work by Yik and Wan (2004). Also mentioned in the work by Yik and Wan (2004) is that for buildings situated in a sub-tropical climate region like Hong Kong, research studies showed that acceptable correlation between OTTV and energy use for air conditioning (with all other things being equal) could be achieved only if the heat transfer in buildings during the cold months were ignored.

When the MS 1525 was recently updated in June 2007 the OTTV formula was revised as:

For a fenestration at a given orientation,

$$OTTV_i = 15\ \alpha\ (1 - WWR)\ U_w + 6(WWR)U_f + (194 \times CF \times WWR \times SC) \qquad \text{Eq. 3}$$

where,

U_f is the thermal transmittance of fenestration system ($W/m^2\ K$);

The limit for the OTTV of building envelope for a building, having a total air-conditioned area exceeding 4000 m^2 and above was revised to 50 W/m^2.

Whilst the solar absorptance was maintained an additional term to include the solar conductance through the fenestration was introduced. This was to improve the accuracy of the equation and also accommodate new technologies such as double glazing, which would not have been reflected in the previous formula.

The Low Energy Office (LEO) of the Ministry of Energy, Water and Communications completed in September 2004, being the showcase of energy efficient building in Malaysia with the most energy efficient features has an OTTV of 31.4 W/m^2.

3. Building Energy Index (BEI)

Building operational energy efficiency is measured by the Building Energy Index (BEI). The BEI is the global yearly energy consumption of the entire building divided by the air conditioned floor area. The target of the LEO was 100 $kWh/m^2/yr$, and the reference value is 275 $kWh/m^2/yr$. Figure 1 shows different key figures of building energy indexes.

In the "*Guidelines for Energy Efficiency in Buildings-1989*" published by the then Ministry of Energy, Telecommunications and Posts (December 1989), four typical buildings are defined to represent different expected levels of energy use in Malaysia. These four levels are: worst case, base case, proposed standard case and good practice case.

- The worst case represents buildings that are among the most energy intensive buildings that might be encountered in Malaysia today. BEI = 240 $kWh/m^2/yr$.
- The base case building reflect a typical range of construction and energy use features now prevalent in Malaysian new commercial building construction. BEI = 166 $kWh/m^2/yr$.
- The proposed standard reflects the level of energy efficiency expected to be achieved by the proposed Guidelines. BEI = 136 $kWh/m^2/yr$.
- The good practice represents a combination of energy efficient practice (including daylighting) that surpasses the requirements of the Guidelines proposed. BEI = 98 $kWh/m^2/yr$.

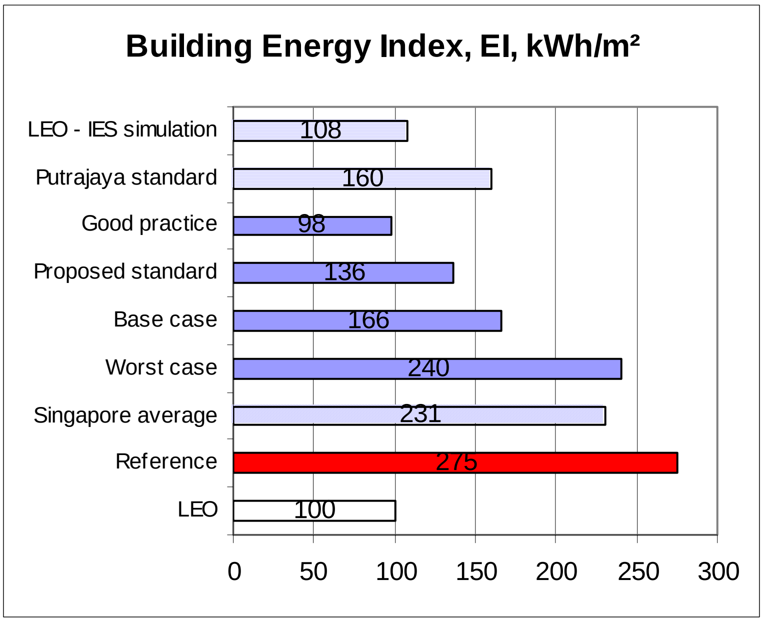

Figure 1: Different values of BEI.

The BEI is used as the indicator for the LEO energy efficiency. The energy consumption of LEO was reduced by installing a number of different energy savings technologies in the building. After one year of monitoring and fine tuning, calculations have shown an BEI of 108 kWh/m²/yr for the LEO. To estimate the savings of the extra energy efficient technologies a reference energy consumption has been defined. The different reference consumptions are described below.

During the design period of the LEO building the building energy index was estimated as 100 kWh/m²/yr and it has been set as a target energy index. Also in the design phase a reference BEI of 275 kWh/m²/yr was estimated according to inefficient practice for new office buildings. The calculation of the reference BEI has been done by running the same model but without any energy savings initiatives. That means an energy saving of 64% has been estimated for the LEO building compared with the reference building. The estimated distribution of the energy consumption for cooling, lighting and equipment (including office appliances) is shown in Figure 2. Both indexes are calculated with the simulation tool – ENERGY-10 with Kuala Lumpur weather as input to the model.

ENERGY-10 is a conceptual design tool for low-energy buildings. It is the software component of a project called Designing Low-Energy Buildings with ENERGY-10, conducted for the U.S. Department of Energy (DOE). The program does hour-by-hour simulations for a typical year.

The BEI is an operational index which indicates the specific energy consumption of the building. In many instances it is used as the performance indicator. It represents the energy consumed by the air conditioning, lighting, office equipment, etc. It was well verified that floor area is a major indicator of energy consumption in commercial buildings, as stated by Lee (2005). The justification for basing the BEI on the conditioned area is that in office buildings the major energy end use is air conditioning and all the service activities take place in the air-conditioned area. Energy consumption is also dependent on the number of hours of operation of the equipment. In the original OTTV analysis, operation hours are taken as 55 hours per week and 50 weeks per year (allowing for two weeks of holidays) resulting in 2750 hours per year.

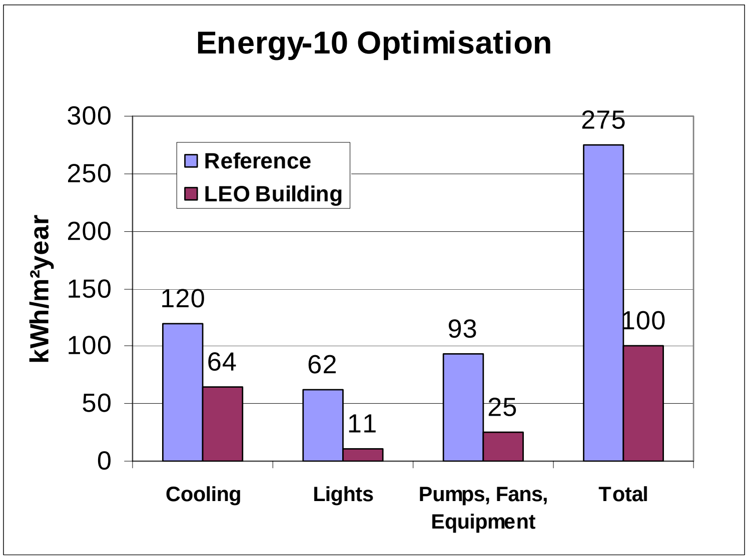

Figure 2: Distribution of the LEO Building energy index

4. Energy Rating System

Both the OTTV and the BEI can be varied during the life time of the building. Major retrofit to the building envelope such as change in the fenestration will change the OTTV. Replacement of equipment/appliances with energy efficient ones, retrofit of lighting and air conditioning systems will change the BEI.

An energy rating system is proposed which will have to incorporate both the OTTV and the BEI. OTTV is representative of the passive features and BEI is representative of the active features. Whereas OTTV is independent of the number of operation hours, BEI will increase with number of operating hours. A specific BEI needs to be introduced which is the BEI divided by the number of operating hours. The weighting of the OTTV and the specific BEI to the energy rating system needs to be considered. It is suggested that the weighting be 30% of OTTV and 70% of specific BEI i.e.

$$\text{Energy rating index} = 0.3(\text{OTTV}) + 0.7\,(\text{specific BEI}) \text{ in units W/m}^2 \qquad \text{Eq. 4}$$

For example, the building conforming to the MS 1525:2001 will have:
Energy rating index = 0.3(45) + 0.7(136 x 1000/2750)
= 48.1 W/m^2

For the LEO building,
Energy rating index = 0.3(31.4) + 0.7 (108 x 1000/2400) based on 2400 operation hours
= 40.92 W/ m^2

Following this, the energy rating system proposed is as in Table 1

Table 1: Proposed Energy Rating System

Energy rating index	Indication	Energy Efficiency Rating
< 45 W/m^2	Very efficient	A
44 W/m^2 - 50 W/m^2	Efficient	B
49 W/m^2 – 60 W/m^2	Satisfactory	C
> 60 W/m^2	Inefficient	D

It must be stressed that rating indicators are intended to allow comparison of energy performance between similar typical buildings. The 'inefficient' performers are most likely to offer the best cost effective opportunities but improvement should even be possible for those classified as 'efficient' and 'very efficient'. As the average performance of buildings continues to improve, what is today considered 'efficient' may eventually be regarded as 'satisfactory' or 'inefficient'. Users should not therefore be content simply because a classification of 'efficient' is achieved under the present ratings, but should maintain efforts to improve efficiency.

5. Conclusion

A building energy rating system for Malaysian office buildings is proposed combining both the Overall Thermal Transfer Value (OTTV) and the Building Energy Index (BEI). The proposal needs to be applied to a number of office buildings before it can be implemented. What is important is that it reflects the contribution of the passive and active elements of the building to its energy performance. It is necessary to emphasize that "green buildings' must be energy efficient and for this purpose at least 30% of the weightage for assessment of "green buildings' should be given to energy efficiency. It is encouraging to note that the Singapore Green Mark criteria has allocated 35% points for energy efficiency.

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