ENERGY SAVING DUE TO DAYLIGHTING: A SIMPLIFIED REDICTION TOOL FOR WALL ENVELOPE DESIGN OF AIR-CONDITIONED OFFICE BUILDINGS IN MALAYSIA

Norhati Ibrahim[1] and Azni Zain-Ahmed[2]

[1]*Faculty of Architecture, Planning and Surveying, Universiti Teknologi MARA, Shah Alam, MALAYSIA*
[2]*Institute of Research, Development and Commercialisation, Universiti Teknologi MARA, Shah Alam, MALAYSIA*

ABSTRACT

Many consider adoption of an energy efficient design approach as vital, so as to achieve a more sustainable built environment. The Malaysian government's growing concerns and seriousness to embrace energy efficiency agenda is evident with the introduction of energy efficiency regulatory for commercial buildings and initiatives such as the government funded energy audit programme. This agenda poses a new challenge for architects and the building community as a whole to play their parts. To effectively produce energy efficient designs, architects need to adopt a quantitative tool to review energy impact of designs options especially at early design stage. The early stage of design is a critical part of the design process. This is when the design takes its shape and what transpired then becomes the basis to establish allocation of project resources in terms of budget, as well as design aids and expertise. A comprehensive method of performing energy saving estimation is through computer simulation. However use and availability of such sophisticated tools in design practices is currently limited. Alternatively a quantitatively derived design tool could serve to predict energy saving thus help architects in making informed design decisions. There are few efforts to develop such tool particularly for the Malaysian climate. This paper presents a research effort to formulate a simple design tool to predict the impact of wall envelope design options on the potential of energy savings due to daylighting. The study used IES<VE> integrated computer simulation programme to perform parametric studies on a generic building form. The results were then correlated with key envelope design variables to establish correlation equation that was later used to formulate the design tool. The reliability of the tool was demonstrated through an exercise to predict energy saving for an envelope design. The saving predicted was compared to the value generated using IES<VE> programme.
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Keywords: Energy efficient buildings, energy savings, design tool, daylighting

1.0 INTRODUCTION

Statistics shows that in Malaysia buildings account for about 12.85% of the total energy consumption and 47.5% of the country's electricity consumption (Department of Electricity and Gas Supply Malaysia, 2001). Of these, commercial buildings consume almost a third of the country's electricity consumption. Electricity use in buildings are mainly for air-conditioning and lighting purposes, accounting for a breakdown of 55-65% and 25-35% respectively of the total building load (Ahmad and Kasbani, 2003).

How effective a building consumes energy during its operative life depends upon its building and system design features, which are primarily determined at the building design stage. Building design parameters that influence energy use in buildings namely plan layout, building configuration and orientation are essentially permanent features over the lifespan of the building. This clearly suggests that those involved in the design of buildings have a large share of responsibility towards the eventual performance of the constructed buildings.

1.1 QUANTIFIED DESIGN TOOLS

Generally there are three forms of design aid used by architects in carrying out their light tasks: design rules and guides, quantitative design tools, and specialists support. Between these, architects are more inclined to adopt design rules which are based on past experiences, and most often these are being applied intuitively. It has been said that 'low-energy design is not intuitive' (Hayter et al., 2001), suggesting that when embarking on energy efficient projects, architects need to adopt a more scientific, or quantitative approach. Quantitative based design aids range from sophisticated computer simulation software to a simplified, design tool such as sunpath diagram and nomograms. In the design of energy efficient buildings, the major concern is understanding the impact of the various design solutions on energy consumption. Not all design variables urban plan affect the performance of buildings in the same way: some have more influence on the decided up building energy performance than others. Changing the window area, for example, would have more impact on the building performance than increasing or decreasing the thickness of a wall (Bouchlaghem, 2000). Quantifying the impact of these measures is essential in helping designers make effective decisions. To this end computer parameters simulation undoubtedly offers comprehensive solutions. However using computer simulation during the design process is still rare even in developed countries (Pedrini, 2003, Shymko, 2000). It has been suggested that this is owing to the fact that the tools need experts to operate and is time consuming (Effis and Mathews, 2001). Alternatively, researchers are using computer simulations to validate established design rules (Nik Ibrahim and Hayman, 2002), and develop simplified design tools (Lam and Li, 1999).

A parametric analysis is the most frequently used method to develop simplified design tools. This method involves modeling of a hypothetical building to assess its performance under various combinations of design solutions. The results are later used to construct graphs, nomograms and diagrams which are simpler to use.

1.2 ENERGY EFFICIENCY MEASURES

Energy performance of buildings can be improved through adoption of energy efficiency measures. There are many possible energy efficiency measures that designers can opt for. Generally, energy efficiency measures can be classified as design measures and behavioural measures. The design measures include building design (passive means) and system design strategies (active means), which correspond to the architectural and service engineering scope of work, respectively. The building design measures as applied to the hot humid climate is aimed at reducing the energy load by maximising use of natural resources such as daylight and natural ventilation, and reducing the cooling load. This is achieved through manipulation of three energy-sensitive design components: the building form, envelope characteristics and choice of materials (Mahdavi, 1998). The goal of system design measures is to lower energy consumption through improvement of equipment design and specifications. Behavioural measures include users/occupants and management strategies. Users/occupants behavioural strategies include shutting off lights in unoccupied rooms, opening and shutting curtains and setting of appropriate temperature for rooms. Management behavioural strategies involve purchasing of efficient air-conditioning systems, installing energy efficient light fittings and regular maintenance of equipment for maximum performance.

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Aspects of building design that affect and influence energy use in buildings are the building configuration, envelope system, and material selection. Examples of building design strategies applicable to the Malaysian context are building siting and orientation, sun shading devices, optimising of window opening for daylighting, good envelope and glazing systems that reduce heat gain, and internal spatial zoning (Hyde, 2000).

From a survey of office buildings built in Kuala Lumpur business district between 1990 and 2000 (Ibrahim et al., 2003), it was evident that the building form and massing were very much dictated by non-energy factors such as cost, space efficiency and urban planning controls. The choice of the building envelopes were more varied, decided upon based on design preference.

For multi storey buildings, concerns are primarily on the wall component, as this building type has higher wall surface area compared to the roof. Past literature has identified window-wall-ratio (WWR) and shading coefficient (SC) as the envelope parameters that are most sensitive to energy consumption (Lam and Hui, 1996). In architectural term this translates to window sizes, types of glass, and the degree of external and internal shading devices. For daylight application another parameter which is of importance is the visible transmittance property of the glazing material.

Like building shapes, envelope design solutions are climate dependent. What constitutes the best envelope design measure in one climate region may not be so in another. In a cold country the design concern is towards balancing heat gain and heat loss because of the seasonal climate condition, whereas in the hot humid climate the concern is on how to reduce heat gain. According to Al-Homoud (1997) the effect of envelope design on reduction of the HVAC load is more critical for cold climates than hot-humid. This is due to the fact that energy load attributed to high humidity in humid conditions cannot be treated entirely through envelope designs. Studies on energy performance of envelope designs for hot humid climates indicate the magnitude of energy savings to be more significant for buildings that utilise daylight (Amorim, 2002, Deringer et al., 1987, Lam and Li, 1999, Ossen, 2005).

1.3 DAYLIGHT POTENTIALS

Two natural resources that can be utilized to reduce energy consumption in buildings are natural ventilation and daylight. It has often been argued that reducing energy consumption through introduction of natural ventilation into an office environment under the Malaysian climate may not produce effective results due to the absence of good wind movement, as well as potential problems associated with the quality of external air. As such, it has been noted that daylight is ‘a logical choice as a prime renewable energy source’ for Malaysia (Woods, 2002 pg. 2). The luminous efficacy of daylight in Malaysia is excellent and could meet most of the required luminance during the day (Zain-Ahmed et al., 2002). This would result in significant savings in terms of energy consumption.

As a source of light, daylighting offers greater benefits over artificial lighting. It is natural and has the range of frequencies needed for the mind, body and soul. The dynamic and ever changing quality of daylight has a stimulating effect and contributes greatly to the well being of human being. This variability, coupled with its intensity however, makes the task of incorporating it into buildings difficult and demands a good understanding of the design parameters in order to realise its potential (Osterhaus Visibility L and Bailey, 1992). Two luminous conditions desired by a human being occupying a space are visual comfort and visibility.

1.4 PREDICTING HUMAN TOLERANCE TO DAYLIGHT EXPOSURE

For the purpose of predicting envelope performance due to daylight, the prime concern is not so much on how to predict glare, but understanding the limit of human tolerance towards the daylight environment.

Based on a field survey conducted in an office environment in Japan, Inoue et al. (1988) suggests that human tolerance to daylight can be associated to the intensity of the sun that they are exposed to. This was determined by observing when occupants in an office environment manually adjust to internal blinds. In this experimentation, the threshold occurred when the façade irradiance was 233 W/m2. Subsequently Lee, DiPartolomeo and Selkowitz (1998) developed Inoue et al.'s the (1988) findings and suggested that visual discomfort due to daylight occurs under the following conditions:

1. The occupant is exposed to direct sun light, and;
2. The intensity of transmitted solar radiation hitting the occupant is above the visual comfort threshold of 94.5 W/m2.

The transmitted solar radiation value of 94.5 W/m2 was calculated from the 233 W/m2 façade irradiance as suggested by Inoue *et al*. (1988). Physically, the facade irradiance and transmitted solar radiation are two different conditions as shown in Figure 1.

The understanding on human tolerance towards direct solar intensity exposure has subsequently been used as basis for what Reinhart and Jones (2004) described as a 'realistic' lighting energy savings prediction. This method takes into account impact of occupant's interaction with light controls, namely blinds and light switches.

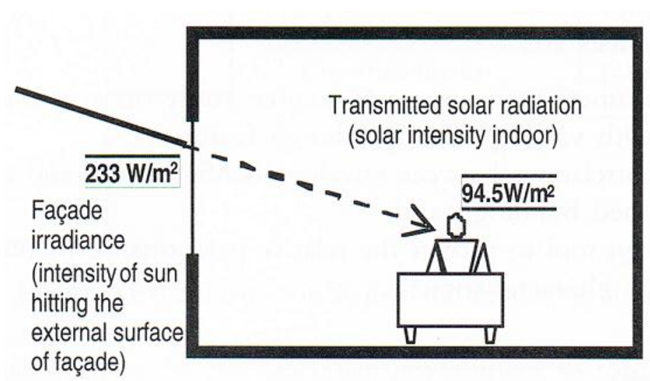

Figure 1: Direct Sun Penetration

1.5 VISIBILITY ASPECT OF DAYLIGHT

The visibility aspect of lighting determines how much light is needed to perform a particular task. Its measurement is referred to as illuminance level, expressed in lux or footcandles (fc). Numerous studies by key institutions such as the IESNA (the Illuminating Engineering Society of North America) and CIBSE (Chartered Institute of Building Service Engineers) have resulted in illuminance recommendations. For offices, the IESNA recommends illuminance levels at 500 lux on the horizontal workplane. No specific illuminance levels are set for other tasks, such as paper work or reading. In Malaysia the recommended illuminance for an office environment is 300-400 lux (Department of Standards, 2001).

When daylight is considered, the most commonly used illuminance measurement is the Daylight Factor (DF). Developed by the UK based Building Research Establishment, DF is a relative value, expressed as a percentage of the outdoor light to the available indoor light under overcast skies (Moore, 1991). This method requires the use of the CIE overcast sky model. The DF remains fairly constant for a given time of day and sky condition regardless of the degree of changes that may be affecting the absolute level of light available outdoor (Scbiler and Japee, 2001). This characteristic makes it practical and therefore used in many daylight studies.

In an illuminance investigation under laboratory conditions using a Malaysian sky simulator, Zain-Ahmed (2000) used the CIBSE criteria to assess daylight performance, taking the 5% DF as the minimum illumination level for the working plan. The same criteria was used in another study by Denan (2004) who carried on site measures and investigated illuminance levels in real office conditions in Malaysia.

2.0 OBJECTIVES

The research objectives are:

- Carryout a parametric energy performance study on a generic air-conditioned office model with varying envelope design features, available)
- Establish the correlations between envelope configurations and energy performance of air-conditioned buildings, and
- Develop a design tool to predict the relative performance of buildings with typical envelope design characteristics.

3.0 METHOD OF STUDY

3.1 Computer Technique

Building energy simulation programmes have been developed and enhanced in the last for 50 years. These are sophisticated performance tools that have integrated capacity, capable of providing detailed information on thermal, energy and other environmental parameters (Crawley et al., 2005). There are many available tools in the market nowadays, which amongst others are DOE 2.IE, ECOTECT, Energy-l0, EnergyPlus, ESP-r and IES<VE>,

The study used the IES <VE> programme, an integrated suite of applications that comprise of several modules, linked by a Common User Interface (CUI). This allows data input for each module to be use by the others. The IES <VE> modules used in the current study are **Model-IT**, the application used to construct the 3D geometry model; **APACHE Sim**, the thermal simulation software; **RadiancelES,** the lighting simulation software, and **SunCast** the solar shading analysis software. APACHE Sim version 5.0, the key software in the suite, has been validated to be in accordance with ANSI/ASHRAE 140 Standard which is based on the internationally A general recognised 'BESTEST' diagnostic tests (Gough and Rees, 2004).

The experimentation steps are briefly ifiustrated in Figure 2. The detail description 3 for the s of procedure has been described by the author elsewhere (Ibrahim, 2006) and therefore A sum is not covered in this article.

3.2 Model Definition

Use of a base case or generic building is essential to a parametric simulation study. A The APA base-case building has design features commonly found in existing buildings of similar weather type. Parametric studies using a generic model has been conducted in Malaysia in 1987, by a committee set up by the Malaysian government to formulate the Malaysian energy code (Deringer et al., 1987). The base case building was developed to reflect a typical range of construction and energy use features prevalent in Malaysian commercial building construction. This base-case model is included in the Malaysian

Guidelines for Energy Efficiency in Buildings (Malaysia Ministry of Energy Telecommunications and Posts, 1989).

The current research adopts the same model for the parametric study with design input set according to the current minimum regulatory requirements, and prevalent construction materials. This base case model is coded as Ti4OuS.

The base case is a centralized core office block, 10 storeys in height, with a 25 m x 25 m footprint. The floor to floor height is 3.75 m and each typical floor is subdivided into 6 zones: a non-air conditioned core area, 4 equally divided 4.5 m deep perimeter zone offices oriented north, south, east and west (referred to as N-cell, S-cell, W-cell and E-ceIl), and a 3 m wide inner zone office space.

The opaque wall component consists of plastered brickwall with U-value of 2.43 W/m2K — a wall construction frequently specified for a standard government building JKK Piawaian dan Kos JPPN, 2000). The window area is 40% of the opaque surface. A general study on daylight availability, periods of solar overexposure and shading performance of envelope designs were performed on these cell models. Refer to Figure 3 for the summary of Base Case model characteristics.

A summary of input data of heat gain items for the base case {Ti4OuS] is as listed in

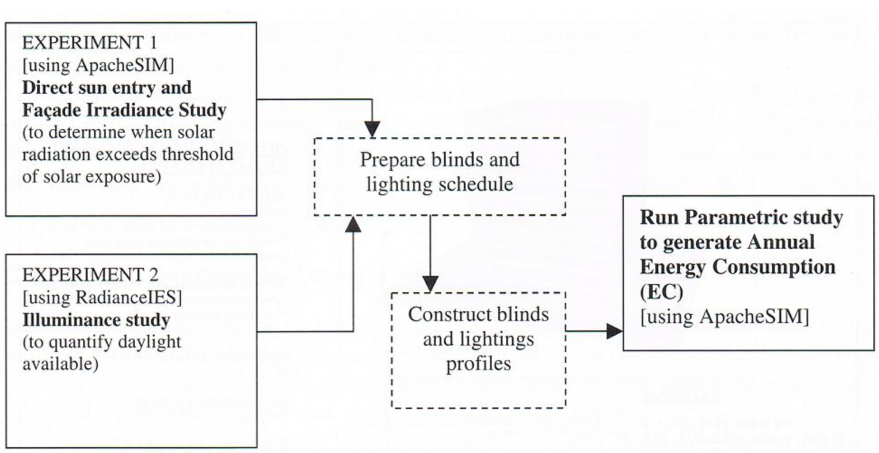

Figure 2: Experimentation steps of the simulation study

3.3 Weather Data

The APACHE Sim programme runs on a full weather data set that contains hourly weather data. Prediction of environmental performance of buildings requires accurate weather data that typify specific region under study. The results of a simulation study, and thus the validity of the recommended design solution produced from the study lies in the accuracy of the weather data.

The current study adopts Subang Test Reference Year (Subang TRY), weather data to represent the prevailing local climatic condition. Developed by Reimann and Zain-Ahmed (2000) the weather data is based on actual climatic data, obtained form the Malaysian Meteorological Station in Subang, Selangor, a suburb area that is currently experiencing urbanisation and rapid socio—economic growth.

3.4 Operational Conditions for Daylight Study

In order to simulate the impact of daylight use, the operational conditions need to be defined, namely the blind operation and amount of artificial light needed. The way past researchers have modeled electric lighting and blind control have been extensively reviewed by Reinhart (2004) and is not covered in this paper.

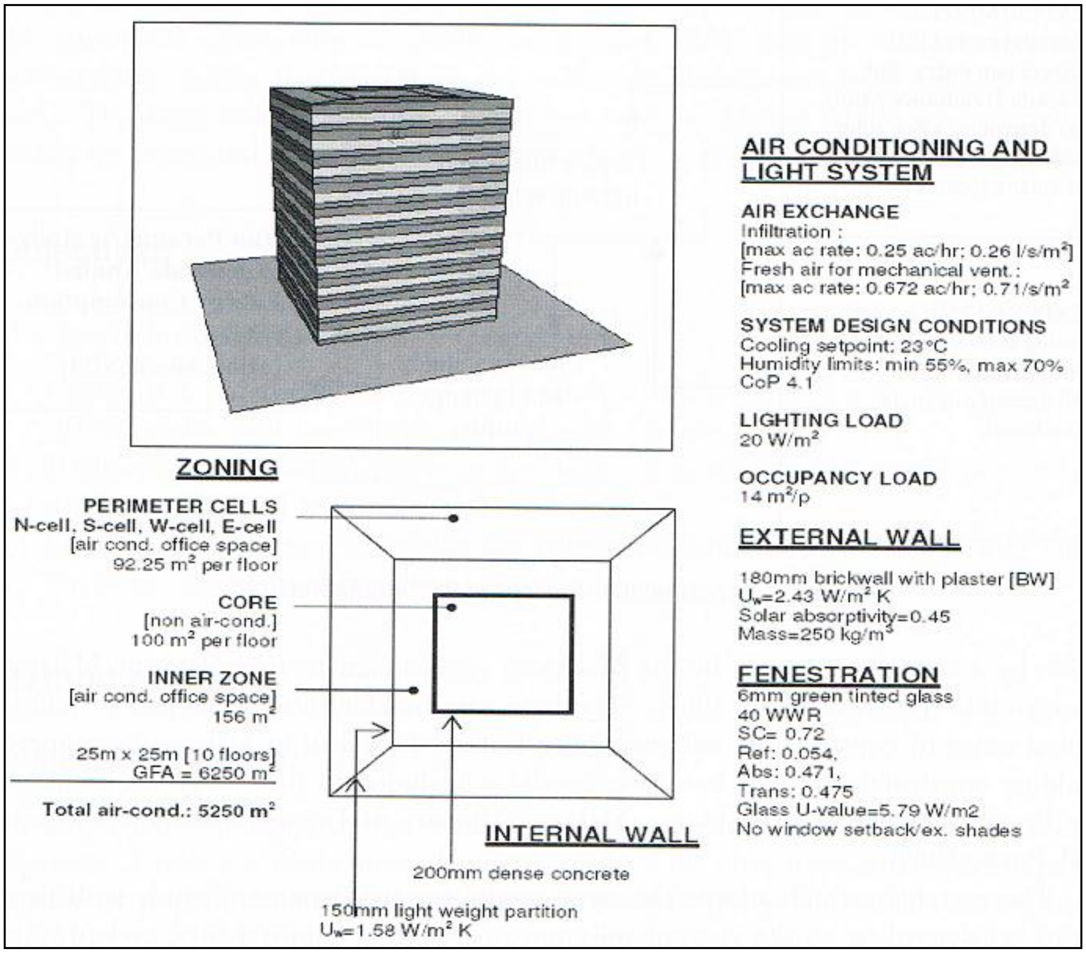

Figure 3: Description of Base Case Model

Table 1: Summary of Heat Gain Items Data Input

Type Of Heat Gain	Heat Gain Load	Operation Profile
Lighting load	20 W/m2 (approx. 500 lux of lighting)	8am — 5pm (50% usage btwn 1pm -2pm)
Small power load	20 W/m2	8am — 5pm (50% usage btwn 1pm -2pm)
People heat gain	14 m2/person sensible gain 80 W/person; latent gain 50 W/person	8am — 5pm
Ventilation fresh air gain	10 1/s per person	8am — 5pm
Infiltration gain	0.25 air change/hr	24 hours

Daylight availability study was conducted using the RadiancelES software, performed on a perimeter cell of the base-case model. The current study adopts the following assumption for the simulation with daylight use:

'Top-up' lights control — the schedule for artificial light for the perimeter cells were constructed in response to the estimated amount of daylight available, taking into account periods when the blinds are to be lowered or raised to meet occupant daylight tolerance.

Dynamic blind control — The study assumed application of blinds when the occupants experience visual discomfort due to solar over exposure. The simulation assumed that the blind would be fully lowered when the direct solar heat gain of 94.5 W/m is exceeded, and fully raised when the intensity drops below the threshold. The blinds were thus, either fully lowered or fully raised. The following block diagram Figure 4 illustrates the electric light switching patterns and the blinds operation adopted for the simulation.

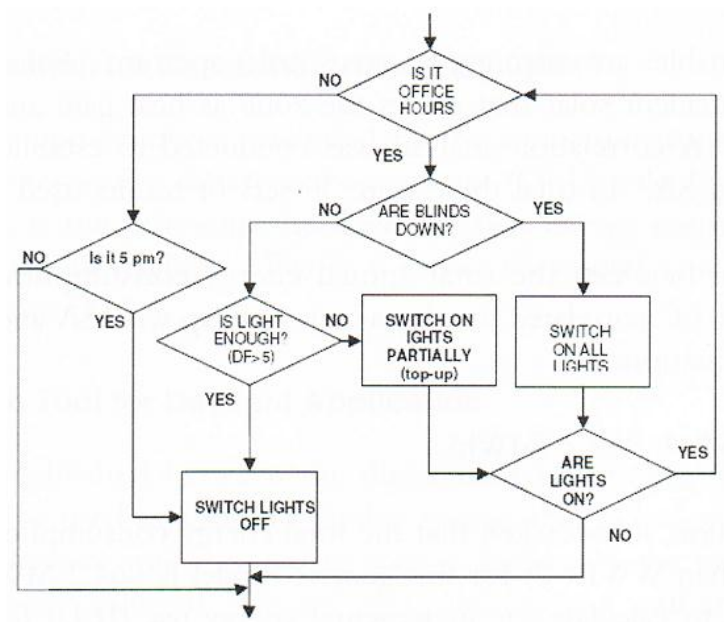

Figure 4: Block Diagram of Light Switching Pattern in Response to Blinds Operation

3.5 Envelope Variables

WWR — In addition to the 40% WWR used for the base case there were 5 options of WWRs examined, ranging from to 25% and 65%, in steps of 10% increase. Ribbon al (1992 window types were assumed for all models with identical facades for all orientations. Maximum WWR tested was 65%.

Glass types — There are numerous glass types in the market. In Malaysia, the most frequently used are 6 mm thick glass with U-value of 5.6 W/m2K, shading coefficient between 0.4 — 0.96, and visible transmittance from 20-80% (Sammy *et al.*, 2004). In this research, three glazing types, namely clear glass, light green and reflective glass were used in the main study.

3.6 Analysis

The one-year simulation performed on each case generated annual electricity consumption in MWh (EC). EC values were then transferred into the Microsoft Excel 150 and computed to express as the Incremental Energy Use (IEU). IEU is the difference between energy consumption of each case to a windowless building model (meaning the WWR is 0).

$$IEU_X = EC_X - EC_{\text{(windowless model)}} \quad \text{[Equation 1]}$$

The windowless building model represents the state whereby the energy performance of the building is not affected by heat gain. IEU is thus a measurement of the extent of solar heat gain affecting energy consumption for a particular case.

4.0 RESULTS AND DISCUSSIONS

4.1 Effects of Fenestration for Cases That Do Not Utilise Daylight

The fenestration variables are often expressed as 'solar aperture'. Solar aperture indicates the proportion of incident solar that enters the zone as heat gain and it is the product of WWRs and SC. A correlation analysis was conducted to establish the relationship between the EC and SA. In total there were 30 sets of results used for the correlation tabulated analysis. The correlation between the total annual energy consumption (EC) with solar aperture, shows that EC correlated in a linear relationship with SA and can be expressed as the following equation:

$$EC = 287.13\ SA + 964.2\ \text{(MWh)} \quad \text{[Equation 2]}$$

From this equation, it was taken that the total energy consumption of a windowless envelope (that is when WWR=O) for this generic model is 964.2 MWh. This becomes the reference point to calculate the incremental energy use (IEU) for each case. IEU for each case is therefore the EC value, less 964.2 MWh.

From the regression analysis, a linear relationship between solar aperture (SA) and incremental energy used (IEU) is observed as illustrated in Figure 5. Similar results have been reported by Lam and Li (1999), a Hong Kong based study, and Sullivan et al. (1992) for California. The analysis shows that the incremental energy use can be expressed in terms of SA as:

$$IEU = 287.13\ SA\ \text{(MWh)} \quad \text{[Equation 3]}$$

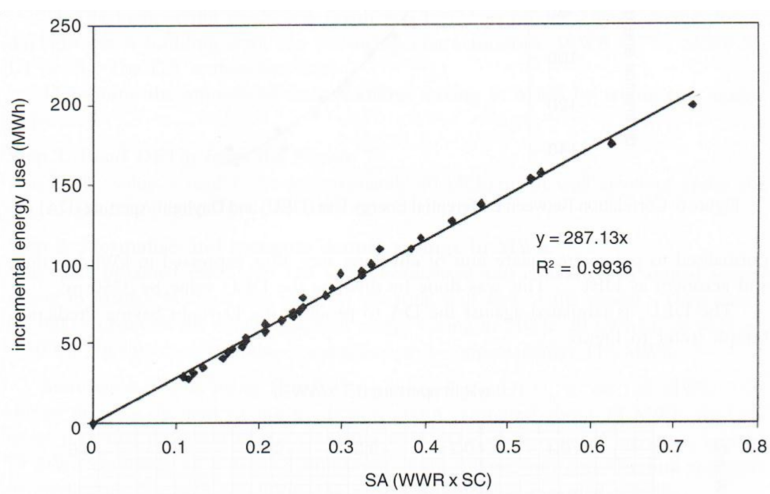

Figure 5*:* Correlation between Incremental Energy Use and SA

4.2 Effects of Fenestration for Cases that Utilise Daylight

The annual energy consumption generated by the simulation runs for each case was tabulated and their respective differential energy use (DEU) calculated. The differential energy use (DEU) is the difference between the two energy consumption results for with and without use of daylight. Figure 6 shows the correlation between DEU and the daylight aperture (DA).

4.3 Energy Prediction Tool for Daylight Application

The correlation established between the differential energy use (DEU) and daylight aperture (DA) can be used as a tool to predict savings due to use of daylight. The DEU is affected by the area of wall exposed to solar radiation. In the parametric study, this was kept at a constant value of 3750 m2 (the total external wall area of the base-case model). To make this nomogram applicable to other buildings, the IEU value was normalised to per metre square unit of envelope area, thus expressed in kWh/rn2 unit, and acronym as DEU. This was done by dividing the DEU value by 3750 m2.

The DEU is tabulated against the DA to produce the Daylight Saving Prediction Graph (refer to Figure *7).*

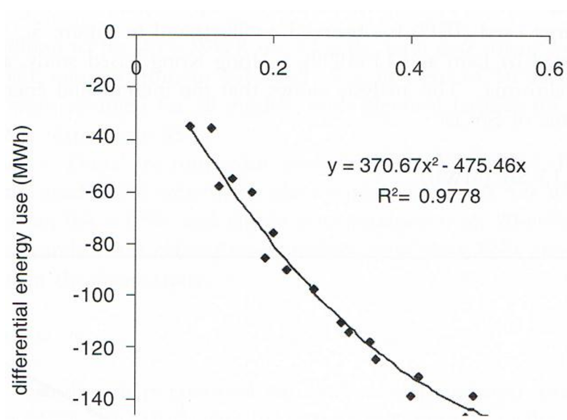

Figure 6: Correlation between Differential Energy Use (DEU) and Daylight Aperture (DA)

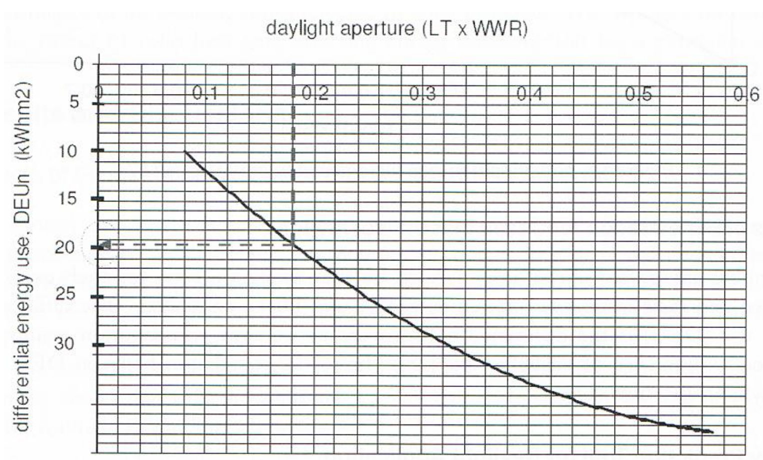

Figure 7: Daylight Saving Prediction Graph

Figure 7: Daylight Saving Prediction Graph

4.3 Using the Tool

Assuming an architect is considering to incorporate daylight in his/her scheme. First he/she needs to calculate the DA of the wall envelope by multiplying the WWR with the light transmittance (L'T) of the glass component. Say, the DA is 0.2. From the DA line, move down to the curve line, then across to the left, and read the DEU. The DEU is read to be approximately 21 kWh/m2. This value is then multiplied with the total area of the building wall to convert it into kWh of energy saving. Then, multiply the value with the conversion rate to translate it into monetary savings.

The daylight saving prediction graph was tested to predict energy saving due to daylight for a building with the following characteristics: WWR=27%, SC= 0.51, LT=0.65. The DA is therefore 0.18.

Determine the amount of annual energy saving in MWh by taking two simple steps:

Step 1: Read DEUn from the Figure 7
The DEU value is read to be approximately 20 kWh/rn2 of wall envelope (refer the circled value in Figure 7).

Step 2: Normalise and compute annual savings in MWh
The value obtained from step 1 is to be normalised and converted to annual energy saving in MWh. Multiply this value by the total wall area of the model. Then divide by 1000 to convert the result to annual energy saving in MWh (20 kWh/rn2 x 5625 rn2 / 1000). In this case the value is calculated to be approximately 113 MWh.

Simulation results using IES<VE> predicted the DEU to be 128 MWh. This shows that the daylight saving prediction graph estimated about 15 MWh, or 12% lesser than that produced by the computer tool. The tool predicted higher savings by 79 MWh compared to a detailed simulation study. Taking into consideration the basis of predictions for each condition, the results produced is regarded reliable.

4.0 CONCLUSIONS

The paper presented a method of deriving at a simple energy saving prediction tool to be used at early design stage. Numerical results generated through computer simulation were correlated with key envelope design variables to establish correlation equation that was later used to formulate the design tool. A worked out example on how the tool can be applied, and the results of its prediction were compared to those produced through the use of computer simulation. The tool predicted similar results as those produced by a computer simulation, thus validates the tool.

Like other simplified design tools, the tool developed in this study is limited in its application. It predicts energy savings due to daylight for a building that operates on a typical air-conditioning system, based on operational and system design assumptions as described in this paper. However the results generated in this study can be further normali2ed to generate prediction graphs applicable for other design conditions, thus widening the potential and significance of the current study.

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