8 FUNDAMENTAL STEPS TOWARD ENERGY EFFICIENCY IN AIR-CONDITIONED BUILDINGS FOR TROPICAL CLIMATE

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Abstract

Energy efficiency in air-conditioned buildings for tropical climate has been a subject of much discussion, especially among the building construction practitioners such as the architects and building services engineers. Experience from designing two demonstration low energy building project in Malaysia (the Low Energy Office Building and Zero Energy Office Building) has exposed that there exist many myths about the effectiveness of various features in the building as energy flows in building remains largely unfamiliar to most. This is because even a simple building has a very complicated energy transfer process converting electrical energy into conveniences for the building occupants (lighting, computers, etc.) and then into heat, where electricity is used again to provide comfort by removing heat from the space and all this while, the climate outside is influencing the space by solar heat gain, conduction heat gain and infiltration of air into the building.

This paper addresses the need for an easy method of understanding energy efficiency in buildings by providing a simple and yet comprehensive picture of energy flows in buildings by providing the 8 fundamental steps for energy efficiency for air-conditioned buildings in tropical climate. This 8 fundamental steps covers all the energy components to achieve an energy efficient building, from architectural, mechanical, electrical and energy management point of view for an air-conditioned building. Steps 1 to 7 are building design steps that are prioritise according to the amount of energy consumptions in a typical air-conditioned building in tropics, while step 8 is for energy management. Step 8 is to ensure that step 1 to 7 is being practised correctly in the actual building after the completion of construction process. A detailed description of each fundamental step is provided to ensure that energy efficiency for air-conditioned building in tropical climate is easily understood and practised by all.

Keywords: Energy Efficient buildings, Tropical climate, Best practices, Passive Features, Active Features.

1. Introduction

The 8 steps towards energy efficiency for air-conditioned building in tropical climate is a resultant of the re-evaluation of the Overall Thermal Transmittance Value (OTTV) in Malaysia in 2005-2006.
The Overall Thermal Transmittance Value (OTTV) was first developed for Malaysia in 1987. The OTTV was developed using computer simulation to provide an easy method for architects and engineers to manually calculate the average heat gain that is being transmitted into a typical office building via the building fabric due to orientation, windows to wall ratio, wall properties and glazing properties. Since 1987 (a time when personal computer is not wide spread yet), there have been no re-evaluation of the OTTV until this study in 2005 undertaken by the Danida project for Energy Efficiency in Malaysian Buildings.

The re-evaluation of the OTTV was conducted using computer simulation to get a fundamental understanding of the behaviour of a typical building thermal and energy characteristic based on Malaysia's climatic data. The results of this study provided remarkable insight into the thermal and energy performance of air-conditioned buildings in tropical climate that not only provided valuable input for the updates of the Malaysian MS1525 (Malaysian Standard for Energy Efficiency in Non-Residential Buildings), but it has also provided a key summary of the steps required for an air-conditioned building to be energy efficient a tropical climate.

The re-evaluation of OTTV was conducted with a simulation of more than 40 case scenarios by varying different properties of the building. The development of the 8 steps towards energy efficiency for an air-conditioned building was largely based on the results of 3 case scenarios that vary the internal energy load of the building while keeping the building envelope constant as this would simplified the complexities of energy flow in building to a manageable analysis while providing enough useful information. The 3 selected case scenarios are:

- Worst Case Building Scenario
- Base Case Building Scenario
- Ministry of Energy, Water and Communication (MEWC)'s Low Energy Office Scenario.

2. The Ottv Model

Three (3) case studies were set up and simulated to get an understanding of how energy is used in a typical office building today. These case studies were:

Worst Case Scenario (2005)

Base Case Scenario (2005)

MEWC's Low Energy Office (2005) - calibrated to an air-conditioned space of 5,200 m2 instead of 19,000 m2

The worst case scenario describe a building with high energy consumption due to high internal load. An internal lighting load of 21 W/m² and a small power consumption of 24.5 W/m² is allocated for this building. In addition, this building is also assumed to have a bad energy management with an approximately 40% of lights and small power still running during non-occupied hours. It was also assumed that the building is very leaky with an infiltration rate of 2 air-changes per hour (ach).

The base case scenario attempts to describe a building with the most likely scenario of current buildings in Malaysia. It has a lighting load of 18W/m² and a small power load of 19 W/m². A moderate scenario of energy management is assumed for this building where approximately 30% of the lighting and small power load is still running during non-occupied hours. It was assumed that this building is also leaky with an infiltration rate of 1 ach as Malaysia do not have a culture of providing air-tightness in buildings.

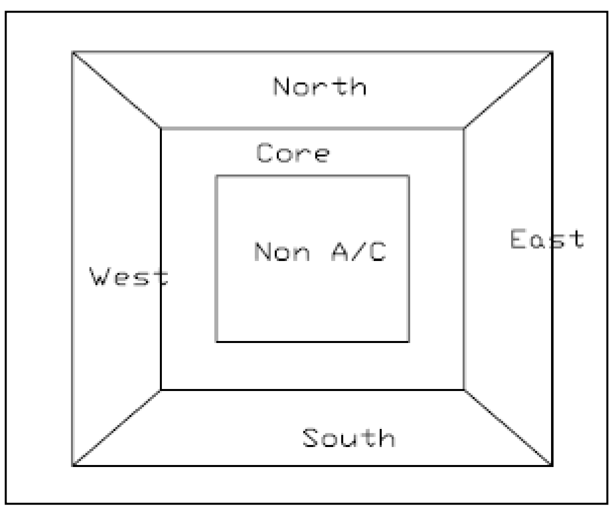

Fig. 1 Plan view of the Malaysian Base Case building with 10 floors

The Low Energy Office (LEO) scenario is based on the actual measurements obtained from the Ministry of Energy, Water and Communication's Low Energy Office building after approximately 9 months of operation. A lighting load of 5.5 W/m² and a small power load of 6 W/m² was measured in this building and is used for LEO case scenario. During non-occupied hours, approximately 20% of the lighting power is still being consumed, while the small power consumption during these hours represented approximately 54% of the peak daytime load. No measurement of air-tightness was made for the LEO building, however, based on the fact that fresh air is not required for the building from the system (CO_2 sensor controlled) and the measured CO_2 in the building range from 400-500 ppm, it is rational to assume that the infiltration rate is 1 ach for this study to represent a fairly leaky building.

The shape and properties of the Malaysian Base Case building in 1987 was retained in this initial study, while the internal loads were varied as shown in the table below. The base case office building shape and dimension of the simulation model in 1987 has the following properties:

Air-Conditioned Space	5200 m²
Core Space	1000 m²
Windows to wall Ratio	0.4
Shading Coefficient of the Glazing	0.69
Brickwall U-value	2.6 W/m²/K
Roof (Highly Insulated)	0.001 W/m²K
Lighting Load	21 W/m²
OTTV	66 W/m²
COP of Chiller	4.1
People Density	9m²/person
Small Power Load	5.35 W/m²
Infiltration	1 ach
Fresh Air	3.3 lit/sec/person
Variable-air-Volume Air Conditioning System	50% minimum flowrate

Table 1. Base Case Building. 10 Story office building.

The roof was simulated with very high insulated value to remove the effect of roof from the simulation, as the OTTV equation only describe the façade of the building excluding roof.

Descriptions	Proposed Worst Case (2005)	Proposed Base Case (2005)	MEWC LEO (2005)
Lighting Load (W/m2)	21	18	5.5
Lighting Operation Hours	100% 8am to 5pm 40% 5pm to 8am	100% 8am to 5pm 30% 5pm to 8am	100% 8am to 5pm 20% 5pm to 8am
People Density (M2/person)	10 as stated in UBBL	10 as stated in UBBL	60
People Working Hours	1% 7:30am-25% 8am 25% 8am-100% 8:30am 100% 8:30am-5pm 100% 5pm-5% 10pm 1% from 10pm-7:30am	1% 7:30am-25%8am 25% 8am-100% 8:30am 100% 8:30am-5pm 100% 5pm-5% 10pm 1% from 10pm-7:30am	1% 7:30am-25% 8am 25% 8am-100% 8:30am 100% 8:30am-5pm 100% 5pm-5% 10pm 1% from 10pm-7:30am
Small Power Load (W/m2)	22.14 W/m2	17.67 W/m2	4.5 W/m2
Small Power Operation Hours	100% daytime 45% nightime	100% daytime 29% nighttime	100% daytime 54% nighttime

Computer Load per person (W/person)	180 (18 W/m2) 100% Daytime, 35% night	150 (15 W/m2) 100% Daytime, 15% night	120 100% Daytime, 15% night
Server Room, Load/AC Area (W/m2)	2.5 100% 24 hours	1.5 100% 24 hours	1.5 100% 24 hours
Shared Office Load (W/m2)	0.5 100% 24 hours	0.25 100% 24 hours	0.25 100% 24 hours
Core Load (W/m2) of Core Area	5 100% Daytime, 50% night	4 100% Daytime, 50% night	4 100% Daytime, 50% night
Fresh Air	AC hours: 2 ach 20 l/s/person (10500 l/s) approx. 650ppm CO2 level Off AC: 1 ach	AC hours: 1 ach 10 l/s/person (5250 l/s) approx. 920 ppm of CO2 Off AC: 1 ach	AC hours: 1 ach 60 l/s/person (5250 l/s) Off AC: 0.5 ach
Fan Static Pressure	1250 Pa	750 Pa	250 Pa
Chiller COP	4.1	4.1	4.1
Air Delivery	VAV	VAV	VAV

Table 2. Description of input data for 3 different case scenarios.

Notes on the LEO case:

Lighting load of 5.5 W/m2 was based on actual monitored usage. Installed lighting capacity is 12 W/m2.
Occupant density in existing MEWC was approximately 60 m2/person.
Small power load of 4.5 W/m2 was also based on actual monitored usage.
Computer load of 120 W/person was assumed in this case as most staff in MEWC would be using flat TFT monitor instead of large energy inefficient CRT monitor.
Server Room, Shared Office Load and Core Load of MEWC were all calibrated based on actual monitored values in the current MEWC office.
Fresh Air intake is also calibrated to the CO2 sensor reading in the building. 1 ach rate is required to keep office CO2 reading below 460 ppm. Monitored CO2 reading in the MEWC is between 400 – 500 ppm in most areas.

3. The 8 Steps Toward Energy Efficiency in Buildings

The simulation results of the 3 case scenarios were tabulated in a bar chart (Fig. 2) to provide an overview of the various breakdown of energy consumption in a building.

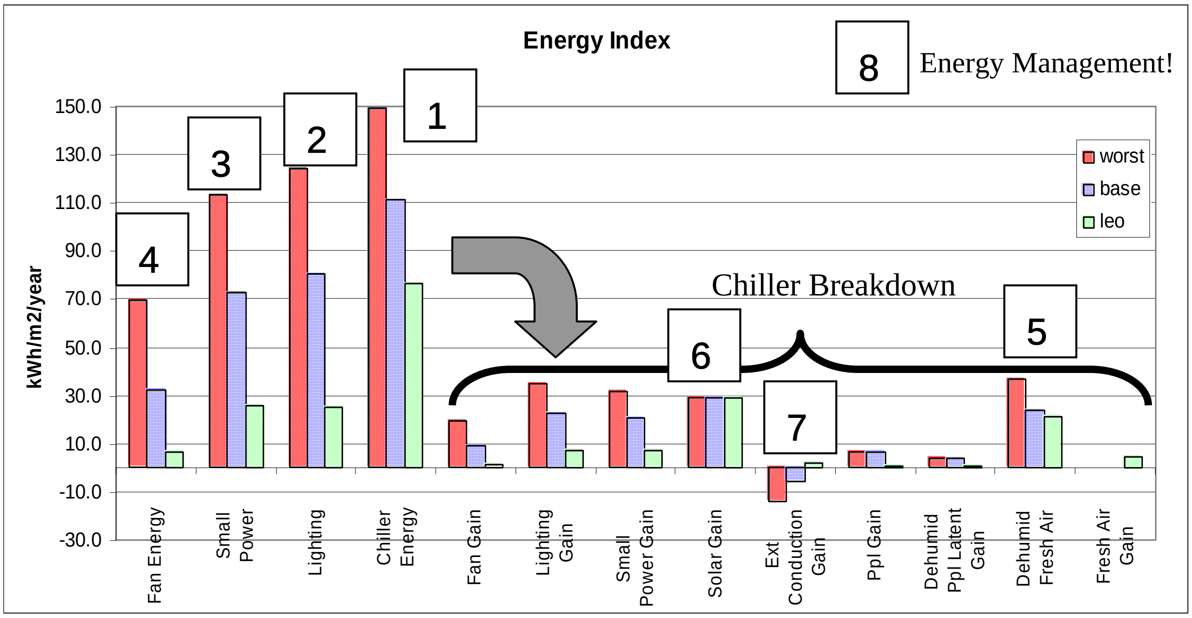

Fig. 2 Energy index breakdown of 3 different types of building scenario

The energy index breakdown in Fig. 2 shows that there are basically 4 major energy consumption in an air-conditioned building in tropical climate. These are:

1. Fan Energy
2. Small Power Energy
3. Lighting Energy
4. Chiller Energy

Usually the chiller energy and fan energy are combined and called as air-conditioning energy, however, for the purpose of understanding the energy flow in building, it is useful to it split up in order to provide a breakdown of chiller energy into each heat element that the chiller is required to remove from the building.

The chiller energy breakdown showed the following heat element that is removed by it from an air-conditioned space:

1. *Fan Sensible Heat Gain.* The fan have a motor that drives it. The motor would then generate waste heat. This heat is introduced directly into the air-conditioned space.
2. *Small Power Sensible Heat Gain.* All equipments that are plugged into the powerpoints constitute of small power energy use. As a law of energy conservation, all electrical energy used by these equipment will end up as heat in the air-conditioned space.
3. *Lighting Sensible Heat Gain*. Similar to the small power sensible heat gain, all electrical energy used by lighting will end up as heat in the air-conditioned space.
4. *Solar Radiation Sensible Heat Gain*. The heat gain due to solar radiation through the building windows are known as solar radiation sensible heat gain.
5. *Conduction Sensible Gain due to External Façade*. The heat gain due to conduction through the building façade excluding the roof space.
6. *People Sensible Heat Gain*. The sensible heat gain from people is the heat emitted by people in the air-conditioned spaces.
7. *Dehumidification of People Latent Heat Gain*. The latent heat gain from people is the moisture emitted by people in the air conditioned spaces.
8. *Dehumidification of Fresh Air Ventilation*. The infiltration of fresh air (outside air) into air-conditioned spaces bring along moisture content of the outside air.
9. *Fresh Air Ventilation Sensible Heat Gain*. The infiltration of fresh air (outside air) into air-conditioned spaces bring along heat/cooling content of the outside air.

The chiller energy is used to remove all the heat generated in the list described above in order to maintain the comfort temperature and humidity in the air-conditioned space.

The chiller energy is the highest contributor to the total building energy use for all the cases. The electricity used for lighting is consistently the second highest, followed by small power and lastly the fan energy that is used to deliver cold air into the spaces.

Fig. 2 is a very insightful chart. It shows that in the worst case scenario the heat generated by lighting and small power is higher than the heat from solar radiation or conduction heat gain in the building.

More interestingly is the fact that the worst case scenario, the net conduction gained over a year is negative, meaning that heat is being conducted out of the building more than being conducted in for a full year scenario.

This is due to the reason that in a worst case scenario, a significant amount of small power equipment and lighting system are still running during non-occupied hours (e.g. night time to early morning), at hours where the outside temperature is low. The air temperature in the office space during night hours would then be higher (due to the internal equipments and lighting that are still in operation) than the outside air temperature.

Therefore, heat is being conducted out of the fabric of the building, helping to cool the building during night time. This chart also shows that conduction gain is high for the base case in 1987 due to the reason that the building in 1987 does not have night load inside the building because it does not have equipments that are running during night such as computers, fax machine, server room, control room and etc.

The dehumidification of fresh air in the worst case scenario is also shown to contribute more energy to the chiller than the solar radiation heat again. This is largely caused by the high moisture content of a hot and humid climate such as Malaysia. In addition the removal of moisture from the air is phase-change process that requires large amount of energy to convert moisture in vapour form into water in liquid form.

It is also interesting to note that the air-conditioning that is used for the primary purpose of providing comfort to the building occupants (people). However, the sensible and latent heat gain from people represented only a fraction of the chiller energy use.

It is also shown in Fig. 2, that the heat generated internally by lighting and equipment (small power) represented a significant amount of heat removed by the chiller, clearly indicating that the reduction on energy consumption of internal loads such as lighting and equipments will also lead to significant saving on chiller energy consumption.

Finally the chart shown in Fig. 2 allows the following general interpretation to be made to provide a sort of checklist of priorities for energy efficiency features in building starting from the items that consumed that highest amount of energy to the item that consume the least:

Energy efficient chiller system. A low efficiency chiller system will increases the total energy use within a building significantly as it increases the energy used to remove heat from the air-conditioned space. The term 'chiller system' consist of the chiller, chill water pumping system, chill water piping system and condenser system such as the fans for the cooling tower and the pumping system of the condenser system. Energy efficiency of the whole 'chiller system' is required in order to gain efficiency in this area.

Reduce artificial lighting load. Natural daylighting is the best because it provide the highest amount of light with the least amount of heat. Other methods include the use energy efficient lighting system, proper zoning of lighting circuit and etc. Night lighting should be carefully considered and should never be over provided.

Reduce small power load. This would means that energy efficient computers, servers, and control system should be used. Nighttimes energy consumption of small power should be closely monitored.

Minimise fan power. The fan is used for the air-conditioning system. The energy use by the fan is mainly contributed by two factors, fan efficiency and ductwork total pressure. Selection of fan with high efficiencies will reduce the energy use by fan significantly, while larger duct sizes will have lower pressure loses and therefore lower overall static pressure and thereby reducing energy use of the fan.

Control of fresh air intake and infiltration. Air-tightness of building is now shown to be more important than preventing solar radiation heat gain as the infiltration of humid air into air-conditioned spaces contributes significantly to the energy used by the chiller. In addition, it is highly recommended to install CO_2 sensor in the air-delivery system to control the amount of fresh air introduced in air-conditioned building in this climate. The CO_2 sensor will ensure that the quality of air is maintained adequately without over providing fresh air via the air-delivery system to minimise the energy used to dehumifidy outside air.

Control of solar heat gain. Building orientation, exterior shading devices and glazing properties should be carefully considered by the architects to minimize heat gain from the sun.

Insulation of building fabric. Building fabric should only be well insulated when night load in the building is well controlled. Otherwise, the insulated fabric will trap the heat generated during night hours. It is also possible to use vegetation (greeneries) outside the building to help to keep the micro-climatic surrounding the building to be cooler.

A low energy building design need to address all these 7 steps, as these are the fundamental steps towards energy efficiency for air-conditioned buildings in tropical climate. It should also be noted that in each proposed step there are many possibilities to achieve the same intended objective as every building is built unique. It is up to the designer of the building to be creative to provide the most appropriate solution for their client while addressing these 7 fundamental steps for energy efficiency in air-conditioned building in the tropical climate.

Step 8 is energy management of the building after construction. This is to ensure that steps 1 to 7 are being practised in the building during the actual operation of the building to achieved the intended effect of a low energy air-conditioned building in tropical climate.

4. Summary

The re-evaluation of the OTTV offers an opportunity for an insightful analysis of typical energy consumption in buildings. As energy flow in building is often a matter of great complexity, this analysis simplified and put in perspective of the relationship and quantity of the possible energy saving potential of each element of a typical building into 8 fundamental steps. More importantly this analysis aided in providing a form of general checklist of priorities in the design of energy efficient buildings for the building designers such as the architect and engineer.

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References

Prof. Kannan & Lawrance Berkeley Lab (1987), Building Simulation Study for the Development of OTTV formulation for Malaysian Climate.