International Journal of Mechanical and Materials Engineering (IJMME), Vol. 3 (2008), No.1, 90-96.

ENERGY AND ASSOCIATED EMISSION ANALYSIS IN OFFICE BUILDINGS

R. Saidur and H. H. Masjuki
Department of Mechanical Engineering
University of Malaya, 50603 Kuala Lumpur, Malaysia
E-mail: saidur@um.edu.my

ABSTRACT

In this paper energy consumption of office buildings have been estimated. Energy consumption of major equipments has been identified. Energy intensity a measure of building performance has been estimated for Malaysia and compared with other countries as well. It has been found that air conditioners are the major energy users (57%) in commercial building followed by lighting (19%), lifts and pumps (18%) and others (6%). Different ways/options to reduce/save building energy consumption have been formulated, amount of energy saved by these options have been quantified and emission reduction associated with the above savings have been quantified as well. From the data analysis, it has been found that huge amount of energy can be saved for the above policy measures/options. Moreover, significant amount of emissions can be reduced for the associated energy savings for different policy/measures.

Keywords: Energy; Emission; Office buildings; Energy savings; Energy intensity.

1.0 INTRODUCTION

1.1 Global commercial energy situation

Energy uses in office buildings is 70–300 kWh/m^2, 10–20 times that in the residential sector (Liu Yang et al; 2008). The rapidly growing world energy use has already raised concerns over supply difficulties, exhaustion of energy resources and heavy environmental impacts (ozone layer depletion, global warming, climate change, etc.). The global contribution from buildings towards energy consumption, both residential and commercial, has steadily increased reaching figures between 20% and 40% in developed countries. Growth in population, increasing demand for building services and comfort levels, together with the rise in time spent inside buildings, assure the upward trend in energy demand will continue in the future. For this reason, energy efficiency in buildings is today a prime objective for energy policy at regional, national and international levels (Lombard et al; 2008). Globalization, improvement of living conditions in emerging regions and the development of communication networks, promote developed nations' life style and raise energy needs to consumption patterns that, without doubt, will exhaust fossil fuels and will produce a serious environmental impact. In this sense, current energy and socio-economic systems are definitively unsustainable (Lombard et al; 2008). Figure 1 shows the declining trend of world fossil fuel reserve at about 20-30 years later.

Table 1 Percentage of commercial sector energy consumption for some selected countries

Country/region	%	Sources
USA	18	Lombard et al; 2008
UK	11	
EU	11	
Spain	8	
Saudi Arabia	50	Omar and Mohammed, 2004
Jordan	9	Jaber et al; 2003
Hong Kong	30	Larry Chuen-ho Chow, 2001
Iran	38	Farhanieh and Sattari, 2006
Japan	26	Yohji Uchiyama, 2002
Bahrain	29	Hassan Radhi, 2008
China	35	Liu Yang et al; 2008
Thailand	33	Yamtraipat et al; 2006

As the building sub-sector consumes 8%-50% of the total energy as shown in Table 1, it has an important position in the energy economy of any country. Energy policy plays an important role in any country's sustainable development. Improving energy efficiency in buildings is one of the most cost-effective measures for reducing CO_2 emission, which is recognised as one of the main causes of global warming (Lombard et al; 2008, Omar and Mohammed, 2004, Jaber et al; 2003, Larry Chuen-ho Chow, 2001, Farhanieh and Sattari, 2006, Yohji Uchiyama, 2002, Hassan Radhi, 2008, Liu Yang et al; 2008, Yamtraipat et al; 2006). Therefore, it is possible to say that commercial buildings are not only a major consumer of energy, but also a significant contributor of CO_2 emissions. However, these buildings offer the greatest and easiest potential for conservation. They can save a considerable amount of energy and reduce CO_2 emissions through efficient operation. In the recent past, many attempts have been made to find the best possible approach to control the energy consumption in commercial buildings and to limit its consequences on the environment.

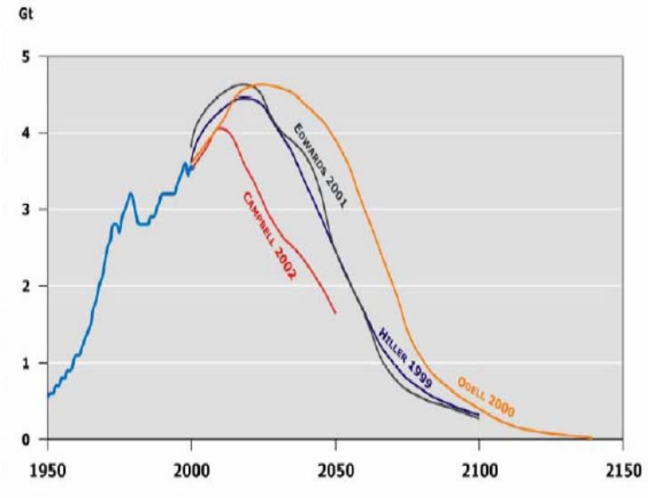

Figure 1 Global oil reserve trend (Bassam, 2008)

The European Energy Performance of Building Directive (EPBD) is such an attempt. This directive aims to ensure energy saving and CO_2 emissions reduction without compromising the local conditions and people's comfort (Lombard et al; 2008).

Greenhouse Gases (GHGs) are normally found in the atmosphere in small quantities. They can absorb the infrared radiation and warm the atmosphere. The major GHGs in the atmosphere are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and ozone (O_3). Water vapor is also considered to be significant GHGs, although on a global scale, its concentrations are not directly affected by human activities. Carbon monoxide (CO), nitrogen oxide (NOx) and non-methane volatile organic compounds (NMVOCs) are indirect GHGs. These gases are involved in the photochemical processes of the atmosphere. However, for simplicity, they are often referred to as GHGs. Greenhouse gases occur naturally in ecosystems. In the past century, as humans interfered with nature, the concentration of the gases in the atmosphere increased. Most of the studies generally have found that global warming has increased annual electricity consumption due to the cooling required by air conditioning (Yamtraipat et al; 2006).

The combustion of fossil fuels contributes emissions of various gases such as NO_x, SO_2, trace of heavy metal contaminants, and organic compounds. In addition, fossil fuel combustion also produces CO_2 which absorbs radiant energy, contributing to the greenhouse gas effect. There is growing recognition that such emissions adversely impact the environment locally, nationally, and globally. Over the past few decades, it has been observed that there is an increasing concentration of greenhouse gases such as carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxide (NO_x) and carbon monoxide (CO) that have a negative impact on the environment. Carbon dioxide, the main contributor of these gases is produced by burning fuels to produce electricity in the conventional power stations. Burning fossil fuels releases emissions that cause the greenhouse effect, acid rain and other negative impacts on the environment and humankind (Mahlia, 2002). However, discussion of this paper is limited to the emission of selected air pollutants (i.e., NO_x, SO_2, CO and CO_2) only.

1.2 Energy situation in Malaysia

There have been growing concerns about energy consumption and its implications for the environment. With high economic growth, Malaysia has seen a dramatic increase in energy consumption in recent years, particularly electrical energy use in commercial and residential buildings. The residential and commercial sector consumed about 48% of total electricity generated. With increasing GDP, electricity demand will increase but in different proportions. Malaysian electricity-GDP elasticity is around 1.5 meaning that for every 1% rise in GDP, electricity consumption increases by 1.5%. On the other hand, the main contributor to increasing atmospheric carbon dioxide (CO_2) concentration is the combustion of fossil fuels from electricity generation, commercial and domestic uses. The demand for energy is expected to grow rapidly in developed countries as well as in the developing countries as they attempt to obtain a higher standard living. This increase energy demand and consequently increase carbon dioxide concentration in the atmosphere (Anon, 2006). Figure 2 shows the commercial sector energy consumption trend in Malaysia. To reduce energy consumption in the buildings and minimize negative environmental impacts, it is necessary to take different measures to save energy and reduce environmental pollution. To comply with that Malaysian government already built Low Energy Office (LEO) building whose energy intensity is $114kWh/m^2$ (Leo Building, 2005). Malaysian energy centre (PTM) also in the process of building zero energy building to be in line with global initiatives to reduce environmental pollution. Government also put 5% renewable energy usage in its 9^{th} Malaysian plan to encourage the usage of renewable energy to reduce environmental burden to the atmosphere. Apart from that University Sains Malaysia's Centre for Education and Training in Renewable Energy and Energy Efficiency (CETREE) actively playing a role to create awareness among the end users about energy efficiency and usage of renewable energy. There are several NGOs' working in creating awareness among the different groups of energy users to save energy and reduce environmental pollution. This also shows

Malaysia's commitment towards energy efficiency and environmental concern in line with the global community.

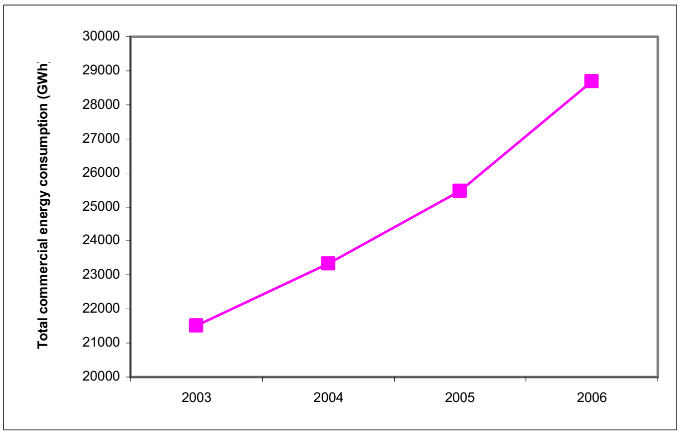

Figure 2 Commercial sector energy consumption trends in Malaysia

Considering the importance of energy efficiency in buildings as discussed earlier, this study may be useful in following aspects:

- Authors hope that it will be beneficial/useful for ASEAN and other countries to compare office building's energy consumption, EI comparison, and amount of emission released in order to compare with global scenario
- The study also shows an indication how much Malaysia can contribute in savings energy and reducing pollution in line with global community
- In this analysis different approaches to save energy and reduce emissions have been applied and highlighted. Some of the work in literatures reported their overall trend in usage consumption and just reported the ways to save energy (Omar and Mohammed, 2004) but no estimation was shown. However in this paper major energy consuming equipment has been identified, energy savings measured have been applied, emission analysis in terms of release and reductions have been estimated.

2 METHODOLOGY

This section explains the data collection procedure, formulations of energy and EI estimation, energy savings and emission reductions. These are elaborated below:

2.1 Data collection procedure and estimation of energy use and EI

Malaysian Energy Centre conducted energy audit on 68 office buildings to collect following information to investigate building energy consumption pattern.

Summary of data collected by energy audit are as below:

- Age of building
- Types of building
- Weekly hours
- Aspect ratio
- Gross floor area
- Air conditioned area
- No. of occupancy
- Equipment/appliances specification/capacity (kW)

Table 2 Data summary of audited buildings

No. of building audited	68
Gross floor area, m^2	983,000
Total Energy consumption, MWh	127,752
Energy intensity (kWh/m^2)	130

Table 2 shows the summary of some data. The data has been collected with personal communication with Mohd Hishamuddin, a PTM (Malaysian Energy Centre) officer (PTM, 2006).

Using their data, energy consumption by air conditioning, lighting, lifts and pumps, and others equipment have been estimated using following equation:

$$AEC^a = UH^y \times C^a \times 0.001 \qquad (1)$$

where:
AEC^a-Annual energy consumption of equipment (MWh)
UH^y-Yearly usage hours of equipment
C^a- Capacity of equipment (kW)
0.001 a factor to convert kWh into MWh

Energy intensity (EI) in kWh/m^2 has been estimated using following Equation:

$$EI = \frac{\sum_i^n AEC}{TFA} \qquad (2)$$

where:
$\sum_i^n AEC$ -Sum of energy consumption of equipments i
TFA-Total floor area (m^2)

2.2 Formulations of energy savings with the introduction of energy savings options

Energy can be saved by regulation such as reducing EI compared to average/base case.
Energy savings as a result of such regulation can be estimated as:

$$AES_{EI} = \left(EI_{avg} - EI_{efficient\_building}\right) \times TFA \quad (3)$$

where:
AES_{EI}- Annual energy savings due to energy intensity improvement
Annual air conditioners energy savings due to raising thermostat set point temperature can be estimated as:

$$AES_{ts} = TEC_{ac} \times \%EST_{22-26} \quad (4)$$

where:
TEC_{ac}-Total AC energy consumption
$\%EST_{22\text{-}26}$-% Energy savings due to raising thermostat set (TS) point temperature from 22 °C to 26 °C
Annual energy savings due to efficient CFL can be calculated as:

$$AES_{lighting} = TEC_{lighting} \times \%ES_{efficient\_lighting} \quad (5)$$

where:
$TEC_{lighting}$-Total lighting energy consumption in MWh
% $ES_{efficient\_lighting}$- % of energy savings due to efficient lighting
Annual energy savings due to advanced glazing can be estimated as:

$$AES_{glazing} = AEC_{whole\_building} \times \%ES_{glazing} \quad (6)$$

Annual energy savings by insulation can be estimated as:

$$AES_{insulation} = AEC_{whole\_building} \times \%ES_{insulation} \quad (7)$$

where:
$AEC_{whole\_building}$-Annual energy consumption of whole building in MWh
$\%ES_{insulation}$-%Energy savings due to improved insulation
Annual energy savings by reducing standby energy consumption can be estimated as:

$$AES_{standby} = AEC_{whole\_building} \times \%ES_{standby} \quad (8)$$

$\%ES_{standby}$-%Energy savings due to standby

Annual energy savings by housekeeping can be estimated as:

$$AES_{housekeeping} = AEC_{whole\_building} \times \%ES_{housekeeping} \quad (9)$$

$\%ES_{housekeeping}$-%Energy savings due to housekeeping

Bill savings (RM) associated with the energy savings can be estimated as:

$$BS = AES \times UEP \quad (10)$$

where:
UEP-Average unit electricity price (RM/kWh)

2.3 Formulations of emission reductions associated with the energy savings

Emission estimation associated with the electricity generation by burning fossil fuels can be expressed by the following equation (Mahlia *et al*, 2002):

$$EM_i = EP_i\left(PE_i^1 \times Em_p^1 + PE_i^2 \times Em_p^2 + ... + PE_i^n \times Em_p^n\right) \quad (11)$$

where:

EM_i : Total emission for unit of electricity generation (ton)

Em_p^n : Fossil fuel emission for a unit of electricity generation of fuel type *n*(ton)

EP_i : Electricity production in year *i* (GWh)

PE_i^n : Percentage of electricity generation in year *i* of fuel type *n*

Tables 3 and 4 show input data needed to estimate amount of emission that can be reduced due to energy savings for different options.

Table 3 Percentage share of fuel used to generate electricity

Coal (%)	Petroleum (%)	Gas (%)	Hydro (%)
16.76	2.44	53.2	27.6

Table 4 Unit emission released by different sources of energy

Fuels	Emission factor (kg/kWh)			
	CO_2	SO_2	NO_x	CO
Coal	1.18	0.0139	0.0052	0.0002
Petroleum	0.85	0.0164	0.0025	0.0002
Gas	0.53	0.0005	0.0009	0.0005

3 RESULTS AND DISCUSSIONS

Using Equation (1), total energy yearly consumption in MWh has been estimated for air conditioning equipments, lighting, lifts and pumps and others equipments and presented in Table 5. Along with the total energy consumption, % breakdown of these equipments have been shown in this table.

Table 5 total energy consumption by all equipments and their breakdown (%)

Equipment/appliances	MWh/yr	% contribution
AC	72819	57
Lighting	24273	19
Lift and pump	22995	18
Others	7665	6

Table 6 Emission released to the atmosphere associated with the total energy consumption in office buildings

Emission released, Kg			
CO_2	SO_2	NO_x	CO
639,35,788	382,719	180,299	38,888

From the Table 5, it has been found that air conditioning equipments consume major portion of total energy consumption, followed by lighting, lifts and pumps and others equipments. Table 6 presents amount of emission released associated with the energy consumption in office buildings. Table 7 compares energy consumption breakdown of few selected countries.

Table 7 Typical percentage of electrical energy consumption breakdown for few selected countries

Country	Percentage of electricity consumption (%)			Reference
	Air-conditioning	Lighting	General equipment	
Malaysia	57	19	24	-
Indonesia	51	14	26	Rizka Elyza *et al.* ,2005
Thailand	59	21	20	Yamtraipat et al; 2006
Singapore	59	7	34	http://www.bca.gov.sg, 20/01/2006c
Saudi Arabia	38	20	42	Ahmad *et al.*,1994
USA	48	22	30	Lombard et al; 2008
UK	55	17	28	Lombard et al; 2008
Spain	52	33	15	Lombard et al; 2008

Using Equation (2), energy Intensity (EI) has been calculated and presented in Table 8. EI of Malaysia has been compared with few other countries as well. From the Table 8, it has been observed that EI in Malaysia is lower than USA, Greece, China, and Thailand but higher than Japan. It seems Malaysian office buildings are more energy efficient than few other countries. However, still there are rooms for improvements to reduce further energy consumption by introducing energy savings policy or options. Even in Malaysia Ministry of Energy, Post, and Telecommunication built a low energy office building whose EI is about 114 kWh/m^2 (Leo Building, 2005). To encourage and practice energy efficiency in office buildings, Malaysian energy center also in the process of building low energy building. Using Equations (3)-(10), energy savings and associated bill savings for different energy savings measures have been quantified and presented in Table 9. Using Equation (11) and data from Tables 3 and 4, amount of different types of emission that can be reduced for the energy savings associated with the different policy measures/options have been estimated and presented in the same table. It has been found that 128 MWh energy and RM21 million bills can be saved by different energy saving options. It also has been found that huge amount of emission can be reduced as a result of energy savings.

Table 8 Energy intensity for commercial building in Malaysia and other countries

Country	Energy intensity (kWh/m^2)	Sources
Malaysia	130	-
Thailand	154	
Japan	121	
Shanghai	180	Saidur et al; 2007
Greece	187	
USA	293	Lombard et al; 2008

Yamtraipat *et al* (2006) carried out some work on indoor AC set point temperature and some experimental work on the influence of temperature on AC energy consumption. Authors found that raising thermostat set point from 22 °C to 26 °C can save 24% energy consumption. Energy savings estimation has been made based on their finding as climatic conditions of Malaysia and Thailand are quite similar. It may be mentioned that 80% of the respondents mentioned that 26 ^{o}C is an acceptable comfort range. Chirarattananon *et al* (2003) reported that 25% of total building energy can be saved if advanced glazing is applied at building windows. Based on their findings, energy savings estimation has been made and presented in Table 9. Authors also mentioned that by insulating buildings, 20% of total energy can be saved. Energy savings estimation has been made and presented in the same table

Table 9 Energy and bill savings for different energy savings measures

Energy savings options	Energy savings, MWh	Bill savings, RM	Emission reductions, kg				Estimated using references
			CO_2	SO_2	NO_x	CO	
EI reduction from 130 to 114	16	33,02,880	16,52,986	9,895	4,661	1005	Present authors
Raising TS	17	36,70,170	87,46,679	52,358	24,666	5,320	Yamtraipat et al; 2006
Housekeeping	8	16,09,650	38,36,087	183,673	10,818	2,333	Yohji Uchiyama, 2002
CFL	0.097	20,389	121,47,860	581,643	34,257	7,389	own
Advanced Glazing	32	67,06,980	159,83,947	765,316	45,075	9,722	Chirarattananon et al; 2003
Insulation	25	57,31,210	255,74,415	12,24,511	72,120	15,555	Chirarattananon et al; 2003
Standby	4	804,903	19,18,294	91,484	5410	1167	Present authors

4 CONCLUSIONS

This paper identified major energy using equipment in Malaysian office buildings and compared energy usage of office building equipments with few selected countries. The paper also estimated and compared EI with few other selected countries. It also has been found that huge amount of energy and bill can be saved and emissions can be reduced by introducing different energy savings options in this sector. It may be mentioned that this estimation has been shown only for few office buildings. However, there are other commercial sub-sectors where significant amount of energy, bill can be saved and associated emissions can be reduced for different energy saving measures.

AKNOWLEDGEMENT

Author would like to greatly acknowledge the help of Mr. Hishamuddin Ibrahim, a PTM officer who provided data to carry out this research.

REFERENCES

1. Ahmad A. Abdelrahman MA. Billote WC (1994), Analysis of electric energy conservation in a commercial building in Saudi Arabia, in Proceedings of the 2nd Saudi Symposium on Energy Utilization and Conservation, Dhahran, 27-30 Nov, Saudi Arabia
2. Anon, 2006, Ninth Malaysian Plane 2006 – 2010, The economic planning unit prime minister's department, Putrajaya, Malaysia.
3. Chirarattananon, S., Taweekun, J., 2003. A technical review of energy conservation programs for commercial and government buildings in Thailand. Energy Conversion and Management 44, 743–762.
4. Farhanieh B., Sattari S., 2006. Simulation of energy saving in Iranian buildings using integrative modelling for insulation, Renewable Energy 31, 417–425
5. Jaber J.O., Mohsen M.S., Al-Sarkhi AAkash., B., 2003. Energy analysis of Jordan's commercial sector, Energy Policy 31, 887–894
6. Larry Chuen-ho Chow, 2001. A study of sectoral energy consumption in Hong Kong (1984–97) with special emphasis on the household sector, Energy Policy 29, 1099–1110
7. LEO Building, 2005, Energy Performance of LEO Building, Ministry of Energy, post, Telecommunication, Putrajaya, Malaysia,.
8. Liu Yang, Joseph C. Lam , C.L. Tsang, 2008. Energy performance of building envelopes in different climate zones in China, Applied Energy (2008), doi:10.1016/j.apenergy.2007.11.002.
9. Luis Perez-Lombard, Jose Ortiz, Christine Pout, 2008, A review on buildings energy consumption information, Energy and Building, Volume 40, Issue 3, Pages 394-398.
10. Mahlia, 2002. Emissions from electricity generation in Malaysia. Renewable Energy 27, 293–300.
11. Naser El Bassam, 2008, Concentrating solar thermal power for electricity and water generation from desert regions, Key note speech, International conference on industrial application of energy systems, Sohar University, Sultanate of Oman, 1-2 April, 2008.

12. Omar M. Al-Rabghi, Mohammed M. Akyurt, 2004. A survey of energy efficient strategies for effective air conditioning, Energy Conversion and Management 45, 1643–1654
13. PTM, 2006, Eenergy audit in Malaysian Office buildings, personal communication with Mr. Hishamuddiin Ibrahim, Pusat Tenaga Malaysia (PTM), Malaysia.
14. Radhi H., 2008. A systematic methodology for optimizing the energy performance of buildings in Bahrain, Energy & Buildings, doi:10.1016/j.enbuild.2007.11.007
15. Rizka E, Yoyoh H, Nasrullah S . (2005). Buku Panduan Efisiensi Energi Di Hotel.Pelangi. Jakarta. See also: http://www.pelangi.or.id
16. Saidur. R, Hasanuzzaman. M, Hasan. M. M. and Masjuki H.H, Energy usage and intensity of commercial building in Malaysia. Conference on Applications and Design in Mechanical Engineering (CADME07) 26-27 October 2007, Kangar, Perlis, Malaysia. Paper no. 83.
17.Yamtraipat, N., Khedari, J., Hirunlabh, J., Kunchornrat, J., 2006. Assessment of Thailand indoor set-point impact on energy consumption and environment. Energy Policy 34 (7), 765–770.
18. Yohji Uchiyama, 2002. Present efforts of saving energy and future energy demand/supply in Japan, Energy Conversion and Management 43, 1123–1131