Establishing Energy Consumption Benchmarks of Office Buildings in Bangkok
การจัดทำเกณฑ์การใช้พลังงานของอาคารสำนักงานในกรุงเทพฯ

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Abstract

This paper presents energy consumption benchmarks of office buildings based on the local context of Bangkok in terms of kWh/m^2/month and kWh/m^2/year. The benchmark is important as a starting point of systematic energy management in office buildings. It has potential to identify energy performance of an office building by comparing against others. If the building performs lower than the standard, the benchmark offers a realistic energy goal. Then systematic energy management—establishing action plan, implementing strategies, monitoring energy consumption and continuous improvement—can be continued.

บทคัดย่อ

บทความนี้นำเสนอเกณฑ์การใช้พลังงานของอาคารสำนักงานในเขตกรุงเทพมหานคร ในหน่วยกิโลวัตต์-ชั่วโมงต่อปี และกิโลวัตต์-ชั่วโมงต่อเดือน ซึ่งสำคัญอย่างยิ่งในการเริ่มการบริหารจัดการพลังงานในอาคารสำนักงานอย่างเป็นระบบ เกณฑ์การใช้พลังงานเป็นเครื่องมือช่วยในการประเมินการใช้พลังงานของอาคารสำนักงานหนึ่ง ๆ โดยเปรียบเทียบกับการใช้พลังงานของอาคารสำนักงานอื่น ๆ หากพบว่าอาคารสำนักงานดังกล่าวมีการใช้พลังงานต่ำกว่าเกณฑ์การใช้พลังงาน เป้าหมายการใช้พลังงานที่เหมาะสมตามเกณฑ์การใช้พลังงานจะถูกกำหนด หลังจากนี้ขั้นตอนการบริหารจัดการพลังงานอย่างเป็นระบบจึงสามารถดำเนินต่อไปได้

Keywords (คำสำคัญ)

Benchmark (เกณฑ์)
Office Building (อาคารสำนักงาน)
Energy Performance (ประสิทธิภาพการใช้พลังงาน)
Energy Management (การบริหารจัดการพลังงาน)

1. Introduction

In 1992, Thai-government promotes an Energy Conservation Promotion Act (ECP Act). The objective is to improve energy efficiency and to reduce energy consumption in buildings. One of the priority segments includes large office buildings. In order to achieve the objective, energy management in office buildings is considered. However, energy consumption benchmark that is a tool to facilitate energy management and support the local context of Bangkok is not available. Therefore, this paper proposed a set of energy management tools consisting of energy benchmarks in terms of kWh/m^2/month and kWh/m^2/year, which are well recognized as a starting point of energy management in buildings.

2. Literature Review

In many countries, the energy consumption benchmarks in office buildings have been studied such as Energy Consumption Guide 19 (ECON19) of United Kingdom [1], on-line benchmark tool of Hong Kong [2], and e-Energy Singapore [3]. All of the benchmarks are based on statistical analysis of survey data and are included all energy consumptions in building. However, calculation methods of normalize energy consumption in terms of kWh/year of database are various. Nevertheless, the details of each method will not mention in this paper. The summary of those three benchmarks is shown in Table 1.

Table 1. Summary of energy consumption benchmarks.

Type			Air-cond.	Energy (kWh/m^2/year)
United Kingdom	Cellular	Typical	N	205
		Good	N	112
	Opened	Typical	N	236
		Good	N	113
	Standard	Typical	Y	404
		Good	Y	225
	Prestige	Typical	Y	568
		Good	Y	348
Hong Kong	Common	P50	Y	218
	Tenant	P50	Y	113
	Common	P50	N	34
	Tenant	P50	N	153
	Whole	P50	Y	304
Singapore	Total	Level 3	Y	199-234
	Landlord	Level 3	Y	128-156
	Tenant	Level 3	Y	107-152

3. Methodology

3.1 Benchmarking Systems

The energy benchmark system in the world has two major categories. The first is 'real world' energy consumption that is based on results of field surveys. The other is baseline energy consumption that is based on results from computer simulations such as Energy Plus, DOE-2, and TAS. Nevertheless, this paper will be focused on field surveys approach.

There are advantages and disadvantages of this approach. The obvious benefit is that the energy consumption benchmark is more practical because it is based on statistical analysis of data collected from a number of existing buildings while baseline energy consumption is based on a result of one representative computer model. However, there is a limitation of field-survey benchmark. As the benchmark relies on a number of building samples, if the entire population is energy inefficient, it would cause a poor milestone. Therefore, the results of benchmark should be compared with other benchmarks in similar climate. If energy performance appears similar, this would ensure reliability of the benchmark.

3.2 Definition and Criteria

According to the concept of the benchmark, only similar kind of buildings can be compared. Therefore, a group of large office buildings that is located in central area of Bangkok, at least 1MW of peak demand, centrally air-conditioned and air-conditioned area more than 1,000 m^2 are considered.

3.3 Data Collections

It is compulsory for buildings in Bangkok that their peak demands exceeding 1 MW to comply with the Energy Conservation Act, 1992 (ECP Act), and biannually submit an energy performance report to the Department of Alternative Energy Development and Efficiency (DEDE). In this case, forty-one designated office buildings are selected, and a data set of an individual sample is derived including monthly as well as annual energy consumption data, operating hours per annum, and air-conditioned area. To be noted that, energy consumption data that takes account for all types of energy used in buildings are recorded for year 2004, and different units of energy used such as liter for diesel and liter or kilogram for Liquefied Petroleum Gas (LPG) are changed to kWh according to a conversion table and submission blank form available at http://www.dede.go.th/dede/file admin/usr/berc/energy save/build. The summary of data is shown in Figure 1-Figure 4.

In addition, two sets of weather data from station named 455201 which located in central Bangkok are obtained from the Climatology Division, Meteorological Department. The first data set is weather data in measured year (2004) and the other is weather data in standard year (average conditions of last 30 years; between 1971 and 2000). The method of Cooling Degree-Day (CDD), which is total differences between outdoor temperature and one specific set point temperature in a period of time, is considered. The method of CDD is

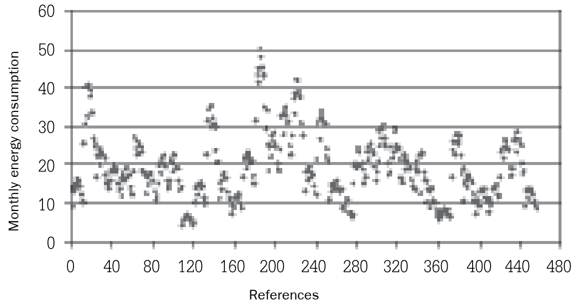

Figure 1. Distribution of monthly energy consumption (minimum = 4 kWh/m^2, and maximum = 50 kWh/m^2).

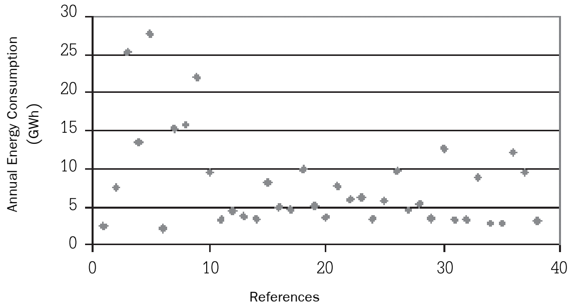

Figure 2. Distribution of annual energy consumption (minimum = 2.15 GWh, and maximum = 27.64 GWh).

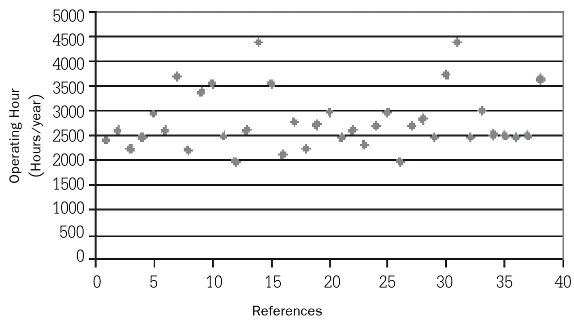

Figure 3. Distribution of operating hour(minimum = 1,968 hours/year, and maximum = 4,380 hours/year).

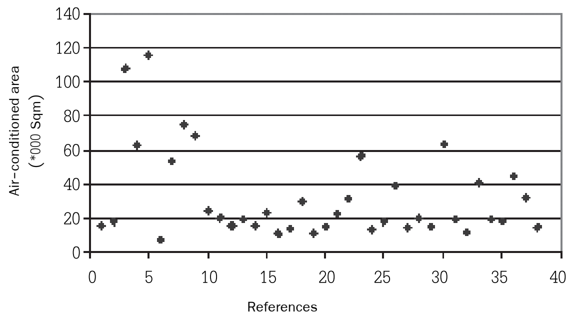

Figure 4. Distribution of air-conditioned area (minimum approximately 7,150 m^2, and maximum approximately 115,250 m^2).

adopted because it shows relationship between outdoor weather condition and energy demanded on cooling system [4]. Moreover, a research on commercial buildings in Singapore has confirmed that variations of energy consumption are contributed by monthly mean outdoor dry-bulb temperature. Only with outdoor temperature, the energy consumption can be well predicted at 90% confidence level [5]. The CDD in measured year is compared to those in standard year and appears different as shown in Figure 5. To be noted that, the room set point temperature for CDD is determined as 23°C due to the desired internal temperature is normally 25°C in Bangkok and 2°C of this is supplied for internal heat sources such as lights, appliance, equipment, and people [6].

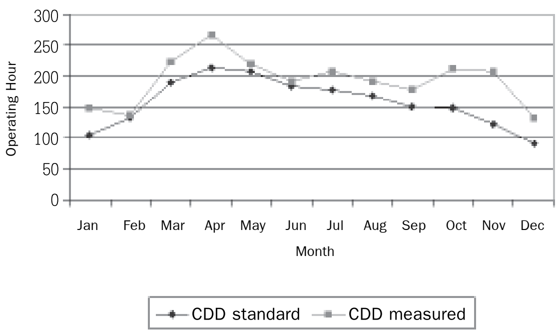

Figure 5. Comparing CDD in standard year and measured year.

Due to weather conditions in measured year differ from those in standard year, Climate Factor (CLF) is considered. It is a ratio of CDD in standard year and CDD in measured year as shown in Equation 1. The annual CDD in standard year and in measured year are found as 1,886 and 2,316 respectively. Then, the annual Climate Factor is calculated as 0.81.

$$CLF = \frac{\text{CDD standard}}{\text{CDD measured}} \quad (1)$$

The corresponding monthly as well as annual CDD and Climate Factor are shown in Table 2.

Table 2. Corresponding annual as well as monthly CDD and Climate Factor.

Month	CDD standard	CDD measured	Climate Factor
Jan	105	149	0.70
Feb	132	137	0.96
Mar	189	223	0.85
Apr	213	267	0.80
May	208	220	0.95
Jun	183	192	0.95
Jul	177	208	0.85
Aug	167	192	0.87
Sep	150	177	0.85
Oct	149	211	0.71
Nov	123	207	0.59
Dec	90	133	0.68
Annual	**1,886**	**2,316**	**0.81**

For a better comparison, operating hours of buildings are normalized. In this case, Operation Hours Factor (OHF) is considered. It is a ratio of Standard Operating Hours of office buildings in Bangkok (OH standard) and Actual Operating Hours in a specific building (OH actual). The Standard Operating Hours of Bangkok is average operating hours of database as 2,786 hours per annum. However, the Standard Operation Hours of 2,860 hours following e-Energy of Singapore neighbor is preferred. Therefore, the Operating Hour Factor of a specific sample is 2,860 divided by its own Actual Operating Hours as shown in Equation 2.

$$OHF = \frac{2{,}860}{\text{OH actual}} \quad (2)$$

3.4 Establishing Benchmarks

After data collection, process to establish annual energy consumption benchmarks in terms of kWh/m^2/year is determined. Firstly, Monthly Energy Consumption (MEC) of an individual sample is summed up to Total Energy Consumption (TEC) in terms of kWh/year. Then TEC is normalized for both CLF and OHF, and finally divided by air-conditioned area to get the energy consumption in terms of kWh/m^2/year as shown in Equation 3.

$$\text{Normalized Annual Energy Consumption} = \frac{\text{TEC x OHF x CLF}}{\text{A/C area}} \qquad (3)$$

Where; TEC = Annual Energy Consumption (kWh/year)

OHF = Operating Hour Factor

CLF = Climate Factor (equal to 0.81)

A/C area = Air-conditioned Area (m^2)

Next, two types of annual benchmarks in terms of kWh/m^2/year are determined based on statistical analysis of database. The first type of benchmark is a median values of the database called energy consumption in 'typical' buildings. The other is better energy consumption and falls in a lower quartile called the energy consumption in 'good practice' buildings.

Apart from the annual benchmark, monthly energy consumption benchmarks in terms of kWh/m^2/month are also established. The monthly energy consumption is Monthly Energy Consumption (MEC) normalized for both OHF and Monthly Climate Factor (CLF Month), and then divided by its own air-conditioned area as shown in Equation 4. The monthly benchmarks are average values of monthly energy consumption of a specific month.

$$\text{Normalized Monthly Energy Consumption} = \frac{\text{MEC x OHF x CLF(Month)}}{\text{A/C area}} \qquad (4)$$

Where; MEC = Monthly Energy Consumption (kWh/month)

OHF = Operating Factor (according to Equation 2)

CLF (month) = Monthly Climate Factor (according to Table1)

A/C area = Air-conditioned area (m^2)

However, there is a constraint of using equations 3 and 4. As energy consumption is proportional to operating hour as well as air-conditioned area and ignores significance of thermal mass of buildings. Therefore, if either operating hour or area is raised twice, the energy consumption will be doubled. In fact, energy used especially in air-conditioning system is unlikely proportional. Unfortunately, process of heat transfer and thermal mass of buildings are complicated and beyond the scope of this paper.

4. Results

4.1 Annual Energy Consumption Benchmark

The summary of normalized annual energy consumption of samples and its distribution is shown in Table 3 and Figure 6. Though the distribution shows a little skew, it is indicated the closeness of symmetrical bell shape and found to satisfy with normal distribution.

In addition, frequency distribution of energy efficiency has been translated into cumulative percentile distribution curve as shown in Figure 7. Moreover, percentages of energy reduction that buildings have to achieve in order to be better performance are shown in Table 4.

Table 3. Minimum, maximum, average, median, and SD of energy consumption.

Energy Consumption	Minimum	Maximum	Average	Median	SD
kWh/ m^2/year	90	488	233	225	89

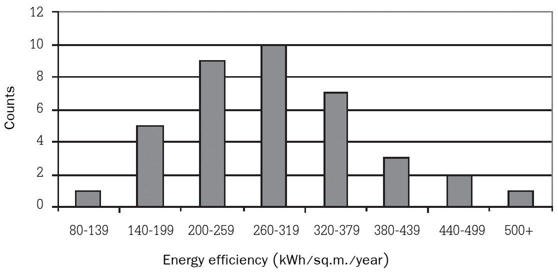

Figure 6. Frequency distribution of energy consumption.

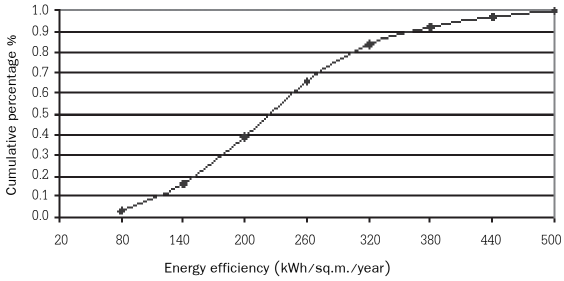

Figure 7. Cumulative percentile distribution curve.

Table 4. Percentages of energy reduction.

Percentile Moved	Energy Reduced
from 90 to 80	18%
from 80 to 70	5%
from 70 to 60	9%
from 60 to 50	9%
from 50 to 40	10%
from 40 to 30	13%
from 30 to 20	10%
from 20 to 10	14%

As mentioned before, there are two types of annual benchmark—typical and good practice performance—determined according to statistical analysis as the 50th and 25th percentile respectively. In this case, typical performance benchmark is found 225 kWh/m^2/year, and good practice performance benchmark is found 170 kWh/m^2/year.

4.2 Monthly Energy Consumption Benchmarks

Apart from annual benchmark, monthly benchmarks are presented. As mentioned before, the monthly benchmarks are average values of normalized monthly energy consumptions of a specific month. The corresponding monthly benchmarks in terms of kWh/m^2/month are found as shown in Table 5.

Table 5. Monthly energy efficiency benchmarks.

Month	Energy Consumption (kWh/m^2/month)
Jan	14.9
Feb	20.6
Mar	20.8
Apr	18.5
May	22.6
Jun	22.4
Jul	21.1
Aug	20.3
Sep	20.4
Oct	16.7
Nov	14.6
Dec	15.0
Total	**227.9**

Though the monthly energy consumptions vary over a year, they do not show significantly different of energy consumption in seasons or seasonal pattern as found in temperate and/or cold climate zones. The highest consumption is found in May as 22.6 kWh/m^2/month, while the lowest monthly consumption is found in November as 14.6 kWh/m^2/month. The difference between the highest and the lowest monthly consumption is 8 kWh/m^2 or changing approximately 35%. In addition, the total of average monthly energy consumptions is 227.9 kWh/m^2/year which is similar to annual benchmark of typical buildings as 225 kWh/m^2/year. Thus, it would say that monthly energy consumption benchmarks are breakdown of annual energy consumption of typical performance buildings.

Moreover, a relationship between the monthly energy consumption benchmarks and the standard CDD of Bangkok is studied as shown in Figure 8.

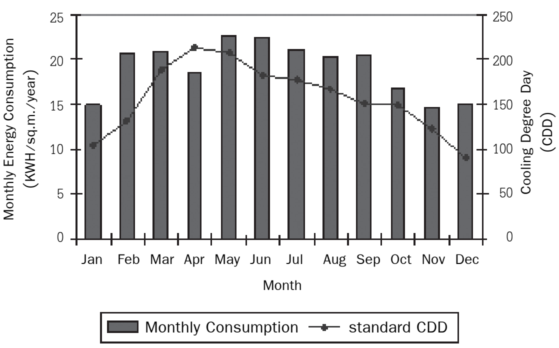

Figure 8. Relationship between monthly consumption benchmarks and standard CDD.

The variations of monthly benchmarks and standard CDD appear similar except April. They are largely because energy consumption in air-conditioning system dominates total energy consumption of buildings, and operation of the system is strongly related to weather [7]. However, the lowest energy consumption in April when temperature reaches the highest could be a result from low operating hours. Like a long holiday during Christmas and New Year in Western world, the traditional New Year of Thailand is in the middle of April. During this period, businesses are paused normally for one week reflecting to decreasing of operating hour and energy consumption in April. Therefore, it would conclude that energy consumption in a specific month of office buildings in Bangkok depends not only on a degree of CDD but also on a number of operating hours. This also confirms the reliability of Equation 3 and 4 that energy consumption of office buildings in Bangkok relies on both Climate Factor and Operating Hours Factor.

5. Discussion

As mentioned, it is important to compare the field-survey benchmark with similar benchmarks from other countries in order to ensure reliability. The median or average values of three energy consumption benchmarks that account for all energy consumptions in building are plotted as shown in Figure 9.

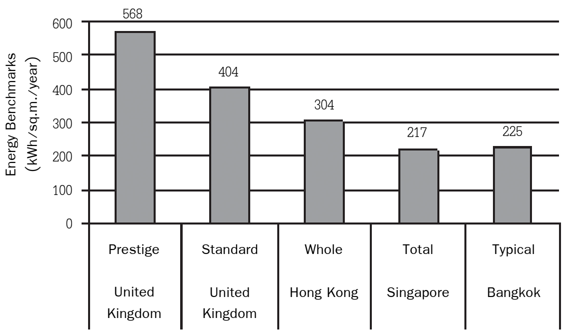

Figure 9. Comparison of energy consumption benchmarks.

The energy consumption benchmark of typical office buildings in Bangkok is similar to those of Singapore and little lower than those of Hong Kong; however, it is significantly different from those of United Kingdom. The difference of the benchmark values would be a result from different climate. In Bangkok and Singapore where are similar in tropical climate, the benchmarks are much alike. To be noted that average annual temperature is around 26°C in Bangkok [8] and around 27°C in Singapore [9], while around 22°C in Hong Kong [10] and around 11°C in United Kingdom [11]. Therefore, it would confirm that energy consumption benchmark developed within one specific climate has little applicability in the others.

6. Conclusion

A set of energy management tool presented in this paper has two parts. The first is annual energy consumption benchmark of office buildings in Bangkok, which is found 225 kWh/m^2/year for typical performance and 170 kWh/m^2/year for good practice one. The other part is breakdown of monthly energy consumption of typical performance.

Considering annual energy consumption benchmark, it plays important role as a starting point of systematic energy management in office building. It has potential to evaluate energy performance of an office building by comparing against others. When energy performance of the building has been assessed, and then target for better energy efficiency has been set up. Therefore, energy reduction plan and action could be continued. For example, if normalized annual energy consumption of a specific building is 275 kWh/m^2/year, the building performs lower than standard. Therefore, an initial goal for better energy performance may be set as 225 kWh/m^2/year equal to those of typical performance benchmark proposed in this paper. On the other hand, if the energy consumption of the building is higher than typical performance, the goal may aim at good practice performance benchmark.

Considering monthly benchmark, it is a breakdown of annual energy consumption. The monthly benchmark helps to establish not only immediate monthly goal but also reduction plan especially when the building performs lower than typical performance benchmark. Moreover, the monthly benchmark has potential to pinpoint a problem period; therefore, effective actions can be quickly launched to improve energy performance.

After assess energy performance, set up energy target, pinpoint problem period, and establish reduction plan; then action on energy reduction, continuously monitor as well as improve energy performance can be continued. After the cycle of energy management moves, the office buildings in Bangkok would be better energy performance and optimize energy consumption.

Regards to recommendation for further research, energy consumption in systems including air-conditioning system, lighting system, office equipment and other systems in terms of kWh/m^2/year should be studied. The system breakdown would help to evaluate and pinpoint a problem on building system efficiency. It also helps to set up an energy target for an individual building service system. If it is joined with the monthly energy consumption benchmark proposed in this paper, it is possible to identify both ‘where’ and ‘when’ the energy consumption problem occurred.

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