

## **Development of a Building Energy Performance Index for Hot-Humid Regions**

**Ravij Kuanprasert**

Department of Architecture, Faculty of Architecture  
Chulalongkorn University, Phyathai Road, Patumwan, Bangkok. 10330, Thailand  
e-mail : ravij.k@dwp.com

### **ABSTRACT**

INDEX is the nationally accepted benchmark in processing and evaluating energy usage in architecture. It has been measured and analysed from the four main impact factors of buildings; site and location, building form, construction materials, and the mechanical efficiency of the equipment inside the buildings. These also attempts to figure out a case study which can be classified according to three characteristics; old building, typical building and the energy efficiency of the building. Main objective of the case study is to find out the mean score of each item and to use the score as benchmark. Afterwards, the relations of factors consider the weighting evaluation, analysed on a similar basis. The consumption coefficient is used to make an index which has been scored into relationship formulation. The total numbers of scores which are based on the four key criteria provide an indication of the energy efficiency of the building. A score of 1 point is given for the standard benchmark. Scores below 1 point indicate better building performances. The outcome of the research was a computer program and formulation. This can be used as a simple tool for layman or as an appropriate guideline for designing and renovating buildings. The research results are used to gain a clear picture of energy performance of buildings and contribute to know how to achieve and improve for better results for the design and construction of high performance green buildings, as well as introduce the basis of energy conservation code for hot humid regions and illustrate how this method can help to meet sustainability targets.

**Keywords:** *Energy Index, Hot-Humid Climate, Building Performance, Evaluation Tools*

### **1. INTRODUCTION**

World population has increased enormous during the last decades and will increase further in future. Energy consumption from fossil fuel will be fully exploited within a few decades. Many countries pay close attention to use renewable resources as an alternative. Energy conservation plays an important role and is directly related to global warming issues today [1]. Conservation of energy in buildings as a component of the architecture is one of the major factors. In the most buildings in Thailand electricity is the main energy form with roughly about 20.2% [2].

### **2. BACKGROUND**

Index is important for several countries and necessary to evaluate building performances. The well-known indexes are, for example, LEED [3] (Leadership in Energy and Environmental Design) in USA, BREEAM [4] (Building Research Establishment Environmental Assessment Method) in UK, CASBEE [5] (Comprehensive Assessment System for Buildings Environmental Efficiency in Japan) and GREENMARK [6] in Singapore. These indexes express similar characteristics, focusing on energy conservation. In addition, some of them also concern about Global Warming and pollution as shown in table 1.

Table 1 Comparison of well-known indexes and their scores.

Index	BREEAM	LEED	Green Mark	CASBEE
Origin	U.K.	U.S.	Singapore	Japan
Assessment items	1. Management 2. Health & Well Being 3. Energy 4. Transport 5. Water Consumption 6. Material 7. Land Use 8. Ecology 9. Pollution	1. Sustainable site 2. Water Efficiency 3. Energy & Atmosphere 4. Material & Resources 5. Indoor Environment Quality 6. Innovation Process	1. Building Management 2. Energy Efficient 3. Water Efficient 4. Indoor Environmental Quality Performance & Environment Protection 5. Innovation	Q Quality of building Q1. Indoor Env. Q2. Quality of service Q3. Outdoor Env. On site  L Environmental Load L1. Energy L2. Resources & Material L3. Off-site Env.
Score	Pass Good Very good Excellent	Uncertified below 30 <b>Certified 30-49</b> Silver 50-69 Gold 79-89 Platinum 90-108	<b>Award 55-70</b> Gold 70-80 Gold plus 80-85 Platinum 85 and above	1 (by law) 2 <b>3 (Ordinary)</b> 4 5 (Excellent)

Each index (Table 1) evaluates the systems with an individual score related to each reference benchmark. However, the higher score points mean better efficiency. These make it easy to be understood. Thailand still does not have such an energy index.

### 3. BUILDING PERFORMANCE FACTORS

Thailand is located in a hot-humid climate. The air contains a large amount of moisture. The temperature of the external environment is mostly higher than the internal environment. The designed comfort zone for human should be maintained at a temperature of about 25°C and a relative humidity of about 50% all the time [7].

This study will analyze and survey the energy components and consumption of buildings in the three groups of the case study; old buildings, typical buildings, and energy efficiency buildings. Although there are many factors that influence the building performance. The Method of this study is based on the amount of energy actually consumed or estimated to meet the different needs, associated with a standardized use of the building. So the main impact factors can be generally defined from the efficiency of electricity usage and can be calculated from equation 1 as follows:

$$E = (\Sigma U \cdot A \cdot \Delta t) / \text{COP} \quad \text{watts} \quad (1)$$

Where E = Electrical Supply (watts) : Electrical Supply for cooling load to maintain internal to comfort condition.

$\Sigma U$  = sum of U-Value (coefficient of heat transmission) : Material  
 A = Building Surface Area (m<sup>2</sup>) : Building form  
 $\Delta t$  = temperature outside - temperature inside (°c) : Site and Location  
 COP = Energy Efficiency Ratio (watts/hr.) : Mechanical Efficiency

From this equation 1, the  $\Sigma U$  ( $1/\Sigma R$ ) can be calculated from the sum of  $U$  which comes from the combination of each material layer from outside through inside[9]. The Building Surface Area is calculated from all surface areas that expose to the outside (roof, floor, and wall). To achieve less electrical supply for buildings the influencing variables should be integrated as:

The lower the building surface area	: the better the cooling loads
The lower the U-Value	: the better the insulation
The lower the $\Delta t$	: the better the micro climate
The lower $COP^{-1}$	: the better the mechanical performance

This tends to result in the evaluation of four index factors and in a further step of the energy conserving philosophy. That is finally indicated in terms of:

### Site and Location

The environment of the building is a factor that can greatly affect the condition of the building. The environment can impact the condition of the building negatively and vice versa it can improve the buildings condition significant if the building environment is appropriately modified. To achieve energy conservation design standards, the understanding of the local climate and geography is very crucial as these are the factors that affect the building environment. Thailand, in particular, has a tropical climate resulting in designs that wind, temperature, local climate, humidity, and landscape must be concerned. These should be an assessment tool for the energy conservation. Figure 1 shows the different air temperatures of the surrounding of buildings comparing when the surface is covered by concrete with a developed environment of a wet grass landscape, which differ from  $39^{\circ}\text{C}$  -  $32^{\circ}\text{C}$  ( $\Delta T = 7\text{ K}$ ). The upper graph shows the air temperatures for a concrete surface, which absorbs heat. If the wind passes through the hot surface it will generate higher temperatures than the lower graph where the surface is covered with wet grass. The internal temperature of the building is controlled at  $25^{\circ}\text{C}$ . The energy demand to keep the temperature at the  $25^{\circ}\text{C}$  level will be two times higher for the improper (concrete covered) environment than for the improved grassland environment. An environmental performance index from site and location is assigned and the benchmark point  $35^{\circ}\text{C}$  is 1.0.(see Table 2).

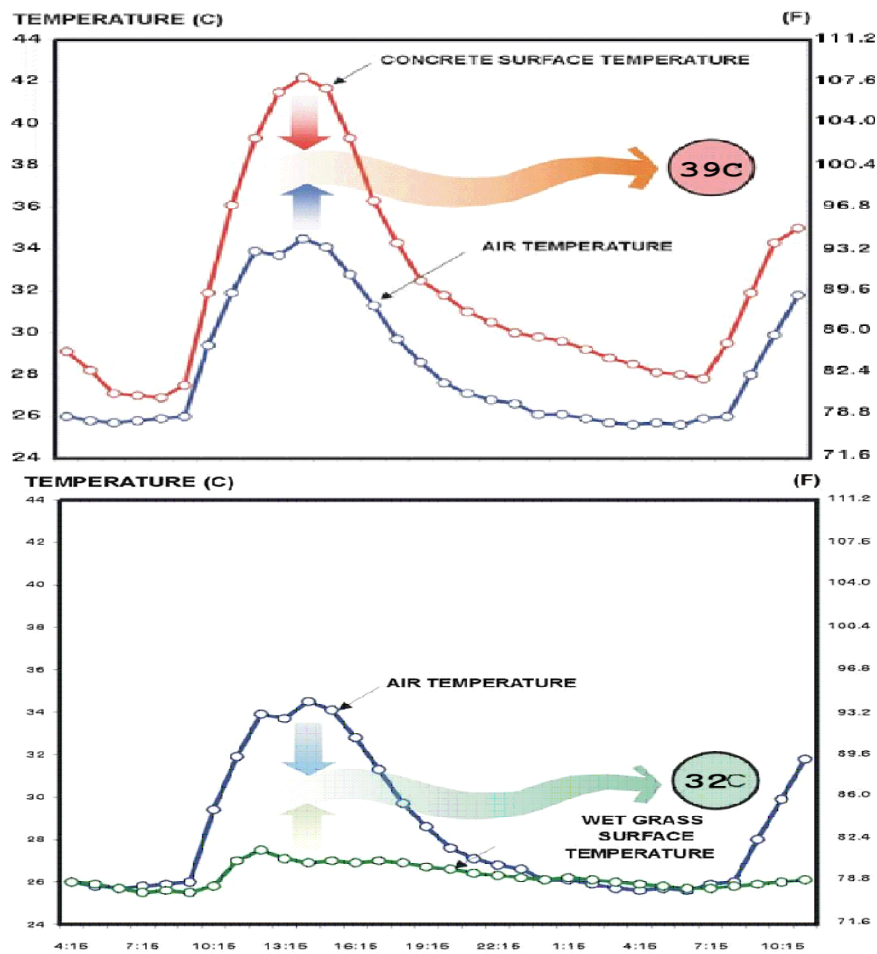


Fig. 1 The comparison of the air temperature between the concrete surface environment and the developed grassland environment. [8]

Table 2 The scoring index of Site and Location factors ( $i_t$ )

Environmental Performance Index	
temp.( °C)	score
39° or upper	1.4
38°	1.3
37°	1.2
36°	1.1
<b>35°</b>	<b>1.0 Benchmark</b>
34°	0.9
33°	0.8
32° or below	0.7

## Building Form Ratio

Another important factor is the building form selection by comparing the outer surface of the building to the usable area (S/A). The general method is the less surface the less heat transfer from outside. The ratio of building surface area per usable area is calculated as score. In order to gain the assessment the result for the buildings are shown in see Fig. 2 [9]. The most optimized S/A is the cylinder or sphere and the worst is the complex form. (see Fig. 2 ) However this ratio is related to the size of the form (see figure 3). If the size is increased, then S/A is decreased . Comparing moreover 100 building case studies, the benchmark S/A of buildings in Bangkok is approximately 1.447. (see table 3)

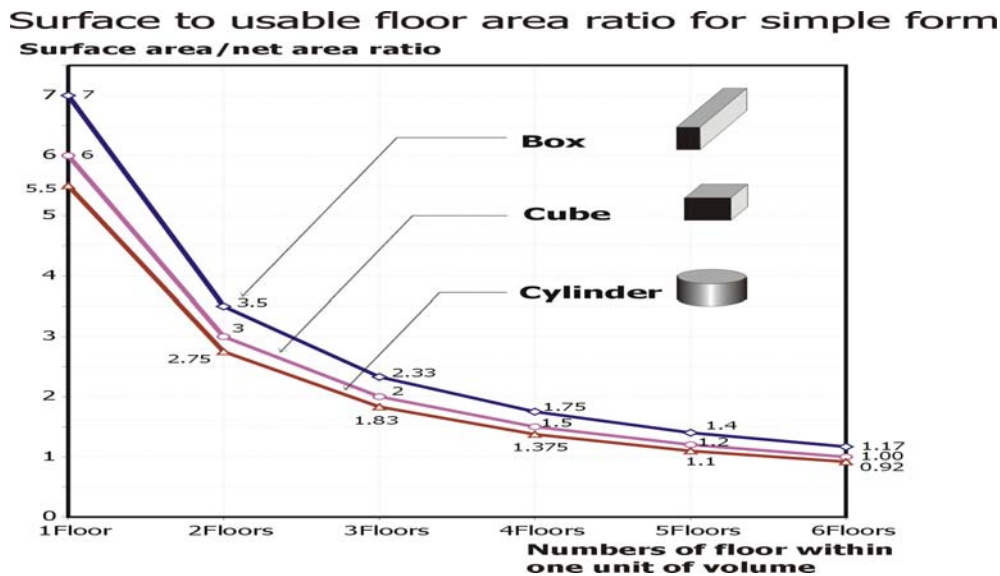


Fig. 2 Surface to usable area ratio

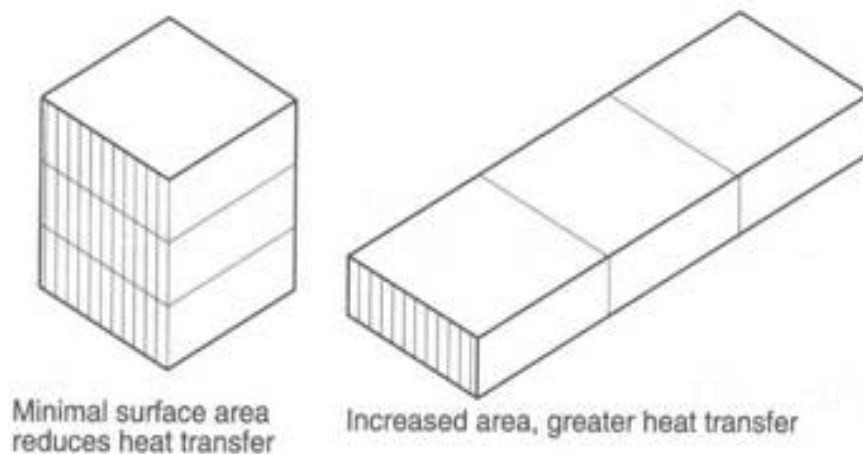


Fig. 3 The example of Surface to usable area ratio. The square shape (3\*3\*3 unit, usable area =27 unit<sup>2</sup>) compare to the rectangular shape (3\*9\*1 unit, usable area =27 unit<sup>2</sup>). The S/A of The square shape (2.0) is better than the rectangular shape (2.89) in the same floor area.

Table 3 The scoring index of Surface to usable area ratio ( $i_b$ )

The Surface area / Usable area Index	
S/A	score
2.500	1.727
2.250	1.555
2.000	1.382
1.750	1.209
<b>1.447</b>	<b>1.000 benchmark</b>
1.000	0.691
0.750	0.518
0.500	0.345
0.250	0.173

### Material

An appropriate material selection for the outer shell of a building is an important factor for saving energy. These materials affect the direct heat transfer from outside to inside of the building. It affects the room temperature and causes the air-conditioner to work harder, which raises costs for electricity. The opaque walls (wo), the roof (ro) and the fenestration (wf) are the most important parts of the buildings skin which have to be considered. The appropriate material to be selected should have a low heat transfer coefficient (u-value), a low thermal capacity and a low thermal mass. Considering this will minimize the cooling loads more precisely.

Refer to The Energy Conservation Promotion Act. B.E. 2535(1992) [9], the code is implemented for large buildings. The OTTV (Overall Thermal Transmission Value) of new buildings should not exceed more than 45 watts/m<sup>2</sup> and the RTTV (Roof Thermal Transmission Value) should not exceed more than 25 watts/m<sup>2</sup>. So the benchmark index of the material is based on this consumption see table 4.

Table 4 The scoring index of Material Performance ( $i_m$ )

Opaque Wall type	U (m <sup>2</sup> · °C/w)	score
Wood 1 side	3.922	4.150
Brick 0.10m.	3.303	3.495
Brick 0.20m.	2.519	2.667
<b>Brick 0.10m.+Foam 0.025m.</b>	<b>0.945</b>	<b>1.000</b>
<b>benchmark</b>		
EIFS wall*+Foam 0.025m.	0.868	0.919
EIFS wall*+Foam 0.050m	0.535	0.566
EIFS wall*+Foam 0.075m.	0.387	0.409

(Exterior Insulation and Finish System: EIFS wall)

Fenestration type		
Clear glass 3 mm.	5.988	1.677
Clear glass 6 mm.	5.882	1.647
Clear glass 10 mm.	5.780	1.619
<b>Laminate clear glass 3+3 mm.</b>	<b>3.571</b>	<b>1.000</b>
<b>benchmark</b>		
Laminate clear glass 6+6 mm.	3.509	0.983
Heat-reflective Hr-74 10 mm.	3.048	0.854
Insulated glass heat stop	1.332	0.373
Floor and Roof type		
Conc. roof tile 12 mm.	2.278	2.568
Conc. roof tile 12 mm. + Alu. Foil	1.524	1.718
Conc. slab 0.10 m.	1.049	1.133
<b>Conc. slab 0.10 m. + fiber glass 25mm.</b>	<b>0.887</b>	<b>1.000</b>
<b>benchmark</b>		
Conc. slab 0.10 m. + fiber glass 50mm.	0.543	0.612
Asphalt roof tile + fiber glass 50mm.	0.482	0.543
Asphalt roof tile + fiber glass 75mm.	0.359	0.405

### Mechanical Efficiency

The Energy Efficiency Ratio (EER) or the Coefficient of Performance (COP) of the mechanical equipment inside of the building is another factor which can be used for categories the energy saving equipment. The higher the COP of equipment is, particularly air conditioner, as cooler temperatures can be produced with less energy consumption [10]. The Mechanical Efficiency benchmark of Thailand is number 5 which is currently the best available technology on the market.(see table 5)

$$\text{COP} = Q_{\text{cold}} / Q_{\text{hot}} - Q_{\text{cold}}$$

Table 5 The scoring index of Coefficient of performance ( $i_e$ )

Number	ERR	COP	1/COP	score
1	6.6	1.934	0.517	1.606
2	7.6	2.227	0.449	1.394
3	8.6	2.521	0.397	1.233
4	9.6	2.814	0.355	1.103
<b>5 Benchmark</b>	<b>10.6</b>	<b>3.107</b>	<b>0.322</b>	<b>1.000</b>
6	11.6	3.400	0.294	0.913
7	12.6	3.693	0.271	0.842
8	13.6	3.986	0.251	0.780

#### 4. EVALUATION TOOLS APPLICATION

The Building Performance Energy Index (BPEI) score is composed by analyzing the the four factors

- Site and Location,
- Building Form Ratio,
- Materials and
- Mechanical Efficiency

as shown. The Benchmark index is equal 1 for an appropriate present building. The research question that has to be identified is the Index inefficiency (<1) and Index efficiency (>1) ratio. Examples of the calculation for the 3 cases are compared as follows:

Index	$= (\text{Site}) \cdot (\text{Bldg Form Ratio}) \cdot (\Sigma u \cdot A) \cdot (1/\text{COP})$ (2)
	$= (i_t) \cdot (i_b) \cdot (i_m) \cdot (i_e)$
Index benchmark	$= (1) \cdot (1) \cdot (1) \cdot (1)$
	$= 1$
Index inefficiency	$= (1.40) \cdot (1.727) \cdot (1.80) \cdot (4.15)$
	$= 18.06$
Index efficiency	$= (0.70) \cdot (0.173) \cdot (0.562) \cdot (0.78)$
	$= 0.053$
Index in: eff. ratio	$= 18.06: 0.053$
	$= 340.75$

From this exemplary calculation, the of Index inefficiency/efficiency ratio is 340.75 . The index number is significant for the energy conservation technique. The aim of optimization is to achieve a lower index than the benchmark. The buildings design should be integrated as:

The lower the building surface area	: the better the cooling loads
The lower the U-Value	: the better the insulation
The lower the $\Delta t$	: the better the micro climate
The lower $\text{COP}^{-1}$	: the better the mechanical performance

Following the objectives and theory underlying the four factors as described. The most significant factors are Bldg Form Ratio and  $\Sigma u \cdot A$  which will be easily adjusted more impact criteria than Site and COP. Those have some constraints such as macro climate and technology innovation.

#### 5. APPLICATIONS

Two examples will explain the how to use the BEPI.

Scheme A;30 building, each floor area 3000 m<sup>2</sup>,10 floor height @4.5m.

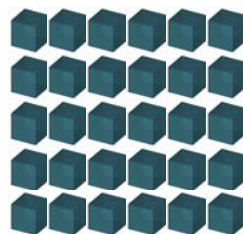


Fig. 4 30 building blocks

Site and Location	
Ordinary environment	$= 37^{\circ}\text{C}$
Site and Location index; $i_t$	$= 1.200$
Building Form Ratio	



Scheme a	= 30	bldgs
Usable area per bldg.	= 30,000	m <sup>2</sup>
Surface area per bldg.	= 14,850	m <sup>2</sup>
Total usable area	= 900,000	m <sup>2</sup>
Total Surface area	= 475,770	m <sup>2</sup>
Total Surface area: Total usable area	= 475,770: 900,000	
	= 0.529	
Building Form Ratio index; $i_b$	= 0.365	
Material		
Brick 0.10m.+Foam 0.025m.	= 1.0	
(60%)	= 1.0	
Laminate clear glass 3+3 mm.	= 1.0	
(40%)	= 1.0	
Conc. slab 0.10 m. + fiber glass 25mm.	= 1.0	
Material index ; $i_m$	= 1.000	
Mechanical Efficiency		
Standard COP.	= No.5	
Mechanical Efficiency index; $i_e$	= 1.000	
Total Building Performance Index	= $i_t \cdot i_b \cdot i_m \cdot i_e$	
	= 1.200 · 0.365 · 1.000 · 1.000	
	= 0.438	
Scheme B; One building, floor area 90000 m <sup>2</sup> , 10 floor height @4.5m.		



Fig. 5 One building blocks

Site and Location		
improved environment	= 32	°C
Site and Location index; $i_t$	= 0.7	
Building Form Ratio		
Scheme B	= 1	Buildings
Usable area per bldg.	= 900,000	m <sup>2</sup>
Surface area per bldg.	= 234,000	m <sup>2</sup>
Surface area: usable area	= 234,000: 900,000	
	= 0.260	
Building Form Ratio index; $i_b$	= 0.180	Material
EIFS wall*+Foam 0.075m.	= 0.409	
Area(60%)	= 0.245	
Insulated glass heat stop	= 0.373	
Area(40%)	= 0.149	
Total wall index	= 0.245+0.149	
$i_w$	= 0.394	
Conc. slab 0.10 m. + fiber glass 50mm.	= 0.612	
$i_f$	= 0.612	
Material index ; $i_m$	= ( $i_w \cdot \text{wall area/SA}$ ) + ( $i_f \cdot \text{floor area/SA}$ )	
	= 0.091+0.471	
	= 0.562	

## Mechanical Efficiency

Best performance COP.

= No.8

Mechanical Efficiency index;  $i_e$ 

= 0.780

Total Building Performance Index

 $= i_t \cdot i_b \cdot i_m \cdot i_e$  $= 1.000 \cdot 0.180 \cdot 0.562 \cdot 0.780$  $= 0.079$ 

The case study of the Building Energy Performance Index allows to compare the two schemes of buildings with similar usable areas. The building scheme B has a better index than the scheme A building, approx. 5.54 times. It must be noted that the significant index factors are the building form ratio and used materials. These factors have more influence than the others and lead to a new concept of how to design appropriate sustainable architecture.

## 6. CONCLUSIONS

Recently, the importance of the building energy performance index in hot-humid region is becoming clearer for the energy causes. But the index guidelines gave only an outline of the principles to be followed. A large number of buildings should be comparatively analysed. The integrated design and building technology must be essential implemented in architecture. In the conclusion of this research, the index should include more factors such as user operation, water resources, cost and carbon index. Further research should be concerned and lead towards an index certification to make it more complete and sustainable. Through this the comparison of efficiency assessments for energy benefits and the cost effectiveness analysis [11] will be an evaluated tool for decision making. The index can be shown in a visual form, formula and label that make it possible for everybody to understand the importance of green architecture design. In other words, BEPI can be a simple and as well a complex tool, depending on the users background. The possibilities of national wide implementation of BEPI will lead to more practice and promote this index for appropriate governmental energy regulations. It may offer some opportunities for whom to concern to overcome the challenges that face the global environment. This will help to make the idea of sustainable architecture well accepted, not only in Thailand or hot-humid region but all over the world.

## Acknowledgements

This study benefited from the contributions of Prof. Dr. Soontorn Boonyatikarn, Assoc. Dr. Vorasan Buranakarn and others who shared their works and insights in my class. I would also like to thank the Department of Architecture of Chulalongkorn University for given this opportunity to me. Last but not least, I reserve my deepest gratitude for my family. That makes the impossible task of completing this research possible.

## References

- [1] Lee, Thomas H, Energy Aftermath, Harvard business school press. Boston, Massachusetts, 1992, pp. 251-255
- [2] Manning, Robert A, The Energy Factor 2000 Myths and Dilemmas of Energy, security and the pacific future, Palgrave<sup>tm</sup>, New York, 2000, pp. 169-186
- [3] LEED <http://www.usgbc.org/>
- [4] BREEAM <http://www.breeam.org/>
- [5] GREEN MARK [http://www.bca.gov.sg/GreenMark/green\\_mark\\_buildings.html](http://www.bca.gov.sg/GreenMark/green_mark_buildings.html)
- [6] CASBEE for new construction. Tool-1(2004 edition) institute for building environment and energy conservation / IBEC
- [7] Olgray, V. Design with climate ; bioclimatic approach to architectural regionalism. 4<sup>th</sup> printing. New jersey ; Printon University press, 1973
- [8] Boonyatikarn, Soontorn. The Shinawatra University : Design for the millennium
- [9] The Energy Conservation Promotion Act. B.E. 2535 <http://www.eppo.go.th/admin/law/doc->

NEPO-ACT2.html

- [10] Boonyatikarn, Soontorn. The Design Techniques of Energy Conserving Home for Better Quality of Life, Chulalongkorn University Press., Bangkok, 254
- [11] Rossi, Peter H. and Freeman, Howard E. Evaluation a systematic approach 7<sup>th</sup> ed. Sage Publications, USA, 2004, pp. 311-342