Net-Zero Energy Buildings: It's not a dream for Thailand

Thailand is located in tropical climate. Vernacular houses and buildings were constructed from materials of low thermal mass. The windows were well shaded and all interior spaces were naturally ventilated. Traditional design features persisted up to the time prior to the introduction of air-conditioning. Presently, all new constructed buildings are air-conditioned. Such buildings have large glazed and closed windows. Heat reflective glass is used to minimize solar radiation gain but daylight cannot penetrate well. These buildings are energy intensive. This present design has a serious limit to energy efficiency improvement. However, daylight can be re-introduced for lighting both the peripheral spaces and the deep interior spaces to largely replace electric lighting. But air-conditioning is major energy consuming. Substantial improvement in energy efficiency of air-conditioning and alternative methods of cooling for thermal comfort including solar cooling and radiant cooling will lead to substantial energy savings. Even if cooling is applied, future new buildings can become net zero or near net zero energy buildings.

Keywords: net zero energy building, daylighting, light pipe, radiant cooling, solar cooling.

1. INTRODUCTION

Thailand is located in a tropical zone where the climate hot and humid, with high solar radiation. With present design concept, modern commercial and residential buildings require air-conditioners to provide comfort and interior lighting is full reliance with light from electric lamps. Electricity consumption in Thailand increases significantly ever since the country began its first economic and social development plan in 1964. Due to incessant effort by energy personnel in state and private sectors, Energy Conservation Promotion Act (ECP Act) was promulgated in 1992. In 1995, requirements for energy conservation for large commercial building were announced in Building Energy Code (BEC) as a by-law of the ECP Act. The BEC was completely revised by 2007 and is now applied in full to new commercial buildings with floor area exceeding 2,000 m^2 [1]. Energy saving potential from application of the revised BEC is reported in [2].

The BEC sets minimum energy performance on the designated commercial buildings. It is expected that energy savings from implementation of BEC is limited. During the last decade, net zero energy, or near zero energy buildings have been constructed and demonstrated, mainly in cool climate regions. It is interesting to investigate if net zero energy commercial buildings and residential buildings are viable in Thailand and what levels of energy consumption and savings could be expected.

This paper describes first the rationale of the Thai BEC, its development, implementation, and the assessment of energy savings from its future implementation. It then examines the concept and some examples of net zero energy buildings.

2. BUILDING ENERGY CODE AND ENERGY LABELING

2.1 Building Energy Code

The BEC was developed and implemented rather dismally on existing buildings in 1995. It was revised in 2007. An energy labeling scheme was developed in 2009. Standard 90-1980 for Energy Efficient Design of New Buildings of ASHRAE, [3], was used by Thailand as the model code for development of the original Thai BEC. The studies led to the inclusion of requirements on (i) building envelope, (ii) air-conditioning system, and (iii) lighting system in the BEC.

A measure of the performance of building envelope, called OTTV or Overall Thermal Transfer Value, was adopted. The revised BEC retains the requirements on the three systems, but is more stringent and includes requirement on energy performance of hot water generation and accredits the use of daylighting and the use of photovoltaic cell for electricity generation. Table 1 lists sample requirements on the three principal systems for an office building.

Table 1: Energy performance requirements of an office building

System	Minimum performance value
Building envelope	
OTTV of wall	< 50 $W_{th}.m^{-2}$ (wall area)
RTTV of roof	< 15 $W_{th}.m^{-2}$ (roof area)
Electric lighting	< 14 $W_{e}.m^{-2}$ (floor area)
Air-conditioning	
Small split type unit (up to 1 RFT)	EER > 9.62
Central air-conditioning system	
large water chiller	COP > 5.87 (< 0.62 $kW.RFT^{-1}$)
all other parts of the system	COP > 7.03 (< 0.5 $kW.RFT^{-1}$)
overall system performance	COP > 3.20 (< 1.14 $kW.RFT^{-1}$)

The new OTTV formula in the new BEC was developed and is applicable to estimate cooling load from exterior walls of a building. An equation was also developed and is used to calculate energy consumption of a building from its design. The equation is used as a part of the procedure for whole building energy compliance evaluation. The minimum performance level of each of the principal system was shown to offer lower life cycle cost as compared to that of a reference system. Each minimum energy performance value was arrived at through close examination and agreement by experts.

2.2 Building Energy Labeling

While the BEC was developed for mandatory application on new large buildings, the energy labeling was developed for voluntary implementation on large buildings. A scheme of Building Energy Labeling (BEL) was developed from a request by the Metropolitan Electricity Authority (MEA) for its ESCO operation [4]. It was perceived that the management of a commercial building may be motivated by a desire to improve energy performance of the building and the ESCO arm of MEA could offer to finance retrofitting the given building and shares the benefit. Five levels of building energy performance were proposed. The minimum performance level for new building in the BEC could be assigned as Level 3 for the labeling scheme. The scheme uses the same energy performance indices. There are two higher performance levels of Level 4 and Level 5.

3. LIFE CYCLE COSTS OF BUILDING SYSTEMS

As mentioned in Section 2, minimum energy performance indices of systems in the BEC were shown to offer lower life cycle costs than those of the reference cases. This section will examine life cycle costs of higher energy performance systems and the corresponding energy savings.

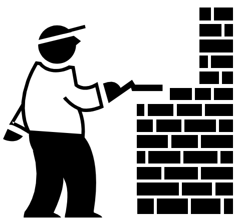
3.1 Life Cycle Cost (LCC)

Life cycle costing is an economic analysis of project that considers the net-present value of costs throughout the life of a project. The LCC of a project or a system includes initial costs, operating cost, energy cost, maintenance cost, and end of project costs of removal and salvage, where discount rate, inflation rate, and energy escalation rate or escalation of labor cost are accounted for. This method of analysis is suitable for use by an agency responsible for resource management of an organization or of a country.

3.2 Life Cycle Costs of Building Systems

In the studies that led to the adoption of new BEC in 2007 [2], and the energy labeling scheme in 2009 [4], LCCs were calculated for different combinations of system components that together form systems of different energy performance indices.

- ***Building Envelope System***



Different opaque walls with insulation of different thicknesses were matched with different glazing types. The OTTV of each wall and glazing combinations were calculated. The total present-value cost of each wall and glazing combination and the corresponding cost of electricity due to heat gain through the building envelope were calculated for each combination for each value of ratio of window area to overall wall area (WWR). The study results indicate that total LCC are lower for walls of lower OTTV [4].

- ***Air-conditioning System***

Similar methodology was applied with air-conditioning system to obtain a plot of the system performance against its LCC. Unlike the case of building envelope where the LCC decreases monotonously with increasing value of its performance index, LCC of an air-conditioning system becomes lowest when its performance is at 0.55 kW.RFT^{-1} and increases for higher performance value. This reflects the fact that the cost of energy performing chillers rises steeply when its kW.RFT^{-1} reaches below 0.55 at present.

- ***Electric Lighting System***

In this case, a model office building was used. The spaces in the building were assumed illuminated to standard levels in accordance with Thai Engineering standard for each type of space in the building. Different lighting devices of different efficacy (lighting efficiency) and costs were used to form different lighting options. In most cases, uniform lighting design was assumed used. The analysis showed that a point of minimum LCC down to a value of lighting power density (LPD) of about 5 Wm^{-2}.

4. ENERGY AND LCC SAVINGS FOR BUILDINGS OF HIGHER ENERGY PERFORMANCE

In this section, the regressed equation for calculation of energy consumption mentioned in Section 3 is used to calculate energy consumption of a model office building when it is equipped with building envelope, air-conditioning system, lighting system, and other equipment of different efficiency levels. The resultant sum of LCC of the principal systems of each comparative case is shown. Following cases are in consideration:

- the reference case,
- the BEC or code compliance case,
- the case of compliance with Building Energy Performance Level 5,
- a case called Econ which is beyond the Level 5, and
- a future case where solar and other novel technologies are used.

Building Energy Science and Technology Laboratory (BEST)

The objective of this laboratory is to facilitate conduct of research and undertaking of professional assignments on energy science and energy technology of buildings as well as to conduct research on low energy buildings that will support implementation of energy conservation programs for buildings in Thailand and countries in the region. Energy efficient building systems and components: Thermal performance and cost-effectiveness of building facade and envelope, efficient electric lighting, and efficient conventional air-conditioning.

Research Projects

- Training project for implementation of new building energy code in Thailand
- Research to develop an energy simulation software for building and evaluation of cost effectiveness of using insulated walls with buildings
- A study on daylight and solar heat gain through window and application of light pipe in building
- Research to support development of higher energy performance standards for new building
- Application of anidolic concentration to enhance the use of daylight and solar radiation in buildings
- Research programme on reducing energy consumption cost and GHG emission for tropical low-income housing: Thailand contribution

4.1 An Equation for Calculation of Energy Use in Buildings

A regressed equation was derived as described in reference [5] to calculate energy consumption of a building. The BEC of Thailand utilizes the equation in the whole building compliance procedure by using rated performance of systems and full zone occupancy during nominal operating time. In real buildings, not all occupants will occupy the zone at all time. Lighting, air-conditioning, and other equipment would also not be operated at rated condition for the full duration. In order to utilize equations for energy calculations that reflect such situations, a diversity factor each is added into each term in the equation. The resultant equation appears below:

$$E_{pa} = \sum_{\substack{i=1 \\ i \neq j}}^{n} \left[d_A \frac{A_{wi}(OTTV_i)}{COP_i} + d_A \frac{A_{ri}(RTTV_i)}{COP_i} + A_i \left\{ d_A \frac{d_L C_l(LPD_i) + d_E C_e(EQD_i) + 130 d_O C_o(OCCU_i) + 24 d_V C_v(VENT_i)}{COP_i} \right\} \right] n_{hi} + \sum_{i=1}^{n} A_i (d_L LPD_i + d_E EQD_i) n_{hi}$$

where A_{wi}, A_{ri}, and A_i are external wall area, roof area, and floor area of each zone, d_A, d_L, d_E, d_O, *and* d_V are diversity factors (DF) of air-conditioning, of lighting, of equipment, of occupancy, and of ventilation, respectively. It is envisaged that the number of usage hours could differ between zones, therefore, the nominal duration of each zone, n_{hi}, could differ.

4.2 Resultant LCC and Building Energy Savings

4.2.1 An Office Building Model

A building model is used to illustrate the extent of changes in building energy consumption when efficiencies of systems change. A building model is five stories building with length, width, and height of each floor of 25, 20, and 3 m respectively.

Other building dimensions appear in Table 2.

Table 2: Dimensions of the building model

Item	Values
Total area of roof, A_r (m^2)	500
Total wall area, A_w (m2)	1,350
Total used area, A_t (m2)	2500
Total area of air-conditioned space, A_{fac}	1875
Un-conditioned area, A_u (m^2)	625
Ratio of wall area to A/C floor area, A_w/A_{fac}	0.72
Ratio of roof area to A/C floor area, A_r/A_{fac}	0.27

4.2.2 Building Energy Scenarios

The energy equation is applied to the under five scenarios, ranging from a reference scenario, to BEC scenario, and higher energy performance scenarios including one that envisages application of advanced technologies that have been demonstrated elsewhere.

Table 3 lists values of energy performance of the building systems and other parameters under the five scenarios. The first four scenarios are achievable and economic under the present market and industrial condition and are described as follows.

Table 3 Performance of building systems and other parameter values of each scenario

System or Equipment	Reference	BEC	Level 5	Econ	New Tech
Building Envelope					
OTTV	61.4	50	30	20	15
RTTV	29.1	15	15	12	10
LCC of wall (B.m^{-2} wall.Y^{-1})	288	274	252	230	?
Air-conditioning					
System COP (kW.RFT^{-1})	2.21 (1.59)	3.13 (1.12)	3.64 (0.97)	4.42 (0.8)	6.30 (0.56)
LCC (B.m^{-2} floor.Y^{-1})	321	304	291	296	?
Lighting					
LPD in air-conditioned area (Wm^{-2})	20	14	9	6	1
Diversity factor	0.95	0.95	0.95	0.95	0.95
LCC (B.m^{-2} floor.Y^{-1})	160	140	80	58	?
LPD in un-condtioned space (Wm^{-2})	10	8	6	4	1
Equipment					
EQD in air-conditioned area (Wm^{-2})	45	45	45	25	20
Diversity factor	0.75	0.75	0.75	0.75	0.75
EQD in un-condtioned space (Wm^{-2})	10	10	10	5	4
Occupancy					
Load from occupant (Wm^{-2})	10	10	10	10	10
Diversity factor	0.85	0.85	0.85	0.85	0.85
Ventilation (l.m^{-2}.s^{-1})	0.75	0.75	0.75	0.5	0.5
Night and off hours security					
Light (Wm^{-2})	2	2	2	1	1
Equipment (Wm^{-2})	1	1	1	0.8	0.8
Number of normal office hours	2340	2340	2340	2340	2340
Number of outside hours	6425	6425	6425	6425	6425
Building energy consumption (kWh.m^{-2}.Y^{-1})	219	175	141	82	55
LCC of 3 systems	769	718	623	584	?
Annual electricity from roof top pv	-	-	-	-	28
Net consumption (kWh.m^{-2}.Y^{-1})	219	175	141	82	27

Reference The values of system performance indices in this scenario are obtained from a data base of energy audit reports of the Department for Alternative Energy Development and Energy Efficiency. The resultant annual energy consumption of 219 kWh.m^{-2}.Y^{-1} falls within expected level for an office.

BEC This is the scenario that energy performance of all systems equal exactly to those required by the Thai BEC and equipment of normal performance, same performance as those of the reference scenario, are used. The resultant annual energy consumption of 175 kWh.m^{-2}.Y^{-1} meets minimum performance level of Thai BEC.

Level 5 This is the scenario that the energy performance of principal systems equal to the lower limits of level of the building energy labeling scheme developed in a project of the MEA. The systems would have lower LCCs than those of the BEC case, but by no means correspond to the upper limits of efficiency of each system considering present available technologies and construction materials. The annual energy consumption reaches 141 kWh.m^{-2}.Y^{-1}, that is about two thirds of that of the reference case.

Econ This scenario corresponds to the situation when the best of present technologies and presently available equipment and materials are used. In most cases, energy performances of principal systems reach the point of lowest LCCs. This scenario may offer lower LCCs when technologies for building design and construction improves in the near future, of 5 years from present. The resultant annual energy consumption reaches 82 $kWh.m^{-2}.Y^{-1}$, that is about one third of that of the reference case.

4.2.3 Net-Zero Energy Buildings

A net zero energy building (ZEB) is a general term applied to a building's use with zero net energy consumption [6]. The development of modern net-zero energy buildings became possible not only through the progress made in new construction technologies, but it has also been significantly improved by academic research, which collected precise energy performance data. The most cost-effective steps toward a reduction in a building's energy consumption usually occur during the design process. To achieve efficient energy use, zero energy design departs significantly from conventional construction practice. Zero-energy buildings are built with significant energy-saving features. The heating and cooling loads are lowered by using high-efficiency equipment, added insulation, high-efficiency windows, natural ventilation, and other techniques. Net-zero energy buildings are constructed successfully for demonstration in Australia, Canada, China, Germany, Ireland, Malaysia, Norway, Singapore, United Arab Emirates, United Kingdom, and United States.

4.2.4 The New Tech Scenario

This is the scenario where new technologies are used in principal systems and equipment, most of which are already demonstrated but are not common and are not widely known in Thailand. No complete LCC has been calculated. Energy performance indices are extremely low and are described in the followings.

Low OTTV and RTTV In Econ and other scenarios, the surfaces of walls and roof of the model building are assumed coated with ordinary paint of light color to give solar absorptance of 0.5. In New Tech Scenario, these surfaces are assumed coated with low solar absorptance coating of 0.1. Coating with solar absorptance of 0.05 is now available.

Highly Energy Efficient Cooling The mode of cooling assumed here is radiant cooling. Occupants in the space are partly radiantly and partly convectively cooled. There is no fan to move air and ventilation air is pre-dried. Such system would require about 50% of electrical energy in comparison to conventional air-conditioning. Cooling load in the space must be minimized. Energy performance of cooling system is about 0.56 $kW. RFT^{-1}$.

Daylighting For a building operated during daytime, daylighting is applicable especially if the glazing used has low emissivity coating. Such coating allows daylight to transmit through but reflects infrared radiation. Daylight through window can be used for general lighting for up to 10 m from window [7]. For a building with narrow floor, daylighting may replace electric lighting totally. Light pipes can be used for a building with large floor.

Energy Efficient Equipment In Thailand, minimum energy efficiency standards (MEPS) and even higher energy performance standards (HEPS) are implemented by legal means. Promotional means also are used in the form of voluntary energy labeling. It is expected that by choice, highly energy efficient equipment would be used.

Overall Energy Consumption of New Tech Scenario Energy consumption in this scenario is 55 $kWh.m^{-2}.Y^{-1}$. But when electricity from the roof top PV is accounted, the net consumption is 27 $kWh.m^{-2}.Y^{-1}$.

5. ENERGY SAVINGS POTENTIAL FOR RESIDENTIAL BUILDINGS

With the same methodology as that used in the case of an office building, we consider a model residential house. Table 4 lists the dimensions of the model.

Table 4: Dimensions of a 2-story house

Dimension	Size	Unit
Total area	150	m^2
Area of roof	75	m^2
Area for solar cooling	50	m^2
Area for PV panel	25	m^2

Table 5 lists end-uses, duration of use, and duty cycle-load cycle of each device, and power rating. The table lists three scenarios, Reference, Energy Efficient, and New Tech.

Table 5 End-use energy consumption in a residential building in three scenarios

End-use Devices	Hours/day	Duty cycle (%)	Reference		Energy Efficient		New Tech	
			Size (kW)	kWh/year	Size (kW)	kWh/year	Size (kW)	kWh/year
Cooling, 3 RFT	12	75	3	9,855	2	6,570	0.4	1,314
Refrigerator	24	50	0.2	876	0.15	657	0.15	657
Lamps (8 standard fluorescents)	12	80	0.4	1,402	0.2	701	0.2	701
Television	3	100	0.15	164	0.1	110	0.1	110
Washing machine	0.5	100	0.36	66	0.3	55	0.3	55
Rice cooker	0.3	100	0.6	66	0.6	66	0.6	66
Electric iron	0.5	100	1	183	1	183	1	183
Total				12,611		8,340		3,084

Reference Scenario The reference scenario represents a typical situation of the use of electricity to satisfy end-use requirements in a small residential household. Total annual consumption of electricity is 12,611 kWh. When air-conditioning is adopted, electricity consumption from conventional air-conditioning constitutes 70% of total.

Energy Efficient Scenario This scenario represents the situation when a householder is conscious and has access to information on energy efficient appliances and electrical devices. The household improves building envelope and chooses highly efficient air-conditioners, chooses to use efficient lamps and ballasts, television set (where LCD is used), and washing machine. Total annual energy consumption is lower than the reference case by 30%.

New Tech Scenario This scenario is similar to the Energy Efficient Scenario except that *solar cooling is adopted together with radiant cooling*. Solar cooling technology has been continually developed so that its COP has reached 0.5. Moreover, research results have demonstrated that occupants perceive the system as providing natural ventilation comfort so that sensation of thermal comfort could be achieved with higher effective temperature in the space. This would reduce the cooling load required even further. Energy consumption in this scenario is 3,084 or 25% of that of the reference case.

CONCLUSIONS

This paper has examined a number of scenarios of energy consumption in the commercial and residential building sectors. It demonstrates that very substantial energy savings are possible. But the society must learn and may need to adjust so that alternative life style may need to be adopted for the future society to be sustainable.

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